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DEVELOPMENT OF HIGHLY RELIABLE CAPSULE TYPE SLIP RING ASSEMBLIES

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PREPARED FOR

GEO C. MARSHALL SPACE FLIGHT CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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POLY-SCIENTIFIC DIVISION

LITTON PRECISION PRODUCTS, INC.

BLACKSBURG, VIRGINIA

ENGINEERING DIVISION

DEVELOPMENT OF HIGHLY RELIABLE CAPSULE TYPE SLIP RING ASSEMBLIES

FINAL SUMMARY REPORT

NASA CONTRACT NO. NAS 8-5091

APPROVED BY

E. W. Glossbrenner
Program Director

1 JUNE 1965

PREPARED FOR
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

DEVELOPMENT OF HIGHLY RELIABLE CAPSULE TYPE SLIP RING ASSEMBLIES FINAL SUMMARY REPORT

ABSTRACT

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This report summarizes the studies of design materials, and processes conducted by Poly-Scientific Division, Litton Precision Products, Inc., under Contract No. NAS 8-5091 to improve the reliability of slip ring capsule assemblies.

The materials studies were contacts, structural metals, plastics, lead wire and bearings. It was found that low expansion, filled epoxy plastics supported by stainless steel members produced the best structural subassemblies. Gold ring surfaces in contact with gold-silver-nickel alloy brushes gave the best performance. Lead wire of silver plated copper conductors insulated with clear Feflon best withstood the rigors of processing and use.

The processes studied included electrodeposition, matte finishing, grinding, welding, lead protection, cleaning and prevention of contamination. Matte finishing improved both the wear and noise of the assemblies. Gold was found to be the best prevention for in situ surface contamination, and capable of uniform electrodeposition properties. Form grinding was developed on the only method of achieving close groove tolerances and grooving abrasive plastics. Welding was determined to be more reliable than soldering as a joining operation. Methods were developed to protect leads during processing. Specific cleaning processes were found necessary for each major step in the manufacture of clean assemblies.

A design concept was evolved for strong reliable, precision capsule assemblies based upon the improved materials and processes. The designs featured precision tolerances and alignment. This concept, with unique tooling and controls, has resulted in highly reliable capsule assemblies, not only of the 80-circuit type, but also for six other applications in the Saturn guidance system.

Discussion of each of these elements is provided along with complete Engineering Specifications and Process Instructions. An Applications Manual is included under separate cover, discussing the technology from the standpoint of the applications engineer.

Author

1.1 FOREWORD

This report is presented as the Final Summary Report on Contract NAS 8-5091 for the "Development of Highly Reliable Capsule Type Slip Ring Assemblies", by Poly-Scientific Division, Litton Precision Products, Inc., upon the conclusion of said contract.

The program has been extensive in its breadth and far reaching in its application. The work has included studies of practically every material, process and design feature of the slip ring capsule assembly. It has resulted in an entirely new reliability philosophy of design, material, process and control for the slip ring industry. This philosophy has already been successfully applied to at least seven slip ring applications and other applications are in the design stage.

These technological benefits in capsule reliability have been developed through the close communication and cooperation between Astronics Laboratory, Marshall Space Flight Center, Huntsville, Alabama and Poly-Scientific Division. We wish to acknowledge the technical assistance rendered by Mr. C. N. Mandel and Mr. E. G. Lowe, Principal and alternate Contracting Officer's Representatives, respectively, for the contract. We are deeply indebted to Mr. Lowe for his continued suggestions, criticisms and encouragements.

1.2 INTRODUCTION

In the late 1950's, Poly-Scientific pioneered in the introduction of capsule type slip ring assemblies. The design was based upon their years of experience in fabricating separate slip ring and brush assemblies. With the manufacture of capsule assemblies, Poly-Scientific assumed the responsibility for their functional performance. This led to the establishment of in-house supported development programs on electrical contacts, plastics, lead wire, and on contamination. By the early 1960's, Poly-Scientific had led in producing the highest quality slip ring capsule assemblies available in the industry.

Despite this background, early capsule slip rings procured by Marshall Space Flight Center for the Saturn platform failed to provide the performance required. These units, operating in this particular mode, had a life expectancy of only about 100 hours and the mean time between malfunction was about 700 circuit hours. This performance and its variety of failure modes fell short of the reliability level demanded for manned space flight.

From its greater experience in the capsule field, Poly-Scientific was more aware than most manufacturers of the need for an improved technology of these components. It was, therefore, proposed by Poly-Scientific that it underwrite financially, with the Marshall Space Flight Center, a program to improve the reliability of slip ring capsule assemblies. This resulted in the contract NAS 8-5091 for the "Development of Highly Reliable Capsule Type Slip Ring Assemblies."

Phase I of the program emphasized the study of materials and processes following the lines of investigation already under way at Poly-Scientific. At the end of this phase, supplemental tasks were added to Phase II to enlarge upon the Phase I results and to incorporate knowledge acquired from production hardware. In addition, during Phase II, it was determined that the program should be redirected to concentrate exclusively on electrodeposition process for the slip ring subassemblies. This, too, grew out of the combined development and production experience and led to additional development tasks. Consequently, most of the program effort has been concentrated upon development studies.

Obviously, the contract has progressed through a number of changes and modifications resulting from an interchange of problems and solutions with concurrent flight hardware. As a consequence, it has been a program of

changing emphasis. It has, however, enjoyed a feedback of information on problems and solutions never before obtained on any similar program. The hardware has greatly benefitted by the immediate introduction and utilization of the developing technology. The result has been significant improvement in every feature of every component of the capsule assembly.

The original contract called for Poly-Scientific to conduct qualification on the capsules developed. During the course of the program, Marshall Space Flight Center conducted qualification tests on flight hardware incorporating the developments of this program. The test results were so satisfactory that further qualification work by Poly-Scientific was felt redundant, and this portion of the work was deleted. These tests demonstrated the improvement of performance indicating a comparable mean time between malfunction of 1,260,000 circuit hours. This is an improvement of 1800 times.

The report which follows presents a summary of the work done and the technology gained in the many facets of the studies. Each section has been prepared by a specialist in the work performed. The individual author credits are to be found in the index.

An annex, under separate cover, is the Applications Handbook. This is a summary of the technology of capsule type slip ring assemblies. It presents the slip ring technology including the knowledge gained under this contract in a form which hopefully will be most useful to the applications engineer in the formulation of his particular slip ring requirements.

TABLE OF CONTENTS

		Page
Abstract		
Title Page		1.0
1.1	Foreword	1.1
1.2	Introduction	1.2
1.3	Table of Contents	1.4
1.4	List of Figures	1.9
1.5	List of Tables	1.13
2.0	Materials	2.0
2.1	Contacts	2.1
2.1.1	Introduction	2.1
2.1.2	Phase I	2.2
2.1.3	Phase II	2.4
2.1.4	Studies Conducted	2.4
2.1.5	Results	2.6
2.1.6	Discussion	2.8
2.1.7	Conclusions	2.9
2.1.8	Further Work	2.10
2.2	Structural Materials	2.12
2.2.1	Introduction	2.12
2.2.2	Choice of Materials	2.13
2.2.3	Results and Discussion of Results	2.14
2.2.4	Further Work	2.22
2.3	Plastics and Ceramics	2.23
2.3.1	Introduction	2.23
2.3.2	Phase I Review	2.24
2.3.3	Phase II	2.27
2.3.4	Discussion	2.45
2.3.5	Conclusions and Recommendations	2.46
2.3.6	Areas for Further Work	2.47
2.4	Lead Wire	2.50
2.4.1	Introduction	2.50
2.4.2	Insulation	2.51
2.4.3	Conductor	2.53
2.4.4	Acceptance Testing	2.62
2.4.5	Vendor Rating	2.63
2.4.6	Process Improvements	2.63
2.4.7	Special Construction	2.64
2.4.8	Conclusions	2.65
2.4-I	Appendix (Teflon Extrusion Process)	2.67

		Page
2.5	Bearings	2.71
	2.5.1 Introduction	2.71
	2.5.2 Bearing Useage and Practice at Beginning of the Program	2.71
	2.5.3 Bearing Failures on Saturn Parts	2.74
	2.5.4 Design Improvements as a Result of Failures	2.74
	2.5.5 Handling and Processing of Bearings	2.82
	2.5.6 Conclusions	2.83
3.0	Processes	3.0
3.1	Contamination Studies	3.1
	3.1.1 Introduction	3.1
	3.1.2 Identification of Haze	3.2
	3.1.3 Plastics and Processes	3.5
	3.1.4 Studies of Assemblies	3.17
	3.1.5 Discussion	3.21
	3.1-I Appendix (Noise Test Method)	3.23
3.2	Converting Stranded Wire to Solid Wire for Electrodeposited Slip Ring Use	3.24
	3.2.1 Introduction	3.24
	3.2.2 Requirements	3.24
	3.2.3 Literature Search	3.27
	3.2.4 Tests and Equipment	3.29
	3.2.5 Application of Insulation	3.32
	3.2.6 Results	3.34
	3.2.7 Conclusions	3.39
	3.2.8 Further Work	3.41
	3.2-I Appendix (Swaging of Lead Wire)	3.51
	3.2-II Appendix (Swaging of Lead Wire)	3.56
	3.2-III Appendix (Swaging of Lead Wire)	3.59
3.3	Gold Electrodeposition	3.64
	3.3.1 Introduction	3.64
	3.3.2 Experimental	3.65
	3.3.3 Discussion	3.73
	3.3.4 Parameters Affecting Anode Corrosion Rate	3.74
	3.3.5 Stress Analysis of Gold Electrodeposits	3.76
	3.3.6 Related Plating	3.81
	3.3.7 Conclusions	3.82
	3.3.8 Recommendations	3.83
	3.3-I Appendix (Figures and Tables)	3.84
	3.3-II Appendix (Procedures)	3.121

		Page
3.4	Grinding	3.132
	3.4.1 Introduction	3.132
	3.4.2 Process Selection	3.132
	3.4.3 Wheel Preparation	3.133
	3.4.4 Wheel Selection	3.139
	3.4.5 Coolant	3.139
	3.4.6 Grinding Gold	3.140
	3.4.7 Summary	3.141
3.5	Cleaning	3.142
	3.5.1 Introduction	3.142
	3.5.2 Contamination Nature	3.142
	3.5.3 Contamination Control	3.143
	3.5.4 Cleaning Processes	3.144
	3.5.5 Conclusions	3.146
3.6	Matte Finishing	3.150
	3.6.1 Introduction	3.150
	3.6.2 Process Background	3.150
	3.6.3 Tests	3.151
	3.6.4 Mechanized Matte Finishing	3.155
	3.6.5 Processes	3.157
	3.6.6 Conclusions	3.158
	3.6.7 Further Work	3.159
3.7	Evaluation of Mechanical and Physical Properties of Soldered and Welded Ring-Lead Connections	3.160
	3.7.1 Introduction	3.160
	3.7.2 Equipment and Testing	3.161
	3.7.3 Results	3.166
	3.7.4 Conclusions	3.182
	3.7.5 Further Work	3.184
3.8	Lead Protection	3.187
	3.8.1 Introduction	3.187
	3.8.2 Protective Devices	3.187
	3.8.3 Rigid Package	3.189
	3.8.4 Insulation of Package	3.189
	3.8.5 Disadvantage of Package	3.190
	3.8.6 Brush Block Lead Protection	3.195
	3.8.7 Summary	3.195
3.9	Processes	3.197
	3.9.1 Introduction	3.197
	3.9.2 Slip Ring Processes	3.197
	3.9.3 Brush Block	3.198
	3.9.4 Capsules	3.199
	3.9-I Approved Manufacturing Documentations	3.202

		Page
4.0	Design	4.1
	4.1 Design of 38 and 80-Circuit Assemblies	4.1
	4.1.1 Introduction	4.1
	4.1.2 Initial Work	4.1
	4.1.3 Slip Ring Sub-assembly	4.1
	4.1.4 Frame	4.5
	4.1.5 Stator Design Advancements	4.6
	4.1.6 Assembly	4.9
	4.1.7 Conclusion	4.10
	4.1-I Appendix (Drawings)	4.11
	4.2 Applications to Other Parts	4.12
	4.2.1 Introduction	4.12
	4.2.2 Conventional Configuration	4.12
	4.2.3 Less Conventional Configuration	4.15
	4.2.4 Discussion of Envelope Requirements	4.16
	4.2.5 Conclusions	4.17
	4.2-I Appendix (Drawings)	4.19
	4.3 Continuous Rotating Capsule	4.20
	4.3.1 Introduction	4.20
	4.3.2 Advantages and Disadvantages of Continuous Rotating Concept	4.20
	4.3.3 Capsule Configuration	4.24
	4.3.4 Problems of Design	4.28
	4.3.5 Problems of Construction	4.30
	4.3.6 Possible Applications For and Limitations of the Continuous Rotating Concept	4.32
	4.3.7 Possible Refinements of Existing Continuous Rotating Capsule Design	4.32
	4.3.8 Conclusions	4.33
	4.4 Brush Forming	4.35
	4.4.1 Introduction	4.35
	4.4.2 Hand Forming	4.35
	4.4.3 Machine Concept	4.38
	4.4.4 Conclusion	4.4.
	4.5 Tooling	4.42
	4.5.1 Introduction	4.42
	4.5.2 Slip Ring Molds	4.42
	4.5.3 Brush Block Tooling	4.51
	4.5.4 Casting Machine	4.56
	4.5.5 Assembly Fixture	4.58
	4.5.6 Summary	4.60
	4.5-I Appendix (Drawings)	

		Page
4.6	Reliability Controls Development	4.62
4.6.1	Purpose	4.62
4.6.2	Development History	4.63
4.6.3	Clean Area	4.63
4.6.4	Inspection Plan	4.64
4.6.5	Process Controls	4.65
4.6.6	Test	4.69
4.6.7	Inspection	4.73
4.6.8	Documentation	4.73
4.6.9	Rework Control	4.74
4.6.10	Conclusion	4.74
5.0	Conclusions and Recommendations	5.0
5.1	Program Conclusions	5.1
5.1.1	General	5.1
5.1.2	Materials	5.1
5.1.3	Processes	5.2
5.1.4	Design	5.4
5.1.5	Tools and Controls	5.5
5.1.6	Results	5.5
5.2	Recommendations	5.7
5.2.1	General	5.7
5.2.2	Major Areas of Future Work	5.7
5.2.3	Suggested Program	
6.0	Specifications, Processes, and Instructions	6.0
ANNEX	Slip Ring Capsule Applications Manual (Under Separate Cover)	

LIST OF FIGURES

Figure		Page
2.3.1	Thermal Shock Test Specimen	2.38
2.3.2	Thermal Shock Test Specimen Casting	2.39
2.3.3	Coefficient of Linear Thermal Expansion of Filled Plastics	2.40
2.3.4	Thermal Expansion of Various Materials used in Development Program	2.42
2.3.5	Thermal Expansion of Slip Ring Components	2.48
2.3.6	Effect of Various Fillers on Coefficient of Linear Thermal Expansion	2.49
2.4.1	Flex Life Versus Wire Size	2.61
2.4.2	The Extrusion Process	2.70
2.5.1	Standard Bearing Installation on Slip Ring Capsule	2.72
2.5.2	Crown and Ribbon Retainers	2.76
2.5.3	Rotor Reinforcements	2.79
2.5.4	Frame	2.80
2.5.5	Housings	2.80
2.5.6	Alignment Washer on Bearing Play Adjustment Mechanism	2.81
3.1-I-1	AC Bridge Noise Test Circuit	3.23
3.2.1	Cross Section of Unswaged Sample	3.42
3.2.2	Cross Section of Swaged Sample	3.42
3.2.3	Cross Section of Swaged Sample after Induction Fusing	3.42
3.2.4	Cross Section of Swaged Sample	3.43
3.2.5	Similar to Fig. 3.2.4. (373X)	3.43
3.2.6	Cross Section of Swaged Sample	3.43
3.2.7	Same as Fig. 3.2.6, different sample (267X)	3.43
3.2.8	Longitudinal Section of Swaged and Fused Wire used in Copper Fluoroborate Wick Test	3.44
3.2.9	Microstructure of Swaged and Fused Sample	3.44
3.2.10	Comparison of Swaged Conductors	3.44

Figure		Page
3.2.11	Dielectric Strength Vs. Temperature H-Film	3.45
3.2-I.1	Rotary Swaging Machine	3.61
3.2-II.1	Conductor Cross Section	3.62
3.2-III.1	Conductor Cross Section Unilay Construction	3.63
3.3.1	Scratch Test on a Plastic Plate	3.85
3.3.2	Scratch Test on a Plastic Plate	3.85
3.3.3	Scratch Test on a Polished Rod Sample	3.85
3.3.4	Photograph of a Mounted Rod Sample	3.85
3.3.5	Sample L4-A2	3.86
3.3.6	Sample L4-17	3.86
3.3.7	Sample L4-17 after Electroetching	3.86
3.3.8	Sample L4-B8 after Electroetching	3.86
3.3.9	Sample L4-C7 Showing Surface of Plated Rod	3.87
3.3.10	Sample L4-C7 after Electroetch	3.87
3.3.11	Sample L4-E4 after Electroetch	3.87
3.3.12	Sample L5-19A after Electroetch	3.87
3.3.13	Sample L5-23 after Electroetch	3.88
3.3.14	Sample L5-27 after Electroetch	3.88
3.3.15	Sample L5-23	3.88
3.3.15B	Plating in Grooves	3.89
3.3.15C	Plating in Grooves	3.89
3.3.15D	Seaming High in Radiused Groove	3.89
3.3.15E	Heavy Seaming in Shallow Groove	3.89
3.3.15F	Cross Sections of Good Sound Plating	3.90
3.3.15G	Same as Fig. 3.3.15F	3.90
3.3.15H	Same as Fig. 3.3.15F	3.90
3.3.16	Diagram of Equipment used to Study the Electrodeposition of 24 Karat Gold	3.91
3.3.17	Chart Showing the Effect of Current Density and Gold Content	3.92
3.3.18	Diagram of Plastic Rods used as Cathodes	3.93

Figure		Page
3.3.19	Typical Tensile Test of Gold Electro-deposit	3.94
3.3.20	Deflection of Strip Versus Time of Electrodeposition	3.95
3.3.21	Deflection of Strip Versus Time of Electrodeposition	3.96
3.3.22	Deflection of Strip Versus Time of Electrodeposition	3.97
3.3.23	Deflection of Strip Versus Time of Electrodeposition	3.98
3.3.24	Deflection of Strip Versus Time of Electrodeposition	3.99
3.3.25	Deflection of Strip Versus Time of Electrodeposition	3.100
3.3.26	Deflection of Strip Versus Time of Electrodeposition	3.101
3.3.27	Deflection of Strip Versus Time of Electrodeposition	3.102
3.3.28	Diagrams Showing Lead to Ring Plate	3.103
3.4.1	Slip Ring Grinding Operation	3.134
3.4.2A	Wheel Crushing	3.135
3.4.2B	Plastic Groove Grinding	3.136
3.4.3A	Wheel Dressing	3.137
3.4.3B	V-Groove Grinding	3.138
3.6.1	Taper Section Treated Surface	3.152
3.6.2	Contact Area on a 6 Gram Brush after 1000 Hours	3.152
3.6.3	Gold Wear Particle	3.154
3.6.4	Frictional Product	3.154
3.6.5	Wet Soda Blasted Ring Contact Areas	3.154
3.7.1	Model 1101 Unitek/Weldmatic Weld Heads	3.162
3.7.2	Model 1048-B Unitek/Weldmatic	3.162
3.7.3	Weld Schedules	3.167
3.7.4	Weld Schedules	3.168
3.7.5	Weld Schedules	3.196
3.7.6	P-S 57 Ring, Large Diameter (45X)	3.172

Figure		Page
3.7.7	P-S 57 Ring, Large Diameter (45X)	3.172
3.7.8	P-S 57 Small Ring Flex Life Probability	3.175
3.7.9	P-S 57 Large Ring Flex Life Probability	3.176
3.7.10	P-S 54 Small Ring	3.177
3.7.11	Hardness (Knoop) Test Sketch	3.178
3.7.12	P-S 57 Ring Solder Joint	3.183
3.7.13	P-S 57 Ring Solder Joint	3.183
3.7.14	P-S 54 Ring, Transverse Section of Weld Joint	3.184
3.7.15	Same as Fig. 3.7.14 (Using Dark Field Illumination of Electroetched Sample	3.184
3.7.16	Same as Fig. 3.7.15	3.184
3.8.1	Protective Devices	3.188
4.3.1	Continuous Rotating Capsule Assembly	4.21
4.3.2	Drawing of Continuous Rotating Capsule Assembly	4.26
4.3.3	Drawing No. 22332	4.28
4.3.4	Connector for Continuous Rotating Capsule	4.31
4.4.1	Brush Forming Fixture	4.37
4.4.2	Brush Forming Machine	4.39
4.4.3	Brush Forming Machine	4.39
4.4.4	Machine Schematic	4.40
4.5.1	Plastic Mold	4.46
4.5.2	Slip Ring Casting Mold	4.52
4.5.3	Mold Plug Detail	4.53
4.6.1	Flow Chart	4.66
4.6.2	Weld Pull Test	4.68
4.6.3	Ring Pull Test	4.68
4.6.4	Circuit Resistance	4.70
4.6.5	X-Ray	4.70
4.6.6	Assurance Test	4.72
4.6.7	Temperature Cycle	4.72

LIST OF TABLES

Table		Page
2.2-I	Physical and Typical Mechanical Properties of Structural Materials	2.15
2.2-II	Mechanical Properties at Elevated Temperature	2.17
2.2-III	Resistance to Corrosion by Specific Agents	2.18
2.3-I	Weight Loss of Plastics	2.28
2.3-II	Mechanical Properties of Unfilled Epoxies	2.28
2.3-III	Thermal Cycling of 80-Circuit Slip Ring Rotors Manufactured by Cast Process	2.29
2.3-IV	Thermal Expansion	2.32
2.3-V	Weight Loss of Epoxy Plastics	2.34
2.3-VI	Weight Gain of Plastics	2.35
2.3-VII	Mechanical Properties	2.36
2.3-VIII	Heat Distortion Temperature	2.37
2.4-I	Properties of Conductor Materials	2.55
2.4-II	Flex Life Ratings for Different Conductor Materials	2.58
2.4-III	Stranded Wire Data Sheet	2.60
2.5-I	Standard Bearing Fits and Concentricities	2.73
2.5-II	Related Bearing Failures in Saturn Parts	2.75
2.5-III	Component Materials	2.77
3.1-I	Haze Producing Characteristics of Alloys	3.4
3.1-II	Plastic Systems Having Low Amine Concentrations	3.7
3.1-III	Weight Loss of Experimental Cure Cycles	3.11
3.1-IV	Heat Distortion Temperature of Pigmented Plastics	3.12
3.1-V	Haze Formed on Contact Materials	3.16
3.2-I	Flex Test Results (127 flexes/min.)	3.46
3.2-II	Flex Test Results (75 flexes/min.)	3.47
3.2-III	Flex Test Results (170 flexes/min.)	3.47
3.2-IV	Pull Test Results	3.48
3.2-V	Resistance Measurements	3.49

Table		Page
3.2-VI	Hot Plastic Wick Test	3.50
3.2-VII	Diametrical Dimensions of Insulated and Uninsulated Wire	3.50
3.3-I	Effect of Gold Content, Free KCN Content, and Current Density on 24 Karat Gold Electroplate in Cyanide Bath @ 35°C	3.104
3.3-II	The Interrelationship of Temperature, Gold Content and C.D. on 24 Karat Gold Electroplate	3.107
3.3-III	Data Obtained while Studying the Electrodeposition of 24 Karat Gold from Two Acid Baths supplied by Technic Corp.	3.109
3.3-IV	Effects of Cathode Configuration on the Physical Characteristics of 24 Karat Gold Electrodeposited from Cyanide Baths @ 35°C	3.110
3.3-V	Effect of Agitation on 24 Karat Gold Electroplate in Cyanide Bath @ 35°C	3.111
3.3-VI	The Effect of Cathode Configuration and Size on 24 Karat Electroplate in Cyanide Bath @ 35°C	3.112
3.3-VII	The Effect of pH on 24 Karat Electroplate in Cyanide Bath @ 35°C	3.113
3.3-VIII	Anode Samples	3.114
3.3-IX	Solution Composition After Plating	3.115
3.3-X	Ratio of Current Density in Amperes per Square Foot to the Gold Content in Troy Ounces/Gal.	3.117
3.3-XI	Tensile Testing Data	3.118
3.5-I	Specific Cleaning Processes	3.147
3.6-I	C.A.T.S. Test - NASA Simulated Slip Rings Torque Data	3.156
3.7-I	Pull Test Data	3.171
3.7-II	Flex Life Data	3.173
3.7-III	Flex Life Data	3.174
3.7-IV	Average Heat-Affect Penetration	3.180
4.2-I	Number of Circuits Vs. Capsule Length	4.18
4.2-II	Number of Circuits Vs. Capsule Cross Section Area	4.18

2.0 MATERIALS

2.1 Contacts
by Wendell D. Hensley, Metallurgist

2.2 Structural Materials
by Wendell D. Hensley, Metallurgist

2.3 Plastics & Ceramics
by Robert D. Bowen, Plastics Technologist

2.4 Lead Wire
by Philip L. Reed, Materials Engineer

2.5 Bearings
by James A. Young, Senior Engineer

2.1 CONTACTS

2.1.1 Introduction

Extensive testing of contacts conducted in Phase I resulted in a recommendation of slip ring fabrication via the "cut-ring process." This process utilizes rings that are cut from tubing or blanked from sheet rather than being electrodeposited.

The Phase I tests showed that electrodeposited 24 karat gold rings (E.S. 118) demonstrated the lowest average noise levels of all the ring materials tested; however, the peak noise values of E.S. 118 were somewhat higher than those of other ring materials. Although there has been no apparent direct relationship between wear and noise, the peak noise values of E.S. 118 were attributed to the gross wear that resulted during tests, and/or to the uncontrolled variables in the electrodeposition processes.

It was postulated that the poor wear characteristics of E.S. 118 might be improved through (a) the use of a contact lubricant; (b) the upgrading of the electrodeposition processes to yield sound, uniform, hard, reproducible electrodeposits; and (c) the strengthening of the electrodeposits through the use of minute quantities of metallic hardening elements in the plating bath. It was felt that further study of methods to improve the wear characteristics of E.S. 118 might find electrodeposited 24 karat gold to be the optimum ring material.

Slip ring assemblies fabricated by the cut-ring process, wherein the rings used are wrought materials, have some features whose reliability could be improved. Jumpers or leads must be soldered or welded to the rings individually. Although each of these joining methods, particularly welding, can be made quite reliable, there exists the disadvantage that faulty connections may not show up until after several subsequent manufacturing processes. Conversely, faulty connections that occur in electrodeposition processes are sometimes immediately apparent during the plating process, and rework may be

instituted on the spot without further fabrication and electrical continuity testing. Furthermore, delivery, chemical composition, physical properties, and mechanical properties of the electrodeposited ring material are controlled in-house and need not be dependent upon manufacturers from whom wrought ring material must be purchased. Scrap loss of precious metal is minimized with electrodeposition processes since less machining is generally required, and plating baths may be recovered, replenished, and reused. There is no handling of individual ring-lead assemblies in electrodeposition and no problem of holding individual ring dimensions, such as flatness and individual ring wall thickness concentricity.

2.1.2 Phase I

The contact material combinations recommended at the conclusion of Phase I were, in order of preference:

Brush	Ring
E.S. 56, Cond. HTW	E.S. 57, Cond. CW2
E.S. 57, Cond. CW2	E.S 54, Cond. CW
E.S. 57, Cond. CW2	E.S. 57, Cond. CW2

This recommendation was based on extended noise and wear studies of simulated slip rings (C.A.T.S.) using 20 different contact material combinations and three (3) and six (6) gram brush forces, friction studies of sixteen (16) of the same twenty (20) material combinations, and current-carrying-capabilities of the four (4) different brush materials used in making up the twenty (20) material combinations.

Other areas were studied, and the results of these studies were considered in the above recommendation:

2.1.2.1 Brush force calculations - Calculated values differ from measured values by as much as .4 gram at forces below 6.5 grams; the deviation increases rapidly as brush force increases above 6.5 grams.

2.1.2.2. Measurement of Modulus of Elasticity of brush materials - Young's modulus in bending changes rapidly with small changes in deflection.

2.1.2.3 Maximum brush force in the elastic range as brush length and brush diameter are changed - maximum force values were tabulated for various materials.

2.1.2.4 Effect of brush force on slip ring torque.

2.1.2.5 Effect of brush force on noise - noise level drops sharply as brush force is increased from 2.5 to 6.0 grams; the noise tends to stabilize above 6.0 grams force

2.1.2.6 Reduction of noise by multiple wipers - noise levels drops in direct proportion to the number of wipers added.

2.1.2.7 Ring groove configuration - V-grooves, as opposed to flat rings, lower the noise level but raise the frictional force.

2.1.2.8 Current effects on modulus of elasticity and proportional limit - effects found to be proportional to electrical resistivity values of the brush materials.

2.1.2.9 Minimum fusing current brushes in simulated slip ring assembly; minimum fusing current versus brush length; fusing current versus time - E.S. 57 material found to be superior to all others.

2.1.2.10 Coefficient of sliding friction between different ring and brush combinations - for constant normal load and speed; for dry contacts; for oiled contacts; for varying normal load and constant speed.

2.1.2.11 Effect of brush alignment on noise - 1 to 2 degrees misalignment (7 mil. dia. brush, 6 gram force, .280" brush effective length) was insignificant.

2.1.2.12 Surface conditioning - pumicing (matte-finishing) of a diamond-machined ring adds an average of 6 milliohms to the single-wiper noise level.

2.1.2.13 Relaxation of brush force - E.S. 120, having the highest elastic modulus of the 4 materials tested, begins to deflect under a 3 gram load (7 mil. dia. samples, 3 grams

suspended at center of .722 in. length) after 165 hours; none of the other samples had deflected after 304 hours.

It was further concluded, from Phase I studies, that a 90° V-groove in the ring strikes the most reliable mean between reduced noise levels and increased frictional forces, as compared to flat rings.

2.1.3 Phase II

The results of the Phase I and some Phase II work led to the decision that Poly-Scientific conduct an extensive study of 24 karat gold electrodeposition process and subsequently fabricate all NASA capsules via the gold electrodeposition process developed using a cyanide bath. Plating bath modifications developed in the study were incorporated into the fabrication processes of NASA capsules. Poly-Scientific has recently conducted another study, under the sponsorship of NASA, the results of which have an important bearing on the selection of optimum contact materials. This study was concerned with the analysis and prevention of an insulating film or haze found to form on contact surfaces during long periods of time at room temperature and ambient pressure or during short periods of time at slightly elevated temperatures with or without slightly reduced pressure imposed.

2.1.4 Studies Conducted

2.1.4.1 24 Karat Gold Electrodeposition Processes - Until recently, very little work has been done on the controls required to produce thick (.001 to .050 in.) 24 karat gold electrodeposits. Poly-Scientific undertook such a study because there were indications that such a material is, potentially, the very best as the ring contact for the most reliable slip ring operation. (Section 3.3.)

Two types of 24K gold plating baths were studied; the cyanide bath, K Au $(CN)_2$ with an excess of free KCN content and the acid bath, AuCl with an excess of free HCl.

2.1.4.1.1 The Cyanide Bath - Scratch hardness testing, indentation microhardness testing (Knoop), and metallographic examinations were relied upon to show which variation of the plating parameters produced the electrodeposits of high hardness, uniform hardness, and microstructural soundness. The following plating parameters and effects were investigated:

Effects of gold content in the plating bath.
Effects of cathode current density.
Effects of free cyanide concentration.
Effects of bath temperature.
Effects of ring diameter.
Plating in grooved surfaces.
Plating on nickel electrodeposits which in turn, had been plated on copper electrodeposits.
Effects of bath agitation.
Effects of bath acidity (low PH).
Corrosion of gold anodes.

2.1.4.1.2 Acid Baths - Two (2) proprietary acid gold plating baths were studied in a manner similar to that for the cyanide bath but not in quite so much detail: "Orosene 999" and "Orotherm HT." These baths are sold commercially by Technic, Inc., Providence, R. I.

2.1.4.2 Surface Films on Contact Materials - This study was prompted by the reported formation of an insulating film or haze on slip ring contacts. The haze was formed under static conditions at room temperature and ambient pressure; the formation was accelerated by slightly elevated temperatures and slightly reduced pressures. The haze was sometimes visible, sometimes invisible and could be temporarily eliminated by slip ring operation and certain cleaning methods. The study is detailed in Section 3.1 of this report.

2.1.4.3 C.A.T.S. - Two Comprehensive Analytical Test System (C.A.T.S.) programs, in which simulated slip rings are used, were conducted. One program was designed primarily to investigate the relationship between wear and noise and wear and time for twelve different contact material combinations at 3-gram and 6-gram brush forces. This program was also intended as a verification of previous work.

The second program was designed to study the effects of different matte-finishing processes upon noise, wear, and torque. The ring material was 24 karat electrodeposited gold, cyanide bath, with a hard gold flash applied on the ring surface over the matte finish from an Orotherm HT bath. The brush material was E.S. 57, Condition CW2. The test was designed to run for 1000 hours in a NASA capsule mode; i.e., oscillation at 5 cps and 2 ± 1° double amplitude. The four (4) different surface treatments investigated were:

Diamond-machined rings (approx. 4 RMS).
Pumiced rings (approx. 32 RMS).
Wet-soda blasted rings (approx. 32 RMS).
Dry-soda blasted rings (greater than 32 RMS).

In each case, the hard gold flash was applied after the surface treatment.

2.1.5 Results

The detailed results of the 24K gold electrodeposition studies are covered in Section 3.3 of this report. In general, it was found that by close control of the plating parameters, an electrodeposit of uniform, high hardness having a metallurgically sound structure can be reproducibly processed from a cyanide bath. The Orotherm HT acid bath was proposed for use as a flash bath to put an even harder, wear-resistant gold flash on the surface of the cyanide gold electrodeposit.

Reference should be made to Section 3.1 for details of the results of the surface film or haze study. Briefly, this study showed that the haze, which increases noise levels by one or more orders of magnitude, cannot be completely eliminated without eliminating all organic materials from the slip ring system. The haze was not chemically identified but was classified as being either organic and/or organo-metallic. Whether or not the mechanism of attachment to the contacts is by chemical adsorption or chemical reaction, it was proved that the haze formed on 24 karat gold contacts is insignificant. Haze formation on the gold, platinum, and palladium

alloys makes the use of these materials prohibitive for slip ring use in highly reliable applications except as the wiping (brush) contact.

The C.A.T.S. study involving different contact material combinations showed 24K electrodeposited gold (E.S. 118) to perform poorly as a ring contact. The three (3) material combinations having E.S. 118 as the ring contact demonstrate higher 99 percentile noise levels than all other material combinations. The average noise levels of E.S. 118 were also higher, and the wear was much more severe on E.S. 118 than on any other ring material. There was very little difference in torque measurements for the 12 different material combinations. The preceding results were also true, in all respects, for the 6 gram brush force. The best-wearing ring materials were E.S. 54, Cond. CW and E.S. 38, Cond. CW (also the hardest ring materials tested). The brush material producing the least amount of ring wear was E.S. 55, Cond. HT; the brush material producing the most amount of ring wear was E.S. 56, Cond. HTA.

Simulated slip rings, other than those above, investigated in the C.A.T.S. study showed that rings surface conditioned with pumice tend to wear adhesively (transfer to brush), producing small wear particles. Diamond-machined rings tend to wear abrasively and non-uniformly, producing relatively large wear particles. Surface conditioning raised the noise level one to two orders of magnitude over diamond-machined rings.

The second C.A.T.S. study was conducted with oscillatory slip ring operation as opposed to the rotary operation of the first study, and with E.S. 118 rings <u>having a hard gold flash</u>. The results showed that there is <u>very little difference</u> in noise level between soda-blasted, pumiced, and diamond-machined surface treatments, when overlayed by a hard gold flash. Details of this study are given in Section 3.6 of this report.

2.1.6 Discussion

The detailed investigations of contact materials conducted under the NASA development contract have touched upon nearly all applicable aspects of contacts that one could possible conceive. Generally, it has been long recognized that only precious metals can be considered for use in Miniature Slip Rings. Ideally, the most noble of metals should be used for most reliable operation insofar as corrosion resistance is concerned. This metal should be relatively hard and have a high melting point and shear strength for wear resistance. It should have a high current-carrying capability and good machinability. The brush material should have all the foregoing characteristics and, in addition, good spring-forming characteristics such as a high creep limit. Metals or alloys that meet all of these requirements to the extent desired do not yet exist; however, the present capsule contact construction comes as close as is currently practical.

The ring is built up in four electrodeposition processes. Copper is first plated onto the exposed cross section of a copper jumper in a groove in the dielectric to make a reliable connection. Nickel is plated over the copper to minimize copper oxidation and diffusion. Finally, 24 karat gold is electrodeposited over the nickel. Gold, unlike the platinum metals, is substantially immune to adsorption of organic vapors which polymerize to yield insulating films. The gold is made uniform and reproducible by close control of important plating parameters. The tendency of cyanide gold electrodeposits to gall, seize, and transfer is minimized by a matte finish and a hard gold flash. The surface conditioning with a soda blast renders a surface metallurgically clean rather than just chemically clean. It has been theorized that the matte finish*, by virtue of its

* "Slip Ring Surface Preparation;" Ney Scope; Vol. 6, No. 3; The J. M. Ney Company; Bloomfield, Conn.; July-August, 1964.

roughness, tends to break up the resonance that may be set up in a brush in slip ring operation. This brush resonance is an important factor in causing stick-slip operation or inconsistent contact, resulting in high noise levels.

Gold is the most noble metal, and all the known oxides and hydroxides of gold are unstable. The only corrosive agents for pure gold at room temperature are chlorine, tellurium, iodine, bromine, fluorine, aqua regia, selenic acid, concentrated nitric acid, mercury, hydrogen cyanide, and potassium cyanide.

The processing documented and the controls instituted in conjunction with the hard gold flash and relatively low brush forces used in fabricating NASA capsules have overcome the disadvantages of electrodeposited 24 karat gold. The use of the hard-gold-flashed 24 karat gold ring in conjunction with E.S. 57, Cond. CWI as a brush in NASA capsules has been the best material combination for the highly reliable application.

2.1.7 Conclusions

2.1.7.1 Electrodeposited 24 karat gold processed in a cyanide bath and conforming to E.S. 118 with a hard gold flash of Orotherm HT is the most reliable ring material for Saturn capsules.

2.1.7.2 E.S. 57, Cond. CWI brush material is the optimum mating contact for these capsules. The spring characteristics are sufficient for the subject designs and the hardness is sufficiently high for good wear results with 24K gold at approximately 2-gram brush forces. The current-carrying capability is the highest of the commercial contact materials.

2.1.7.3 Matte finishing with pumice slurry or soda blasting minimizes stick-slip noise, provides metallurgical cleaning, promotes adhesive wear with smaller wear particles and less total wear volume, and promotes uniform noise and wear.

2.1.7.4 Gold plating of contacts prevents organic haze formation. Plating of the ring

only is sufficient, since plating of the brush has only a slight effect in reducing noise and may cause other problems such as high torque and galling.

2.1.8 Further Work

2.1.8.1 Creep tests of brush materials to find the minimum temperature and time at which the material will yield under static loads (10 grams and less) which are below the yield strength.

2.1.8.2 Fatigue tests of brush materials to find the endurance limit at various temperatures and small deflections.

2.1.8.3 Oxidation studies of contact materials in order to classify oxidation resistance via contact resistance measurements for the popular contact alloys in comparison to 24 karat gold.

2.1.8.4 Establishment of run-in procedures that will optimize subsequent noise, wear, and torque characteristics.

2.1.8.5 Definition of all physical and mechanical properties of contact materials in order to better understand contact phenomena that cannot now be fully explained.

2.1.8.6 Study of inorganic dielectrics in order to replace organics and minimize or eliminate haze (organic films).

2.1.8.7 Study of 24K gold-clad brush wire springs that have high current-carrying capabilities and are haze resistant.

2.1.8.8 Brazing of brushes to leads and jumpers to leads with miniature torches in order to replace solder joints with joints that retain high strength at process temperatures.

2.1.8.9 Resistance and/or induction brazing of jumpers to leads for the same reason as in 2.1.6.8.

2.1.8.10 Study of gold and gold alloy powder metallurgy rings that can possibly be impregnated or molded or sintered with a dry film lubricant, in small quantities, to make a highly noble 24K ring with improved wear characteristics.

2.1.8.11 Study of gold alloy electrodeposits that are harder than 24K gold electrodeposits but which may, due to their structure, be as resistant, or nearly so, to the adsorption of organic films as is 24K gold.

2.1.8.12 Study of newly-developed, high-strength precious metal alloys with high current-carrying capability for brush spring application.

2.1.8.13 Study of intermetallic compound strengthening of gold using only minute additions of base metals or other precious metals that will minimize loss of nobility, yet provide strengthening.

2.1.8.14 Study of Flame-Plating* of slip ring contacts with hot 24K gold particles. This process is reported to yield a wear-resistant coating of a higher density than can be attained by any other method.

* Trade name of coating process developed strictly for overcoming wear problems by Union Carbide Corp., Linde Division.

2.2 STRUCTURAL MATERIALS

2.2.1 Introduction

The structural members of the capsules developed under the subject contract are the frame and the slip ring base. These are the two members which must hold the brush blocks and the slip ring together in a single unit and provide sufficient structural rigidity to allow the slip ring capsule to withstand the stresses of manufacture and to withstand oscillatory and rotary motion as well as shock and vibration requirements imposed during handling and operation.

The structural materials must be resistant to corrosive action from cleaning solvents, contact with mating members (galvanic corrosion, organo-metallic compounds), lubricating oil, humid atmospheres, atmospheric contaminants, and oxygen. The strength of the structural members must be sufficiently high to withstand the rigors of handling, plastic curing, environmental testing, assembly, and fabrication. The ease of fabricating structural materials is important in maintaining the close dimensional tolerances, intricate shapes and design features, and the high surface finishes required in slip ring applications. The weight of structural members, although usually not a critical requirement, can be an important consideration in certain applications. Even in miniature slip rings, a reduction in weight is advantageous, providing the savings does not sacrifice other desirable characteristics.

One of the most important requirements of the structural member is relative thermal stability. During the processes of curing slip ring and brush block dielectrics, potting compounds; and cements, and during thermal qualification testing, it is imperative that differential thermal expansion and contraction be minimized. Excessive expansion of the slip ring base will cause cracking of the slip ring dielectric; excessive contraction of the dielectric against the slip ring base will also cause cracking of the dielectric. Similarly, excessive expansion of the brush block dielectric, which is anchored

to the frame, can cause cracking of the dielectric.

Even if differential expansion and contraction is not severe enough to cause cracking, it may cause separation between the slip ring base and the dielectric, reducing the usefulness of the slip ring base as a supporting member. Separations between the slip ring base and the dielectric and separations between the flange and the slip ring dielectric serve as areas for contaminants to become entrapped. Such contaminants can later escape into contact areas causing malfunction or corrosion of structural materials that would not otherwise be a problem. The need for structural members to be thermally compatible with dielectric materials is now obvious.

The structural materials must be nonmagnetic to the extent that the magnetic permeability is 1.02 maximum at 200 oersteds, since the magnetic characteristics of the materials could affect other system components.

AISI Type 303 stainless steel has been chosen as the structural material that best fulfills the above requirements.

2.2.2 Choice of Materials

The criteria for selecting the structural materials have been outlined above. Obviously, there are a number of materials which meet most or all of the requirements to some extent -- the question is which material is best suited to the application.

2.2.2.1 Materials considered - Aluminum and aluminum alloys were considered because they are proved, reliable materials in aerospace applications and have been used for years for structural application in the slip ring industry. Aluminum is generally used because of its appearance, fabricability, physical or mechanical properties, corrosion resistance, light weight, or a combination of these attributes.

Stainless steels are superior to aluminum alloys in some ways and inferior in others. They have greater weight, but also higher stiffness.

Stainless steels are also proved, reliable structural materials and are frequently used in the slip ring industry.

Magnesium alloys are used in great quantities in aircraft primarily because of the lightweight and excellent machinability. The poor corrosion resistance of magnesium quickly eliminated it from consideration, however. Other promising materials were eliminated because of limited background information on fabricating these materials, plus the fact that they offered no apparent advantage over the wide range of aluminum alloys and stainless steels.

2.2.2.2 Processing - No modifications of the various processes used in manufacturing the capsules should be required as a result of the choice of structural materials, with the exception of whether or not the member is to be anodized or passivated. Both stainless steels and aluminum alloys are compatible with all the processes. Protection (anodizing or passivating) is desirable in both cases during electrodeposition.

2.2.2.3 Tests - No tests were conducted on the structural materials alone. Mechanical and physical property data as well as corrosion resistance data are readily available for the aluminum alloys and the stainless steels. This data is presented in Tables 2.2.-I - 2.2.-III. Such data is authoritative; therefore, all the testing felt to be necessary is the fabrication and qualification testing of the final capsule.

2.2.3 Results and Discussion of Results

2.2.3.1 Aluminum Members - Aluminum alloy 6061T6 was used at one point for structural members because it apparently met all the requirements for the structural material and has an excellent machinability rating. It also matched, fairly closely, the dielectric material being used (E.S. 137) insofar as thermal expansion properties. 6061T6 also demonstrates better over-all corrosion resistance than do most other aluminum alloys. It was later decided, however, that aluminum alloy 2024T4 would be a more reliable structural material since it is

TABLE 2.2 - I

PHYSICAL AND TYPICAL MECHANICAL PROPERTIES OF STRUCTURAL MATERIALS

PROPERTY	6061T6 ALUMINUM	2024T4 ALUMINUM	303 ANNEALED STAINLESS STEEL
Density @ 68°F (G/CC)	2.70	2.77	7.9
Liquidus Temperature (°F)	1200	1180	2590
Solidus Temperature (°F)	1080	935	2550
Thermal Expansion, 68 to 212°F (Micro-in./in./°F)	13.0	12.7	9.6
Specific Heat @212°F (Btu/lb./°F	.23	.23	.12
Thermal Conductivity @ 77°F (Btu/hr./sq.ft./ft/°F)	101.0	101.0	9.4
Electrical Resistivity @ 68°F (Microhm-Cm)	4.31	5.75	73.00
Electrical Conductivity (% IACS)	40	30	2
Electrolytic Solution Potential versus N/10 Calomel Electrode (53 G NaCl + 3 G H_2O_2 Solution) (volts)	.83	.68	---
Ultimate Tensile Strength (PSI)	45,000	68,000	90,000
Yield Strength (PSI)	40,000	47,000	35,000

(cont'd)

TABLE 2.2 - I (cont'd)

PROPERTY	6061T6 ALUMINUM	2024T4 ALUMINUM	303 ANNEALED STAINLESS STEEL
Elongation (%) (1/2 in. Dia. Round Specimen)	17	19	50
Brinell Hardness (500-KG Load, 10-mm Ball)	95	120	160
Shear Strength (PSI)	30,000	41,000	---
Fatigue Limit (PSI) ($.5 \times 10^6$ cycles, R.R. Moore Type Rotating-Beam Machine)	14,000	20,000,	35,000
Modulus of Elasticity, Tension ($\times 10^6$ PSI)	10.0	10.6	28
Heat Treatment	Solution anneal for 10 min. to 1 hr. at 960 to 1010°F, water quench, precipitation harden for 6 to 10 hrs. at 345 to 355°F	Solution anneal for 10 min. to 1 hr. at 910 to 930°F, water quench, precipitation harden for 48 hrs. at room temperature.	Not hardenable by heat treatment but by cold working only.
Machinability (Based on AISI B1112 = 100)	190	150	65

TABLE 2.2.-II

MECHANICAL PROPERTIES AT ELEVATED TEMPERATURES

TEMPERATURE	6061T6			2024T4			303 STAINLESS		
	T.S.	Y.S.	EL.	T.S.	Y.S.	EL.	T.S.	Y.S.	EL.
75	45,000	40,000	17	68,000	47,000	19	90,000	35,000	50
300	34,000	31,000	20	45,000	36,000	17	---	---	--
400	19,000	15,000	28	27,000	20,000	27	---	---	--
500	7,500	5,000	60	12,000	9,000	55	---	---	--
600	4,500	2,500	85	8,000	6,000	75	---	---	--
700	3,000	2,000	95	5,500	4,000	100	---	---	--
800	---	---	--	---	---	--	61,000	35,000	35
1000	---	---	--	---	---	--	55,000	34,000	34
1200	---	---	--	---	---	--	45,000	30,000	30
1400	---	---	--	---	---	--	30,000	21,000	31
1600	---	---	--	---	---	--	20,000	10,000	34

T.S. - Ultimate Tensile Strength (PSI)

Y.S. - Yield Strength (PSI)

EL. - Elongation (%)

TABLE 2.2-III

RESISTANCE TO CORROSION BY SPECIFIC AGENTS

AGENT	6061T6 & 2024T4	303 STAINLESS
Acetone	Excellent	Good
Amines	Excellent	
Ammonia	Excellent	Excellent
Carbon Tetrachloride	Fair	Fair *
Chlorine (Dry)	Excellent	Fair
Copper Compounds	Poor	Good
Nickel Compounds	Fair	Good
Hydrochloric Acid	Poor	Poor
Hydrofluoric Acid	Poor	Poor
Methylene Alcohol	Poor	Good
Methylene Chloride	Poor	Good *
Nitric Acid	Good	Excellent
Oxygen	Excellent	Excellent
Hydrogen	Excellent	Excellent
Nitrogen	Excellent	Excellent
Perchloroethylene	Excellent	Excellent *
Potassium Cyanide	Poor	Good
Rosin	Excellent	Good
Silver Compounds	Poor	Good
Sulfur	Excellent	Excellent
Sulfuric Acid	Fair	Poor
Toluene	Excellent	Excellent
Sodium Chloride	Excellent	Excellent
Trichloroethylene	--	Good *
Trichloromonofluoro-ethane	--	Excellent

* If water is present, these compounds hydrolyze to form hydrochloric acid and sometimes organic acids.

stronger and more ductile than 6061T6. The machinability rating and corrosion resistance of 2024T4 are slightly inferior to that of 6061T6.

No problems were encountered with fabrication of the aluminum structural members, nor was the magnetic requirement of any concern with aluminum.

No problems of a corrosive nature were detected. Aluminum, actually a very active metal, owes its corrosion resistance to its ability to form a very thin oxide film that is highly resistant and protective. In most environments, this film, once broken, is self-healing. Galvanic corrosion of aluminum alloys must be considered, because the anodic potential of aluminum alloys may cause them to corrode sacrifically when in contact with most other metals in corrosive environments. Where practicable, direct metallic contact with a more cathodic metal, such as copper, brass, stainless steel, chromium, should be avoided.

More reliable corrosion resistance of aluminum alloys is provided by purposely producing oxide films of substantial thickness by anodic treatment in certain electrolytes, usually of an acid character. The anodic coating is minutely porous, and during the anodic treatment the current carried by the electrolyte in the pores converts the base metal into aluminum oxide. Therefore, during formation, the oxide film actually grows into the metal, leaving the first-formed oxide on the surface. The oxide coating is integral with the aluminum, accounting for the excellent adhesion between the aluminum base metal and the coating. Usually, it is necessary to make the submicroscopic porous coating nonadsorptive with a sealing operation. Sealing may be accomplished with hot water or by adsorption of a corrosion inhibitor by treatment with chromate solutions.

Aluminum alloys are most widely used for structural parts within an operating temperature range of -400 to +400^{o}F. Certain alloys may be used at temperatures up to about 600^{o}F in special applications.

One disadvantage of aluminum is the relatively low modulus of elasticity. This results in a flexible (low force/deflection ratio) when used in long, slender reinforcing shafts for small diameter rotors. In cases such as this, a material with a higher modulus should be chosen. In the particular 80 circuit units, the change from aluminum to stainless eliminated rotor eccentricity as a cause of manufacturing rejection.

Another problem that became evident with aluminum structural members was the occurrence of stress cracks in the rotor. The differential thermal expansion between the aluminum slip ring base and the E.S. 137 dielectric was great enough to cause cracks in the dielectric during standard processing temperatures. None of these rotors were subjected to the thermal cycling portion of qualification testing where temperatures even more extreme than these encountered in processing would be used. It became necessary, therefore, to correct the differential thermal expansion problem.

2.2.3.2 Stainless Steel Members - After some study, a change in dielectric materials was made from E.S. 137 to E.S. 218. E.S. 218 is superior to E.S. 137 in many ways and has a much lower coefficient of thermal expansion: 17.1 microinches/inch/^{o}C from +30^{o}C to +90^{o}C for the former, as opposed to 37.6 microinches/inch/^{o}C from +30^{o}C to +90^{o}C for the latter. 2024T4 aluminum, which has a coefficient of thermal expansion of 22.8 microinches/inch/^{o}C from +20^{o}C to +100^{o}C, is not as compatible with E.S. 218 as is stainless steel. Consequently, the structural materials were changed to 303 stainless steel, which has a coefficient of thermal expansion of 17.3 microinches/inch/^{o}C from 0^{o}C to +100^{o}C. Differential thermal expansion between the E.S. 218 dielectric and 303 stainless steel structural members is insignificant; no stress cracks have been found since the above change was instituted.

Although the housing is not actually a structural member, the choice of housing material is dependent upon the frame material. To minimize problems of galvanic corrosion and differential thermal expansion, the

housing and frame, which are in direct contact with each other, should be made from the same material.

Type 303 stainless steel is not as easily machined as the aluminum alloys, although no difficulties have been encountered in holding tolerances on stainless steel members. Slower speeds and feeds are necessary, so that it takes longer to fabricate an aluminum member.

The magnetic permeability of annealed 303 stainless steel is 1.003 at 200 oersteds, which is below the maximum requirement of 1.02 at 200 oersteds.

No corrosion problems with 303 stainless steel members have been noted. Most investigators agree that the resistance of stainless steels to corrosion results from the presence of a thin hydrous oxide film on the surface of the metal, rendering the metal passive. The film varies in composition from alloy to alloy and with different treatments (rolling, pickling, heating). This film, stabilized by chromium, is considered to be continuous, nonporous, insoluble and self-healing.

Passivation is not a constant stage; it exists only in certain conditions. The range of conditions over which stainless steels exhibit passivity may be broad or narrow, and passivity may be destroyed by slight changes in conditions. Under circumstances favorable to passivity, the stainless steels have a solution potential approaching that of the noble metals. When passivity is destroyed, the potential approaches that of ordinary iron.

Stainless steels are normally passive but, when exposed to corrosive solutions whose oxygenating power is low, these steels become active. Oxygenating agents must be present and replenished constantly to maintain passivity. Passivation in stainless steels is quite important as there is no middle ground -- the corrosion resistance is either very good or very bad.

Nickel increases the tendency of the chromium steels to become passive; thus, the austenitic stainless steels with 3.5 to 13% nickel are generally more corrosion resistant than the ferritic and martensitic stainless steels which contain 0 to 2.5% nickel. AISI 303 stainless steel is of the austenitic type.

The austenitic stainless steels are subject to severe attack at the grain boundaries by a number of corrosive media after exposure to temperatures in the range from 700 to 1650°F. This intergranular corrosion is believed to result from precipitation of chromium carbide and consequent depletion of chromium in the area adjacent to the grain boundaries.

Type 303 stainless steel is purchased under Military Specification QQ-S-763c, June 20, 1963, "Steel Bars, Shapes, and Forgings, Corrosion-Resisting," Class 303, Condition A, Round Bar, Cold Drawn, low magnetic permeability. After fabrication, the stainless steel member is passivated per Poly-Scientific E.S. 19.

2.2.4 Further Work

It is suggested that a study be conducted on the properties and fabrication of titanium and titanium alloys for use as slip ring structural members where equal strength and minimum weight advantages offset the higher cost. It is suggested that beryllium also be studied for use as structural members where the higher strength advantages offset the higher cost and difficulties in fabrication.

2.3 PLASTICS AND CERAMICS

2.3.1 Introduction

For a number of years, prior to the inception of this program, slip ring manufacture consisted of encapsulating the various components in a dielectric material that was easily handled, flexible enough to normally prevent cracking and rigid enough to normally resist warpage. The materials used were, generally, the thermosetting plastics that were relatively inexpensive and met most of the requirements set down by the slip ring users. This was the state of the art and in most cases was adequate.

The advent of the space age, meant that meeting most of the requirements was no longer good enough. Dielectrics must be developed that will be among the stronger links in the chain of components of which a slip ring assembly is composed.

This program was initiated with the following being the primary considerations in selecting a dielectric material for use in a highly reliable slip ring capsule assembly.

2.3.1.1 Chemical Stability - The material must be stable, with a minimum of outgassing when exposed to the different operating environments.

2.3.1.2 Chemical Resistance - The material must be resistant to the various plating solutions and cleaning solvents used in the manufacturing process.

2.3.1.3 Rigidity (Cast Process) - The material must have the rigidity to resist warpage during manufacture and operation.

2.3.1.4 Thermal Expansion - The material must have a coefficient of linear thermal expansion approximating the average thermal expansion of the dissimilar materials of which the capsule is composed.

2.3.1.5 Mechanical Strength - The material must have the mechanical strength to overcome

stresses introduced by differential expansion between itself and the metal components.

2.3.1.6 Adaptability - The material must be adaptable to slip ring manufacture.

The most serious problems to overcome in this program were warpage, stress cracking and outgassing. In studying the various types of dielectric materials that could be used, it was concluded that the most likely candidates for overcoming these problems were ceramics, diallyl phthalates and epoxies.

The state-of-the-art of ceramics at this point prohibited their use in an assembly requiring such close dimensional tolerances. Diallyl phthalates, available only as molding compounds, also proved unsuccessful. Only the epoxies remained as a potential dielectric for slip ring manufacture and extensive testing proved them to be well suited to this application.

During this program epoxy based materials were developed that have the properties required. These materials have excellent chemical resistance and chemical stability, have exceptional mechanical strength and exceed all thermal cycling requirements specified.

2.3.2 Phase I Review

2.3.2.1 Materials Screening and Development

2.3.2.1.1 Ceramics(1) - Several suppliers of ceramic materials were contacted to get their views on the feasibility of producing a slip ring with all-ceramic dielectrics. Alumina, Beryllium Oxide, Glass bonded mica and silicone bonded ceramics were some of the materials considered.

Though some of the simpler brush block insulators were made with a ceramic material, it was generally concluded that complex slip ring configurations are beyond the present state-of-the-art of ceramics materials.

(1) See Phase I Summary Report

2.3.2.1.2 Diallyl Phthalates [1] - Diallyl Phthalate molding compounds were used in making test assemblies by the transfer molding process. Several problems arose, the most serious being broken connections and lead washout. Glass fibers being exposed on the machined surface and lack of adhesion to itself and other materials were also cause for concern.

The diallyl phthalates are generally considered good in a high vacuum atmosphere but tests have shown that several of the epoxies are superior.

2.3.2.1.3 Epoxies - The epoxies as a class are probably the most versatile of the thermo-setting plastics. They can be varied in an infinite number of ways producing materials having a variety of properties. In searching for the "ideal" plastic a number of the epoxies were tested to determine their suitability for slip ring applications. The materials most extensively investigated were:

2.3.2.1.3.1 Bisphenol A Epoxies - bisphenol A epoxies are supplied in both liquid and solid form. The liquid resins have been widely used in slip ring applications and when cured with a suitable hardener have most of the properties required of a slip ring dielectric.

The solid resins are essentially high molecular weight forms of the liquid resins but are less stable in a high vacuum atmosphere.

2.3.2.1.3.2 Novolak Epoxies - This class of epoxies is characterized by more dense crosslinking than the bisphenol A resins and as a rule are more resistant to high temperature.

2.3.2.1.3.3 Flexibilizing Resins.- Flexible epoxy resins are products developed to overcome some of the specific disadvantages of the bisphenol A and novolak resins. The bisphenol A and Novolak resins cure to hard, rigid compositions with rather low impact and

(1) See Phase I Summary Report

elongation characteristics. The addition of a flexibilizing resin improves impact strength, elongation and in some cases, tensile strength. Flexibilizing resins have a deleterious effect on the chemical resistance and chemical stability of the material.

2.3.2.1.3.4 Curing Agent - Curing agents investigated were primarily the aliphatic and aromatic amines, and the anhydride curing systems.

The aliphatic amines are generally used in quick curing compounds used for small potting and cementing operations. These materials are characterized by low heat distortion temperatures and a high degree of flexibility. Chemical resistance and chemical stability are generally poor.

The aromatic amine cured compounds are used for somewhat larger castings than the aliphatics and are characterized by moderately high heat distortion temperatures, good chemical resistance and generally good chemical stability.

The anhydride cured compounds are stable to very high temperatures, up to 260°C, but are very brittle materials. A tertiary amine accelerator is usually used with the anhydrides.

2.3.2.1.3.5 Fillers - Inert fillers were used in several formulations to lower thermal expansion. The two fillers most extensively investigated were calcium carbonate and lithium aluminum silicate.

2.3.2.1.4 Miscellaneous Plastics[1] - Silicones, polyesters, urethanes and acrylics were also investigated, but were found inferior to the epoxies and so were dropped.

2.3.2.2 Testing[1]

2.3.2.2.1 Chemical Stability - Chemical stability was determined by baking the cured

(1) See Phase I Summary Report

plastics at 150°C at pressures reduced to 2 mm Hg. Plastics were weighed before and after bake with the loss of weight being the criteria of chemical stability. Test specimens were 1-1/2" diameter, 1/8" thick discs.

Table 2.3-I shows that the chemical stability of the unfilled aromatic amine cured bisphenol A (E.S. 84, E.S. 134) and Novolak (E.S. 151) epoxies is considerably better than diallyl phthalate (E.S. 144) and the flexibilized epoxy (E.S. 149).

2.3.2.2.2 Mechanical Strength - Mechanical strength of the unfilled epoxies are generally in the same range with the exception of the anhydride cured compounds which are somewhat lower than the amine cured materials. Table 2.3-II.

2.3.2.2.3 Thermal Cycling - Several test rotors were thermal cycled per NASA specification then sectioned to determine the extent of internal cracking. Table 2.3-III shows that none of the dielectric materials developed under Phase I of this program withstood thermal cycling without plastic fracture.

2.3.2.3 Phase I Conclusions - The conclusions reached as a result of the various tests performed in Phase I of this program were:

2.3.2.3.1 In order to eliminate plastic cracking, a material must be used having a coefficient of thermal expansion approximating that of the slip ring components and the mold.

2.3.2.3.2 Due to poor chemical resistance and chemical stability, a flexibilized compound is not suitable for slip ring applications.

2.3.2.3.3 Ceramic materials are not adaptable to slip ring manufacture.

2.3.2.3.4 Chemical and structural integrity of the diallyl phthalates in slip ring applications are questionable and therefore not recommended.

2.3.3 Phase II

In attempting to formulate a material having a

TABLE 2.3-I

WEIGHT LOSS OF PLASTICS

Plastic	Percent Weight Loss after 72 hours at 150°C and 2 mm Hg.
E.S. 84	0.08
E.S. 134	0.07
E.S. 149	0.55
E.S. 151*	0.09
E.S. 144	0.35

* This particular test shows a weight loss of the aromatic amine cured epoxy novolak to be higher than that of the two bisphenol A epoxies. Similar tests have shown the Novolak to be consistently lower.

TABLE 2.3-II

MECHANICAL PROPERTIES OF UNFILLED EPOXIES
(Tests Performed at P.S.)

Plastic	Flexural Strength In. Hg.	Impact Strength In.
E.S. 84	12.03	2.86
E.S. 134	14.48	1.91
E.S. 151	14.39	2.50
E.S. 167	14.56	3.75
A-67-3*	11.00	1.65
A-72-1**	12.65	1.50

* Anhydride cured bisphenol A Epoxy.
** Anhydride cured Novolak Epoxy.

TABLE 2.3-III

THERMAL CYCLING OF 80 CIRCUIT SLIP RING ROTORS MANUFACTURED BY CAST PROCESS

Part No.	Plastic	Observations
D1386	E.S. 134	Severe cracking in barriers and around bearing pin.
D1287	E.S. 137*	Severe cracking around bearing pin. Large internal cracks occurred parallel to slip ring axis.
D1287	E.S. 151	No cracking at bearing pin, slight cracking of barriers.
D1287	E.S. 161**	Severe cracking occurred both in barriers and around bearing pin.
D1386	P-38***	Large internal cracks occurred parallel to slip ring axis. No cracked barriers.

* Anhydride cured, lithium aluminum silicate filled Epoxy Novolak.

** Aromatic amine cured, calcium carbonate filled bisphenol A epoxy.

*** Filled proprietary epoxy compound supplied by Bacon Industries.

coefficient of thermal expansion approximating that of the other slip ring components, there are two basic considerations. First, the material must be adaptable to slip ring manufacture and second, the material must be mechanically capable of withstanding the rigors of processing and handling.

2.3.3.1 Materials

2.3.3.1.1 The Anhydrides - The first attempts to develop this material were based on the anhydride cured compounds because of these high heat resistance plus, it was believed that a higher filler loading could be attained with these materials. The most stable novolak resin was tried initially but its high viscosity prevented the filler loading required so a low viscosity bisphenol A resin was substituted.

The bisphenol A resin permitted a higher filler loading but still not to the extent that the thermal expansion was lowered sufficiently.

2.3.3.1.1.1 Liquid Anhydrides - Nadic methyl anhydride was the most extensively used material in these compounds because its low viscosity permits it to also serve as a diluent. Hexahydrophthalic anhydride and alkendic anhydride were also used but neither were found to have the advantages of nadic methyl anhydride.

2.3.3.1.1.2 Solid Anhydrides - Little was done with the solid anhydrides except to make some preliminary castings. Trimellitic anhydride, pyromellitic dianhydride and boric anhydride were the only materials of this class investigated.

Solid anhydrides are insoluble in epoxy resins but are capable of curing the resin while in suspension. Epoxies cured with these materials are very brittle and have little strength.

2.3.3.1.2 The Aromatic Amines

2.3.3.1.2.1 4,4' Methylene Dianiline MDA - Methylene dianiline produces one of the more stable compounds when used with the liquid bisphenol A or novolak epoxies. This material is supplied as a solid with a melting point of 89°C and is used with the liquid epoxies at the

stoichiometric ratios of 25 to 28 PHR. Working temperatures with these compounds are 90 to 120°C depending on the reactivity of the resin used.

2.3.3.1.2.2 Meta-Phenylene Diamine (M-PDA) - This material is also supplied as a solid and has a melting point below 60°C. Being a more reactive material than methylene dianiline, processing temperatures are somewhat lower. m-Phenylene diamine is used at the stoichiometric ratio of 14 to 16 PHR.

2.3.3.1.2.3 Curing Agent Z (Shell Chemical Co. - Curing agent Z is supplied as a liquid eutectic mixture of methylene dianiline and m-Phenylene diamine with phenyl glycidel ether as a coupling agent. Stoichiometric ratios are 20 to 22 PHR. Working temperature is 90 to 120°C.

2.3.3.1.2.4 Diaminodiphenylsulfone (DADS) - This material is supplied in solid form and has a melting point of 175°C. It is soluble in an epoxy resin at about 120°C. Stoichiometric ratios are 30 to 35 PHR and working temperatures up to 180°C.

Working temperatures of (a) MDA, (b) m-PDA and (C) Z are too low to permit the high filler loading required to sufficiently lower the thermal expansion but with (d) DADS, processing temperatures up to 180°C allow very high filler loadings. With DADS, usable compounds have been developed with thermal expansion coefficients as low as 13.4×10^{-6} in/in/°C.

2.3.3.2 Testing

2.3.3.2.1 Thermal Expansion - Coefficient of linear thermal expansion of plastics was determined by ASTM method D696-44. Table 2.3-IV shows that the aromatic amine cured, lithium aluminum silicate filled E.S. 209 and E.S. 218 and Bacon Industries P-38 have the required thermal expansion.

TABLE 2.3-IV

THERMAL EXPANSION

Plastic	Thermal Exp. $in/in/^{\circ}C \times 10^{-6}$	Description
E.S. 84	61	Typical unfilled, aromatic amine cured bisphenol A epoxy.
E.S. 115	32	Aromatic amine cured, calcium carbonate filled bisphenol A epoxy.
E.S. 137	37.6	Anhydride cured, lithium aluminum silicate filled epoxy novolak.
E.S. 149	74	Aromatic amine cured, flexibilized epoxy (unfilled).
E.S. 151	61.5	Unfilled, aromatic amine cured epoxy novolak.
E.S. 193	69.5	Typical unfilled, aliphatic amine cured bisphenol A epoxy.
E.S. 209	13.4	Aromatic amine cured, lithium aluminum silicate filled bisphenol A epoxy.
E.S. 218	17.1	Aromatic amine cured, lithium aluminum silicate filled bisphenol A epoxy.
P-38	16	Proprietary epoxy compound - Bacon Industries.
A-79-28	22.5	Anhydride cured, lithium aluminum silicate filled bisphenol A epoxy.

2.3.3.2.2 Chemical Stability - Chemical stability of plastics was determined by baking plastics shavings at 150°C and 200°C and 2 mm Hg pressure. Plastics were weighed before and after bake with the loss of weight being the criteria of chemical stability. Shavings were used in these tests to increase the surface area.

Table 2.3-V shows the superiority of E.S. 209 and E.S. 218 over all plastics tested plus it shows the superiority of the unfilled, aromatic amine cured novolak epoxy (E.S. 151) over the unfilled bisphenol A epoxies and the filled, anhydride cured novolak epoxy.

2.3.3.2.3 Chemical Resistance - Chemical resistance was determined by immersing the plastics in the various cleaning solvents and plating solutions for a period of 24 hours. Plastics were weighed before and after immersion with the change in weight being the criteria of chemical resistance.

Table 2.3-VI compares E.S. 209 and E.S. 218 plastics with a typical aromatic amine cured, unfilled epoxy. The weight change of E.S. 209 after immersion in acid solutions indicates that it has been attacked rather severely while E.S. 218 and E.S. 84 are, for all practical purposes, left uneffected.

2.3.3.2.4 Mechanical Properties - Mechanical properties were determined by ASTM test methods performed by the United States Testing Company.

Table 2.3-VII shows the superiority of E.S. 209 and E.S. 218 plastics in all tests performed except impact strength.

2.3.3.2.5 Heat Distortion Temperature - Heat distortion temperature of plastics was also performed by ASTM test methods by the United States Testing Company.

Table 2.3-VIII shows the heat distortion temperature of the anhydride cured compounds to be better than that of the aromatic amine cured compounds.

TABLE 2.3-V

WEIGHT LOSS OF EPOXY PLASTICS

Plastic	% Weight Loss	Description
E.S. 65	17.77	Modified aliphatic amine cured, bisphenol A epoxy.
E.S. 193	4.34	Pure Aliphatic amine cured, bisphenol A epoxy.
E.S. 84	7.06	Modified aromatic amine cured, bisphenol A epoxy.
E.S. 167	5.23	Aromatic amine cured, bisphenol A epoxy.
E.S. 151	1.51	Aromatic amine cured epoxy novolak.
E.S. 137	2.57	Anhydride cured, filled epoxy novolak.
P-38	1.15	Filled, proprietary epoxy compound.
E.S. 209	0.98	Aromatic amine cured, filled, bisphenol A epoxy.
E.S. 218	0.79	Aromatic amine cured, filled, bisphenol A epoxy.

TABLE 2.3-VI

WEIGHT GAIN OF PLASTICS

Immersion Fluid	Weight gain after 24 hr. immersion %		
	E.S. 84	E.S. 209	E.S. 218
Distilled Water	0.0730	0.0426	0.0562
Copper Fluoborate	--	-3.1500	-0.2820
$CuSO_4$-H_2SO_4	0.0469	-0.9080	0.0113
Sodium Zincate	0.0230	0.0182	0.0266
K(Ag)CN	0.0232	0.0389	0.0433
K(Au)CN		0.0894	0.0512
Nickel Sulfamate		0.0028	0.0535
NaOH		-0.0310	0.0166
20% HCl		-1.8500	0.0259
Alkaline Soak Cleaner	0.0698	0.0575	0.0459
Blacosolv	0.1988	0.0113	0.0252
Acetone	0.3175	0.0000	0.0170
Solox	0.1594	0.0168	0.0362
Chlorethene	0.0000	0.0000	0.0155
Freon	0.1328	-0.0028	0.0084
AP-20		0.0139	0.0197
Isopropanol		-0.0046	0.0292
FC 43	0.0448	0.1440	0.0171
Methylene Chloride	1.360	0.0082	0.0808
Dimethyl Formamide	0.6570	0.0000	

TABLE 2.3-VII

MECHANICAL PROPERTIES

Plastic	Izod Impact Strength Ft. lb/in. of notch	TENSILE PROPERTIES		FLEXURAL PROPERTIES		COMPRESSIVE PROPERTIES	
		Tensile Strength, PSI	Modulus of Elasticity, x 10^6 PSI	Flexural Strength, PSI	Flexural Modulus, x 10^6 PSI	Compressive Strength, PSI	Compressive Modulus, x 10^6 PSI
E.S.137	0.23	8,810	1.01	13,300	1.19	37,300	0.77
E.S.149	1.08	10,200	0.43	16,700	0.44	39,700	0.37
E.S.151	0.53	13,800	0.44	20,100	0.47	36,100	0.41
*E.S.167	0.74	12,500	0.40	21,200	0.48	35,800	0.38
**A-72-4	0.31	7,750	0.47	15,200	0.53	33,900	0.43
***E.S.246	0.25	8,150	1.53	13,800	1.52	40,000	0.81
E.S.209	0.32	12,300	2.96	16,500	2.84	49,300	1.33
E.S.218	0.33	14,400	2.87	21,000	2.56	48,200	1.45

* Aromatic Amine Cured, bisphenol A epoxy.

** Anhydride Cured, Novolak Epoxy.

*** Anhydride cured, lithium aluminum silicate filled, novolak epoxy.

TABLE 2.3-VIII
HEAT DISTORTION TEMPERATURES

Plastic	E.S.137	E.S.149	E.S.151	E.S.167
HDT °C	163 182*	93	133	111

Plastic	A-72-4	E.S.246	E.S.209	E.S.218
HDT °C	156	189 188*	154 179*	152 166*

* Postcured an additional 24 hours at 150°C.

2.3.3.2.6 Thermal Cycling - Several 80 circuit rotors were made by the plating process with E.S. 218 plastic. These rotors were thermal cycled per NASA Specification then sectioned and examined for internal cracks. No cracking occurred in any of these parts.

Thermal cycling and thermal shock tests were also performed on E.S. 209 and E.S. 218 plastics using a 1-1/4" diameter stainless steel washer. These castings were thermal cycled 5 times from -18°C to + 100°C then one time from -55°C to +150°C and one time from -55°C to +250°C. No cracking occurred in either plastic. See Figures 2.3.1 and 2.3.2 for washer and casting dimensions.

2.3.3.3 Processing

2.3.3.3.1 Cast Process

2.3.3.3.1.1 This method of slip ring manufacture consists of loading the required number of rings into a mold then encapsulating the precut rings with the dielectric material. The advantantages of this method of fabrication are:

Only one machining operation required.
No contact with plating solutions.
Relatively simple, inexpensive tooling required.

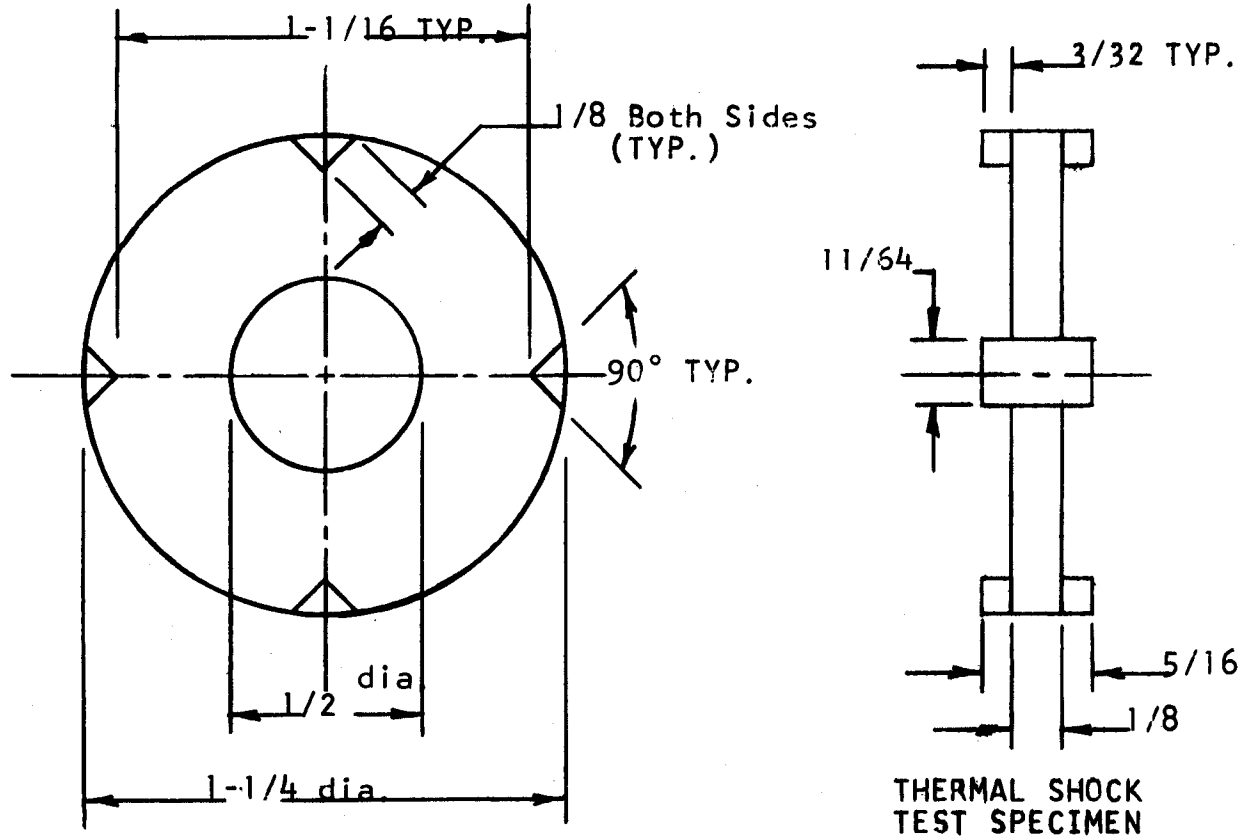

1-1/16 TYP.
1/8 Both Sides
(TYP.)
90° TYP.
1/2 dia
1-1/4 dia.
MATERIAL - STAINLESS STEEL
3/32 TYP.
11/64
5/16
1/8
THERMAL SHOCK
TEST SPECIMEN

Fig. 2.3.1

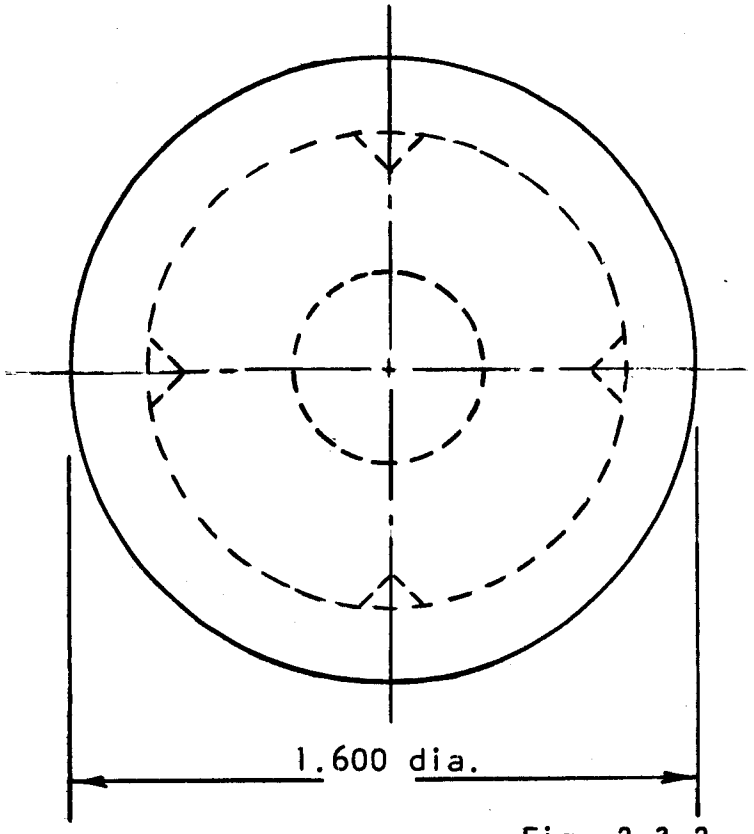
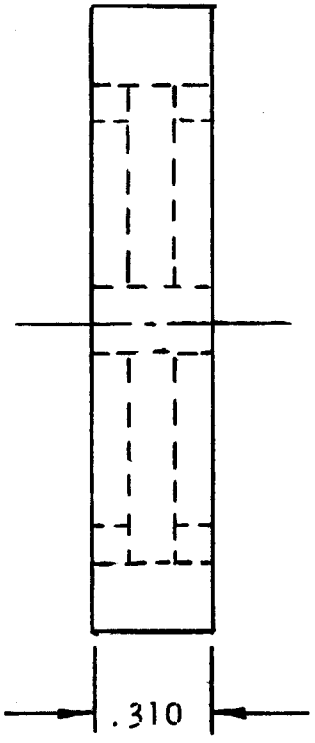


Fig. 2.3.2



THERMAL SHOCK
TEST SPECIMEN
CASTING

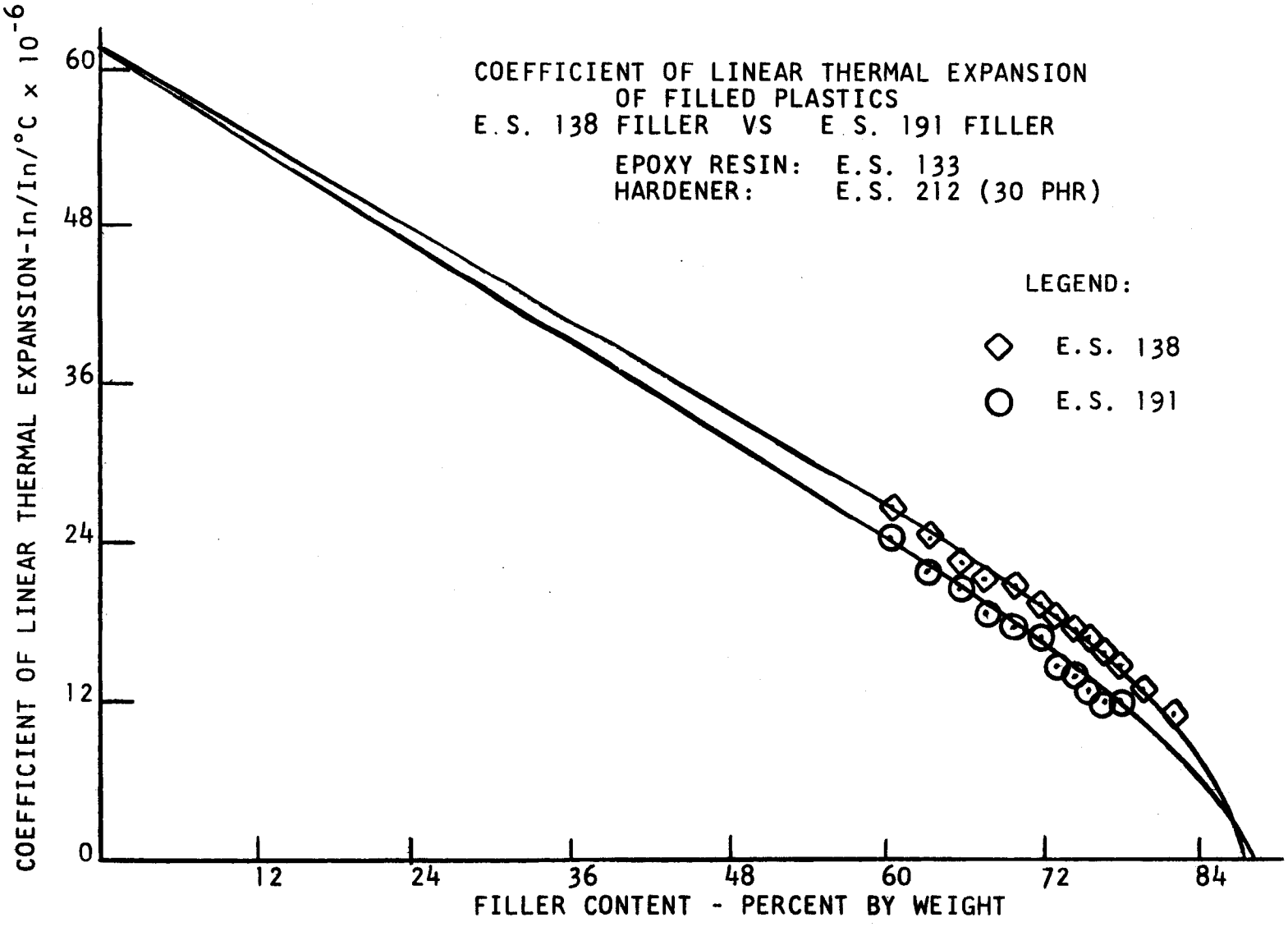

COEFFICIENT OF LINEAR THERMAL EXPANSION
OF FILLED PLASTICS
E.S. 138 FILLER VS E.S. 191 FILLER
EPOXY RESIN: E.S. 133
HARDENER: E.S. 212 (30 PHR)
LEGEND:
E.S. 138
E.S. 191
COEFFICIENT OF LINEAR THERMAL EXPANSION-In/In/°C x 10-6
0
12
24
36
48
60
12
24
36
48
60
72
84
FILLER CONTENT - PERCENT BY WEIGHT

Fig. 2.3.3

2.3.3.3.1.2.1 Mold Materials - The mold material should be one that nearly matches the thermal expansion of the slip ring components and the encapsulating plastic. A matching material would eliminate the need for shrinkage factors and decrease cracking due to differential expansion and contraction.

Mold materials used in making slip rings by the cast process were:

Vega Steel.
Cerro Base and Cerrotru Alloys.
Diallyl Phthalate.
Filled Epoxy.

Steel molds have little advantage over the other materials in slip ring manufacture by the cast process. Steel molds can be used over and over again but cleaning them is probably more expensive than using "throwaway" plastic molds. The difference between steel and plastic molds in dimensional stability is so slight that it warrants no consideration.

Cerrobase and Cerrotru alloys have been used with the lower temperature casting and curing plastics, but their low melting point, 124°C and 138°C, prohibits their use with the heavily filled plastics. Dimensional stability of these materials is questionable.

Diallyl Phthalate molds have been used quite extensively in casting slip ring rotors with both filled and unfilled encapsulating plastics, and work well. Generally the unfilled casting epoxies have elastic moduli sufficiently low to tolerate residual differential thermal expansion and the lower thermal expansion, filled epoxies have a compressive strength sufficient to resist fracture.

Heavily filled epoxies have been used as mold materials to match the thermal expansion of the encapsulating plastic and the other slip ring components but they have shown no particular advantage over diallyl phthalate in practice.

See Figure 2.3.4 for thermal expansion of mold materials.

THERMAL EXPANSION OF VARIOUS MATERIALS USED IN DEVELOPMENT PROGRAM
COEFFICIENT OF LINEAR THERMAL EXPANSION
In/In/°C x 10-6
0
20
40
60
80
E.S. 65
E.S. 84
E.S. 115
E.S. 134
E.S. 137
E.S. 149
E.S. 151
E.S. 193
E.S. 199
E.S. 209
E.S. 218
E.S. 220
Bacon P-38
E.S. 222
E.S. 144
Cerrobase
Cerrotru
VEGA FM Steel
63/37 Solder
303 St.Steel
2024T4 Alum.
Yellow Brass
Elect.Copper
Elect.Gold
Elect.Nickel
E.S. 57 Gold

Fig. 2.3.4

2.3.3.3.1.3 Plastics Entrance - With most of the unfilled plastics the opening into the mold cavity makes little difference. Their low viscosity permits penetration and filling of even the most complex configurations relatively simple. The heavily filled plastics however, have comparatively high viscosities that demand a large, unrestricted opening into the mold cavity. This is usually best accomplished by using a slot opening the full length of the frontshaft.

2.3.3.3.1.4 Encapsulation - Encapsulating a part made with precut rings consists of preheating the mold to a predetermined temperature, mixing the plastic and filling the mold reservoir. The part is then evacuated to 2 mm Hg to deaerate the plastic and mold, then remove the vacuum allowing the plastic to be forced into the mold cavity by atmospheric pressure.

2.3.3.3.1.5 Machining - Regardless of the type plastic used - filled or untilled - machining is best accomplished by grinding. Dimensional tolerances are more easily held by this method, it is less time consuming therefore, more economical.

2.3.3.3.2 Plating Process - This method of slip ring manufacture consists of loading the lead wire only into a steel mold then performing successive casting, grinding and plating operations until the part is completed.

2.3.3.3.2.1 Tool Design - A four piece mold is used for first casting with each parting line having tiny slots for lead positioning. When loaded and sealed the mold is cast with the mold cavity being filled through runners located on four sides of the mold cavity, usually extending the full length of the frontshaft.

Second and third castings are made in a two piece mold by casting through a slot in the side of the mold that opens into, and extends the full length of the frontshaft. See Section 4.4 for more detailed mold description.

2.3.3.3.2.2 Mold Materials - Due to the method by which the mold must be loaded and cast, steel molds are mandatory for first casting and

preferred for second and third castings. Differential expansion and contraction between the steel mold and the casting plastic (E.S. 218) is so small that shrinkage and cracking are not a problem.

2.3.3.3.2.3 Encapsulation - In fabricating slip rings and brush blocks by the plating process two methods of casting the plastic into the mold have been used. The first method tried was by using a controlled velocity casting machine which is essence is a combination of vacuum casting and transfer molding. The second method was by the conventional vacuum casting technique.

2.3.3.3.2.3.1 Controlled Velocity Casting - The controlled velocity casting machine consists of a heated, vibrating platform mounted on an enclosed frame. Centered in the platform is a cylinder with an air driven piston. In the casting operation, a sufficient amount of plastic is placed in the cylinder, then the mold, preheated to 150°C, is bolted to the platform. An aluminum vacuum chamber is placed over the mold, pressure is reduced to 2 mm Hg, vibrator is turned on and piston is raised. Piston moves at a rate of 0.130"/minute and is raised until all plastic is forced into the mold with excess plastic escaping through a small weep hole in the top of the mold. The mold is then removed from the machine and cured in an oven.

2.3.3.3.2.3.2 Vacuum Casting - This method was briefly described under "Cast Process" and is described in detail in P.I.'s 75 and 79.

In casting with the controlled velocity casting machine small separations would occur in the plastic. These separations were apparently caused by a hot flow of plastic being forced by a cooler mass of plastic then failing to fuse back together.

This condition does not exist in parts made by the vacuum casting method, so use of the casting machine was discontinued in favor of vacuum casting.

2.3.3.3.2.4 Machining - All machining of plastics is accomplished by cylinder grinding techniques which is required for two reasons. The rigid dimensional requirements are more easily held by grinding and, the abrasive filler in the plastic makes machining by conventional methods impractical.

2.3.3.3.2.5 Cements - E.S 193, E.S. 199 and E.S. 222 are used for repairing small cracks and voids that occasionally occur in rotors and brush blocks. These materials are based on DER 332 epoxy resin cured with triethylenetetramine, one of the more stable aliphatic amines.

E.S. 193, an unfilled material, has a very low viscosity and flows readily into tiny cracks. When cured, the bond strength approaches that of the material being repaired.

E.S. 199 and E.S. 222 are moderately filled versions of E.S. 193 and are used primarily for filling small voids and air bubbles.

E.S. 156, Loctite Grade E sealant, a polyester activated by catalytic metals, is used for retaining tiny screws in the capsule assembly. The very low viscosity of this plastic permits penetration into the threaded hole around the screw and when cured, locks the screw into place.

2.3.4 Discussion

The superiority of the filled epoxy over ceramics, diallyl phthalate, unfilled epoxies and other plastics is apparent in all areas of slip ring manufacture and operation. Its thermal expansion approximates that of the other slip ring components, and it is structurally capable of absorbing residual stresses introduced by differential thermal expansion. It has proven itself to be stable in thermal cycling, chemical resistance, and in low pressure atmospheres. The dimensional stability of the filled epoxy is unsurpassed by any of the materials tested.

Like all organics, the filled epoxy contributes to the formation of a thin film of a polymeric material, commonly referred to as "Haze," on the surface of certain of the precious metal alloys.

This phenomena occurs to a lesser extent when a heavily filled rather than an unfilled plastic is used and is non-existent when the alloy is replaced by a 24K gold contact surface. See Section 3.1, for a more detailed description of haze formation.

2.3.5 Conclusions and Recommendations

2.3.5.1 In testing the various materials it is concluded that a bisphenol A epoxy filled with particulate lithium aluminum silicate and cured with an aromatic amine produces a material that is:

2.3.5.1.1 More chemically stable than any material adaptable to slip ring manufacture.

2.3.5.1.2 Resistant to all plating solutions and solvents in which it comes in contact.

2.3.5.1.3 Rigid and highly resistant to warpage during manufacture and operation.

2.3.5.1.4 Filled to the extent that it has a coefficient of linear thermal expansion approximating that of the other slip ring components.

2.3.5.1.5 Mechanically capable of overcoming residual stresses introduced by differential thermal expansion.

2.3.5.1.6 Most suitable to slip ring manufacture.

2.3.5.2 Based on the above conclusions it is recommended that the dielectric materials used in the manufacture of a highly reliable slip ring capsule assembly be:

2.3.5.2.1 Slip ring rotor - The components of the slip ring rotor should be encapsulated with the filled, aromatic amine cured epoxy described in P.S. Engineering Specification No. 218.

This material should be "Gel-Cured" eight hours at 120°C minimum, and "Post-Cured" four hours at 150°C minimum.

Maximum cure of this material is not to exceed twenty-four hours at 200°C.

2.3.5.2.2 Slip ring stator - The components of the slip ring stator should be encapsulated with the filled, aromatic amine cured epoxy described in P.S. Engineering Specification No. 209 or 218, the two plastics being interchangeable for this application.

These materials should be "Gel-Cured" eight hours at 120°C minimum, and "Post-Cured" four hours at 150°C, minimum. Maximum cure of these materials is not to exceed twenty-four hours at 200°C.

2.3.5.2.3 Coating of slip ring spline to ensure adequate insulating should be accomplished with the polyimide varnish described in P.S. Engineering Specification No. 220.

2.3.5.2.4 Retention of screws in capsule assembly should be accomplished with Loctite, Grade E Sealant as described in P.S. Engineering Specification No. 156.

2.3.6 Areas for Further Work

Further work should be performed in the areas of high vacuum stability and thermal shock.

Work performed in this development program and published literature indicate that high vacuum stability can be improved in some cases by the addition of certain of the reactive diluents to the epoxy casting compounds.

Slip ring capsule assemblies should be thermal cycled and/or thermal shocked to structural failure to determine failure mode.

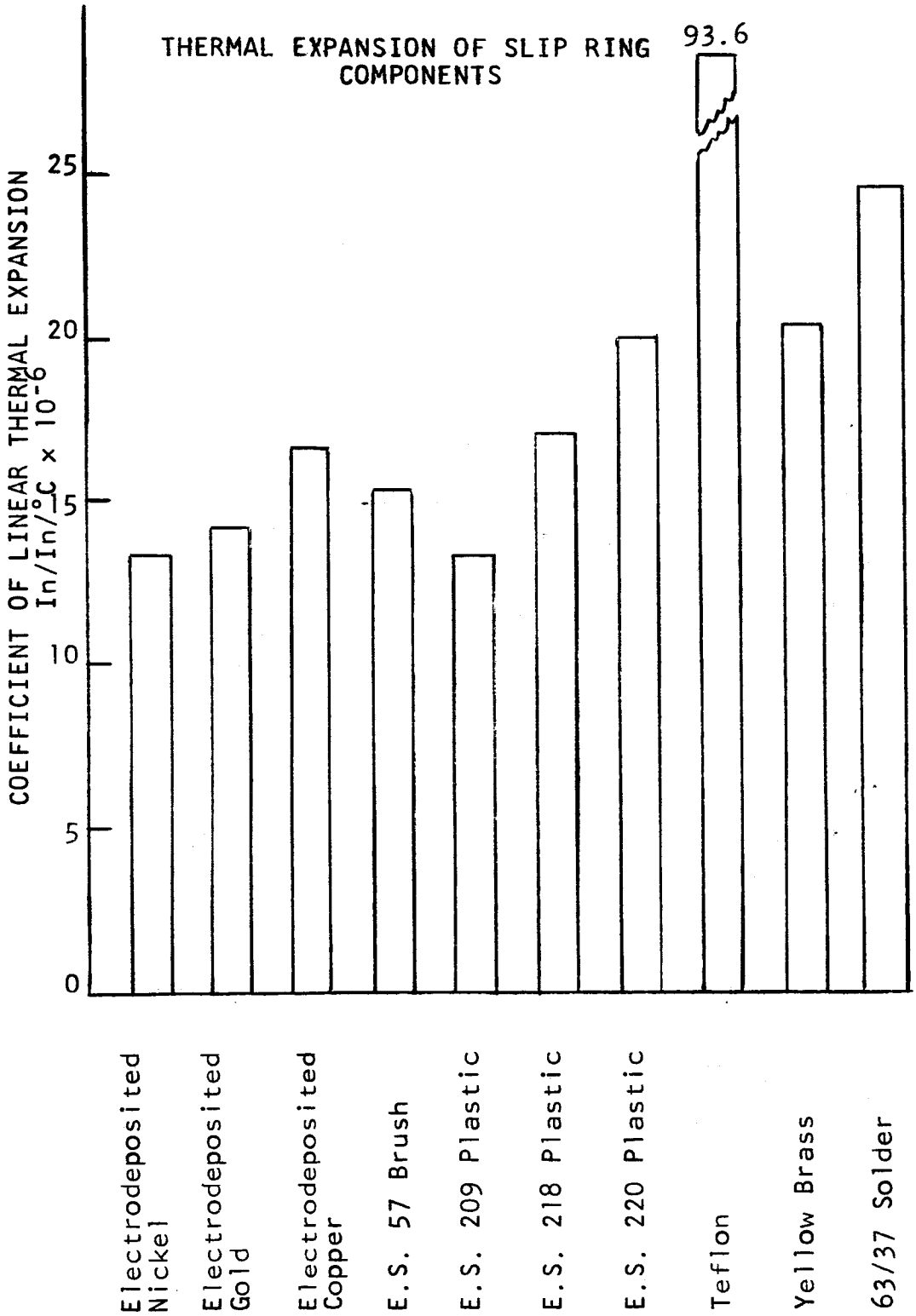
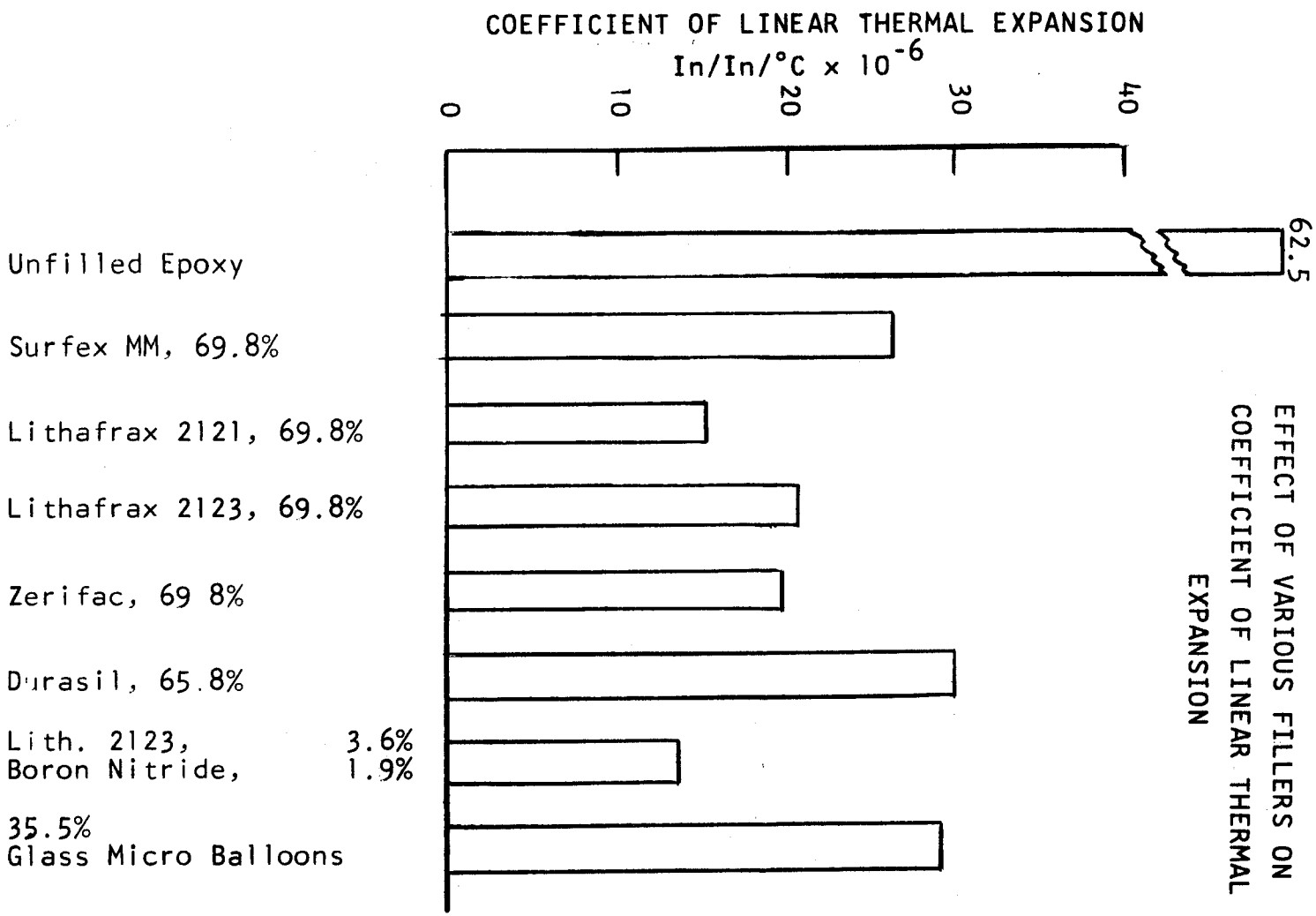

THERMAL EXPANSION OF SLIP RING COMPONENTS
93.6
COEFFICIENT OF LINEAR THERMAL EXPANSION
In/In/°C x 10⁻⁶
0
5
10
15
20
25
Electrodeposited Nickel
Electrodeposited Gold
Electrodeposited Copper
E.S. 57 Brush
E.S. 209 Plastic
E.S. 218 Plastic
E.S. 220 Plastic
Teflon
Yellow Brass
63/37 Solder

Fig. 2.3.5



EFFECT OF VARIOUS FILLERS ON COEFFICIENT OF LINEAR THERMAL EXPANSION

Fig. 2.3.6

2.4 LEAD WIRE

2.4.1 Introduction

Lead wire problems have plagued the slip ring industry since its inception. The product commercially available in the lead wire industry has failed to meet the increased demands for greater and greater reliability.

At the beginning of this contract in 1962 the most serious lead wire problems were conductor breakage and color coding tracer flaking. Both problems were evaluated carefully and after extensive testing, solutions to each problem were recommended.

To prevent color coding tracer flaking an extruded tracer was recommended. At that time only one such construction was available, that being the Revere patented tracer manufactured by Thermatics.(1)

To reduce lead breakage a change from the then used nickel plate to silver plate was recommended and approved.

These two modifications yielded a usable product for several months until insulation problems began to appear more and more frequently. Visits to Thermatics resulted in the decision that their control of process and their horizontal extruder and horizontal ovens were not sufficient to insure good quality in the finished wire.

Soon thereafter another vendor, Philadelphia Insulated Wires (2) became qualified to supply extruded wire under their own patent, Lokstripe. After working with PIW to correct some initial problems of tracer fade out and color mixing the product appeared satisfactory for reliable slip ring application.

(1) Thermatics, Inc. - Elm City, North Carolina.

(2) Philadelphia Insulated Wire - Moorestown, New Jersey.

Early in the summer of 1964, DuPont had suggested reducing the amount of coloring pigment used in Teflon insulated wire. Dupont felt that the most reliable Teflon would be the natural color with no pigment. PIW pointed out that not only would the Teflon itself be of better quality but that it would enable convenient dection of insulation and/or conductor flaws. The adoption of clear Teflon insulation in the fall of 1964 has eliminated all or most of the insulation problems.

The state-of-the-art in insulated wire technology is, at the conclusion of this program, many times more reliable than at the outset. Conductor and insulation failures are virtually nonexistent. There is nevertheless a definite need for conductor improvement to completely eliminate the potential threat of copper corrosion due to poor silver plating and galvanic action.

This section of the report describes the characteristics of the presently used product, its merits and its shortcomings. In light of these shortcomings, the ultimate product and its projected availability are discussed.

The presentation herein will be subdivided into two main sections; the insulation and the conductor.

2.4.2 Insulation

2.4.2.1 Teflon stands uncontested as the logical choice for reliable insulation material. Teflon is a DuPont Company's registered trademark for its fluorocarbon resins, including the TFE (tetrafluoroethylene) and FEP (fluorinated ethylenepropylene) resins. Teflon has a minimum dissipation factor, a low dielectric constant, the highest volume and surface resistivity of any solid insulating material -- all constant over a wide range of frequencies and temperatures; plus, high dielectric strength.

FEP resin is capable of continuous service to at least 400°F (205°C). TFE resins are capable of continuous service to at least 500°F (260°C). Cracking and embrittlement caused by heat aging is eliminated. Both types of Teflon are flame resistant.

Teflon is among the most chemically stable materials known and is unharmed by exposure to the sun, freezing cold, or salt spray. It has associated with it high flexibility and mechanical strength and experiences no fraying, embrittlement, or impact cracking.

2.4.2.2 More and more our trend is to extruded, as opposed to wrapped insulation and this trend will continue. Several of the important points to consider in choosing between these two methods of applying insulations are listed below:

2.4.2.2.1 Insofar as the mechanical properties of flex life and tensile strength are concerned, neither construction indicates superiority.

2.4.2.2.2 Wrapped insulation, if improperly sintered, can, in addition to splitting and forming flaws observed in improperly sintered extruded insulation, unwrap. In the absence of unwrapping, an imperfect bond could be prone to accept moisture, then fail during a subsequent high potential subjection.

2.4.2.2.3 There is no successful method of color coding wrapped wire as there is with the extruded stripe in extruded constructions. The only method is the intolerable Teflon base ink stripe which tends to flake off during lead life. This is, of course, no problem in NASA clear insulation.

2.4.2.2.4 Poly-Scientific processing experience has shown wrapped wire to be more prone to the capillary flow of plastic "wicking" during casting operations. The plastic tends to wick between conductor and insulation and follows the lay of the tape up the lead. This same capillary that allows plastic wicking can also accept and hold moisture to accelerate galvanic oxidation. This condition has been observed on wrapped wire, in the form of a spiral up the conductor.

2.4.2.2.5 Wrapped insulation yields an irregular outer surface which tends to collect dirt and foreign matter much more so than does extruded insulation.

2.4.2.3 Raw Teflon is purchased by each lead wire vendor from E. I. DuPont de Nemours and Company and is received in batches or drums. The raw material is in particle form, the maximum particle size determining to a large extent the minimum reliable insulation wall thickness that can be applied to the conductor.

It is hoped that lead wire vendors will, in the near future, begin identifying each run of lead wire with the particular batch of Teflon used. This would enable one to trace an insulation flaw back to the batch of Teflon and to ascertain whether a number of flaws are traceable to the same batch of Teflon. In this manner, some knowledge for the quality level of the raw Teflon would be obtained.

A description of the Teflon extrusion process and insulation sintering may be found in Appendix 2.4-I.

2.4.3 Conductor

As a result of recommendations by DuPont and others, a change was made to natural colored Teflon. Many conductor problems became apparent that were especially important in light of the potential threat of "Red Plague." Scrapes and unplated strands which became visible on the conductor were soon causing extremely high incoming rejection rates. The acceptance levels were seldom above 50%. A visit to the conductor manufacturing facilities of both of the major supplier (Hudson Wires of Ossining, New York and International Wire Products of Midland Park, New Jersey) led to the temporary discontinuation of the use of International conductor and the specification of Hudson 55 microinch silver plated OFHC copper conductor. Further improvement in conductor material and/or plating is considered essential by Poly-Scientific for the Saturn Program.

2.4.3.1 Material - Probably the most popular of all hook-up conductor material has been soft annealed copper in either the electrolytic tough pitch (ETP) or oxygen free high conductivity (OFHC) form. Copper has been popular as conductor material due to its mechanical and electrical suitability to this application and also because

of its availability. Table 2.4-I compares the electrical conductivity, tensile and yield strengths, and elongation of copper with three other metals.

Electrolytic copper and oxygen free copper differ, as is implied by the name, in their oxygen content. ETP has a composition of approximately 0.02 - 0.07% oxygen depending on the sulfur content, 0.01% impurities and the remainder Cu. OFHC copper has a minimum of 99.95% Cu and is oxygen free as defined by the following excerpt. The Metals Handbook[1] defines OFHC copper as "ETP copper manufactured under such conditions that the product is free from cuprous oxide as determined by microscopic examination at 75X magnification." At present, all copper conductor used in Poly-Scientific products is OFHC material; however, Poly-Scientific has no evidence that ETP copper is more prone to oxidize than is OFHC when used in silver plated conductor applications.

2.4.3.2 Protective Platings - Since copper does oxidize when exposed to oxidizing atmospheres, expecially at elevated temperatures, it becomes advisable to protect the copper by plating the surface with a more stable material. Silver has been a popular plating material largely because of its mechanical properties. Silver also possesses high conductivity (108% IACS) and does not deteriorate in oxidizing atmospheres.

The elongation of silver (50%) is greater than that of the copper base material (38%) and is therefore able to withstand extensive flexure without breaking.

Nickel, another common plating material, has an elongation (30%) less than that of the copper base material. Repeated flexure of nickel plated conductors can cause breaks in the nickel plate. Subsequent flexure is concentrated in that area under the break and flex life is diminished. Testing at Poly-Scientific has shown silver plated

(1) Metals Handbook; Volume 1, 8th Edition; American Society for Metals, pg. 1012.

TABLE 2.4-I

PROPERTIES OF CONDUCTOR MATERIALS

PROPERTY	METAL OR ALLOY					
	Copper		Silver	Gold	Chromium	EC Aluminum
	ETP	OFHC				
Elongation	38.5%	same	48-54%	4%	18	1.5%
Yield Strength	4,800*	same	7900*	30,000*	43,000*	24,000*
Volume Conductivity	99-101%	same	105-108.4%	73.4%	80-90%	62%
Tensile Strength	34,500*	same	18,200*	32,000*	55,000*	27,000*

(*) PSI

leads to have 30-40% greater flex life than nickel plated leads. The test method subjected each sample to numerous 90° bends over a 0.025 inch radius at a flex rate of 120 flexes per minute. Each sample was loaded with a 214 gram weight.

Tin cannot be considered as a protective plating for such applications due to its low melting point (232°C).

2.4.3.3 Corrosion - In using a plating to protect copper from oxidation another problem is introduced. At imperfections in the plating and in the presence of moisture, the two dissimilar metals (copper and plate) can react in the fashion of a galvanic cell. The anodic metal will be oxidized by the reaction of metal ions with the electrolyte (water).

In using silver over copper, the copper is anodic and will oxidize to form Cu_2O (cuprous oxide) commonly called "Red Plague." The oxidation product here is a red powder on the surface of the silver plate usually observed in the intersticies of the strands in early stages. This is due to the capillary between strands providing moisture for the electrolyte. The formation of Cu_2O can be minimized by insuring that the silver plate is continuous and free from imperfections. All lead wire for NASA use is inspected visually (30X) on a 100% basis in the cut lead stage to detect wire having poor plating. Additional precautions currently being taken to minimize Cu_2O formation are:

2.4.3.3.1 Allow no water immersion testing of leads either in-house or during lead manufacture by vendor.

2.4.3.3.2 Keep lead tips (free ends) out of all solvents and water during in-house handling (plating and cleaning).

2.4.3.3.3 Specify 10% silver plate (MIL-W-16878D specified 8% silver) on all NASA conductor. The plating thicknesses involved are 55 microinches for 10% and 40 microinches for 8%.

2.4.3.4 High Flex Alloys - Certain copper alloys are available from conductor manufacturers that give increased flex life at the expense of a decrease in electrical volume conductivity. Chrome copper and zirconium are of this category. Due to the limited amount of data on hand concerning the flex life comparisons of chrome-copper and soft copper, some additional tests were conducted.

The test results were in close agreement with data recorded previously. The test results show that the bend endurance of copper is increased 50% by alloying with 1% chromium. The alloy is harder (110 KHN versus 71 KHN) and does not bend as sharply as soft copper, which could account for the increased flex life.

The alloying of such elements as zirconium with soft copper increased the flex life by virtue of a grain refining effect. Surprenant's Alloy 63 is of this category.

Chrome-copper and various other high flex alloys are available from the wire vendors. MIL-W-16878D states that conductors having higher tensile strength than copper may be required in conductor sizes smaller than 24 AWG by the procuring activity for special application, or by the wire manufacturer for processing reasons.

Whenever feasible to meet with engineering requirements for conductivity, these alloys should be considered for use in production (see Table 2.4-II).

2.4.3.5 Stranding - Initial tests comparing flex life of various lead wire constructions indicated superiority of 7 strand wire. In all of the cases, 7 strand wire exhibited greater flex life than the corresponding gage in the single strand conductors. Each individual strand of the 26 AWG 7 strand conductor exhibited 70% greater flex life than the single strand sample. The number of flexes that were required to cause complete breakage of the 7 strand conductor were double the number required to break the single strand on 26 AWG wire.

In comparing 7 and 19 strand lead wire as to their flex life characteristics, 19 strand consistently proved superior. However, the degree of superiority seemed to decrease with decreasing

TABLE 2.4-II

FLEX LIFE RATINGS FOR DIFFERENT CONDUCTOR MATERIALS

CONDUCTOR MATERIALS	FLEX LIFE COMPARISON
Surprenant Alloy 63 90% IACS	40 to 200% greater flex life than soft copper wire.
Chrome Copper Alloy 80% IACS	54% greater flex life than soft copper wire.
Soft Annealed Copper 100% IACS	Good

wire size (see Figure 2.4.1). For instance, for 26 AWG uninsulated conductor, tests indicated the 19 strand construction to be 176% superior to the 7 strand construction. A similar test conducted on uninsulated 30 AWG conductor indicated the 19 strand conductor to be only 6.2% better than the corresponding 7 strand conductor. In the smaller gages (30-32 AWG) when 19 strand conductor is used, the very small (2.5 mil for 30 - 19/42) individual strand cannot support heavy tensile loading; consequently, individual strand breakage begins to become a problem. If a pure silver conductor is decided upon, 7 rather than 19 strand may be recommended for the above reason (since the tensile strength of silver is less than that of copper). A repeat of flex testing using 30 AWG Teflon <u>insulated</u> (extruded) lead wire, showed the 19 strand construction to have 86% greater flex life than the corresponding <u>insulated</u> 7 strand construction. Figure 2.4.1 serves as a summary on the effect of stranding upon flex life and also on the difference between silver and nickel platings insofar as flex life is concerned.

19 strand conductor also exhibits less resistance than does the corresponding gage in 7 or 1 strand constructions. See Table 2.4-III for a tabulation of standard conductor data.

The stranded configuration of small gage conductor is termed concentric. The inner or base lay (core) consists of seven strands. The outer twelve strands are applied with a lay opposite in direction to the core lay.

A construction available in larger gages from the Hudson Wire Company has the lay of all strands in the same direction and is appropriately called Unilay. This construction allegedly has a higher flex life than concentric stranded wire but as yet is not available in the 30 AWG construction.

2.4.3.6 <u>Conductor Control</u> - Common conductor discrepancies observed on 30 AWG 19/42 conductor are:

2.4.3.6.1 <u>Scraped Silver</u> - The scrapes may or may not expose the base copper. These scrapes most likely occur during stranding where the bare conductor passes through many eyelets. These scrapes are not generally visible until after Teflon extrusion at which time the scraped portion discolors slightly.

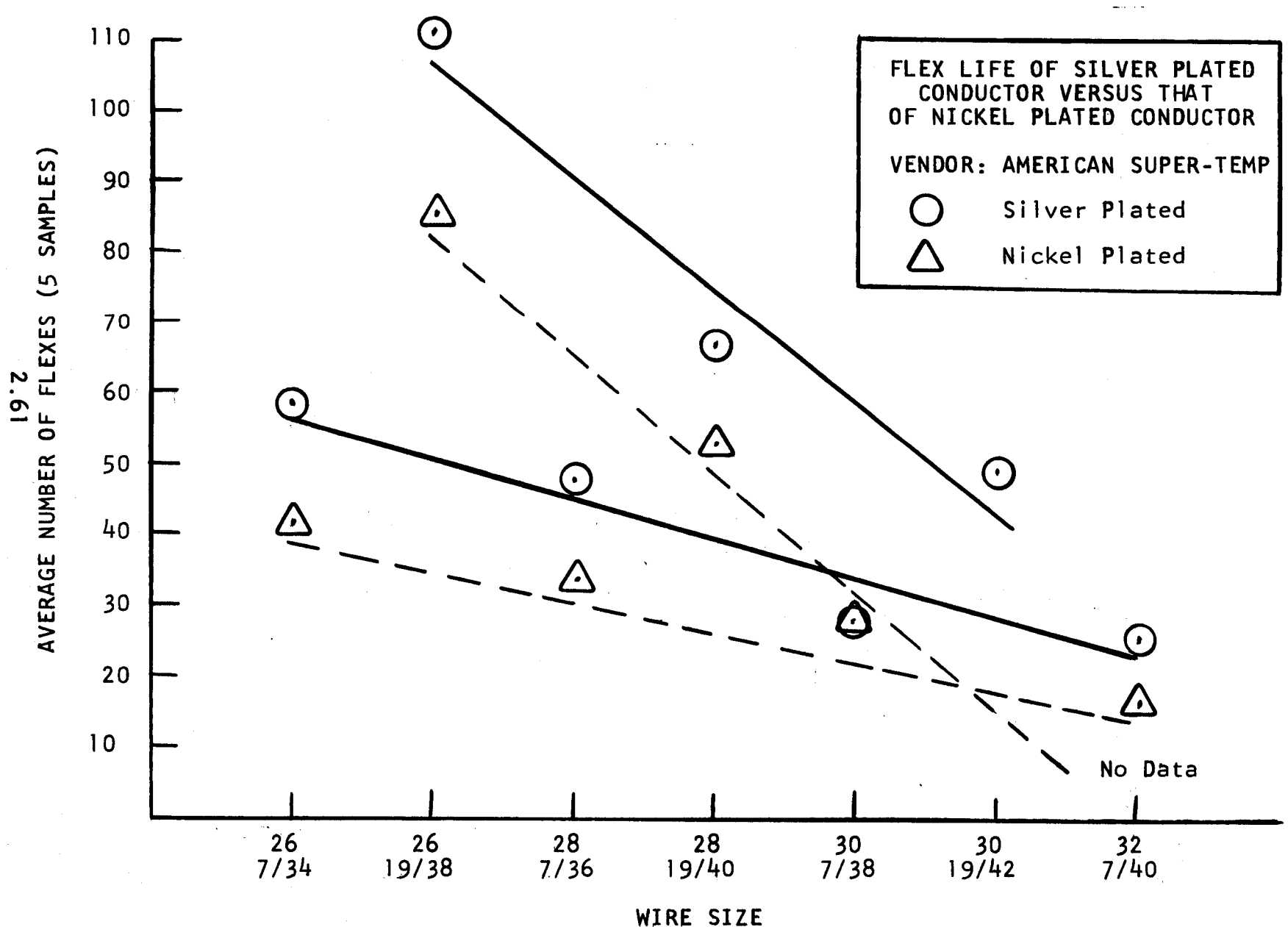
TABLE 2.4-III

STRANDED WIRE DATA SHEET

AWG	CONSTRUCTION	NOMINAL CIRCULAR MIL AREA	NOMINAL RESISTANCE (ohms/ft.)	MAX.RES.OF INS. Ag PLATED Cu (ohms/ft.)	MAX.RES.OF INS. Ni PLATED Cu (ohms/ft.)	MAX.RES.OF BARE STR. Ag PLATED Cu (ohms/ft.)	MAX.RES.OF BARE STR. Ni PLATED Cu (ohms/ft.)	* MAX. WEIGHT PER 1000 FT.	MAX. O. D.
20	7/28	1111.	.009335	.009904	.001032	.009806	.001022	3.540	.0381
	19/32	1216.	.008529	.009183	.009769	.009092	.009672	3.931	.0405
22	7/30	700.0	.01481	.01572	.01638	.015560	.01622	2.23	.0303
	19/34	754.1	.01375	.01491	.01586	.014760	.01570	2.448	.0320
24	7/32	448.0	.02315	.02469	.02627	.02445	.02601	1.435	.0243
	19/36	475.0	.02183	.02387	.02539	.02363	.02514	1.557	.0255
26	7/34	277.8	.03733	.04008	.04264	.03968	.0422	.8933	.0192
	19/38	304.0	.03412	.03768	.04141	.03731	.04100	1.006	.0205
28	7/36	175.0	.05926	.06417	.06825	.06353	.06757	.5683	.0153
	19/40	182.6	.05680	.06368	.06998	.06305	.06929	.6140	.0160
30	7/38	112.0	.09260	.1013	.1113	.10030	.1102	.3675	.0123
	19/42	118.75	.08733	.09954	.1131	.09855	.1120	.4052	.0130
32	7/40	67.27	.1542	.1712	.1945	.1695	.1926	.2240	.0096
	19/44	76.00	.1365	.1588	.1805	.1572	.1787	.2649	.0105
34	7/42	43.75	.2371	.2675	.3040	.2649	.3010	.1479	.0078
36	7/44	28.00	.3704	.4268	.4850	.4226	.4802	.09667	.0063

(*) Lbs.

Fig. 2.4.1 - FLEX LIFE VERSUS WIRE SIZE



2.4.3.6.2 Bare copper strands - Sections of individual strands in lengths from one-eighth inch to five inches occasionally occur in incoming conductor. This is a conductor supplier problem more frequently experienced with International conductor than with Hudson conductor.

2.4.3.6.3 Conductor lay problems - Individual strands occasionally protrude above other strands on a conductor. This condition causes complete conductor breakage during Teflon extrusion if a "high strand" hangs in the needle valve. This condition is more frequently observed on Hudson conductor than on International conductor.

All three of the above described conditions have been observed from time to time on clear wire and at times have caused up to 95% rejection of an incoming wire order.

Aluminum spools used to spool conductor for shipment to the extruder from the conductor supplier have proved to be inadequate. The aluminum "sheds" and introduces contamination (embedments) to the Teflon insulation. Both International Wire Products and the Hudson Wire Company have been instructed to begin supplying conductor for the Saturn program on non-returnable plastic spools sealed in polyethylene bags.

2.4.4 Acceptance Testing

Lead wire is electrically and dimensionally tested upon receipt from the vendor. The MIL-W-16878D minimum dielectric breakdown requirement for type ET wire is 1500 volts. Poly-Scientific tests incoming ET wire at 1700 volts and questionable wire (i.e., visually questionable from standpoint of texture, embedment, or insulation discoloration) at 2400 volts RMS. Dimensionally the requirements for 30 AWG are 0.029 $\pm$ .001 inch. The leads are examined on a 100% basis (30X) after cutting to length for conductor and/or insulation discrepancies.

2.4.4.1 The final product should not be hi-pot tested by water immersion since water-wicks through dielectric failures in the insulation can move many feet up a lead. This trapped moisture can then serve as a catalyst for the formation of Cu_2O on the conductor surface. As opposed to immersion testing, a wet sponge should be used as one electrode through which the completed wire passes.

2.4.5 Vendor Rating

2.4.5.1 Conductor Supply

2.4.5.1.1 Hudson Wire Company, Ossining, New York is very interested in supplying quality conductor and possesses excellent capabilities, especially in silver plating.

2.4.5.1.2 International Wire Products Corporation, Midland Park, New Jersey is a quantity house whose capability for supplying wire of very high quality has not yet been proved.

2.4.5.2 Extrusion of Clear Teflon

2.4.5.2.1 Philadelphia Insulated Wires of Moorestown, New Jersey is an established company very interested in supplying a quality product. This company possesses excellent capability in extruding TFE Teflon.

2.4.5.2.2 Tensolite - All conductor received on the prototype order from Tensolite was discolored with silver sulfide and tended to further discolor in processing.

2.4.5.2.3 American Super Temperature Wires - The conductor as seen through clear insulation was very poor with many bare copper strands and much scraping evident. The insulation was cloudy and dirty. Over-all dimensions were widely variant.

2.4.5.2.4 Thermatics, Inc. - Thermatics has very poor process control resulting in many Teflon insulation problems (over and undersintering).

2.4.6 Process Improvements

Early processing of leads involved slipping the insulation ("milking") up over the conductor-lead solder joint to insulate the joint. This operation not only caused unnatural stresses in the insulation over the joint but was causing breakage of individual conductor strands. Two development tasks were initiated to devise a lead preparation not requiring the lead-jumper construction. One of these tasks is described under swaging in this report. However, during the development period, an interim method for preparing leads was required. A procedure was developed and is documented

in Poly-Scientific Process Instruction No. 800. In brief, this method involves no "milking" of the insulation but rather a lap solder joint insulated with a small section of mylar heat shrink tubing.

2.4.7 Special Construction

2.4.7.1 Dual Insulation - A sample of wire was received from Gore as being representative of a specially constructed double-wrap insulation. The sample was 28 AWG - 7 strand silver plated copper with a green 3 mil TFE wrap. Over this was wrapped a clear 2 mil FEP wrap. Investigations were conducted to develop a satisfactory method to cleanly strip the FEP wrap. Methods investigated employed the fact that the FEP melts at 260°C; whereas, the TFE melts at the higher temperature of about 327°C. If a satisfactory method of stripping had been developed, the outer wrap could have been stripped, leaving the thin wall of insulation which could be employed all of the distance to the ring without the use of magnet wire extensions. In addition, the FEP wrap would provide a protective shield to prevent flaking or rub-off of the color coding tracer. Inability to remove the FEP successfully made this construction unacceptable for its intended application. It was noted that during the application of the outer FEP tape some of the black stripe was removed from the base wrap, but this condition was not considered serious. There were no incipient cracks.

Mechanically, the wire performed as a thin wall insulated sample would be expected to perform, indicating that the outer FEP wrap tended to bunch up under even small loads. In fact, tests could not be performed due to the accordion-like bunch-up of the insulation. However, it is to be noted that if the wire could be run to the ring without the use of a magnet wire extension, there would be no reason to have to slip the insulation. It should also be realized that a longer length of plastic wick could be tolerated if the insulated wire ran completely to the ring.

W. L. Gore also developed a multi-layer construction intended for Poly-Scientific use. The construction was 30 AWG 19/42 with four separate insulation layers. Innermost were two tape wraps of

0.002 inch polyimide. Over the polyimide was wrapped green TFE Teflon (0.004 inch). A black tracer was painted on the Teflon. Outermost was a 0.002 inch FEP Teflon jacket (wrapped) to prevent flaking of the color coding tracer. The intended use was to enable the Teflon to be removed and the polyimide to be run to the ring (replacing a magnet wire jumper).

This construction was evaluated and declared unsatisfactory for the following reasons:

The dimensions (0.019 inch over polyimide and 0.034 over the FEP) were too large to enable this wire to be used in the intended manner.

This construction was available only with a wrapped Teflon.

Philadelphia Insulated Wires Company is currently working on a similar development contract for Poly-Scientific that deals with a product intended to replace the need for a magnet wire jumper assembly. The resulting construction will have two insulation layers. The innermost layer will be a 0.0005 inch polyimide tape wrap. (Ultra-thin polyimide became commercially available during the latter weeks of 1964.) The maximum diameter over the polyimide will be 0.016 inch. There is a possibility that the diameter over polyimide will be even less, perhaps 0.014 inch. The dry dielectric strength over polyimide will be not less than 500 V D.C. Over the polyimide a clear TFE Teflon will be extruded.

The intended application assumes that the Teflon can be heat stripped from the polyimide and that the polyimide can be mechanically removed from the conductor. No problems are anticipated in stripping this construction.

2.4.8 Conclusion

The lead wire situation has changed very rapidly in conjunction with this program. Changes in both conductor vendor and extruder have been made as well as a deletion of all insulation coloring pigment and an increase in silver thickness on the conductor. Today's product is much different and many times more reliable than yesterday's and the ultimate lead construction is now envisioned.

A specification was devised to incorporate all of the findings during recent wire investigations. The ultimate lead wire as envisioned by Poly-Scientific will consist of either 7 or 19 strands (depending on the AWG No.) of commercially pure silver insulated with unpigmented TFE Teflon. This ultimate product is defined (with the exception of the pure silver conductor) by the new specification (E S 47-05). According to the specification, all lead wire received at Poly-Scientific is substandard and will continue to be until the industry has had sufficient time to catch up.

The only 100% sure prevention of galvanic reaction would be the use of a conductor material not affected by an oxidizing atmosphere. The electrical and mechanical characteristics required of this material eliminate most metals from consideration. Commercially pure silver to date is the only material considered presently practical.

The characteristics of silver with the exception of tensile strength (see Table 2.4-I) indicate that silver would perform satisfactorily. The only anticipated reaction of pure silver in oxidizing atmospheres would be a possibility of tarnish (silver sulfide) formation.

We are now awaiting development of new materials to be used in conductor manufacture. Pure silver is at present the most promising material. Only with such a change in conductor material can 100% assurance be given that the conductor will remain free from degradation by oxidation.

With a homogenous (unplated) conductor, either 7 or 19 strand, and a clear TFE Teflon insulation, the slip ring industry would be well on its way to obtaining a 100% acceptable wire.

APPENDIX 2.4-I

TEFLON EXTRUSION PROCESS

The raw material is first made up into cylindrical billets for loading into the extruder. These billets are prepared by mixing raw Teflon, up to 2% color pigment if required, and lubricant (naptha or mineral oil). The effect of this 2% pigment on the mechanical or electrical properties of Teflon is not known but would be assumed to be derogatory to some extent. This mixture is then placed into a cylindrical mold perhaps five inches in diameter and twelve inches long. Pressure is applied through a piston arrangement to compress the mix. This pressure can be applied manually or hydraulically, the latter being the more consistent method. At Thermatics this operation is accomplished manually, at Philadelphia hydraulically.

If a color coding scheme in excess of ten colors is required, the lead must be coded by means of a tracer (stipe). A stripe painted on the surface of the finished wire is not acceptable. To date, the only acceptable scheme of color coding is by extruding a stripe into the body of the insulation. There are two patented processes to accomplish this end. One process was developed by the Revere Company and results in a pie-shaped tracer cross-section. The other process is patented under the name of Lokstripe by Philadelphia Insulated Wires and results in a tracer with a semicircular cross-section. Thermatics, Inc. operates under the Revere patent and American Super Temperature Wires, under this patent, recently began manufacturing an extruded stripe. Although the details of these patented processes are not known, the intermediate result is a billet with the stripe built in as pictured in Figure 2.4.2-a.

These billets are then removed from the cylinder and loaded into the extruder. Basically, this extruder consists of a needle valve, pressure application mechanism, and a polished die. A simplified version is shown in Figure 2.4.2-b.

The conductor to be insulated, moves through the interior of the cylindrical needle valve (which passes through a hole in the center of the Teflon billet) and through the die opening. Pressure is applied to the billet by a screw jack arrangement and this Teflon material is forced onto the conductor and through the die. The needle valve can be positioned logitudinally to serve as a valve at the die opening. Variation in needle valve setting and applied pressure regulate the amount of insulation-conductor adhesion in the completed wire.

The insulated wire leaves the extruder and enters the first extrusion oven as shown in Figure 2.4.2-b. At this point, the insulation is held together as a result of the compression experienced during extrusion. The material is very porous, these pores being filled with extrusion lubrication.

Upon entry into the sintering oven, the lubricant is quickly driven off and the forces of coalescence begin to close the pores. For this reason, the density increased (see Figure 2.4.2-c). The density continues to increase due to this closing of the pores until such a time that the decrease in density due to the destruction of the resin crystallinity exceeds the increase due to the closing of the pores. This occurs when the insulation temperature reaches 621°F. At that point, the density begins to drop as the extruded fibers in the insulation begin to fuse, one to another. The oven temperature is held constant (850-950°F) unitl all fibers have fused together. At that point, the density levels off.

Properly sintered wire should be removed after complete fusing (while the density is constant). If sintering is not terminated at that point, the Teflon resin begins to degrade and the molecular weight decreases. The density again increases due to an increase in the crystallinity.

Wire produced in region A or B of Figure 2.4.2-c will be undersintered. The individual fibers have not completely fused together. The wire may appear streaked and will be prone to form splits or separations of the fibers parallel to the run of the wire. This insulation in unpigmented construction is characterized by an opaque white coating or in pigmeted constructions by a milky, hazy appearance with little depth of color. In addition, unsintered fibers, under tension as a result of the extrusion operation, when nicked or abraded are prone to snap and curl up to form what are commonly called "hairs." Grossly undersintered wire will have a high dielectric failure rate.

A good visual examination for the detection of undersintered wire is as follows:

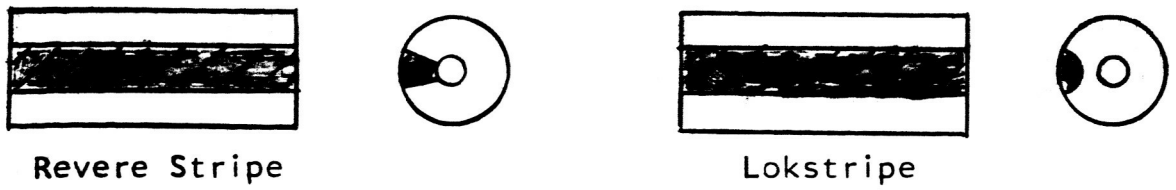
Remove the conductor from the Teflon insulation by slipping the insulation off. Slice several thin (2-3 mil) cross-sections from the insulation tube with a razor blade. Mount these wafers between two clean glass slides and place on an optical comparator screen. The thin wafers will be translucent and if properly sintered will be homogeneous in the cross-section. If undersintered, the inner portion of the wafer will appear darker due to the more dense section of Teflon. This is, of course, due to the fact that the Teflon sinters from the outer surface inward, the density dropping off accordingly.

Wire produced in region D of Figure 2.4.2-c will be over-sintered. This insulation will appear muddy in pigmented constructions and discolored in unpigmented constructions. When elongated, this insulation will tend to neck down in spots rather than to thin out gradually as does properly sintered insulation. Insulation produced in this manner will be break prone, those breaks occurring radially around the periphery of the insulation.

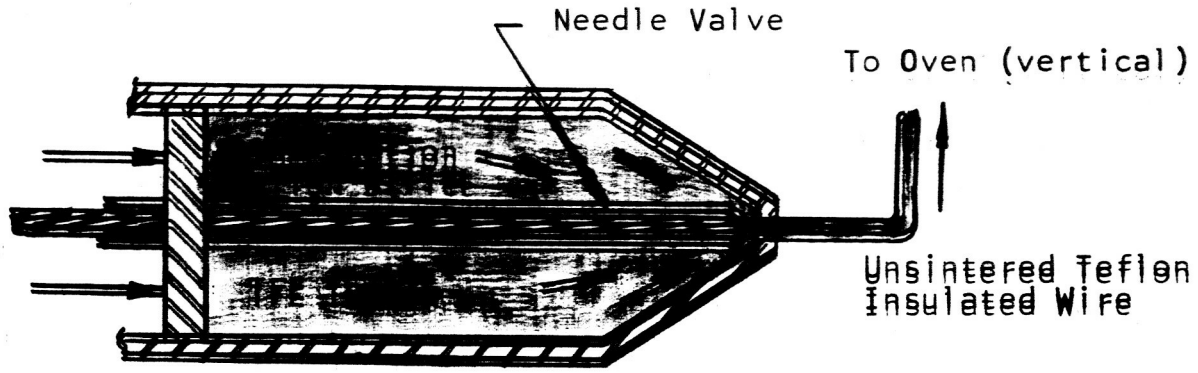
A degradation of the silver plate and/or a fusing of the conductor strands may be observed on over-sintered wire. This is due to the improper correlation of time and temperature in the ovens, which allows the conductor to heat to a destructive temperature. Such a silver degradation could allow the conductor to be susceptible to copper oxides at a future time and is therefore unsatisfactory.

If the construction is to include an extruded stripe, the stripe will be parallel to the run of the wire upon exit from the sintering ovens. The insulation must then be twisted to form a helical tracer. Some vendors have stated that this operation is detrimental to the insulation. However, those taking this position are the same people with an unsatisfactory method of color coding. Poly-Scientific has no current information indicating any damage to the insulation resulting from imparting the tracer helix by twisting. However, there is evidence that the flex life of twisted constructions is somewhat decreased.

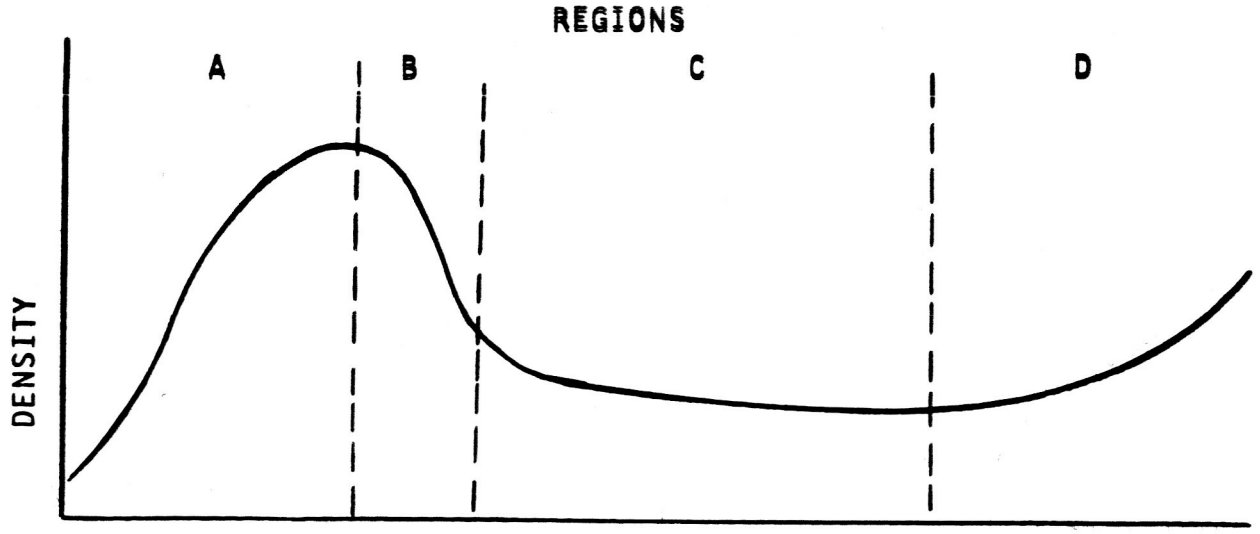
Fig. 2.4.2 - THE EXTRUSION PROCESS



a) The Teflon Billets



b) The Extruder



c) Teflon Insulation Density versus Degree of Sintering

2.5 BEARINGS

2.5.1 Introduction

This section deals with the function, requirements, and specifications of ball bearings used in the highly reliable slip rings developed by Poly-Scientific under provisions of contract NAS 8-5091 and Saturn flight slip rings.

2.5.2 Bearing Usage and Practice at Beginning of the Program

2.5.2.1 Bearing Function - The ball bearings in any slip ring capsule serve to maintain alignment of rotor to stator and hence of brushes to rings in directions axial and radial to the capsule axis. The bearings must maintain this alignment during the useful life of the capsule, regardless of the mode of operation, or environment of the capsule. Bearings must not contribute significant torque, because one of the performance specifications of a slip ring capsule is a limitation on torque required to drive the rotating member. Bearings must be capable of performing throughout the capsule life with a very small amount of lubrication, since the presence of excess organics, such as oil, can cause chemical phenomena which affect contact performance.

2.5.2.2 Bearing Installation - Installation of bearings is generally as a preloaded pair, with the preload applied by a nut on the internal member bearing against the inner race (see Figure 2.5.1). Normal practice has been to leave the preloading up to the assembly operator, with the understanding that the minimum preload necessary to remove all but .0001 - .0003 inch end shake is the maximum preload applied.

Tolerances on capsule components which support the bearings generally have been as follows:

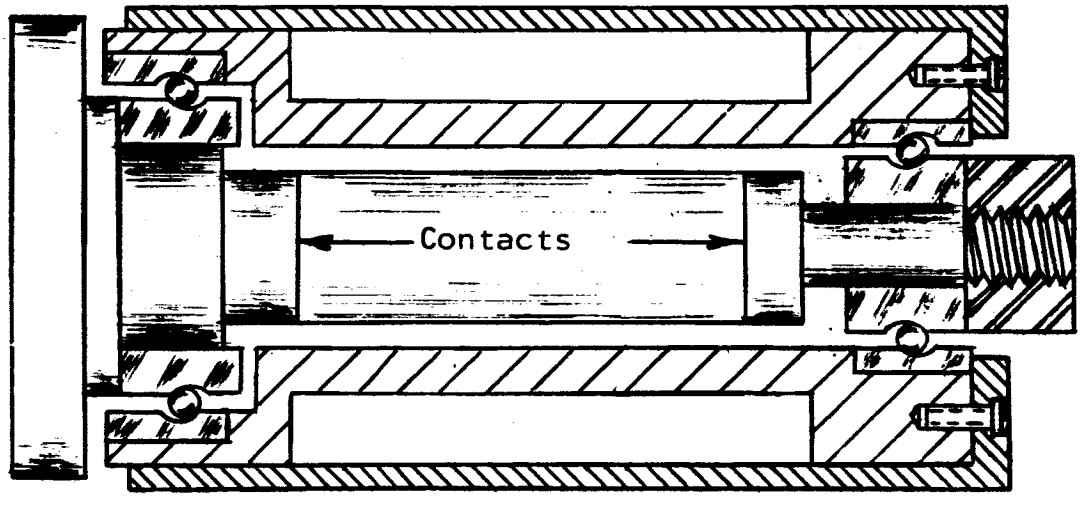


Fig. 2.5.1

Standard bearing
Installation on slip ring capsule

TABLE 2.5-I

STANDARD BEARING FITS & CONCENTRICITIES

Fit - bearing O.D. to bore in external capsule member -- line to line to .0005 loose.
Fit - bearing I.D. to shaft dia. of internal capsule member -- line to line to .0005 loose.
Concentricity - bearing bores in external members -- .001 T.I.R. maximum.
Concentricity - bearing seat dias. of internal members -- .001 T.I.R. max.

These tolerances are specified with the intention of limiting angular misalignment of races in any bearing to within those limits recommended by the bearing manufacturer.

2.5.2.3 Bearing Specification Practices - Normal practice in the slip ring industry has been to purchase standard miniature bearings from the many manufacturers of these products The dimensional accuracy, performance characteristics, and reliability over extended running time has resulted in very few failures. The slip ring designer generally has selected the following characteristics of the bearings for a given slip ring capsule assembly.

2.5.2.3.1 Physical size - I.D., O.D., width (very seldom do these deviate from catalog sizes).

2.5.2.3.2 Special features - shields, flanges.

2.5.2.3.3 Manufacturing tolerance - ABEC 7.

2.5.2.3.4 Material - Stainless steel in most cases (440C balls and races).

2.5.2.3.5 Radial Play - Usually the bearing manufacturer's lowest stock range of radial play.

2.5.2.3.6 Lubrication - Bearing manufacturer's recommended standard, in most cases.

Although items 2.5.2.3.3 through 2.5.2.3.6 have been specified in a great many cases; sometimes bearings have been selected and specified only by the bearing manufacturer's part number.

The loads imposed on bearings by installation in slip ring capsules, and the operating speeds of most applications are almost negligible in comparison with the bearing manufacturers' load-life charts.

All capsules built through the early portion of the program, had followed the practices outlined above. Widely random failures on unrelated programs over several years had given no cause for special concern for bearings in the Saturn and NAS 8-5091 capsules.

2.5.3 Bearing Failures on Saturn Parts

The standard bearing practices appeared to provide adequate bearing performance in Saturn parts until April and May, 1964. At that time, five bearing failures brought about an analysis of the bearing design and usage. Failures are shown in Table 2.5-II.

2.5.4 Design Improvements is a Result of Failures

As a result of the failures described above, three areas were investigated for possible improvements:

Bearing Design.
Design of parts into which bearings are installed.
Handling and processing of bearings.

2.5.4.1 Bearing Design - Since the crown type retainer was a contributing factor in all five failures, the retainer design was changed to a ribbon type. (Figure 2.5.2.) Since oscillating motion, even in a poorly lubricated bearing, does not tend to deform a ribbon retainer toward the outer race, the possibility of a failure similar to those described above appears impossible.

2.5.4.2 Design of Capsule Bearing Supports - The bearing failures raised doubts about the mechanical integrity of the slip ring bearing

RELATED BEARING FAILURES IN SATURN PARTS

TABLE 2.5-II

CAPSULE DESCRIPTION	DESCRIPTION OF BEARING	MODE OF FAILURE	AFFECT OF FAILURE ON SLIP RING CAPSULE	DESCRIPTION OF BEARING AFTER FAILURE	PRESUMED CAUSES OF FAILURE
DP 1418 S/N 3 (100 ckt. capsule) on life test at P-S. Had accumulated 40-60 hrs. at 10 rpm.	.500 O.D. - .312 I.D. shielded bearing - used at flange end of slip ring.	One prong of the crown retainer wedged between a ball and the outer bearing.	With bearing locked up, and life test fixture driving through the leads, bearing slipped on O.D until it froze to external structural member at which time leads twisted off	Excessive wear tracks on raceways, evidence of heating, warped retainer, edges of several prong coined evidently by balls	Oscillatory mode of capsule operation caused the very lightly lubricated retainer to rub, heat, bend out toward the outer race, and ultimately become pinched between ball and outer race
DP 1410 S/N 6 (10 ckt. accelerometer capsule) 1100 hours testing in oscillatory NASA mode.	.1562 O.D. - 0469 I.D. shielded bearing, used at brush lead exit end of capsule.	One prong of the crown retainer wedged between a ball and the outer bearing.	Slip ring broke in two pieces, between the bearings	Excessive wear tracks on raceways, evidence of heating, warped retainer, edges of one prong coined evidently by balls.	Bearing seats were not concentric, resulting in excessive angular misalignment of small bearing, which, along with light lubrication and retainer design allowed ball to pinch retainer.
DP 1410 S/N 4	.2500 O.D. - .1250 I.D. shielded bearing used at ring lead exit end.	One prong of the crown retainer wedged between a ball and the outer bearing.	Locked rotor.	Excessive wear tracks on raceways, evidence of heating, warped retainer, edges of one prong coined evidently by balls.	Essentially same as DP 1418 - S/N 3.
DP 1420 S/N 3 (12 ckt. prism drive capsule) Failed during 100 hr. quality assurance test.	.3125 O.D. - .1562 I.D. shielded bearing used at ring lead exit end.	One prong of the crown retainer wedged between a ball and the outer bearing.	Locked rotor.	Excessive wear tracks on raceways, evidence of heating, warped retainer, edges of one prong coined evidently by balls.	Essentially same as DP 1418 - S/N 3.
DP 1405 (80 ckt. Gimbal axis capsule) failed during 100 hr. qual. assurance test, at Poly-Scientific	.2500 O.D. - .1250 I.D. shielded bearing used at brush lead exit end.	One prong of the crown retainer wedged between a ball and the outer bearing.	Slip ring reinforcing aluminum member twisted into two pieces.	Excessive wear tracks on raceways, evidence of heating, warped retainer, edges of one prong coined evidently by balls.	Essentially same as DP 1418 - S/N 3.

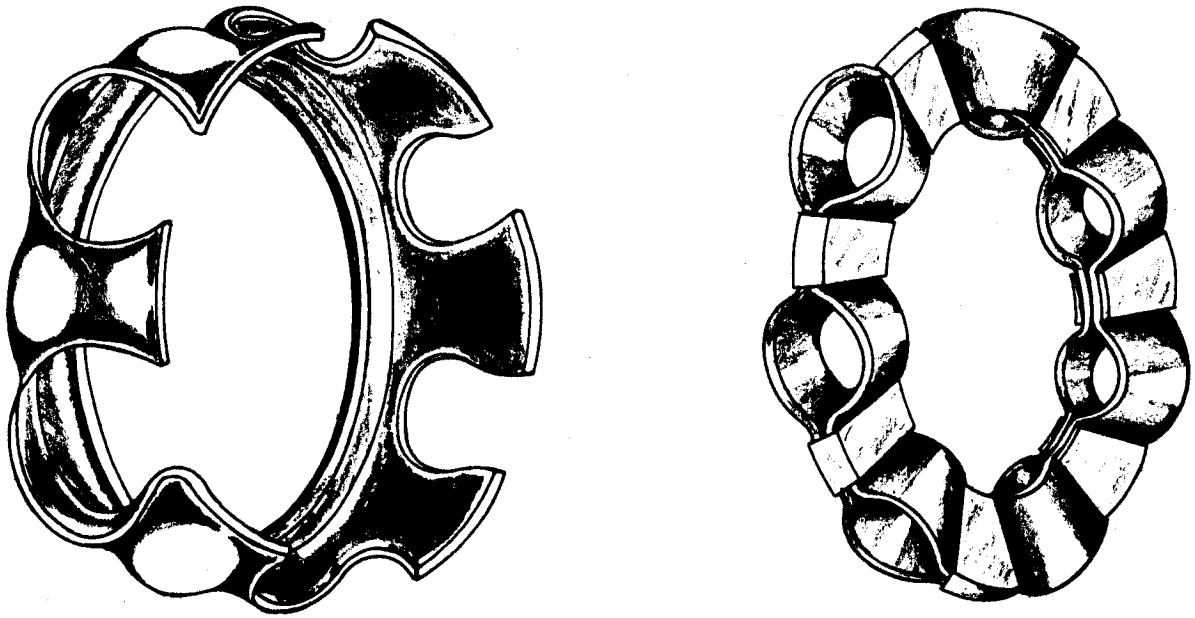


Fig. 2.5.2 - CROWN AND RIBBON RETAINERS

seats, the frame and its ability to maintain the proper relationship between its bearing seats. Four significant areas were changed.

Slip ring reinforcement.
Frame stiffness.
Housing attachment.
Bearing nut design.

2.5.4.2.1 Rotor-Reinforcement and Bearing Seats - Rotor design at the time of the bearing failures included three (3) structural parts:

TABLE 2.5-III
COMPONENT MATERIALS

NAME	FUNCTION	MATERIAL
Flange	Lead spacer, bearing seat	Stainless Steel
Spline	Reinforcing member under for stiffness	Aluminum*
Bearing Pin	Bearing seat, threads for play adjustment nut	Aluminum*

* Accelerometer capsules used steel.

Coincident with the time of bearing failure, Poly-Scientific materials laboratory developed a filled casting epoxy which has the same coefficient of thermal expansion as does steel. This allowed the three parts of Table 2.5-III to be combined into one stainless steel part. The new one-piece structural member insured that bearing seats would be concentric and that rotor stiffness would be improved.

2.5.4.2.2 Stator Frame - The frame design on gimbal axis capsules at the time of the bearing failure already incorporated four axial members to support the brush block and maintain the proper relationship between the two bearing seats. Accelerometer and prism drive capsules, like most other capsules in production at that time, depended on two axial members, because of the very small size and attendant difficulty in fabricating frames. The ability of the two small beams to maintain proper geometry between bearing seats was seriously questioned.

The frames for the accelerometer and prism drive capsules were redesigned to include 4 additional stiffening members, (see figure 2.5.4). Frame material and specifications had previously been changed from aluminum to stainless steel at Poly-Scientific request in recognition of the potential structural stiffener problem.

2.5.4.2.3 Housing and Method of Attachment - At the time of the bearing failures, housings were aluminum (stainless steel on accelerometer capsules) tubes, held to the frame with straps and screws mounted parallel to the capsule axis. This method of mounting caused tensile loading of frame, compressive loading of the housing and allowed uneven screw tightening with a subsequent tendency to cock bearing seats.

The new plastic permitted the replacement of aluminum by stainless steel. The clamp and housing were made one integral piece, and the tube length was reduced so that tightening of the mounting screws imposed no loads on frame or housing members

2.5.4.2.4 Bearing play adjustment - In practically all capsules designed up to the 2nd generation of improved reliability parts, bearing nuts were designed to have relatively loose threads, so that the nut seats on the bearing inner race and not a thread (see Figure 2.5.1). This was intended to reduce any cocking of the inner race due to uneven axial loads imposed by the nut.

To provide a more uniform application of preload, the "universal joint" washer (see figure 2.5.6) was introduced. The capsule outline dimension requirements were relaxed to allow the slip ring bearing seat threads to extend outside the housing. Since the Loctite which the specification previously required can creep and possibly get into a bearing, the material to be used for securing the bearing nut was changed from Loctite to a viscous epoxy cement.

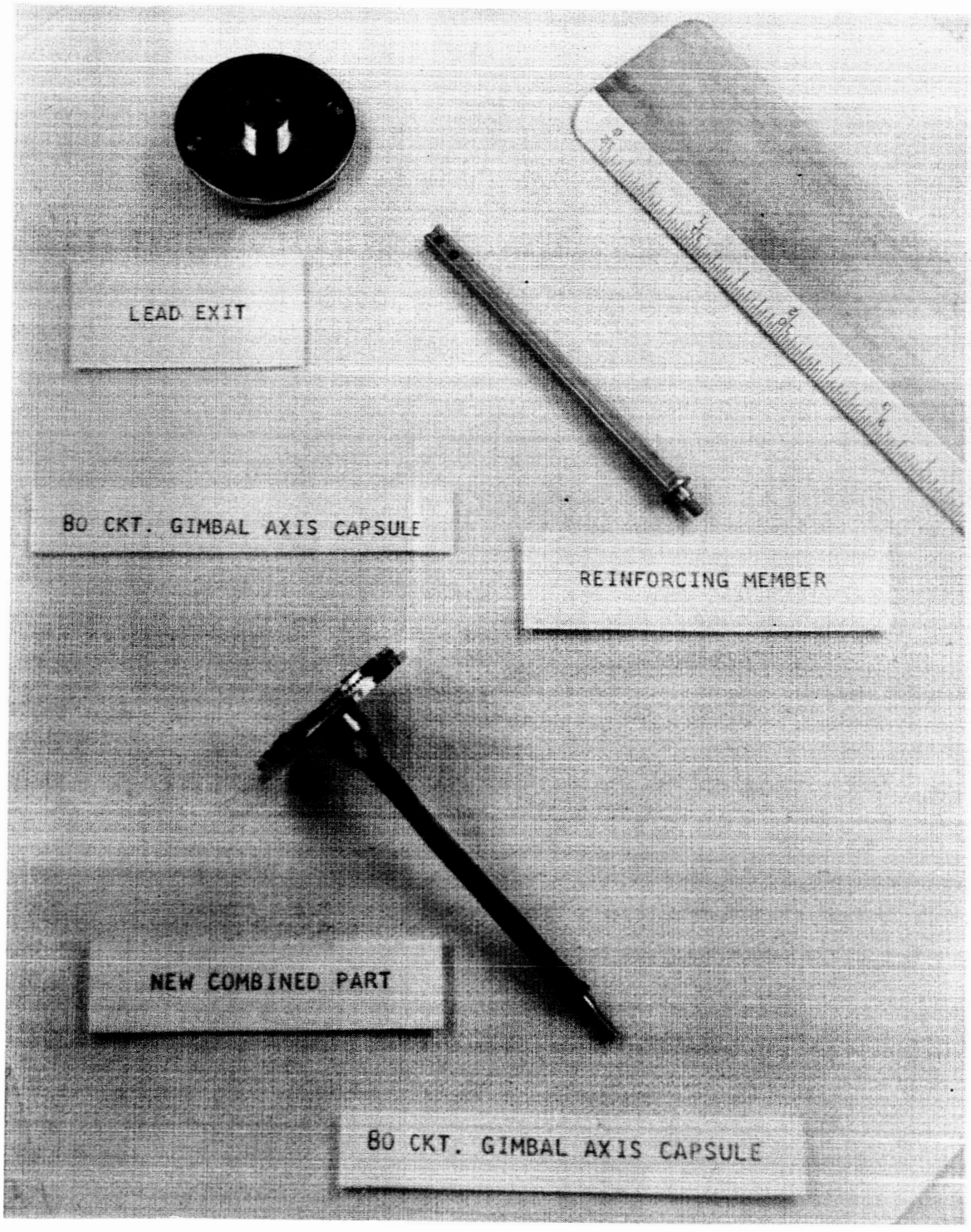


Fig. 2.5.3 Rotor Reinforcement

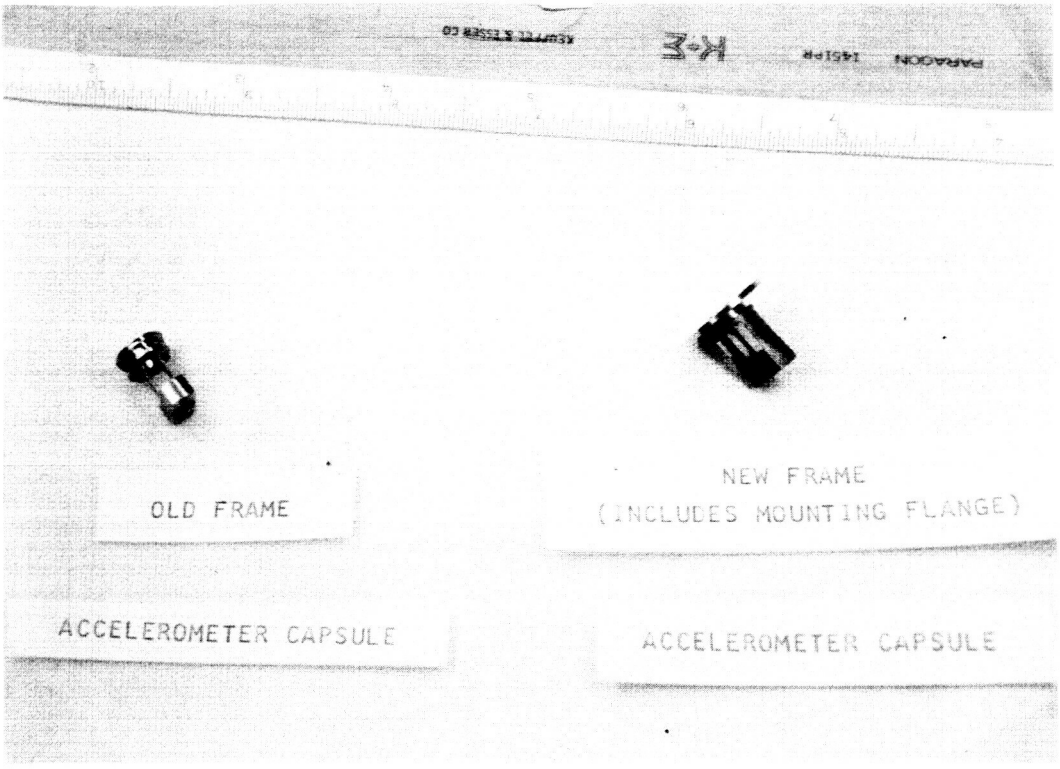


Fig. 2.5.4 Frame

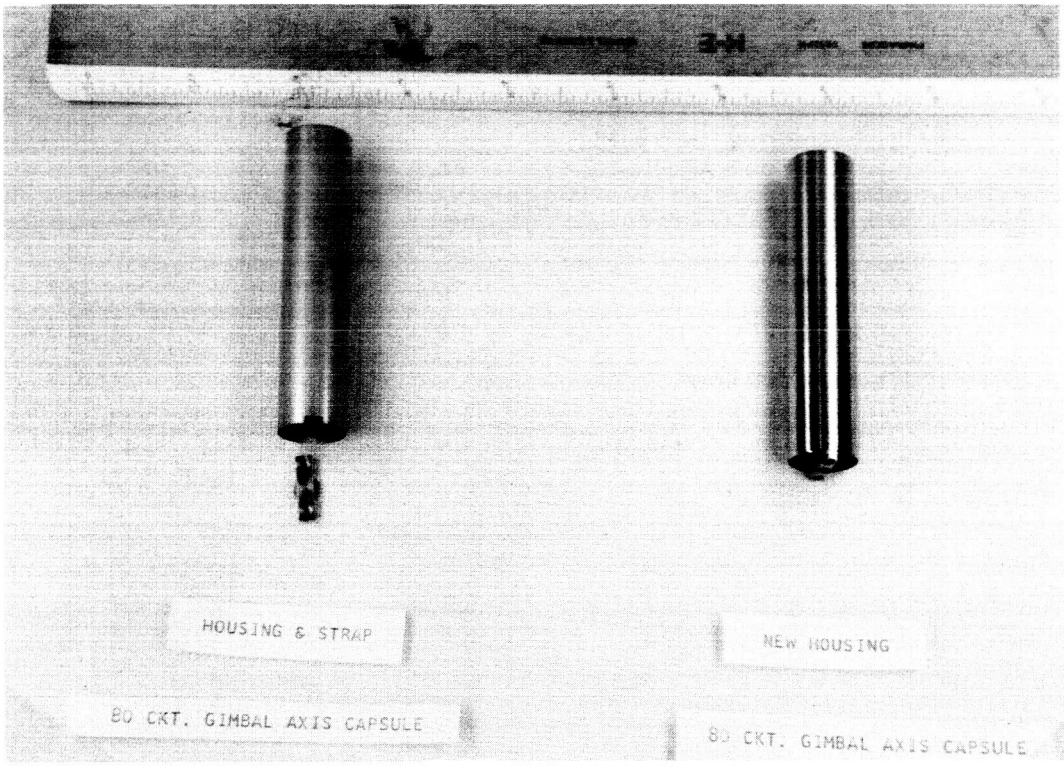


Fig. 2.5.5 Housing

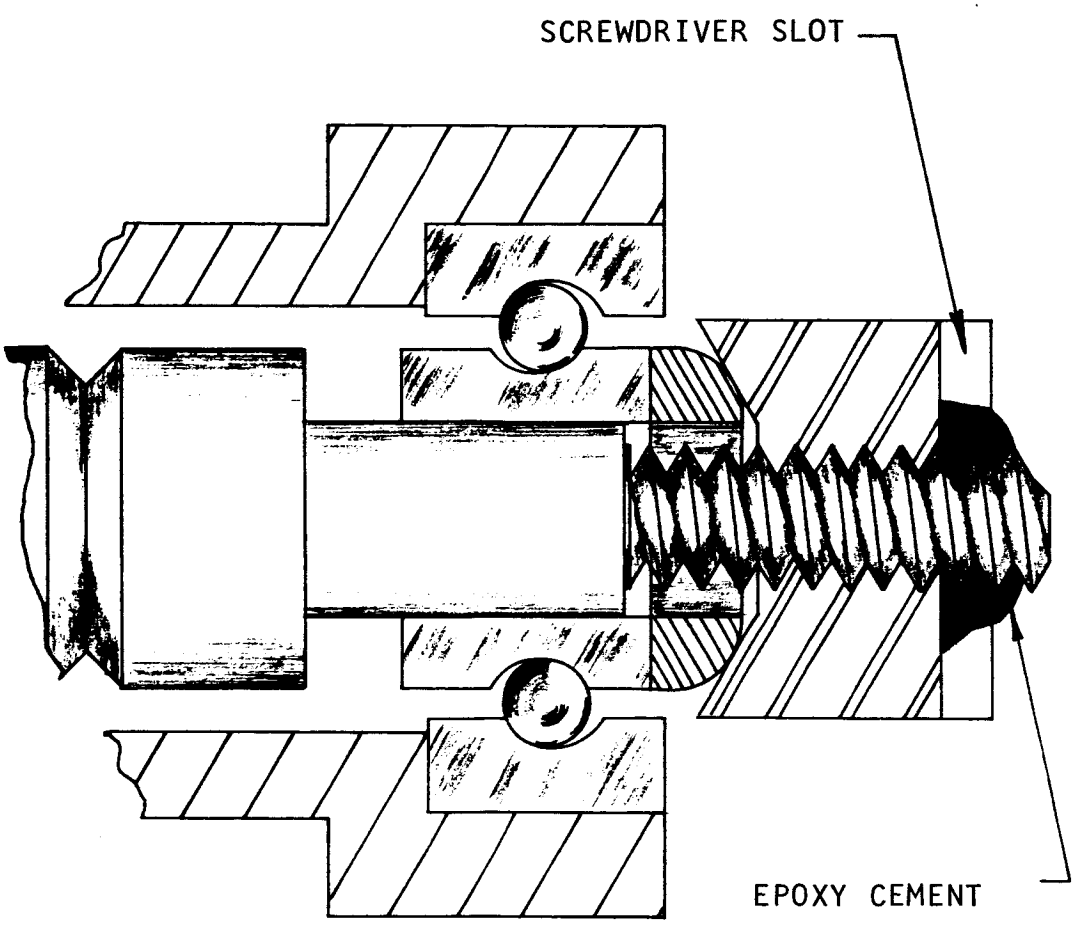


Fig. 2.5.6: Alignment Washer on Bearing Play Adjustment Mechanism

2.5.5 Handling and Processing of Bearings

2.5.5.1 Vendor requirements - Although the new bearing callout was for stock bearings, the reliability of the end product dictated that the quality and history of each bearing be more closely controlled and monitored than would be the case for off-the-shelf bearings.

In order to have proof of consistent performance from one bearing to the next, and to have a record of over-all lot quality levels, each bearing is required to be torque tested and the torque trace shipped with the bearing.

Each bearing is to be individually packaged in a vial, with enough ESSO UNIVIS P-38 oil to cover the bearing. The oil prevents the bearing from coming in contact with any of contaminants emitted during sealing of the package, and the use of individual containers prevents contaminating other bearings when only one bearing is required. The oil specified is the same used to lubricate bearings in the capsule.

2.5.5.2 In-house Handling - The bearing package is not to be opened after leaving the bearing manufacturer's plant, until capsule assembly in the clean bench. Incoming inspection at the slip ring manufacturer's plant is waived, on the basis of a certificate of compliance which accompanies each lot of bearings.

The bearings are not to be installed with ordinary tweezers, finger, pliers or any other tool which might damage the bearing. Special tools which grip the O.D. or which grip the I D. are used in order to prevent possible uneven forces to the bearing races.

2.5.5 3 Installation and Lubrication - The preload is to be checked on a fixture which measures the axial play at a predetermined axial force. No substitute has been found yet for the skill and delicate touch of the assembler in applying the preload, but the new design improvements, and the continual monitoring, make his chance for error nearly zero.

Lubrication of bearings had been accomplished previously by submergint the whole capsule in a solvent containing 1% by weight of P-38 oil.

Since contact lubrication has been suspected of contributing to contact resistance variation, and because contact lubrication has been proven unnecessary, the bearings are oiled in a solvent bath prior to assembly into the capsule. The quantity of oil is closely controlled to prevent bleedout onto contact surfaces.

2.5.6 Conclusions

The bearings currently specified and used, as a result of their design, installation, and controlled processing are capable of performing their intended function. Since the design changes described in Section 2.5.4, were introduced, no bearing failures have occurred during 41,200 bearing hours.

3.0 PROCESSES

3.1 Contamination Studies
by Curtis G. Morris, Laboratory Manager

3.2 Converting Stranded Wire to Solid Wire for Electro-deposited Slip Ring Use
by Wendell Hensley, Metallurgist

3.3 Gold Electrodeposition
by Curtis G. Morris, Laboratory Manager

3.4 Grinding
by Wayne Starkey, Manufacturing Engineer

3.5 Cleaning
by Curtis G. Morris, Laboratory Manager

3.6 Matte Finishing
by Wayne Starkey, Manufacturing Engineer

3.7 Evaluation of Mechanical and Physical Properties of Soldered and Welded Ring-Lead Connections
by Wendell Hensley, Metallurgist

3.8 Lead Protection
by Wayne Starkey, Manufacturing Engineer

3.9 Processing
by Wayne Starkey, Manufacturing Engineer

3.1 CONTAMINATION STUDIES

3.1.1 Introduction

Electrical contacts, particularly those operating at light brush forces are sensitive to any contamination appearing on the contacts. Special precautions must be taken in the specification of metals, plastics and components to prohibit contamination from being introduced into the product. Since the outset of this program, over 100 materials specifications and 300 process instructions have been prepared in the effort to control such items.

At the time this program was initiated functional failures of slip ring assembly contacts could be classified in two groups: Static failures and dynamic failures.

Static failures occurred after an extended period with limited or no relative motion between the rotor and stator. The failures were observed as noise level increases one or more orders of magnitude greater than that occurring at the time of acceptance test. The problem would occur in general in groups of adjacent circuits over the majority of the circuits. This noise, which occurred after a period of two weeks to several months, at room conditions, was normally apparent over 360° of rotation.

The dynamic noise on the other hand appeared in a somewhat different manner. It developed after extended periods of operation and was characterized by its proximity to areas where sliding had occurred.

Since the static phenomenon seemed unique to slip rings and the dynamic problem had already been studied for relays by Hermance and Egan,(1) it was decided that a concentrated study should be made to characterize and eliminate the static noise problem. This problem was termed "haze" and this study was directed at its solution.

The approach to the solution of the problem was characteristic of such a problem.

Identification of haze.
Study of materials and processes to determine causes and elimination.
Study of assemblies to determine cause and elimination.

Many laboratories across the country have been engaged in various aspects of the identification of the cause, because of these concentrated efforts, Poly-Scientific has concentrated more on the detection and elimination of the source of the haze.

3.1.2 Identification of Haze

3.1.2.1 The identity of this haze has been sought for years by several organizations. Formal programs have been run by Poly-Scientific, A. C. Spark Plug, N.A.S.A., Crobaugh Laboratory, Bell Laboratories, Stanford Research Institute, Illinois Institute of Technology, and others. Possible characterizations of the haze have been:

3.1.2.1.1 An exudate or volatile outgassing of the dielectric material(s).

3.1.2.1.2 A residue of solder flux or other in-process material.

3.1.2.1.3 An oxidation product of one or both contact materials.

3.1.2.1.4 Interaction of materials with atmospheric or in-process elements or solutions. (Hydrogen, sulphur, lubricants, cleaning solutions, atmospheric contaminants, plastics, or other organic materials.)

3.1.2.2 Analysis by Radiotracer Techniques - Experiments using radiotracer techniques were conducted using the Virginia Polytechnic Institute Physics Department research reactor by Dr. A. K. Furr and his associates. The major problem encountered was one of sampling. The quantity of haze was so small and the techniques of removal without extraneous effects was so difficult that consistent results were difficult to obtain. However, the problem was resolved by using

a small pure spectrographic carbon electrode which had been machined to proper dimensions. The electrode was drilled to accommodate small samples derived from direct abrasion of the prepared electrode against a slip ring test rotor contact surface which had an obvious haze film. Consistent results were then obtained. The elements which appeared in most cases were Au, Cu, Fe, Na, and Cl. The results have been strictly qualitative to date.

3.1.2.3 Electron Diffraction Study - N.A.S.A., George Marshall Space Flight Center ran an electron diffraction study on one of Poly-Scientific's test capsules. This was an E.S. 38 amine cured epoxy assembly. The E.S. 38 rings of this assembly had an obvious irridescent film of contamination. A transmission technique was used. Except for the ring material, there was no crystalline material present. The scattered and smeared pattern which did result was interpreted to be caused by a film of organic or organic-metallic material. Dr. Pscherra, on the basis of his findings, concluded that the haze film is either organic or organo-metallic.

3.1.2.4 Battelle Analysis - Samples were prepared to be analyzed by Battelle Memorial Institute. (Non-Ferrous Metallurgy Division) The samples were prepared and were baked at 150°C for 39 hours. A small area was then scraped on the exposed surface of each sample with an orange stick. This provided a clean spot where contact resistance could be measured with a fine wire probe. Adjacent areas to the cleaned spots were then checked in the same manner to detect the presence of an insulating film. Results of the Battelle tests and description of the samples are shown in Table 3.1-I.

3.1.2.5 Correlation with in-house production data - An analysis of some in-house data was made in an attempt to find some variables common to all of the slip ring capsule assemblies presently being manufactured. The parameters which were checked were; plastic, pigment, contact materials, brush force, noise. This information represents approximately 3000 parts manufactured during the

TABLE 3.1-I

HAZE PRODUCING CHARACTERISTICS OF ALLOYS

Sample Number	Alloy and Percentages	Epoxy (*)	Visual Film	Indirect Illum. 10X	Film Pres. by con.res.	Battelle Findings
1	E.S. 55 - 35% Pd, 30% Ag, 14% Cu, 10% Pt, 10% Au, 1% Zn.	E.S. 151	Yes	Tan Haze	Yes	NaCl
2	E.S. 55 - (same)	E.S. 84	Yes	Tan haze	Yes	NaCl
3	E.S. 38 - 90% Au, 10% Cu	E.S. 84	Yes	Tan-white haze	Yes	Inconclusive
4	E.S. 38 - (same)	E.S. 151	No		Yes	Not run
5	E.S. 118 - 99.5% + Au.	E.S. 84	No		No	Nothing
6	E.S. 118 - (same)	E.S. 151	No		No	Not run

three month period from January to March 1964. A noise value of at least an order of magnitude greater than the noise specification was used as a criterion for film presence. (Repeated experiments have shown that the haze will increase noise values many times the specification level.) After extensive study, it was concluded that there were no common variables to be found among those considered.

3.1.2.6 The occurrence of haze in microscopic quantities requires very sophisticated techniques to determine identity. Consultants at Virginia Polytechnic Institute and Crobaugh Laboratories exhausted their use of analytical methods without obtaining a positive identification. Others tried various techniques with only limited success. Dr. Doris K. Wilsdorf and Dr. Heinz G. F. Wilsdorf at the University of Virginia, experts at electron diffraction, felt that a problem of this nature would take at least a year of study with a positive solution doubtful. This analysis technique was not pursued farther by Poly-Scientific. The repeated failures of analysis indicate the unlikely possibility of ever identifying the contaminant by analytical techniques.

Two separate analysis therefore (N.A.S.A. and Battelle) had detected Na and Cl on the prepared samples. Our consultant, Dr. W. L. Hunter, Professor of Chemistry at the Virginia Polytechnic Institute, speculated that the NaCl was possibly a product of impurities introduced during the epoxy preparation. This resin is prepared by a reaction involving epichlorohydrin (a possible source of Cl) in the presence of caustic (NaOH), a possible source of Na.

3.1.3 Plastics and Processes

As has been indicated above the analytical work has pointed to the materials and processes used in slip ring construction.

3.1.3.1 Simultaneous with the effort to analyze and identify the haze, studies were conducted in an attempt to determine any cause of the haze which might be related to the dielectric material used in the assembly. The work in this area was channeled into several areas:

3.1.3.1.1 Plastic Formulations

3.1.3.1.2 Cure Studies

3.1.3.1.3 Synthetic Contamination

3.1.3.2 Plastic Formulations - Acting on the suggestion by our consultant, Dr. W. L. Hunter, Virginia Polytechnic Institute Chemistry Department, soxhlet extractions were made on cured Poly-Scientific formulation E.S. 151 samples. The purpose of this experiment was to attempt to remove and identify unreacted material which could subsequently escape and contaminate the rings. Extractions were made with carbon tetrachloride, carbon disulfide, epichlorohydrin, chloroform, water, dimethylformamide, and "Freon". The only thing which the infrared spectrophotometer could pick up from the extractions was the stopcock grease used to seal the joints of the extraction apparatus. No unreacted material was identified.

It might be interesting to note two extractions in particular - the carbon tetrachloride and the chloroform. These two solvents turned the clear E.S. 151 shavings to a brillant dark blue color. Samples of epoxy with other amine curing agents turned brown, green, or blue - depending on the curing agent and cure cycles used. Dow Chemical believes the coloring to be the result of electron rearrangement accelerated by the presence of halogens. This is related to the ability of the amines to act as complexing agents thus to potentially cause film formation. This characteristic of amine cured epoxy prompted a study of a change in plastic formulation.

3.1.3.2.1 An anhydride cured plastic system utilizing a much smaller proportion of amine curing agent as an accelerator looked promising. The brittleness inherent to anhydride cured plastics could partially be overcome by using fillers. Several plastic systems having low amine concentrations were investigated to determine if the reduced amine content would prevent or reduce haze formation on slip ring contacts, (Table 3.1-II).

Four (4) test units were completed with this concept. Three (3) were fabricated from Poly-Scientific A-79-36 plastic formulation whereas one (1) was constructed with A-72-3 formulation.

TABLE 3.1-II

PLASTIC SYSTEMS HAVING LOW AMINE CONCENTRATIONS

PLASTIC SYSTEMS	TEST CAPSULE DESIGNATIONS	CURE CYCLE	CASTABILITY	COMPLETED CAPSULE PERFORMANCE
A-79-36	P/N 1 P/N 4 P/N 5 P/N 10 P/N 11 P/N 12 P/N 13 P/N 14 P/N 15 P/N 16	CC 6 CC 8 CC 5 CC 9 CC 9 CC 9 CC 9 CC 10 CC 10 CC 10	Fair	Haze was observed on all units following 120°C vacuum bakes, except those having hard gold flashed contacts.
A-72-3	P/N 6 P/N 7	CC 5 CC 9	Good	Haze was observed on all units following 120°C vacuum bakes, except those having hard gold flashed contacts.
A-72-4	P/N 8 P/N 9	CC 9 CC 9	Good	Haze was observed on the completed unit.

In all four cases, vacuum (3 mm Hg pressure) baking (120°C) for 24 hours, resulted in a noise increase of a factor of at least 5; on three of the four capsules noise increase resulted in a factor of 10 and greater.

With all other parameters held constant, the low amine concentration systems did not show more favorable characteristics than the regular amine systems insofar as haze formation is concerned. Although the castability is good, the high modulus of elasticity and the relatively low tensile strength result in a brittle material which cracks easily. On the basis of consistent haze-producing characteristics of the low amine systems, it was concluded that these systems offered no advantage over those having regular amine content.

3.1.3.2.2 A plastic system denoted A-110-1, was formulated with no amine, to determine if test capsules fabricated with this material would form haze. This anhydride cured system was very difficult to fabricate due to its high modulus and low tensile characteristics. Only one test unit was processed to completion to evaluate this material, 24 hours at 120°C, 3 mm Hg pressure was sufficient to cause a visible haze and an increase in noise levels by factors of 10. Two additional rotors made with this material exhibited no visible haze following 11 hours at 120°C, 3 mm Hg. The anhydride cured plastic systems, although acknowledged as more heat stable than amine cured formulations, did not eliminate or affect the degree of film contamination on the slip ring contacts. In addition, the anhydride systems are not compatible with standard production processes, and therefore are not advantageous as casting resins for slip ring use either structurally or chemically.

3.1.3.2.3 Attention was then turned to a plastic system having an amine with a high melting point (175°C). It was considered that this high melting amine would be less likely to be driven off during baking if it were the actual source of the film contaminant. Two test capsules were constructed using this formulation denoted E.S. 218. A noise test on each capsule, following 40 hours at 120°C, (3 mm Hg) revealed an increase in the noise level by a factor of 30.

However, it was noted that no visual haze could be detected by 60X microscopic examination. Haze was visible following 96 hours at 105°C, 3 mm Hg. It was concluded that the high melting amine cured plastic system offered no advantages in haze prevention.

3.1.3.2.4 It was decided that a formulation completely different from the plastic systems currently in use should be evaluated. Two polyester systems (Selectron 5016 and Hetron 197) were selected for evaluation. The polyester material was very difficult to cast, but one unit was constructed using Hetron 197 with a Lithafrax filler. Twenty-four (24) hours at 120°C, 3 mm Hg pressure was sufficient to increase noise levels by as much as a factor of 20. Also the rings developed a brownish visible haze. The polyester plastic systems offered no advantage over other systems evaluated in haze prevention.

3.1.3.2.5 The conclusion which must be drawn is that all plastic materials suitable for use in slip ring assemblies will produce haze to a significant degree on electrical contacts.

3.1.3.3 Cure Studies

3.1.3.3.1 Time Temperature Graphs - If all plastics will create haze, it was felt that improvements of cure could be made which would reduce the tendency for haze formation. One of the first concerns was the temperature of the molds during cure cycles.

Time-temperature graphs of mold interiors were obtained with the ovens used in curing plastics. Temperatures were recorded by means of an iron-constantan thermocouple held in place against the interior of a master mold by silastic. These master molds were identical to the one used for casting the test capsules described in this report. Blanks or plastic slugs were cast in the molds and the temperature change monitored by means of a digital voltmeter or potentiometer. It was learned in short, that the desired temperatures were not being attained. This information enabled temperature rise and fall times to be considered in subsequent rotor castings to insure that the desired time at the desired temperature was being realized within the

molds. Rise and fall time lags were known to exist, but the true nature of the rate of change was not known until this work was completed.

3.1.3.3.2 Optimum Cure Cycle - There had been speculation for some time that the plastic system or other organic material within the slip ring assembly could be outgassing and reacting with the contact surfaces. A series of experiments were conducted to examine the weight loss characteristics of E.S. 151 plastic samples prepared by controlled methods and given known cure cycles. Temperature of mold interiors were monitored by means of an iron-constantan thermocouple inside the mold, and a potentiometer.

The temperatures examined corresponded to the standard cure temperatures recommended for the E.S. 151 formulation by Dow Chemical Laboratories. The criteria for excellence were:

The relative epoxy absorption on the infrared spectra at 10-9 microns.

The weight loss under heat and vacuum.

The samples used in this experiment were cast and cured according to Table 3.1-III.

Samples M, N, O, and P were used as controls in that they duplicated the conditions of C, D, I, and J respectively. Time-temperature data was obtained for each plastic sample during cure.

The cure time of sample "C" corresponded to the recommended cure time for the E.S. 151 formulation. Dwell times longer than those recommended were evaluated in this experiment. The plastic samples cast and cured by each schedule given were lathe machined to obtain shavings.

Infrared spectra were obtained on each sample. Infrared skills and techniques limited the quantitative analysis to the extent that only gross differences in epoxy absorption bands could be interpreted. Based on the infrared spectra of E.S. 151 plastic for the recommended cure, it was determined that inadequate cure was being achieved under normal conditions.

TABLE 3.1-III

WEIGHT LOSS OF EXPERIMENTAL CURE CYCLES

Sample	Mold and Component (Preheat Temp.-°C)	Gel Cure Time (60°C)	Final Cure Time (120°C)	Percent Weight Loss* after 24 hrs. @ 150°C
A	80	4 hours	4 hours	2.1
B	80	8 hours	4 hours	.9
C	90	4 hours	4 hours	10.4
D	90	8 hours	4 hours	1.0
E	100	4 hours	4 hours	1.0
F	100	8 hours	4 hours	.9
G	80	16 hours	4 hours	.9
H	80	8 hours	6 hours	1.0
I	90	16 hours	4 hours	1.0
J	90	8 hours	6 hours	.8
K	100	16 hours	4 hours	.8
L	100	8 hours	6 hours	.8
M	90	4 hours	4 hours	.8
N	90	8 hours	4 hours	.8
O	90	16 hours	4 hours	.8
P	90	8 hours	6 hours	.6

(*) Based on 4 grams samples of blue pigmented E. S. 151.

TABLE 3.1-IV

HEAT DISTORTION TEMPERATURE OF PIGMENTED PLASTICS

Cure #1 - 4 hours at 60°C and 4 hours at 120°C

Color:	Neutral	Red	Green	Blue
HDT	146°C	149°C	144°C	146°C
HDT	147°C	148°C	131°C	148°C
HDT	149°C			

Cure #2 - 16 hours at 55°C, 2 hours at 125°C, 2 hours at 175°C

Color:	Neutral	Red	Blue
HDT	185°C	192°C	181°C
HDT	188°C	194°C	183°C
HDT			183°C

Plastic shavings were also weighed into dried, weighed, beakers and placed in a 150°C vacuum oven for 24 hours. Weight loss exhibited by each sample is given by Table 3.1-III. The weight loss as a function of temperature dwell time indicated that a longer gel cure time gave a better cure.

It should be noted that weight loss studies are considered questionable as a direct measure of the degree of cure unless extremely well controlled equipment and procedures are utilized. Handling time, location in the oven, and moisture absorption all combine to raise the level of error in such measurements. Further weight-loss studies as a measure of cure were therefore not considered advisable.

3.1.3.3.3 Curing in Controlled Atmosphere - It was suggested by Dow Chemical that the plastic might oxidize and develop a brown color during cure cycle in air. This was believed to relate to the development of haze producing materials. To verify this, identical samples of E.S. 151 were final cured in vacuum, nitrogen, and air and the results compared visually. There was a difference in color between the materials. Those cured in vacuum developed a much lighter color supporting the Dow hypothesis that oxygen can affect the curing plastic.

3.1.3.3.4 Pigments and Cure - P. S. consultants suggested that pigments used in plastic could affect the degree of cure of the plastic. Dow Chemical advised that heat distortion temperature was the best criteria for cure completeness.

Heat distortion temperature as determined by ASTM D-648 was used as means to evaluate E.S. 151 with different pigments. Cure #1 samples were cast according to the Poly-Scientific process and cure cycles. Cure #2 samples were cast using the Dow recommended cure cycle. Table 3.1-IV shows a list of the samples, prepared by Poly-Scientific Engineering Laboratory and evaluated by Dow Chemical Corporation, with their corresponding cure cycles and resulting heat distortion temperatures.

As can be seen, there is a slight difference in heat distortion temperature for the green pigmented sample. Dow Chemical Corporation data reveals the optimum heat distortion temperature for E.S. 151 to be 200°C - 206°C. It is readily apparent that none of the samples listed above had received full cure. However, the longer time higher temperature cure samples indicated a higher HDT.

3.1.3.3.5 From these cure studies it was concluded that:

3.1.3.3.5.1 The heating and cooling rates of the molds have a significant effect on the cure of the assemblies.

3.1.3.3.5.2 The state of cure is principally detectable by infrared studies.

3.1.3.3.5.3 Curing in an inert atmosphere (nitrogen or vacuum) can reduce extraneous chemical reaction with the environment during cure.

3.1.3.4 Synthetic Contamination - Development of contamination in situ on actual assemblies was a time consuming and costly process. Numerous efforts were made to duplicate the haze on simpler samples by various means. These efforts produced some of the most enlightening results.

3.1.3.4.1 Vapor condensation techniques were suggested by Dr. W. L. Hunter. Slip ring of known noise character were manipulated within a nitrogen tent and were subjected alternately to dry ice temperature and a vapor from heated plastic ingredients. This caused a condensation of vapor on the cold sample. The condensate identity was verified by infrared analysis on NaCl plates treated in the same manner. Only the amine curing agent (p p'methylene dianiline) was found to affect the noise value. The condensate did not, however, have the same visual appearance as the haze or the physical characteristic. This demonstrated the volatility of the amine and indicated the possibility of it as a contributor to contamination.

3.1.3.4.2 Numerous experiments were conducted in an attempt to contaminate a medium such as polished glass, NaCl, and Irtran. If possible, these materials could have been used to obtain contamination traces on the infrared spectrophotometer. In one experiment, glass slides were placed above samples of plastic while vacuum baking. The proximity of the glass slides to the plastic shavings was varied from three inches to actual physical contact, with no haze forming on the glass. Similar experiments using NaCl and Irtran discs were equally negative as with the glass. Plastic in several forms; components, premix, and final cured material in chunks and shavings, were tested. Haze could not be detected in any case by microscopic visual observation.

This suggested the possibility of unique interaction between a metallic surface and the haze producing substance.

3.1.3.4.3 A series of experiments was designed to study haze formation reproduced by a simple technique that could be used as an alternate method of evaluating various parameters. Several frequently used contact alloys were cast in clear E.S. 151 in the fashion of metallurgical samples. These samples were then polished and cleaned to remove the polishing compounds. Individual samples (one alloy per casting) were made as well as a group casting (several alloys per casting). The samples were vacuum baked for nearly 100 hours at 120°C vacuum (2 mm Hg pressure). The visual observations at 15X and 45X by four laboratory personnel were as shown in Table 3.1-V.

The conclusion drawn was that there is a relationship between the nature of the metal contact and the haze. Since in all cases the alloys with the highest gold content had the least haze, it was concluded that gold is less susceptible to the haze formation.

3.1.3.4.4 A Sauereisen (ceramic) slug was cast with a piece of E.S. 55 rod and a piece of E.S. 38 tubing in the fashion of a metallurgical sample. The sample was polished, cleaned, and then baked at 150°C for 48 hours. The sample came out of the oven with clean alloy surfaces.

TABLE 3.1-V

HAZE FORMED ON CONTACT MATERIALS

Contact Alloy	1st Group Casting	Repeat Casting	Individual Casting
E.S. 38 CW	Slight amount of haze	Significant amount of haze	Slight amount of haze
E.S. 54 CW	Questionable	Heavy	Heavy
E.S. 55 HT	Significant	Slight	Slight
E.S. 56 HTA	Heavy	Heavy	Heavy
E.S. 57 CW2	Slight	Significant	Heavy
24K Anode	None	None	None
E.S. 118 (99.9% - 100% Au)	None	None	None

The sample was then suspended over a beaker partially filled with E.S. 151 shavings. This assembly was placed in a 150°C oven for 24 hours. The E.S. 55 sample maintained its original clean surface. The E.S. 38 had a definite layer of haze which could be removed with slight difficulty by mechanical abrasion with an orange wood stick. The area surrounding the E.S. 38 ring was also "brown", presumably from the E.S. 38 particles smeared during polishing. These particles also had collected a brown haze.

This indicated that the haze forms from plastic vapor deposited on or reacting with the contact material, and that the E.S. 38 is more susceptible than E.S. 55.

3.1.4 Studies of Assemblies

Simultaneous with the analytical studies and the investigation of plastics and processes, the assemblies themselves were being considered for a better definition of the haze problem.

3.1.4.1 Noise Stabilization - It had been assumed by some that procedures of repeated cleaning and vacuum baking could be devised to remove or prevent formation of the haze and hence stabilize the noise. Noise stabilization is herein construed to mean the maintenance of noise within one order of magnitude of initial noise level under accelerated environment of high temperature (up to 150°C) and/or vacuum (3 mm Hg pressure).

3.1.4.1.1 Six (6) Poly-Scientific test capsules were constructed. The proposed program had three purposes.

3.1.4.1.1.1 Further investigation of the variation in noise levels due to haze formation.

3.1.4.1.1.2 The effects of cleaning and/or run-in on haze formation.

3.1.4.1.1.3 To ascertain the degree of noise stabilization that could be achieved by successive vacuum bake-outs and cleanings.

3.1.4.1.2 The run-in referred to in this experiment was achieved by holding the rotor stationary and rotating the stator at 300 rpm for 5 minutes. The six slip ring capsules used for this experiment were assembled using E.S. 151, E.S. 38, and E.S. 55 for plastic, ring, and brush components respectively. Leads were attached to rings and brushes by high temperature solder. Noise levels were recorded on a Sanborn 150 dual channel recorder, from the assembly in a resistance bridge circuit described in Appendix 3.1-I. Since many noise tests were necessary only a representative number of circuit pairs were checked in most cases. The interpretation of results was made by studying the performance of each individual part as a function of the conditions to which the part is subjected. Some results of given treatments were as predicted while others appeared to be strictly random.

One cleaning process demonstrated an ability to reduce the formation of the haze film. Six slip ring units were assembled and cleaned ultrasonically in "Freon" PCA for 1 to 2 hours. All capsules maintained small noise increases after extended periods of time in 150°C vacuum bake at a 2 mm mercury pressure. This noise increase was lower than that normally associated with haze that is a factor of 10, but did increase by a factor of 3 or 4 on most circuits. This represents a significant although limited gain in the prevention of haze.

No other cleaning process or vacuum bake produced any stabilization of noise levels.

3.1.4.2 Removal of Haze from Contact Alloys with selected solvents and solutions - This experiment was conducted in order to determine the chemical nature of haze. Previous attempts to remove haze by common solvents had failed. The following information is at best an indication of solubility based on visual observation at 15X to 60X. The test capsules used in this experiment were constructed of E.S. 84 plastic with E.S. 38 rings and E.S. 55 brushes. These capsules were stored for three weeks at 15.6 - 26.7°C and ambient pressures to produce haze on the rings. Ultrasonic generation for 2 minutes with dimethylformamide removed much of the haze. Haze reappeared, however,

on the contacts after 48 hours in a 70°C oven (2 mm Hg pressure). The newly formed haze appeared to be thicker and less adherent to the rings than did the original.

3.1.4.2.1 Ultrasonic generation for two minutes in the following solvents and solutions failed to remove the haze.

Ethyl Alcohol	1,1,1-trichloroethane
Freon PCA	Water, distilled, boiling
Methylethylketone	Chloroform
Acetone	Benzene
Ethyl Ether	Ethyl Acetate
83% perchlorethylene/ 17% Ethyl Acetate	Pyridine
Petroleum Ether	Isopropanol
Potassium Cyanide (5%)	Sulfuric Acid (5% and concentrated)
Alconox solution (5%)	Sodium Metasilicate (25%).

3.1.4.2.2 The following solvents and solutions resulted in partial removal. The percentages are estimates based on visual observation at 15X - 60X.

Solvent	Mixture	Haze Removed
Dimethylforamid	--	100%
Sodium Hydroxide	25% aqueous	75%
Acetic Acid	30% aqueous	75%
Hydrochloric Acid	18% aqueous	50%
Nitric Acid	20% aqueous	5%
Aqua Regia	--	50%
Thiourea (with equal parts per vol. of conc. Fluoboric acid	50% aqueous	90%, but damaged the components.
Fluoboric Acid	10% aqueous	20%

3.1.4.2.3 This experiment demonstrates the inert nature of the haze by the general insolubility of the haze in all solvents, except a few of the most active acids and alkalies. It further indicates the polymeric nature of the haze by its solubility in dimethylforamide. The fact that the film did reform in vacuum bake demonstrates that the cleaning affected only the surface and did not attack the underlying cause.

3.1.4.3 Coating of Contacts - All plastic materials have shown a tendency to produce haze on slip ring contacts. Only a limited advantage was gained by cleaning to remove the source of the haze. It was considered that a coating might prevent the haze, and a brief feasibility study of preventive coatings was conducted.

3.1.4.3.1 A surfactant coating of FX-161 material from Minnesota, Mining and Manufacturing Company was applied in dilute solution to the assemblies.

The surfactant treatment involved a 2 minute generation in a Freon - 1% (isopropyl alcohol/ surfactant) mix, the surfactant being premixed with the isopropyl alcohol (1% surfactant). The capsule was then air dried while rotating the rotor some 10-15 revolutions by hand.

It was hypothesized that such a material coated onto the contacts would remain in place as a thin film and prevent or reduce the tendency for the unwanted haze film to form. Two capsules were treated in this manner and observed and noise tested at intervals following elevated temperature treatment both with and without vacuum.

The results indicated that the surfactant suppressed the haze formation temporarily. Extended bakeouts and subsequent rotation tended to break up the thin surfactant film into small brown particles. It should be noted, however, that the surfactant did serve to decrease the torque of the test capsules. It was apparent that surfactants did not offer a permanent solution to the formation of haze.

3.1.4.4 Effects of Hard Gold Flashing - It was suggested at this point that a haze protection coating might be chemically bonded to the surface of the contacts providing greater protection to the contacts than from surfactants. Initially, a chromate film similar to that of oxide on aluminum or chrome plated metal was proposed. However, a literature review disclosed that precious metals were so stable that such protective films on gold were impossible to form. Since gold was so stable, it was suggested that we try pure gold on the contacts instead of the

conventional E.S. 38 and E.S. 55 alloy combination used in the previous test capsules. This concept was further supported by the results of 3.1.3.4.3 in synthetically contaminating of the metals.

3.1.4.4.1 Samples of contact alloy rods and tubes were sandwiched between flat pieces of epoxy plastic. Of the alloys used only E.S. 118, pure gold, developed no haze in 24 hours at 150°C and 2 mm of mercury. This confirmed the haze preventing ability of the 24 karat gold.

3.1.4.4.2 Several rotors with alloy rings were prepared by gold flashing alternate rings with various high karat gold plating. These, too, were sandwiched between epoxy flats. No plated surfaces developed haze while all unplated surfaces did produce visible haze. This confirmed that the particular high karat alloy is not significant, only that the gold content be greater than 23 + karat (96 + %).

3.1.4.4.3 Rings of 24K gold were subjected to the same test after preparation by; machining 1/3 the rings, electroetching 1/3 the rings, and electroplating with gold 1/3 the rings. These rings showed no haze after the same test conditions indicating that the nature of the gold surface finish was unimportant in the haze formation.

3.1.4.4.4 A variety of similar experiments were performed i.e., gold flashing bad performing units, interchanging good rings in bad assemblies, etc., etc. In each and every case those rings which had high karat gold surfaces had no haze formation.

3.1.5 Discussion

From the varied studies of this effort it must be recognized that the haze film originates primarily in the organic nature of the plastics used within the slip ring assembly. It is, however, the complex nature of the interaction between organic materials and metals that creates the haze. The exact nature of this phenomena has been studied (1)(2)(3), but is not well understood. Indications and that it is related to the catalytic tendencies and/or the oxidation of the contact materials themselves.

Its formation can be limited by reducing the quantity of volatile organics in the unit and/or by selection of most stable metals available. The reduction of volatile organics can be attained by the effective curing, cleaning of the interfaces deep within the assembly, or by coating the surface with a suitable protective coating. Of course the only certain method would be the development of a suitable ceramic for capsule use, combined with a hermetically sealed capsule package, and total elimination of undesirable processing materials. The ceramics were shown in Phase I to be well beyond the state of the art.

The work herein indicates that contact metals of the nobility of 24 karat gold have the immediate solution to the problem. The most practical approach at the present is to utilize high karat gold alloys on the exposed surfaces of all contacts.

(1)
Hermance, H. W. and Egan, T. F., "Organic Deposits on Precious Metal Contacts"; Bell Telephone Technical Journal; Vol. 37; May 1958.

(2)
Chaikin, Saul W.; "Study of Effects and Control of Surface Contaminants on Electrical Materials; Stanford Research Institute.

(3)
Angus, H. C., "Surface Films on Precious Metal Contacts" The International Nickel Co., April 1961.

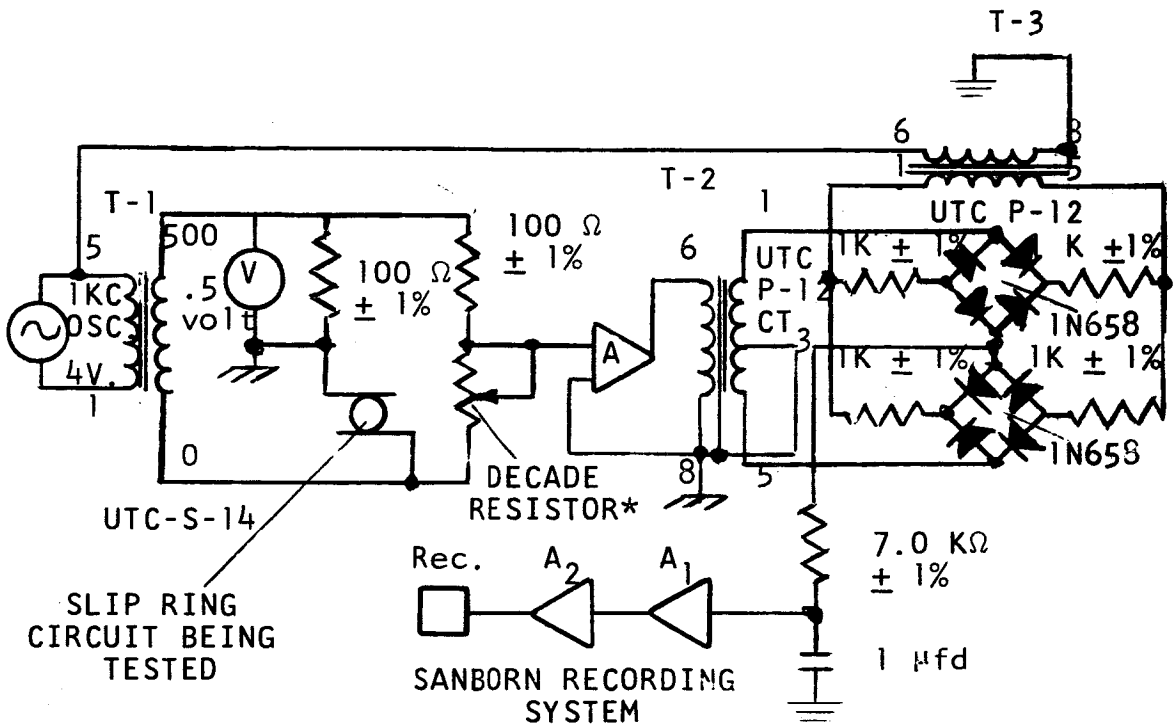
APPENDIX 3.1-I

NOISE TEST METHOD

The noise testing throughout this program was conducted using an AC bridge (Fig. 3.1-I.1) and a strip recorder. The actual components of this test system were:

1) Kintel amplifier - Model 112-A.
2) Sanborn AC-DC Preamplifier - Model 150-1000
3) Sanborn Strip Recorder - 152-100B.
4) Hewlett Packard - Model 200 ABR oscillator.

As can be seen from the associated schematic (below) the test current is 5 milliamps at 1000 cycles. The calibration is effected so that 30 millimeters peak to peak movements on the strip recorder represents 150 microvolts contact potential variation. The chart speed is adjusted to 2.5 millimeters/sec.



* .010Ω/STEP

A - KINTEL AMP.

A_1 - A_2 - SANBORN RECORDING SYSTEM

Fig.3.1-I.1 - AC BRIDGE NOISE TEST CIRCUIT

3.2 CONVERTING STRANDED WIRE TO SOLID WIRE FOR ELECTRODEPOSITED SLIP RING USE

3.2.1 Introduction

The purpose of this study has been to determine the feasibility of a process to eliminate the 30 AWG solid copper jumper used in NASA contract capsules to provide electrical connection between the slip ring and the 30 AWG (19/42) lead wire. This jumper is connected to the lead wire by soft-soldering, a process which does not have as high a reliability as desired and which involves a high probability of contamination with solder flux. A reliable process which would allow the 30 AWG (19/42) lead wire to be extended through the slip ring to the ring contact, thereby eliminating the jumper, would be a major improvement in over-all slip ring capsule reliability.

3.2.2 Requirements

The construction to replace the solid wire jumper must meet the requirements imposed upon the jumper in order to demonstrate its feasibility.

3.2.2.1 Dimensional - The 30 AWG jumper has a diameter of .010 inch which is increased to .0112 to .0122 inch by the polyimide insulation. The uninsulated 30 AWG (19/42) lead wire has an over-all diameter of .0120 inch (nominal). Consequently, the solid jumper could not be replaced by the stranded conductor without a reduction in diameter of the stranded lead wire or a design modification of the slip ring assembly, since an insulation of .0001 inch wall thickness is not possible. The wire diameter must therefore be reduced to approximately that of the jumper, i.e., .010 inch maximum. The only known practical means of reducing the diameter of the lead wire to meet the requirement of a .0122 inch over-all diameter over the insulation, was by rotary swaging.

3.2.2.2 Sealing - The construction to replace the jumper must be compatible with electrodeposition processing since the contract for the capsules requires that the slip ring contact be fabricated through a combination of electrodeposition processes. The first of these processes is the electrodeposition of copper directly onto an exposed cross section of the slip ring lead at the bottom of each ring groove.

If the slip ring lead is to be a stranded, rather than a solid wire lead, the strands must be fused together at a point where the cross section will be exposed to the plating solution; otherwise, the plating solution, such as copper fluoroborate, will be entrapped (wick) between the strands and be a potential cause of discontinuities or short circuits, via corrosive action. The strands might be fused or sealed by the following methods:

Soft soldering.
Silver soldering.
Polyimide enamel filling.
Induction brazing.
Induction paste soldering.
Induction hot dip soldering.
Epoxy filling.
Induction Heating and fusing.
Swaging.
Pressure welding

The process or combination of processes selected to seal the lead wire must meet the following requirements:

3.2.2.2.1 The sealing agent used must not be corrosive to silver or copper nor act as an electrolyte or catalyst for galvanic corrosion.

3.2.2.2.2 The sealing agent must be machinable and not subject to leaching action by plating solutions, machining lubricants, and cleaning solvents.

3.2.2.2.3 The sealing agent must not impair the plating bond strength of the lead.

3.2.2.2.4 The process must insure that all the space between strands in the cross section of the lead and along its exposed length are completely sealed or filled.

3.2.2.2.5 The process must be repeatible with a high reliability and must be the most economical process that will meet all requirements.

3.2.2.3 Mechanical and Electrical - The flex life of the construction must average 15* flexes average minimum at a flex rate of 127* flexes/minute. The pull strength of the construction must average 2.78* lbs. average minimum using a Hunter Spring Pull Tester, and the electrical resistance must be 8.9* milliohms per inch or less.

3.2.2.4 Insulation - The dielectric material selected to insulate the swaged portion of a prepared lead must perform as well as does the currently used magnet wire insulation. (The magnet wire referred to in this section is a single strand of copper insulated with a polyimide coating, namely DuPont's HML.) Specifically, the insulating material would have to qualify in each of the three areas listed:

3.2.2.4.1 Mechanical

3.2.2.4.1.1 The material must have sufficient elongation and tensile characteristics to permit limited flexure (bends less than or equal to 90 degrees over a 25 mil radius) without cracking, splitting, or exhibiting other failures.

3.2.2.4.1.2 The thickness of the dielectric wall over the swaged conductor must be equal to or less than 0.0015 inch. This wall thickness would provide an over-all dimension comparable to the diameter of the corresponding gage magnet wire.

3.2.2.4.1.3 The insulating layer must be uniform having no pits, pinholes, or other imperfections which expose the conductor.

* These are test values using jumper samples from a randomly selected spool of wire in current use on contract capsules.

3.2.2.4.2 Electrical

3.2.2.4.2.1 The dielectric breakdown voltage from the outer surface of the insulation to the conductor must be 500 volts d.c. minimum.

3.2.2.4.2.2 The dielectric strength must not be significantly affected by temperatures to 150°C, the maximum continuous operating temperature of the capsule dielectrics.

3.2.2.4.3 Chemical - The dielectric material must not be attacked by commercial fluorinated and/or chlorinated cleaning solvents.

3.2.2.4.4 In addition, the material should be readily processable by present production methods and the availability should be good.

3.2.3 Literature Search

The program was begun with a literature search for insulating materials with properties equivalent to or better than the materials used in the past, and to review processes for sealing the leads.

3.2.3.1 From previous study of magnet wire insulations, the following insulating materials were eliminated from consideration in this study for the reasons listed:

Formvar - brittle.
Formvar and glass - brittle; glass over the formvar tends to fray with handling; organic binders applied with the glass prevent fraying, but the organic-bound glass is brittle.
Teflon - poor abrasion resistance for the small wall thickness required, resulting in low dielectric strength.
Ceramic - poor abrasion resistance.
Mylar - poor heat resistance.

3.2.3.2 DuPont's ML polyimide enamel has been found to have the following properties:

Toughness.
High heat resistance (zero strength point at 815°C).
Good abrasion resistance.
Excellent flexibility.
Resistance to the chlorinated and other cleaning solvents used.

Consequently, ML polyimide enamel was selected as the insulating material best meeting all requirements

3.2.3.3 In searching the literature for methods to fuse or seal the conductor strands, the processes listed in Section 3.2.2.2 were narrowed down to three methods:

3.2.3.3.1 The soldering processes were disregarded for one or more of the following reasons:

Flux contamination.
Excessive process temperature.
Inability to completely fill all voids.

3.2.3.3.2 Filling of the voids with dielectric materials was eliminated for many reasons, the most important being that complete filling of all voids along a sufficient length of conductor is a highly unreliable process.

3.2.3.3.3 The pressure welding, induction heating and fusing, and swaging operations appeared to be applicable. Both pressure welding and induction fusing are commercial processes used to bond stranded wires. Induction fusing has the advantages of being more reliable and less expensive in equipment cost, than pressure welding. Pressure welding or more specifically, resistance-seam welding, utilizes welding electrodes shaped like wheels or discs which produce overlapping spot welds. The unreliability of this process stems from the uncertainty that all voids in the conductor cross section would be closed. No results could be found on the use of this method on small stranded conductors having as many as 19 strands. Larger conductors with fewer strands have apparently been welded into completely solid conductors with pressure welding techniques.

3.2.3.3.4 It was not believed that swaging would yield a completely solid conductor, whereas it had been proved that induction fusing would. Induction fusing however, could not reduce the diameter of the conductor to the required size. Therefore, the literature search resulted in the selection of a combination of processes to investigate for sealing the stranded conductor into a solid conductor — swaging and induction fusing.

3.2.4 Tests and Equipment

Samples of 30 AWG (19/42) lead wire were sent to The Torrington Company, manufacturers of rotary swaging machines, and swaged to a uniform overall diameter of 0.010 inch. Since it was immediately apparent that swaging alone would not fuse the strands together into a construction unpenetrable by plating solutions, the swaged samples were sent to Lepel High Frequency Labs., Inc., to be induction fused into a construction of solid cross-section.

3.2.4.1 Swaging - The swaging process was found to be the most critical aspect of this study; the successful establishment of a reliable swaging process became absolutely necessary in order to achieve the purpose of this study. Therefore, much emphasis was placed upon the swaging process. The machine used was a Torrington No. 100 Bench Model Swager.

3.2.4.2 Induction Fusing - Induction fusing of swaged 30 AWG (19/42) lead wire was accomplished with a Lepel Bench Model Induction Heating Machine, Model T-1-WH. This equipment, a megacycle frequency unit, is designed primarily to locally bond multi-stranded, tinned wire to allow stripping of the insulation without unraveling of the strands. The bonding is accomplished by melting the tin plate without melting the plated wire. The tin plate on each strand fuses to the tin plate on adjacent strands.

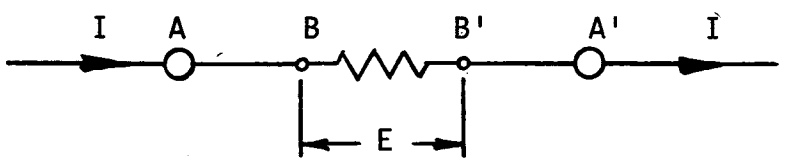
3.2.4.3 Metallographic Examination - Metallographic techniques were used to examine the effects of swaging, induction heating and fusing, and, in some cases, wicking. In most cases the samples were mounted in a normal cross-sectional view in a self-curing plastic and ground and

and polished. The microstructure of the construction was then observed after etching, on a Unitron Model U-11 Binocular Metallograph, capable of magnifications ranging from 50X to 2,667X.

3.2.4.4 Flex Life - The flex life of the wire construction under study, was tested on the fixture of Poly-Scientific design described in Phase I. The sample is clamped in a grip affixed to the specimen holding arm, and extended down through the arm slot. A 217 gram weight is clamped to the opposite end of the sample. A lead connects the weight to the specimen holding arm support, thereby making the sample a segment of an electrical circuit which is closed by the drive unit switch. Failure of the sample opens the circuit, shuts off the drive mechanism, and stops an automatic counter recording the number of flexes. The flex rate is varied and controlled by means of a powerstat.

3.2.4.5 Pull Strength - The pull strength of the construction was measured on a Hunter Spring Pull Tester, Model No. TTH. The Hunter Spring - Model L-5000M mechanical force gage used with the pull tester has a maximum capacity of 5000 grams with an accuracy of ± 25 grams.

3.2.4.6 Resistance - The electrical resistance of the wire was determined by using Hewlett - Packard Model 721A power source supplying 100 ma. Minimum sample lengths of 0.7 inch were connected into a circuit and voltage drops were measured, accurate to 0.1 milliohm, with a Cimron digital voltmeter Model 6200A as described in the following diagram:



A,A' - Current Terminals.
B,B' - Potential Terminals.
I = 100 ma.

The voltage E, is current times the resistance from B to B', and does not include any contact drop that may be present at terminals A and A'. Resistors of low values are measured in terms of the voltage drop between the potential terminals, which thus becomes exact in value and independent of contact drop at the current terminals. Contact drop at the potential terminals need not be a source error, as the current crossing these contacts is usually extremely small -- or even zero for null methods.

3.2.4.7 Wick Test - To determine whether or not the interstitial voids between strands of the construction had been sealed by the swaging and induction fusing operations, the following test was used:

One end of a two-inch sample was inserted through a small hole in the side of a paper cup, allowing 1/32-inch to protrude inside the cup. The hole in the cup around the sample was then sealed with silastic. The cup was then filled above the level of the hole and sample with E.S. 84 unfilled epoxy plastic, vacuum-cast, and cured. After curing, the sample was cut at the exit from the cup, the silastic removed by hand, and the sample was placed in a watch glass. Concentrated nitric acid was applied to completely dissolve the metal. If wicking of the plastic had occurred, the E.S. 84 was readily visible as a yellow-to-red solid material in the acid.

Two other wick tests were used. One of these tests was to dip the end of the sample into an anthraquinone dye and merely observe, under a microscope, for traces of wicking. The other was to dip the end of the sample into the copper fluoroborate plating bath and observe, under a low power microscope, for evidence of wicking. Since the copper fluoroborate attacks copper, some of the samples were also metallurgically mounted, in a longitudinal cross section, and examined at high magnification on the metallograph for attack of the copper strands.

3.2.5 Application of Insulation

The requirements for the insulating material greatly narrowed the list of materials that could be considered. The most logical choice was a polyimide of some form since this insulation had been used successfully on the smaller magnet wire constructions, while other insulating materials were proved inferior to polyimide.

3.2.5.1 E. I. DuPont de Nemours and Company recommended that we experiment with their RC-W-98759 polyimide experimental varnish. This varnish has a viscosity comparable to syrup and can be further thickened by using silicon dioxide (Cabosil). To prevent bubbling during cure, the varnish must be cured in at least two successive stages. The primary stage must be carried out at relatively low temperatures (90°C) to slowly drive off volatiles. The secondary stage must be carried out at a higher temperature (150 - 200°C). In each stage, a cure time of at least one (1) hour would be required.

Investigation into the use of this varnish failed to yield consistent results. Dielectric breakdown, even after three successive dippings, was below 300 volts DC. Bubbles invariably formed on the surface of the insulation. American Super Temperature Wires suggested pulling the wire through baby bottle nipples after each dipping. However, they speculated that coating such short lengths of wire would be most difficult. This material as applied to short lengths of small conductor had proved unreliable and the process very lengthy. After numerous attempts at coating, the insulating varnish was abandoned as an insulating material.

3.2.5.2 At that time Philadelphia Insulated Wires of Moorestown, New Jersey had developed an "extruded" polyimide tubing and was supplying samples to interested companies. We requested a sample of this tubing with an inside diameter of approximately 10 mils.

Evaluation of this product indicated that it would be suitable for insulating the swaged portion of the prepared leads. The tubing was easily applied in sections of 1/2-inch length. Longer lengths could not be applied, without a lubricant, because the swaged conductor was not rigid enough to withstand the frictional force of sliding on the insulation without buckling. Lengths of 1 to 1-1/2 inches could be slipped on using a mineral oil (Nujol) lubricant; however, mineral oil is a potential troublesome contaminant and should not be used. The diameters before and after applying tubing are listed in Table 3.2-VII.

Mechanically, the tubing was the equal of the polyimide coating on HML magnet wire of the same gage. Microscopic examination (60X) of this tubing after a 90 degree bend over a 0.025 inch radius and subsequent straightening revealed no insulation deterioration. In addition, the area of bend withstood the 1000 volts AC requirement.

It can be seen from Table 3.2-VII that, assuming a tight insulation-conductor fit, the wall thickness of the polyimide tubing is approximately 1.5 mils. Application of heat from a 300°C heat gun failed to cause a reduction in the diameter over insulation. (However, this heat did seem to increase tubing-conductor adhesion.)

The polyimide tubing was slipped over the flared conductor exiting from the Teflon so that the end of the polyimide tubing was flush with the Teflon tubing. If insulated lengths of conductor greater than 1-1/2 inches are required, the most logical approach would be to slip several one-inch sections of polyimide tubing end to end and apply a drop of polyimide varnish at each junction. This approach would require additional investigation. Visually, (40X) the tubing appeared uniform with no irregularities portending failure. This method was found to be the best method of insulating the swaged lead wire.

3.2.5.3 Dielectric Breakdown Testing - Dielectric testing of five, 2-inch insulated samples indicated the insulation to be electrically sound throughout the testing range (from 0 to 1000 volts AC applied for less than one second). A graph showing the relation of dielectric strength for H-Film (synonomous with ML polyimide enamel) and temperature is shown in figure 3.2.11.

3.2.6 Results

3.2.6.1 Swaging - At the beginning of this study, samples of swaged wire were obtained from The Torrington Company. The samples that were swaged from 0.012-inch nominal over-all diameter with 0.010 inch grooved swaging dies actually measured 0.011 inch in diameter. The difference in final diameter was due to the elastic recovery of the wire. Metallographic examination of this wire showed (Fig. 3.2.2) that swaging alone did not fuse the strands together sufficiently to fill the interstitial volume between strands. Even after these samples were induction fused, voids in the cross section remained (Fig. 3.2.3). The unswaged wire cross section is shown, for comparison, in Fig. 3.2.1.

An idealized calculation, Appendix 3.2-II, was made to determine whether or not there was, theoretically, sufficient silver on the wire to fill the interstitial voids. This calculation was idealized because the following assumptions were made:

3.2.6.1.1 The original over-all diameter of the #30 AWG (19/42) conductor is 0.0125 inch.

3.2.6.1.2 The original diameter of each strand is 0.0025 inch over the silver.

3.2.6.1.3 The silver thickness is the minimum allowable at 40 microinches.

3.2.6.1.4 There is no plastic deformation of the strands during swaging; i.e., all the reduction in area is taken up by the interstitial volume between strands.

The last of the above assumptions definitely contributes some error to the calculations. Also, the final diameters were assumed to be 0.010 inch and 0.008 inch, which were not quite realistic. In any case, the calculations showed that, theoretically, 72.5 microinches of silver thickness on each strand would be necessary to fill all interstitial volume by swaging to a 0.010 inch diameter and induction fusing the wire. Since such an increase in silver thickness seemed too great, and since the diameter was actually 0.011 inch, which allowed only 0.0012 inch of insulation to be applied in order to meet dimensional requirements, it was decided to consider swaging to 0.008-inch diameter swaged construction.

The calculated required silver thickness for 0.008 inch diameter wire is only 46 microinches; however, some safety factor is necessary to compensate for error in the calculation, so adding 20% for a safety factor, the required silver thickness became 55 microinches.

Swaging dies, with a 0.008 inch groove were purchased from Torrington, and acquisition of sample wire with 55 microinches silver thickness was pursued. The samples submitted by Torrington actually measured 0.0092 inch average diameter, rather than 0.008 inch. It was noted at this time that the above calculations of required silver thickness had been computed for a Unilay wire construction, Appendix 3.2-III, while a concentric construction of #30 AWG (19/42) lead wire was being swaged, not Unilay. In a concentric construction, five strands are wrapped around a center strand and the remaining 12 strands are wrapped around the first six in a direction opposite to that in which the five were wrapped. In a Unilay construction, the wrapping of all 19 strands is done in a single direction. The

calculations were repeated for the concentric construction and for the Unilay construction, using a final swaged diameter of 0.0092 inch. (See Appendix 3.2-III.) The required silver thicknesses for a 0.0092-in. diameter concentric construction then becomes, theoretically, 138 microinches and 72 microinches for the Unilay construction, allowing a 20% safety factor.

In order to expedite the acquisition of swaged samples and to learn the details of the swaging operation, a swaging machine was obtained, on loan, from The Torrington Company. The results of the work performed on this machine are detailed in Appendix 3.2-I.

The wire having 55 microinches of silver thickness was easier to swage than the wire having a 40-microinch thickness. Most of the deformation exerted upon the wire during swaging is effected upon the outermost strands. Figures 3.2.2, 3.2.4, and 3.2.5 show how the outer strands have been flattened during swaging. The strain hardening that accompanies cold deformation has made these strands quite brittle as shown in Flex Test Results (Section 3.2.6.4). Figures 3.2.6 and 3.2.7 show cross sections of the 55-microinch silver thickness wire. The added ductility imparted by the increased silver thickness has prevented severe flattening and embrittlement of the outer strands.

Several attempts to relieve the strain hardening resulting from swaging were made; however, a simple stress relief anneal cannot offset the impairment to flex life caused by the reduction in area of the outer strands.

3.2.6.2 Induction Fusing - The induction fusing operation resulted in the establishment of a definite time of 0.25 to 0.80 second required to fuse strands together, depending upon the length to be fused. Visual observation showed that the exposed silver on the outside strands had melted and flowed inward "Due to surface energy

considerations"*, filling the void space between strands. "The movement of the silver may have been accomplished by capillary action and/or the magnetic field."*

Fusing by induction before stripping the Teflon insulation minimized oxidation of the conductor.

The length of fused conductor may be varied, by varying the length of the inductor coil and/or the length of time cycle and power level, depending on whether it is desired to fuse the sample in the center of its length or on the ends. Our samples were fused in each manner, some on the ends, some in the center, bare and insulated, over a length controlled from 1/8 inch to 3 inches.

3.2.6.3 Metallographic Examination - Photomicrographs were made of lead wire samples in each stage of processing; some of these are discussed under other sub-headings in this report.

Figure 3.2.9 is typical of the cross section of lead wire that has been swaged and induction fused. Relatively massive areas of silver were evident inside the wire and between the copper strands. The silver had evidently melted and moved toward the center of the conductor by capillary action, filling the interstices between strands, and nearly depleting the exterior of the conductor of silver. Etching of the copper in the conductor showed that there was no discernible evidence of the copper having melted or of the copper and silver having alloyed. Copper grain growth and formation of annealing twins within the copper grains were obvious. There was no evidence of silver evaporation.

* Quoted from Lepel High Frequency Labs. Inc., Lab. Report No. 9309.

In no case was the fusing of strands complete. Some bonds between strands may have been broken in the cutting and mounting of the samples, but voids created in this manner would have had sharp, irregular edges. The smooth edges of the voids seen in Figures 3.2.3 and 3.2.9 indicated that these voids remained after induction fusing and not all of the interstitial space between strands was filled with silver.

Figure 3.2.10 compares various swaged samples to an unswaged sample.

3.2.6.4 Flex Life - The flex test results are tabulated in Tables 3.2-I through 3.2-III. The flex life of the swaged conductor was much inferior to that of the unswaged conductor. Various methods were used however, to improve flex life; induction fusing alone results in improved flex life.

3.2.6.5 Pull Strength - The pull test results for the unswaged conductor, the swaged conductor, the jumper wire, and the swaged and fused conductor are given in Table 3.2-IV. The pull strength of the 30 AWG jumper was greater than that for lead wire swaged to .0092 inch diameter, annealed or unannealed.

3.2.6.6 Resistance - The results of resistance measurements, made on all types of samples of concern, are given in Table 3.2-V. The resistance of the 30 AWG jumper was less than that for lead wire swaged to .0092 inch diameter, annealed or unannealed. The calculated resistance of solid copper wire of .0092 inch diameter is 10.35 milliohms/inch, as compared to a measured resistance of 11.40 milliohms/inch for lead wire swaged to a .0092 inch diameter.

3.2.6.7 Wick Test - Figure 3.2.8 shows a longitudinal cross section of a swaged and fused sample, one end of which was immersed in copper fluoroborate solution for four hours. The sample, upon being observed after removal from the solution, showed no wicking that could be detected at low magnification. However, after the sample was metallurgically mounted, ground and

polished to show the cross-sectional view in Figure 3.2.8, it was obvious that copper fluoroborate fumes or wicked solution had effectively etched the copper in the conductor over a substantial length.

The copper fluoroborate wick test was discarded as being too indefinite; the anthraquinone dye wick test was also inconclusive. Therefore, the hot plastic wick test was attempted, with meaningful results. These results are tabulated in Table 3.2-VI. All three types of samples wicked plastic over the two inch length exposed, as indicated by "positive" in Table 3.2-VI. The percentages given in parentheses indicate the approximate relative quantity of plastic that wicked into each sample, ranging from 100% for the worst condition to 15% for the best sample.

3.2.6.8 It was found that some of the restrictions imposed on the subject construction at the outset of this study were too stringent. For example, the pull strength and flex life of the construction need not be as high as stated in Section 3.2.2, since the values for these parameters are sufficiently high to maintain the high reliability of the capsule. Recognizing that these requirements were unduly stringent, it becomes apparent that the subject construction is feasible with minor modifications of component or assembly design.

3.2.7 Conclusions

3.2.7.1 It is feasible to eliminate the 30 AWG solid copper jumper used in slip ring sub-assemblies to provide electrical connection between the slip ring and the 30 AWG (19/42) lead wire, if the process steps and material limitations given below are incorporated. Eliminating this jumper also eliminates the solder (and contaminating solder flux) which is now used to connect the jumper to the lead wire.

3.2.7.2 The jumper can be eliminated by employing the process developed under this study.

3.2.7.2.1 Strip the conductor of Teflon insulation.

3.2.7.2.2 Swage the conductor to .010 inch over-all diameter.

3.2.7.2.3 Induction fuse the conductor into a conductor of solid cross section over the length required.

3.2.7.2.4 Reinsulate the swaged and fused conductor with ML polyimide tubing to a maximum over-all diameter of .0122 inch.

3.2.7.2.5 Encapsulate the swaged, fused, and reinsulated end of the conductor, plating the ring contact directly onto a cross section taken through the swaged and fused portion. The conductor exits from the slip ring at the point where swaging had been stopped, leaving the Teflon-insulated, unswaged portion of the lead wire as the external slip ring lead.

3.2.7.2.6 No slip ring solder connections are required.

3.2.7.3 In order for the process to be reduced to practice, there are certain limitations imposed on the lead wire that is used, the construction produced, and the methods used.

3.2.7.3.1 The silver plate on the 30 AWG (19/42) lead wire must be greater than 40 microinches thick in order for induction heating to melt the silver and fuse the strands into a solid wire, leaving no voids between strands. For wire of the concentric construction, at least 138 microinches of silver thickness are required; for wire of the Unilay construction, at least 72 microinches of silver thickness are required.

3.2.7.3.2 A lead wire construction having 200 microinches of silver thickness on each strand, after being swaged to .010 inch diameter, induction fused, and annealed has a calculated resistance of 8.5 milliohms/inch. The 30 AWG jumper has a resistance of 8.7 milliohms/inch.

3.2.7.3.3 The flex life, pull strength, and resistance properties of the 30 AWG jumper are superior to these same properties of a 40 microinch-silver thickness lead after it is swaged to .0092 inch diameter, and even after it is annealed. The strain hardening of the copper strands that occurs during swaging impairs the flex life and improves the pull strength.

3.2.8 Further Work

3.2.8.1 Hot rotary swaging should be investigated as a means of reducing lead wire diameter while at the same time preventing the severe strain hardening that results from cold rotary swaging. It is possible that the temperature of hot rotary swaging could simultaneously fuse an alloy lead wire (90% copper 10% silver, for example).

3.2.8.2 A study should be conducted to compare the physical properties and commercial availability of Unilay lead wire construction as opposed to the concentric construction to see which is superior for slip ring application. It is expected that the Unilay construction will exhibit a longer flex life than the concentric construction and minimize the reduction in flex life that accompanies swaging. The use of the Unilay construction would make it even more practical to eliminate the jumper since there is less interstitial volume to be filled in the Unilay construction than in the concentric construction.

3.2.8.3 A study paralleling the one discussed in this report should be conducted using a lead wire construction having a thick silver plate on the order of .0002-inch thick. This should be pursued for development of the best possible construction.

3.2.8.4 The application of a silver plate on the over-all diameter of the swaged lead wire, only on the swaged length, should be investigated in order to provide sufficient silver to completely seal all interstitial voids between strands by subsequent induction heating.

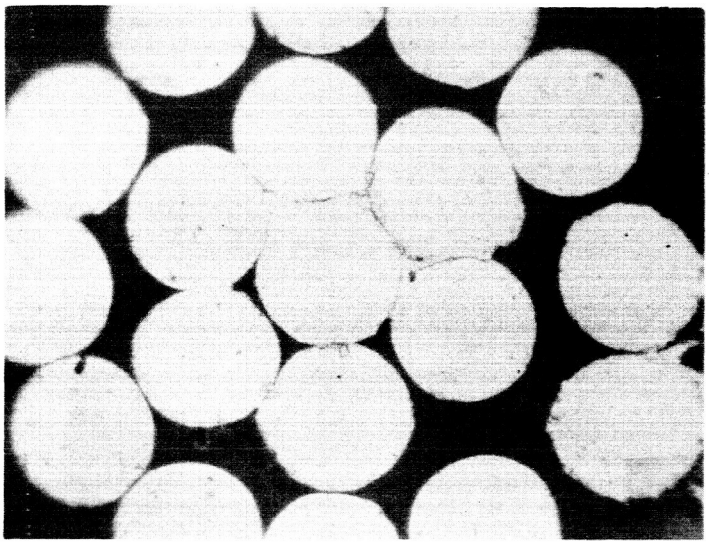


Fig. 3.2.1 - (267X)

Cross Section of Unswaged Sample

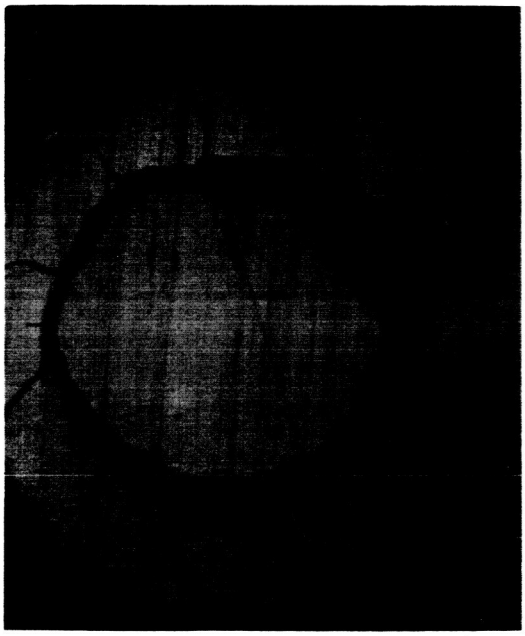


Fig. 3.2.2 - (267X)

Cross Section of Swaged Sample

Fig. 3.2.3 - (260X)

Cross Section of Swaged Sample after Induction Fusing, shows that not all interstitial voids have been filled.

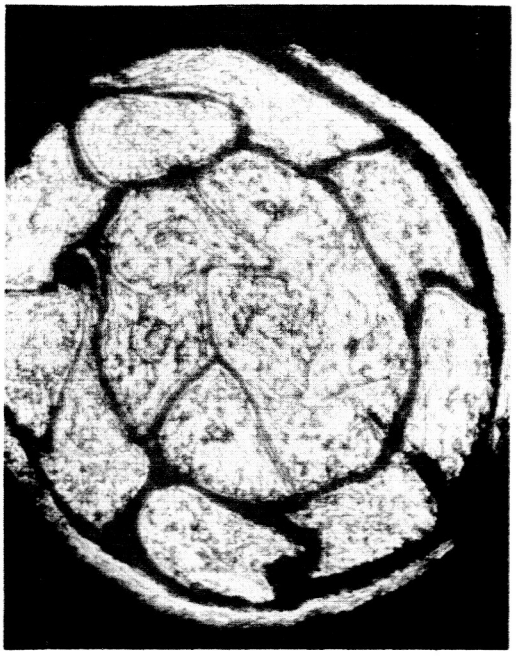


Fig. 3.2.4 - (260X)

Cross Section of Swaged Sample, lightly etched to show silver plating.

Fig. 3.2.5 - (373X)

Similar to Fig. 3.2.4. Each scale div. = .002 inch.

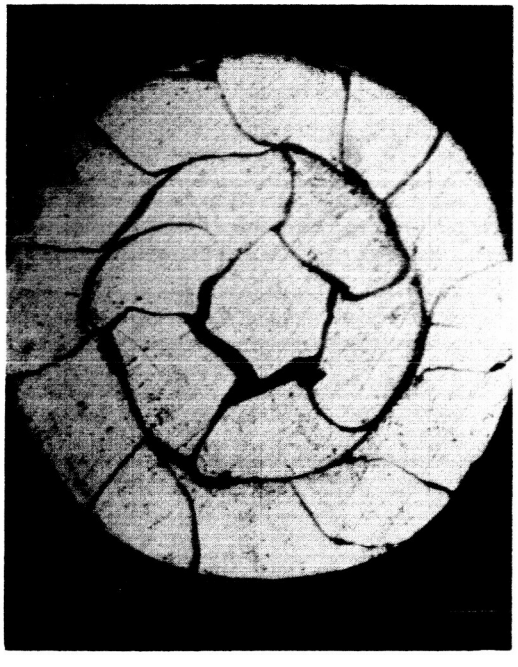


Fig. 3.2.6 - (267X)

Cross Section of Swaged Sample having 55 micro-inch silver thickness.

Fig. 3.2.7 - (267X)

Same as Fig. 3.2.6, different sample, lightly etched.

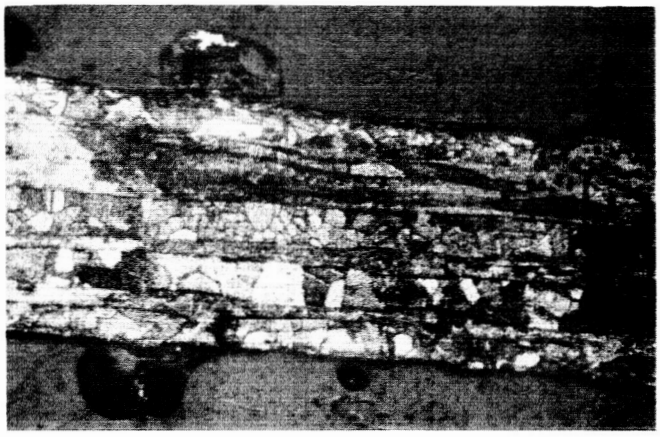


Fig. 3.2.8 - (130X)

Longitudinal section of swaged and fused wire used in Copper Fluoroborate Wick Test. Copper grains are evident as a result of chemical attack.

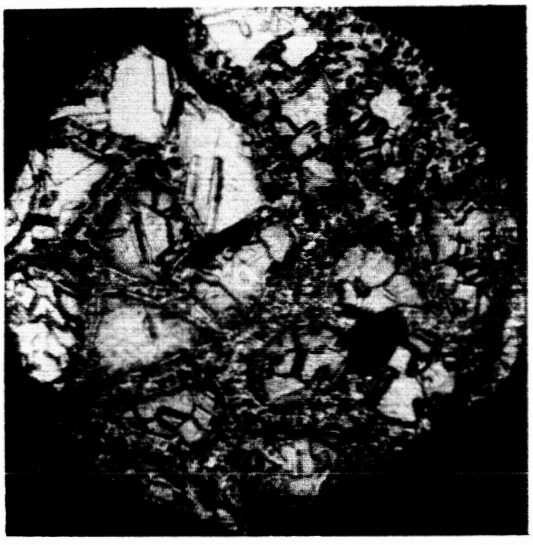


Fig. 3.2.9 - (267X)

Microstructure of swaged and fused sample etched in NH_4OH, 3% H_2O_2 and water shows grain growth of copper, thermal twins, depletion of silver on wire O.D. with massive concentration of silver between strands, two large voids between strands

Fig. 3.2.10 - (45X)

From L.to R.are:wire swaged by Torrington to.009 in.dia. wire swaged at P-S to.009 in dia.(one of best samples); average sample of P-S swaged wire; poor sample of P-S swaged wire (broken strand); unswaged sample of wire.

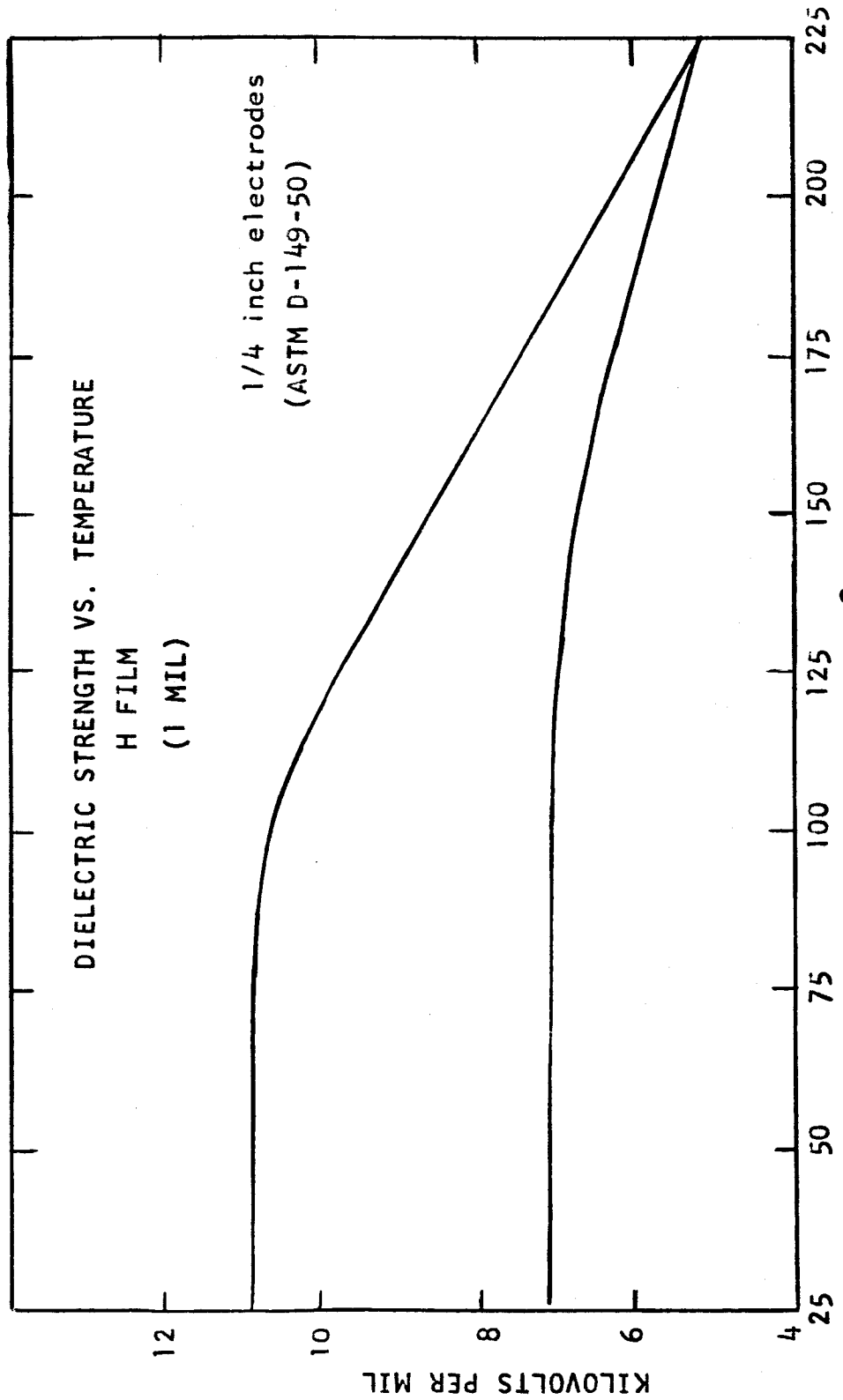

DIELECTRIC STRENGTH VS. TEMPERATURE
H FILM
(1 MIL)
1/4 inch electrodes
(ASTM D-149-50)
KILOVOLTS PER MIL
TEMPERATURE, °C
4
6
8
10
12
25
50
75
100
125
150
175
200
225

Fig. 3.2.11

TABLE 3.2-I

FLEX TEST RESULTS (NO. OF FLEXES; FLEX RATE: 127 FLEXES/MIN.)

SAMPLE NO.	30 AWG JUMPER	30 AWG (19/42) CONDUCTOR SWAGED TO .0092 IN.Dia.	.0092 IN. DIA. SWAGED 30 AWG (19/42) CONDUCTOR ANNEALED AT 92°F. FOR 10 MIN.
1	15	15	--
2	13	10	9
3	17	18	7
4	13	12	11
5	16	9	21
6	21	9	13
7	15	1	11
8	13	7	--
9	12	9	5
AVERAGE	15	10	11
RANGE	9	14	16

TABLE 3.2-II
FLEX TEST RESULTS (NO. OF FLEXES:
FLEX RATE: 75 FLEXES/MIN.)

SAMPLE NUMBER	30 AWG JUMPER	30 AWG* CONDUCTOR	BARE 30 AWG* CONDUCTOR, IN-DUCTION FUSED	30 AWG* CONDUCTOR IN-DUCTION FUSED OVER TEFLON INSULATION	30 AWG* CONDUCTOR, SWAGED TO.011" DIAMETER AND INDUCTION FUSED
1	14	44	9	11	15
2	16	50	6	7	4
3	14	39	12	9	9
4	15	30	6	8	
5	15		8		
6	12		8		
7	14				
8	13				
9	14				
10	14				
AVERAGE	14	41	8	9	9
RANGE	4	20	6	4	11

TABLE 3.2-III
FLEX TEST RESULTS (NO. OF FLEXES;
FLEX RATE: 170 FLEXES/MIN.)

SAMPLE NUMBER	30 AWG* CONDUCTOR, SWAGED TO .011" DIAMETER	30 AWG* CONDUCTOR SWAGED TO .0092 IN. DIAMETER
1	35	5
2	35	5
3	32	1
4	36	1
5	41	1
6	41	3
7	33	5
8	36	4
9	26	8
10	29	3
AVERAGE	34	4
RANGE	15	7

(*) All wire where indicated, was 30 AWG (19/42) - silver plated.

TABLE 3.2 - IV

PULL TEST RESULTS (HUNTER SPRING PULL TESTER)

SAMPLE NO.	30 AWG JUMPER (KG)	30 AWG (19/42) CONDUCTOR SWAGED TO .0092 IN. DIA.	30 AWG (19/42) CONDUCTOR SWAGED TO .0092 IN. DIA. ANNEALED @ 920°F - 10 MIN.
1	1.26	1.08 KG	0.71
2	1.26	1.16	0.56
3	1.27	0.62	0.47
4	1.26	1.14	0.69
5	1.26	1.07	0.76
6	1.26	1.10	0.45
7	1.26	1.01	0.58
8	1.24	1.06	0.55
9	1.23	0.76	0.94
AVERAGE	1.26*	1.00 KG (2.21 lbs.)	0.63 KG (1.40 lbs)
RANGE	0.04**	0.54 KG (1.19 lbs.)	0.49 KG (1.08 lbs.)

* (2.78 lbs.)

**(0.09 lbs.)

TABLE 3.2 - V

RESISTANCE MEASUREMENTS (MILLIOHMS PER INCH @ 100 MA)

SAMPLE NUMBER	30 AWG JUMPER	30 AWG (19/42) CONDUCTOR SWAGED TO .0092 IN. DIA.	30 AWG (19/42) CONDUCTOR SWAGED TO .0092 IN. DIA. & ANNEALED @ 920°F-10 MIN.
1	8.7	11.3	10.9
2	8.8	15.7	10.4
3	9.1	19.5	10.7
4	8.6	15.1	--
5	9.0	14.4	12.4
6	8.9	17.2	10.8
7	9.2	12.1	13.3
8	9.0	15.2	11.0
9	8.6	13.1	--
AVERAGE	8.9	14.8	11.4
RANGE	0.6	8.2	2.0
MINIMUM SAMPLE LENGTH	2.0 IN.	0.7 IN.	0.8 IN.

TABLE 3.2-VI

HOT PLASTIC WICK TEST

Type of Sample	Results (Approx. Relative Quantity of Wicked Plastic)
30 AWG (19/42) Conductor	Positive - (100%)
30 AWG (19/42) Conductor Swaged to .0092 in. Dia.	Positive - (20%)
30 AWG (19/42) Conductor Swaged to .0092 in. Dia. Induction Fused	Positive - (15%)

TABLE 3.2-VII

DIAMETRICAL DIMENSIONS OF INSULATED AND UNINSULATED WIRE

Over Swaged Conductor	Over Insulation
9.2 mils	12.4 mils
9.0 mils	12.2 mils
9.1 mils	12.1 mils
9.1 mils	12.1 mils
9.2 mils	12.2 mils

3.2 APPENDIX I

SWAGING OF LEAD WIRE

Rotary swaging is accomplished by two opposed dies as shown in Figure 3.2.1. These dies move radially in a plane perpendicular to the axis of the work piece (lead wire) and rotate around this axis. The centrifugal force caused by the spindle's rotation keeps the backers against the roller back. The backers and dies move radially inward when the backers "ride over" successive pairs of rollers. With the spindle rotating at approximately 600 rpm and 12 rollers, there would be almost 7,000 blows per minute, but this is reduced somewhat because the roller back rotates within the outside ring. The dies are of hardened steel with a groove having a diameter slightly smaller than the finished wire. One end of the dies is tapered to allow the wire to enter and reduce the wire diameter gradually. The distance between the dies in the full inward position may be adjusted by placing a shim at A (Fig. 3.2.1), closing the dies by rolling the spindle as far up on a set of rollers as possible, and tightening the backer bolts, then removing the shim. The amount of force each die exerts on the work piece can be adjusted by placing shims at B (Fig. 3.2.1) which remain in place while swaging. Dies are of standard over-all dimensions allowing interchangeability for different size finished work; therefore, each set of dies has to be shimed for blow and opening corresponding to the optimum for that particular type material and work.

Swaging is actually performed more by pressure than by blows.* In the case of lead wire swaging, the maximum force exerted on the wire is approximately 80,000 pounds. Hence, there is a flow and readjustment of the grain of the swaged metal. Metallographic cross-sections of swaged lead wire show, that as a general rule, the 12 outer strands receive the majority of reduction in areas, accompanied by work hardening and loss of ductility. The usual cause of rejecting a swaged sample lead wire was rapid fracture of one or more outer strands as a result of severe reduction in area during swaging.

* Metals Handbook, American Society for Metals; 1948 Edition pp.35.

It has been shown that swaging of the lead wire to .009" (nom.), using .008" swaging dies is possible, judging from the samples swaged for us by The Torrington Company. This increase of finished wire over the die diameter is due to the elasticity remaining in the swaged wire. In order to obtain a better understanding of the operation and its reliability, it was felt necessary to obtain a swaging machine on loan from The Torrington Company and prepare our samples at Poly-Scientific before proposing purchase of such a machine. The following is a description of this swaging work performed in-house. Based on instructions with the machine and measured space in the die cavity, several sets of shims of .060" - .070" and .000" - .010" thickness were used to adjust the blow and determine the die opening, respectively (Fig. 3.2.1). The first groups of blow shims were made of a combination of five or six smaller shims from .002" - .015" each. This grouping of shims may have created a leaf like spring due to the curvature of each shim. This spring may have opposed the centrifugal force needed to open the dies thereby altering the optimum A dimension and reducing the effective blow. Later groups contained only two shims each (1/16"≈.0625" + variable), which may have decreased this spring effect.

The best results, insofar as lead feeding and consistent final results, were obtained with blow shims 1/16" + .005" thick and a die opening shim .004" thick.

The removal of all copper and/or silver flash which accumulates on the die faces is necessary to allow the dies to open properly and maintain good die contact. Potassium cyanide (10% in an aqueous solution) was used to dissolve the copper and silver from the dies without harming the dies; large flakes of copper can be removed with an X-Acto knife under the microscope, taking care not to scratch the dies. If necessary, fine grit abrasive paper and polishing compounds may be used. This removal of copper may be tedious and time consuming, but for lack of a faster method was the only way that would assure clean, free working dies. The method of feeding each lead also determined the end result. Care must be taken not to over-feed (feed too fast) the lead into the dies because over feeding will cause the dies to "bite" the lead thereby increasing the possibility of broken strands and a greater flash build-up on the dies. One recommendation of The Torrington Company, was to allow the lead to rotate while swaging, this technique is questionable since it decreases feed control and our results indicated that no rotation is best.

The Torrington Company representative recommends only clean leads be used, without oil or grease lubrication; therefore, each group of leads was ultrasonically generated in chlorothene to remove oil and dirt. Leads used in this evaluation were all heat stripped, cut to proper length, and the ends trimmed and rolled to assure a smooth entry into the swaging dies.

One-hundred (100) prepared leads were swaged for a statistical study. Of this number, ninety-one were considered acceptable and nine were rejected because of broken strands. Some of the ninety-one were even better than those swaged samples previously submitted by Torrington.

One small group of leads having a thicker (55×10^{-6} in.) silver plating on the strands produced very good swaged leads. The indication is that the increased silver thickness, silver being more ductile than copper, decreased the work-hardening ability of the lead during swaging and minimized the possibility of fracture of individual strands.

It was observed during the statistical study that individual strands after passing through the swaging dies tended to flare or separate from the group for approximately 1/8" back from the end, probably due to a "bundle tie squeeze" action; i.e., when a group of parallel, flexible objects are tied or compressed close to the end, a flaring action at the end results. This action is probably aggravated by the centrifugal force exerted by the machine (890 rpm spindle speed) and vibration of the roller blows (5,420 blows/min.). When the lead is extracted back through the dies, the end of the lead, where the flaring has occurred, is again swaged. On this second pass, the opened ends are sometimes caught outside the die groove causing flashing of the lead material into the flat die faces. This problem could most probably be eliminated by changing the die groove exit to match the entrance.

The handling of swaged but unfused leads is of great importance since flexure or abrasion will result in broken strands aggravated by the previously mentioned work hardening. The problem can only be overcome with care and delicate handling by the operator. The handling problem is improved by induction fusing of the strands into a solid conductor and further improvement should be possible by annealing the swaged conductor. Since these tests, it has been realized that the inner group of

strands are laid in the opposite direction to the outer strands. This fact suggests that the outer strands may be forced to lay over the inner strands which may cause interstices.

In summary, the most difficult and important variables to determine were proper shim thicknesses for setting the blow and die opening, proper operator technique, delicate handling of leads, and care of swaging dies.

The following is a list of variables which is now considered best: -

1. Setting up the swaging machine and its care.

    a. Remove all copper and/or silver from die faces.

        1) Remove large flakes with X-Acto knife under a microscope greater than 30X.

        2) Etch with potassium cyanide for two (2) minutes.

        3) Remove etchant with water, acetone and chlorothene.

    b. Swab die area of spindle with chlorothene.

2. Lead preparation

    a. Leads should be heat stripped 1/4" more than 2/3 of the desired final length (due to a one/half increase in length from swaging).

    b. The heat stripped section of insulation should be rotated off the bare wire in the direction of the tracer.

    c. The bare end should be recut with a sharp X-Acto knife 1/8" from the end.

    d. The strands should be laid smooth by rotating the wire through the operators fingers (protected with finger cots), making sure the cut end is burr free.

    e. Groups of approximately fifty (50) leads each should be generated in chlorothene for three (3) minutes and remain immersed in chlorothene until swaged.

3. Operator Techniques

   a. Hold and support leads only by insulation, thereby keeping the conductor clean and dry.

   b. Feed slowly (1/8" per sec.).

   c. Hold firmly, restraining rotation.

Recommendations:

1. "B" shims should be one piece ground to optimum dimension.

2. 55 microinches silver coated wire should be further studied and possibly adopted.

3. Swaged "Unilay" wire should be compared with presently swaged wire for a comparison of interstices.

4. The exit of the die should conform to the entrance.

At this point, swaging is considered a means of reducing lead wire over-all diameter with good degree of consistency.

3.2 APPENDIX II

SWAGING OF LEAD WIRE

Calculations were made to determine whether or not there was, theoretically, sufficient silver plating on the conductor strands to fill the interstitial voids between strands during induction fusing, after the conductor had been swaged to .010 in. and .008 in. diameters. Figure 1 depicts the cross-section of a 30 AWG (19/42) stranded copper conductor, plated with 40 microinches of silver thickness on each strand. To calculate the volume of exposed silver per inch of conductor length, we have:

V_s = 6 strands x 2/3 strand cross-sectional silver area (strand area incl. silver minus strand area not incl. silver) plus 6 strands x 1/2 strand cross-sectional silver area (strand area incl. silver minus strand area not incl. silver)

or

$$V_s = (6)(2/3)\left(\frac{\pi D_1^2}{4} L - \frac{\pi D_2^2}{4} L\right)+(6)(1/2)\left(\frac{\pi D_1^2 L}{4} - \frac{\pi D_2^2 L}{4}\right),$$

and since L = 1 in. we have,

$$V_s = 2.1639 \times 10^{-6} \text{ in.}^3.$$

To calculate the free-space interstitial volume, or the volume that a V_s quantity of silver will attempt to fill upon induction heating, we have:

V_1 = 12 x (area of parallelogram ABCO minus area of 6 sectors of the total strand cross-sectional area) x length.

Area ABCO = OH x AB; $OH = \frac{\sqrt{3}}{2} D$, and $AB = D_1$

Area of one strand sector = $1/6 \times \left(\frac{\pi D_1^2}{4}\right)$ and

length = 1;

$$V_1 = 12\left[3/2\ D_1^2 - (6)(1/6)\frac{(\pi D_1^2)}{4}\right] = 6.0488 \times 10^{-6}\ \text{in.}^3.$$

If the conductor is swaged to 0.010 in. dia. over-all, the percentage reduction in area is:

$$\frac{A_o - A_f}{A_o} \times 100 = \frac{D_o^2 - D_f^2}{D_o^2} = \frac{(12.5 \times 10^{-3}(10.0 \times 10^{-3})^2}{(12.5 \times 10^{-3})^2}$$

$$= 36.00\%$$

Assuming that the 36% reduction in cross-sectional area is taken up by the interstices without plastic deformation of the strands (which is actually not the case but an idealized assumption) the value for V_1 after swaging becomes:

$$6.0488 \times 10^{-6}\ \text{in.}^3 \times (100\% - 36\%) = 3.8712 \times 10^{-6}\ \text{in.}^3.$$

V_1 after swaging is still greater than V_s for a conductor swaged to .010 in. diameter.

Performing a similar calculation for a conductor swaged to .008 in. diameter, it is found that $V_1 = 2.4800 \times 10^{-6}$ in.^{3} after swaging Even this value of V_1 is greater than the calculated V_s.

In order to find out just how much silver thickness is required to make $V_s = V_1$ for a .010 in. dia. conductor and for a .008 in. dia. conductor, V_1 is set equal to V_s, and the equation is solved for D_2.

For .010 in.dia. $V_1 = 3.8712 \times 10^{-6}\text{in}^3 = 6(2/3)$

$$\left(\frac{\pi D1^2}{4} - \frac{\pi D_2^2}{4}\right) + 6(1/2)\left(\frac{\pi D_1^2}{4} - \frac{\pi D_2^2}{4}\right)$$

$$D_2 = .002355\ \text{in.}$$

$D_1 - D_2 = .002500 - .002355 = .000145$ in., which is equivalent to 72.5 microinches silver thickness.

Similarly, for .008 in. dia. conductor: D_2 = .002408 in.

$D_1 - D_2$ = .002500 - .002408 = .000092 in., which is equivalent to 46 microinches silver thickness.

3.2 APPENDIX III

SWAGING OF LEAD WIRE

Since the calculations in Appendix II were made considering Unilay construction, the calculations have been repeated for the concentric construction. The purpose of the calculations is the same; i.e., to determine whether or not there is sufficient silver plate on each strand to fill, through induction fusing, all the interstitial volume between strands. Figure 1 shows the cross-section of a 30 AWG (19/42) stranded copper conductor, plated with 40 microinches of silver thickness on each strand, of concentric construction. To calculate the volume of exposed silver per inch of conductor length, we have:

V_s = 12 strands x 7/12 strand cross-sectional silver area (strand area incl. silver minus strand area not incl. silver).

$$V_s = 12\left[7/12\left(\frac{D_1^2}{4} L - \frac{D_2^2}{4} L\right)\right], \text{ where } L = 1 \text{ in.}$$

$$V_s = 2.17 \times 10^{-6} \text{ in.}^3$$

To calculate the free-space interstitial volume, or the volume that a V_s quantity of silver will attempt to fill upon induction heating, we have:

V_1 = 6 (area ABCD - strand area inside area ABCD) + 12 (area BCE - strand area inside area BCE)

$$V_1 = 6\left[(BC)^2 - R_1^2\right] + 12\left[1/2\,(CE)h - 1/2\,R_1^2\right], \text{ where}$$

$$h = \sqrt{(BC^2) - (1/2\,CD)^2}$$

$$BC = CE = D = .0025 \text{ in.}$$

$$h = 2.165 \times 10^{-3} \text{ in., and}$$

$$V_1 = 11.0701 \times 10^{-6} \text{ in.}^3$$

If the conductor is swaged to a .0092 in. dia., the percentage reduction in area is:

$$\frac{A_o - A_f}{A_o} \times 100 = \frac{D_o^2 - D_f^2}{D_o^2} = \frac{(12.5 \times 10^{-3})^2 - (9.2 \times 10^{-3})^2}{(12.5 \times 10^{-3})^2}$$

Assuming that the 45.80% reduction in cross-sectional area is taken up by the interstices without plastic deformation of the strands (which is actually not the case but an idealized assumption), the value for V_1 after swaging becomes:

$$11.0701 \times 10^{-6} \text{in.}^3 \times (100\% - 45.8\%) = 6.0000 \times 10^{-6} \text{in.}^3$$

V_1 after swaging is much greater than V_s.

To find the volume of silver thickness theoretically required to fill a V_1 volume of 6.0000×10^{-6} in.^{3}, V_1 is set equal to V_s, and the equation is solved for D_2:

$$V_1 = 6.0000 \times 10^{-6} \text{ in.}^3 = 12 \left[7/12 \left(\frac{\pi D_1^2}{4} - \frac{\pi D_2^2}{4} \right) \right]$$

$$D_2 = .00227 \text{ in.}$$

$D_1 - D_2 = .00250 - .00227 = .00023$ in., which is equivalent to 115 microinches silver thickness.

With a requirement of 115 microinches of silver thickness in order to fill all the interstitial volume of a concentric construction lead wire swaged to .0092 in. dia., it would seem appropriate to consider the Unilay construction more seriously; through calculations similar to these above, only 60 microinches of silver thickness are required to completely fill all interstitial volume of a Unilay construction lead wire swaged to .0092 in. dia.

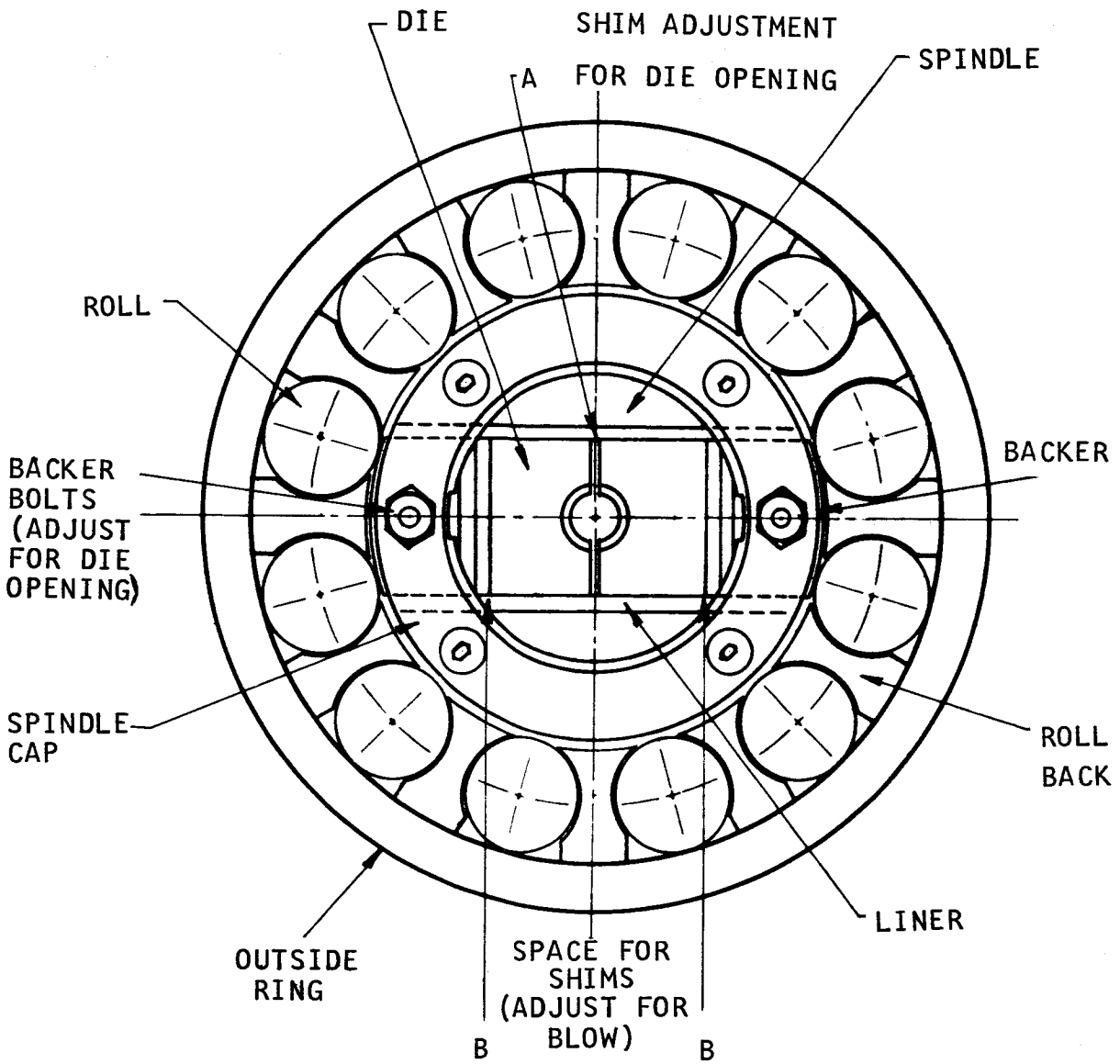


FIG. 3.2-I.1 - ROTARY SWAGING MACHINE
FRONT VIEW SCHEMATIC

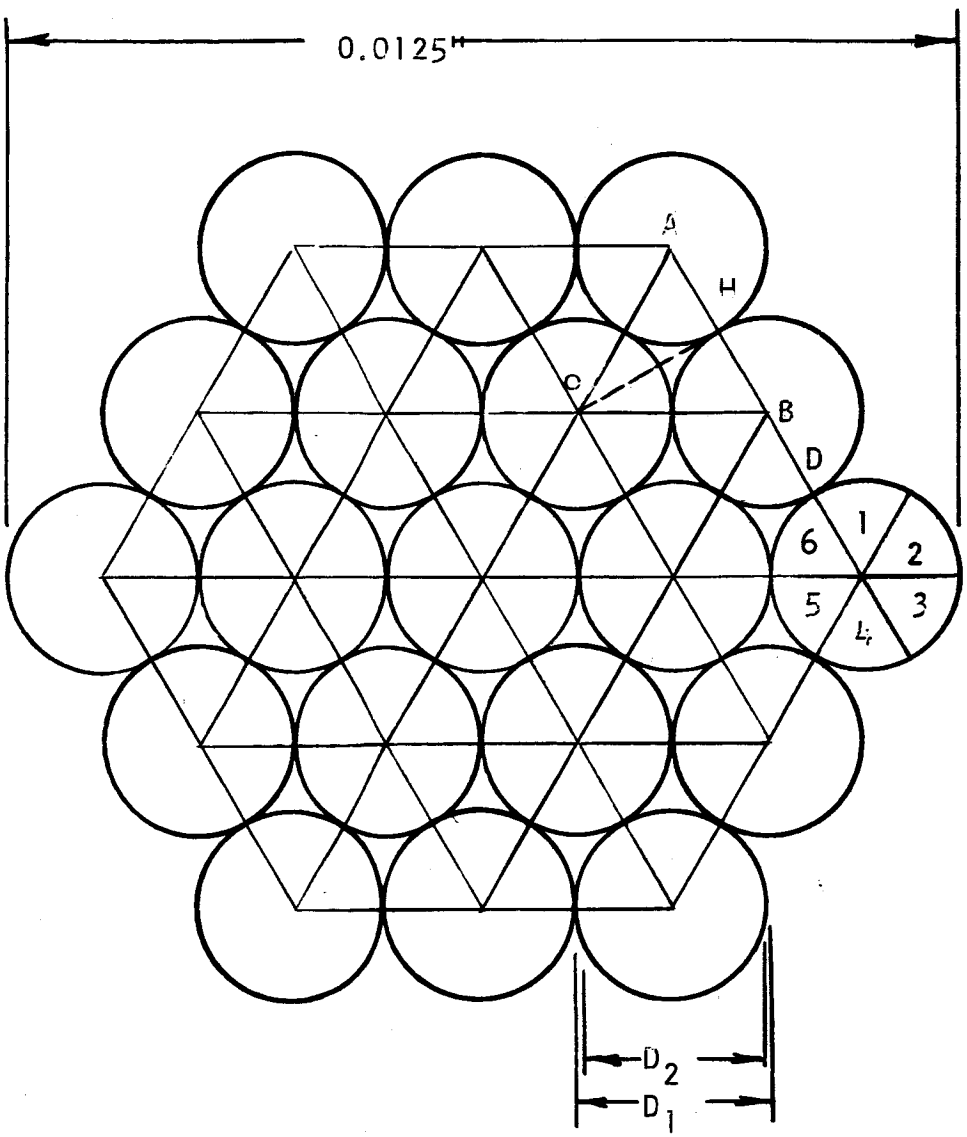


DIAGRAM - #30 AWG (19/42)
CONDUCTOR CROSS SECTION

CONCENTRIC CONSTRUCTION

D_1 = 0.00250 = Diameter over Silver
D_2 = 0.00242 = Diameter over Copper
(Silver thickness is 40 X 10^{-6} in.; MIL-W-16878D)

Fig. 3.2-II.1

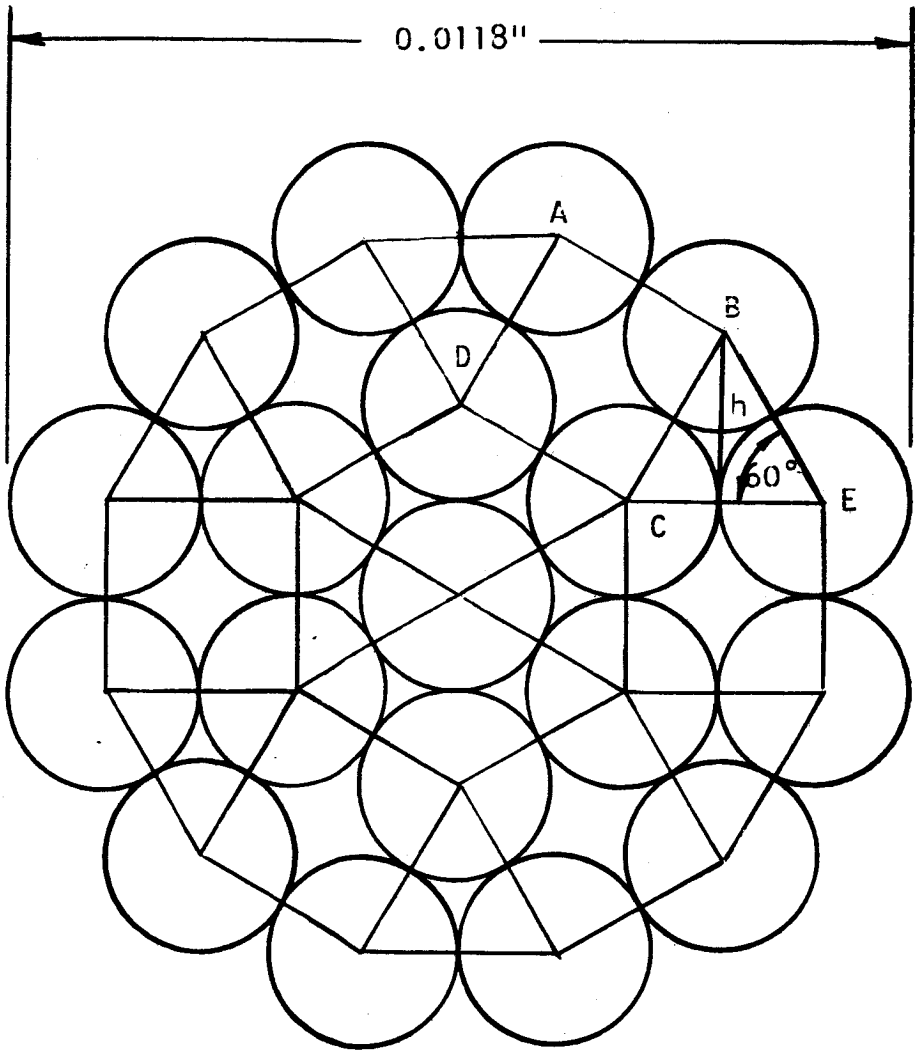


DIAGRAM - #30 AWG (19/42)
CONDUCTOR CROSS SECTION
UNILAY CONSTRUCTION

FIG. 3.2-III.1

3.3 GOLD ELECTRODEPOSITION

3.3.1 Introduction

The following section covers experimental work performed at Poly-Scientific on 24 karat gold electroforming between May 1, 1962 and March 1, 1965. This report is not intended to be complete in every detail. All the significant points are covered and important results are discussed.

In the past there has been little demand for thick gold electroplate. Most gold plating was done for decorative purposes and the thickness was usually less than 0.01 mil. Recently there has been an increasing need for gold plate up to 50 mils for slip ring use. The preliminary study of this new application revealed that the mere ability to produce a heavy, uniform deposit was not sufficient. Such a plate must have high, uniform hardness (about 120 Knoop), be machineable, and withstand thermal shock and heat cycling test. Finally, it must be consistently produced without serious variation in these qualities.

Heavy gold electroplates have been obtained from both acid and cyanide baths; the acid bath being AuCl plus an excess of HCl and the cyanide bath being K $Au(CN)_2$ with an excess of free KCN. Very little was known about the effect of the various parameters on electroformed 24 karat gold plate. Faced with these problems, Poly-Scientific started a research program in an attempt to deposit heavy, uniform 24 karat gold plates with controlled hardness and to determine the effect of temperature, current density, gold content and free KCN on the physical properties of electroformed gold plate.

Prior to the work covered in this report considerable work was done on 24 karat gold plating. Hull cell studies had been made using steel plates and plastic sheets as cathodes. Attempts had been made to study the effect of temperature but no satisfactory deposits had been obtained.

A fairly complete series of experiments had been carried out to study the effect of gold content in the bath and the current density. Poor deposits were obtained at low current densities (1-4 asf) and gold content (1-5 oz/gal) but there were indications that at high gold and high current densities good deposits could be obtained

3.3.2 Experimental

This section contains a description of the various tests carried out in an attempt to plate a hard, uniform 24 karat gold plate. One-fourth (1/4) inch diameter plastic (Engineering Specification No. 84) rods were used for most tests (see Figure 3.3.18). A one and one-half (1-1/2) inch lengtn of the rod was plated. The rods were made electrically conductive by coating with a reduction coat of gold (see special procedures). In some instances actual slip rings were plated in order to study the effect of configuration. In the final studies of the effect of configuration, grooved slip rings were plated. A discussion of the results obtained will be given for each study to facilitate assimilation of this report.

3.3.2.1 Effect of Gold Content in the Plating Bath - A series of tests was made to determine the effect of gold content in the plating bath on the physical properties of the plate obtained. Preliminary studies had indicated that good results could be obtained when the free KCN was 7 oz. per gallon and the temperature was at 35°C. These conditions were held constant and deposits were made from baths containing the following gold concentration: 5.5, 7.25, 8.25, 9.0, 10.0, 11.0, 12.0, 13.0, 14.5, and 16.0 troy oz. per gallon. The current density was held constant at 10 amps per square foot throughout this series of tests (see Table 3.3.-I). All figures and tables are included in Appendix 3.3-I. The circuit diagram for the equipment is shown in Fig. 3.3.16.

At low gold concentrations the deposit was found to be hard, brittle and highly stressed. As the gold concentration increased, the deposit became soft and less brittle with the best deposits being obtained between 9 and 10 troy oz. per gallon of $KAu(CN)_2$. At gold concentrations greater than 10 troy oz. per gallon, the grain structure became coarse with "cones" being present (Fig.3.3.6, 3.3.7 and 3.3.13). Increasing the gold content appeared to have the opposite effect on the deposit as increasing current density. Because of this obvious interaction of current density and gold content, a study was made to see if the characteristics of the electrodeposited gold could be predicted or explained from a ratio of current density to gold content in the bath. It was found that at 35°C and seven ounces of free cyanide per gallon; good, hard, uniform, fine grained deposits could always be obtained when the ratio of current density (ASF) to gold content (troy ounces) was equal to one.

3.3.2.2 Effect of Cathode Current Density - Deposits were made from a cyanide bath on 1/4" diameter plastic rods. Several values of temperature, gold content, and free cyanide content were selected for each current density value chosen. The following current densities were studied: 5.0, 7.0, 8.0, 9.5, 11.0, 12.5, 14.0 and 15.5 amps/ft^2 (see Table 3.3-I).

It was found that increasing the current density had almost the opposite effect to increasing the gold content in the bath. At high current densities compared to gold content (ratio greater than 1.2) the plate was brittle and cracked (see Fig. 3.3.17). At medium current densities compared to gold content (ratio between 1.2 and 0.85) the deposit was sound and uniform in hardness with a more regular, uniform grain structure (see Fig. 3.3.17).

At low current densities compared to gold content (ratio of less than 0.85) the deposit had cones (bumps) and was non-uniform in hardness (see Figures 3.3.6, 3.3.9,

3.3.10, 3.3.12, 3.3.14 3.3.15 and 3.3.17). From these observations it was concluded that at a ratio of current density in amps per ft^2 to gold content in troy oz. per gallon of about one (1.0) the deposit obtained from a gold cyanide bath will be sound and uniformly hard. It was also observed that the best plating was obtained at gold contents of 8 to 10 troy oz. per gallon and current densities of 8 to 10 amperes per square foot, (see Fig. 3.3.15F, 3.3.15G and 3.3.15H).

3.3.2.3 Effect of Free Cyanide - A series of 1/4" diameter rods were placed at constant current density and gold content and varying free KCN. The temperature was held constant at 35°C. The following concentrations of free KCN were studied: 0,2,4,6, 8,10 and 12 and 14 oz. per gallon (see Table 3.3-I).

The concentration of free KCN appeared to have little effect on the physical properties of the deposit as long as the concentration was held between 2 and 10 oz. per gallon. At concentrations below 2 oz. per gallon the deposit appeared to be highly stressed and was brittle (see Fig. 3.3.8). At concentrations greater than 10 oz. per gallon the deposit became porous (see Fig. 3.3.5). Free KCN above that which is needed reduces the stability of $KAu(CN)_2$ in the bath. Based on the above observations 7 oz/gallon is recommended for cyanide gold plating baths.

3.3.2.4 Effect of Temperature - An extensive study of the effect of temperature on various cyanide gold baths was carried out. By using the data obtained one can predict the effect of slight changes in plating bath temperature on the physical properties of the gold deposit. The following temperatures were studied: 25, 30, 35, 40 and 45°C (see Table 3.3-I and 3.3-II). At each of the temperatures studied various levels of gold concentration and current density were also studied. In this series of tests more than fifty (50) gold cyanide plating baths were studied. The free KCN

concentration was held constant at 7 oz/gallon throughout these studies of the effect of temperature. Plastic rods (1/4 inch diameter) were used as the cathode. The average electrodeposit was about 40 thousandths of an inch thick.

Contrary to prevailing opinion, it was found that slight changes in temperature greatly affected the physical properties of gold deposits. Changes in bath temperature of only one or two degrees Centigrade gave considerably different gold deposits from the same bath. As the temperature was lowered for a given bath the deposit became brittle and highly stressed. On increasing the temperature for a given bath the deposit became soft and non-uniform in hardness with cones and bumps appearing as would be expected if the gold content were too high or the current density were too low (see Figures 3.3.6, 3.3.7, 3.3.9 and 3.3.10). From these observations it could be determined that the effect of temperature on the deposit for a given gold content and current density was directly equivalent to a change in gold content. The effect of current density was directly equivalent to a change in gold content in the bath or the inverse to a change in the applied current density.

At all of the temperatures studied, good, sound deposits could be obtained if the proper gold content and current density were used. It was found that as the temperature was increased the range of current density or gold content that would give good deposits became wider. At 25°C, the usable range was very narrow. There is a limit to how high the temperature can be increased since the cyanide starts to decompose rapidly above 40°C.

As a result of these studies the recommended temperature range to use for gold plating from cyanide baths is between 30 and 40°C with best results being obtained at 35°C. It should be emphasized that the optimum current density to gold content ratio of one holds only if the plating bath temperature is 35°C. At any other temperature there is an optimum ratio but it is not

1:1. Above 35° the optimum ratio of current density to gold content is greater than one and will increase as the bath temperature is increased, whereas, below 35°C the ratio is less than one and will decrease as the temperature of the bath is decreased.

3.3.2.5 Acid Baths - Two proprietary acid gold plating baths were studied. These baths were Orosene 999 and Orotherm bath from Technic, Inc., Providence, R.I. Current densities of 2, 3 and 4 amps per square foot were used and the length of the plating time varied between 24 and 38 hours.

It was found that long plating times were required in order to get thick deposits with both Orosene and Orotherm baths, indicating a low cathode efficiency. Sound deposits were obtained but there was large variation in the hardness results (see Table 3.3-III). Extremely high hardness was obtained with Orotherm HT (130 - 190 Knoop) while the hardness for the Orosene deposit was low (40 - 120 Knoop). Based on this work, recommendations were made that Orotherm HT bath be used as a flash bath to put the hard wear resistant coating on slip rings. Results have been satisfactory.

One of the distinct disadvantages of these baths is their high operating temperature, thus requiring frequent additions of water because of evaporation. Concentration control also becomes difficult. Another disadvantage is the low efficiency of these baths (25% or less). Because of this and the low current density used, extremely long times are required in order to obtain the required thicknesses (25 - 40 mils). Another distinct disadvantage is the required use of inert anodes thus requiring frequent additions of gold salts to replenish the gold content of the bath. These baths were, in actuality, designed for gold plating and not for gold electroforming, therefore poor results were obtained when used for electroforming of thick deposits.

3.3.2.6 Study of the effect of Configuration and Size - Several sizes of slip rings have been plated during the early part of this study. Also, plastic rods having the following diameters were plated: 1/8, 1/4 and 3/8 of an inch.

The preliminary studies indicated that size is not an important variable. Further study using designed experiments and 1/8, 1/4 and 3/8 inch diameter plastic rods confirmed earlier conclusions that size is not an important variable. Good plates were obtained on all three sizes of rods from the same baths. (See Table 3.3-VI). In addition to these tests, good plates were obtained on actual slip rings in this range of sizes. Based on these studies, it was concluded that the diameter of the cathode has very little, if any, effect on the physical properties of gold deposited from cyanide baths.

3.3.2.7 Study of Groove Plating - Many tests have been carried out in an attempt to plate sound, uniform deposits in various size grooves. During the early phases of these studies, attempts were made to plate grooved rods which were completely covered with gold reduction. The grooves were from 10 to 20 mils deep and from 10 to 20 mils wide. Various baths, positions in the bath, agitations of the bath and rotation of the bath were studies without greatly improving the deposit. Fairly good deposits were obtained in the bottom of the groove, however, near the top of the groove the two sides would grow together leaving a void (see Figures 3.3.15B, 15C, 15D and 15E). The test results were obtained when the outside corners of the groove were broken (see Figure 3.3.15B). By breaking the outside corners, it is possible to obtain sound deposits completely filling grooves whose depth is less than one half the width.

After completing the above study, it was decided that better deposits could be obtained if the gold reduction coat were removed from the side of the groove. Good deposits were then obtained in grooves whose depths (about 15 mils) were equal to their width. The gold reduction coat was removed by machining it off the sides of the

grooves. Several parts were prepared where the desired groove was about 2 mils wider than the original groove. These parts were coated with gold reduction and then about 0.2 of a mil of gold was deposited over the entire part. After this, the grooves were plunge-cut to give the desired groove width, thus removing the gold from the sides of the grooves and leaving a thin gold ring in the bottom of the groove. This method was satisfactory for most parts as long as the plastic could be easily machined. A further refinement of this process was to grind the groove and remove the gold from the sides with the same type of grinding. This method has been used for parts where the plastic was difficult to machine.

3.3.2.8 Study of Gold Strike under Gold on Nickel Plating - A brief investigation was undertaken to determine if a gold strike was necessary prior to gold plating on nickel and what steps were needed in preparing nickel for gold plate. There should be a gold strike on nickel prior to gold plating. The strike should be flashed at high C.D. The hydrogen gassing at the cathode surface should be violently active. The cathode should be mildly agitated during the gold strike application. 0.5 troy oz./gallon Au strike bath was superior to 2.0 troy oz./ gallon Au. If test samples were gold struck at a low current density, there was an immersion film causing poor bond. The high current density gold strike causing hydrogen gassing from the part prevented a weak immersion film and at the same time the gas bubbles cleaned the part with a scrubbing action.

The best bond of gold to nickel plate was produced with a bath low in gold content and high in free cyanide plated on nickel surface, with a flash of gold being applied at the first stages of gassing with agitation. This process of gold striking has been incorporated into the pertinent process instructions.

3.3.2.9 Study of Agitation - A study of the effect of agitation on the physical properties of gold electrodeposit was made during these studies. The bath was agitated by a laboratory stirrer. A bath containing ten ounces per gallon of gold was used throughout this study. The following current densities were used: 8, 9, 10, 11, 12, 13, 14 and 15.5 amps per square foot. It was found that agitation had almost the same effect as decreasing the current density (see Tables 3.3-I and 3.3-V). Agitation permits good deposits to be obtained at current densities higher than could be normally used. Also it was noted that the current density range in which the desired fine grain structure is obtained was much wider. However, the deposits usually appeared rough on the surface because of the inclusion of dust particles and other impurities in the bath. The hardness of the deposit did not appear to be affected by agitation. Agitation, however, appears to increase the uniformity of the grain structure. It is believed that with further work agitation could be used to refine the plating process.

3.3.2.10 Study of the Effect of pH - The pH of several cyanide baths was lowered by adding phosphoric acid. Cyanide baths with pH values between 3.0 and 12.0 were studied. The gold content in the baths was kept constant at 10 troy oz. per gallon and the current density was held constant throughout this study at 10 amperes per square foot. The free cyanide content was held constant at 7 ounces per gallon. Good deposits were obtained at all pH's studied (see Table 3.3-VII). The grain structure appeared to be finer at low pH and the deposit appeared to be somewhat smoother. The deposits appeared to be harder at a low pH but not as much harder as was expected. Even though the grain of the deposits obtained at low pH's was finer (see Fig. 3.3.15F) the hardness of the deposit did not appear more uniform. From these studies it appeared that little could be gained by electroforming at low pH unless a fine, uniform grain structure was specifically desired.

3.3.3 Discussion

3.3.3.1 Physical Tests - One of the first tests devised to determine the desirability of a sample of plated gold was the scratch hardness test. (It is felt, by some researcheers in the literature, that scratch hardness testing is more indicative of the wear to be expected than indentation hardness testing. It was hoped that scratch hardness testing would supplement and support our standard indentation hardness testing and, at the same time, broaden our knowledge of wear.) A small fixture was made, the elements of which were a guide along which to slide the plate and a spring member having a brush holder on one end. The brush holder was suspended over the plate and pressed down by the tension of the spring. As the plate was drawn under the brush wire, a "scratch" was made in the plate (see Figures 3.3.1 and 3.3.2).

Preliminary tests showed that the width of the scratch could not be measured accurately because of the roughness of the plated material and the shallowness of the scratch. Also, the force needed to scratch the surface sufficiently exceeded 100 grams. For these reasons, the spring and brush holder were discarded and replaced by a V-90° diamond tool and a counter-balance mechanism. The new scratches were much more easily measured and much deeper (see Fig. 3.3.3). However, these tests were also discontinued after a short time for lack of correlation to plating results.

Another physical test to be performed on the plated samples was the Knoop Hardness Test, to be done on the Wilson Tukon Hardness Tester. With this instrument, a diamond shaped indenter (120° included angle) is impressed into the sample under a known force. The major dimensions of the indentations were measured by the use of a microscope equipped with a filar micrometer eyepiece.

A third test was electro-etching the mounted and polished sample in a 5% potassium cyanide solution in order to bring out the grain structure of the material. The sample was then studied on the metallograph, and photomicrographs of the structure were made.

The Knoop Hardness Tests and electro-etching with visual observation were used as criterion for good plating throughout the study.

3.3.3.2 Interrelations of Parameters of Bath Operation - In an effort to explain the effects of the parameters, the cathode film must first be described. This is the area of solution around the cathode with less metal (gold) than the surrounding solution. A concentration gradient exists in this film with gold concentration being very low at the surface of the cathode (cathode film).

There is evidence to support the belief that the physical characteristics of the gold plate depend largely upon the thickness of the cathode film. It is known that changes in temperature, changes in gold content, changes in current density and agitation affect the thickness of the cathode film.

It is believed that increasing the thickness of the cathode film increased the energy required to plate out gold, thus giving smaller crystals and harder gold plate with high internal stress; while thin cathode films give larger crystals and softer plates with less internal stress.

From these studies, it can be concluded that the physical properties of gold electrodeposited from a cyanide bath are greatly influenced by the thickness of the cathode film.

3.3.4 Parameters Affecting Anode Corrosion Rate

3.3.4.1 It was determined that the anode material condition was a significant factor in the electrodeposition of gold.

Two (2) lots of gold anodes were used. Both were spectro-analyzed and found to have no impurities of a metallic nature. First group of anodes were determined to have a hardness of 38.5 (Knoop 100 gram) and to the major axis cut parallel to the rolled direction. The second anodes were checked at 82.3 KHN_{100}

and were observed to have been cut transverse to the rolled direction. All anodes were 1/2 x 4 x 1/16 inches. Solutions for plating contained ten (10) troy ounces of potassium gold cyanide and seven (7) ounces (avoir.) of free potassium cyanide. The temperature was maintained between 35 ± 1 while the cathode current density was held to 9 ± 0.2 ASF.

The results of the plating obtained from the two sets of anodes were vastly different. First, the harder anodes resulted in an inferior deposit being much rougher with plating rate much lower than the normal .0015 inches per hour. Furthermore, the solution had much reduced "throwing power" in areas where convection or concentration was reduced by the part configuration. Analyses of plating solutions showed that the gold concentration, using harder anodes, had become so variable that proper current density/gold concentration ratios of .9 to 1.2 were impossible to maintain.

This erratic concentration was paralleled by the erratic erosion of the harder gold anodes. These anodes disintegrated more than they dissolved. The disintegration resulted in considerable flakes and scraps of gold settling to the bottom of the bath. No such behavior of the softer anodes had been experienced.

Samples of the hard anodes were annealed at 300°C for one hour to 70.6 KHN_{100} and at 650°C for a second hour to 54.2 KHN_{100}. Further work was deemed necessary to determine the anode condition required for controllable plating.

The standard potassium gold cyanide bath (10 troy oz. Au, 7 oz. free KCN per gallon) was used at a temperature of 35°C (± 1°C). The C.D. was maintained at 9 ASF. Chemically clean gold strips were used as cathodes. Eighteen (18) anodes of varying hardnesses for use in these tests were purchased from Handy and Harman. The condition, direction of cut relative to the direction of rolling, sizes and average KHN of these sample anodes are shown on Table 3.3-VIII. For each test a bath volume of 333 ml. was used initially. The bath was returned to its original volume before each sampling for chemical analysis

at specified intervals (2, 4, 8, 16 hours) after start of each test. The gold and free KCN content were determined for each sample to detect any changes in concentration. (See table 3.3-IX and 3.3-X).

3.3.4.2 Results

3.3.4.2.1 Anodes 1/8" thick, 80 (plus) KHN hardness, and cut transverse to the grain, produced erratic results.

3.3.4.2.2 Gold anodes 1/16 x 1/2 x 4 inches, KHN 40-75, Au 99.95% by weight cut parallel to direction of rolling, generally held the bath within the desired limits.

3.3.4.2.3 Anodes with hardnesses less than 60 KHN held the gold level in the baths more uniformly than anodes that were harder, approximately 80 and plus KHN.

3.3.4.2.4 Flaking anodes was more prevalent in the harder anodes cut transverse with respect to the grain structure.

3.3.4.2.5 Anode material should be specified and purchased to Poly-Scientific Engineering Specification Number 206.

3.3.5 Stress Analysis of Gold Electrodeposits

3.3.5.1 Tensile test data was obtained on a number of different electrodeposited specimens of 24 karat gold. The object of obtaining the data was to determine elastic modulus values for the 24 karat gold electrodeposits. Knowing what value to expect of good material this information could be used as an indication of whether a plating bath was functioning as it should be. These values could also be used for assembly design purpose. The equation in calculating the stress in the electrodeposit requires that the elastic modulus and thickness of both the electrodeposit and the basis strip be known in order to make accurate calculations. This equation was taken from: Brenner, A. & Senderoff, S.; "Calculation of Stress in Electrodeposits from the Curvature of a Plated Strip;" Research Paper RP 1965;

Journal of Research of the National Bureau of Standards; U. S. Department of Commerce; Vol. 42; February, 1949; pp. 105-123.

The work by the above authors was the most complete and accurate work that was found in the literature, and in the opinion of our Electrodeposition Consultant, Dr. Nelson Murphy of the V. P. I. Chemical Engineering Department, was the research on which we should base our study.

3.3.5.2 Messrs. Brenner and Senderoff cite three different methods of measuring the stresses of electrodeposits by the creature of a plated strip.

The deposit is plated on a strip that is allowed to bend continuously during plating. This is the method most commonly used, but, prior to the work of Brenner and Senderoff, there has been no satisfactory discussion in the literature of the calculations involved for this method or for the second method.

The equation developed for method is as follows:

$$S = \frac{E_b t\ (t + Rd)}{6\ rd}$$

Where S = stress in the electrodeposit.

E_b = Young's modulus of the basis strip.

$R = E_c/E_b$ = ratio of Young's modulus of the electrodeposit to Young's modulus of the basis strip.

d = thickness of the electrodeposit.

r = radius of curvature of the stressed electrodeposit.

3.3.5.3 Group I Tests - Since the elastic modulus of the electrodeposit was unknown, we had each of nine electrodeposits tensile tested and determined the elastic modulus.

The plating bath was set up so that the plating conditions were:

Current Density - 10 amps/sq. ft. (10.5 for samples 1 & 2),

10 ± 0.5 troy oz. of gold/gallon,
7 ± 1 oz. of free KCN/gallon,
Bath temperature: 35 ± 1°C.,
K_2CO_3 content < 4.0 oz/gallon.

The basis strips used were copper, of varying thicknesses depending upon the thickness of gold to be electrodeposited. The electrodeposit thickness is recommended to be 5% of the basis strip thickness or less in order to keep the error from assumptions made in developing the stress formula on the order of the experimental error, which is 5-10%.

During electrodeposition, deflection measurements were made by use of a goniometer, sighting on the bottom of the cathode. When the electrodeposit thickness was built up to the desired level, the electrodeposit was removed from the bath, and the copper basis strip was dissolved away chemically to permit subsequent tensile testing of gold strip only.

In some cases "thieves" or copper strips identical to the cathode were placed on either side of the cathode to prevent excessive gold build-up on the edges of the cathode, resulting in some error in reading deflection. A stop-off lacquer was painted on the edges and backs of the cathode and thieves to prevent electrodeposition at these places.

No thieves were used in the electrodeposition of samples 1, 2 or 9. Samples 3 and 5 were thieves for sample 4; samples 6 and 8 were thieves for sample 7.

Table 3.3-XI gives the tensile data obtained on samples 1-5 which were tested by Instron Engineering Corporation. Table 3.3-XI also shows the tensile data for samples 6-9 which were tested by Tinius Olsen Testing Machine Company. Some difficulty was encountered in the tensile testing of samples 1-5: A gage

length of only 1/2 inch could be used, and samples 1-3 slipped in the grips but were tested to failure. A high cross-head speed of 0.2 in/min was used on samples 1 and 2 while a slower speed of 0.05 in/min was used on samples 3-5. Strain for samples 1-5 was calculated on the basis of cross-head motion per unit of time. This method does not eliminate errors arising from grip slippage, machine deformation, and non-uniform length and non-uniform cross-section of exposed specimen between grips.

In the tensile testing of samples 6-9, an X-Y recorder and a counterbalanced extensometer was used, eliminating the possible errors mentioned above. The curves, in general, appear to indicate more valid testing than that obtained for samples 1-5. A representative curve, taken on sample 9, is given in Fig. 3.3.19.

The tensile data for all nine samples show the proportional limit to be so low that a constant ratio of stress to strain cannot be obtained. Therefore, all modulus values were taken from the stress-strain curves in a manner described in ASTM Standard E111-61, using the initial tangent modulus.

Figures 3.3.20 - 23 show plots of electrodeposit deflection as taken in the plating bath with the goniometer, versus the plating time. These plots simply show that the rate of stress buildup was not constant.

Table 3.3-XII lists values for the necessary parameters required to solve the stress equation and also the computed stress values. In addition, Table 3.3-XII shows the percent error involved by letting R ($R = E_c/E_b$) in the stress equation equal unity. This is a simplification of the formula that has been used.

3.3.5.4 Group II Tests - Additional stress study samples were made using copper and E.S. 218 plastic as basis strips. The thickness of gold on the copper was made thicker, nominally .015 in., than those made previously, in order to simulate the thickness of gold being electrodeposited for the capsule slip

rings. The thickness of gold on E.S. 218 plastic was made the same as that used on some previous copper basis strips, in order to allow comparison of results obtained from different basis materials.

No tensile tests have been performed on these samples as yet, therefore no stress calculations can be reported. Figures 3.3.24 - 27 do show however, the relationship between the measured deflection of stress samples while in the plating bath and elapsed time. As shown in Figure 3.3.24 (Sample #13), the electrodeposit stress was sufficiently high to cause the electrodeposit to break loose from the E.S. 218 basis strip after 1-1/2 hours. Since readings were being taken from the back of the basis strip, the points plotted in Fig. 3.3.24 after 1-1/2 hours are invalid; this is why the data has been extrapolated.

No thieves were used in electrodepositing sample #13, and it is felt that perhaps the resultant excessive gold build-up on the edge of the basis strip may have contributed to the stress significantly and caused the electrodeposit to break loose. Consequently, sample #15 (Figure 3.3.25) was electrodeposited with thieves, and no separation between basis strip and electrodeposit resulted.

Table 3.3-XIII compiles deflection data for all samples made to date. Comparison of the total deflection of sample #15 to samples #6 - 9 shows that the deflection is three times greater for sample #15, all other variables being equal. The same result is seen by comparing the total deflection of sample #13 (extrapolated) to those of samples #1 and #2. Since deflection is a function of elastic modulus, the elastic modulus of E.S. 218 plastic was roughly approximated by considering the above deflection comparisons and the known elastic modulus of copper, at 6×10^6 PSI. The measured modulus of E.S. 218 subsequently reported by U.S. Testing Labs is 2.9×10^6 PSI.

3.3.5.5 K-24 Stress Study Recommendations

3.3.5.5.1 The ratio of the electrodeposit thickness to the basis strip thickness (d/t) should be held to 0.05 or less to maintain accuracy of the stress equation.

3.3.5.5.2 The basis strip should be of copper rather than E.S. 218 since it is difficult to obtain a good bond to E.S. 218, causing a non-uniform electrodeposit and error in determining stress.

3.3.5.5.3 The basis strip thickness should be between .050" to .100" thick to minimize experimental error.

3.3.6 Related Plating

A necessary sub-study of plating of gold for slip rings has been performed on the plating of lead tips (bump), the metallizing of the plastic and the plating of nickel. Brief summarys are included. A gold reduction process developed and reported was in Phase I.

3.3.6.1 Copper "Bump prior to Copper Plating of Rings - In order to have a good connection (bond) with the copper lead to copper ring, it was found necessary to plate a .003 ± .001 high bump on the lead ends. There were several reasons for this application. Lead ends, as designed, join the plated ring vertically making a small area to plate, if a "bump" is not plated, there is a good chance of breaking the connection with the copper reduction along the periphery of the lead since the copper reduction must be removed from the lead to get a good bond of the lead to the ring. It is difficult to locate the lead end to abrade without a "bump." The "bump" gives a good starting foundation for the ring, and is easy to work with. The "bump" not only helps in securing a plated bond, but also forms a mechanical lock for the copper plate (Fig. 3.3.28).

3.3.6.2 Copper and Nickel Plating - Good copper reductions were obtained from a proprietary bath manufactured by Enthone, Inc., New Haven,

Conn. Good smooth uniform copper deposits were obtained from a copper fluoroborate bath at about 40 amperes per square foot. In order to obtain good adherence of the nickel on the copper, the copper surface must be free from copper oxide. Also in order to obtain good adherence of the gold deposit on the nickel, the surface of the nickel must be free from nickel oxide. By careful handling and cleaning of parts it was found that good deposits of nickel on copper and gold on nickel could be obtained (see procedures).

3.3.7 Conclusions

3.3.7.1 Increasing the gold content in a cyanide bath reduces internal stress, and tends to give softer gold deposits.

3.3.7.2 Increasing the current density for all baths, increases internal stress, and tends to give harder gold deposits.

3.3.7.3 Increasing the temperature reduces internal stress and tends to give softer gold deposits.

3.3.7.4 Free cyanide concentration has very little effect as long as it is between 2 and 10 oz. per gallon.

3.3.7.5 Proprietary acid baths give a non-uniform plate with wide variation of hardness.

3.3.7.6 At 35°C a bath with current density to gold ratio equal to about one (1.0) gives a hard uniform plate when the gold content is greater than 5 troy oz/gallon.

3.3.7.7 Slight changes in temperature greatly changes the physical properties of 24 karat gold deposits.

3.3.7.8 Slip ring configuration and size of the cathode have very little, if any, effect on the physical properties of gold electrodeposited from a cyanide bath.

3.3.7.9 Plating in grooves is practical and good results can be obtained by the use of proper procedures and precautions.

3.3.7.10 A good bond can be obtained between gold and nickel and nickel and copper if proper cleaning and strike are used.

3.3.7.11 Agitation of a cyanide bath has an effect similar to increasing temperature.

3.3.7.12 A more uniform grain structure can be obtained by the use of agitation.

3.3.7.13 Lowering the pH of a cyanide bath has little effect but appears to produce a finer, more uniform grain structure.

3.3.7.14 Anodes of 60 KHN maximum, rolled in the long direction only should be used.

3.3.7.15 Gold strike on nickel before gold plate insures better bond.

3.3.7.16 To obtain a good bond between copper plated bump on lead end and copper plated substrate ring-bump must be free of PdCl and copper reduction.

3.3.7.17 Stress increases with electrodeposit thickness; there is apparently no grain coarsening in the thickness range tested.

3.3.7.18 The average elastic modulus of the gold electrodeposit, is 8.0×10^6 psi.

3.3.7.19 The average stress in the (previously established standard bath) electrodeposit is 14,700 + 6% - 11%; this tolerance is the magnitude of the experimental error.

3.3.8 Recommendations

3.3.8.1 A new gold analysis system based on the electrodeposition of the gold be perfected.

3.3.8.2 Alloy plating be studied, especially gold alloys of noble metals.

3.3.8.3 Proprietary baths be more fully investigated.

3.3.8.4 Further work should be done on agitation of the plating solution as work to date indicates that agitation offers promise of some refinement in the plating processes.

APPENDIX 3.3-I

FIGURES AND TABLES

Fig. 3.3.1 - Scratch Test with Round Brush (Flat Plate, 100 gm Force, 182X)

Fig. 3.3.2 - Scratch Test with Round Brush (Flat Plate, 300 gm Force, 182X)

Fig. 3.3.3 - Scratch Test with V-90° Diamond (Polished Rod, 15 gm Force, 182X)

Fig. 3.3.4 - Cracks in Plated Gold Tube (Top arrow, radial crack. Bottom arrow, radial & circumferential with separation from copper base, 10X)

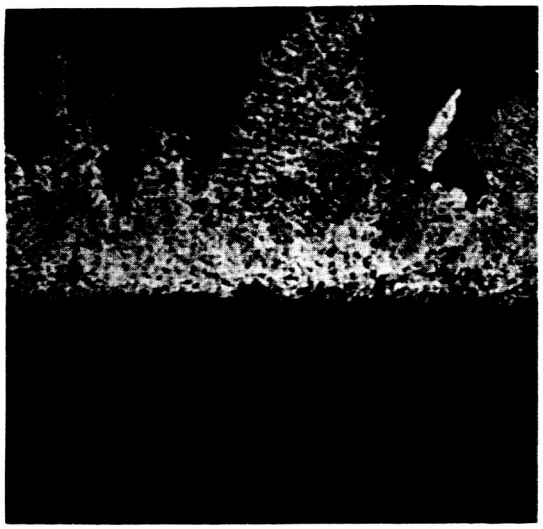


Fig. 3.3.6 - "Bumpy" Deposit - Low Current Density:Gold Ratio Plating (10X)

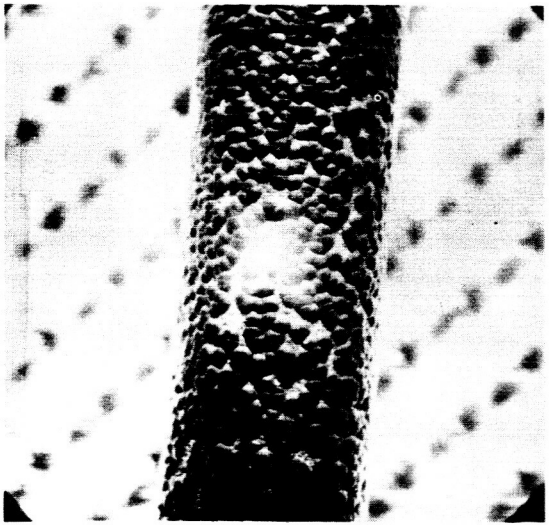


Fig. 3.3.5 - Amorphous Deposit - Very High Current Density:Gold Ratio. Complete lack of structure and irregular shapes. (128X)

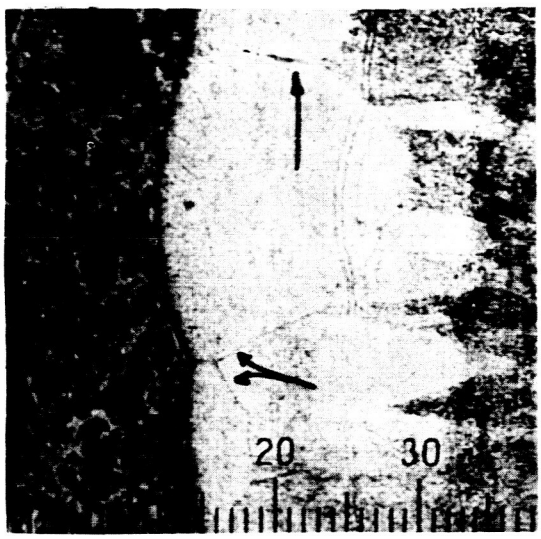


Fig. 3.3.7 - Cone Structure illustrating Cross Section of "Bumps" and cracks between cones(91X)

Fig. 3.3.8 - Stress Crack, continuous (Amorphous) structure in center enveloped by a crystal structure. (65X)

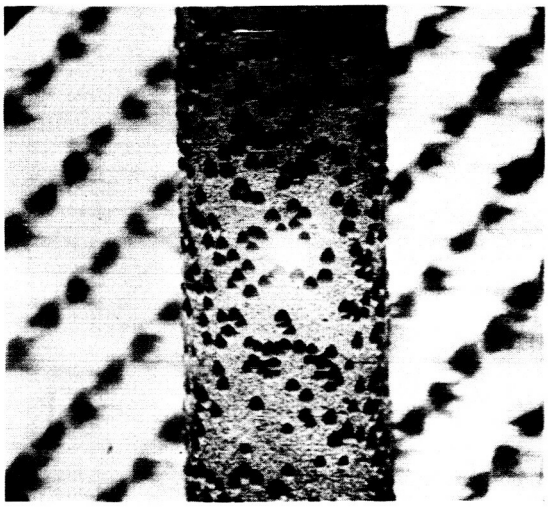


Fig. 3.3.9 - "Bumpy" Deposit illustrative of slightly low Current Density (10X).

Fig. 3.3.10 - "Banded Cone" in midst of homogeneous structure. (91X)

Fig. 3.3.11 - Crystalline structure. The line due to a Current Break during Plating (182X).

Fig. 3.3.12 - Crystal Structure and Dark Cone (91X).

Fig. 3.3.13 - Dark Cones Laminar Plate due to Current Density Changes. (91X)

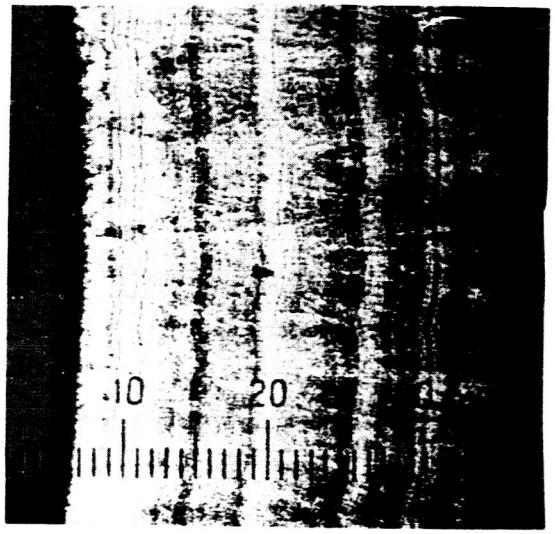


Fig. 3.3.14 - Fine Grain Wavy Structure (91X).

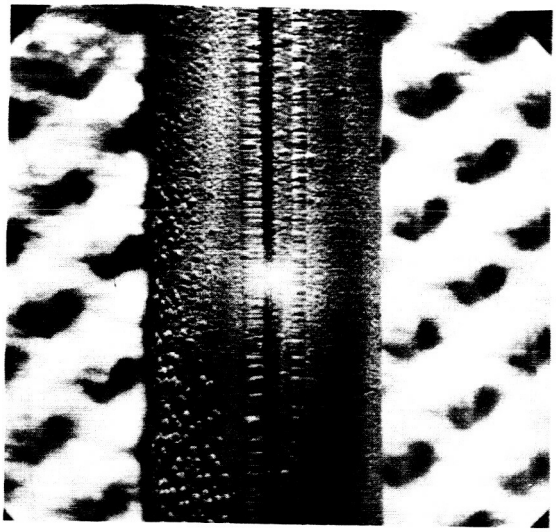


Fig. 3.3.15 - Stress Break due to Copper Conductor Configuration (10X).

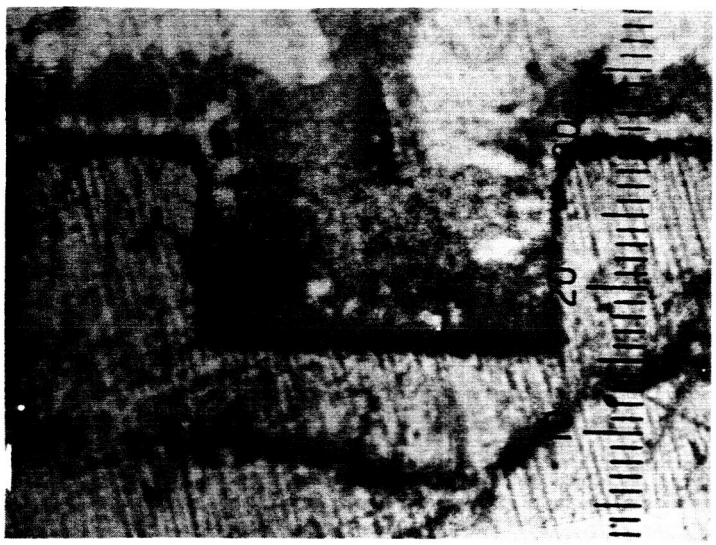


Fig. 3.3.15B:Plating in Grooves. Note Void in Plating. (91X)

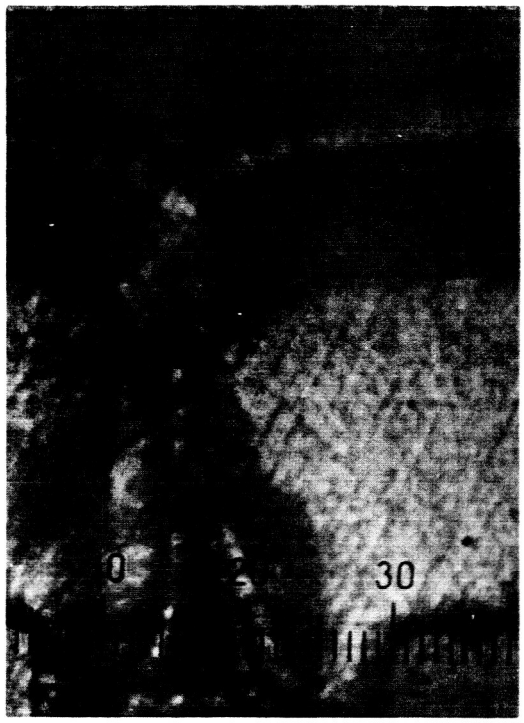


Fig. 3.3.15C:Plating in Grooves. Note heavy Seaming in Groove. (91X)

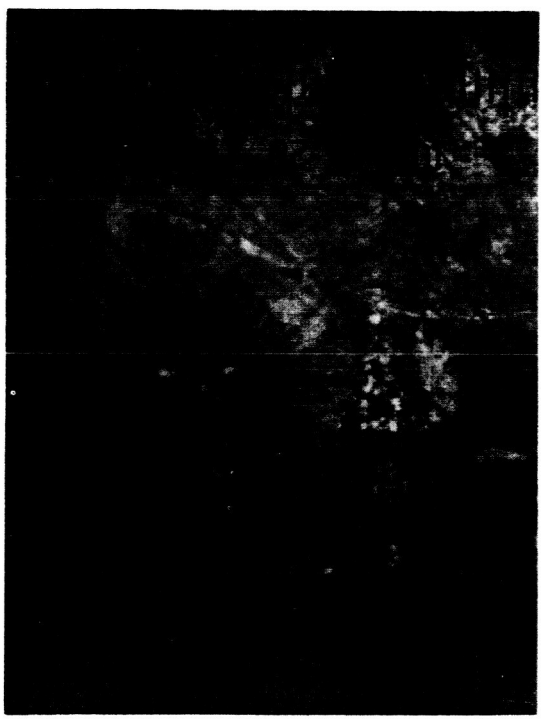


Fig. 3.3.15D:Seaming High in Radiused Groove (91X)

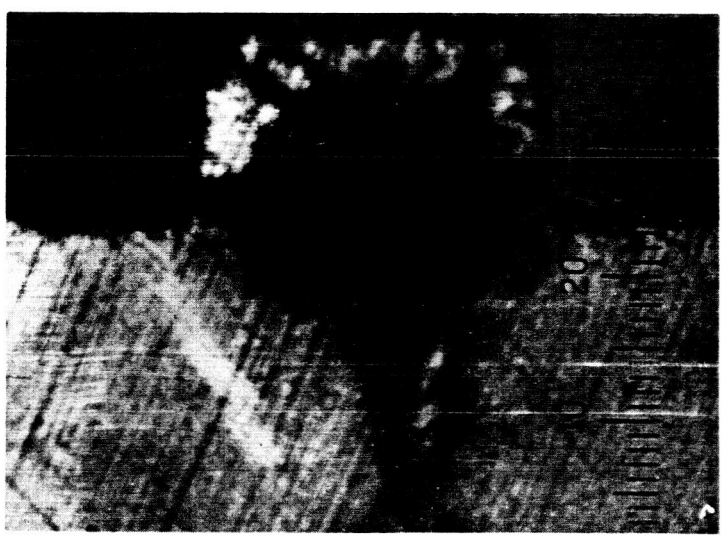


Fig. 3.3.15E:Heavy Seaming in Shallow Groove. (91X)

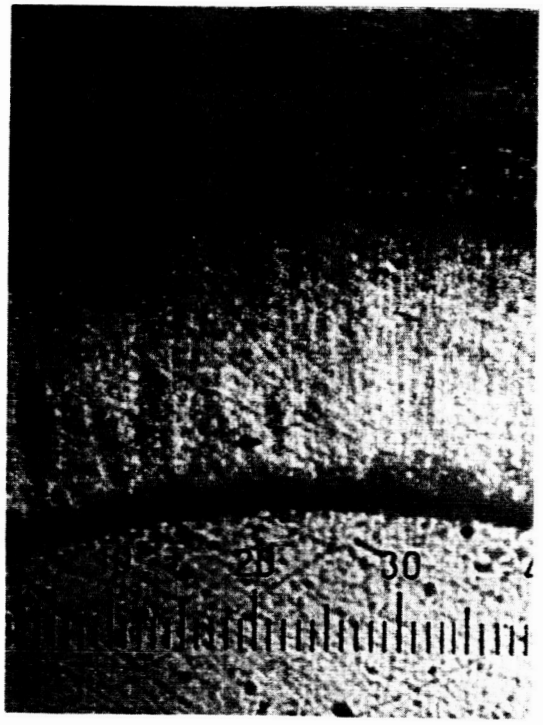


Fig. 3.3.15F:

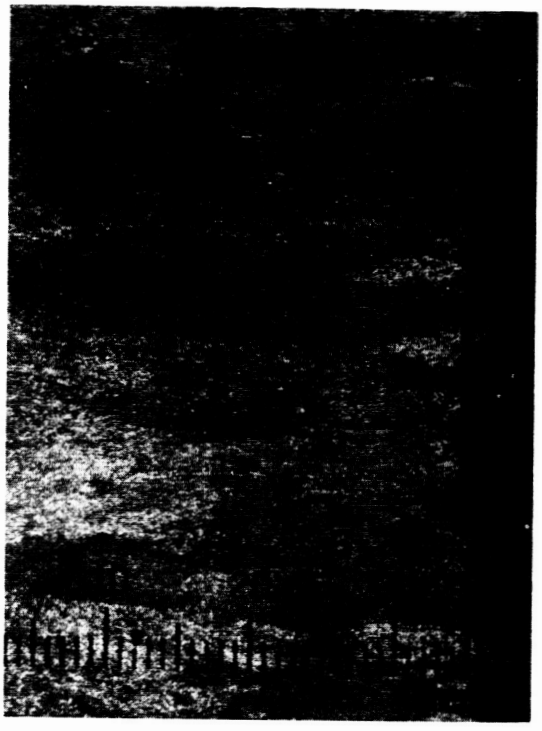


Fig. 3.3.15G:

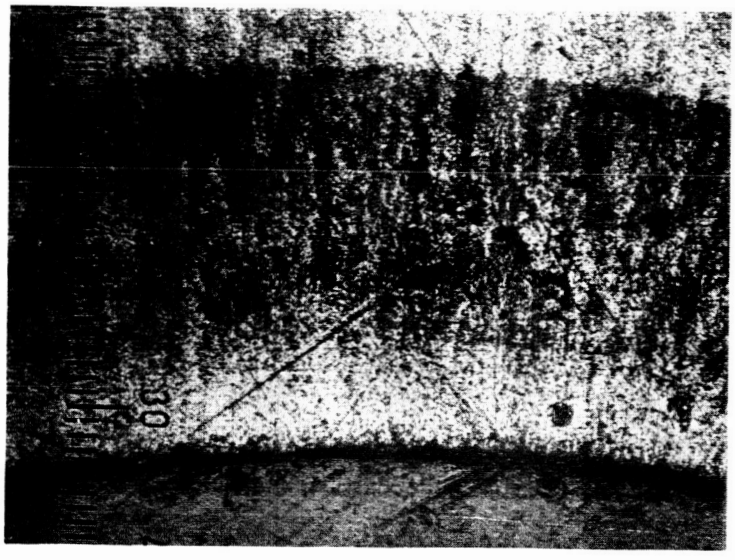


Fig. 3.3.15H:

Cross Sections of Good Sound Plating resulting from recommended Conditions.
Current Density (ASF) to Gold Ratio (Troy oz./gal.)
1:1 @ 35 °C with 7 oz./gal. KCN.

(91X)

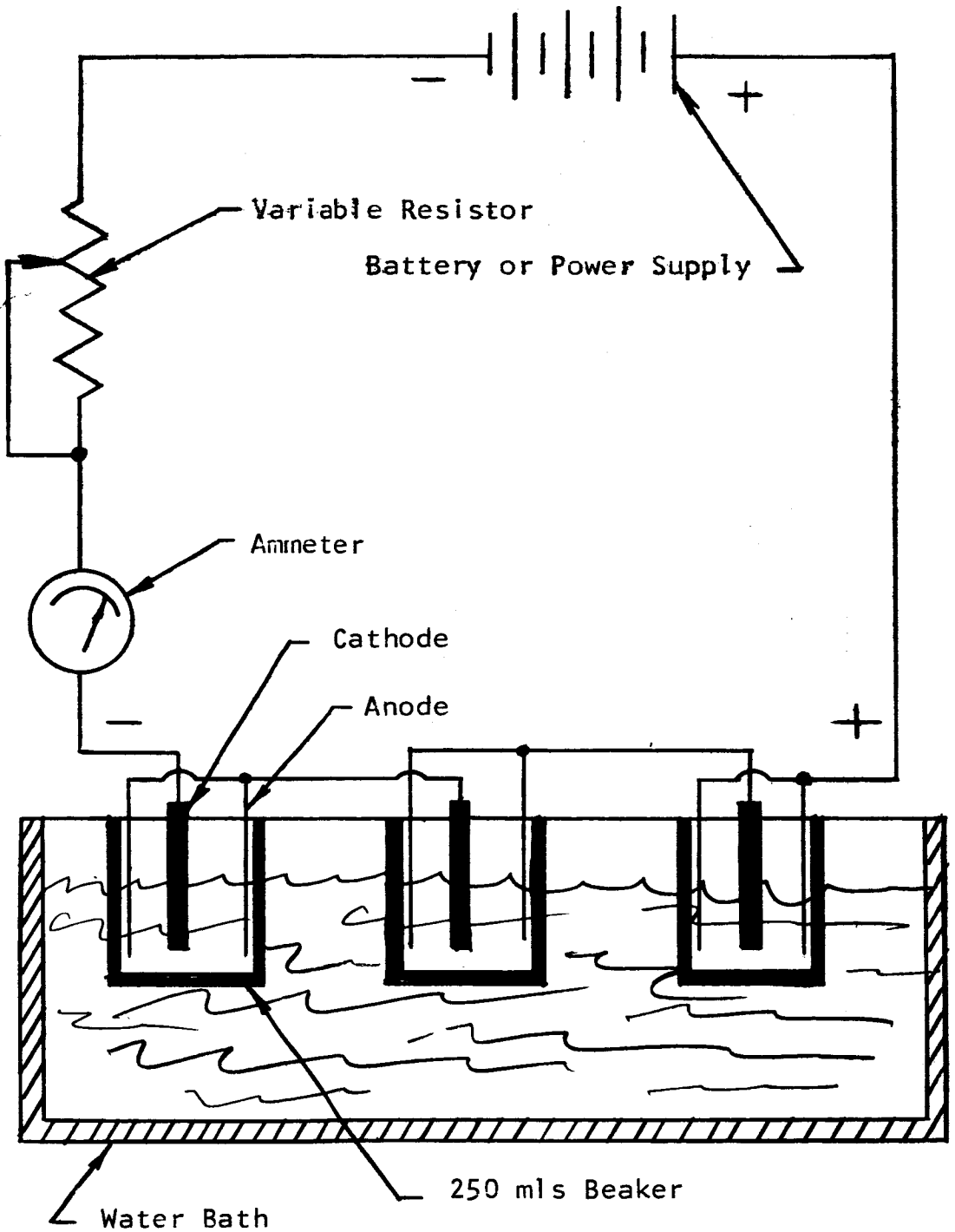


Fig. 3.3.16: Diagram of Equipment used to Study the Electrodeposition of 24 Karat Gold

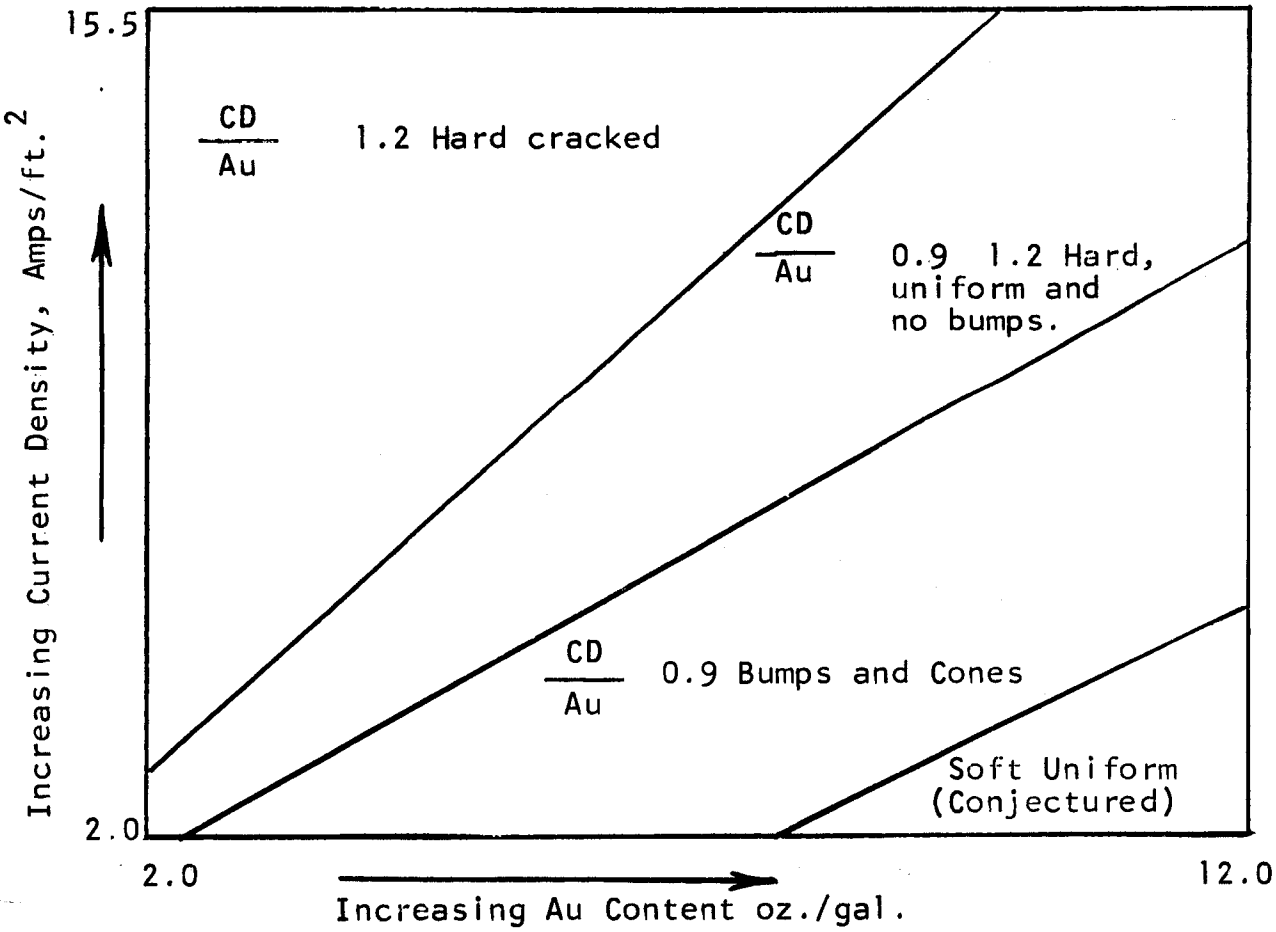


Fig. 3.3.17: Chart Showing the Effect of Current Density and Gold Content at 7 oz/gal. Free KCN and 35 °C

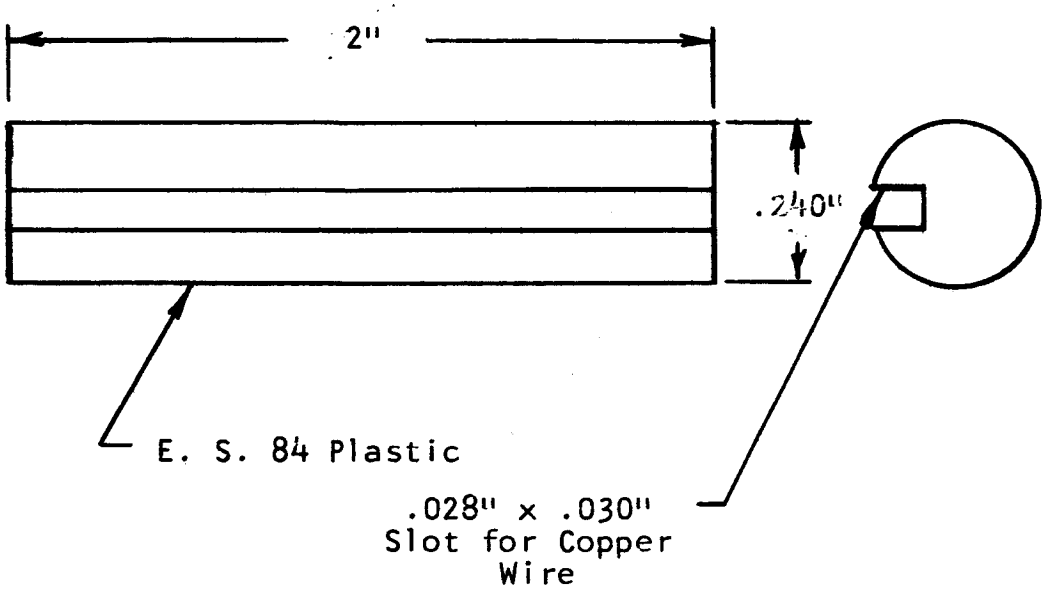


Fig. 3.3.18: Diagram of Plastic Rods Used as Cathodes in the Study of the Electrodeposition of 24 Karat Gold

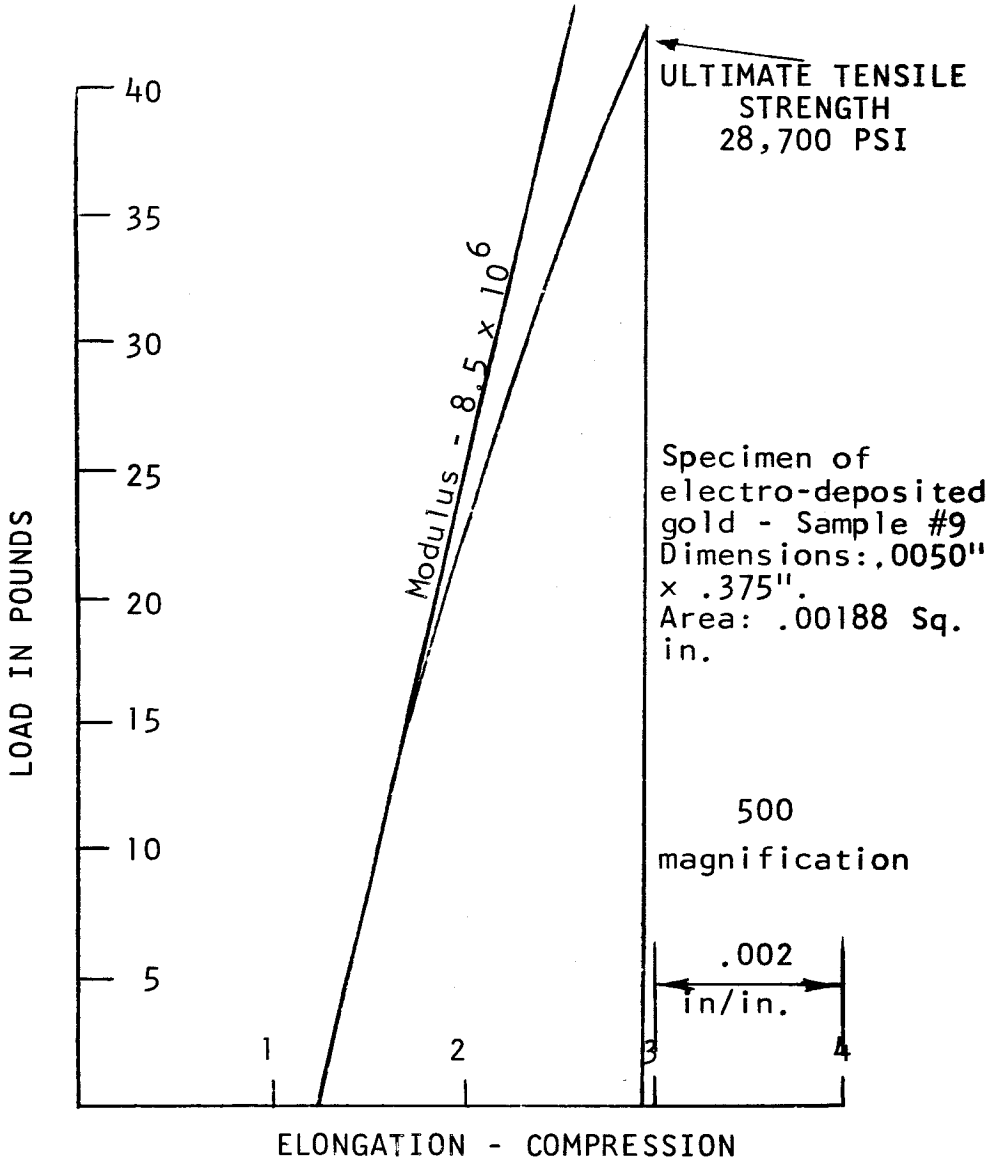


Fig. 3.3.19: Typical Tensile Test of Gold Electrodeposit

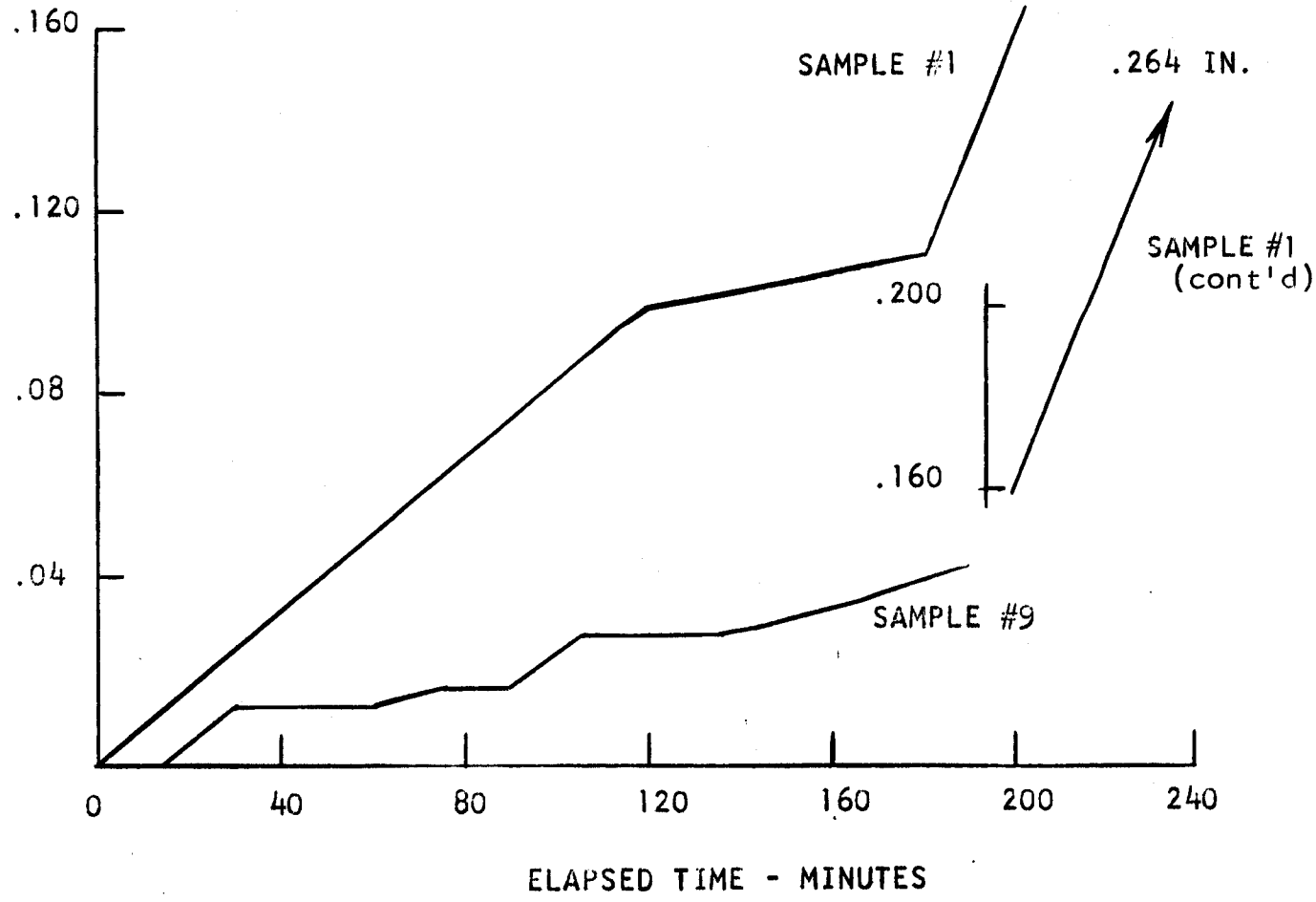


Fig. 3.3.20: Deflection of Strip Versus Time of Electrodeposition

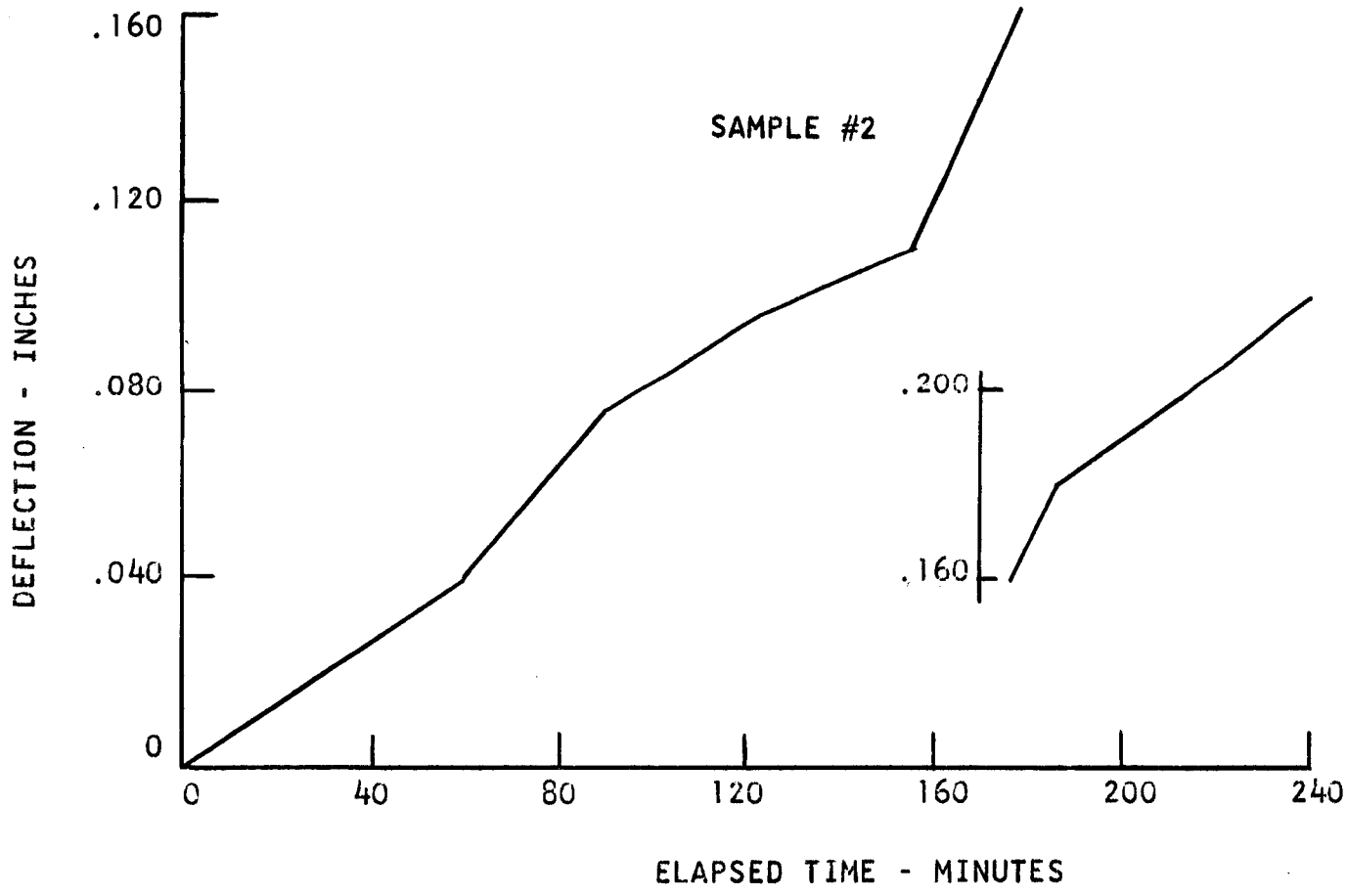


Fig. 3.3.21: Deflection of Strip Versus Time of Electrodeposition

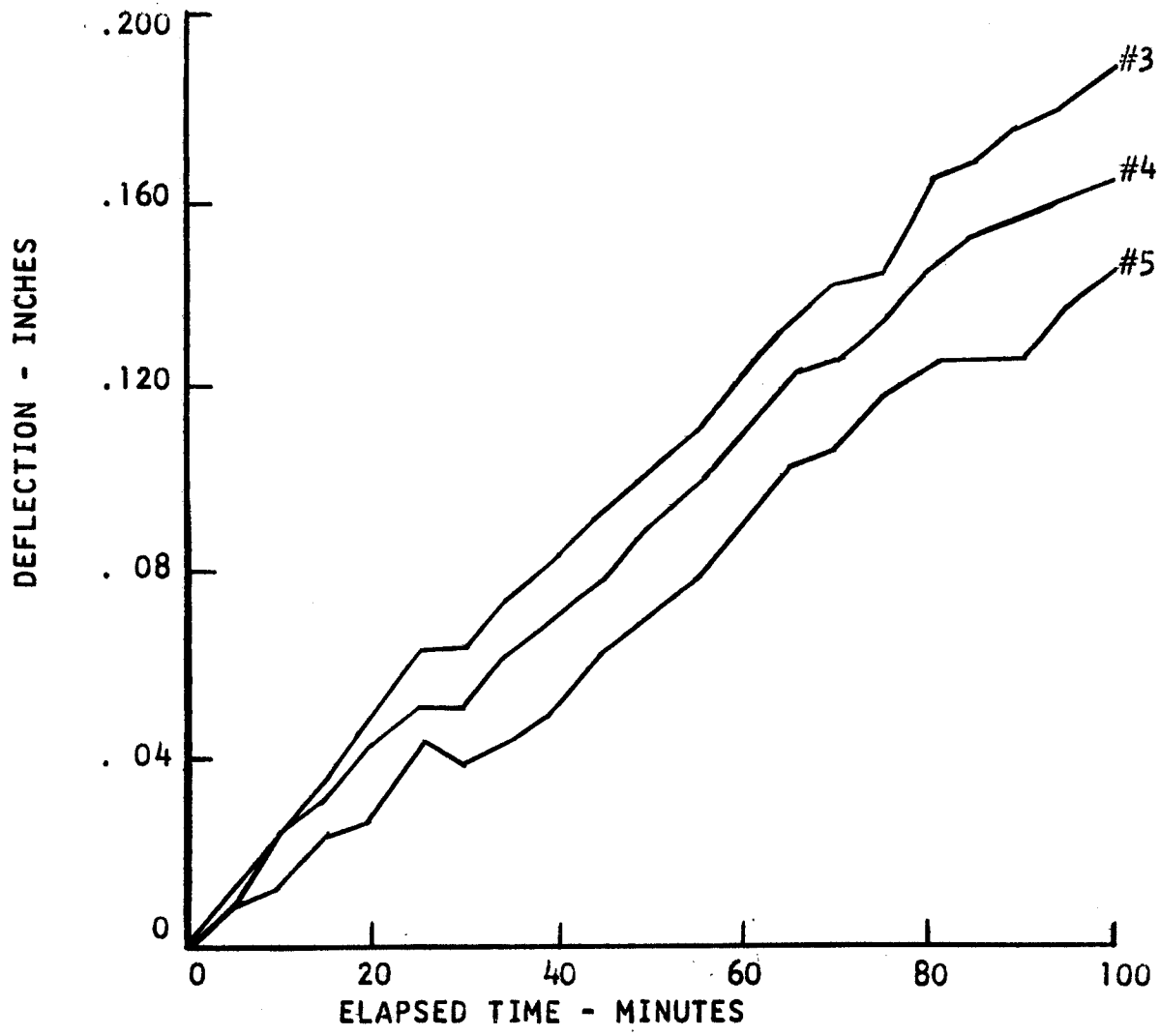


Fig. 3.3.22: Deflection of Strip Versus Time of Electrodeposition

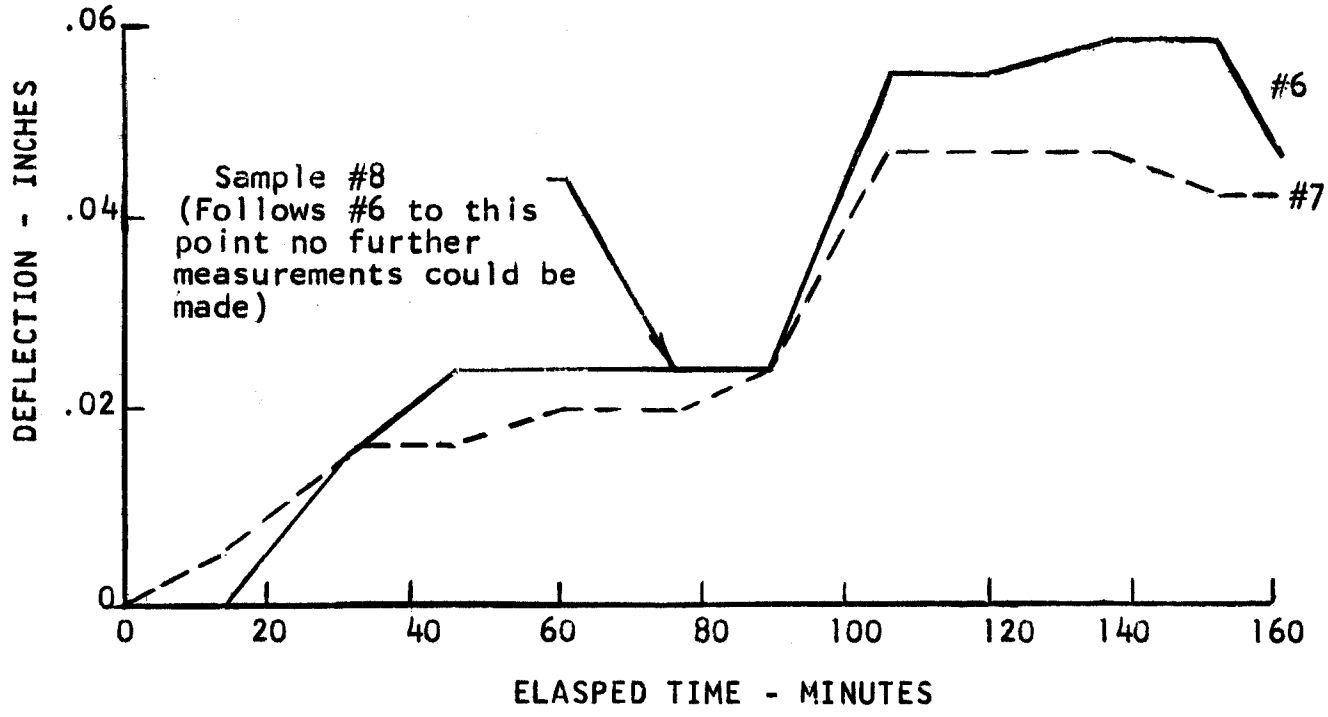


Fig. 3.3.23: Deflection of Strip Versus Time of Electrodeposition

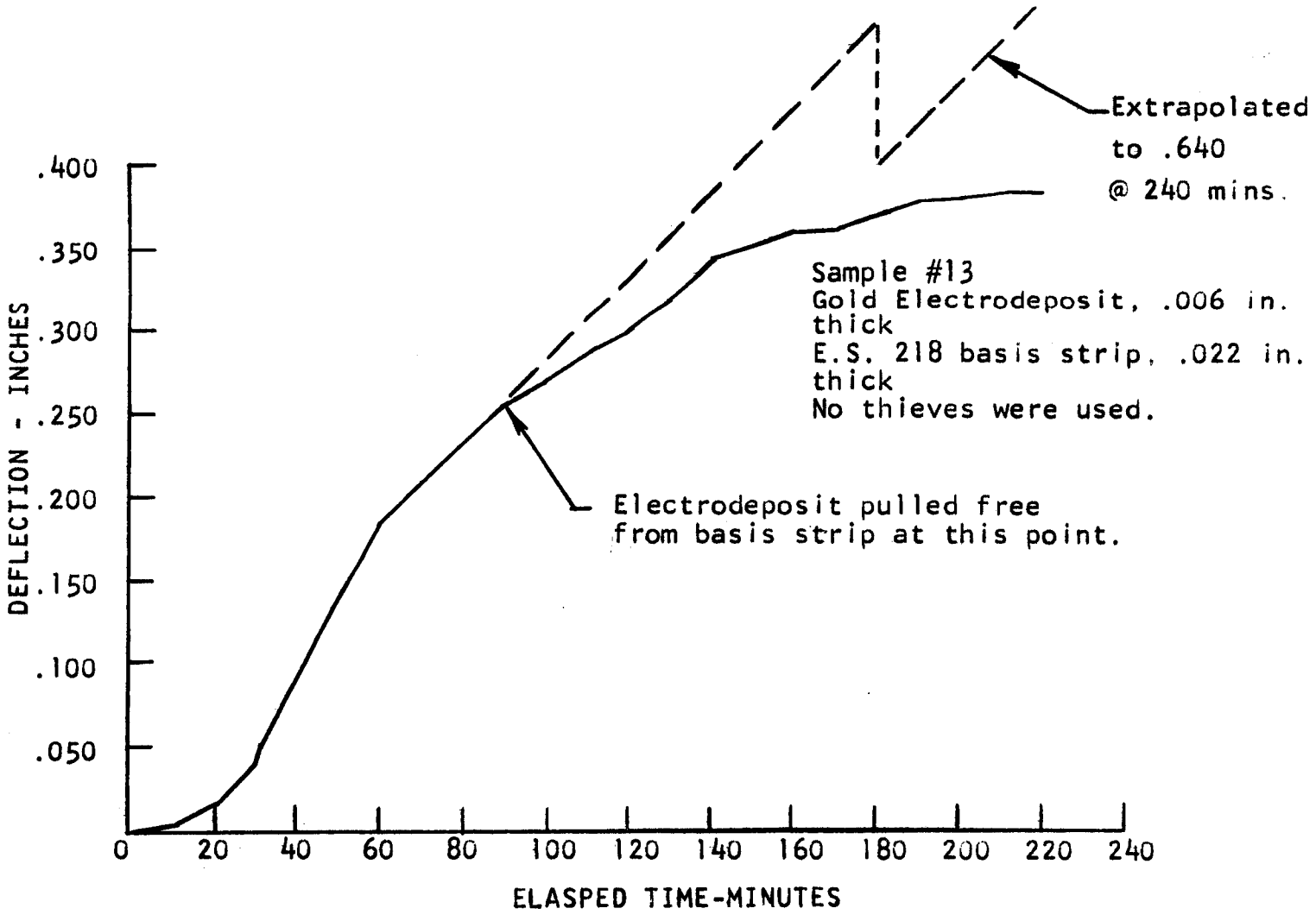


Fig. 3.3.24: Deflection of Strip Versus Time of Electrodeposition

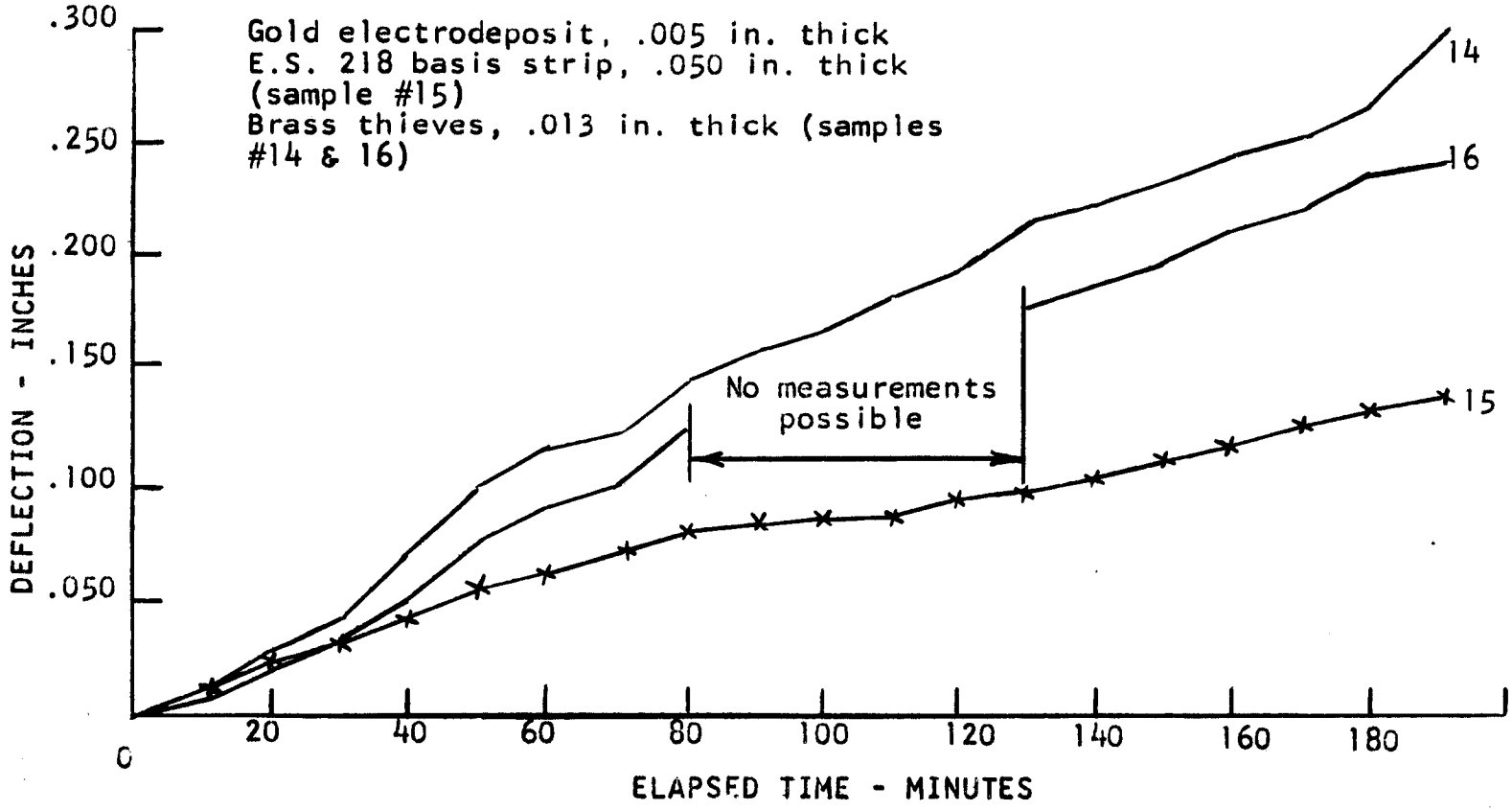


Fig. 3.3.25: Deflection of Strip Versus Time of Electrodeposition

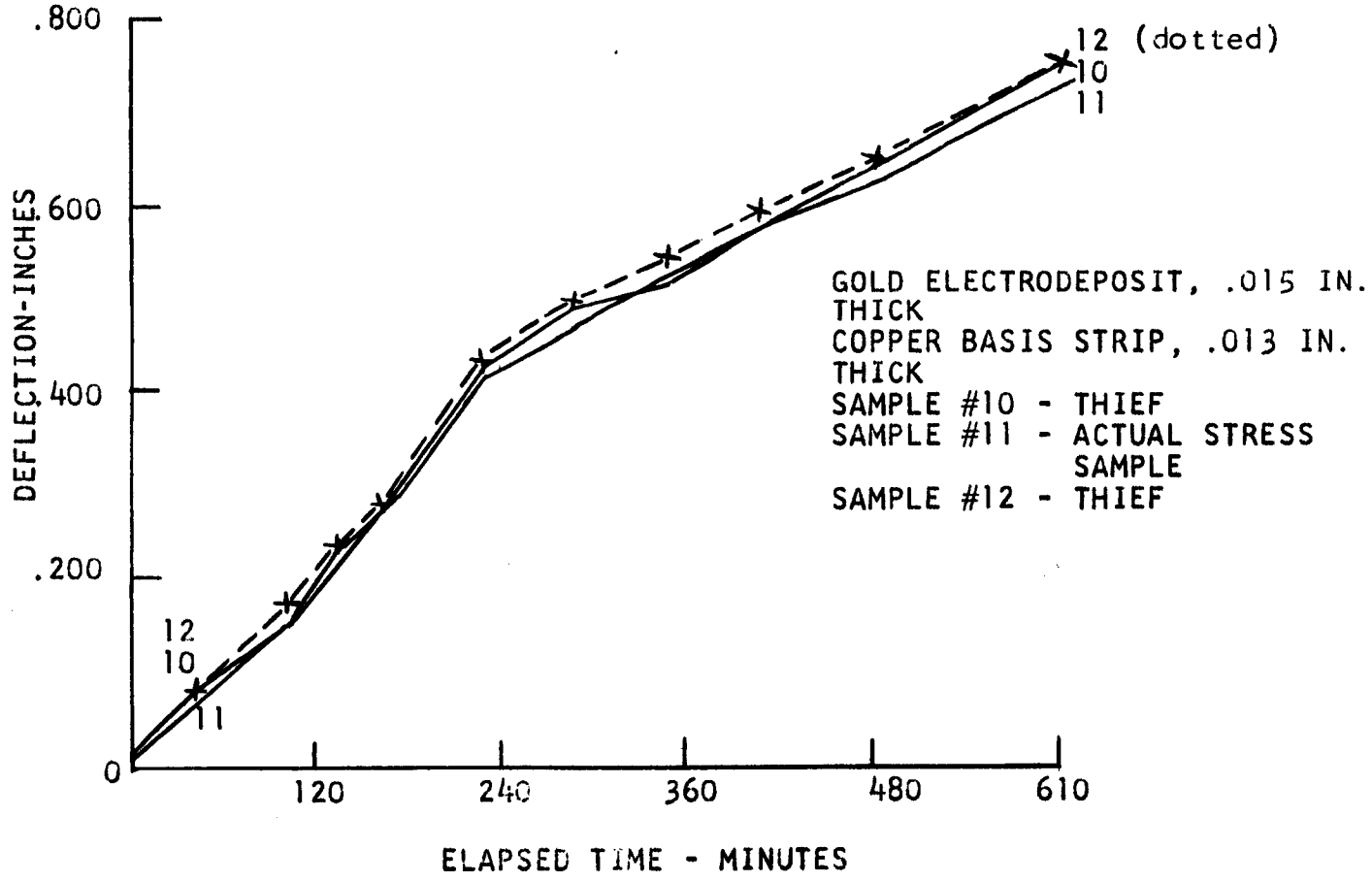


Fig. 3.3.26: Deflection of Strip Versus Time of Electrodeposition

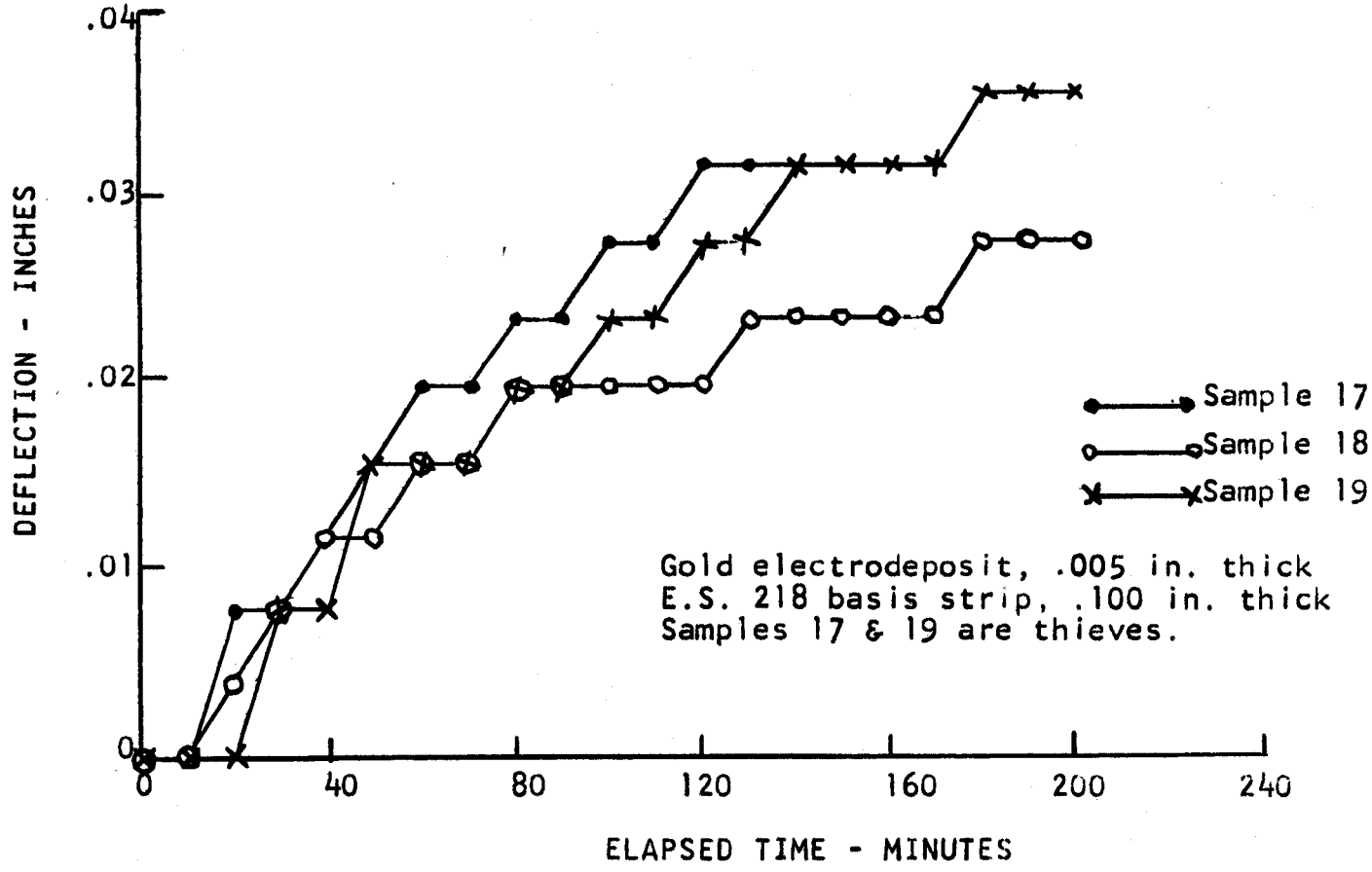


Fig. 3.3.27: Deflection of Strip Versus Time of Electrodeposition

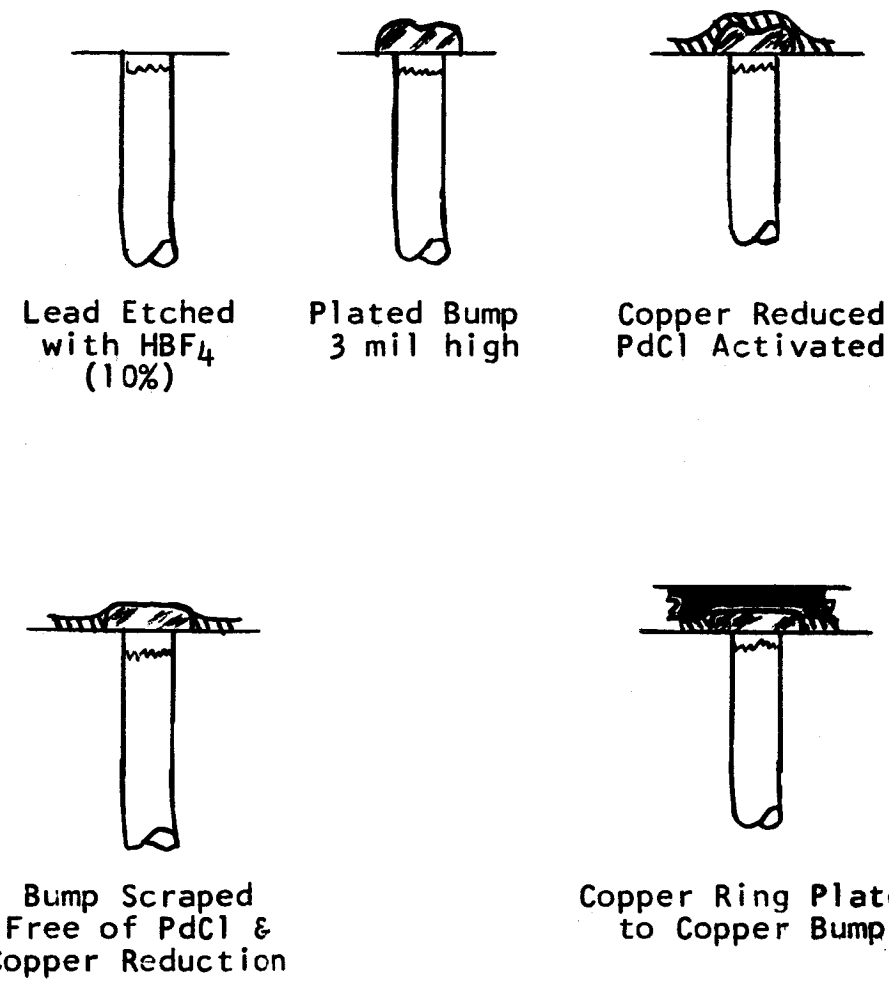


Fig. 3.3.28: Diagrams Showing Lead to Ring Plate

TABLE 3.3-I

Effect of Gold Content, Free KCN Content, and Current Density on 24 Karat Gold Electroplate in Cyanide Bath @ 35°C

Test Number	Current Density Amp/ft^2	Gold Content Troy oz/gal.	CD to Au Ratio	Knoop Hardness Avg. Values at Two Locations		Knoop Hardness Range	Free KCN oz/gal	Observations
L4-F8	5.0	5.5	0.909	110	128	37	7	
L4-18	5.0	7.25	0.690	114	112	28	7	
L4-F9	7.0	5.5	1.27	122	122	0	7	
L5-4A	7.0	7.25	0.933	123	123	5	7	Smooth Good
L5-16	7.0	8.25	0.845	123	122	5	7	Some bumps
L5-6A	7.0	9.0	0.778	116	124	24	7	Many bumps
L5-39	7.0	10.0	0.70				6	
L5-38	7.0	11.0	0.64				6	
L5-37	7.0	12.0	0.59				6	
L5-34	5.0	10.0	0.50				6	
L5-35	5.0	11.0	0.46				6	
L5-36	5.0	12.0	0.42				6	
L5-12	8.0	7.25	1.14	121	121	7	7	Smooth Good
L5-10	8.0	8.25	0.970	124	127	8	7	Smooth Good
L5-14	8.0	9.0	0.889	132	121	17	7	Smooth Good
L5-17	8.0	10.0	0.80	125	119	14	7	Some bumps
L5-28	8.0	11.0	0.727	124	123	13	7	Bumps

(continued)

TABLE 3.3-I (Cont'd)

Test Number	Current Density Amp/ft^2	Gold Content Troy oz/gal.	CD to Au Ratio	Knoop Hardness Avg. Values at Two Locations		Knoop Hardness Range	Free KCN oz/gal.	Observations
L5-13	9.5	7.25	1.36	123	125	7	7	Cracked
L5-11	9.5	8.25	1.15	129	130	10	7	Smooth Good
L5-15	9.5	9.0	1.06	125	125	3	7	Smooth Good
L5-18	9.5	10.0	0.950	127	125	16	7	Smooth Good
L5-21	9.5	11.0	0.864	124	127	8	7	Some bumps
L5-20	11.0	9.0	1.22	124	122	10	7	Smooth Good
L5-19	11.0	10.0	1.10	120	120	5	7	Smooth Good
L5-22	11.0	11.0	1.0	115	121	17	7	Smooth Good
L5-30	11.0	12.0	0.971	127	126	9	7	Smooth Good
L5-23	12.5	9.0	1.39	129	130	21	7	Cracked
L5-24	12.5	10.0	1.25	130	124	15	7	Smooth Good
L5-25	12.5	11.0	1.14	124	126	6	7	Smooth Good
L5-31	12.5	12.0	1.042	128	129	12	7	Smooth Good
L5-26	14.0	10.0	1.40	128	126	9	7	Smooth Good
L5-27	14.0	11.0	1.27	129	128	6	7	Smooth Good
L5-32	14.0	12.0	1.16	128	132	9	7	Cracked
L5-29	15.5	11.0	1.409	128	129	12	7	Cracked
L5-33	15.5	12.0	1.292	124	123	16	7	Cracked

(continued)

TABLE 3.3-I (Cont'd)

Test Number	Current Density Amp/ft^2	Gold Content Troy oz/gal.	CD to Au Ratio	Knoop Hardness Avg. Values at Two Locations	Knoop Hardness Range	Free KCN oz/gal	Observation
L6-1	10.5	10.0	1.05	129	22	0	Cracked
L6-2	10.5	10.0	1.05	130	15	2	Smooth Good
L6-3	10.5	10.0	1.05	125	9	4	Smooth Good
L6-4	10.5	10.0	1.05	122	5	6	Smooth Good
L6-5	10.5	10.0	1.05	122	7	8	Smooth Good
L6-6	10.5	10.0	1.05	123	15	10	Smooth Good
L6-7	10.5	10.0	1.05	128	18	12	Dark Rough
L6-8	10.5	10.0	1.05	119	22	14	Dark Rough
L6-9	8.0	10.0	0.8	113	19	6	Many bumps
L6-10	9.0	10.0	0.9	116	22	6	Few bumps
L6-11	11.5	10.0	1.15	121	9	6	
L6-12	14.0	10.0	1.40	122	9	6	
L6-13	11.0	13.0		125	12	3	Cracked
L6-14	11.0	13.0		128	4	3	Cracked
L6-15	12.5	13.0		126	8	3	Smooth Good
L6-16	10.5	8.0		121	11	6	Smooth Good
L6-17	10.5	9.0		124	12	6	Smooth Good
L6-18	10.5	9.5		128	12	6	Smooth Good
L6-19	10.5	10.5		124	17	6	Few bumps
L6-20	10.5	11.0		125	6	6	Bumps
L6-21	10.5	12.0		117	10	6	Many bumps

TABLE 3.3-II

Data on Test to Determine the Interrelationship of
Temperature, Gold Content and C.D. on 24 Karat Gold Electroplate

Test Number	Current Density Amp/ft^2	Gold Content Troy oz/gal.	CD to Au Ratio	Knoop Hardness Average Value	Temperature °C	KCN Content Oz/gal.	Observations
L7-2	12.5	10.0	1.25	132	25	7.0	Cracked
L7-3	12.5	8.25	1.50	130	25	7.0	Cracked
L7-5	9.5	10.0	0.95	130	25	7.0	Cracked
L7-6	9.5	8.25	1.14	138	25	7.0	Cracked
L7-7	8.0	10.0	0.80	131	25	7.0	Cracked
L7-9	7.0	8.25	0.85	138	25	7.0	Cracked
L7-10	12.5	12.0	1.04	127	30	7.0	Cracked
L7-11	12.5	10.0	1.25	134	30	7.0	Cracked
L7-12	12.5	8.25	1.50	139	30	7.0	Cracked
L7-13	9.5	12.0	0.79	118	30	7.0	
L7-14	9.5	10.0	0.95	128	30	7.0	Smooth Good
L7-15	9.5	8.25	1.14	132	30	7.0	Cracked
L7-16	7.0	8.25	0.85	122	30	7.0	Smooth Good
L7-17	8.0	10.0	0.80	124	30	7.0	Good
L7-18	15.1	12.0	1.26	127	30	7.0	Cracked
L7-28	12.5	12.0	1.04	126	45	7.0	Bumps
L7-29	12.5	10.0	1.25	126	45	7.0	Few Bumps

(continued)

TABLE 3.3-II (Continued)

Test Number	Current Density Amp/ft^2	Gold Content Troy oz/gal.	CD to Au Ratio	Knoop Hardness Average Value	Temperature °C	KCN Content Oz/gal.	Observations
L7-30	12.5	8.25	1.50	123	45	7.0	Cracked
L7-31	9.5	12.0	0.79	124	45	7.0	Many bumps
L7-32	9.5	10.0	0.95	118	45	7.0	Many bumps
L7-33	9.5	8.25	1.14	121	45	7.0	Few bumps
L7-34	7.0	8.25	0.85	121	45	7.0	Bumps
L7-35	8.0	10.0	0.80	117	45	7.0	Bumps
L7-36	15.5	12.0	1.29	131	45	7.0	Cracked
L7-37	12.5	12.0	1.04	127	40	7.0	Smooth Good
L7-38	12.5	10.0	1.25	131	40	7.0	Smooth Good
L7-39	12.5	8.25	1.50	129	40	7.0	Cracked
L7-40	9.5	12.0	0.79	122	40	7.0	Few bumps
L7-41	9.5	10.0	0.95	124	40	7.0	Good
L7-42	9.5	8.25	1.14	127	40	7.0	Good
L7-43	7.0	8.25	0.85	120	40	7.0	Few bumps
L7-44	8.0	10.0	0.80	128	40	7.0	Bumps
L7-45	15.5	12.0	1.29	131	40	7.0	Cracked

See Table 3.3 - I for 35°C Plating and observations.

TABLE 3.3-III

Data Obtained while Studying the Electrodeposition of 24 Karat Gold from Two Acid Baths supplied by Technic Corporation

Name	Current Density	Temperature °C	Knoop Hardness	Observations
Orosene	2	60	49 - 70	---
Orosene	3	60	32 - 86	---
Orosene	4	60	44 - 124	---
Orotherm	2	60	49 - 165	---
Orotherm	3	60	92 - 153	---
Orotherm	4	60	112 - 194	---

TABLE 3.3-IV

Data Obtained while Studying the Effects of Cathode Configuration on the Physical Characteristics of 24 Karat Gold Electrodeposited from Cyanide Baths @ 35° C (Slip Rings)

Part Number	Current Density	Gold Content	KCN Content	CD to Au Ratio	Knoop Hardness	Observations
DP 1300	7.0	6.0	5.0	1.2		Cracked
DP 1300	7.0	7.25	4.0	1.03		One ring cracked on machining
C 282	10.5	10.0	6.0	1.05	120	Good plate
C 282	10.5	10.0	6.0	1.05	125	Good plate
C 282	10.5	10.0	6.0	1.05	129	Good plate
C 282	10.5	10.0	6.0	1.05	125	Good plate
C 282	10.5	10.0	6.0	1.05		Did not complete plating
C 282	10.5	10.0	6.0	1.05		Did not complete plating
C 282	10.5	10.0	6.0	1.05		Did not complete plating

TABLE 3.3-V

Data Obtained on Test to Determine
Effect of Agitation on 24 Karat Gold Electroplate in
Cyanide Bath @ 35°C

Specimen Number	Agitation Propeller @ 60 RPM	Gold Content Troy oz/gal.	Current Density Amps/ft^2	Avg. Knoop Hardness	Free KCN oz/gal.	Observations
L10-1	Yes	10.0	8	120.8	7	Some bumps
L10-2	Yes	10.0	9	121.2	7	Few bumps
L10-3	Yes	10.0	10	120.8	7	Smooth Good
L10-4	Yes	10.0	11	125.5	7	Smooth Good
L10-5	Yes	10.0	12	122.6	7	Some roughness
L10-6	Yes	10.0	13	128.6	7	Rough
L10-7	Yes	10.0	14	127.7	7	Rough Dark
L10-8	No		15.5			Cracked
L10-9	No		17			Cracked

TABLE 3.3-VI

Data on Test to Determine the Effect of Cathode Configuration and Size on 24 Karat Electroplate in Cyanide Bath @ 35°C

Specimen Number	Current Density $Amps/ft^2$	Gold Content Troy oz/gal.	Free KCN Oz/gal.	Average Knoop Hardness	Rod Size	Observations	
L8-1	9.0	10.0	8.28	125	0.125	Smooth	Good
L8-2	9.5	10.0	8.28	121.7	0.125	Smooth	Good
L8-3	10.0	10.0	8.28	124.7	0.125	Smooth	Good
L8-4	10.5	10.0	8.28	124	0.125	Smooth	Good
L8-5	11.0	10.0	8.28	121.7	0.125	Smooth	Good
L8-6	10.0	10.0	5.0	119	0.125	Smooth	Good
L8-7	10.0	10.0	7.0	119.3	0.125	Smooth	Good
L8-8	10.0	9.0	7.0		0.125	Smooth	Good
L8-9	10.0	11.0	7.0	123.7	0.125	Smooth	Good
L8-10	9.0	10.0	7.0	128.2	0.375	Smooth	Good
L8-11	10.0	10.0	7.0	121.7	0.375	Smooth	Good
L8-12	11.0	10.0	7.0	124.2	0.375	Smooth	Good

TABLE 3.3-VII

Data on Test to Determine the Effect of pH
on 24 Karat Electroplate in Cyanide Bath @ 35°C

Specimen Number	pH Lowered throughout with H_3PO_4	Gold Content Troy oz/gal.	Free KCN Oz/gal.	Average Knoop Hardness	Current Density$_2$ Amps/ft^2	Observations
L9-1	11	10.0	7	128.8	10	Some bumps
L9-2	10	10.0	7	124.3	10	Smooth Good
L9-3	9	10.0	7	132.9	10	Smooth Dark
L9-4	8	10.0	7	126.5	10	Smooth Good
L9-5	7	10.0	7	126.7	10	Smooth Good
L9-6	6	10.0	7	124.3	10	Smooth Good
L9-7	5*	10.0	7	133.0	10	Smooth Good
L9-8	5	10.0	7	138.8	10	Smooth Good
L9-9	9	10.0	7	123.8	10	Smooth Good
L9-10	7	10.0	7	129.7	10	Bumps
L9-11	5	10.0	7	129.8	10	Smooth Good
L9-12	3	10.0	7	126.3	10	Smooth Good

(*) Less than

TABLE 3.3-VIII

ANODE SAMPLES

SAMPLE	CONDITION	CUT	SIZE	KHN
1A	Fully Annealed	Parallel	1/32" x 1/2" x 4"	46.5
1B	Fully Annealed	Parallel	1/16" x 1/2" x 4"	56.4
1C	Fully Annealed	Parallel	3/32" x 1/2" x 4"	58.0
2A	60% Cold rolled	Parallel	1/32" x 1/2" x 4"	83.2
2B	60% Cold rolled	Parallel	1/16" x 1/2" x 4"	82.2
2C	60% Cold rolled	Parallel	3/32" x 1/2" x 4"	83.2
3A	30% Cold rolled	Parallel	1/32" x 1/2" x 4"	70.2
3B	30% Cold rolled	Parallel	1/16" x 1/2" x 4"	73.8
3C	30% Cold rolled	Parallel	3/32" x 1/2" x 4"	73.6
4	Purchased	Transverse	1/16" x 1/2" x 4"	82.3
5	Test Annealed	Transverse	1/16" x 1/2" x 4"	70.6
6	Test Annealed	Transverse	1/16" x 1/2" x 4"	54.2
7	Specified	Parallel	1/8" x 1/2" x 3"	59.7

NOTES: Two anodes of each size and condition were used in each test. The samples of anodes, numbered 4, 5 and 6, are all from a shipment received from Goldsmith Brothers for production use, and were originally of the same heat treat condition. These were added to this study as a result of our experience with anode erosion peculiarities during production plating. This was reported in the February Progress Report.

The sample anodes, numbered 7, were from a shipment which was received March 23, 1964 from Goldsmith Brothers. These were ordered to the specification of a parallel to grain cut and maximum KHN of 60. These were included in this study after we obtained good results from their use in electroforming rings for 80 circuit assemblies.

TABLE 3.3-IX

Solution Composition After Plating

Sample Number	Composition	Hours				
		0	2	4	8	16
1A	Au	9.35	9.55	9.36	9.45	9.31
	Free KCN	6.05	5.71	5.78	5.58	5.65
	K_2CO_3	0.1	----	----	----	0.38
1B	Au	10.10	10.49	10.88	10.74	10.66
	Free KCN	6.68	6.61	6.25	6.30	6.20
	K_2CO_3	0.1	----	----	----	0.38
1C	Au	8.83	8.83	8.80	10.25	8.93
	Free KCN	6.40	6.39	6.23	5.47	6.05
	K_2CO_3	0.1	----	----	----	0.63
2A	Au	10.0	10.50	9.76	9.42	9.27
	Free KCN	6.68	6.68	6.83	7.03	7.11
	K_2CO_3	0.1	----	----	----	0.38
2B	Au	10.10	10.00	10.44	10.59	10.29
	Free KCN	6.68	6.64	6.44	6.34	6.35
	K_2CO_3	0.1	----	----	----	0.41
2C	Au	8.83	9.27	8.98	9.07	9.27
	Free KCN	6.40	5.85	5.99	5.92	5.76
	K_2CO_3	0.1	----	----	----	0.68
3A	Au	9.91	9.06	9.17	9.27	9.47
	Free KCN	6.54	6.78	6.64	6.52	6.34
	K_2CO_3	0.1	----	----	----	0.46
3B	Au	9.98	9.08	9.32	9.40	9.76
	Free KCN	6.82	7.06	6.99	6.79	6.42
	K_2CO_3	0.1	----	----	----	0.46
3C	Au	10.12	11.50	11.80	11.27	10.75
	Free KCN	7.12	6.26	6.24	6.17	6.40
	K_2CO_3	0.1	----	----	----	0.53
4	Au	10.60	----	----	----	7.50
	Free KCN	6.96	----	----	----	5.50
	K_2CO_3	0.1	----	----	----	2.3

(continued)

TABLE 3.3-IX (Cont'd)

Sample Number	Composition	Hours				
		0	2	4	8	16
5	Au	11.66	11.37	11.61	11.68	11.74
	Free KCN	7.17	7.30	7.03	6.98	6.90
	K_2CO_3	0.1	----	----	----	0.46
6	Au	11.66	11.32	11.47	11.67	12.90
	Free KCN	7.17	7.30	7.21	7.03	6.38
	K_2CO_3	0.1	----	----	----	0.46
7	Au	11.66	10.98	11.76	11.76	11.78
	Free KCN	7.17	7.48	7.17	7.09	6.90
	K_2CO_3	0.1	----	----	----	0.53

TABLE 3.3-X

Ratio of Current Density (C.D.)in Amperes per Square Foot (a.s.f.) to the Gold (Au) Content in Troy Ounces / Gal.

Sample	After Plating for Hours					Max. Change in Ratio	Cut	Thickness	KHN
	0	2	4	8	16				
1A	0.96	0.94	0.96	0.95	0.97	0.03	Parallel	1/32"	46.5
1B	0.89	0.86	0.83	0.84	0.84	0.06	Parallel	1/16"	56.4
1C	1.02	1.02	1.02	0.88	1.01	0.14	Parallel	3/32"	58.0
2A	0.89	0.86	0.92	0.95	0.97	0.11	Parallel	1/32"	83.2
2B	0.89	0.90	0.86	0.85	0.86	0.05	Parallel	1/16"	82.2
2C	1.02	0.97	1.00	0.99	0.97	0.05	Parallel	3/32"	83.2
2A	0.91	0.99	0.98	0.97	0.95	0.08	Parallel	1/32"	70.2
3B	0.90	0.99	0.97	0.96	0.92	0.09	Parallel	1/16"	73.8
3C	0.89	0.78	0.76	0.80	0.84	0.13	Parallel	3/32"	73.6
4	0.85	----	----	----	1.20	0.35	Transver.	1/16"	82.3*
5	0.77	0.79	0.78	0.77	0.77	0.02	Transver.	1/16"	70.6*
6	0.77	0.80	0.78	0.77	0.70	0.10	Transver.	1/16"	54.2
7	0.77	0.82	0.77	0.77	0.77	0.05	Parallel	1/8"	59.7

(*) Considerable undissolved gold particles visible on the bottom of the plating solution at the end of the test.

TABLE 3.3-XI

Tensile Testing Data

Electrodeposit Sample Number	Thickness (Inches)	Width (Inches)	Cross-Sec. Area (Sq. In.)	Ultimate Tensile Strength		Elastic Modulus (PSI x 10^6)
				Lbs.	PSI	
1	.0069	.500	.00345	77.0	22,300	2.0
2	.0061	.500	.00305	103.0	33,800	4.6
3	.0030	.500	.00150	43.0	28,700	5.0
4	.0029	.500	.00147	42.5	28,900	4.5
5	.0033	.500	.00164	49.5	30,200	2.7
6	.0050	.374	.00187	50.5	27,000	7.2
7	.0043	.363	.00156	39.25	25,200	8.4
8	.0046	.374	.00172	35.9	20,900	7.8
9	.0050	.375	.00188	42.7	22,700	8.5

TABLE 3.3-XII

$$S = \frac{E_b t(t+Rd)}{6\,rd} \quad \text{and} \quad R = L^2 / 2Z' \text{ if } Z' \ll 20\%L$$

PARAMETER	SAMPLE NUMBER																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
L	3.03	3.05	3.00	2.98	3.02	3.00	3.00	3.00	3.00	3.06	3.03	3.05	2.99	3.00	3.04	2.98	2.78	2.86	2.85
20%L	.606	.610	.600	.596	.604	.600	.600	.600	.600	.612	.606	.610	.598	.600	.608	.596	.556	.572	.570
L^2	9.18	9.30	9.00	8.88	9.12	9.00	9.00	9.00	9.00	9.36	9.18	9.30	8.94	9.00	9.24	8.88	7.73	8.18	8.12
Z'	.2638	.2205	.1890	.1654	.1457	.0472	.0433	.0472	.0433	*.6772	*.6654	*.6811	*.6400	.2756	.1339	.2441	.0354	.0354	.0276
2Z'	.5276	.4410	.3780	.3308	.2914	.0944	.0866	.0944	.0866	1.3544	1.3308	1.3622	1.2800	.5512	.2678	.4882	.0708	.0708	.0552
r	17.40	21.09	23.81	26.84	31.30	95.34	103.93	95.34	103.93	6.91	6.90	6.83	6.98	16.33	34.50	18.19	109.18	115.54	147.10
Avg. t****	.0220	.0221	.0135	.0131	.0134	.0500	.0500	.0500	.0500	.0130	.0131	.0131	.0230	.0128	.0520	.0128	.1002	.0997	.1012
Width	.500	.500	.500	.500	.500	.374	.363	.374	.375	.500	.500	.500	.500	*‡‡.500	.500	*‡‡.500	.500	.500	.500
d	.0069	.0061	.0030	.0029	.0033	.0050	.0049	.0050	.0055	.0133	.0120	.0114	.0055	.0046	.0042	.0057	***.0093	.0040	.0042
$E_b(X10^6)$	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	15	2.87	2.87	2.87
$E_c(X10^6)$	8	8	8	8	8	7.2	8.4	7.8	8.5	8	8	8	8	8	8	8	8	8	8
$R=E_c/E_b$	.4706	.4706	.4706	.4706	.4706	.4235	.4941	.4588	.5000	.4706	.4706	.4706	2.7875	.5333	2.7875	.5333	2.7875	2.7875	2.7875
**d/t	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	1.0	0.9	0.9	0.2	0.4	0.1	0.4	0.09	0.04	0.04
S(PSI)	13,100	12,200	8,000	6,900	5,500	15,500	14,600	15,500	13,000	7,700	8,400	8,800	11,000	6,500	11,000	4,900	6,000	11,000	8,800

* Z' is greater than 20%L but should be much less than 20%L for accuracy.
** d/t should be .05 or less for accuracy.
*** d ranges from 7.8 mils to 11.0 mils.
**** greatest range from top to bottom of t is +.0056".
***** the basis strip was wider than the electrodeposit at 5/8".

TABLE 3.3-XIII

DEFLECTION DATA ON STRESS SAMPLES

SAMPLE NUMBER	BASIS STRIP			GOLD ELECTRODEPOSIT		TOTAL DEFLECTION
	MATERIAL	THICKNESS	MODULUS	THICKNESS	MEASURED MODULUS	
1	Copper	.0220 in.	17×10^6 psi	.0069 in.	*2.0×10^6 psi	.2638 in.
2	Copper	.0221 in.	17×10^6 psi	.0061 in.	*4.6×10^6 psi	.2205 in.
3	Copper	.0135 in.	17×10^6 psi	.0030 in.	*5.0×10^6 psi	.1890 in.
4	Copper	.0131 in.	17×10^6 psi	.0029 in.	*4.5×10^6 psi	.1654 in.
5	Copper	.0134 in.	17×10^6 psi	.0033 in.	*2.7×10^6 psi	.1457 in.
6	Copper	.0500 in.	17×10^6 psi	.0050 in.	7.2×10^6 psi	.0472 in.
7	Copper	.0500 in.	17×10^6 psi	.0049 in.	8.4×10^6 psi	.0433 in.
8	Copper	.0500 in.	17×10^6 psi	.0050 in.	7.8×10^6 psi	.0472 in.
9	Copper	.0500 in.	17×10^6 psi	.0055 in.	8.5×10^6 psi	.0433 in.
10	Copper	.013 in.	17×10^6 psi	.0150 in.	---	.6772 in.
11	Copper	.013 in.	17×10^6 psi	.0150 in.	---	.6654 in.
12	Copper	.013 in.	17×10^6 psi	.0150 in.	---	.6811 in.
13	E.S.218	.022 in.	2.9×10^6 psi	.0060 in.	---	.3898 in.**
14	Brass	.013 in.	2.9×10^6 psi	.005 in.	---	.2756 in.
15	E.S.218	.050 in.	2.9×10^6 psi	.005 in.	---	.1339 in.
16	Brass	.013 in.	2.9×10^6 psi	.005 in.	---	.2441 in.
17	E.S.218	.100 in.	2.9×10^6 psi	.005 in.	---	.0354 in.
18	E.S.218	.100 in.	2.9×10^6 psi	.005 in.	---	.0354 in.
19	E.S.218	.100 in.	2.9×10^6 psi	.005 in.	---	.0276 in.

(*) Questionable value
(**) .640 - Extrapolated

APPENDIX 3.3-II

PROCEDURES

POLY-SCIENTIFIC DIVISION
LITTON PRECISION PRODUCTS, INC.

LABORATORY PROCEDURE

Procedure No. 132 Rev. 0

Issued May 12, 1964

Revised _____

TITLE: GOLD ANALYSIS OF 24-K Bath

1. PURPOSE

The purpose of this test is to determine the amount of gold in a cyanide plating solution.

2. SAFETY PRECAUTIONS

In addition to the usual laboratory precautions; when adding the concentrated H_2SO_4, and when heating the flasks - must be under an exhaust hood.

3. EQUIPMENT AND MATERIALS

3.1 Water, distilled or deionized, per P-S E.S. No 88.

3.2 Pipette - transfer (capacity 25 ml.).

3.3 500 ml. flask (narrow neck and vial mouth).

3.4 17 ml. crucible.

3.5 Crucible tongs.

3.6 Hot Plate (heats 700°F) operates on 115 volts A.C.

3.7 Funnel - 6" stem, 60° angle and diameter 65 mm.

3.8 Filter paper - Whatman, No. 42 (Dia. 12.5 cm., and max. ash per circle 0.00012 grams).

3.9 Muffle Furnace - Pyrometer calibarated in 50° increments to 2000°F and 1000°C. Operates on 115 volt A.C.

3.10 Two (2) 600 ml. beakers.

3.11 3" diameter watch glass.

3.12 100 ml. graduated glass cylinder.

3.13 Concentrated (H_2SO_4) acid 95.0% min. - 98.09 max.

3.14 Gram-atic balance.

4. PROCEDURE

4.1 Heat plating solution under an exhaust hood, and stir, making sure that all crystals are in solution.

4.2 Pipette 25 ml. sample of plating solution into 500 ml. flask.

4.3 Add 25 ml., of concentrated H_2SO_4 <u>under the exhaust hood</u>.

4.4 Heat (under exhaust hood) until the solution clears and gold coagulates.

4.5 Add 125 ml. distilled water after flask has cooled for few minutes and filter through a #42 Whatman filter paper.

4.6 Rinse flask with distilled H_2O and filter mixture, making sure all gold particles have been removed.

4.7 Weigh crucible, then put filter paper and gold residue into the crucible and heat in furnace under exhaust hood until filter paper is ashed.

4.8 Cool and weigh crucible to determine weight of gold.

5. CALCULATIONS

Multiply weight of gold in grams by 4.88 to determine troy ounces/ gallon of Au when using standard liter of total solution.

POLY-SCIENTIFIC DIVISION
LITTON PRECISION PRODUCTS, INC.

LABORATORY PROCEDURE

Procedure No. 133 Rev. 0

Issued May 13, 1964

Revised _____

TITLE: ANALYSIS OF POTASSIUM OR SODIUM CARBONATE IN A CYANIDE 24-K GOLD BATH

1. PURPOSE

To determine the amount of carbonates in a plating solution.

2. SAFETY PRECAUTION

In addition to the usual laboratory precaution, heat sample under an exhaust hood and wash hands immediately after analysis.

3. EQUIPMENT AND MATERIALS

3.1 10 ml., Pipette

3.2 Two (2) 250 ml. Erlenmeyer flask.

3.3 Distilled water, per P-S E.S. No. 88.

3.4 Hot plate

3.5 10% Barium Nitrate solution

3.6 100 ml. graduated cylinder

3.7 Funnel - 6" stem 60° angle and diameter 65 mm.

3.8 Filter paper - Whatman, No. 42, (diameter 12.5 cm., and maximum ash per circle 0.00012 grams).

3.9 Methyl Orange Indicator solution (0.1%).

3.10 1.0 Normal HCl acid

3.11 Glass stirring rod

3.12 Automatic Buret subdivided to 1/10 ml., capacity 10 ml. with reservoir bottle attached.

4. PROCEDURES

4.1 Heat and stir plating solution.

4.2 Pipette 10 ml., of plating solution into a 250 ml. Erlenmeyer flask.

4.3 Add approximately 100 ml. distilled water.

4.4 Heat to approximately 140°F.

4.5 Add 25 ml. of 10% Barium Nitrate solution.

4.6 Let stand for at least 20 minutes.

4.7 Filter, using #42 Whatman paper catching the filtrate in another 250 ml. flask.

4.8 Test filtrate with 1 ml. of the Barium Nitrate solution.

4.9 If a dense white precipitate occurs, heat, add 20 ml. more of the Barium Nitrate solution and refilter.

4.10 Wash the flask and precipitate at least six (6) times with hot distilled water, filling the filter paper to the top.

4.11 Transfer the filter paper and precipitate back into original 250 ml. flask.

4.12 Add approximately 25 ml. of water and five (5) drops of methyl orange indicator solution.

4.13 Titrate with 1.0 N HCl acid until the color changes to pink and does not change back on shaking and stirring.

5. CALCULATIONS

Na_2CO_3 present (number of ml. of acid used) X 0.706 = oz/gal.

K_2CO_3 present (number of ml. of acid used) X 0.924 = oz/gal.

POLY-SCIENTIFIC DIVISION
LITTON PRECISION PRODUCTS, INC.

LABORATORY PROCEDURE

Procedure No. 134 Rev. 0

Issued May 13, 1964

Revised _____

TITLE: CYANIDE ANALYSIS OF 24-K BATH

1. PURPOSE

To determine amount of free Potassium Cyanide in a cyanide plating solution.

2. SAFETY PRECAUTIONS

Cyanide analysis should be made under an exhaust hood and hands washed thoroughly immediately after analyses.

3. EQUIPMENT AND MATERIALS

3.1 125 ml. flask (Erlenmeyer)

3.2 10 ml. pipette (measured in 1/2 ml. increments)

3.3 25 ml. graduated cylinder

3.4 One (1) liter of 10% KI and 0.1% KOH, indicator solution, 100 grams KI and 1 gram of KOH in enough distilled water to make one (1) liter of solution.

3.5 One (1) liter of 0.1 N. Silver Nitrate - 17 grams of $AgNO_3$ in enough distilled water to make one (1) liter of solution.

3.6 Automatic buret subdivided to 1/10 ml., capacity 10 ml. with brown bottle.

3.7 Medicine dropper (0.5 - 1.0 ml. capacity)

3.8 Distilled water

4. PROCEDURE

4.1 Heat and stir to make sure cyanide is in solution.

4.2 Pipette 2.5 ml. sample of plating solution into a 125 ml. flask.

4.3 Add 25 ml. of distilled water.

4.4 Add two (2) droppersfull of 10% KI and 0.1% KOH indicator solution, and shake.

4.5 Titrate with 0.1 N. Silver Nitrate until a light yellow precipitate remains after shaking thoroughly.

5. CALCULATION

Multiply ml. of $AgNO_3$ used by 0.696 to get ounces/gallon of free potassium cyanide.

SAMPLE CALCULATIONS

This section contains examples of all calculations used in studying the deposition of 24 karat gold plate.

Current Calculations - The following method was used to calculate the current where the desired current density was known.

$$\frac{(\text{Area of Cathode, in.}^2)(\text{Current density, amps/ft}^2) = \text{amps}}{\text{in.}^2/\text{ft}^2}$$

e.g.: Cathode diameter = 0.256 inch

Length of plated area = 1.5 inches

Current density = 12.5 amps/ft^2

$$\frac{(\pi)\ (0.256)(1.5)\ (12.5)}{(144)} = 0.1047 \text{ amps}$$

Gold Concentration in Plating Solution - The following method was used to calculate the amount of $KAu(CN)_2$ to be added to a plating bath to give a desired gold concentration.

$$\frac{(\text{Desired gold conc., troy oz/gal.})(\text{solution volume, liters})}{(\%\text{ gold in } KAu(CN)_2)\ \frac{(\text{troy oz/gal.})}{(\text{grams/liter})}} = \text{grams } KAu(CN)_2$$

e.g.: Desired gold concentration = 8.0 oz/gallon

Liters desired = 0.2 liters

% Au in $KAu(CN)_2$ = 0.67%

Conversion factor = 0.122 troy $\frac{\text{oz/gallon}}{\text{grams/liter}}$

$$\frac{(8)(0.2)}{(0.67)(0.122)} = 19.58 \text{ grams } KAu(CN)_2$$

Free Cyanide Concentration in Plating Solution - The following method was used to calculate the amount of KCN to add to a plating solution to give a desired free cyanice concentration.

$$(\text{Free Cyanide oz/gal.})(\text{volume of bath, liters})\frac{(\text{grams/L})}{(\text{oz/gal.})} = \text{grams KCN}$$

e.g.: Desired free cyanide = 5.0 oz/gal.

Volume = 0.2 liters

Conversion factor = 7.5 grams/liter

$(5)(0.2)(7.5) = 7.5$ grams KCN

SPECIAL PROCEDURES

This section contains several special procedures used in these studies not normally encountered in ordinary laboratory work.

Preparation of Rods to be used as cathodes - Engineering Specification No. 84 plastic was molded into 1/4" diameter rods. These were cut into 3 inch sections and a groove which corresponded with the diameter of a #21 copper wire was cut 1-1/2 inches down the side. The wire was inserted in the groove and about 6" of bare wire extended beyond the end of the rod. The rod was then cleaned with pumice and water and gold reduced to produce a conductive cathode (see Figure 3.3.18).

Gold Reduction - A thin film of gold was deposited on each of the above plastic rods from a gold chloride solution containing 0.388 percent gold by weight. This solution was prepared by dissolving a piece of pure gold in aqua regia ($3HCl:1HNO_3$). The solution was heated to increase the reaction rate. After the reaction reached completion, a large volume of distilled water was added and the solution was boiled to remove all excess HCl (about 48 hours). After removing the HCl the solution was diluted to the correct volume. Other solutions used included a 0.5 normal solution of $NaCO_3$ used as a buffer and a 2% solution of formaldehyde.

An equal quantity of buffer and gold chloride solution were mixed. About 5 milliliters of the formaldehyde was added for each 100 milliliters of solution. The plastic rod to be coated is then placed in the solution until the reduction reaction is near completion (this is indicated by a change in color of the solution). Often two or three coats of reduction gold are required to give a conductive coating.

Plating Procedure - Anodes were placed in the bath and positioned on stainless steel holders. The cathode rods were immersed in the bath immediately after placing the anodes in the bath. The cathodes and anodes were connected so that a series circuit was made as soon as the cathodes were immersed in the bath (see Figure 3.3.16). The amperage was adjusted to the desired level at the start of the test and usually was not adjusted during the test to account for increased diameter because of the thickness of the deposit.

Analytical Procedure - The gold content was determined by precipitating solid gold from the cyanide bath by adding sulphuric acid. The precipitated gold was filtered, washed, dried and weighed. The free cyanide was determined by titration with silver nitrate.

3.4 GRINDING

3.4.1 Introduction

Poly-Scientific had for many years prior to the initiation of this program produced slip ring sub-assemblies exclusively by a process of casting liquid plastic around precut rings located in machined grooves of a mold. This process had proven more accurate than required by applications to that time. The extreme tolerance limits required by the developments during the program made evident the many sources of inaccuracy inherent in this process. A more accurate method of ring location had to be developed.

Simultaneously, the studies of low expansion plastics (Section 2.3) indicated that highly abrasive fillers would be required in order to match the expansion rates of the various metals. Plastics produced with these abrasive fillers could not be machined practically. A better method of cutting abrasive plastics had to be developed.

Form grinding was investigated and proved to be the method which would solve both problems -- and more. Form grinding was found to be capable of grinding grooves for plating rings with an accumulated tolerance of less than $\pm$ .0005 inches. Grinding could simultaneously cut 50 or more grooves with less danger to fragile plastic barriers. Grooves would have the same spacing from one unit to the next. Grinding techniques offered a method for producing exact duplication of V-groove spacing on both slip ring and brush assemblies.

3.4.2 Process Selection

Grinding was chosen as the method for achieving the Saturn slip ring and brush alignment in order to accomplish the dimensional requirements and because of the choice of plastic material. The highly abrasive filler used in the plastic for dimensional stability is extremely difficult to machine using metal cutting tools. Carbide tools can be used when the nature of the work permits frequent resharpening of the tools.

Plunge cutting a series of grooves in this material, with the longitudinal spacing held to ±.0005 non-accumulative and the root diameters held to .001 with a single point grooving tool, would be completely impractical if not impossible.

Since close tolerances are required for both ring grooves in the plastic of the slip ring and for V-grooving metal in both the slip ring and brush block, a machine was chosen on which both these operations could be accomplished -- the Sheffield form and thread grinder (Model 101). Figure 3.4.1.

3.4.3 Wheel Preparation

A hardened steel multi-ribbed crusher roll is used to produce rectangular grooves in the grinding wheel of precise width and pitch for plunge cutting operations in the slip ring. Crush forming the wheel is accomplished by feeding the idling crusher roll into the slowly revolving (90 RPM) grinding wheel until the crusher roll form penetrates the wheel to the required depth. Figure 3.4.2 (A). As the name implies, the crusher roll actually crushes its form into the wheel by fracturing the grit away from the hard, but friable, vitrified bond. The crushed grit and bonding residue are flushed away by a copious flow of oil. Crushing is the only known method of obtaining the required rectangular grooved wheel configuration.

A multi-ribbed diamond dresser is used to obtain equally precise V-grooves in the wheels used for final machining operations of both slip ring and mating brush block. The dresser consists of a diamond dressing tool held in a geared, cam operated mechanism. The diamond tool shapes the 'V's' into the wheel by shearing the grits as it traverses the configuration across the face of the wheel. Figure 3.4.3 (A) With both the crushed wheel for grinding rectangular grooves and the diamond dressed wheel for 'V' grooving operations, exact duplication can be obtained between sub-assemblies and assemblies. Accumulative spacing between sets of crushed wheels and diamond dressed wheels varies no more than .00015 in/inch. In

Fig. 3.4.1 - SLIP RING GRINDING OPERATION

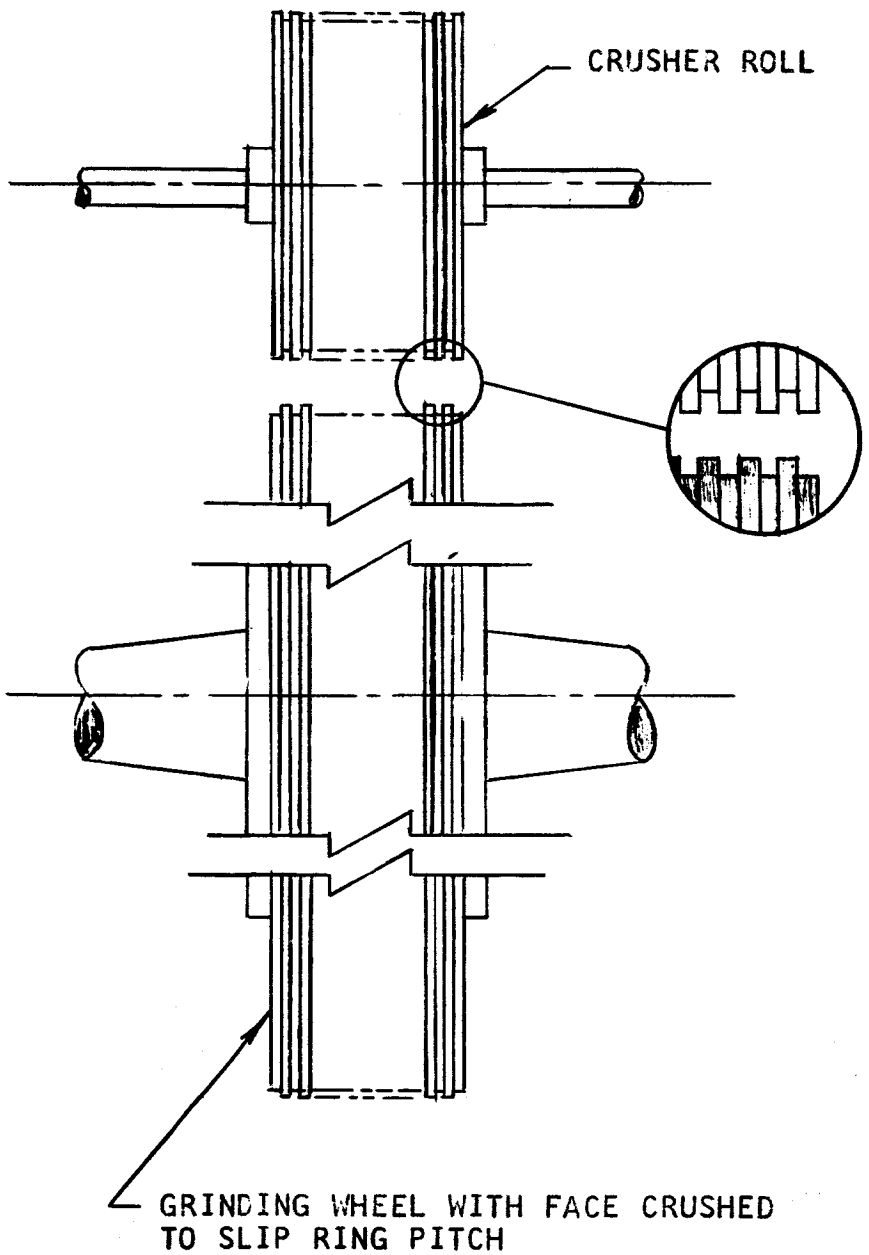


FIG. 3.4.2-A WHEEL CRUSHING

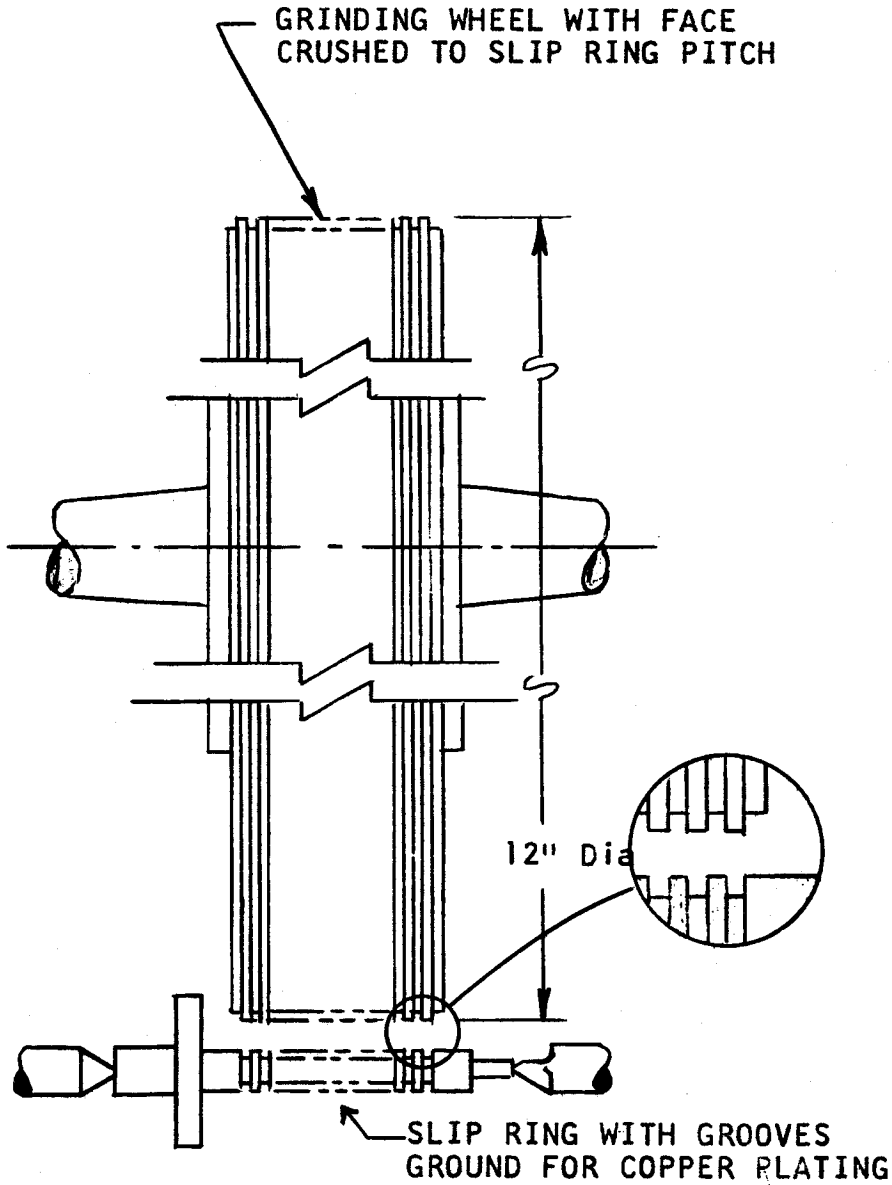


FIG. 3.4.2-B PLASTIC GROOVE GRINDING

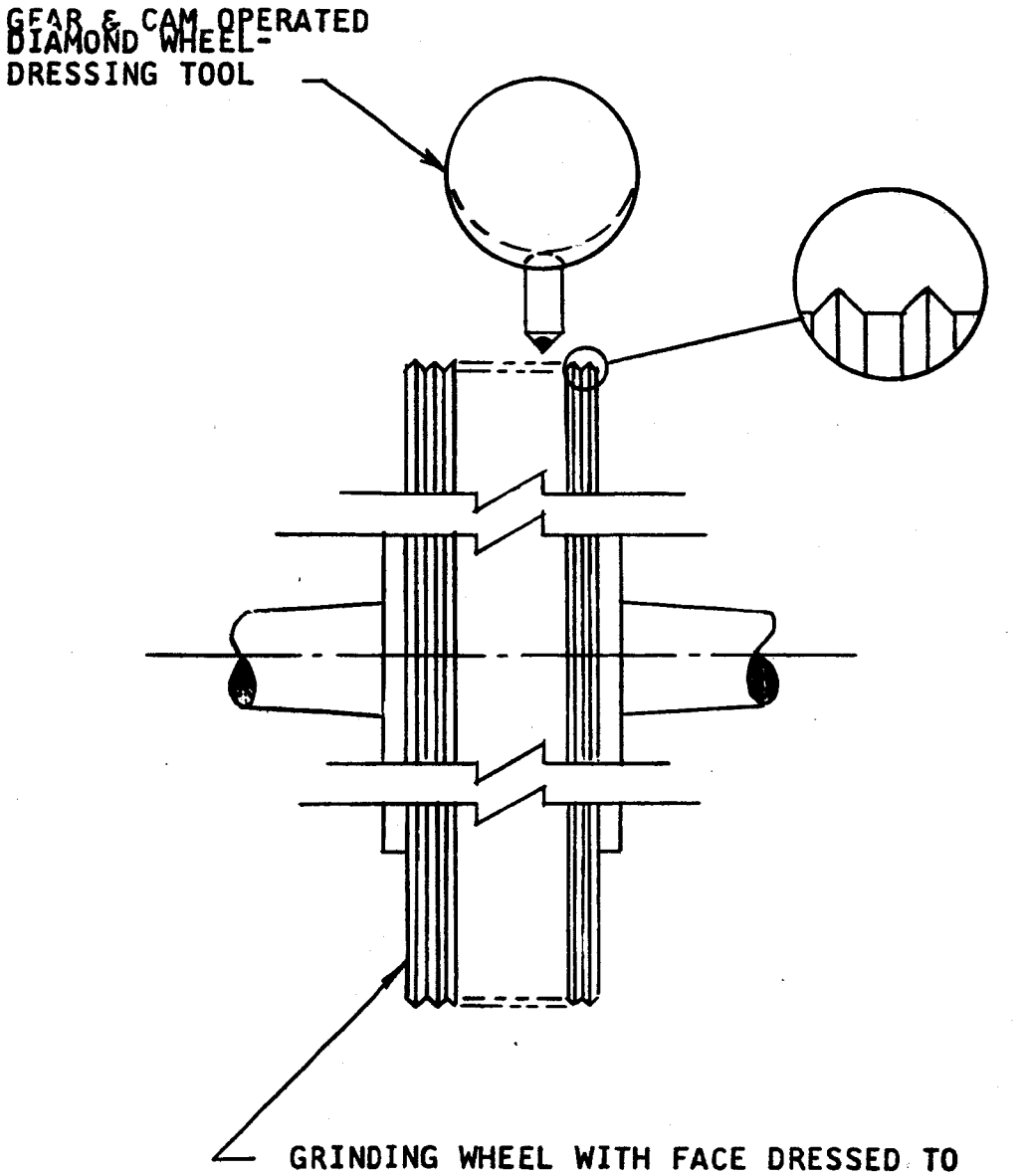


FIG. 3.4.3-A WHEEL DRESSING

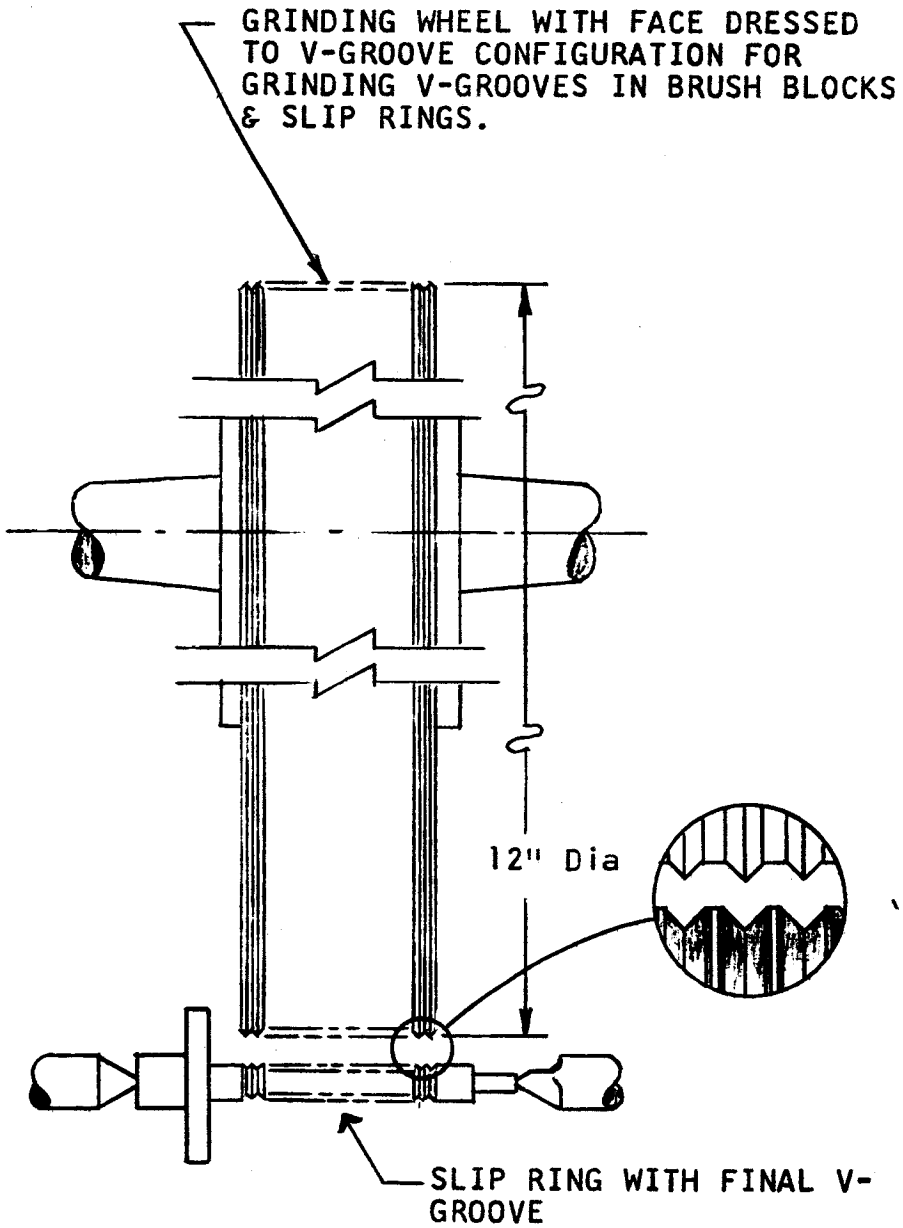


FIG. 3.4.3-B V-GROOVE GRINDING

addition to obtaining more accuracy and better duplication, grinding a series of grooves simultaneously saves considerable machining time.

3.44 Wheel Selection

The crushable grinding wheel which has proven most satisfactory for plunge cutting the plastic is designated by Norton as 32A400 KVG. The fine grain size of the abrasive is essential for obtaining the narrow and relatively high barriers on the wheel and for maintaining sharp corners on the barriers. Figure 3.4.2 (B). A fine grit wheel cuts more slowly than a course wheel; consequently, the wheel must be fed slowly into the work piece to prevent push away of the work piece and the resultant stress on the part as it is ground between centers. The actual in feed is less than .0001" per revolution of work piece.

Grinding wheels containing somewhat courser abrasive grain size have performed best for V-grooving operations in the 24K slip ring gold and the brass junction plates of the brush blocks. Figure 3.4.3 (B). The necessary sharp corners (.001 max. rad.) can be diamond dressed on wheels with 220 grain size, even though the individual grains of abrasive are considerably larger than .002 dia. This wheel maintains the sharp corners satisfactorily and cuts more freely than 400 grit wheel. Grinding wheels with grit coarser than 220 cannot be successfully dressed to the required .001 radius.

3.45 Coolant

The choice of coolant was initially limited by three restrictions: (1) The fluid must be sulfur free to avoid the formation of corrosion in the part. (2) Oil is definitely essential for crushing the narrow deep grooves. (3) All traces of the coolant must be removable from the part before proceeding to subsequent plating operations. Other considerations desirable in the coolant are rapid cooling action, low toxity, lack of tendency to decompose or become rancid, transparency and good

lubricity for critical areas of the machine. Texaco's Cleartex 110' paraffin base oil meets the established requirements for grinding the Saturn parts.

3.4.6 Grinding Gold

The grinding of V-grooves in the plated gold has been and continues to be a problem that has avoided complete solution. Different coolants and grinding wheels tried at the suggestion of manufacturer's specialists in grinding problems have failed to produce any noticeable improvement. Wheels with grit sizes varying from 150 to 400, and bond grades varying in hardness from 'N' to 'Q' have been tried. Dow's Polyglycol E-200, kerosene, castor oil and Solox mixture, paraffin impregnation, and water soluble oil are among the coolants that have been used.

Spasmodic success has been experienced with grinding but at present, the final V-grooving of the slip ring is being accomplished with a diamond tool on a jewelers lathe. This technique does not allow precise duplication; however, by working under 10X magnification on rings that are perfectly spaced by the previously ground grooves, spacing and diameters of the V-grooves can be held well below allowable tolerances.

Specifically, wheel loading is the problem which prevents complete success in grinding the gold rings. A small particle of gold adheres to the wheel and quickly increases in size by a welding action as it contacts the rotating ring. This enlarged bump causes a hammering action which severely damages the ring on which it occurs. The shock imparted to the assembly by the hammering effects the finish on all the other rings in the assembly. Wheel loading has not been a problem with any material other than plated gold. Various gold alloys have been ground with no loading problem.

The Sheffield Corporation has recently developed a device which will probably eliminate the wheel loading problem and allow consistently successful grinding of plated gold. It is called "The Super Jet Wheel Cleaner." The device directs a hi-pressure stream of coolant against the wheel, knocking off the metal bits before

impregnation of the wheel can occur. The use of such a device appears essential to the precise, reliable grinding of V-grooves in the electrodeposited gold.

3.4.7 Summary

Grinding has been developed for the manufacture of Saturn brush blocks and slip rings for two main reasons: (1) Superior dimensional accuracy in both slip ring and brush block resulting in precise brush alignment and (2) the highly abrasive plastic material is virtually impossible to machine other than by grinding.

A hardened steel multi-ribbed crusher roll is used to produce rectangular grooves in the grinding wheel for plunge cutting operations in the slip ring.

A multi-ribbed diamond dresser is used to obtain equally precise V-grooves in the wheel used for final machining operations of both slip ring and mating brush block.

Wheels of very fine abrasive grain size (400) have been found to be best for plunge cutting operations. A 220 grain size wheel has proven most satisfactory for the V-grooving operations. Both wheels are vitrified bonded.

The coolant which has shown most satisfactory results is Texaco's paraffin based oil designated Cleartex 110.

Wheel loading; i.e. particles of gold adhering to the grinding wheel during the final V-grooving operation on the slip ring has been the only problem remaining in the otherwise completely successful grinding operations of the Saturn parts. This is expected to be eliminated by the use of wheel cleaning devices in the near future.

3.5 CLEANING

3.5.1 Introduction

Cleaning has always been recognized in the industry and by Poly-Scientific as a primary concern in the processing of slip ring capsule assemblies. There has been a great deal of emphasis upon the final cleaning of the sub-assemblies and assemblies. In fact, at the outset of this contract, there was too much emphasis on "final" cleaning of a unit after all processing had been completed.

Within this program there has been no one major cleaning study. There have been many small cleaning studies; several for haze (section 3.1), several for plating (section 3.3) and some in connection with grinding (section 3.4). Matte finishing (section 3.6) is in itself both a cleaning and a contaminating process requiring additional specialized cleaning. In short, a major portion of the work in developing highly reliable slip ring capsule assemblies has been the development of cleaning in one form or another.

In this section is contained only an outline of the principles learned and processes developed.

3.5.2 Contamination Nature

Contaminants are any undesired substances on the contact surface which may affect the performance of components within a system. Three general classifications can be made.

3.5.2.1 Inherent Contaminants - Inherent contaminants are those contaminants resulting directly from materials which are intentionally used in the product or in the process of manufacture. In this category would fall the metals (contact and structural), dielectrics (encapsulants, insulations, adhesives), coolants, lubricants, polishes, cleaning agents, and plating chemical residues.

3.5.2.2 Incidental Contaminants - Incidental contaminants which are not planned into the design or manufacturing process. These include airborne materials (dust, lint, vapors), human residues (oils, skin flakes, cosmetics, food) and non-approved methods or processes.

3.5.2.3 Environmental Contaminants - Environmental contaminants are produced by chemical action, or reaction of product materials with the post-manufacturing environment. Upon completion at Poly-Scientific, the capsule must face transportation, handling, storage installation, cleaning and operation environments. Each of these has its own chemical and atmospheric influence for which the part must be designed and processed.

3.5.3 Contamination Control

With this definition of contaminants and the many sources, it is easily seen that contamination control must mean more than dust control or final cleaning. Everything to become a part of the product, to be used in the manufacture, and that is present in the environment of operation must be studied for assurance that its existence, actions, or reactions are not detrimental to quality. Contamination control must include:

Material selection.
Material control.
Process selection.
Process control.
Contamination prevention.
Contamination removal.
Product protection.

The development of materials selection and controls has been discussed elsewhere in this report. This section is concerned with the reduction of contamination by prevention and since some contamination is inevitable by its removal.

3.5.3.1 Process Reactions - Processes for transforming raw materials into finished products involve many operations. Invariably they include the use of cleaning solvents, lubricants,

coolants, abrasives, and other chemical treatments. Residual materials from the processes can inhibit or react with future chemical treatments or environments. This can subsequently affect performance. Such processes must be thoroughly understood to prevent these undesirable side reactions. Each chemical process treatment must be immediately followed by a sequence of one or more cleaning operations to neutralize, to dilute, and to remove previous treatment residues. In addition, each process material must also have a high degree of purity to insure against recontaminating the contacts.

3.5.3.2 Contamination Prevention - Incidental contamination from human and atmospheric sources is best controlled by prevention. Dust, food particles, fingerprints, saliva, cosmetics, and the others so frequently mentioned must be controlled. Fingerprints, for example, on critical components can inhibit plastic processes and leave residues impossible to remove. Saliva, also, cannot be tolerated since the dried material is a known source of noise and its removal practically impossible. Prevention of the many incidental contaminants requires not only adequate facilities, equipment and the various other aids (e.g. protective clothing), but also employee training in this critical discipline.

3.5.4 Cleaning Processes

To remove in-process contaminating materials which are of a known (and generally single) origin requires the proper selection of a solvent and application technique. The selection of material is made simply on the basis of chemistry; matching the solvent to the contaminant solubility. It is equally important to select a solvent which is not degrading to the basic component or product being cleaned. The same criterion applies to cleaning techniques. To prevent damage the mechanical strength and physical characteristics of the specimen must be considered. There are generally several solvents and techniques available for cleaning

at any point in time and process stage. By use of the above criteria and by consideration of the processing sequences and standardized practices, cleaning processes can be designed for removal of each known contaminant. Principal areas of concern were as follows:

3.5.4.1 Casting - After casting, the cleaning problem is one of particulate removal and preparation for further operations.

3.5.4.2 Grinding - Removal of coolants and lubricants from ground surfaces is particularly important to prevent interference of chemicals with critical plating conditions. Also removal of any microscopic areas of poorly cured resinous materials is essential to plating success and subsequently product performance since the material has high electrical resistivity. It is therefore a problem source if it can reach the contact surfaces.

3.5.4.3 Soldering - Soldering is a particular problem because of the latent effects of residual solder flux. All fluxes must be removed whether corrosive or not.

3.5.4.4 Plating - Plating salts must be completely removed to prevent corrosion or subsequent exudation into critical areas. The moisture inherent in the plating operations must, of course, be removed.

3.5.4.5 Bearings - Bearings must be cleaned to remove shipping oil in order to introduce the proper controlled quantity, and to remove particulate material which has been introduced in handling either in manufacture or use. Bearings must be demagnetized to prevent magnetic particle attraction.

3.5.4.6 Sub-Assemblies - Each sub-assembly must be cleaned to insure that all contaminants of any sort have been removed to the lowest possible level.

3.5.4.7 Detailed process instructions for specific operations and their purposes are listed in Table 3.5-I. The instructions are appended to Section 3.9.

3.5.5 Conclusions

3.5.5.1 Cleaning cannot be general in the sense that there is a cure-all cleaning material or technique.

3.5.5.2 Prevention of contamination is the best cleaning method.

3.5.5.3 Each cleaning operation and technique must be designed for the contaminant, the component to be cleaned and the future processing of that component.

TABLE 3.5-I
SPECIFIC CLEANING PROCESSES

Following the Process of:	Cleaning to Remove:	Procedure or Process Instruction Used:
1. Casting	Loose plastic chips, oils, mold release, resin residue.	P.I. 102
2. Preparing internal-external leads and other components before casting	Fingerprints, particles, other materials with higher surface tension than "Freon" or soluble in "Freon".	P.I. 123
3. After casting, after machining, after handling	Mechanical removal of exposed surface layer of materials and to "peen" remaining surface.	P.I. 147 E.S. 89
4. Machining or grinding operations using Kerosene or "Cleartex" as lubricant-coolant	Kerosene or "Cleartex"	P.I. 129
5. After soldering lead ends	Solder flux, alcohol or soluble residues.	P.I. 159
6. After electroforming copper, gold, or nickel, soda blasting or soda water spraying, etc.	Water soluble residues.	P.I. 143

TABLE 3.5-I (CON'T)

Following the Process of:	Cleaning to Remove:	Procedure or Process Instruction Used:
7. After soldering major components	Gross solder fluxes, oils, other chlorinated Hydrocarbon soluble residues.	P.I. 176
8. After major handling of slip ring rotor assemblies	Oils, resins, fingerprints, particles, other chlorinated Hydrocarbon soluble materials, materials with higher surface tension than "Freon PCA".	P.I. 175
9. After handling and sub-storage operations of brush block assemblies	Particles, fingerprints, materials soluble in oil with higher surface tension than "Freon PCA"	P.I. 177
10. Received, inspection and sub-storage of miniature bearings	Particles, oil, surface films and replace with a known clean material and quantity of lubricant.	P.I. 161
11. After final preparation of sub-assemblies brush blocks, frames, misc., components and final assemblies	Oil, wax, resins, fingerprints, particles, coolants, lubricants, other organic and inorganic residues.	P.I. 174

TABLE 3.5-I (CON'T)

Following the Process of:	Cleaning to Remove:	Procedure or Process Instruction Used:
12. After plating gold and hard gold flash	Surface removal of water soluble residues	P.I. 134
13. After working, handling and preliminary cleanings for other than inorganic residues	Inorganic residues, particles, water, soluble residues, surfactant and detergent removable residues.	P.I. 103
14. After handling or subs storage of basic simple components	Particles, chlorinated Hydrocarbon soluble materials.	P.I. 101

3.6 MATTE FINISHING

3.6.1 Introduction

Until several years ago, it was believed that the smoothest slip ring surface produced the least-noisy and longest-wearing contact possible. In the early 1960's, Poly-Scientific discovered that this was not true; i.e., surfaces finished by diamond machining or polishing were not consistent in their performance. At the start of this contract, Poly-Scientific had developed a process of surface finishing using pumice and a manual brushing action to roughen the surace resulting in improved noise and wear performance. Early program units produced with this type of surface finish, lacked the desired uniformity and improvements of process and mechanization were sought.

The principal purposes for considering matte finishing on this program have been:

3.6.1.1 To determine the differences of matte finishing treatment on performance.

3.6.1.2 To develop a mechanized process for surface matte finishing.

3.6.2 Process Background

Matte finishing, as it pertains to slip ring manufacturing is the alteration of contact surfaces in order to obtain mechanical surface cleaning and better wear and noise performance. Three types of matte finish have been studied in the course of the work on this program. These finishes, when used on the Saturn units have been applied to a diamond-machined surface of electrodeposited gold. The matte-finished slip ring surfaces have been overplated with a deposit of hard gold applied from an electroplating gold bath containing a metallic hardening agent.

3.6.2.1 Brush and pumice - The cutting action of the sharp edged pumice particles are applied with an axial and tangential brush motion. The action both works and abrades a wide surface area of the component.

3.6.2.2 Dry soda blast - The abrasive sodium bicarbonate particles are impelled at high velocity onto the component surface. The use of a small nozzle and high velocity particles both abrades and cuts a narrow path on the component surface. This process is in accordance with GC125298.

3.6.2.3 Wet soda blast - A slurry of soda and water is impelled at high velocity by wide angle nozzle at the component surface. The use of the slurry and the wide angle nozzle give a smooth uniform working of the surface of the component.

3.6.3 Tests

In an effort to determine the measurable differences of performance of slip ring surfaces produced by a hard gold plate over various finishes, the following samples were prepared.

Eight test heads were produced for the Comprehensive Analytical Test System (CATS) for an oscillation type test. All units were produced from E. S. 118 which had been diamond finished to 4 RMS microinches or better. Six units were brushed manually with pumice to a 32 RMS microinch (approximate) finish. Of these, two were dry soda blasted and two were wet soda blasted. The last two units were left in the diamond turned condition. All eight were then given a hard gold electrodeposit of .0004 inches thick.

3.6.3.1 Microstructure - The first test to be performed was a study of microstructure. One of each condition of sample surface was prepared as a taper section for metallographic and hardness testing of the cross section to determine the depth and extent of the hardening caused by the surface treatment (see Fig. 3.6.1). Microscopic examination of the sections at magnifications as great as 2,667X revealed no distorted layer. Therefore, since no distorted layer could be found, it was concluded that the existance of a work-hardened or stress-relieved layer was questionable and therefore no hardness measurements were made.

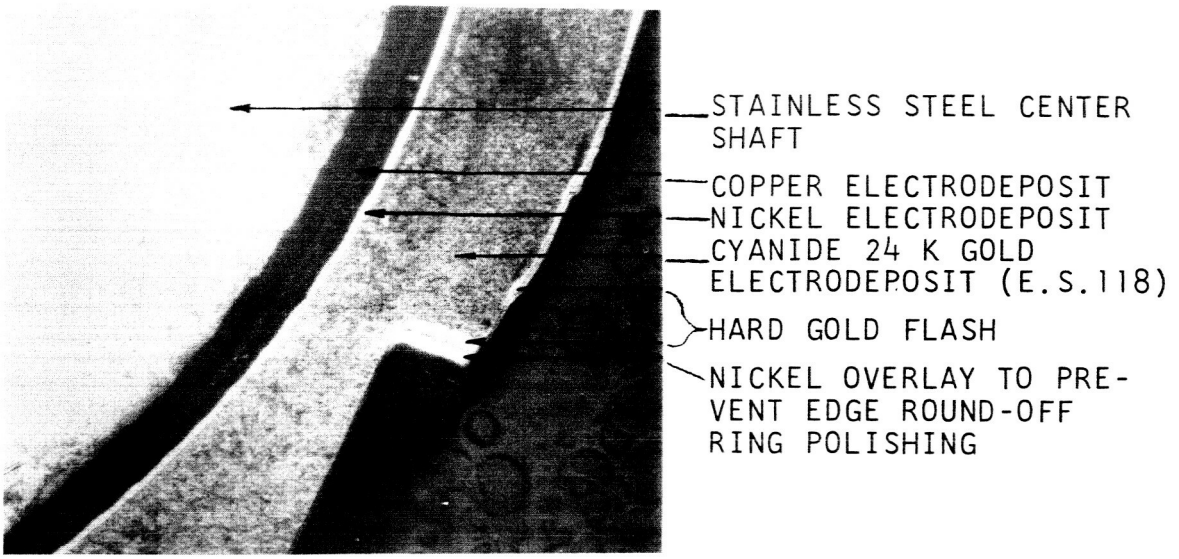


Fig. 3.6.1 - 67X - Taper Section of Treated Surface 45° Taper Cross Section of C.A.T.S. Test Head; Electroetched; taper section angle and coincidence with 90° V-groove allows examination of .0013 inch wide hard gold flash and substrate; whereas, a 90° transverse cross section would allow examination of only .0004 to .0006 inch wide hard gold flash.

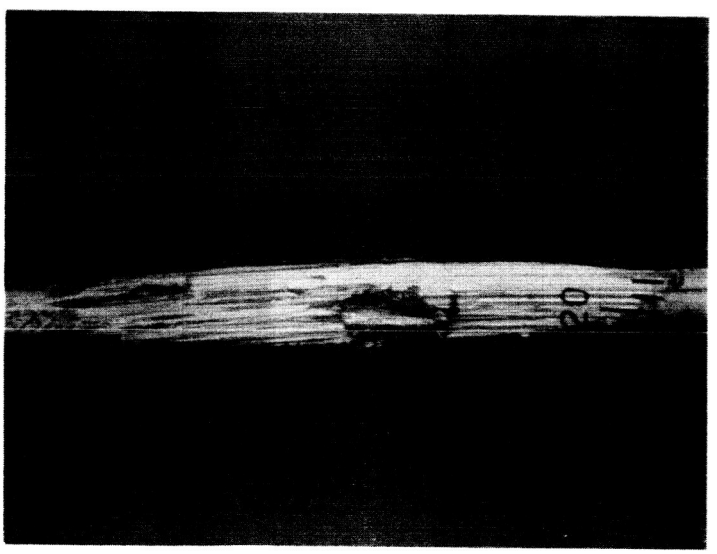


Fig. 3.6.2 - 187X- Contact Area on a 6 Gram Brush after 1000 hours test from wet-soda blasted test head; deposit in center of area is ring material transferred and adherred to brush; each scale division = 4×10^{-4} inches.

3.6.3.2 Wear - These studies confirmed once again that wear is the least understood physical phenomena. All of the contacts showed both transfer of ring material to the brush and a worn area on the brush. Figure 3.6.2 shows a brush with a large amount of transfer in a typical contact area on the brush. The type of wear considered to be most desirable is one with little build-up on the brush, with an evenly worn track in the ring. Rather large loose wear particles were found only on the diamond machined test head as evidenced by Figure 3.6.3.

There was no significant difference in the wear of the various contacts. Approximate measurements ranked the surfaces in terms of transfer (from least to greatest) as: wet soda blasted, diamond machined, dry soda blasted, and pumiced. In brush wear, from the least to the greatest, the surfaces were ranked: pumiced, diamond machined, wet soda blasted, dry soda blasted. This would indicate that the wet soda blasting provided the most desirable surface from the wear standpoint, but no conclusion could be established from this test.

In all cases, large quantities of wear product of a black-to-brown color was found on brushes and rings. Chemical test showed that some material could be dissolved by aqua regia, demonstrating a metallic nature. The remainder dissolved in a chromic-sulfuric acid mixture which is an accepted indication of friction polymer produced from airborne organic vapors. Figure 3.6.4 shows a wear product particle and Figure 3.6.5 shows some wear product on the test head. Here again there was no significant quantitative or qualitative differences attributable to the surfaces.

3.6.3.3 Noise - The noise test results were surprising as there was very little difference in noise levels among the four (4) different surface finishes. The noise trace was cyclic with noise peaks occurring at the end of each oscillation half-cycle and cycle and minor noise peaks at each quarter-cycle.

The highest average single-wiper noise value was 4.4 milliohms at 6 grams brush force and 4.0 milliohms at 3 grams brush force. The highest

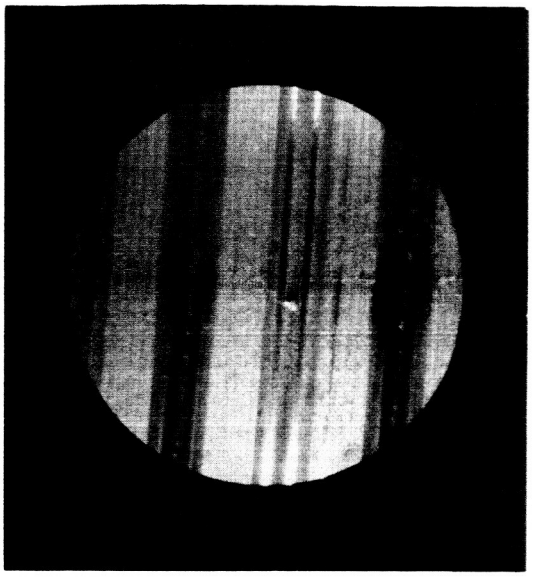


Fig. 3.6.3 - 60X - Gold Wear Particle in Slip Ring Groove of Diamond Machined Test Head; Ea. Scale Div.= $6.6X10^{-5}$in.

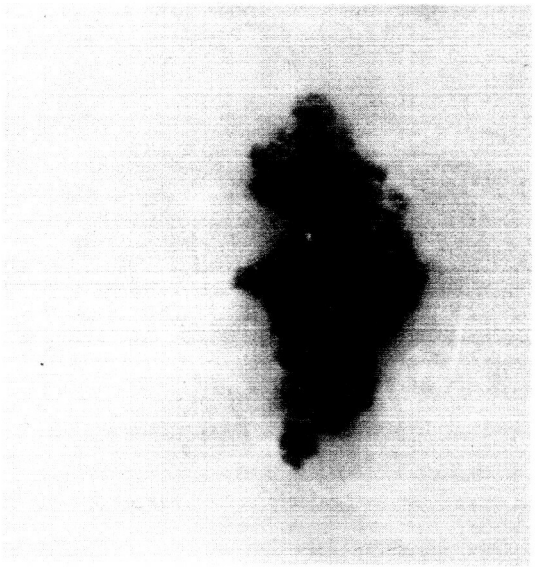


Fig. 3.6.4 - 267X - Frictional Product (Polymer) found on wet-soda blasted ring surface after 1000-hr. Black product appears to be an aggregate.

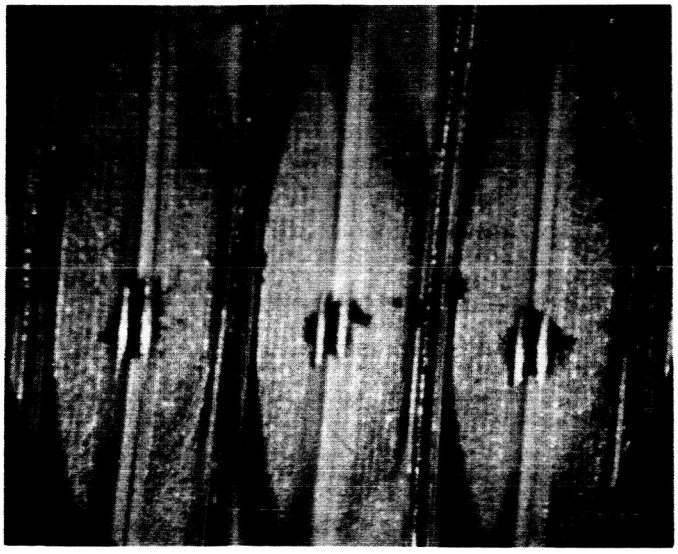


Fig. 3.6.5 - 60X-Wet-soda Blasted Ring Contact Areas (3 gram brush force) after 1000-hr. test; also, showing black frictional product.

peak single-wiper noise value was 14 milliohms at 6 grams and 13 milliohms at 3 grams. All of these highest readings were on the pumiced and dry soda blasted test heads. The greatest peak noise difference between the 3 gram brush force and the 6 gram brush force was 10.8 milliohms. Noise values taken at the end of the test at 10 RPM were of the same order of magnitude as the oscillation noise at 15.6 milliohms maximum average value. The maximum average noise value of the four (4) test heads after 1000 hours of operation at a 6 gram brush force was 1.24 milliohms and 1.06 milliohms at a 3 gram brush force.

3.6.3.4 Torque - The torque measurements proved to be the most significant of all the studies. The wet soda blasted surface demonstrated the lowest initial torque, the lowest final torque, and the least torque increase of all test heads. However, this test had to be removed after 807 hours of testing because of drive unit malfunction, while the other test heads ran for a minimum of 1000 hours. Ranking the other test head surface treatments in torque performance from lowest to highest torque: pumiced, dry soda blasted, and diamond machined. The detailed torque data is given in Table 3.6-I. This torque data shows significant differences between surface treatments and is the only test data taken which relates surface treatment to performance.

3.6.3.5 Test Summary - It is apparent from the above results that there is not a great difference between the test results of the various finishes except for torque. It would be expected that little detectable difference would occur in the characteristics of sliding contacts which have been overplated with the same hard gold flash. No explanation is available for the low torque on the wet soda blasted finish.

The only conclusion lies in the fact that, considering the small differences in the surface, the wet soda blasted finish, over a pumiced, diamond machined gold ring provides the best performance.

3.6.4 Mechanized Matte Finishing

3.6.4.1 A machine for matte finishing by brush impelled pumice has been constructed in association with this program using Poly-Scientific

TABLE 3.6-I

C.A.T.S. TEST - NASA SIMULATED SLIP RINGS TORQUE DATA

TEST HEAD NO.	SURFACE TREAT-MENT	TORQUE (GRAM-CM)		
		Direction and Where Taken	Initial	After 1000 Hour Test
55	Diamond Machined	CW, Maximum	40	95
		CW, Wear Spot	--	95
		CW, Average	--	72
		CCW, Maximum	50	110
		CCW, Wear Spot	--	110
		CCW, Average	40	85
56	Pumiced	CW, Maximum	33	75
		CW, Wear Spot	--	75
		CW, Average	--	53
		CCW, Maximum	35	82
		CCW, Wear Spot	--	82
		CCW, Average	--	58
57	Wet Soda Blasted	CW, Maximum	29	42
		CW, Wear Spot	--	42
		CW, Average	--	36
		CCW, Maximum	34	41
		CCW, Wear Spot	--	41
		CCW, Average	--	35
58	Dry Soda Blasted	CW, Maximum	29	88
		CW, Wear Spot	--	88
		CW, Average	--	70
		CCW, Maximum	20	88
		CCW, Wear Spot	--	72
		CCW, Average	--	65

support. This process consists of a rotating mylar brush and a rotating and reciprocating drive for the slip ring subassembly. A stiff paste of pumice and water is applied to the brush as it rotates. The bristles of the brush strike the reciprocating assembly in a semi-random fashion producing a very uniform finish. Not only does this provide a good matte finish, but it also is most effective in removing gold burrs.

3.6.4.2 Dry soda blasting equipment described in GC125298 was assembled in accordance with the specification.(1) The sodium bicarbonate and air blast process was tested on a number of scrap assemblies and determined to be a non-uniform process less consistent than either manual brushing with pumice or a wet soda blast process previously in use at Poly-Scientific. As a result, the process could not be used on production assemblies and the equipment was modified as indicated in 3.6.4.3.

3.6.4.3 The basic drive mechanisms of the dry soda blast process were removed and used to construct a wet soda blast process. The wet soda blast (soda slurry) uses a wide angle nozzle to spray a rotating and reciprocating slip ring surface. This results in a matte finish better than that obtained by dry soda blasting. This process does not have a capability of cutting off minute burrs on the edges of rings, but it also does not damage barriers or bearing seats.

3.6.5 Processes

Two types of matte finish are now applied to the Saturn parts at various stages of manufacture: (1) brush pumice finish, and (2) soda blasted finish.

3.6.5.1 Brush pumicing is accomplished with a nylon bristle brush to which ground pumice stone (grade FFF) is applied. The part is brushed with a reciprocating action parallel to the contact surfaces. The soft abrasive pumice imparts a series of rather short scratched lines which are

(1) Progress Report 25 February 1964.

generally parallel to each other, yielding a surface which to the unaided eye has a dull satin appearance. The pumice finish has about the same character as a ground finish except that the lines are not continuous and are not exactly parallel.

Brush pumicing of the slip ring assembly is necessary for one reason only.

Both grinding and single point tool cutting tend to extrude the relatively soft plated gold and copper in the slip ring assemblies. The extrusion, visible only under magnification, is noticeable at the edges of rings where the gold tends to flow over the plastic leaving ragged projections as the extruded band breaks away from the parent ring. Since subsequent plating tends to concentrate on sharp corners or edges, these projections would be magnified in size if not removed.

The cutting action of the pumice is much more effective than the peening action of soda blast in removing these burr-like projections. Although it is possible to remove the rough edges by soda blasting alone, the amount of blasting required would excessively errode the plastic barriers. Since it is possible for particles of pumice to adhere to the contact surface, brush pumicing a contact surface is always followed by soda blasting.

3.6.5.2 Soda blasting as normally practiced at Poly-Scientific is done by spraying the parts with soda slurry at approximately 100 PSI from a distance of 2-1/2". The slurry is a mixture of 2 lbs. of bicarbonate soda (grade U.S.P. P-20) per gallon of water, which is kept agitated during use. A soda blasted pre-machined gold on brass surface has a bright, non-reflective appearance to the unaided eye and an orange-peel appearance under 10X magnification.

The details of the process are given in P.I. 147.

3.6.6 Conclusions

From the experimental testing and production processing of assemblies, the most satisfactory surface for electrodeposited gold is the pumice brushed finish, soda blasted with a wet slurry and plated with a hard gold plate of.0004 minimum thickness of 150 Knoop gold. This provides

satisfactory wear, noise and life characteristics for Saturn Gimbal axis slip ring capsule assemblies.

3.6.7 Further Work

Additional work should be undertaken to determine the true effect of the roughening of the surface on the performance of the contact. This study to determine the presence and depth of a Beilby layer (amorphous strain-hardened or stress - relieved area) produced on 24 K gold electrodeposits by matte-finishing is recommended. This study should utilize X-ray diffraction, and possibly electron diffraction and microscopy.

3.7 EVALUATION OF MECHANICAL AND PHYSICAL PROPERTIES OF SOLDERED AND WELDED RING-LEAD CONNECTORS

3.7.1 Introduction

The electromechanical function of a slip ring is dependent upon connection of leads to the rings, and no matter how appropriate the slip ring design and choice of materials, nor how perfected the various processes of manufacture, the slip ring can be no more reliable than is this connection of leads to rings. Generally speaking, the connection must be strong, free from contamination, stable under subsequent process and service conditions, electrically conductive, and reproducible. The method of making such a connection must not cause deleterious chemical, physical, or metallurgical effects upon the ring and lead. Specifically, the connection must be sufficiently strong to withstand the large variations in temperature which will occur in assembling the capsule, the handling and mold loading operations, and the mechanical and thermal stresses applied during casting of the slip ring. Also, the process of connecting the lead to the ring should, ideally, not require the addition of a fluxing agent, which would be a possible source for contaminating the assembly.

At the time this study was proposed, the contract capsules were to be fabricated via the "cut-ring" process rather than the electrodeposition process in current use. That is, the rings were cut from a wrought gold-base alloy tubing or were blanked from rolled gold-base alloy sheet. The leads used were #30 AWG (19/42) stranded silver-plated copper leads, Teflon insulated. At this stage on the slip ring capsule development program, solid #30 AWG copper jumpers were not being used to connect external leads to the rings. All work on this study was done then, considering only direct connection of stranded leads to rings without an intervening jumper. Two methods of connecting leads to this type of ring were employed: soft-soldering and resistance welding. The purpose of this study was to determine which of these two connecting methods is the more reliable.

The reliability of both soft soldering and resistance welding was evaluated against the following parameters:

3.7.1.1 Strength (pull strength, flex strength, hardness).

3.7.1.2 Contamination.

3.7.1.3 Mechanical, chemical, and thermal stability.

3.7.1.4 Reproducibility.

3.7.1.5 Microstructural integrity (heat-affected zone, brittle intermetallic compounds).

3.7.1.6 Size of connection.

3.7.1.7 Uniformity of connection.

3.7.1.8 Economy.

3.7.1.9 Weight of connection

Resistance welding was found to produce a more reliable connection than does soft soldering for the particular materials and design considered.

3.7.2 Equipment and Testing

3.7.2.1 Resistance Welding - The resistance spot welding equipment is composed of a weld head and a power supply. The weld head and its associated actuating mechanism serves the purpose of holding the welding electrodes and providing necessary forging pressure. The weld head must possess low inertia to allow the electrodes to follow the minute expansions and contractions that take place in the work materials during the welding operation. The weld head must also be capable of providing repeatable forging pressure. The Unitek/Weldmatic Model 1101 weld head, shown in Figure 3.7.1, meets the above requirements. The weld head exerts forging pressure over a rangeof 0 to 300 ounces controllable to 0.1 ounce.

The power supplies for resistance spot welding are usually of the stored-energy type for precision of electrical operation and for low capacity, bench welding. The Unitek/Weldmatic Model 1048-B power supply, shown in Figure 3.7.2, stores electrical

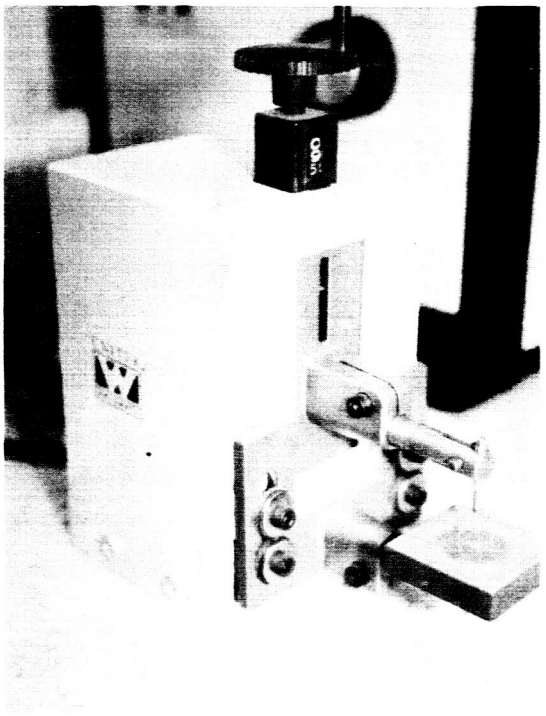


Fig. 3.7.1 - Model 1101
Unitek/Weldmatic Weld Head

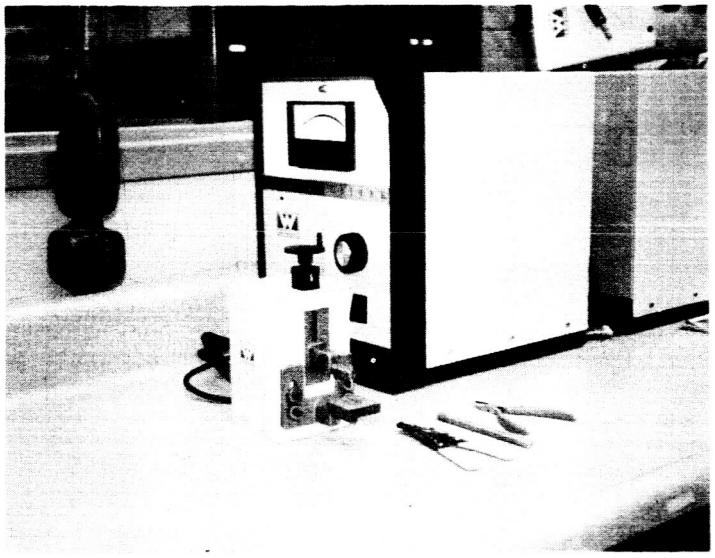


Fig. 3.7.2 - Model 1048-B
Unitek/Weldmatic Power Supply

energy in a capacitor bank which can be discharged when current is needed. The work to be welded is part of the secondary circuit of a transformer which transforms the high voltage, low amperage input into suitable high amperage, low voltage welding energy. When the weld head is actuated, the electrodes are brought into contact with the work until a preset electrode force is reached. At this force a firing circuit switch triggers, discharging a preset amount of energy from the capacitor bank through the weld transformer, resulting in a single pulse of current through the weld zone. The higher the voltage stored, the higher the pulse amplitude and the greater the amount of current that is delivered. The pulse duration is constant and is usually within the range of one (1) to three (3) milliseconds. The inherent resistance of the parent metals to the flow of current at their contacting surfaces, heats the metals to their welding temperature. The welding heat generated may be expressed by:

$$H = I^2RT$$

Where:

H = Heat generated as indicated on the watt-second meter of the power supply.

I = Welding circuit current, amps.

R = Total resistance in the welding circuit, ohms.

t = Capacitor discharge time, seconds.

The capacitor discharge time is fixed by the power supply design, and the welding current is controlled by the operator. The welding circuit resistance is more difficult to control and is a complex factor. The types and sizes of work pieces to be welded must be studied in order to make a proper choice of type and configuration of electrodes. Once this has been done, the resistances of concern are those created at the point of contact between each electrode and work piece and at the point of contact between work pieces. The resistance at these points vary with electrode pressure, electrode geometry, work piece resistivities and hardnesses, and cleanliness. There are a total of fifteen (15) resistances in the welding circuit which must be considered. A weld schedule must be established by varying the welding current, electrode pressure, and electrode

material and configuration, if necessary, in order to obtain the most reliable welding conditions, on a trial-and-error basis, by maximizing the resistance between the two work pieces in relation to all other resistance. Once this has been done, the operator has only to maintain the conditions and settings to assure reproducibility.

3.7.2.2 Soldering - Soldering of leads to rings was accomplished utilizing Kester 1544 solder flux (which is non-corrosive and non-conductive), 63% Sn - 37% Pb eutectic solder, and a soldering iron with voltage control. The lead was first "tinned" with solder to control the amount of solder to be used rather than applying solder directly to the joint. The soldering iron was applied to the ring as the tinned lead was touched to the ring. As soon as the area of the ring adjacent to the lead was brought to the proper temperature, solder flowed to the fluxed area of the ring and fused there to make a connection. Residual solder flux was then meticulously removed with Kester Rosin-Residue Remover and alcohol.

3.7.2.3 Samples - At the conclusion of Phase I of the contract, two (2) gold alloys were recommended for use as the ring contact: E.S. 54 and E.S. 57, with the latter alloy preferred. The lead wire used was as per the type recommended persuant to the contract at that time: #30 AWG (19/42) stranded silver-coated copper, TFE Teflon-insulated, per MIL-W-16878-D. Two sizes of rings were of concern:

3.7.2.3.1 .127" I.D. x .173" O.D. with a .250" O.D. silver overlay, .0160" thick.

3.7.2.3.2 .210" I.D. x .251" O.D. with a .281" O.D. silver overaly, .0180" thick.

Samples were made up from E. S. 57 material for each ring size and from E.S. 54 ring material in the smaller ring size only, and since there were two processes to study, there was a total of six (6) different types of samples.

3.7.2.4 Pull Test - This is a simple test by which the mechanical strength of joints is determined by measuring the force required to break the joint.

There were six (6) different types of samples involved, and since a sample size of five (5) is necessary for statistical comparison of strength, a total of 30 samples were prepared. The pull test was performed by simply securing the ring in a horizontal position so that the connected lead wire extended downward. The free end of the lead wire was attached to a platform to which weights were added until the ring-lead connection failed.

3.7.2.5 Flex Test - It is believed that the primary mode of failure of soldered or welded ring-lead connections is a fatique failure of the connection or of the lead wire immediately adjacent to the connection. A flex test was incorporated into the study, allowing the comparison of the number of flexes required to cause complete fatique failure of the various types of samples. Again, the total statistical sample size required was thirty (30).

The flex test used employs a motor driven yoke which is oscillated in a manner designed to impose two 90° flexes per cycle on the ring-lead joint. The ring is positioned on top of the yoke, while the connected lead extends downward through the arms of the yoke. A weight (217 grams) clamped to the free end of the lead concentrates stresses at the ring-lead connection when the yoke is oscillated. The sample being flexed is made a part of the electrical circuit that contains a drive switch to the motor. Thus, when the sample fails, the driving mechanism automatically stops, and the number of flexes attained is shown on a mechanical counter in the system. A powerstat is used to vary the flex rate.

3.7.2.6 Hardness Test - An area of concern in any method of joining metals that employs the use of heat is the effect of the heat upon the metals being joined. In welding processes the concern is emphasized by the high temperatures required to produce coalescence of metal. Although soft-soldering employs the use of relatively low temperatures, these temperatures are sometimes held for relatively long periods of time. The concern of heat effect in soldering is emphasized by the tendency for gold alloys and tin-lead solders to form brittle intermetallic compounds, and the small size of components being joined.

It was decided that microhardness measurements taken adjacent to the connection, on both the ring and the lead, would be a good tool with which to determine

the size and severity of the heat-affected zone. Any significant alteration of mechanical properties induced by heat should be detectable by hardness testing. The Wilson Tukon Hardness Tester with a Knoop Indenter and a 100-gram load was utilized in the hardness testing. The statistical sample size required was three (3) samples per sample type for a total of 18 samples.

3.7.2.7 Metallographic Examination - Etched and un-etched mounted samples of each sample type were prepared for examination on a Unitron Model BU-11 Metallograph. These examinations facilitated comparisons of grain size, bond, contamination, and heat-affected zones.

3.7.3 Results

3.7.3.1 Weld Schedules - The completed weld schedules for the three (3) types of rings are depicted in Figures 3.7.3 - 3.7.5. The data on which the weld schedule development is based was obtained by pull testing a minimum of four (4) welded samples at each weld setting. The average pull strength, thus determined, was used to calculate the standard deviation and the "Weld Quality Coefficient."

$$N = \frac{\bar{X}w - 5\sigma \times 100}{\bar{Y}m}$$

Where:

N = Weld quality coefficient.

$\bar{X}w$ = Average pull strength of the weld.

σ = Standard deviation.

$\bar{Y}m$ = Average pull strength of the weaker member being welded.

A particular weld setting was selected, and at least four (4) samples were welded at that setting. Higher and lower weld settings were selected around this original setting and samples welded. Pull tests were made on all samples in order to determine N, σ, and $\bar{Y}m$ for each setting. The setting which maximized N and $\bar{Y}m$ and minimized σ was temporarily selected as the optimum setting. Further evaluation of additional settings proceeded in the same manner until there was no question as to what the optimum setting was. The shaded area around each optimum weld setting in Figures 3.7.3 - 3.7.5 indicates that

Company: Poly-Scientific Division Litton

Engineer: Sherwood Caldwell

Part No.: DP 1341

Weld Power Supply:

Manufacturer - Unitek/ Weldmatic

Model No. 1048-B

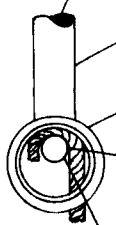
Serial No. 48B 1881

Weld Head:

Manufacturer - Unitek/Weldmatic

Model No. 1101

Serial No. 101A 1016



Shank Dia. 1/8 in.

Tip Size 1/8 in.

Polarity Negative

Groove Size .281 in.

RWMA No. #2

Size .210 x .251 x .281

Material E.S. 57 w/ Ag overlay

Size #30 AWG (19/42)

Material Ag-Coated Cu

RWMA No. Molybdenum

Groove Size .010 in.

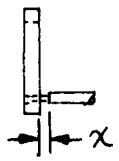
Polarity Positive

Tip Size 3/32 in.

Shank Dia. 3/32 in.

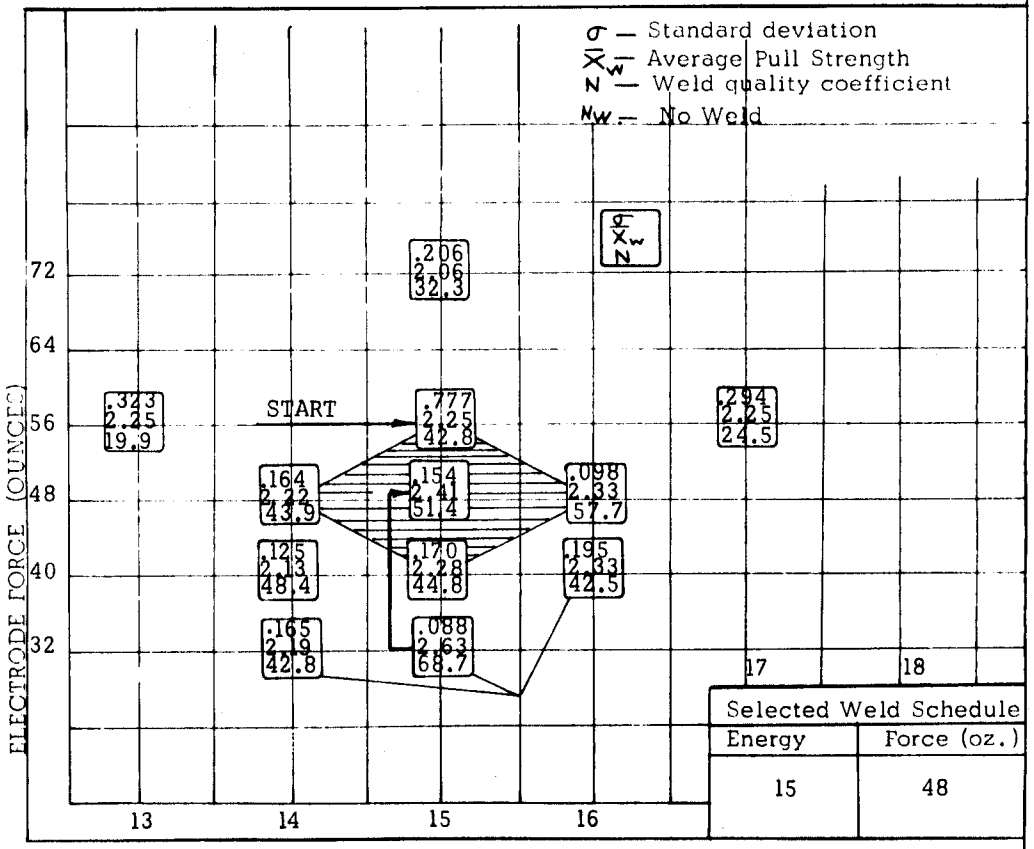
Included Angle ----

Lead Bend Dimension χ 90° .005 in. max.



Date: April 6, 1965

Iso-Strength Diagram No. 2



Selected Weld Schedule

Energy	Force (oz.)
15	48

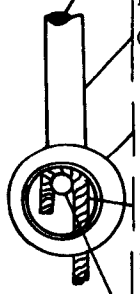
FIGURE 3.7.3

Company: Poly-Scientific Division Litton
Part No.: DP 1340

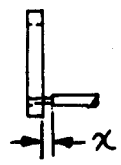
Engineer: Sherwood Caldwell

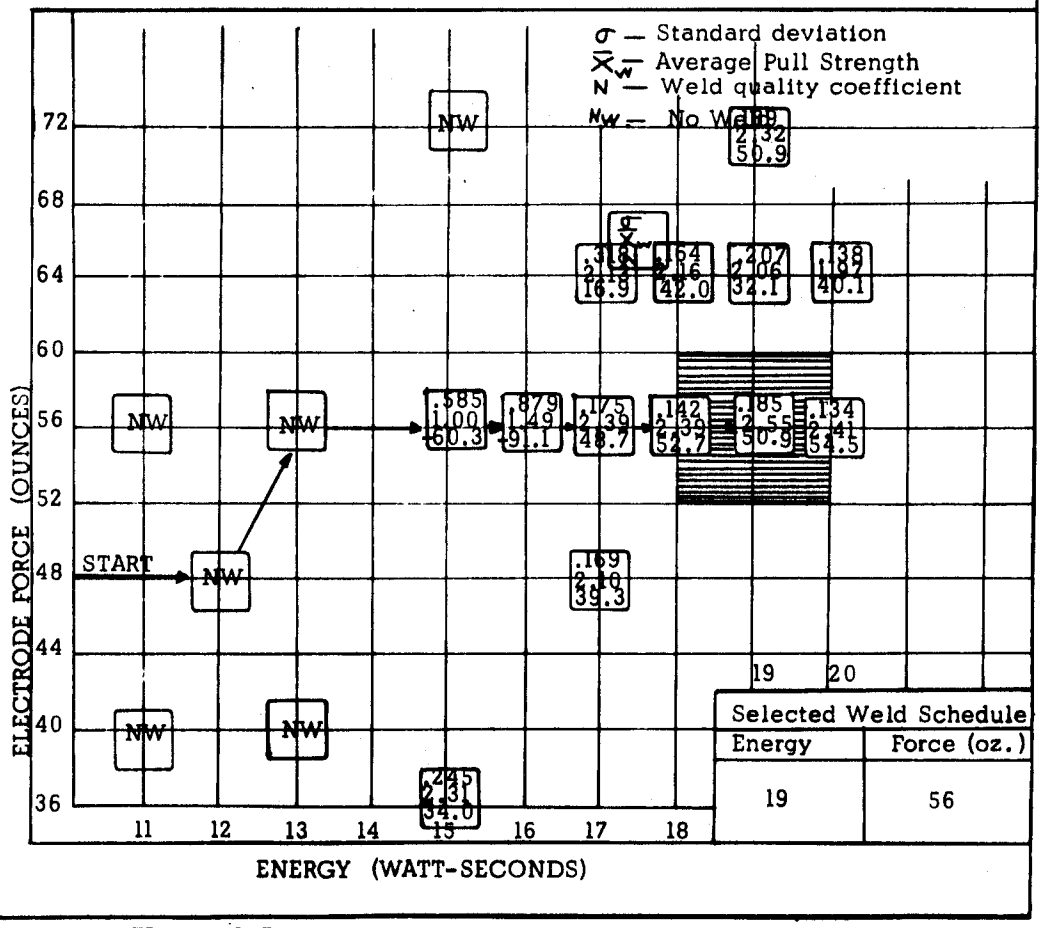
Weld Power Supply:
Manufacturer - Unitek/Weldmatic
Model No. 1048-B
Serial No. 48B 1881

Weld Head:
Manufacturer - Unitek/Weldmatic
Model No. 1101
Serial No. 101A 1016



Shank Dia. 1/8 in.
Tip Size 1/8 in.
Polarity Negative
Groove Size .250 in.
RWMA No. #2
Size .127 x .173 x .250
Material E.S. 57 w/ Ag overlay
Size #30 AWG (19/42)
Material Ag-Coated Cu
RWMA No. Molybdenum
Groove Size .010 in.
Polarity Positive
Tip Size 3/32 in.
Shank Dia. 3/32 in.
Included Angle ---
Lead Bend Dimension χ 90° .005 in. max.





Date: April 6, 1965
Iso-Strength Diagram No. 3

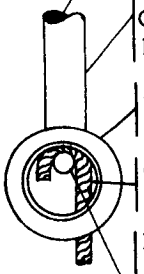
FIGURE 3.7.4

Company: Poly-Scientific Division Litton
Part No.: DP 1340

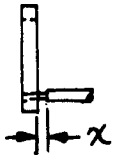
Engineer: Sherwood Caldwell

Weld Power Supply:
Manufacturer - Unitek/Weldmatic
Model No. 1048-B
Serial No. 48B 1881

Weld Head:
Manufacturer - Unitek/Weldmatic
Model No. 1101
Serial No. 101A 1016



Shank Dia. 1/8 in.
Tip Size 1/8 in.
Polarity Negative
Groove Size .250 in.
RWMA No. #2
Size .127 x .173 x .250
Material E.S. 54 w/Ag overlay
Size #30 AWG (19/42)
Material Ag-Coated Cu
RWMA No. Molybdenum
Groove Size .010 in.
Polarity Positive
Tip Size 3/32 in.
Shank Dia. 3/32 in.
Included Angle ----
Lead Bend Dimension χ 90° .005 in. max.



Date: April 6, 1965
Iso-Strength Diagram No. 4

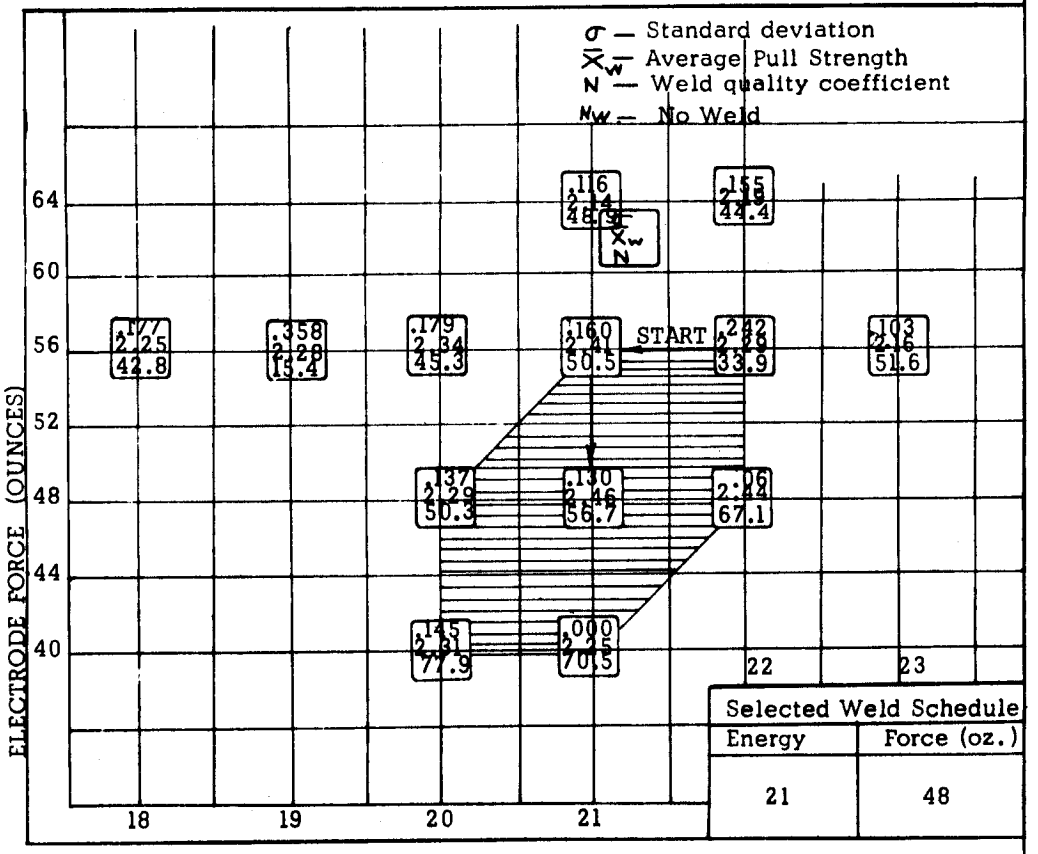


FIGURE 3.7.5

weld settings within this area will produce very nearly optimum welds.

3.7.3.2 Pull Test - The pull test data given in Table 3.7-I shows that there was not much difference in the pull strengths of the welded samples as compared to the soldered samples. Statistical analysis of this data shows that the difference in pull strength between welded and soldered joints was insignificant. The average pull strength of the #30 AWG (19/42) lead wire was 1,447 grams, which was higher than the pull strength of either type of connection. Figure 3.7.6 shows a typical pull test failure.

3.7.3.3 Flex Test - The flex test data is summarized in Table 3.7-II. Statistical analysis of the flex data shows that the welded connections had a significantly greater flex life than the soldered connections. Figure 3.7.7 shows a typical flex test failure. Since, as stated earlier, it is believed that the primary mode of failure of soldered or welded ring-lead connections is a flex (fatigue) failure, the results of this test were emphasized. The welded connections were adjudged to be stronger and more reliable than the soldered connections, therefore, it became important to determine the reliability of welded connections. Forty (40) more samples of each ring type were welded and flex tested, a sample size of 40 being statistically sufficient to determine reliability. The data from these tests are presented in Table 3.7-III. From this data, probability curves were plotted as shown in Figures 3.7.8 - 3.7.10. The 99 percentile reliability is as follows:

Alloy 57 small diameter ring - 44.5 flexes
Alloy 57 large diameter ring - 34.3 flexes
Alloy 54 small diameter ring - 40.3 flexes

The confidence limits placed upon the probability curves may be used, with a 95% confidence, to predict the maximum and minimum number of flexes that a particular percentage of welded connections will withstand. For example, Figure 3.7.8 shows that 75% of the welds will withstand a maximum of 62.5 flexes and a minimum of 52 flexes without failing.

3.7.3.4 Hardness Test - Microhardness measurements were taken in a manner shown in Figure 3.7.11. Initial measurements showed that the heat-affected

TABLE 3.7-I

PULL TEST DATA

FORCE REQUIRED TO PRODUCE FAILURE (GRAMS)

	P-S 57 CW 1 RING SMALL DIAMETER		P-S 57 CW 1 RING LARGE DIAMETER		P-S 54 CW RING SMALL DIAMETER		OVERALL AVERAGE
WELD SAMPLES	988 968 878 862 1056		1022 1091 1098 928 1048		1166 1085 1032 1095 1043		1024
	Avg. 950	Range 194	Avg. 1037	Range 170	Avg. 1084	Range 134	
SOLDER SAMPLES	939 905 1333 1066 991		1173 919 1040 978 1146		998 951 966 878 909		1013
	Avg. 1047	Range 428	Avg. 1051	Range 254	Avg. 940	Range 120	
OVERALL AVERAGE	999		1043		1012		

Fig. 3.7.6 - P-S 57 Ring, Large Dia.
45X Magnification Showing Typical
Failure in Pull Testing of Welded Joints

Fig. 3.7.7 - P-S 57 Ring, Large Dia.
45X Magnification Showing Typical
Failure in Flex Testing of Welded Joints

TABLE 3.7-II

FLEX TEST DATA

NUMBER OF FLEXES REQUIRED TO PRODUCE FAILURE

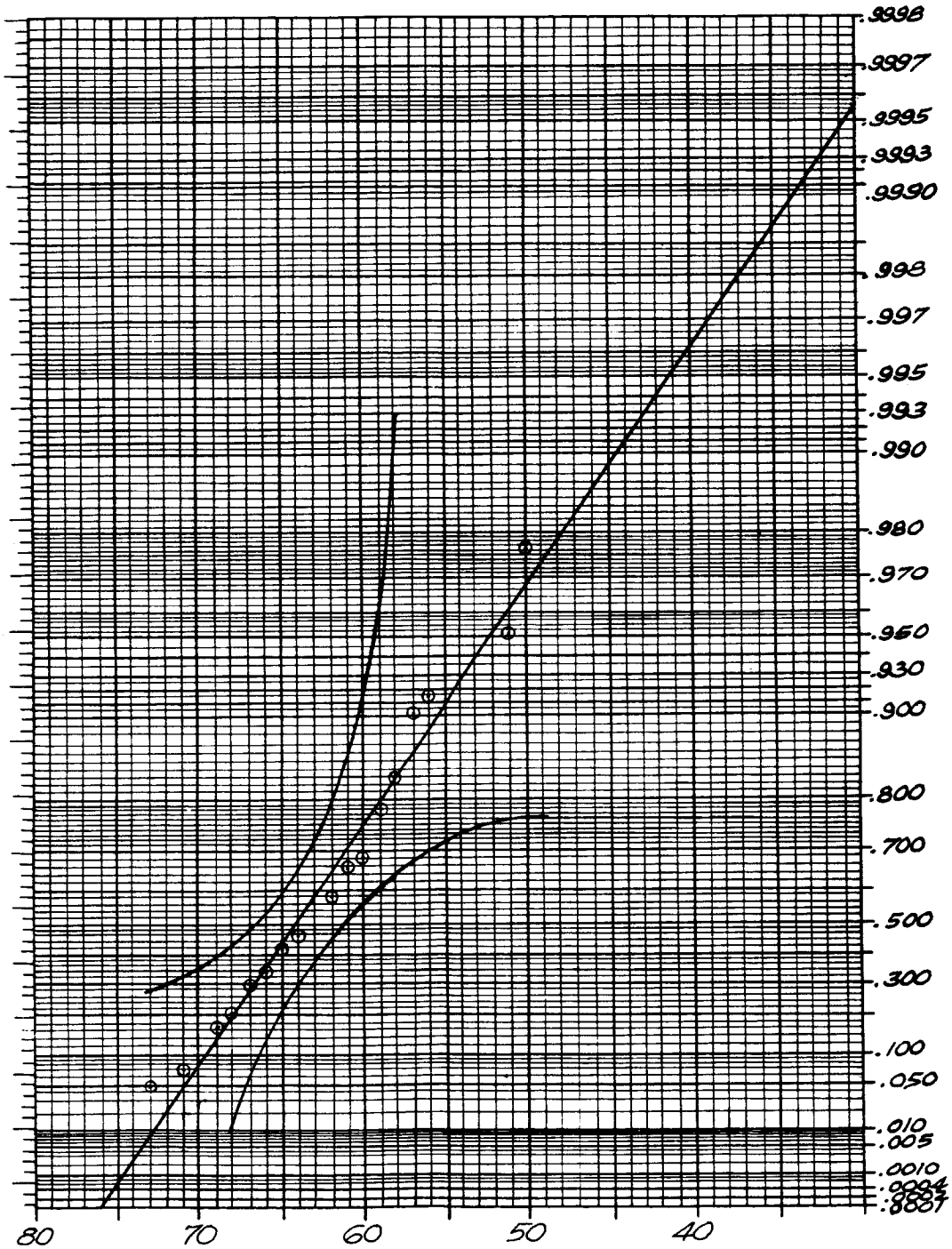
	P-S 57 CW1 RING SMALL DIAMETER		P-S 57 CW1 RING LARGE DIAMETER		P-S 54 CW RING SMALL DIAMETER		OVERALL AVERAGE
WELD SAMPLES	50 52 56 62 65		68 71 66 57 65		62 56 58 66 60		61
	Avg. 57	Range 15	Avg. 65	Range 14	Avg. 60	Range 10	
SOLDER SAMPLES	18 26 32 31 14		9 25 16 8 26		8 20 25 16 18		19
	Avg. 24	Range 18	Avg. 17	Range 18	Avg. 17	Range 17	
OVERALL AVERAGE	41		41		39		

TABLE 3.7-III

FLEX TEST DATA
WELDED SAMPLES, NUMBER OF FLEXES
REQUIRED TO PRODUCE FAILURE

P-S 57 CW1 Ring Small Diameter	68	61	59	59	64	62	73	61	$\Sigma = 2,518$ $\bar{X} = 62.95$ Range = 23
	71	62	66	67	62	69	68	73	
	66	57	50	69	69	59	60	65	
	57	56	62	51	67	64	58	67	
	65	62	58	69	57	65	59	61	
P-S 57 CW 1 Ring Large Diameter	50	51	60	58	53	49	55	52	$\Sigma = 2,302$ $\bar{X} = 57.55$ Range = 28
	52	63	60	53	49	63	61	60	
	56	62	61	48	55	51	53	73	
	62	57	57	58	72	61	55	57	
	65	47	72	45	49	66	69	62	
P-S 54 CW Ring Small Diameter	62	65	67	63	48	52	63	74	$\Sigma = 2,395$ $\bar{X} = 59.875$ Range = 27
	56	58	58	69	60	60	61	63	
	58	61	64	57	60	59	63	58	
	66	63	57	48	56	47	68	63	
	60	60	60	53	52	55	63	65	

P-S 57 SMALL RING



NUMBER OF FLEXES

FIG. 3.7.8 - FLEX LIFE PROBABILITY

3.175 EXTREME PROBABILITY PAPER COURTESY E. J. GUMBEL

P-S 57 LARGE RING

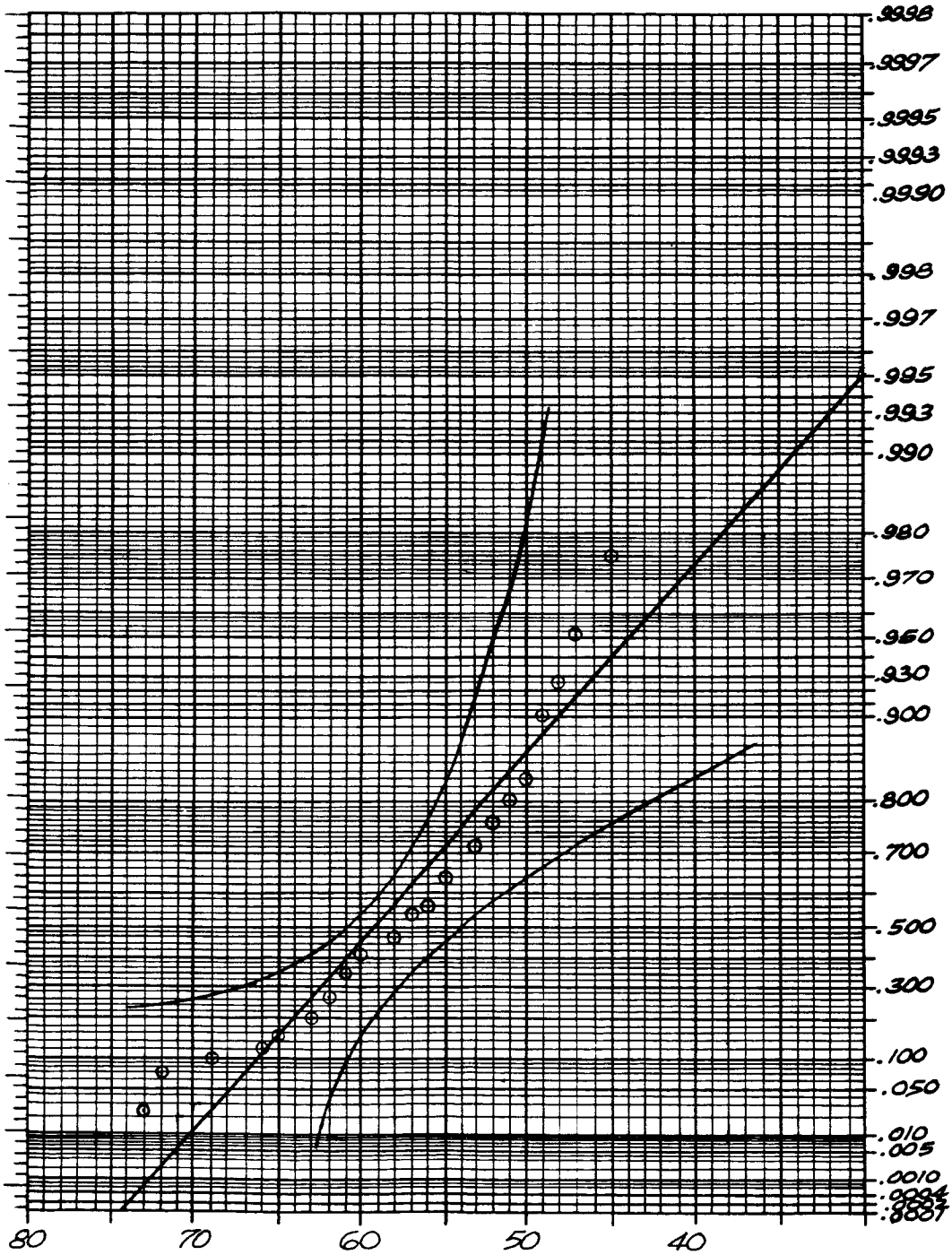


FIG. 3.7.9 - FLEX LIFE PROBABILITY

EXTREME PROBABILITY PAPER COURTESY E. J. GUMBEL

P-S 54 SMALL RING

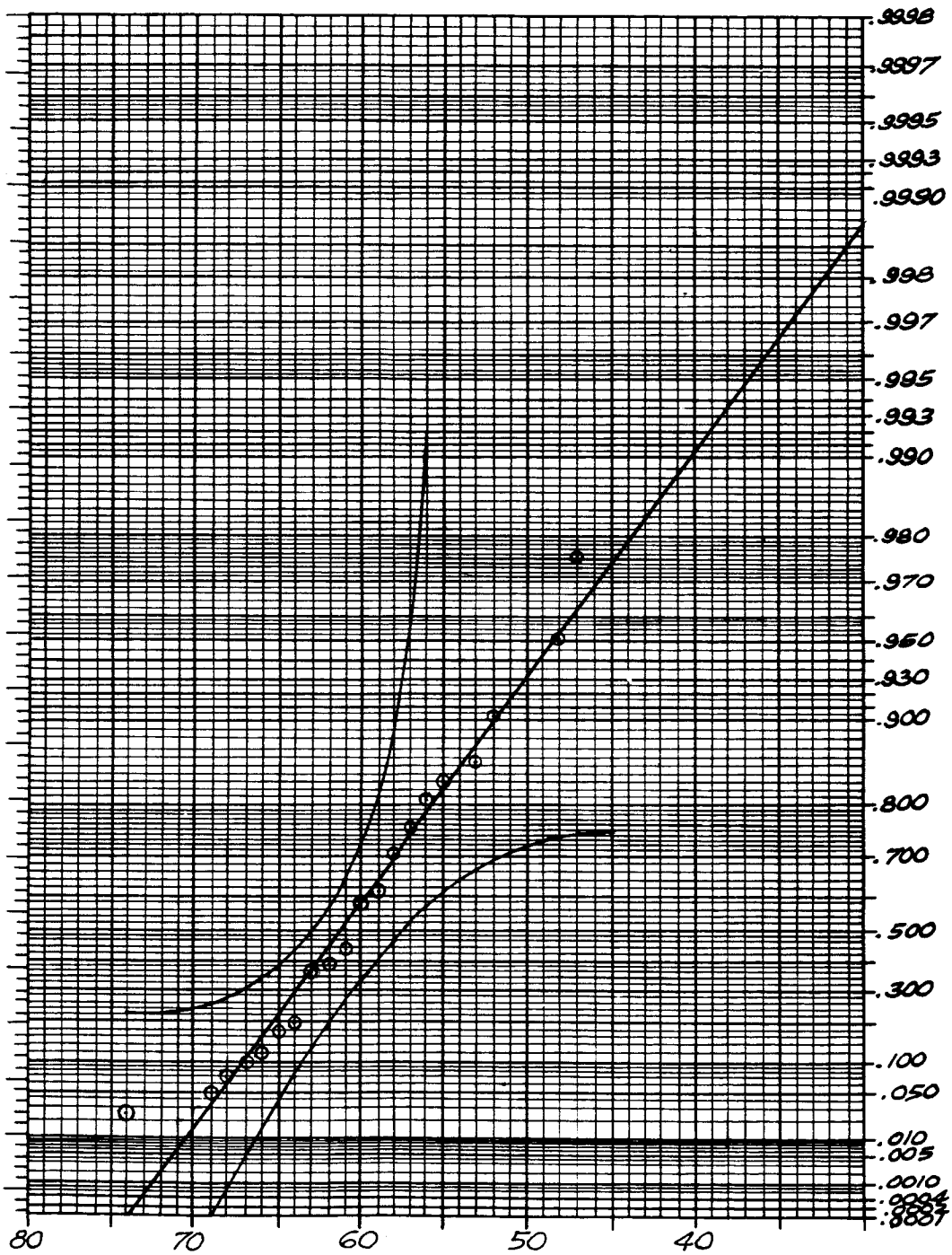
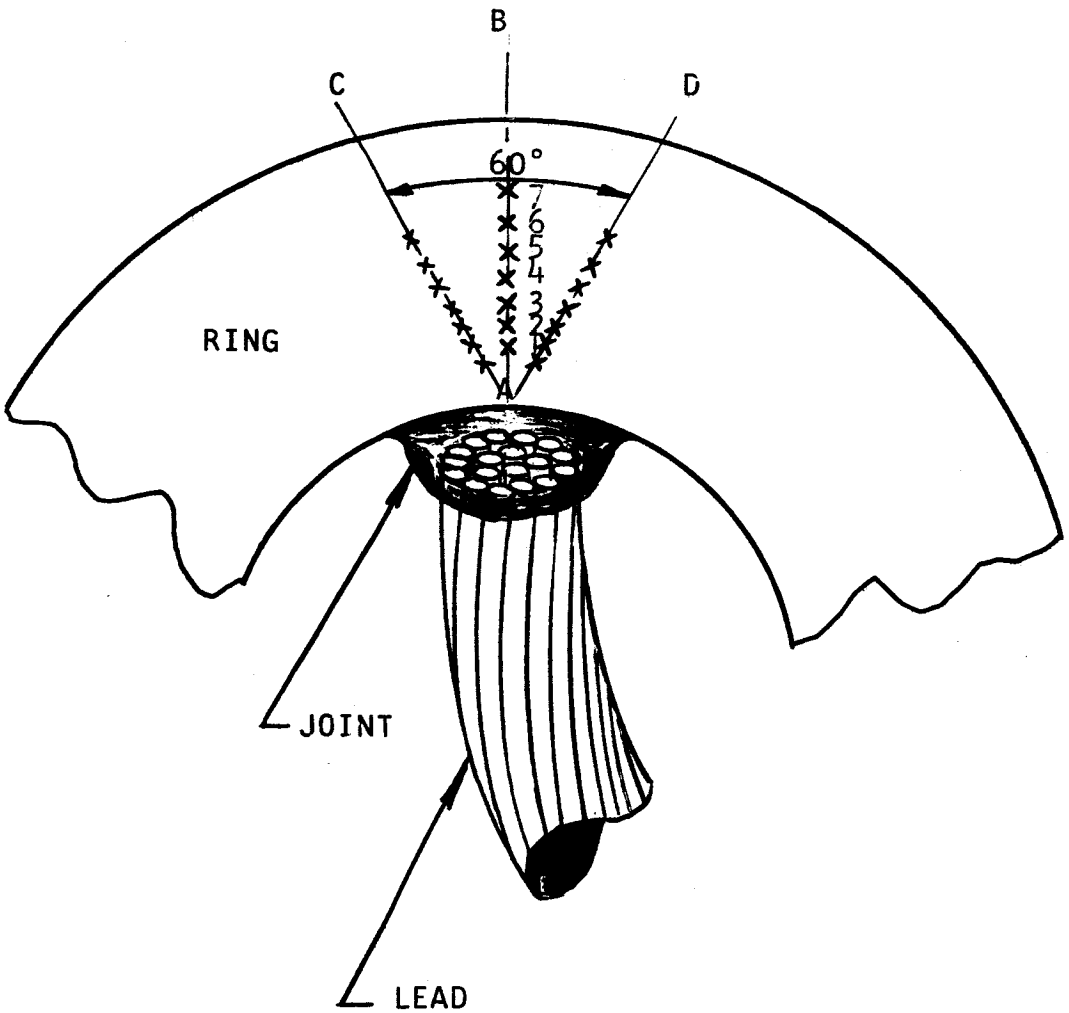


FIG. 3.7.10 - FLEX LIFE PROBABILITY

EXTREME PROBABILITY PAPER COURTESY E. J. GUMBEL



Hardness readings to be taken along AC, AB, and AD at even increments on arcs struck through 1, 2, 3, 4, etc., thousandths inch from joint.

FIG. 3.7.11 - HARDNESS (KNOOP) TEST SKETCH

zone was confined to an area on the ring included in a 60° angle whose vertex is at the midpoint of the welded or soldered connection. The average hardness of the ring in an area 180° from the connection was used as a control standard to compare to the readings taken around the connection and to determine how deeply any measureable heat-affected zone penetrated into the ring. The average heat-affect penetration, in inches, as determined by microhardness testing is given for each type of sample, as shown in Table 3.7-IV.

The extent of heat affect was dependent upon the type of ring sample. The alloy 54 small diameter ring exhibited the greatest heat-affect penetration, the alloy 57 large diameter ring exhibited slightly less heat-affect penetration than the alloy 54 ring, and the alloy 57 small diameter ring exhibited the least amount of heat-affect penetration. As far as this study is concerned, heat affect in alloys 57 and 54 is defined as partial annealing (softening) only. There are no crystallographic structure changes or age-hardening reactions that take place in these two (2) alloys at slightly elevated temperatures to cause hardening, embrittling, or softening. Soft-soldering of alloys 57 and 54 caused some hardening and embrittling of the alloy; however, this occurs on a microscopic scale over extremely small areas, and hardness testing will not usually show up this minute hardening.

Although the heat-affect (softening) penetration into the rings was as great as .015 inch for welding and .005 inch for soldering, the hardness at the softest point (.001 to .002 inch penetration), as close as measurable to the connection, was well within the hardness range specified for cold-worked ring material purchased under E.S. 57 (alloy 57) and E.S. 54 (alloy 54). Consequently, the heat-affect was insignificant.

Since it was observed that all the pull test and flex test samples, upon being tested to failure, failed at a point along the lead wire a finite distance from the connection, it was postulated that there was some heat-affect on the lead wire as well as on the ring. Microhardness measurements were made on individual strands of welded and soldered ring-lead samples, beginning as close as possible to the connection and proceeding outward. The

TABLE 3.7-IV

AVERAGE HEAT-AFFECT PENETRATION (INCHES)

	P-S 57 CW 1 RING SMALL DIAMETER	P-S 57 CW 1 RING LARGE DIAMETER	P-S 54 CW RING SMALL DIAMETER
WELD SAMPLES	0.013 0.011 0.013	0.015 0.015 0.013	0.015 0.015 0.015
SOLDER SAMPLES	0.003 0.003 0.003	0.005 0.005 0.003	0.005 0.005 0.005

purpose, once again, was to measure the severity of the heat-affect and the depth to which it penetrated into the lead wire. It was found that some of the inner strands had annealed slightly to a distance approximating that at which the lead wire failed on pull and flex tests. The outer strands showed no evidence of annealing as they apparently are able to transfer most of their heat to the atmosphere, which the inner strands cannot do. As a result, the outer strands, being less ductile than the inner strands, were always the first to fail in pull and flex testing. Since the pull strengths of soldered and welded connections were similar, while there was a large difference in flex life between the two types of connections, it is believed that the lead wire heat-affect was significant insofar as determining:

The absolute value of pull strength.
The point of failure in pull testing.
The point of failure in flex testing.

The absolute value of flex life is believed to be controlled by the restraint imposed upon each individual strand at the exact point of the connection. The solder connection covers more length of the lead wire than does the welded connection and restrains this extra length from deflection under flexing tests. This added restraint creates higher stress levels than result from a connection imposing lesser restraint. The stresses are concentrated at the point along the lead wire where the heat-affected zone terminates because of the decrease in ductility at this point, and failure eventually ensues at this point.

3.7.3.5 Metallographic Examination - Examination on the metallograph of welded and soldered ring-lead specimens showed no detectable grain growth or other crystallographic changes in the heat-affected zones of the rings or the leads. This is further proof that the severity of heat affect was very mild. It is impossible, in soft-soldering of precious metals and copper to prevent the formation of a brittle zone since lead forms brittle intermetallic compounds with the precious metals and with copper. Tin also forms brittle compounds with gold. Some alloying between the solder and the metals being joined must be accomplished in order to obtain a solder connection. Reliable soldering operations of copper leads to precious metal rings must

minimize the amount of brittle compounds formed by putting a maximum limitation upon the soldering temperature and upon the time that a soldering iron is held in contact with the metals. All the soldered samples examined showed that the formation of the brittle compounds was confined to the interface between the lead and ring with no penetration of the compounds into grain boundaries of the ring or the lead.

Even though these compounds can cause a drastic reduction in pull strength and flex life, it is doubtful that they affected the tests on the subject samples since the formations were held to a bare minimum.

Figures 3.7.12 and 3.7.13 show typical cross sections of soldered ring-lead joints, demonstrating the large, non-uniform quantities of solder that result even in closely-controlled soldering operations. Figures 3.7.14, 3.7.15, and 3.7.16 show a typical cross section of a welded ring-lead joint demonstrating that the weld is of the forge type in which a diffusion band of weld alloy is formed rather than a weld nugget. The diffusion band is only.0004 inch wide, uniformly. There are no blowholes, indicative of metal expulson during welding, and no evidence of heat unbalance, which would be seen as a displacement of the fusion band and heat-affected zone away from the interface and into either the ring or the lead.

The pressure applied during welding has caused no excessive indentation of the ring or lead. Finally, there are no contaminants in the weldment, such as oxides or fluxing agents, since no flux is required.

3.7.4 Conclusions

3.7.4.1 The difference in pull strength between welded and soldered joints is insignificant. The welded ring-lead joints have a greater flex life than comparable soldered ring-lead joints, and high reliabilities in flex life. With emphasis placed on flex strength, welding of ring-lead connections is much superior to soldering.

3.7.4.2 Even though all pull and flex failures for all types of samples occur in the lead, adjacent to the connection, the connection is not necessarily stronger than the lead. Normally, the lead wire has a higher pull strength than it does after

Fig. 3.7.12 - P-S 57 Ring. Small Dia.
Showing Solder Joint; 91X; Unetched
Each Large Scale Division = 0.008 in.
(Micrographs are Cross Sections of Joints)

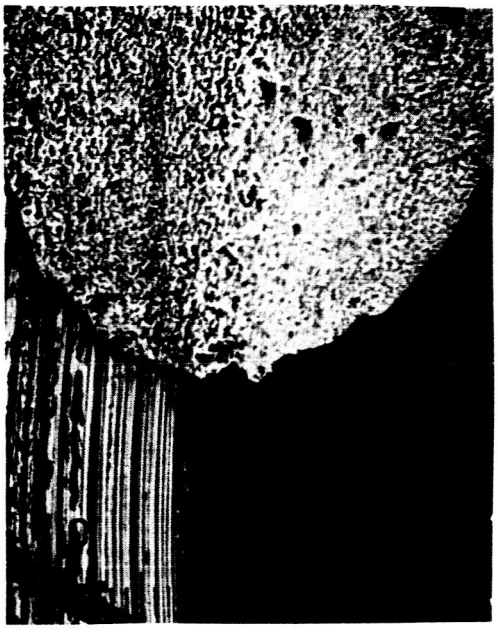


Fig. 3.7.13 - P-S 57 Ring. Large Dia.
Showing Solder Joint; 91X; Unetched
Each Large Scale Division = 0.008 in.
(Micrographs are Cross Sections of Joints)

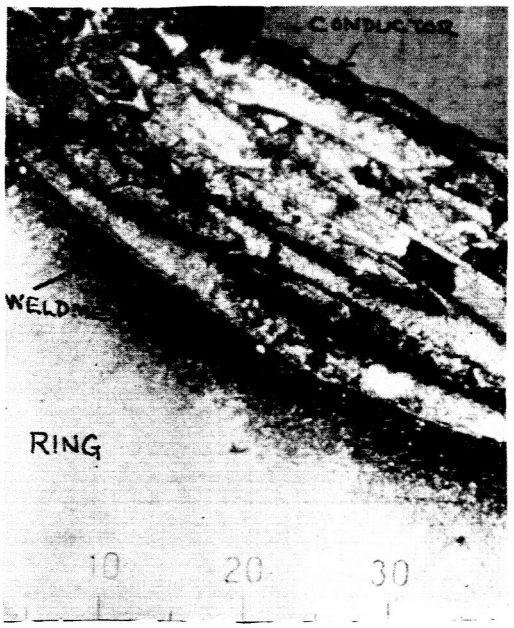


Fig. 3.7.14 - P-S 54 Ring, Dia. 91X; Transverse Section of Weld Joint; Etched; Each Small Scale Division = 0.008" Weldment = 0.0004".

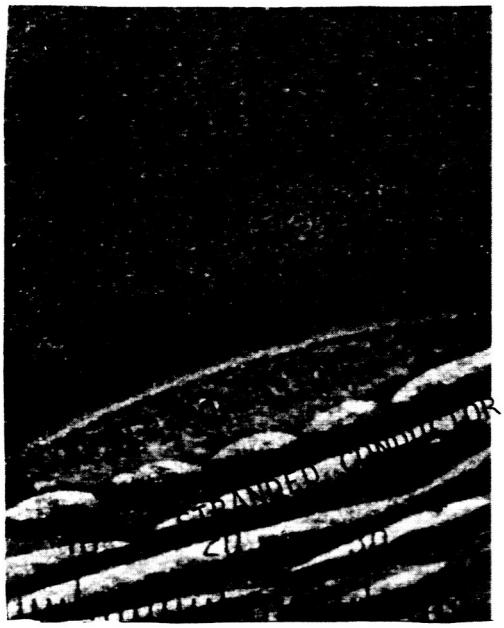


Fig. 3.7.15 - Sample Same as Fig. 3.7.14 - Using Dark Field Illumination on Electro-etched Sample

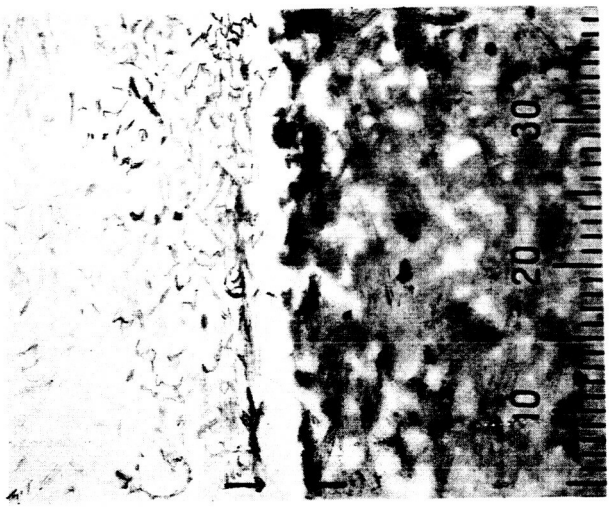


Fig. 3.7.16 - Sample Same as Fig. 3.7.15 728X with Incident Illumination Showing Weldment 0.0004" Wide - Each Small Scale Division = 0.0001".

soldering and welding to a ring. Therefore, some annealing of the lead wire is indicated. The hardness test verified that annealing of the inner strands had occurred during soldering and welding. The heat affect on the ring is insignificant, though measurable, with soldering or welding. The heat-affected zone produced during welding is not severe enough to have any effect on wear, noise, or life.

3.7.4.3 Welded connections are cleaner than soldered connections and invariable in physical form from one connection to the next. The amount of solder from one connection to the next is seldom the same.

3.7.4.4 Welded connections are lighter than soldered connections since no filler metal need be added. Thousands of such connections in a system can amount to a significant savings in weight. Welded connections are more economical to make because welding is a faster operation than soldering, plus the fact that less rework is required.

3.7.4.5 The thermal, chemical, and mechanical stability of welded connections are superior to soldered connections. There are no embrittling compounds formed; strength is retained at temperatures much in excess of the 361°F solder fusion point; 60-40 soft solder retains only 34% of its room temperature tensile strength at 125°C which is in the range of many slip ring process temperatures. Solder is composed of base metals and does not have the corrosion resistance of precious metals.

3.7.4.6 Resistance welding has been found to produce a more reliable connection of leads to rings than does soft soldering.

3.7.5 Further Work

The following items are listed as areas where a need for investigation for potential improvement of slip ring reliability has been pointed out by this study.

3.7.5.1 Roll welding of stranded lead wire into a solid construction.

3.7.5.2 Study of optimum soldering techniques for soldering the brush to the junction plate on NASA capsules.

3.8 LEAD PROTECTION

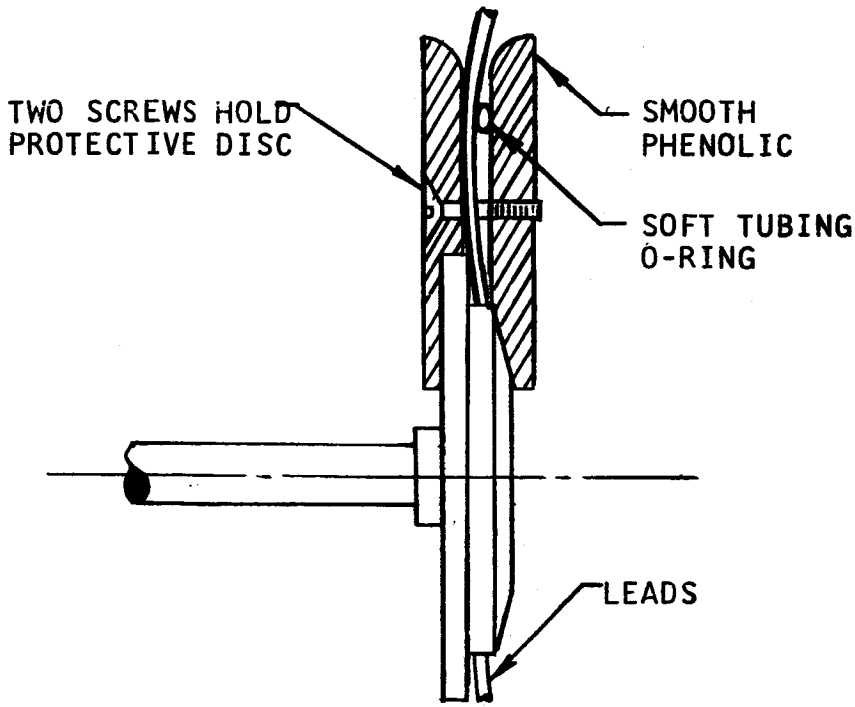
3.8.1 Introduction

Leads of both slip rings and brush blocks are of necessity subjected to a considerable amount of handling all the way from the lead preparation stage through the final inspection of the completed capsule. Most of the operations put no more stress on the leads than that caused by the negligible weight of the lead as the part is worked on in different positions. Several of the operations, however, such as the mechanical removal of flash from the lead exit area of brush blocks and the machining operations on slip rings, require strenuous handling of the leads.

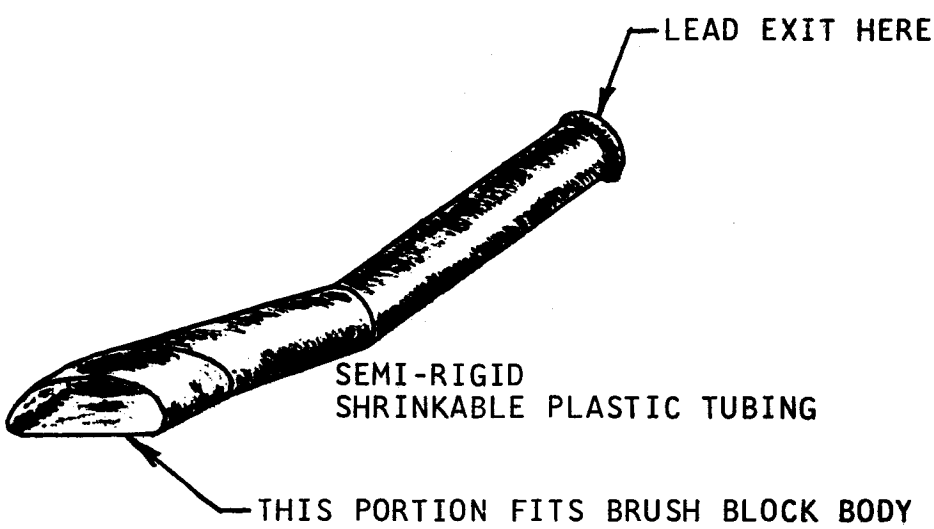
As a result conductor strand and lead breakage became a consistant problem on lead wire particularly in the slip ring subassemblies and to a lesser extent with brush block assemblies.

3.8.2 Protective Devices

Simple protective devices (Fig. 3.8.1) have been developed for the larger slip rings and brush blocks to minimize flexure of the leads at the critical area of exit from the subassembly. Any movement of the lead bundle tends to concentrate bending at the exit area thereby subjecting this section of the lead to much more flexing and resultant stress than the remaining length. The protective devices serve to prevent repeated flexure at this critical area and distribute any necessary bending of the lead over a relatively large radius some distance from the exit point. These fixtures are applied to the part immediately after flash removal and remain on the part, except when removed for cleaning operations, through all operations up to final assembly. The problem of broken strands at the lead exit area has virtually been eliminated by these protective devices. They do not, however, protect the lead from mechanical damage or other hazards beyond the device itself.



SLIP RING LEAD PROTECTION



BRUSH BLOCK LEAD PROTECTION

FIG. 3.8.1 - PROTECTIVE DEVICES

3.8.3 Rigid Package

Any lead flexure, regardless of how mild, reduces the reliability of the lead to some extent. It follows that to obtain parts with optimum reliability, the leads must receive an absolute minimum of flexure. A rigid package completely encasing the leads has been developed for DP 1505 (80 circuit) slip rings to provide minimum lead movement. This three piece package (Fig. 3.8.1) consists of a housing, spool and cover plate. The housing and cover plate are cast in special molds from epoxy plastic. The spool is machined from 2024 aluminum.

The package has been successfully used on three units to date. It was installed after the first casting operation and remained on the parts through dimensional inspection following grinding of V-grooves in gold.

3.8.4 Installation of Package

To install the package, the spool is first fastened to the cover plate. The flange of the slip ring is next bolted to the spool. The previously tagged leads are then wound on the spool. Approximately the last six inches of leads are threaded through the four rectangular plug holes in the cover plate. The leads are then soldered to the connector plugs. Tags are used for circuit identification. After cleaning the solder joints, the cover plate screws are removed to allow the spool to rotate until the leads are completely wound on the spool. The cover plate screws are again installed and the plugs secured to the cover plate. The two screws which hold the slip ring flange to the cover plate are temporarily removed until the housing is attached.

The original plan was to liquid seal the package, but the possibility of inadvertently trapping cleaning solutions inside the package during vacuum extraction of the part made this approach rather risky. To insure that all machining coolant was removed from the package, the housing was removed for each cleaning. The housing was also removed for machining the bearing seat. Removal of the housing in no way disturbs the leads. Installation of the package requires approximately three hours including tagging of the leads. Most, if not all of this time is regained in machining

and inspection operations. The cover of the package has a molded depression (Dwg. 28961) to accomodate the face plate driving lug. The packaged part is simply mounted between centers with no attention to the leads necessary.

Electrical inspections are made by mating plug connections rather than by identifying and attaching each lead to the test panel.

The package was designed so that it could be used on a completed capsule as a shipping package for the slip ring leads. As such, it would not only mechanically protect the leads, but also provide the customer a quick and simple method of electrical inspection. A similar package for the brush blocks could conceivably be built and used for shipping.

3.8.5 Disadvantages of Package

A disadvantage of the lead package is its size. The large number (80) of long (33") leads requires a bulky housing. Plating containers and solution quantities must be considerably larger than is necessary for non-packaged parts.

Another disadvantage, or problem, with the lead package is that the leads must be soldered to the plugs before the leads can be completely wrapped on the spool. This results in different effective lead lengths which requires doubling of some of the leads.

The size and weight of a rigid package for the smaller parts such as the DP 1520 makes its use prohibitive. The strength of the frontshaft is simply not sufficient to withstand the forces induced by the package during machining operations. Machining between centers is the only technique with which Poly-Scientific has had success in maintaining the required concentricities on Saturn slip rings. A lead package would prevent this technique.

Fortunately, leads of slip rings which exit axially (DP 1520) rather than radially (DP 1505) require little flexing. A full length tube large enough to accomodate the lead bundle has proven to be excellent protection for the small slip rings with axially exiting leads.

DP 1405

REV.	28959 00

REVISIONS			
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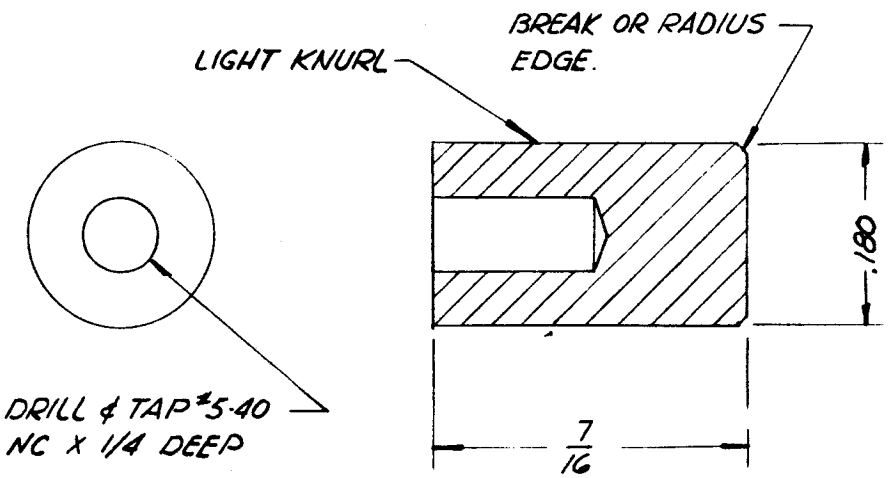

MATERIAL : STAINLESS STEEL TYPE 303

NEXT ASS'Y	P.S. FILE	QTY. REQ'D.

APPLICATION

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DECIMALS ± .005	DRAWN DATE D.H. DEW 4-24-64		
FRACTIONS ± 1/64	CHECKED DATE		
ANGLES ± 1/2°	APPROVED DATE WHH	SCALE: None	DWG. SIZE A — 28959 00
FED. SUPPLY CODE NO. 99932			SHEET 1 OF 1

3.191

DP 1405

DP 1405

REV.	28960 ee

REVISIONS				
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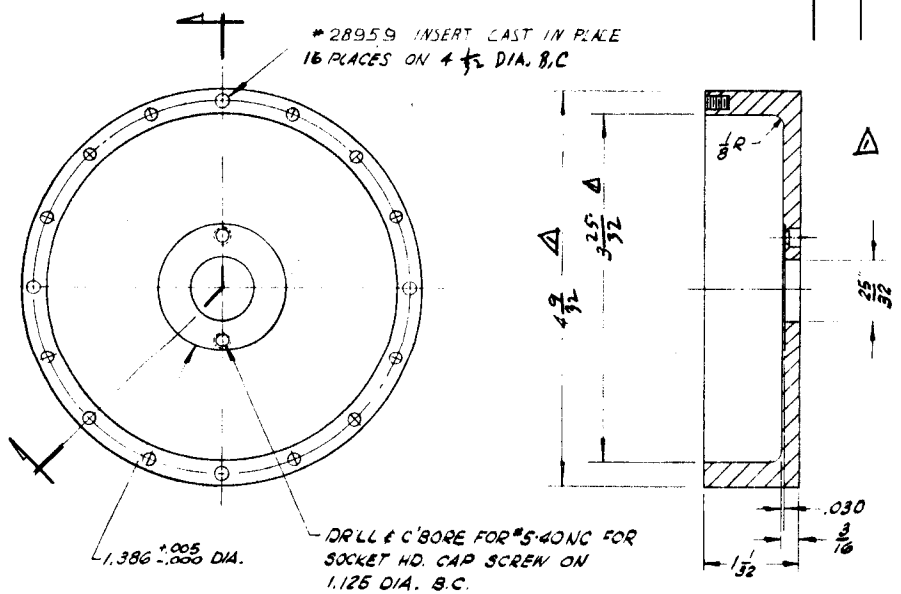

△ DRAFT PERMISSABLE

NOTE:
1. MATERIAL - P.S. SPEC. 151

ITEM	REQ'D	PART NO.	DESCRIPTION

LIST OF MATERIAL

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ANGLES ± 1/2°	APPROVED DATE		
FED. SUPPLY CODE No. 99932		SCALE: NONE WEIGHT:	SHEET 1 OF 1

DP 1405

DP 1405

REV.	28961 22

REVISIONS				
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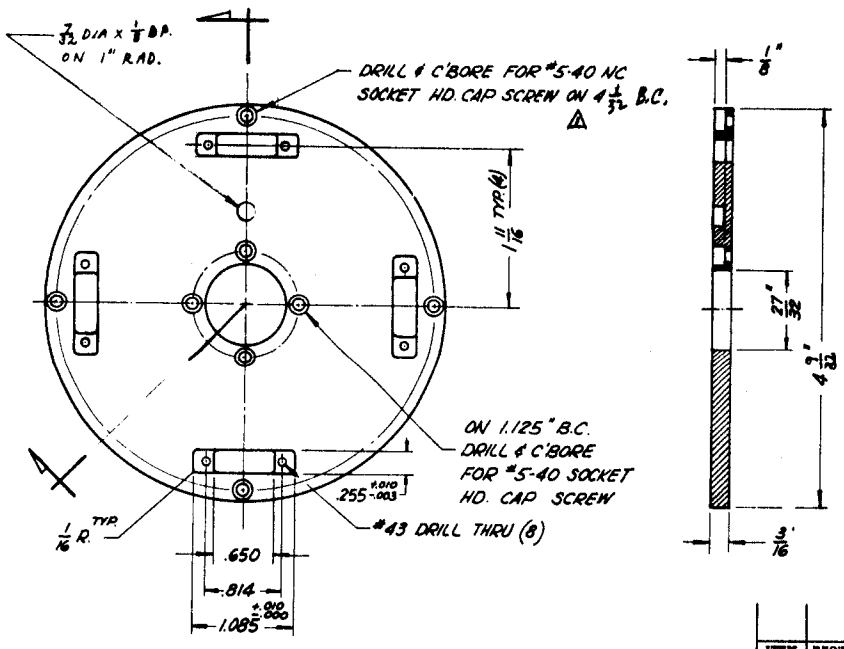

⚠ TO MATCH BOLT CIRCLE OF HOUSING # 28960--1 DP1405

NOTE:
1. MATERIAL - P.S. SPEC. 151
2. DEBURR - PER P.S. SPEC 49, CLASS "C"

ITEM	REQ'D	PART NO.	DESCRIPTION

LIST OF MATERIAL

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DECIMALS ± .005	DRAWN D.H.DEW	DATE 4/8/64
FRACTIONS ± 1/64	CHECKED	DATE
ANGLES ± 1/2°	APPROVED MK	DATE
FED. SUPPLY CODE No. 99932		

COVER PLATE

SCALE: 1/1 WEIGHT:

POLY-SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG, VIRGINIA

DWG. SIZE B — 28961 22

SHEET 1 OF 1

DP1405

DP 1405

REV.	28962 ee

REVISIONS

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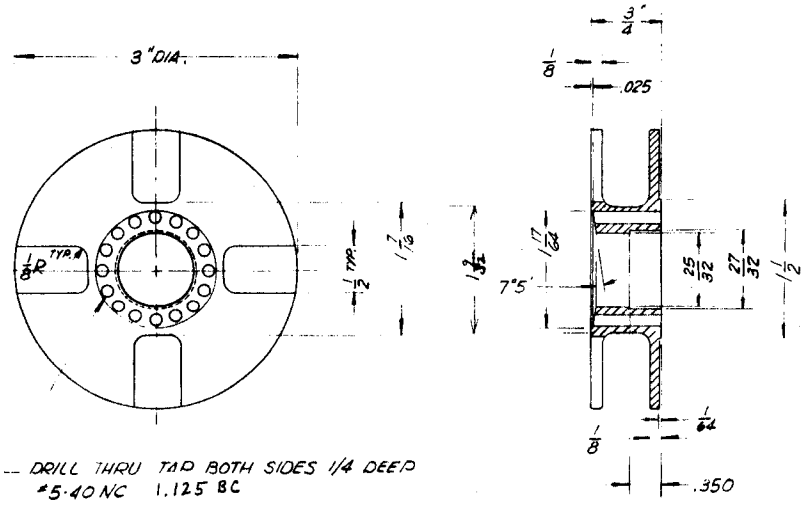


-- DRILL THRU TAP BOTH SIDES 1/4 DEEP
#5-40 NC 1.125 BC

NOTES.
1. MATERIAL - ALUMINUM
2. ANODIZE PER P.S. SPEC. 41
3. BREAK OR RADIUS ALL EDGES

ITEM	REQ'D	PART NO.	DESCRIPTION

LIST OF MATERIAL

TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED DATE	HUB	POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC. BLACKSBURG, VIRGINIA
DECIMALS ± .005	DRAWN DATE D.H.DEN 4-8-64		
FRACTIONS ± 1/64	CHECKED DATE		
ANGLES ± 1/2°	APPROVED DATE		DWG. SIZE B — 28962 ee
FED. SUPPLY CODE No. 99932		SCALE: 1/1 WEIGHT:	SHEET 1 OF 1

DP 1405

A rigid package attached to both slip ring and brush block ends of a completed capsule for use as shipping containers could put dangerous stresses on the ball bearings. The weight and size of the packages would magnify any shock applied to the part. A one foot drop, for example, could jeopardize the bearings even with the best of cushioning.

3.8.6 Brush Block Lead Protection

The processing of Saturn brush blocks requires much less handling of the leads than required of slip rings. After the flash cleaning operation (which has been reduced to a bare minimum), the leads are handled very little. Machining of brush blocks does not require special lead spools or holders. The special device mentioned previously (Para. 3.8.2) offers complete protection at the critical area. Little or no benefit could be derived from a rigid lead package for the brush blocks.

Another approach to achieveing greater lead reliability is that of installing leads near the end of the process. With this technique, applicable only to slip rings with radially exited leads, the internal leads are left long enough for preliminary electrical inspections. After all machining operations are completed, the external leads are soldered inside the flange. The solder joints are then completely encapsulated when the flange is potted. Two DP 1505 slip rings have been built with this technique. No serious problems were encountered and the results were completely satisfactory.

3.8.7 Summary

The leads of Saturn slip rings and brush blocks are subjected to a considerable amount of handling due to the lengthy manufacturing process. To insure that maximum lead reliability is maintained, some form of lead protection is essential. Simple devices have been developed and are presently being used to minimize lead flexure at the critical lead exit area.

A rigid package, completely encasing the leads, has also been developed and used on sample DP 1505 slip rings with good results. This package provides maximum lead protection even though

it is rather bulky and somewhat difficult to install. This type of package is adaptable only to the larger slip rings with radially exited leads. Full length tubing slipped over the leads offers sufficient lead protection for the small slip rings with axially exited leads.

Installation of leads after all operations up to hard gold flash has been tried with success on two DP 1505 slip rings. This technique can be used only on parts with flanges of sufficient size for secondary soldering operations.

3.9 PROCESSES

3.9.1 Introduction

Processing for Saturn capsules has evolved over a period of many months. In fact, process changes are still being made as improvements in technique or quality, are developed and proven.

A set of reproducible planning sheets (Appendix 3.9-I) accompany every slip ring and brush block from the pre-cast stage through completion of the capsule. The planning sheets list every operation to be performed in its proper sequence. The simpler operations are described in sufficient detail on the plannings. However, all operations requiring the preparation and casting of plastics, cleaning, or plating have a process instruction (P.I.) indicated which gives detailed directions for the particular operation. Inspection operations also have detailed instructions (RL). (Reference Appendix 3.9-I).

3.9.2 Slip Ring Processes

The included DP 1505 slip ring planning is typical of the planning for all Saturn slip rings. The DP 1505 drawing (DWG. #36511) will help make the planning meaningful.

Two castings are required before any machining can be performed on the slip ring. Operations 10 thru 60 are concerned with loading the components (i.e., lead wire and slip ring base) into the mold and making the first casting. The diameter of the first casting insures that the lead wires are held to a diameter smaller than that of the grooves which are ground into second casting material. The operations of the second casting are described in steps 70 thru 130.

Operations 140 thru 160 are machining operations, requisite to the copper plating processes. Grinding of the grooves in the frontshaft, into which rings are plated, can be considered one of the most important operations in that the ring spacing and the width of the rings is determined here. All machining operations on the slip ring are performed with the part mounted between centers which assures

that concentricity is maintained. Operations 180 thru 200 are cleaning, inspection and miscellaneous operations essential in the preparation of the slip ring for plating.

After copper plating (operations 210 thru 230), the slip ring is cleaned (operation 232) to remove plating residues. The slip ring is then turned (operation 240) to remove excess copper preliminary to grinding the barriers below that of the present O.D. of the frontshaft. Turning the copper reduces wheel loading problems in the succeeding grinding operations.

Operations 260 thru 310 are cleaning and inspection operations necessary in the third casting (operation 320). The technique of grinding the barriers necessitates a third casting operation (320) but this procedure has eliminated a problem of slivers of copper which come loose from the sides of the grooves, causing numerous broken barriers. The present technique of grinding the barriers followed by a third casting allows grinding to about half the depth as formerly and there are no copper slivers to wedge between the wheel and barriers.

The third and final casting is made and the frontshaft is turned to an oversized dimension (operation 350) and grooved (operation 360) to expose the copper rings. After cleaning to remove the machining coolant, and inspecting, (operation 370 thru 400) nickel and gold plating is completed. Plating residues are removed by a vacuum extraction technique (operation 430).

The O.D. of the frontshaft and the bearing seats are next turned to final diameter (operation 440) and the V-grooves are then ground in the gold (operation 450).

After the part is cleaned completely (operation 530) and inspected (operation 535 and 537), it is temperature cycled (operation 550). The slip ring is ready to assemble into a capsule after final inspection operations (565 thru 570).

3.9.3 Brush Blocks

The manufacturing process for the Saturn brush blocks is considerably shorter than for slip rings. By referring to the DP 1505 brush block planning, which is typical, and to the DP 1505 brush block drawing

(Dwg. #36514) each step of the process may be understood. The leads are first resistance welded to a one-piece junction plate (operation 10). The strength of the weld joints is verified by a pull test performed on a identifiable representative pull test sample (operation 15). The junction plate and lead assembly is loaded into a mold (operation 20) and the brush block is cast (operation 40). A lead protector is applied after the part is unloaded and the flash removed (operation 60) to prevent flexure of the leads at the exit area of the brush block. (See Section 3.8 on lead protection.)

The brush block is then machined (operation 70). This operation removes the solid back from the junction plate, leaving the mechanically separated and electrically independent junction bars in the brush block.

After temperature cycling, the individual junction bars are V-grooved (operation 100) with the same wheel that is used to grind the V-grooves in the mating slip rings. The V-grooves in the junction bars accurately locate the brushes for soldering in the capsule assembly stage.

Grinding is followed by cleaning (operation 110) to remove all coolant. The junction bars are then chromated (operation 130) to insure that no corrosion occurs to inhibit soldering of the brushes.

Final inspections (operations 145 thru 149) insure that the brush block is ready for assembly into the capsule.

3.9.4 Capsules

Processing for the assembly of Saturn capsules was developed to insure that the assembly of the capsules is accomplished in the manner and sequence which guarantees greatest reliability. Each operation as described on the typical DP 1505 planning sheet, in conjunction with the capsule (Dwg. #36511) is, in most cases, self-explanatory. Therefore, only these operations which may need further explanation will be mentioned.

In operation 10, temporary bearings and a rigidly tolerenced slip ring dummy are used for the initial assembly operations to insure that no damage or contamination occurs to the operating bearings or

slip rings during the soldering and drilling operation to follow.

Even though the spacing between the V-grooves in the brush block and the slip ring is exactly the same, necessary tolerances on the relationship of the grooves to locating surfaces makes it necessary to individually align each set of brush blocks to the slip ring in the capsule stage. The brush block V-grooves are aligned with the slip ring grooves by shifting the brush block longitudinally on the frame. After optimum alignment is obtained (operation 20), the frame is drilled for dowels to maintain the alignment.

Brushes are installed and soldered to the junction bars with alignment assured by the V-grooves in the slip ring and junction bars.

The brush block is given a circuit resistance inspection (operation 95) after soldering to insure that the heat of soldering has not adversely effected the block.

The capsule is next completely disassembled (operation 100). The frame, brush blocks and miscellaneous components are cleaned to remove all solder flux (operation 110).

All sub-assemblies and components are given a final cleaning under the clean bench immediately before final assembly begins (operation 130 thru 150). Bearings are demagnitized (operation 160) because of the magnetic field to which they are subject in ultrasonic cleaning (operation 150). X-ray (operation 197) is the only occasion in which the capsule or any of its components is removed from the clean bench after final cleaning is completed. The capsule is placed into a clean transparent Teflon bag under the clean bench and moved to the X-ray machine where it is X-rayed without removal from the bag. After X-ray, the part is removed from the bag under the clean bench.

Upon completion of all assembly operations, the capsule is given a two-hour run-in at 100 RPM (operation 190). This ensures that all brushes are seated and that any contingency, such as excessive contact surface wear, will appear. The housing is removed after the run-in and a careful inspection is made for any type of discrepancy.

The housing is replaced and the part is next subjected to a 100 hour assurance test at 2 RPM (operation 220) after which it is again inspected visually before the remaining operations are completed.

Every operation on the slip ring, brush blocks, and the capsule must be initialed and dated by the operator performing the work. It is essential that each operation be completed in its proper sequence.

Flow charts (Figure 4.6.1) show graphically the required operations for every component and assembly as well as the sequence of all assembly operations.

APPENDIX 3.9-I

MANUFACTURING DOCUMENTATION

DRG. NO.	36512	DRG REV	02	PLNNG NO.	4	JOB CLASS		FILE			PAGE	1	OF	5
NAME	SLIP RING ASSEMBLY			PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON	36511			DATE	10-28-64			RVSD BY						
F. A. NO.	DP 1505			YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.		ITM	QTY.	SPC	DRG. NO. – MATERIAL
10	CLEAN (1) SET OF COMPONENTS		1900	PI 123					
20	LOAD MOLD	MOLD #29109	1900	MI 200					
	1. Use 5-40 TAPPED HOLE TO DOG DOWN FLANGE TO MOLD QTR #1								
	2. LOAD ODD LEADS 1 THRU 39 INTO MOLD QTR #1								
	3. ASSEMBLY MOLD QTR #4				LEAD RECEIVING REPORT				
	4. LOAD ODD LEADS 41 THRU 79								
	5. LOAD EVEN LEADS 80 THRU 42								
	6. ASSEMBLY MOLD QUARTER #2								
	7. LOAD EVEN LEADS 40 THRU 2								
	8. ASSEMBLE MOLD QUARTER #3								
	9. REMOVE TEMPORARY DOG & INSTALL FLANGE CAP.								
30	SEAL MOLD		1900						
40	PREPARE PLASTIC E.S. 218 CAST & CURE		1900	PI 79					
50	UNLOAD MOLD (REMOVE #3 QTR FIRST, THEN #4 & #2). CLEAN & MOLD RELEASE MOLD. SCRIBE S/N ON BACK OF FLANGE		1900						
60	CLEAN FLASH (DO NOT REMOVE SILASTIC FROM ASSEMBLY) CUT LEADS .025 LONG		1900						
65	INSPECTION (INSUL. RESIST.)		3919	RL 313					
70	SODA BLAST ENTIRE F'SHAFT		1600	PI 147					
80	LOAD INTO 2nd CASTING MOLD (CHECK TO INSURE ALL LEADS ARE STRAIGHT BEFORE LOADING INTO MOLD)	MOLD #28607	1900						
90	SEAL MOLD		1900						

DRG. NO.	36512	DRG REV 02	PLNNG NO.	3	JOB CLASS		FILE			PAGE	2	OF	5
NAME	SLIP RING ASSEMBLY		PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON	36511		DATE	7/14/64			RVSD BY						
F. A. NO.	DP 1505		YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.		ITM	QTY.	SPC	DRG. NO. - MATERIAL
110	PREPARE PLASTIC (E.S. 218) CAST & CURE		1900	PI 79					
120	UNLOAD MOLD, CLEAN AND MOLD RELEASE MOLD		1900						
130	CLEAN FLASH & REMOVE SILASTIC FROM ASSEMBLY		1900						
140	CHECK ON F'SHAFT. TURN CAST SPUD ON BACK OF FLANGE 5/16LG. x .375 DIA. & C. DRILL. ATTACH LEAD PROTECTOR. MOUNT BETWEEN CENTERS. TURN F'SHAFT TO .262 DIA. TURN .350 DIA. STEP TO .155 FROM FLANGE		1900						
160	GRIND (80) GROOVES. 016 WIDE TO .244 DIA. (USE CLEARTEX COOLANT)		1900						
170	REMOVE LEAD PROTECTORS & CLEAN. ATTACH LEAD PROTECTORS AFTER CLEANING		3800	PI 129					
175	INSPECTION (VISUAL)		3919	RL 314					
177	INSPECTION (DIMENSIONAL)		3919	RL 314					
180	SOLDER LEADS TOGETHER FOR PLATING		1900						
190	CLEAN SOLDER JOINT		1900	PI 159					
200	APPLY FLANGE PROTECTOR & APPLY STOP OFF LACQUER TO BEARING PIN		3800	PI 617					
210	COPPER PLATE LEAD ENDS (RECORD S/N OF PULL TEST SAMPLE)	( )	3800	PI 608					
220	COPPER REDUCTION COAT		3800	PI 601					
~~230~~	~~ELECTROFORM COPPER~~		3800	PI 602					

DRG. NO.	36512	DRG REV 02	PLNNG NO.	3	JOB CLASS		FILE			PAGE	3	OF	5
NAME	SLIP RING ASSEMBLY		PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON	36511		DATE	7/14/64			RVSD BY						
F. A. NO.	DP 1505		YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.		ITM	QTY.	SPC	DRG. NO. - MATERIAL
232	CLEAN		1900	PI 143					
240	TURN O.D. F'SHAFT TO .258	(CASTOR OIL &	1900						
	(MOUNT BETWEEN CENTERS)	SOLOX COOLANT)							

DRG. NO.	36512	DRG REV	02	PLNNG NO.	4	JOB CLASS		FILE			PAGE	4	OF	5
NAME	SLIP RING ASSEMBLY			PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON	36511			DATE	10/28/64			RVSD BY						
F. A. NO.	DP 1505			YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.	.	ITM	QTY.	SPC	DRG. NO. – MATERIAL
250	GRIND BARRIERS TO .248 DIA X .014 WIDE. RECORD DIM. FROM END OF BEARING SEAT TO CENTER NO. 1 RING	( )	1900						
260	REMOVE LEAD PROTECTORS & CLEAN ATTACH LEAD PROTECTORS AFTER CLEANING.		1900	PI 129					
270	BRUSH WITH PUMICE TO REMOVE LOOSE PARTICLES OF COPPER.		1900						
275	INSPECTION (VISUAL)		3919	RL 315					
277	INSPECTION (DIMENSIONAL)		3919	RL 315					
279	INSPECTION (CIRCUIT RESIST)		3919	RL 316					
280	SODA BLAST		1600	PI 147					
300	REMOVE LEAD PROTECTOR LOAD MOLD FOR 3rd CASTING	MOLD #28604	1900						
310	SEAL MOLD		1900						
320	PREPARE PLASTIC E.S. 218 CAST & CURE		1900	PI 79					
330	UNLOAD. CLEAN & MOLD RELEASE MOLD		1900						
340	CLEAN FLASH		1900						
350	ATTACH LEAD PROTECTORS. TURN O.D. F'SHAFT TO .287. EXPOSE ORIGINAL BEARING SEAT SHOULDER		1900						
352	CLEAN IF PATCHING OF VOIDS IN F'SHAFT IS TO PRECEDE GRINDING		1900	PI 129					
360	GRIND .016 W. GROOVES TO .255 DIA.		1900						

DRG. NO.	36512	DRG REV 02	PLNNG NO.	4	JOB CLASS		FILE			PAGE	5	OF	5
NAME	SLIP RING ASSEMBLY		PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON	36511		DATE	10/28/64			RVSD BY						
F. A. NO.	DP 1505		YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.		ITM	QTY.	SPC	DRG. NO. - MATERIAL
370	REMOVE LEAD PROTECTORS & CLEAN		1900	PI 129					
	ATTACH LEAD PROTECTORS AFTER								
	CLEANING								
380	CUT OFF SOLDER JOINT & STRIP		1900						
	LEAD ENDS								

DRG. NO.	36512	DRG REV	02	PLNNG NO.	3	JOB CLASS		FILE			PAGE	6	OF	5
NAME	SLIP RING ASSEMBLY			PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON	36511			DATE	7/14/64			RVSD BY						
F. A. NO.	DP 1505			YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.		ITM	QTY.	SPC	DRG. NO. – MATERIAL
383	INSPECTION (VISUAL)		3919	RL 317					
385	INSPECTION (DIMENSIONAL)		3919	RL 317					
387	INSPECTION (CIRCUIT RESIST.)		3919	RL 316					
389	INSPECTION (INSUL. RESIST.)		3919	RL 323					
390	SOLDER LEADS FOR PLATING & CLEAN		1900	PI 159					
400	APPLY FLANGE PROTECTOR & COAT BEARING PIN WITH STOP OFF LACQUER		3800	PI 617					
410	ELECTROPLATE NICKEL		3800	PI 605					
415	INSPECTION (VISUAL)		3919	RL 318					
420	ELECTROFORM GOLD		3800	PI 606					
430	CLEAN		1900	PI 134					
440	TURN O.D. F'SHAFT TO .276 + .0002 = .0015 TURN AND FACE C'SHAFT & BEARING SEAT (HOLD 2.570 length)	CASTOR OIL & SOLOX COOLANT	1900						
450	GRIND V-GROOVES IN GOLD		1900						
455	INSPECTION (DIMENSIONAL)		3919	RL 319					
460	REMOVE LEAD PROTECTORS & CLEAN ATTACH LEAD PROTECTOR AFTER CLEANING		1900	PI 129					
470	REMOVE ANY REMAINING SILASTIC. PATCH ANY AIR BUBBLES IN FLANGE.		1900						
475	INSPECTION (CKT RESIST.) REPRODUCIBLE COPY		3919	RL 320					
476	DISASSEMBLE		1900						
480	SURFACE CONDITION E.S. 89		1600						

DRG. NO.	36512	DRG REV 02	PLNNG NO.	3	JOB CLASS	FILE		PAGE	7	OF	5
NAME	SLIP RING ASSEMBLY		PLNND BY	W. H. STARKEY		PLNNG REV					
USED ON	36511		DATE	7/14/64		RVSD BY					
F. A. NO.	DP 1505		YIELD			DATE					

OPERATION INFORMATION

NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.	
490	SODA BLAST - WET		1600	PI 147	
500	SODA REMOVAL		1600	PI 143	
510	APPLY FLANGE PROTECTOR		3800	PI 617	

BILL OF MATERIAL

ITM	QTY.	SPC	DRG. NO. - MATERIAL

DRG. NO.	36512	DRG REV 02	PLNNG NO.	4	JOB CLASS		FILE			PAGE	8	OF	5
NAME	SLIP RING ASSEMBLY		PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON	36511		DATE	10/28/64			RVSD BY						
F. A. NO.	DP 1505		YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.		ITM	QTY.	SPC	DRG. NO. - MATERIAL
520	APPLY GOLD FLASH .0004 THICK		3800	PI 607					
530	CLEAN		1900	PI 143					
535	INSPECTION (VISUAL)		3919	RL 321					
537	INSPECTION (DIMENSIONAL)		3919	RL 321					
550	TEMPERATURE CYCLE		3919	RL 337					
560	CUT LEADS & STRIP		1900						
565	INSPECTION (VISUAL) PULL TEST		3919	RL 322					
	MUST BE PERFORMED BEFORE								
	CONTINUING WITH NEXT OPERATION								
567	INSPECTION (DIMENSIONAL)		3919	RL 323					
569	INSPECTION (INSUL.RESIST.)		3919	RL 323					
570	SOLDER SLIP RING LEADS TOGETHER.		1900	PI 159					
	CLEAN SOLDER JOINT.								
999	DELIVER TO SUB-STORAGE		1900						

DRG. NO.	36514	DRG REV 02	PLNNG NO.	2	JOB CLASS		FILE			PAGE	1	OF	1
NAME	BRUSH BLOCK ASSEMBLY		PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON	36511 (ODD)		DATE	12/16/64			RVSD BY						
F. A. NO.	DP 1505		YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.		ITM	QTY.	SPC	DRG. NO. - MATERIAL
10	WELD LEAD TO JUNCTION PLATE		1900	PI 909					
15	PULL TEST (S/N PULL TEST SAMPLE( ))		3900	PI 950					
17	INSP-VISUAL (WELD JOINTS)		3919	RL 303					
20	LOAD MOLD	MOLD #28730	1900	MI 200					
30	SEAL MOLD		1900						
40	PREPLASTIC (ES 209) CAST & CURE		1900	PI 75(02)					
50	UNLOAD, CLEAN AND MOLD RELEASE MOLD. MARK SERIAL NO. ON PART		1900						
60	CLEAN FLASH. APPLY LEAD PROTECTOR		1900						
70	MILL BRUSH BLOCKS TO LENGTH. MILL OFF JUNCTION PLATE	FIXT #28731	1000						
80	TEMPERATURE CYCLE			RL 306					
100	GRIND V-GROOVES(USE CLEARTEX COOLANT)	FIXT #28731	1900						
110	CLEAN(SLIP LEAD PROTECTOR BACK FROM PLASTIC DURING CLEANING. REPLACE AFTER CLEANING)		1900	PI 129					
120	SODA BLAST TERMINAL PLATES		1600	PI 147					
130	CHROMATE TERMINAL PLATES(E.S.44)		1600						
140	HEAT STRIP LEAD ENDS		1900						
145	INSPECTION (VISUAL)		3919	RL 307					
147	INSPECTION (DIMENSIONAL)		3919	RL 307					
149	INSPECTION (INSULRESIST)	REPRODUCIBLE COPY	3919	RL 304					
999	DELIVER TO SUB-STORAGE								

DRG. NO.	36512 36678	DRG REV	03	PLNNG NO.	8	JOB CLASS		FILE			PAGE	1	OF	3
NAME	CAPSULE ASSEMBLY			PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON				DATE	12/16/64			RVSD BY						
F. A. NO.	DP 1505 DP 1500			YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.		ITM	QTY.	SPC	DRG. NO. - MATERIAL
10	INSTALL TEMPORARY BEARINGS IN FRAME. ASSEMBLE DUMMY SLIP RING. APPLY NUT & ADJUST TO OBTAIN CORRECT END PLAY. ASSEMBLE BRUSH BLOCKS & INSTALL SCREWS WITH LIGHT PRESSURE. INSTALL (2) 1/4" WIDE RETAINING RINGS.		1900		BRUSH BLOCK S/Ns _____				
20	MOUNT ASSEMBLY BETWEEN CENTERS ON COMPARATOR. SHIFT BRUSH BLOCKS TO OBTAIN OPTIMUM ALIGNMENT OF BRUSH BLOCK GROOVES WITH SLIP RING GROOVES. SECURE SCREWS.		1900		BRUSH RECEIVING REPORT # _____				
30	DRILL (2) .0625 DOWEL HOLES IN FRAME USING BRUSH BLOCKS AS JIG.		1900						
40	CLEAN DOWEL HOLES WITH CHLOROTHENE SPRAY		1900						
50	INSTALL DOWELS		1900						
60	TIN JUNCTION PLATES		1900						
70	CLEAN		1900	PI 176					
80	INSTALL BRUSHES. SOLDER BRUSHES TO TERMINAL BARS. CLEAN IMMEDIATELY AFTER THE SOLDERING OF EACH BLOCK IS COMPLETE		1900	PI 176					
90	TAG LEADS (BRUSH BLOCK)		1900						
95	INSP-CKT RESIST. (REPRODUCIBLE COPY)		3919	RL 329					

DRG. NO.	36512 36678	DRG REV	03	PLNNG NO.	8	JOB CLASS		FILE			PAGE	2	OF	3
NAME	CAPSULE ASSEMBLY			PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON				DATE	12/16/64			RVSD BY						
F. A. NO.	DP 1505 DP 1500			YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.		ITM	QTY.	SPC	DRG. NO. – MATERIAL
100	REMOVE BRUSH BLOCKS AND MOUNT ON HANDLING FIXTURE. REMOVE DUMMY SLIP RING. REMOVE TEMPORARY BEARINGS. DEBURR DOWEL HOLES.	FIX #29243 #29371 DP 1500 DP1505							
110	CLEAN BRUSH BLOCKS ON HANDLING FIXT. CLEAN FRAME & MISC. COMPONENTS		1900	PI 174					
120	CEMENT NAMEPLATE		1900						
	ALL FOLLOWING OPERATIONS ARE TO BE PERFORMED UNDER CLEAN BENCH								
130	CLEAN SLIP RING		1900	PI 175					
140	CLEAN BRUSH BLOCKS & ALL OTHER COMPONENTS EXCEPT BEARINGS		1900	PI 177					
150	CLEAN & LUBRICATE NEW BEARINGS		1900	PI 161					
170	INSTALL NEW BEARINGS IN FRAME. INSTALL SLIP RING. INSTALL COLLAR & NUT. TIGHTEN NUT TO OBTAIN CORRECT END PLAY. CEMENT NUT WITH ES 199 PLASTIC		1900				BEARING	S/N	LG SM
180	ASSEMBLE BRUSH BLOCKS WITH SLIP RING & FRAME ASSY. APPLY LOCTITE TO BRUSH BLOCK SCREWS. ASSEMBLE HOUSING & CHECK FIT BUT DO NOT SECURE	NOTE: APPLY 1-1/2 IN-OZ TORQUE TO TIGHTEN	1900						
190	1ST RUN-in 2 HRS @ 100 RPM		1900	PI 701					
193	INSPECTION (DIMENSIONAL)		3919	RL 336					
195	INSPECTION (INTERNAL VISUAL)		3919	RL 330					
197	INSPECTION (X-RAY) NOTE: THIS OPERATION MAY BE PERFORMED AFTER OPERATION #289		3919						

DRG. NO.	36512 36678	DRG REV 03	PLNNG NO.	8	JOB CLASS		FILE			PAGE	3	OF	3
NAME	CAPSULE ASSEMBLY		PLNND BY	W. H. STARKEY			PLNNG REV						
USED ON			DATE	12/16/64			RVSD BY						
F. A. NO.	DP 1505 DP 1500		YIELD				DATE						

OPERATION INFORMATION						BILL OF MATERIAL			
NO.	DESCRIPTION	TOOLING	DEPT	PROC. INST.		ITM	QTY.	SPC	DRG. NO. – MATERIAL
200	CHECK TORQUE		3900	RL 322					
210	CHECK NOISE		3900	RL 333					
220	RUN-IN (100+10 HRS) AT 5 RPM		3900	PI 702					
230	REMOVE HOUSING FOR INSPECTION		1900						
233	INSPECTION (VISUAL) DOD WITNESS		3919	RL 334					
235	INSPECTION LOCTITE TORQUE TEST		3919	RL 338					
240	REASSEMBLE HOUSING. APPLY LOCTITE TO SCREWS & SECURE	NOTE: APPLY 1/2 IN-OZ TORQUE							
245	INSP-(CKT RESIST) (REPRODUCIBLE COPY) (DOD WITNESS)		3919	RL 331					
250	CHECK NOISE		2000	RL 333					
260	CUT OFF SOLDER JOINT		1900						
262	TAG SLIP RING LEADS		1900						
265	INSP (INSUL RESIST), HI-POT & CON'T. REPRODUCIBLE COPY (DOD WITNESS)		3919	RL 331					
270	CHECK TORQUE (DOD WITNESS)		2000	RL 332					
280	CUT LEADS TO LENGTH. DO NOT STRIP		1900						
285	INSPECTION (LEAD LENGTH)		3919	RL 336					
287	LOCTITE TORQUE TEST		3919	RL 338					
289	INSPECTION (VISUAL)		3919	RL 336					
999	PACKAGE		1900	PM 73					

4.0 DESIGN

4.1 Design of 38 and 80 Circuit Assemblies
by Frank Gordon, Product Engineer

4.2 Applications to Other Parts
by James A. Young, Senior Engineer

4.3 Continuous Rotating Capsule
by Robert B. Keel, Development Engineer

4.4 Brush Forming
by Wayne Starkey, Manufacturing Engineer

4.5 Tooling
by James Cherry, Tool Designer

4.6 Reliability Controls Development
by R. E. Wrenn, Process Control Coordinator

4.1 DESIGN OF 38 AND 80 CIRCUIT ASSEMBLIES

4.1.1 Introduction

The earliest slip ring capsule assemblies procurred by NASA for the Saturn program were standard commercial components with certain special modifications. These units were built to standard specifications of design, structure, workmanship, quality and performance which had proven satisfactory in many flight hardware systems. Extensive tests by NASA indicated, however, that a number of improvement areas were required to develop the reliability necessary for manned space flight.

These results pointed to the need for improved design, processing, workmanship and controls as well as technological development. In this section, the solutions to the significant design problems are discussed.

4.1.2 Initial Work

The first phase of this program concentrated most heavily upon the material and process aspects of the program. During this phase, and well into Phase II, the effort was principally directed toward slip ring subassemblies by the casting process concept which offered the greatest versatility of contact materials. In the period, lead conductors were drastically improved, plastics of very low expansion were developed, improvements of stator design were initiated, and contacts were improved. Subsequently, because of the significant parallel developments which had been made in the quality and control of electrodeposited gold, it was decided that all work should be channelled into the single process concept for manufacturing slip ring assemblies - electrodeposition. This decision resulted in several changes of processes which naturally affected the design of the slip ring subassembly. Since all of the design, process, and materials developments throughout the program are so interrelated we shall discuss the design, feature by feature.

4.1.3 Slip Ring Subassembly

4.1.3.1 Reinforcement - One of the first detected

problems of the structural integrity was the adherance of the small bearing pin to the plastic of the slip ring body. These bearing pins were subject to pull out when the pin/plastic interface was under extreme mechanical or thermal stresses. As a direct result of the consideration and use of a variety of reinforcing members, the following principles have been evolved.

4.1.3.1.1 The principal purposes of a reinforcing member are to provide flexural support for the slip ring subassembly during fabrication and tensile support to the capsule assembly.

4.1.3.1.2 A reinforcing member is not desirable for use with unfilled plastics which have adequate strength and rigidity. Unfilled plastics as a class have high coefficients of thermal expansion. The resulting differential between plastic and metal reinforcement will create axial (and radial) stress conditions producing problems of eccentricity and stress cracks. (When a reinforcing member is not used, bearing seats must have adequate anchoring incorporated into the design.)

4.1.3.1.3 The use of a reinforcing element is essential to the fabrication of reliable slip ring subassemblies produced with filled plastics. Filled plastics, even those with very low filler content, have much lower strength than unfilled plastics, resulting in fragile subassemblies.

4.1.3.1.4 To be effective, the reinforcing members must have sufficient rigidity and strength to support the rotor assembly. Cross sections with the highest moment of inertia to area ratios are most desirable. Tubular sections are structurally excellent but create fabrication problems in lead routing. Cruciform (4 rib) sections are the most desirable for use with electrodeposited designs permitting convenient spacing of leads and lead exits. Triform (3 rib) sections are convenient for minimum space allowance in cast designs since leads are naturally spaced into 60° and 120° lattices. Round cross sections are adequate to all concepts of manufacture where adequate space exists for shaft and leads.

4.1.3.1.5 Reinforcing members must not be locked mechanically or bonded to the plastic along

its entire length without adequate expansion (contraction) allowance.

4.1.3.1.6 The most structurally stable assembly is one in which the reinforcing member, the bearing seats, the assembly nut and the flange (or backshaft) for the slip ring subassembly are made from a single piece of metal. This is the concept specifically evolved for this program. Dwg. # 36513 shows a reinforcing member of the 80-circuit assembly. Such a design has eliminated bearing pin failures and fractured slip ring shaft in these designs.

4.1.3.2 Grooves - One of the problems found to exist in the slip ring capsule assemblies, as originally designed, was that of performance. The performance criteria which was of a particular problem was electrical contact resistance variation, or noise. The noise performance of a slip ring assembly depends in part upon the relative stability of the brush and ring surface as they slide together. The earliest studies on this program showed that grooves of V-shape with a 90° included angle are quite effective at stabilizing the brush with respect to axial motion relative to the slip ring surface. The use of the V-groove does in fact, reduce contact noise, but with a slight sacrifice of low friction, or torque.

The choice of V-groove angle as 90° is nearly optimum. It is, in fact, a compromise between the increase in torque and the improvement of noise. The torque is proportional to the cosine of the included half angle of the V-groove. Probably the most critical factor in the shape of the groove, is the radius at the bottom of the groove. This radius must at all times be kept small enough so that there is a definite clearance between the bottom of the brush and bottom of the groove. It has been found that a one mil radius at the bottom of the groove is normally the smallest radius which can be reliably maintained. This means that to maintain a desirable one mil clearance, angles more acute than 90° must be specified for wipers smaller than .007.

The use of groove angles more acute than 90° requires an increase in ring thickness to allow for the greater depth of the groove. This increase in ring thickness can often increase critical slip

ring diameter requirements.

Where axial space has permitted, two grooves have been designed into each ring to enable the use of double brushes. The double brush, each with two wipers for a total of four wipers has been found to increase the reliability and lower the noise level of the slip ring circuit. Double grooves normally require about one and one-half times as much axial space as a single groove. Where axial space is at a premium, the use of double grooves severely increases the tightness of all required tolerances, on ring, groove, and brush location. Under this program, 80-circuit assemblies of single and double groove circuits have been designed, as well as a double groove 38-circuit assembly.

4.1.3.3 Ring Material - The ring materials for contacts has been extensively discussed in Section 2.1. The choice of material does not directly affect the design configuration: the choice of process does. It had been found, during the program, that accuracy of ring spacing was more difficult to achieve with the pre-cut rings than by electroforming. This selection of electroforming improved the ring spacing and therefore improved the accuracy of brush to groove alignment.

The principal design feature which is affected by the use of the electrodeposition process is the ring connection. With wrought rings, joints were made by soldering or welding (see Section 3.7). With electrodeposited rings, the joint is formed by deposition directly to the wire. This required that the wire present a solid face to the plating solution with no possible avenues of solution entrapment. For this reason, a solid jumper wire is used between the ring and the hook-up wire exiting the assembly and necessitates a joint between the two.

Efforts have been made to eliminate the jumper but more remains to be done (Section 3.2).

A combination of the material choices, their hardness and their finish, as well as the shape of the grooves have largely eliminated wear-out and noise as a cause of contact malfunction when tested in the mode specified for Saturn gimbal capsule assemblies.

4.1.3.4 Surface Finish - One of the sources of failure frequently found in early assemblies, was that of erratic wear-out of the contact surface. This type of failure has been virtually eliminated by the development of an improved slip ring surface finish. The surface finishing processes have been discussed extensively in Section 3.6 of this report. The final choice of surface finish used for slip ring assemblies produced under this contract consists of a matte finish applied to the gold ring by soda blasting with an overlay of .0004 inch gold plate in excess of 150 Knoop hardness.

4.1.4 Frame

The frame is the major structural member of the stator. It is machined in its entirety from a single piece of stainless steel and incorporates the bearing seats. The frame must supply the alignment and support for the brush assemblies, and provide a means for attaching the housing. It must match closely the coefficient of expansion of the rotor, as well as the two brush assemblies mounted to it.

4.1.4.1 The earliest design of assemblies in this program, consisted of frames with two longitudinal members running between bearing seats. This two-member frame supported plastic brush insulators which were cemented to it. The two-member frame had adequate strength for the particular design, but the cemented-on brush insulators were not adaptable to removal for cleaning, inspection or other purposes. This required a change of frame concept.

4.1.4.2 The four-member frame - In order to incorporate the feature of removability to the brush block, it was necessary to add locating and retaining devices to mount and dismount the brush assembly. This had to be done with minimum axial space utilization. To accommodate this, a four-member frame was conceived and developed. The four-member frame allows the brush blocks to be firmly seated and accurately located on flat surfaces by spanning two of the members. The other brush block is similarly located on the other side. The two brush block support members are each effectively divided into two members by an axial slot in the frame. This slot, running the

entire length of the assembly, enables inspection of the brush contact points with the brush assembly in place, therefore, giving a four-membered frame. The four members of the frame provide more support and stiffness than would be required for any miniature capsule assembly. (See Dwg. No. 36516.)

4.1.4.3 One of the principle features required in any frame is a method of attachment of the housing to the frame. The earliest method used for these assemblies was a simple pin cemented into place through the housing into the frame. This, however, made the removal of the housing almost impossible. Subsequent methods tried include the use of a radially tapped hole fitted with a screw which performed the same function as the cemented-in dowel. Since the screws must almost always be locked with cement or locking compound, this presented many of the same problems as the cemented-in pin and at the additional disadvantage of tending to radially misalign the housing O.D. with the frame.

To continue the use of screws, but avoid radical misalignment, the subsequent design had a strap across the end of the capsule assembly which clamped the housing against a small flange or rim on the other end of the frame. This placed the housing in compression and the frame members in tension. Since the strap was held in place with two axial screws, this was an improvement, but it could result in some distortion of the frame and misalignment of the bearing seats if the screws were not equally tightened.

The present housing, which is believed to be the best, consists of an integral strap and housing which is machined from one piece of metal. This strap, too, is held on by axial screws, but since there is no clamping action, there is no tension in the members of the frame, and therefore, no tendency to twist the frame.

4.1.5 Stator Design Advancements

4.1.5.1 Removable Brush Blocks - As has been stated above, the earliest slip ring assemblies utilized brush assemblies which were cemented to the frame. Since this presented some problems in ability to remove the brush assembly, it was decided that removable brush assemblies would be required. Over the period of the program, a number of methods of attaching the removable

brush blocks have been considered. Only the best of these concepts have been reduced to practice.

The earliest concept of the removable brush block consisted of a brush assembly and frame which had V-grooves at each end. The V-grooves were machined simultaneously into the brush block and into the frame, after the brush block had been located at the proper position. The brush assembly was held in place with respect to the frame by use of two retaining rings, which maintained the axial position as well as the radial support of the brush assembly. There were, however, some disadvantages to this concept in that tolerances were fairly close between the retaining rings and the housing and the frame and brush block and the retaining rings were somewhat difficult to install and remove. In addition, the accuracy of alignment and position was obtained only when the housing was in place.

Subsequently, when an additional axial space was made available on the 80-circuit assembly, screw holes were installed in the brush block design and mating tapped holes were located in the frame. Two screws and a dowel were then used to provide both the alignment and the retention required for each brush assembly. This has worked satisfactorily. This design does depend entirely upon the accuracy of the location of the dowel in both the brush assembly and the frame.

4.1.5.2 Brush Design - The original brush design prior to the program was a Poly-Scientific concept quite similar in appearance to the present brush in that it was triangular in form,it was installed over the brush assembly and onto the slip ring and then locked into place. It did, however, have a round cross section which was flattened to increase its stiffness. It is made of a heat-treated precious metal alloy E.S. 55. The flattening was done after the heat-treating operation, which could result in over-working of the metal. This was found to contribute to brush breakage. Present day brushes are all of round cross section and formed from a work-hardened (not heat-treated) alloy of precious metal E.S. 57. It is necessary because of the high gold content of the present brush alloy to protect it from amalgamation with solder during the brush soldering operation. This is

done by plating a thin deposit of nickel on the area to be soldered and then overplating with a film of gold. The nickel acts as a barrier and the gold serves to improve the adhesion of the solder to the brush.

4.1.5.3 Brush Assembly Design - The earliest assembly used on the capsules consisted of the triangular shaped brush which was fitted into slots in the plastic brush insulator and onto the ring. These brushes were cemented into place on the insulator, and the leads were soldered to the back of the brushes. A layer of epoxy cement was flowed over the solder joints for insulation protection. This design had a number of disadvantages:

1) The brush location could be affected by any disturbance during the curing of the cement.

2) The brush location and force could be disturbed during the soldering of the leads when the brush and plastic were being heated.

3) The curing of plastic in the vicinity of the contact (brush or ring) could cause harmful films to form on the surface of the contacts.

4) The lead wires were not encapsulated in plastic and therefore could interfere with the effective function of the brush.

A much improved design, conceived under Phase I by Poly-Scientific, was developed during the course of the program which solved all of these problems and provided a convenient means for brush alignment also. This was the concept of the junction bars. The junction bar consists of a series of brass bars to which the leads are welded. In most cases, these bars are machined into a single piece of brass known as a junction plate. After the casting and curing is complete, the back of the plate is cut away, leaving only the precisely located individual junction bars. V-grooves are ground to match exactly the location of the corresponding V-groove on the slip ring sub-assembly. The grooves on the junction bars align the brushes to a "dummy" slip ring prior to soldering into position.

There is no subsequent casting or curing to affect the contacts; there is no danger of leads interfering with the performance, since they are cast into the brush assembly, there is no danger of brush misalignment, due to subsequent operations since there are none, except cleaning; and the use of grooves for alignment between brush and ring have provided a bonus in the accuracy of brush-to-ring alignment of better than .0015.

4.1.5.4 Special considerations for the 38-circuit stator - The 38-circuit assembly with its small capsule diameter of 3/8 inch has presented special problems, during the entire program. 38-leads, each having a diameter of approxiamtely 0.030 of an inch, take up nearly all of the angular space at the back of the capsule. The 3/8 diameter capsule does not provide sufficient space for a conventional removable brush assembly and the four-member frame mentioned above, but the brush assembly itself, of this size, does not have sufficient strength without the support of a frame.

The result is that the 38-circuit brush assembly has required unique design solution to incorporate the principle features developed under the program. This design makes use of the entire angular space for leads by cementing the brush assembly to the frame. The brush assembly was made removable by the frame being made as a two piece member. The two pieces are made at the same time, thereby, giving accuracy of alignment and dimension. The entire assembly is held together by the housing, which with a close fit over the stator results in good retention. This design features all of the advantages developed for the 80-circuit assembly with the exception of the requirement for a plastic pin to hold the housing to the frame. This general type of capsule was conceived and developed at Poly-Scientific specifically for this program and applied to solve this particular problem. It has proven quite reliable in other applications and it is believed at this time to be the only concept which will meet the intent of the specification within the size allowed.

4.1.6 Assembly

The entire capsule assembly is held together by a bearing nut which loads the slip ring in tension and the frame in compression. A unique ball and

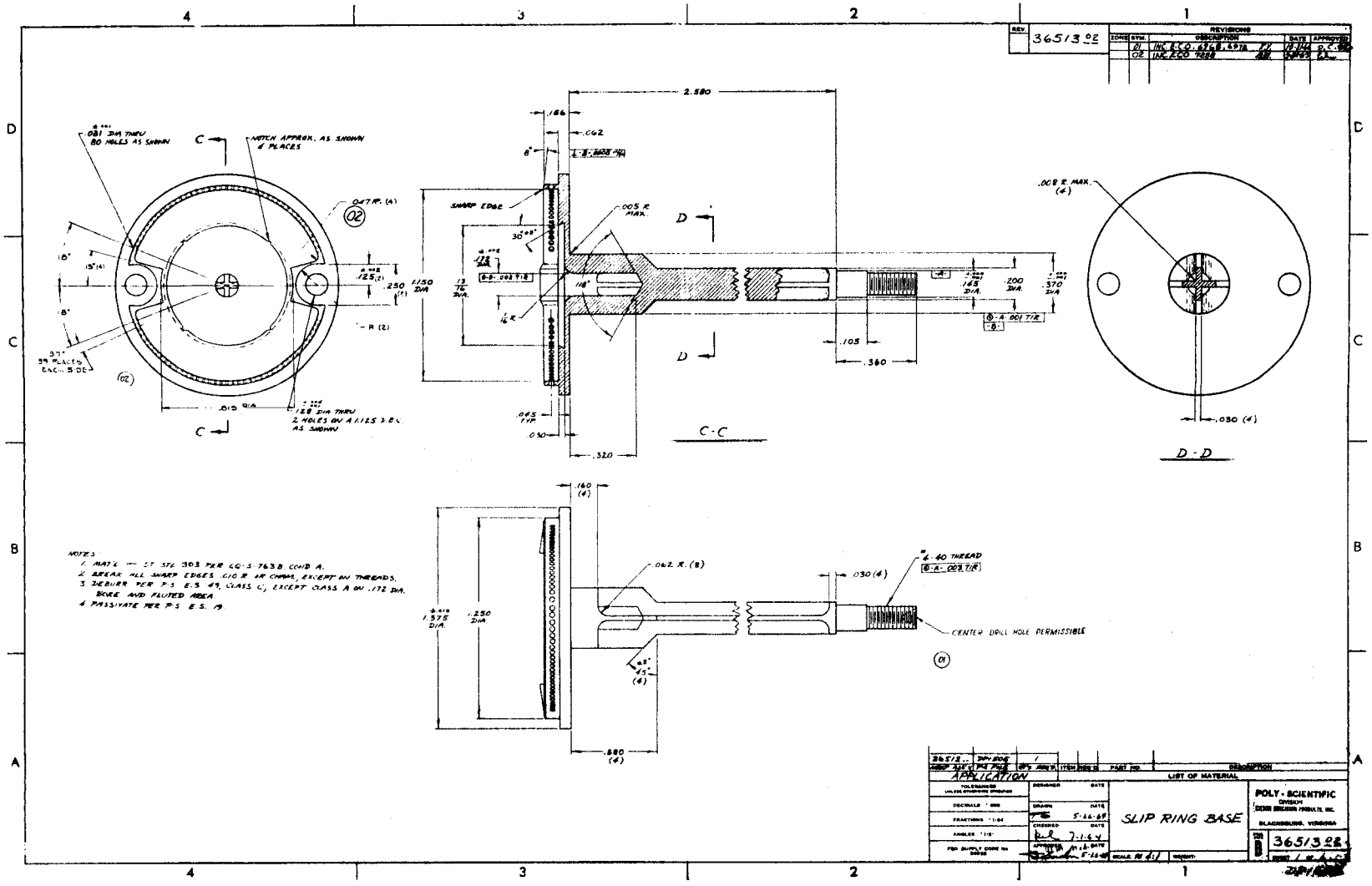
socket joint is provided by a spherical washer and a counter-sunk retention nut. This permits adjustment of the end play without danger of cocking the inner race of the bearings (see also Section 2.5).

4.1.7 Conclusion

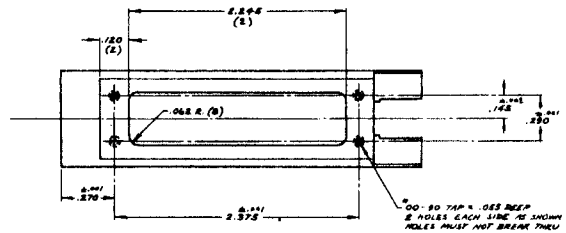
The continuing emphasis on the improvement of design during the course of the program has produced a group of design concepts which collectively applied have eliminated or drastically reduced all of the failure modes observed on earlier capsule assemblies for the Saturn guidance application. The improvement has been demonstrated by successful environmental tests, 100 times improvement of insulation resistance and 1,000 times improvement in mean time between circuit malfunctions.

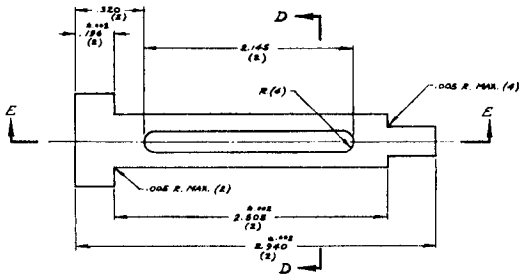
APPENDIX 4.1-I

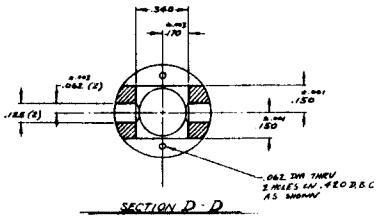
DRAWINGS

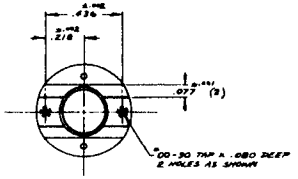

.081 DIA THRU 80 HOLES AS SHOWN
NOTCH APPROX. AS SHOWN 4 PLACES
.047 TYP. (4)
02
.810 DIA
.128 DIA THRU 2 HOLES ON A 1.125 B.C. AS SHOWN
2.580
.166
.062
SHARP EDGE
.005 R MAX.
.118
.105
.360
.045 TYP.
.030
.320
C-C
D-D
.009 R MAX. (4)
.030 (4)
.160 (4)
.062 R. (8)
.030 (4)
6-40 THREAD
CENTER DRILL HOLE PERMISSIBLE
01
1.375 DIA.
.250 DIA
.880 (4)
NOTES:
1. MATL — ST. STL. 303 PER QQ-S-763B, COND A.
2. BREAK ALL SHARP EDGES .010 R OR CHAM, EXCEPT ON THREADS.
3. DEBURR PER P.S. E.S. 49, CLASS C, EXCEPT CLASS A ON .172 DIA. BORE AND FLUTED AREA.
4. PASSIVATE PER P.S. E.S. 19
APPLICATION
LIST OF MATERIAL
SLIP RING BASE
POLY-SCIENTIFIC
365132
365132 02
REVISIONS
02 INC. ECO 6768, 6978
01 INC. ECO 7288

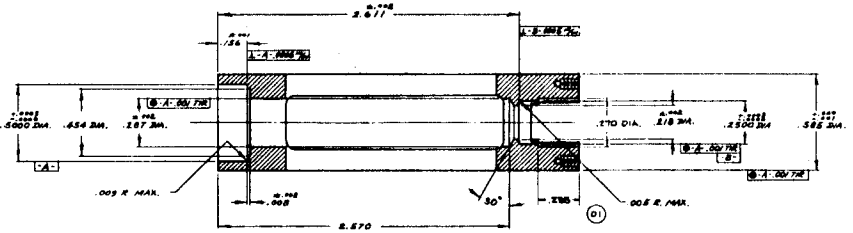
REV.	REVISIONS				
	ZONE	SYM	DESCRIPTION	DATE	APPROVED
01		01	CHANGED PER E.C.O. 3614	11-4-69	R.D.M.











SECTION E - E

NOTES:
1. MAT'L. — ST. STL. 303 PER QQ-S-763B, COND A
2. BREAK ALL SHARP EDGES .010 R OR CHAM.
3. DEBURR PER P.S. SPEC. 49, CLASS C.
4. PASSIVATE PER P.S. SPEC. 19.

ITEM	PART NO.	DESCRIPTION
		LIST OF MATERIAL

APPLICATION

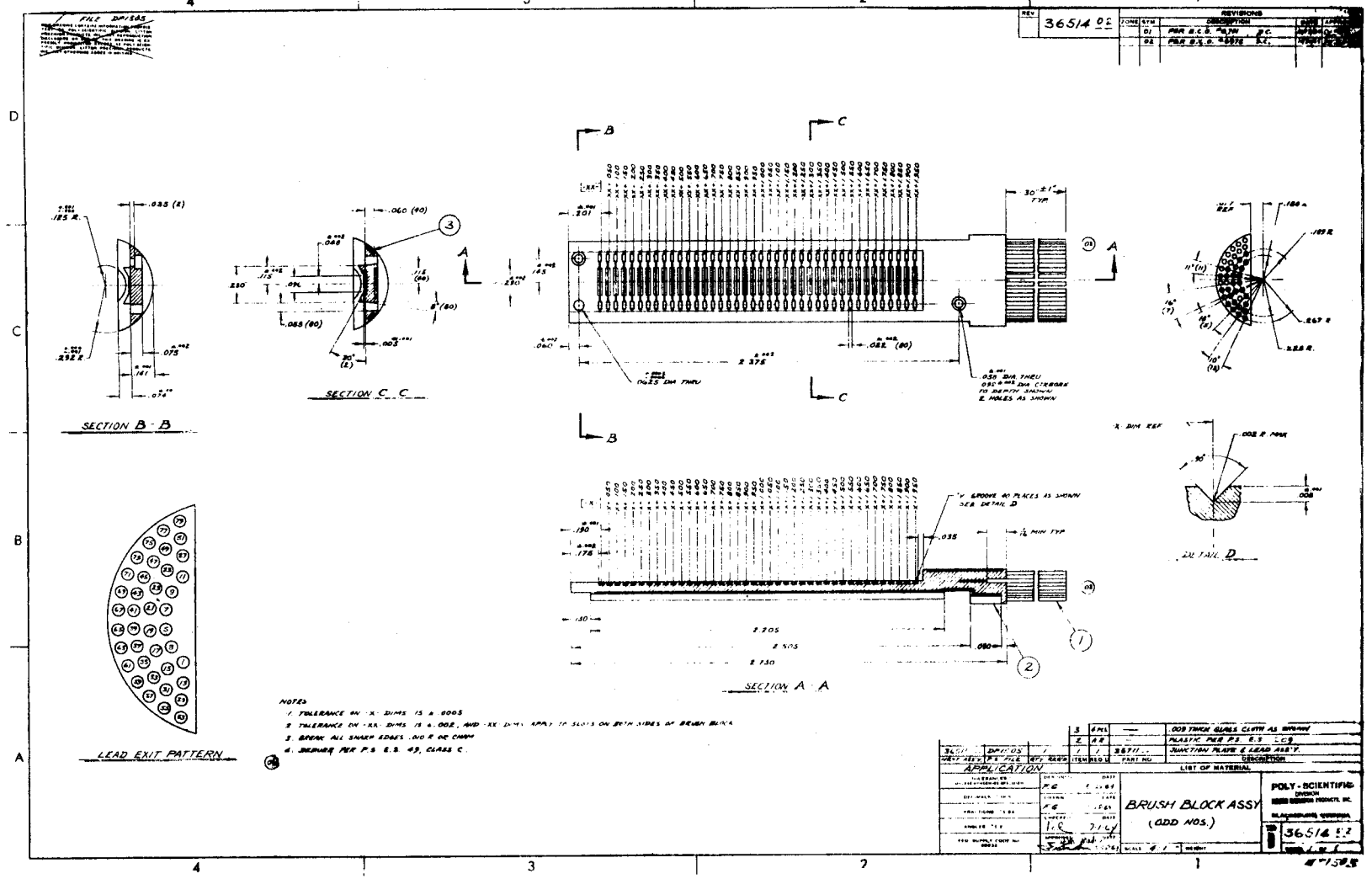
	DESIGNED	DATE
TOLERANCES UNLESS OTHERWISE SPECIFIED	PE.	5-26-69
DECIMALS ± .005	DRAWN	DATE
	PE.	5-26-69
FRACTIONS ± 1/64	CHECKED	DATE
ANGLES ± 1°	RR	7-1-69
FED. SUPPLY CODE NO.	APPROVED	DATE
		5-26-69

FRAME

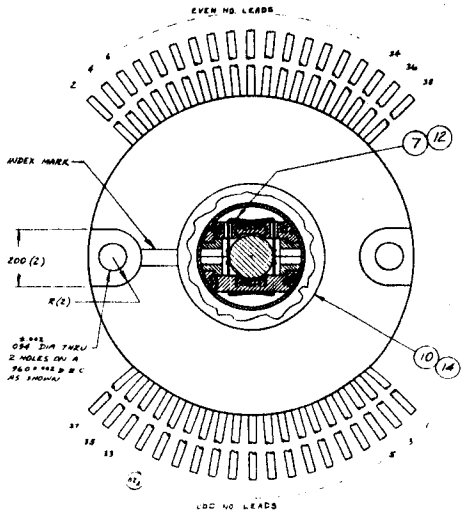
Poly Scientific Corporation
BLACKSBURG, VIRGINIA

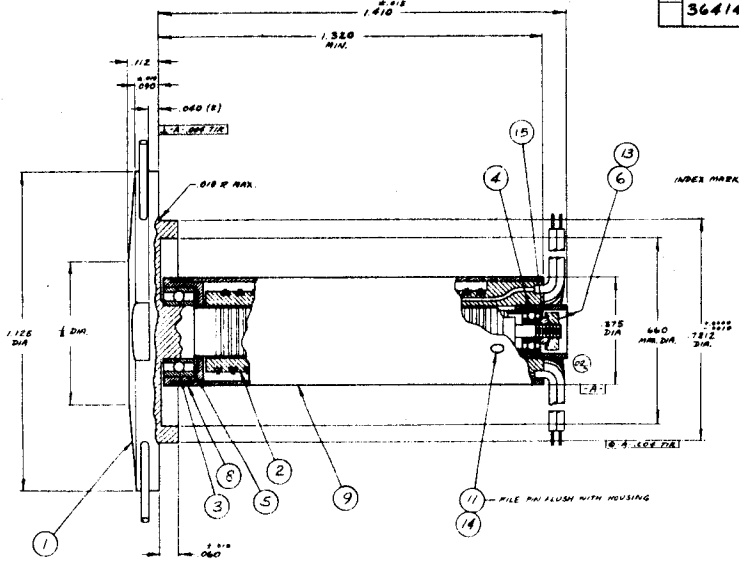
SIZE D — 365161

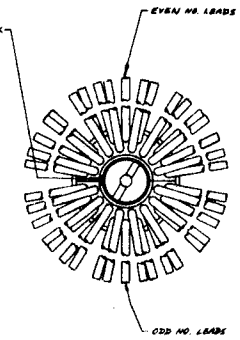
SCALE 1/2 — SHEET 1 OF 1


SECTION B-B
SECTION C-C
SECTION A-A
LEAD EXIT PATTERN
DETAIL D
NOTES:
1. TOLERANCE ON "X" DIMS IS ± .005
2. TOLERANCE ON "XX" DIMS IS ± .002, AND "XX" DIMS APPLY TO SLOTS ON BOTH SIDES OF BRUSH BLOCK
3. BREAK ALL SHARP EDGES .010 R OR CHAM
4. DEBURR PER P.S. 6.5. 49, CLASS C
REVISIONS
APPLICATION
LIST OF MATERIAL
BRUSH BLOCK ASSY
(ODD NOS.)
POLY-SCIENTIFIC
DIVISION
36514 01
36514 02

FILE: DP1452







NOTES:
1. LEAD LENGTH MUST BE SUFFICIENT TO TAG EACH LEAD WITH PROPER CIRCUIT NO. WITHIN 3/8" OF FREE END.
2. MARK WITH SERIAL NO. & SHIPPING DATE IN PROPER LOCATION ON NAMEPLATE. SHIPPING DATE MUST INCLUDE MONTH & YEAR.
3. THE BRUSH BLOCK "I" GROOVES AND SLIP RING "I" GROOVES MUST BE ALIGNED WITHIN .002.
4. AXIAL PLAY BETWEEN ROTOR & STATOR MUST BE .000 - .003 WITH A 100 GM. REVERSING LOAD.

REV	36414 09

REVISIONS

ZONE	SYM	DESCRIPTION	DATE	APPROVED
D-2	01	DASH 2 AND DASH 3 OF SER. 36400 DIV. WAS ASSY. 36414	7-10-64	
	05	PER ECO 6782	7-24-64	
	08	PER E.C.O. 6781	8/19/64	
	09	PER ECO # 7434	10-2-64	

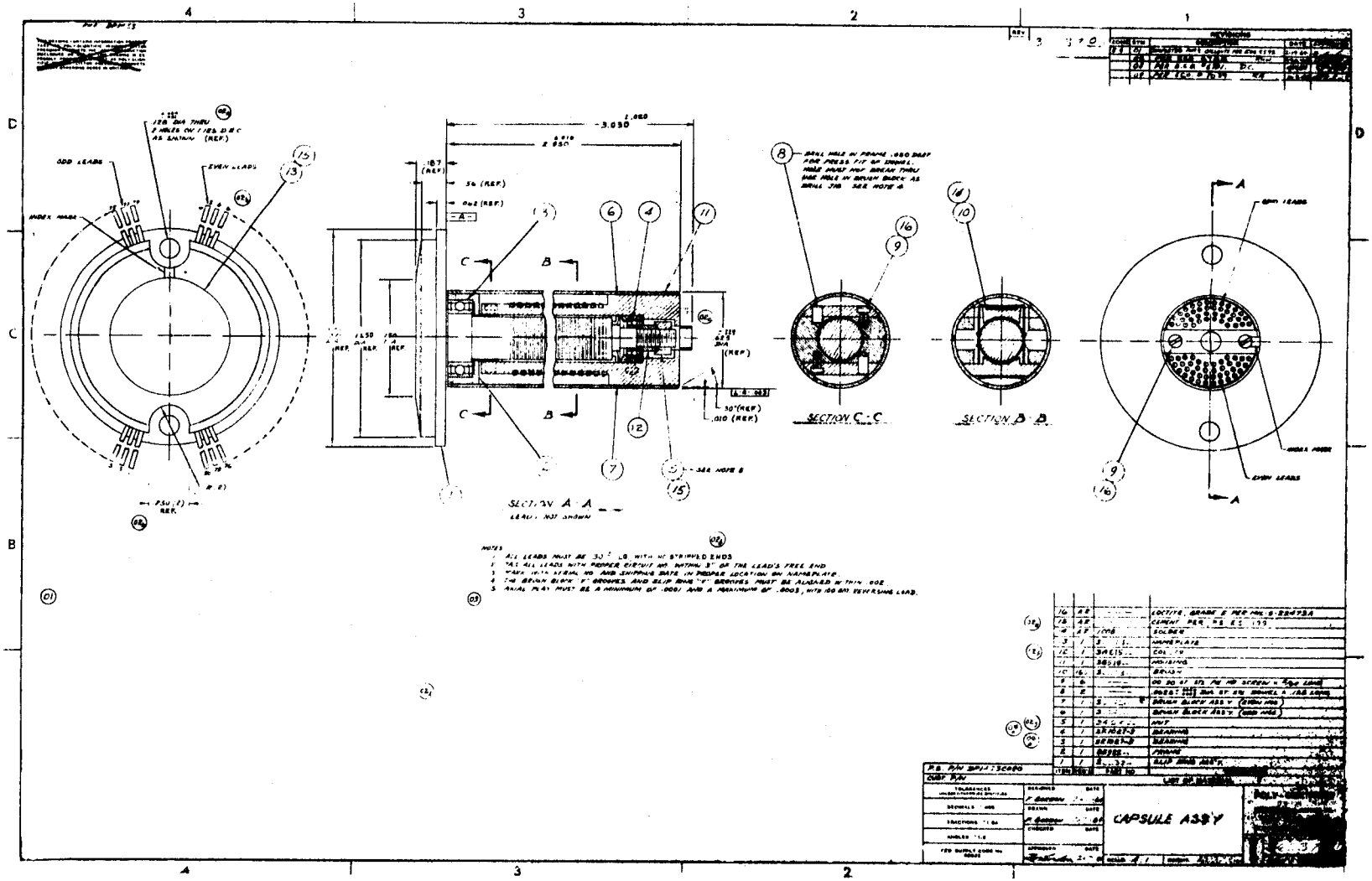
ITEM	REQ'D	PART NO.	DESCRIPTION
15	1	36613..	COLLAR
14	AR	——	CEMENT PER MS E.S. 193
13	AR	——	CEMENT PER MS E.S. 195
12	AR	1008	SOLDER
11	1	36507..	RETAINING PIN
10	1	36506..	NAMEPLATE
9	1	36505..	HOUSING
8	1	36504..	RETAINING RING
7	76	36503..	BRUSH
6	1	36502..	NUT
5	(REF)	36501..	SHIM
4	1	3E1077-6	BEARING
3	1	3E1027-7	BEARING
2	1	36456..	BRUSH BLOCK & FRAME ASS'Y.
1	1	36415..	SLIP RING ASS'Y.

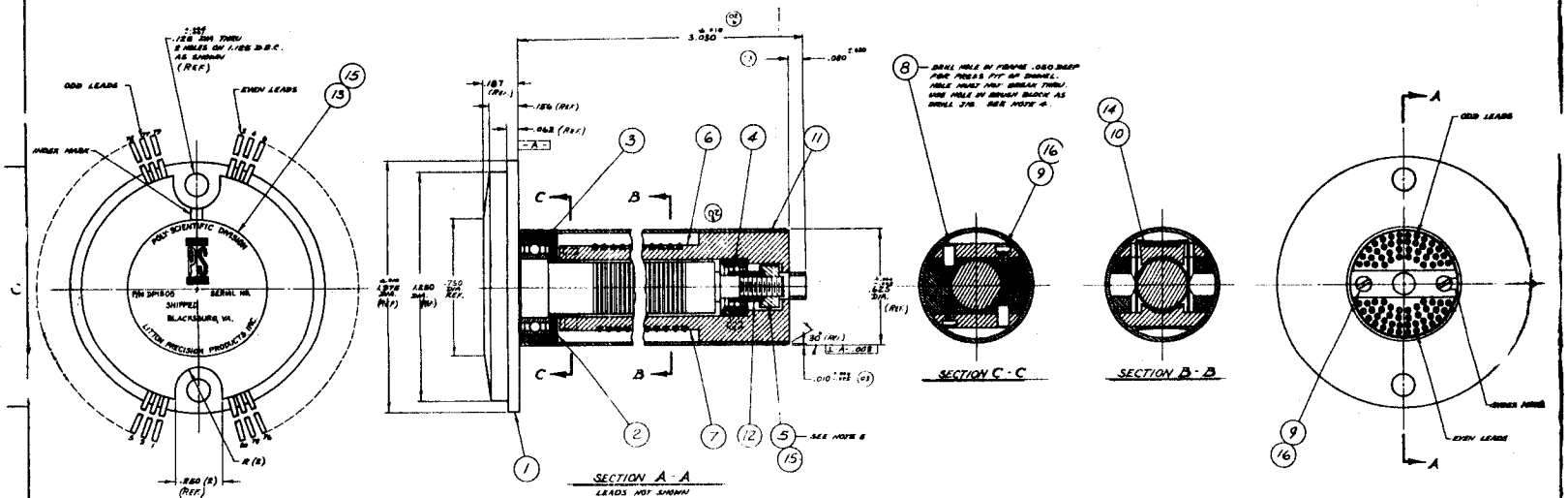
LIST OF MATERIAL

P.S. P/N DP1452C03E

TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED	DATE	CAPSULE ASS'Y.
DECIMALS ± .005	DRAWN	DATE 6-17-64	POLY-SCIENTIFIC BLACKSBURG, VIRGINIA
FRACTIONS ± 1/64	CHECKED	DATE	SIZE D 36414 09
ANGLES ± 1°	APPROVED	DATE 6-17-64	SCALE 10 & 1:1 WEIGHT SHEET 1 OF 1

DP1452


CAPSULE ASS'Y
SECTION A-A
SECTION C-C
SECTION B-B
ODD LEADS
EVEN LEADS
INDEX MARK
NOTES



NOTES

1. ALL LEADS MUST BE [illegible] LEAD, WITH NO STRIPPED ENDS.
2. TAG ALL LEADS WITH PROPER CIRCUIT NO. WITHIN ½" OF THE LEAD'S FREE END.
3. MARK WITH SERIAL NO. AND SHIPPING DATE IN PROPER LOCATION ON NAMEPLATE.
4. THE BRUSH BLOCK "A" GROOVES AND SLIP RING "M" GROOVES MUST BE ALIGNED WITHIN .002.
5. AXIAL PLAY MUST BE A MINIMUM OF .001 AND A MAXIMUM OF .003.
6. FOR MAT'LS, ACCEPTANCE & QUALIFICATION REQUIREMENTS, SEE P.S. S.S. 2269.

REV		DESCRIPTION	
36511 02	01	PER E.C.O. # 4701	
	02	PER E.C.O. # 5121	
	03	PER E.C.O. # 5491	

ITEM	QTY	PART NO.	DESCRIPTION
16	AR	———	LOCTITE, GRADE A PER MIL-S-22473A
15	AR	———	CEMENT TYPE E.S. 199
14	AR	1008	SOLDER
13	1	36520	NAMEPLATE
12	1	36518	CELLAR
11	1	36519	HOUSING
10	80	36629	BRUSH
9	4	———	00-90 ST. SCL. PH. HD. SCREW x 5/32 LONG
8	2	———	.062 ± .000 DIA. ST. SS. DOWEL x .188 LONG
7	1	36515	BRUSH BLOCK ASS'Y. (SHOWN HERE)
6	1	36514	BRUSH BLOCK ASS'Y. (SHOWN HERE)
5	1	36517	NUT
4	1	———	BEARING — BARDEN #R1446SHX3K23
3	1	———	BEARING — NPB #SR6/8 KHPP5
2	1	36516	FRAME
1	1	36512	SLIP RING ASS'Y.

P.S. P/N 2P150SC080
CUST P/N

LIST OF MATERIAL

DESIGNED	F. Barron	DATE	5-21-64
DRAWN		DATE	
CHECKED		DATE	7-1-64
APPROVED		DATE	5-24-64

CAPSULE ASS'Y.

POLY-SCIENTIFIC DIVISION
LUTTON PRECISION PRODUCTS, INC.
BLACKSBURG, VIRGINIA

SIZE D | 36511 | REV 03

SCALE 4:1 | WEIGHT | SHEET 1

4.2 APPLICATIONS TO OTHER PARTS

4.2.1 Introduction

Although contract NAS 8-5091 was primarily concerned with developing highly reliable capsules in an 80-circuit configuration, the construction features evolved through the development contract and through Saturn platform parts proved applicable to a variety of other envelope and circuit number configurations. The following paragraphs describe features of the 80-circuit capsule which are directly applicable, areas of design in which substitution can be made and special problems involved in applying the concept to various envelope configurations.

4.2.2 Conventional Configuration

Designs described under this heading are classified as conventional because they meet the following standards:

Ring and brush assemblies obtain relative alignment from ball bearings integral to the capsule.

No through bore.

Adequate space allowance to permit use of catalog size bearings at each end of the capsule.

Ring leads exit axially or radially at one end of capsule, brush leads exit axially at opposite end.

The most common problem in adapting these new concept features to other designs is mounting the brush block. The contact materials, dielectric materials, improved lead wire, slip ring reinforcing member, structural materials, and specially controlled bearings are included in all these capsules. The exact configuration of the slip ring reinforcing member depended on space available for it, but all these capsules included a reinforcing member.

The following Saturn flight parts are described below:

100 circuit gimbal slip ring capsule.
12 circuit prism drive capsule.
10 & 12 circuit accelerometer capsule.

4.2.2.1 100-circuit gimbal slip ring capsule - The differences between the 80 ring capsule originally developed and the 100 ring capsule are minor. No significant difference in design features were required.

The envelope allowance of the 100 circuit capsule is larger in every significant dimension than the 80 circuit capsule. The length limitation does require a smaller pitch than on the 80 ring capsule.

The slip ring reinforcing member, the method used to locate and secure the brush block and the frame design differ only in detail dimensions from the 80 circuit design.

4.2.2.2 12-circuit prism dirve capsule - The envelope allowed on this capsule appears to be generous, when compared to the 80 ring capsule. With the equivalent 80 ring capsule dimension assigned the value of 1, the main envelope dimensions of the 12 circuit capsule are:

	Actual Dim. (12 ckt.)	Ratio
Length:	1.11 in.	.44
Main barrel dia.:	.500 in.	.80
Contained volume:	.218 in^3.	.28

With 28% of the volume allowed and only 15% of the number of circuits required, it would appear to be a simple matter to scale down the 80 circuit capsule design. Not all components (screws, lead wire, bearings) can be scaled exactly, so the part is relatively more crowded than the 80 circuit capsule.

The original design of the prism drive capsule included only two stiffening members on the frame. The brush blocks were located by the close fit of the brush block on the frame, since there was no room for dowels. Screws were used to clamp the brush block in place.

The four stiffening members added to eliminate the possibility of bearing seat distortion could have

replaced the two existing stiffening members, allowing a redesign of the brush block. This was not done, because of the delay in delivery required to make new brush block molds.

The prism drive capsule consistently performs at lower noise levels than any other Saturn part, because each ring is wiped by two brushes. This also causes the average torque per circuit to be higher than other capsule designs, but well within the needs of the application.

4.2.2.3 10-circuit accelerometer capsule - The requirements of this application were significantly different in two main areas: Physical size greatly reduced and allowable torque greatly reduced.

Using the volume of the 80-circuit capsule exclusive of slip ring flange as a reference, the size of the 10-circuit accelerometer is compared as follows:

	Actual	Ratio
Length:	.61 in.	.20
Diameter:	.37 in.	.59
Contained volume:	.066 in^3.	.07

With 12-1/2% of the number of circuits and 7% of the allowable volume, the crowding problem is readily apparent.

The principal area of design from which the space was made up is the brush block assembly and its method of attachment. In the 80-circuit capsule, a screw and a dowel were used within the same length of capsule occupied by the contacts. These fastening devices are mounted perpendicular to the capsule axis and are all parallel to each other. On the accelerometer capsule, there was insufficient diameter to use fastening devices within the length of capsule occupied by the contacts, so a system of clips was devised. These clips shared the portion of the capsule length occupied by the bearings. The locating means was not as positive as the dowels and screws used on the 80-circuit capsule, but the requirement for brush block removability and alignment was met.

A similar accelerometer capsule containing 12 circuits was also designed, but the solutions to the problems of the 10-circuit accelerometer capsule applied to all problems on the 12-circuit.

The torque requirement on the accelerometer capsule is 4 gm-cm maximum, which allows .4 gm-cm

per circuit. Since the 80-circuit capsule may have 2 gm-cm per circuit and the ratio of diameters is .59, an allowance of 1.18 gm-cm per circuit on the accelerometer slip ring would be no problem. With the brush force used on the 80 circuit capsule, torque has been 130 gm-cm, or 1.65 gm-cm per circuit. The same brush force applied to the accelerometer capsule would provide .96 gm-cm per circuit. From these figures, it can be seen that brush force on the accelerometer capsule must be no more than .42 of the value used on the 80 circuit capsule. This has necessitated a correspondingly higher noise allowance at acceptance.

4.2.3 Less Conventional Configurations

The capsule designs discussed in this section fail to meet the standards for conventional capsules outlined in Section 4.2.1. Some of the basic design concepts evolved during the development program were altered due to the nature of the application.

Capsule designs discussed are:

10 circuit resolver capsule.
4 circuit resolver unit.
50 circuit air swivel capsule.

4.2.3.1 Ten circuit resolver capsule - One of the basic brush design features proven early in the development phase of the highly reliable capsule concept was the pre-formed shape of the brush. The brush wire is bent to a triangular form open at one corner. The open place is spread apart and slipped over the appropriate slip ring V-groove and the side opposite the open corner is soldered to a metal junction plate in the brush block. This capsule does not utilize the triangular pre-formed, separate brush, but has straight brushes cast into a plastic brush block.

The reason for violating this good design practice was scheduling and cost expediency. Tools and components were available for a capsule assembly adaptable to the requirements for this unit. When the features of the 80 circuit capsule were performance proven, the existing resolver assembly was modified in design, materials and processes to incorporate most of the proven features.

The most significant design feature of the 80 circuit assembly not incorporated into the 10 circuit resolver capsule, is the triangular (prestressed) brush. The available annular space between bore and outside diameter would have made such a redesign incorporate unproven inovations in brush block configuration. The through bore placed a restriction on the minimum possible ring diameter, and the ring diameter to capsule O.D. has significant effect on the suitability of a particular envelope configuration to the use of the triangularly formed (prestressed) brush. The original cast brush assembly design had been shown reliable for the application, and therefore, only an upgrading of materials was made in the brush assembly.

4.2.3.2 4 circuit resolver unit - Note that this assembly is called a "unit" in this report, and not a capsule. This unit consists of a matched set: one 4-circuit slip ring and one 4-circuit brush block.

Extremely tight space and torque requirements and unusual processing problems of the next assembly preclude the use of a conventional capsule assembly.

Although the brush alignment is not maintained by integral bearings and frame, all the materials, processing and quality assurance provisions which apply to normal capsule assemblies apply to this assembly. The slip ring reinforcement is more complex due to the addition of special alignment surfaces. The brush block uses cast-in brushes, rather than separable brushes.

4.2.3.3 50 circuit air swivel capsule - The slip ring function of this capsule presented no unusual problems, because the envelope dimensions were sufficient to allow the use of all the desirable design features. The main design innovation was the addition to the capsule of a rotating joint for transmitting air through a tube in the center of the rotor.

4.2.4 Discussion of Envelope Requirements

This section shows some relationships between number of circuits and physical size. No consideration is given here for current carrying ability, but obviously the extremely crowded capsules will have lower total heat emission to I^2R heat generated ratios and should be rated accordingly. The main

consideration is the ability to incorporate all the desirable design features for the maximum number of circuits within a given envelope, or to provide the minimum envelope for a given number of circuits.

The envelope is defined here as the barrel diameter from the slip ring flange to the end of the barrel, including all protrusion on the housing. The slip ring flange itself can take many configurations, and is considered to be outside the critical envelope. The volume of the critical envelope is occupied by electrical and mechanical components and by air space. In capsules of many circuits (80 and 100), it is possible to utilize more efficiently the volume available, than with capsules of few circuits (10 and 12).

To illustrate, consider the effect on capsule length of the bearings and associated mounting seats. Table 4.2.I shows that while length of capsule occupied by contacts increases by a factor of 11.5, the length of capsule required to hold the contacts increases by a factor of only 2.5.

The difference in utilization of cross section area between the 100 circuit and the 10 circuit capsules is illustrated in Table 4.2.II.

The preceding table also shows that non-electrical cross section area of the smaller capsule is greatly reduced in comparison with the larger capsule. The brush block mounting hardware and other components affected by cross section are significantly more crowded in the smaller capsule, since screws, dowels, etc., can not be scaled down in the same ratio as the number of circuits.

4.2.5 Conclusions

The wide variety of envelope configurations, and number of circuits designed with the Saturn - contract NAS 8-5091 features, indicate that any application could employ most of the desirable features with a high expectation of capsule reliability of performance.

TABLE 4.2-I

NUMBER OF CIRCUITS VERSUS CAPSULE LENGTH

CAPSULE NAME	CAPSULE LENGTH (in.)	LENGTH FOR BEARINGS, ETC. (in.)	LENGTH FOR CONTACTS (in.)	% TOTAL LENGTH FOR CONTACTS
100-circuit gimbal axis	3.21	2.30	.91	71.5
10-circuit accelerometer	.61	.20	.41	32.8

TABLE 4.2-II

NUMBER OF CIRCUITS VERSUS CAPSULE CROSS SECTION AREA

CAPSULE NAME	CAPSULE AREA ($in.^2$)	CROSS SECTION AREA OF RING AND BRUSH WIRE ($in.^2$)	TOTAL AREA LESS AREA OF WIRES ($in.^2$)	% TOTAL AREA USED BY WIRES
100-circuit gimbal axis	.441	.141	.300	32.0
10-circuit accelerometer	.107	.0141	.093	13.2

APPENDIX 4.2-I

DRAWINGS

FILE: SP1478

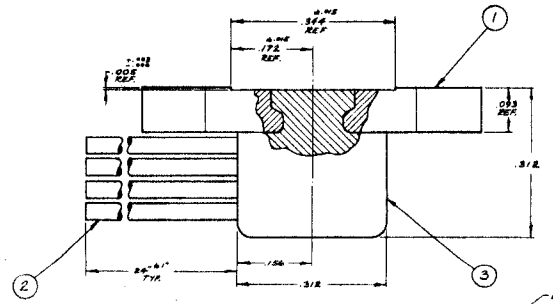
REV.	3625022

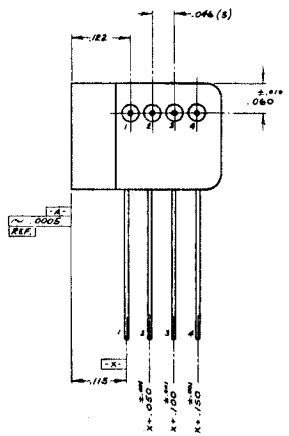
REVISIONS

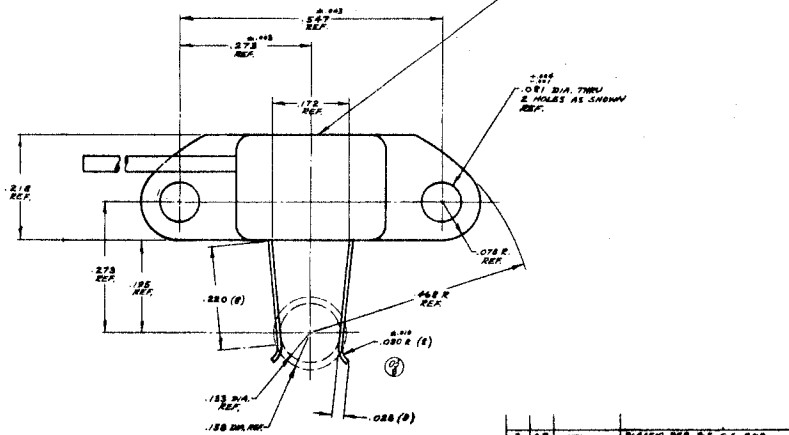
CONFIG SYM	DESCRIPTION	DATE / APPROVED
01	[illegible]	[illegible]
02	[illegible]	[illegible]
03	PER E.C.O. # 27011 TO 11 D.E.	[illegible]

NOTES:

1. BREAK ALL SHARP EDGES .010 R. OR CHAM.
2. DEBURR PER P-S SPEC. 49, CLASS A.
3. ALL RADII MUST BE 1/32 UNLESS OTHERWISE SPECIFIED.
4. SURFACE -A- MUST BE PARALLEL TO E OF BRUSHES WITHIN .006 TIR.
5. LEADS MUST BE CAPABLE OF WITHSTANDING A 2 LB. LINEAR PULL.
6. SET BRUSHES TANGENT TO .122 DIA. AS SHOWN. BRUSHES MUST EXERT A FORCE OF 3±1 GM. ON A .122 DIA. LOCATED AS SHOWN. BRUSHES MAY BE FREE OF SCRATCHES, NICKS, CUTS, & CONTAMINATION. CONTACT AREA OF BRUSHES MUST HAVE A FINISH OF 4 MICROINCHES RMS, OR BETTER, MEASURED ALONG THEIR LENGTH, AND 8 MICROINCHES RMS, OR BETTER, MEASURED AROUND THEIR DIA.
7. HI-POT — 500 V. DC, FOR 1 MINUTE.
8. BRUSH BLOCK MUST BE "RUN-IN" WITH A DP1879 SLIP RING WHILE BRUSHES ARE ALIGNED WITH RING GROOVES WITHIN .002. THE RUN-IN MOUNTING DIM. BETWEEN THE MOUNTING FACE OF THE BRUSH BLOCK (SURFACE A) AND THE FRONT SHAFT END OF THE SLIP RING (SURFACE B) MUST BE DETERMINED TO THE NEAREST TEN THOUSANDTH OF AN INCH, RECORDED, AND SUPPLIED TO THE CUST. WITH THE SERIAL NOS. OF BRUSH BLOCK & SLIP RING.
9. UNIT MUST MEET ALL REQUIREMENTS OF P-S E.S. 225.







ITEM	REQ'D	PART NO.	DESCRIPTION
3	A.R.	———	PLASTIC PER P-S E.S. 203
2	1 EA.	[illegible]	BRUSH & LEAD ASS'Y.
1	1	362522	BASE PLATE

LIST OF MATERIAL

P-S P/N SP1478-06

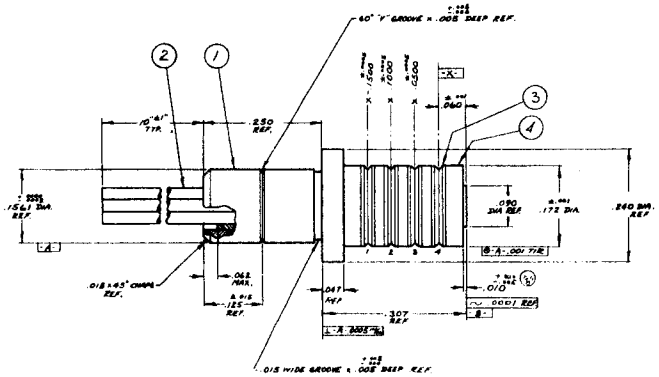
TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED	DATE	Poly-Scientific Corporation BLACKSBURG, VIRGINIA
DECIMALS ± .005	DRAWN	DATE 7-7-69	BRUSH BLOCK ASS'Y
FRACTIONS 1/64	CHECKED	DATE 7-8-69	SIZE D DWG NO. 3625022
ANGLES ± 1/2°	APPROVED	DATE 7-8-69	SCALE 1/1 WEIGHT SHEET 1 OF 1
FOR SUPPLY SOURCE INC. ONLY			

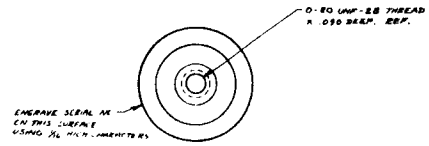
FILE: 3P/1678

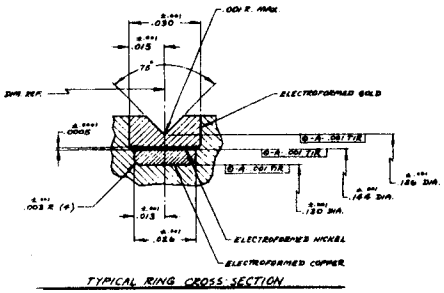
REV.	36256 03

REVISIONS

ZONE	STH	DESCRIPTION	DATE
	02	[illegible]	7-9-69
	03	PER E.C. #4791 & #4785 P.C.	[illegible]







TYPICAL RING CROSS-SECTION

NOTES:

1. BREAK ALL SHARP EDGES .010 R OR CHAM.
2. DEBURR PER P.S SPEC. 49, CLASS A.
3. LEADS MUST BE CAPABLE OF WITHSTANDING A 2 LB. LINEAR PULL.
4. HARDNESS OF ELECTROFORMED GOLD MUST BE 125 KHN100 MIN. 100 GM. LOAD.
5. RING GROOVES MUST BE FINISHED TO A 32 MICROINCH RMS MATTE FINISH, AND THEN GOLD PLATED. GOLD PLATE MUST BE .0004 +.0001 THICK AND 180 MIN. KNOOP HARDNESS.
6. HI-POT — 500 V DC, FOR 1 MINUTE

(03)

7. SLIP RING MUST BE "RUN-IN" WITH A 3P/678 DAVIN BLOCK WHILE BRUSHES ARE ALIGNED WITH RING GROOVES WITHIN .002". THE RUN-IN MOUNTING DIM. BETWEEN THE MOUNTING FACE OF THE DAVIN BLOCK (SURFACE A) AND THE FRONT SHAFT END OF THE SLIP RING (SURFACE B) MUST BE DETERMINED TO THE NEAREST TEN THOUSANDTH OF AN INCH, RECORDED, AND SUPPLIED TO THE CUST WITH THE SERIAL NOS OF DAVIN BLOCK / SLIP RING.
8. UNIT MUST MEET ALL REQUIREMENTS OF P.S E.S. 22E

REV	QTY	ITEM	PART NO	DESCRIPTION
	4	AR		PLASTIC PER P.S. E.S. 818
	3	AR		WIRE WRAP, AS LISTED
	2	4	36257--	LEAD
	1	1	36267	SLIP RING BASE

NEXT ASSY: P.S. FILE QTY REQ'D: 1 — 36800 — 3P/1679

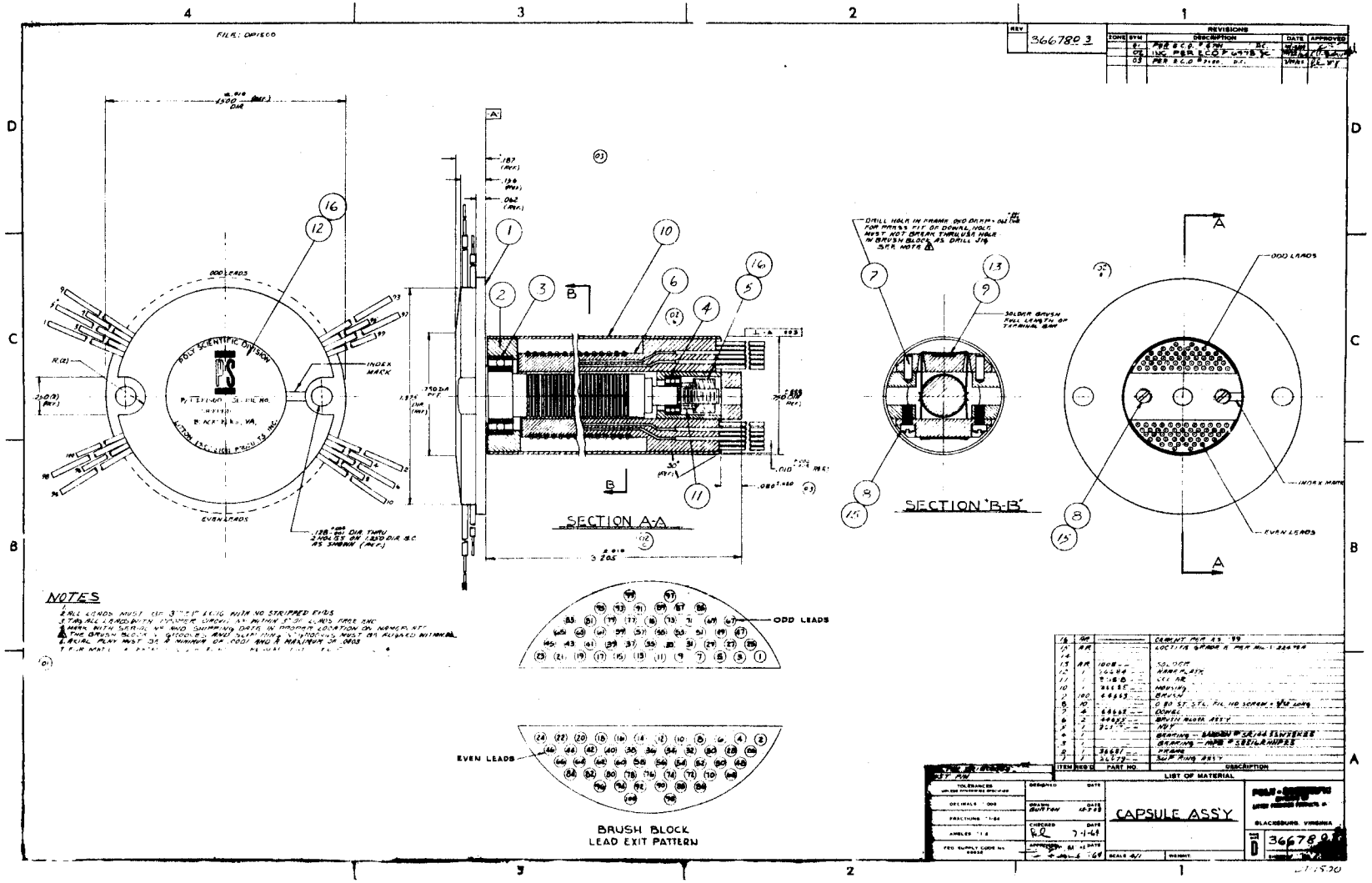
APPLICATION — LIST OF MATERIAL

TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED — DATE
DECIMALS .XXX	DRAWN FG — DATE 7-9-69
FRACTIONS 1/64	CHECKED J.K. — DATE 7-9-69
ANGLES 1°	APPROVED — DATE 7-9-69
FED SUPPLY CODE NO 09922	SCALE 10:1 — WEIGHT

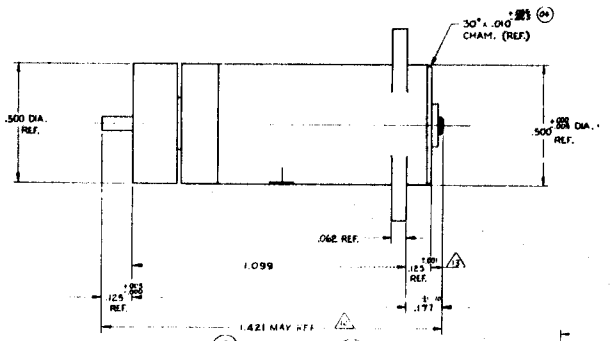
SLIP RING ASS'Y

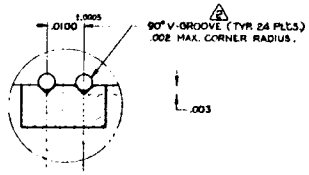
Poly Scientific Corporation
BLACKSBURG, VIRGINIA

SIZE D — 36256 03 — SHEET 1 OF 1

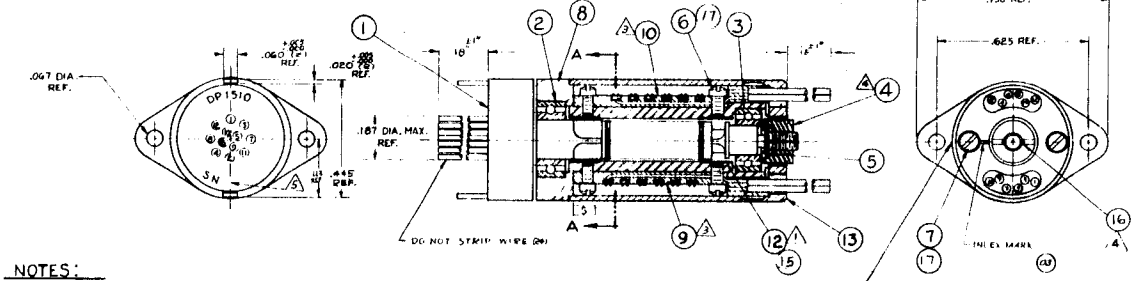

SECTION A-A
SECTION 'B-B'
ODD LEADS
EVEN LEADS
INDEX MARK
BRUSH BLOCK
LEAD EXIT PATTERN
NOTES
CAPSULE ASS'Y
LIST OF MATERIAL
REVISIONS
366780 3

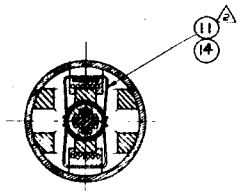
FILE: DP1510





TYP. BRUSH BLOCK GROOVE DET.
SCALE: NONE





SECTION A-A

NOTES:

(9) ⚠1 PERENT TYPE AT (2 PCS.) IN PLACE WITH CEMENT PER POLY-SCIENTIFIC E.S. 195 SO THAT THE FOUR OD-90 TAPPED HOLES ARE COMPLETELY SEALED OFF FROM THE FRAME BORE.

⚠2 PLANE OF EACH BRUSH MUST BE ⊥ TO SLIP RING ℄ WITHIN .002, AND THE PLANES OF BOTH BRUSHES ON A RING MUST BE PARALLEL WITHIN ..0005. SOLDER JOINT MUST BE .050 LONG MIN., AND BE SOLDERED PER POLY-SCIENTIFIC E.S. 41

⚠3 ITEMS 9 AND 10 ARE TO BE FLUSH WITH SURFACE (S) BEFORE TIGHTENING ITEM 8 (4 PLACES)

⚠4 SEAL ITEM 4 WITH CEMENT PER POLY-SCIENTIFIC E.S. 195

⚠5 APPLY SERIAL NUMBER IN THIS AREA

6 CAPSULE ASSEMBLY IS TO BE MANUFACTURED IN ACCORDANCE WITH POLY-SCIENTIFIC E.S. 277

(26) 7. TAG ALL LEADS WITH PROPER CIRCUIT NOS. 3" ± ½" FROM END.

8. TORQUE MUST BE 30 GM-CM. OR LESS - STARTING (REF.)

9. NOISE MUST BE 10 MILLIOHMS OR LESS PER CIRCUIT WHEN TESTED AS FOLLOWS (REF.)
SPEED 2 RPM. OPEN CIRCUIT VOLTAGE 10 VDC MAX.
SUPER-IMPOSED OSCILLATION 95 ± 10 DB AT 3 ± 1 CPS.
CURRENT 100 DB FREQUENCY RANGE 5 - 30 CPS.

10. CIRCUIT RESISTANCE IS TO BE .006 OHMS ± LEAD LENGTH IN INCHES (+ .000 -.003 OHMS) (REF.)

11. INSULATION RESISTANCE MUST BE 1000 MEGOHMS MINIMUM AT 500 ± 50 VDC (REF.).

⚠12 THIS IS NOT A CUSTOMER REQUIREMENT.

⚠13 CUSTOMER ALLOWS .125 ± .005

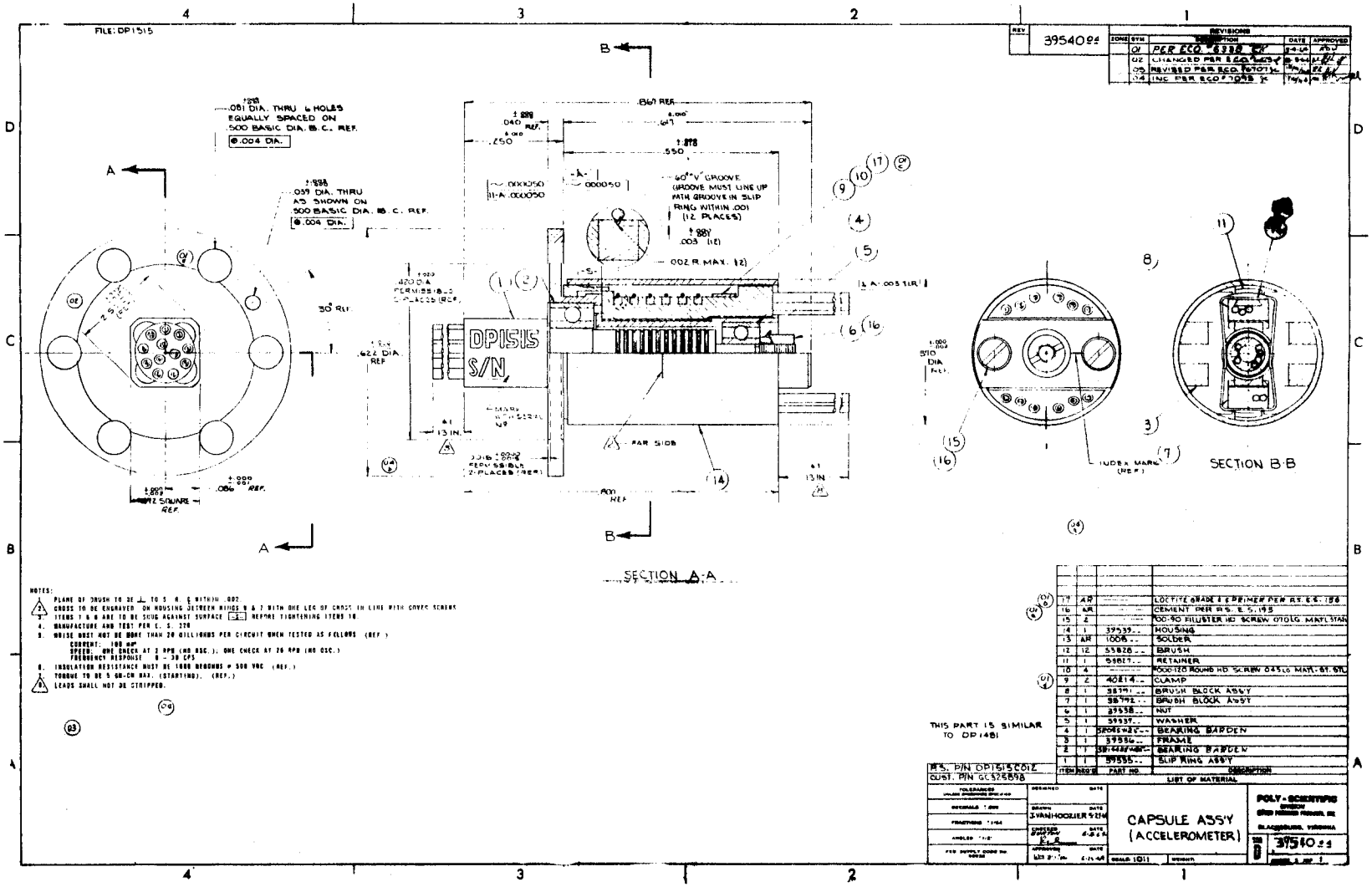
ITEM	REQ'D	PART NO.	DESCRIPTION
17	AR		LOCKTITE GRADE F PRIMER PER P.S. E.S. 198
16	AR		CEMENT PER POLY-SCIENTIFIC E.S. 195
15	AR		CEMENT PER POLY-SCIENTIFIC E.S. 192
14	AR	1006	SOLDER
13	1	47543	HOUSING
12	2	47544	SEAL
11	24	44648	BRUSH
10	1	47579	BRUSH BLOCK ASSY. (EVEN)
9	1	47578	BRUSH BLOCK ASSY. (ODD)
8	1	47540	FRAME
7	2	——	0-80 FILLISTER HD. SCREW ¼ .090 LONG
6	4	——	00-90 FILLISTER HD. SCREW ¼ .078 LONG
5	1	47542	WASHER
4	1	47541	NUT
(92) 3	1	——	BEARING SK 1027-2
2	1	——	BEARING SK 1627-4
1	1	47537	SLIP RING ASSY.

LIST OF MATERIAL

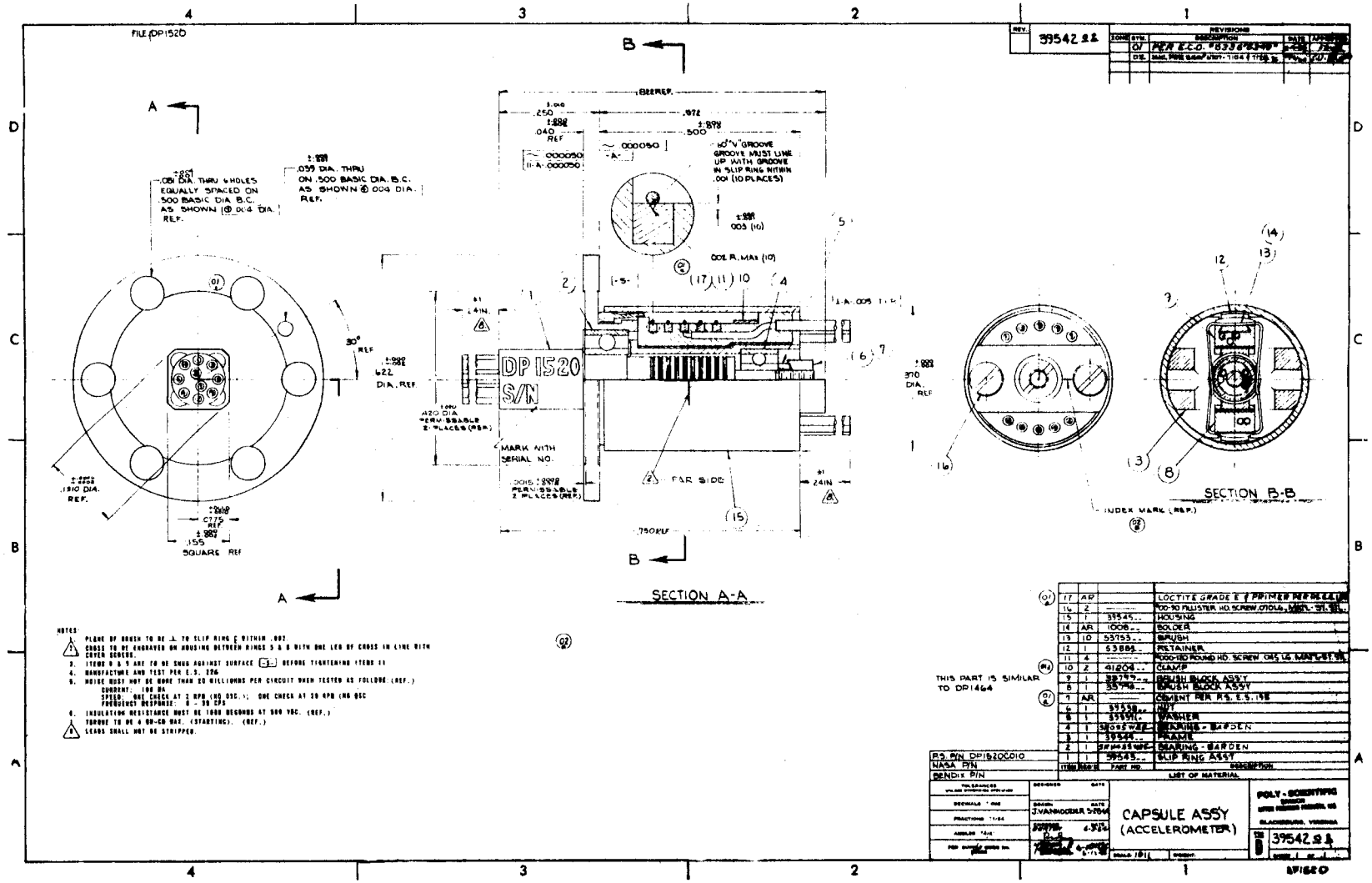
SIMILAR TO DP1420
P.S. P/N DP1510 C012
CUST. P/N GC 3E5765

DESIGNED		DATE	CAPSULE ASSY. (SATURN PRISM DRIVE)
DRAWN	STURGILL	5-29-64	POLY-SCIENTIFIC DIVISION, LITTON INDUSTRIES, INC., BLACKSBURG, VIRGINIA
CHECKED			SIZE D 47536 Q4
APPROVED		DATE	SCALE 5:1 WEIGHT SHEET 1 OF 1

FILE: DP1510



NOTES:
1. PLANE OF BRUSH TO BE ⊥ TO S. R. ℄ WITHIN .002.
2. CROSS TO BE ENGRAVED ON HOUSING BETWEEN PINS 5 & 7 WITH ONE LEG OF CROSS IN LINE WITH COVER SCREWS
3. ITEMS 7 & 8 ARE TO BE SNUG AGAINST SURFACE [4] BEFORE TIGHTENING ITEMS 10
4. MANUFACTURE AND TEST PER C. S. 378
5. NOISE MUST NOT BE MORE THAN 20 MILLIVOLTS PER CIRCUIT WHEN TESTED AS FOLLOWS (REF.)
   CURRENT: 100 MA
   SPEED: ONE CHECK AT 2 RPS (NO OSC.), ONE CHECK AT 26 RPS (NO OSC.)
   FREQUENCY RESPONSE 0 - 30 CPS
6. INSULATION RESISTANCE MUST BE 1000 MEGOHMS @ 500 VDC (REF.)
7. TORQUE TO BE 5 OZ-IN MAX. (STARTING). (REF.)
8. LEADS SHALL NOT BE STRIPPED.

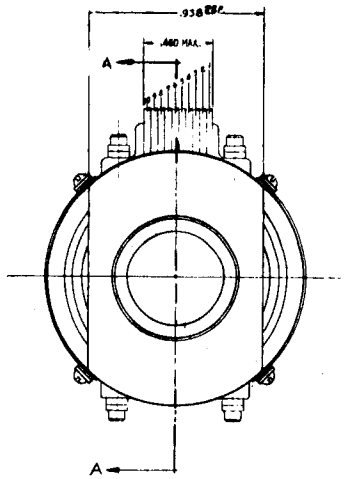


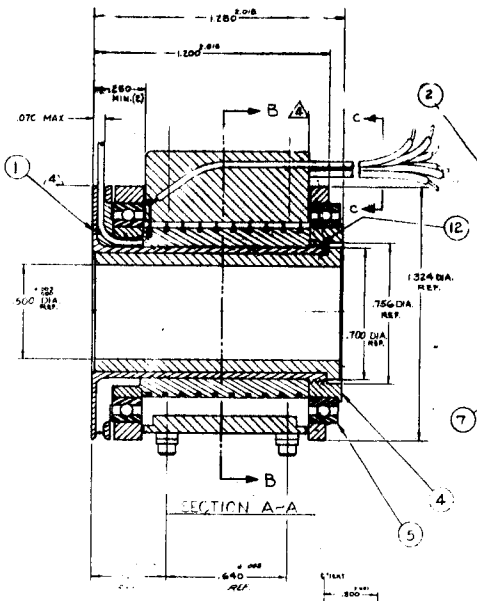
ITEM	QTY	PART NO	DESCRIPTION
17	AR		LOCTITE GRADE E (PRIMER NF) OR EQUIV.
14	2		00-90 FILLISTER HD. SCREW, 0100 LG., MAT'L. ST. SS.
15	1	39545...	HOUSING
14	AR	1008...	BOLDER
13	10	53753...	BRUSH
12	1	53884...	RETAINER
11	4		000-120 ROUND HD. SCREW, 0125 LG. MAT'L. ST. SS.
10	2	41204...	CLAMP
9	1	38749...	BRUSH BLOCK ASSY
8	1	38748...	BRUSH BLOCK ASSY
7	AR		CEMENT PER MIL. E.S. 198
6	1	39538...	NUT
5	1	39539...	WASHER
4	1	SR0855Z	BEARING - BARDEN
3	1	39544...	FRAME
2	1	SR1855Z	BEARING - BARDEN
1	1	39543...	SLIP RING ASSY

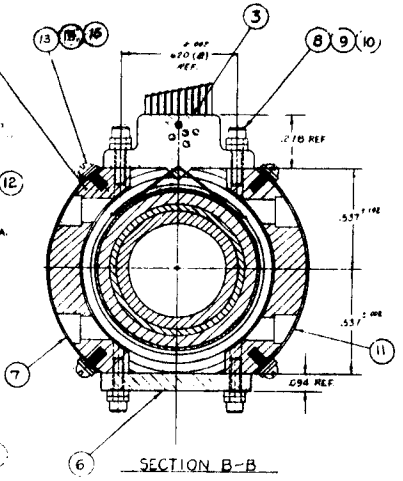
LIST OF MATERIAL

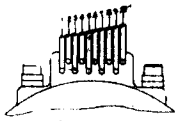
P.O. P/N DP1520C010	
NASA P/N	
BENDIX P/N	

DESIGNED J.VANHOOSER 5-7-64
DRAWN J.VANHOOSER 5-7-64
CHECKED 6-9-64
APPROVED 6-9-64
SCALE 10/1
SHEET 1 OF 1
SIZE D
39542 02





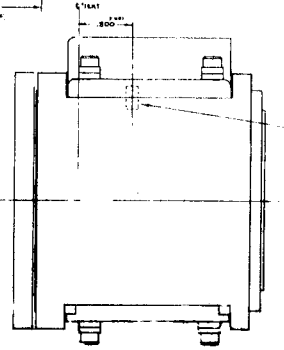




SECTION C-C
(BRUSH BLOCK LEAD EXIT PATTERN)

NOTES :

1. PLANE A PRODUCT [illegible]
2. LEADS AT BOTH ENDS [illegible] WITH ¼ HT AT END [illegible]
3. INSULATION RESISTANCE [illegible] TERMINALS TO FERRULE
4. EQUALIZE [illegible] MEASURED [illegible] PERIODICITY [illegible] INDICATED [illegible] MINIMUM [illegible] THE SERVO AMP [illegible] THE ACTUATION OF THE SERVO MOTOR.
5. NOISE [illegible] AS FOLLOWS [illegible] OSC) [illegible]
6. INSULATION RESISTANCE MUST BE [illegible] MEGOHMS @ 500 VOLTS.
7. CIRCUIT RESISTANCE IS TO BE .600 +.125 -.125 OHMS, INCLUDING LEADS
8. TORQUE TO BE 120 GM. CM. (MAX.)
9. TAG ALL LEADS WITH PROPER CIRCUIT NUMBER WITHIN 3" OF LEADS FREE END.
10. BRUSH BLOCK MUST BE MARKED WITH THE SAME S/N AS THE CAPSULE ASS'Y.
11. AFTER FINAL ASSEMBLY (BEFORE THE HOUSING IS SEALED) THE CAPSULE ASS'Y SHALL BE SUBJECTED TO A 100 HOUR LIFE TEST AT 5 R.P.M. THE PART MUST PASS NOISE, TORQUE, [illegible] A 20 X VISUAL EXAMINATION OF THE WEAR [illegible] BEFORE [illegible] AFTER LIFE TEST. FAILURE SHALL BE CAUSE TO REPEAT [illegible] ENTIRE PROCEDURE



ITEM	REQ'D	PART NO.	DESCRIPTION
15	8	------	#00 ST STL LOCK WASHER
14	8	------	#00 90 ST STL FD HD SCR., .125 LONG
13	8	------	#00 ST ST'L FLAT WASHER
C	AR	------	LOCTITE GRADE E (PRIMER PER E-5.150
11	1	100178	NAMEPLATE
10	8	16163	WASHER-LOCK, SPRING
9	8	11123	FLAT WASHER
8	8	14164	SOCKET HEAD CAP SCREW
7	1	100177	P.S. SYMBOL NAMEPLATE
6	1	100167	COVER PLATE
5	2	16165	BEARING, RING BALL
4	1	13426	BEARING RETAINER
3	1	100178	BRUSH BLOCK ASS'Y.
2	1	100174	HOUSING
1	1	100175	SLIP RING ASS'Y.

LIST OF MATERIAL

B3 P/N	DP1580C010
CUST P/N	

TOLERANCES UNLESS OTHERWISE SPECIFIED: DECIMALS ± .005, FRACTIONS ± 1/64, ANGLES ± 1°

DRAWN	DWB	12-17-64
CHECKED	J.V.	12-22-64
ENG APPR.		
MFG APPR.		

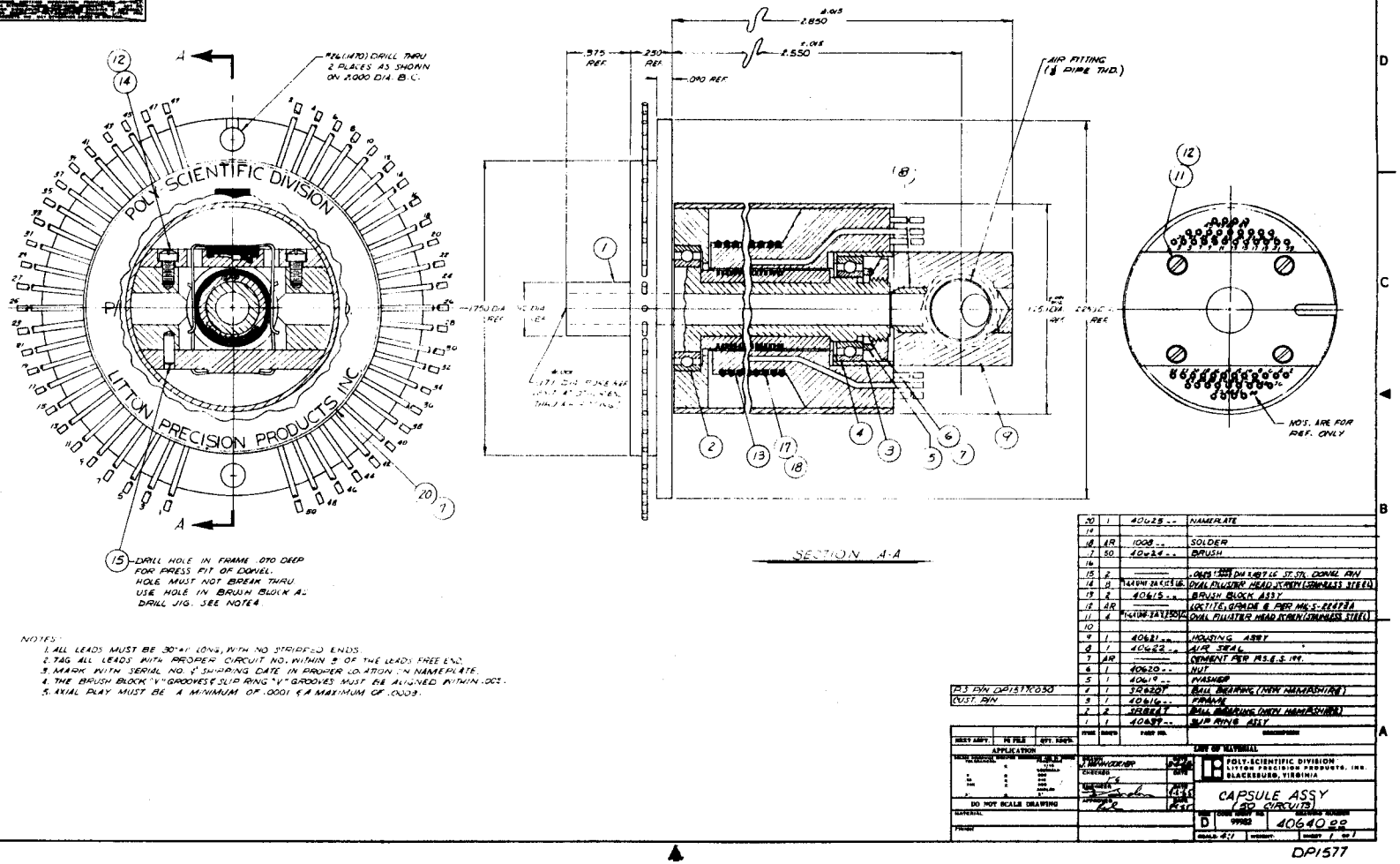
CAPSULE ASS'Y.

POLY-SCIENTIFIC DIVISION, BLACKSBURG, VIRGINIA

100178 02

DP1580

4 3 2 1



NOTES:
1. ALL LEADS MUST BE 30" ± 1" LONG, WITH .10 STRIPPED ENDS.
2. TAG ALL LEADS WITH PROPER CIRCUIT NO. WITHIN ⅜" OF THE LEADS FREE END.
3. MARK WITH SERIAL NO. & SHIPPING DATE IN PROPER LOCATION ON NAMEPLATE.
4. THE BRUSH BLOCK "V" GROOVES & SLIP RING "V" GROOVES MUST BE ALIGNED WITHIN .002".
5. AXIAL PLAY MUST BE A MINIMUM OF .0001 & A MAXIMUM OF .0003".

20	1	40625--	NAMEPLATE
19			
18	AR	1008--	SOLDER
17	30	40624--	BRUSH
16			
15	2	———	.062" DIA X .187" LG ST. STL. DOWEL PIN
14	8	4-40UNF-2A X.125 LG.	OVAL FILLISTER HEAD SCREW (CHEM. PASS. STEEL)
13	2	40615--	BRUSH BLOCK ASSY
12	AR		LOCTITE, GRADE B PER MIL-S-22473A
11	6	4-40UNF-2A X.750 LG.	OVAL FILLISTER HEAD SCREW (STAINLESS STEEL)
10			
9	1	40621--	HOUSING ASSY
8	1	40622--	AIR SEAL
7	AR	———	CEMENT PER MS.S.S. 199.
6	1	40620--	NUT
5	1	40619--	WASHER
4	1	38620P	BALL BEARING (NEW HAMPSHIRE)
3	1	40616--	FRAME
2	2	SR8BZZT	BALL BEARING (NEW HAMPSHIRE)
1	1	40627--	SLIP RING ASSY
ITEM	QUAN.	PART NO.	DESCRIPTION

P.3 DIN DP1577C030
DUST PIN

LIST OF MATERIAL

NEXT ASSY.	PC FILE
QTY. REQ'D.	

APPLICATION

DO NOT SCALE DRAWING

MATERIAL

FINISH

DRAWN J. VANDERHEP 9-7-67
CHECKED
ENGINEER
APPROVED

POLY-SCIENTIFIC DIVISION
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG, VIRGINIA

CAPSULE ASSY
(30 CIRCUITS)

SIZE D | DRAWING NO. 99982 | REVISED NUMBER 4064000

SCALE 4:1 | WEIGHT | SHEET 1 OF 1

DP1577

4.3 CONTINUOUS ROTATING CAPSULE

4.3.1 Introduction

In normal operation, many slip ring capsule assemblies undergo variable cyclic oscillations of from 3° to 8° about a point on the contact surface of the slip ring. Occasionally, this mode of operation includes rotation; but this is the exception rather than the rule. During the long periods of oscillation the wear product being generated is built up on the surface of the ring at each end of the cycle. If and when the oscillation changes to rotation, the wear product which has built up during oscillation is seen in the circuit as a resistance pulse or noise spike. Although this spike usually disappears after relatively short periods of rotation, it would be desirable to eliminate it from even the first rotating cycle.

The continuous rotating capsule, or capsule within a capsule, was designed with one basic factor in mind - to eliminate the noise spike caused by the conditions stated above. (See Figure 4.3.1.) By using the capsule within a capsule concept, the mode of motion can be changed from oscillation only, so that the actual contacts experience this oscillation superimposed on a continuous rotation. This is accomplished by using a motor to rotate the brushes of the inner capsule and the rings of the outer capsule continuously at approximately 3 RPM relative to the inner rings and the outer brushes.

4.3.2 Advantages & Disadvantages of the Continuous Rotating Concept

4.3.2.1 Advantages - There is but one advantage to the continuous rotating concept and it is on this advantage that the entire design concept is based. This advantage is that with a continuous rotating capsule you eliminate a build-up of wear product in one area on a slip ring normally undergoing oscillation only. By eliminating this wear build-up you also eliminate the noise spike which is a result of initial rotation of the contacts over the area where the wear build-up has occurred.

4.3.2.2 Disadvantages

4.3.2.2.1 Size and resulting weight are two of

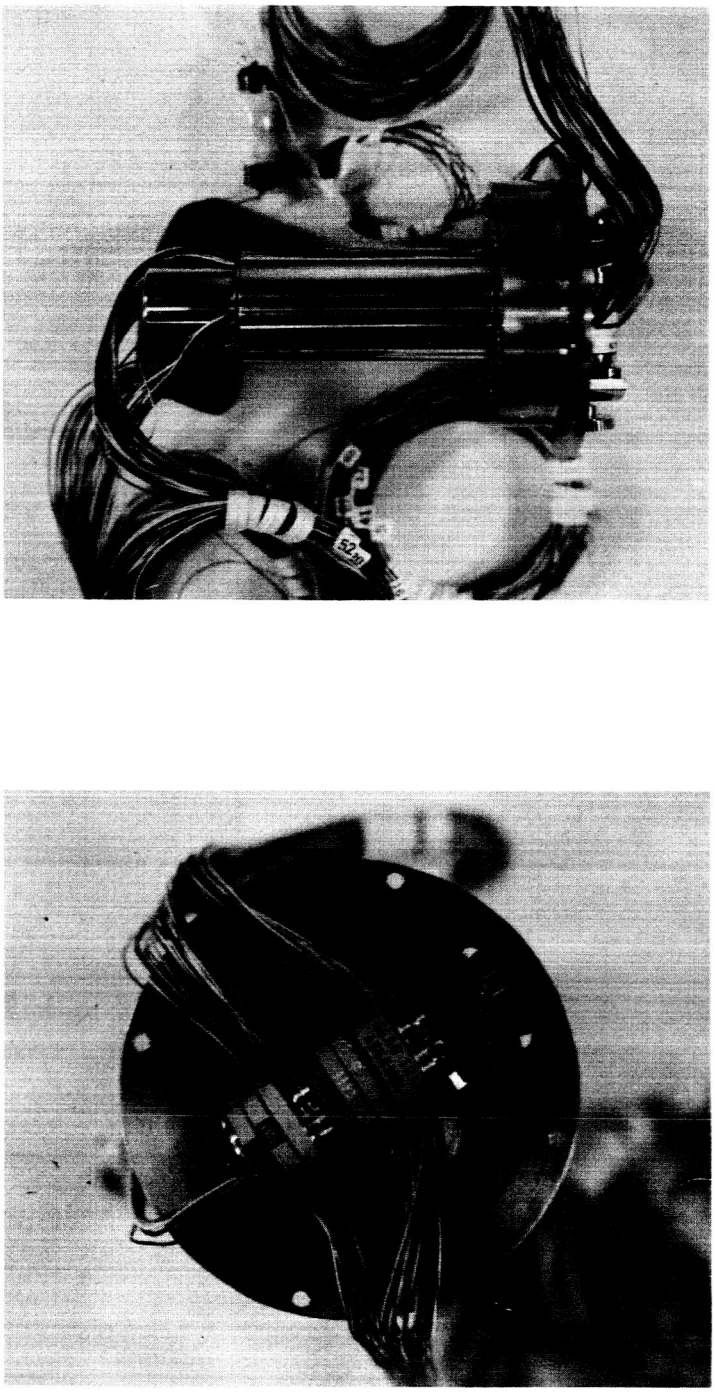


Fig. 4.3.1 - CONTINUOUS ROTATING CAPSULE ASSEMBLY

the major disadvantages of this concept. The size requirement is due to having the "capsule within a capsule." This naturally will result in a unit with a larger outside diameter than a unit which contains only one set of rotating contacts.

For comparison, the housing outside diameter on the 80 circuit capsule for the Saturn platform is .625" while the same dimension on the housing for the continuous rotating capsule we built (DP1386), which also had 80 slip ring circuits, was 1.250".

4.3.2.2.2 The added length of the unit due to additional components such as motor and gears also adds to the size of the unit. Length must also be added to the unit to allow room for the inner brush lead to outer slip ring lead connections. The over-all length on the Saturn capsule is 3-1/4" while the over-all length on the DP1386 was 4-3/4" (approx.).

4.3.2.2.3 Higher capsule torque was also a definite disadvantage on the DP1386. It should be pointed out here that this is not a disadvantage of the design concept itself. The higher torque on the DP1386 resulted from a decision as to where and how to mount the motor which provided the continuous rotation. The decision was to mount it on the slip ring flange - in the case of the DP1386, this is the inner slip ring flange. This meant that the starting torque for the final assembly would be the torque due to the set of contacts on the outer capsule. It is possible to mount the motor on the outer capsule so that the starting torque of the completed unit will be the torque due to the inner set of contacts; however, this means an even greater addition to the outside diameter of the part because the motor would have to be mounted along the housing.

4.3.2.2.4 There are several other disadvantages to the continuous rotating concept which should be mentioned here. Their nature is such that they may be definite disadvantages for one application, but of no immediate concern in another. These are mentioned here and will not be gone into in detail.

4.3.2.2.4.1 This capsule uses more of the systems' power because of the additional power required to drive the motor.

4.3.2.2.4.2 This concept requires two sets of contacts in series which means higher circuit resistance and noise.

4.3.2.2.4.3 The life of the motor and/or gears used to provide continuous rotation may be a deciding factor in the useful life of the finished part.

4.3.2.2.4.4 There is no question about the fact that a continuous rotating capsule contains more components than a standard slip ring capsule assembly. This is naturally going to make a continuous rotating capsule more expensive. At the same time, these additional components greatly add to the complexity of the finished capsule and increase the need for better control of production in order to keep the loss in Reliability, due to the increase in number and the complexity of the components, to a minimum.

4.3.2.2.4.5 The volume of "wear product" generated within a continuous rotating capsule is going to be greater than the volume generated in a capsule which normally is undergoing oscillation only due to the greater distance traveled. This fact is compounded even further by the fact that you have two sets of contacts - one of which is on a much larger slip ring diameter.

4.3.2.3 Comments on Advantages and Disadvantages

In the preceding sections, the advantages and disadvantages of this concept were presented without emphasis on their relative merit. It is quite apparent that the list of disadvantages is much longer than the list of advantages which includes only one.

The important thing to remember is that when weighed on a basis of part performance, the one advantage definitely outweighs the performance disadvantages. The fact that more wear is generated is outweighed by the fact that this greater volume of wear is prohibited from accumulating in any one area on the contacts. Add to this the fact that, although the initial noise levels

are increased slightly, there is no tendency to generate an undesirable noise spike throughout the life of the unit.

The question then becomes whether or not the noise requirement for a given system is critical enough for the one performance advantage to outweigh the performance, and physical disadvantages. Questions which must be answered are: Can the size of the continuous rotating capsule be tolerated? Can the weight be tolerated? Can the system spare the power to drive the motor? Is the cost reasonable for the system? Basically can you afford to trade off the disadvantages for the advantage?

It is interesting to note that a negative answer to any one of the above questions concerning the physical disadvantages can rule out the use of a continuous rotating capsule. At present, these are disadvantages of the concept and there is no known way to eliminate them. Extensive research might eliminate or effectively reduce some of these problems, but at present, they must be tolerated in order to use a continuous rotating capsule in a system.

NOTE: Those portions of this report which consist of 4.3.3, 4.3.4 and 4.3.5 will deal specifically with the 80 circuit capsule which was built and shipped to NASA. The other areas in Section 4.3 will deal with the design concept.

4.3.3 Capsule Configuration

4.3.3.1 General - The unit which was built consisted of two 80 circuit capsules which were designed, and assembled to provide a continuous rotating 80 circuit assembly. The selection of materials and internal design features followed the other NASA development work as closely as possible, but the fact that this was not intended to be a production part necessitated the use of design features which required minimum tooling.

The capsule consisted of two standard Nooteboom designs with the slip ring base of the outer capsule actually serving as the housing for the inner capsule. The inner frame and the outer slip ring base were mechanically locked together

and these in turn fastened onto a gear which was driven by a servo motor. This action imparted continuous rotation to the brushes of the inner capsule and the rings of the outer capsule, leaving the inner slip ring flange and the outer capsule housing free for any relative motion which is desired.

NOTE: See Figure 4.3.2 for an explanation of the terms mentioned above.

Both slip rings were cast units using rings cut from gold tubing. Brushes were standard Nooteboom designs. There was one brush per circuit. Using normal Poly-Scientific methods for assembly, the brushes were individually assembled onto the slip ring, then the brush leads soldered in place. This unit does not have removable brush blocks.

4.3.3.2 Materials - As far as possible, selection of materials was based on the materials being used on the NASA development parts at the time of the design.

4.3.3.2.1 Contact Materials were:

4.3.3.2.1.1 Rings for the inner slip ring are of P.S. Engineering Specification 57, Cond. CW1, the Poly-Scientific equivalent to NASA Spec. 10-M-1753.

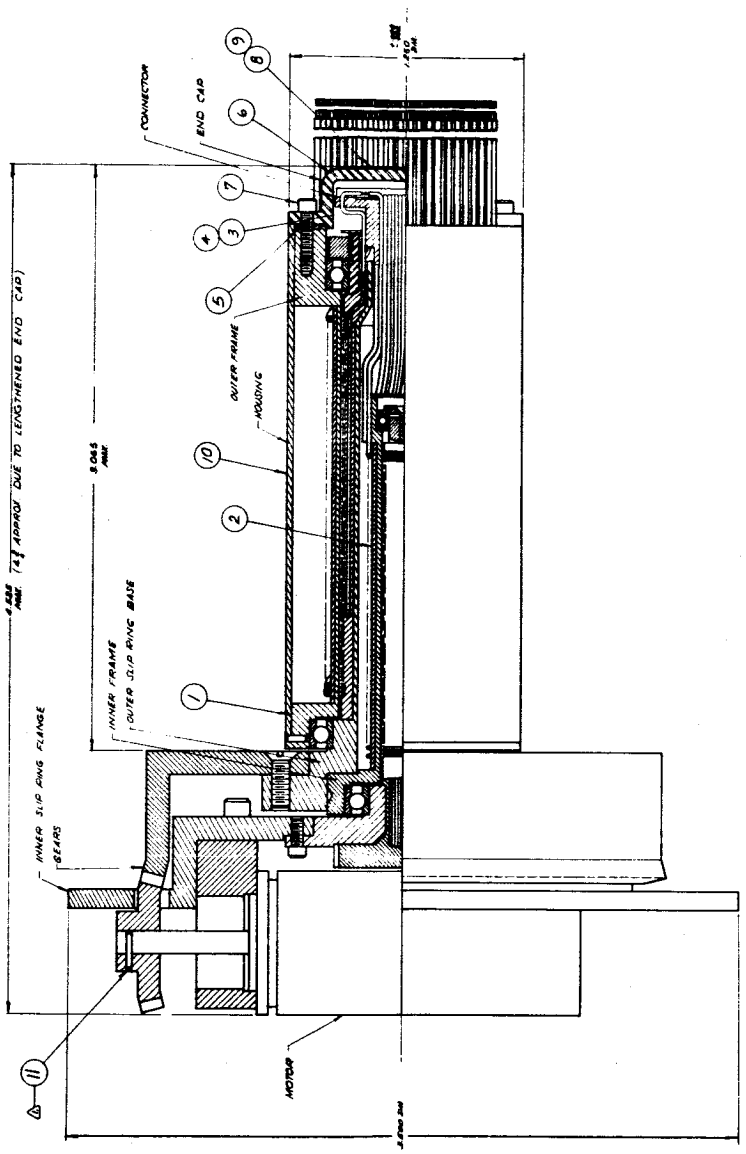
4.3.3.2.1.2 Rings for the outer slip ring are of P.S. Engineering Specification 57, Cond. CW2.

4.3.3.2.1.3 Brushes for the inner capsule are of P.S. Engineering Specification 57, Cond. CW2.

4.3.3.2.1.4 Brushes for the outer capsule are of P.S. Engineering Specification 56, Cond. HTW, the Poly-Scientific equivalent to NASA Spec. 10-M-1758.

4.3.3.2.2 Hardware - All hardware used on the DP1386 is of AISI stainless steel per QQ-S-763b, Class 303, Cond A.

4.3.3.2.3 Motor - The motor used to drive the capsule is a Daystrom Motor (Part No. S8M6).



DRAWING OF CONTINUOUS ROTATING CAPSULE
FIGURE 4.32

The motor, as used, comes with a gearhead. This gearhead provides a 694: 1 reduction ratio to provide shaft rotation in the range desired.

4.3.3.2.4 Gears - Due to the physical limitations on the design and the available motor, it was necessary to design, and have made, a special set of bevel gears (See Dwg. No. 22332. This set of gears provided a further 4:1 reduction of the shaft speed while at the same time transferring the rotation to the desired structural members.

4.3.3.2.5 Plastics

4.3.3.2.5.1 Inner slip ring plastic is per P.S. Engineering Specification 151, an unfilled, aromatic, amine cured epoxy.

4.3.3.2.5.2 Outer slip ring plastic is per P.S. Engineering Specification 149, a low modulus, semi-flexible epoxy.

4.3.3.2.5.3 Brush block plastic is per P.S. Engineering Specification 84, an unfilled aromatic, amine cured epoxy.

4.3.3.2.5.4 Other plastic components (such as lead exit spacers) are per P.S. Engineering Specification 84 or 151.

4.3.3.2.6 Bearings - Each unit contains four bearings. One of these is Poly-Scientific P/N 1165. The other three are New Departure Numbers SS, Q, MT6, ZA; SS, Q, MT10, ZA; and SS, Q, MT12, ZA.

4.3.3.2.7 Lead Wire - External lead wire used on these assemblies was the .026 max. O.D. color coded teflon insulated lead wire which was in use on the NASA development parts (DP1340) at the time these units were built. Due to crowded conditions inside the capsule, a special roll of .019 max. O.D., teflon insulated, #30 AWG (7/38) lead wire was ordered and used for the lead wire connections from the inner brush block to the outer slip ring leads.

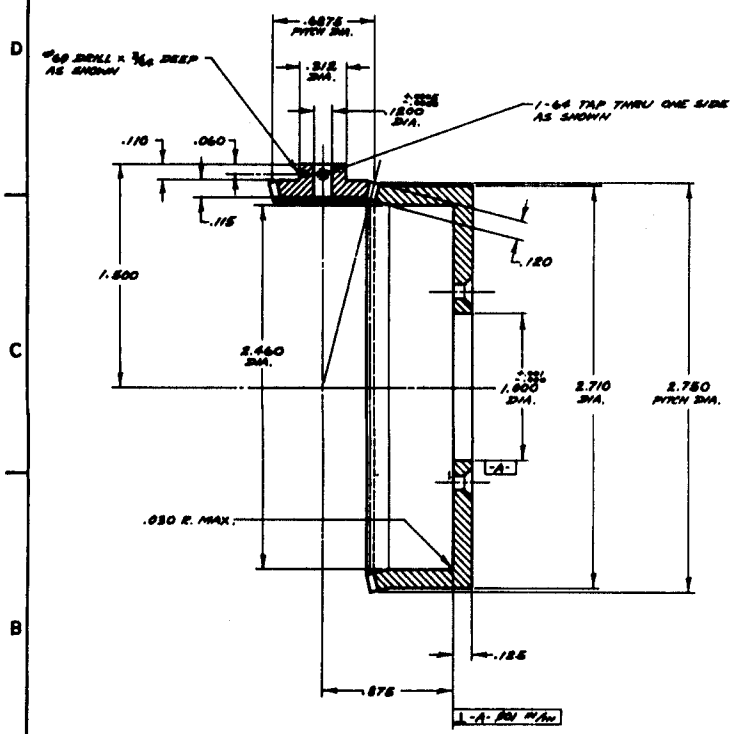
4.3.3.3 Dimensions - Several of the basic

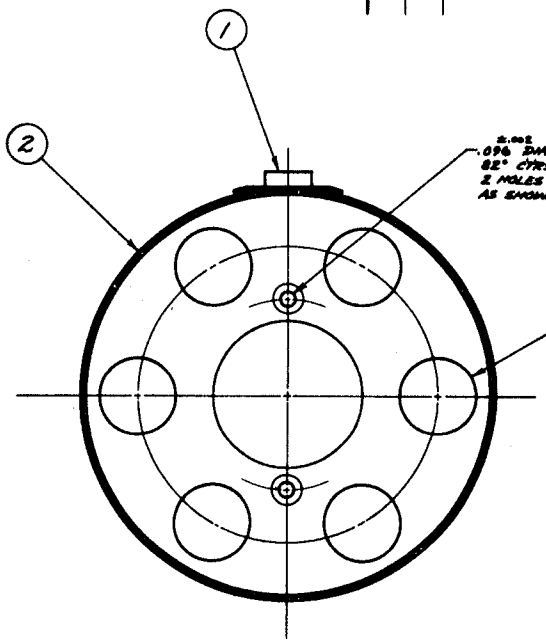
FILE: DP/386

REV.	2233200

REVISIONS

ZONE	STBL	DESCRIPTION	DATE	APPROVED





NOTES:

1. MAT'L. — ST. STL. PER QQ-S-763b, CLASS 303, COND. A.
2. ALL DIAMETERS MUST BE CONCENTRIC WITHIN .003 TIR.
3. TOLERANCES ON GEAR & PINION TEETH MUST BE A.G.M.A. QUALITY #10, OR BETTER.
4. GEAR & PINION DATA:
   RATIO = 4:1
   DIAMETRAL PITCH = 64
   NO. OF TEETH — PINION = 44
   GEAR = 176
   CIRCULAR PITCH = .049"
   PRESSURE ANGLE = 20°
5. BREAK ALL SHARP EDGES .010 R. OR CHAM.
6. DEBURR PER ANSI B. SPEC. 49, CLASS C.
7. PASSIVATE PER ANSI. SPEC. 19.

ASSY'T	DP/386		2	1	22332-2	GEAR (AS SHOWN)
22333..	DP/386	1	1	1	22332-1	PINION (AS SHOWN)
NEXT ASS'Y.	ASS. PER	QTY REQ'D	ITEM	REQ'D	PART NO.	DESCRIPTION
APPLICATION			LIST OF MATERIAL			

TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED	DATE
DECIMALS ± .008	F. Gordon	6-24-65
FRACTIONS ± 1/64	DRAWN F. Gordon	DATE 6-24-65
ANGLES ± 1/2°	CHECKED	DATE
FED. SUPPLY CODE No. 99932	APPROVED R.K.	DATE 6-25-65

BEVEL GEAR & PINION ASS'Y.

SCALE: 2:1 WEIGHT:

POLY-SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG, VIRGINIA

SIZE C | 2233200 | SHEET 1 OF 1

DP/386

dimensions for the DP1386 are given here as reference. Some of these dimensions are also shown on the attached drawing (see figure 4.3.2) which shows, among other things, an axial section of the completed assembly.

Housing O.D.	1.250
Over-all length	4-3/4"(approx)*
Dia. of bolt circle for mounting holes	3.257
Slip ring flange O.D.	3.500
Inner slip ring pitch	.020
Outer slip ring pitch	.025

* Length of end cap was increased due to manufacturing problem.

4.3.4 Problems of Design

Several problems were encountered during the initial design of the DP1386. Most of these were problems related to the disadvantages of the concept. One of the most time consuming problems was attempting to locate a motor which had output shaft rotation of approximately 10 RPM at the same time in a small enough envelope to be used with the capsule. The next major design problem we faced was having to design a special set of bevel gears to transfer the rotation to the desired slip ring components. This required some research on our part due to a lack of familiarity with gear design. It also meant having to have the gears made outside Poly-Scientific since P.S. does not presently have the proper equipment for this type of work.

The initial design included 2 brushes (4 wipers) per circuit to give the unit the best possible chance of success. However, to do this and still keep the unit within reasonable dimensional limits several basic design features were compromised. One of these was the slip ring length to diameter (L/D) ratio. Normal limits for the L/D ratio is a maximum of 10:1. However, the inner slip ring had nearly an 11:1 L/D ratio. A second fact was the ring width to barrier ratio should be kept below 2 to 1, but to control the length of the part a narrow barrier was used.

These two facts led to failure of the first slip ring cast and resulted in a redesign. Since dimensional requirements for a highly reliable capsule with two brushes per circuit would have been unreasonable, this feature was dropped and the capsule redesigned with one brush per circuit. This resulted in a length to diameter ratio of approximately 8 to 1 on the inner slip ring. The ring to barrier ratio was reduced to 1.5 to 1.

4.3.5 Problems of Construction

Initially, the problems encountered in construction of this capsule were the result of compromised design features. During the final machining operation, the first slip ring developed excessive runout. As mentioned in the previous section, this resulted in a change in the design of the unit. This change solved the problems of component construction.

The only other problems encountered in the construction of these units were those which came about during assembly of the inner and outer capsules as a finished unit. Initially, the motor shaft was not long enough and an adaptor had to be made to provide the connection between the gear and the shaft.

A major problem developed in attempts to solder the inner brush leads to the outer slip ring leads. These solder joints took up more axial space on the first unit than was allowed. As a result a special plated connector was designed and was used on the second part built (see Figure 4.3.4). This connector allowed proper spacing of the solder joints and eliminated the need for considerable axial length to make the 80 connections required.

One problem was anticipated but never fully materialized. This was the process to be used for final cleaning the assembled part. We anticipated some difficulty here due to the soldering operation which was one of the last steps in the assembly of the part. Minor variations to our normal cleaning procedures proved to be sufficient and both units were final cleaned successfully on the first cycle. This consisted of inverting the capsule after soldering

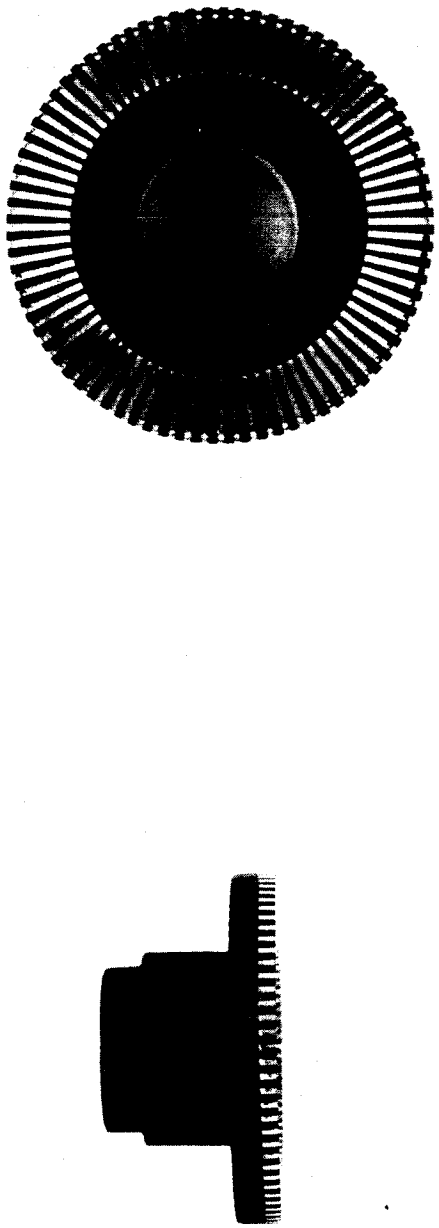


Fig. 4.3.4

CONNECTOR FOR CONTINUOUS ROTATING CAPSULE

the leads together and generating only this end of the capsule in a chlorothene solution to remove the solder flux. Normal cleaning procedures were then followed using a larger beaker in order to cover the unit with the cleaning solutions.

4.3.6 Possible Applications for and Limitations of the Continuous Rotating Concept

To a certain extent, this section of the report is tied closely with the section on "Advantages and Disadvantages of the Continuous Rotating Concept." There is no specific reason that the continuous rotating concept could not be used on every capsule design provided the finished part is within acceptable physical limits. Basically, the nature of the application depends on the limitations set forth.

Size is definitely the most restrictive limitation. To adopt a continuous rotating concept in place of a normal capsule consisting of one set of rotary contacts, the following general rules will apply.

4.3.6.1 Increase the housing O.D. by 1/2" to 3/4" depending on the number of circuits and whether or not the existing capsule is "crowded" already.

4.3.6.2 Add 1-1/2" to 2" to the capsule length to provide for motor, gears, and internal solder connections.

4.3.6.3 Assuming the motor is to be mounted on the slip ring flange, a minimum slip ring flange O.D. of 3.500" will be required.

4.3.6.4 If it is necessary to mount the motor to the normally rotating member of the assembly as used in a system, add a sufficient number of slip ring circuits in order to supply power from the stationary source to the motor.

4.3.7 Possible Refinements of Existing Continuous Rotating Capsule Design

During the course of building the two units which were shipped to NASA it was noted that there are two areas in the existing design which could be refined considerably. One such area is the internal

connections which are necessary to mate the inner capsule to the outer capsule. It was recognized in the initial design of the unit that it would be desirable to have a connection here which would permit disassembly of the unit. Since this would have been a separate research project in itself, the idea was dropped. However, as pointed out elsewhere in this section of the report, it became necessary to design a connector which did provide a means of spacing the solder joints. This is definitely an area which could be refined considerably. To do so would mean a significant increase in the reliability of the unit since it would not only eliminate a soldering operation in the final assembly, but it would also provide a means for disassembly of the completed part.

Another refinement would be to find a better and/or less costly means of supplying the continuous rotation. Although the cost did prohibit it on this particular contract, there is no reason to doubt that a torque motor, or torque motors, could be developed for specific applications. This would result in elimination of a significant number of components and would, in all probability, restore a large percentage of the additional length needed at present for the continuous rotating concept.

4.3.8 Conclusions

Successful construction of the two continuous rotating capsules has proven the feasibility of this design concept. In doing so, this work has shown that it is conceivable to design a slip ring capsule assembly capable of uniform electrical performance when being operated in a system in which the mode of operation is primarily oscillation only but must undergo occasional rotation.

Although this work has proven the feasibility of the design concept, it has opened the doors to several areas which need extensive development and refinement before any further work is done along these lines. A suitable connector should be developed. Development of a torque motor suited to this type of application would certainly be necessary. Sufficient design and development time should be spent in an attempt to reduce the size and cost of the unit as much as possible.

There is no doubt that this concept has some possibilities for future use. But, as is generally the case, it will not be suited for practical application in the slip ring industry until extensive research and development time has been expended.

4.4 BRUSH FORMING

4.4.1 Introduction

The performance of a slip ring and brush block assembly is basically dependent upon the relationship of the sliding contact surfaces; i.e., material combination, geometric configuration, surface treatment, brush force, and brush alignment. Consequently each individual brush is equally as important as the slip ring for optimum performance of the assembled capsule.

The alloy from which the brushes are made consist of 75 percent gold, 22 percent silver and 3 percent nickel. The material is drawn into wire with a maximum surface finish of 4 RMS when measured axially and 8 RMS when measured perpendicular to the center line of the material. The temper is designated as CW1 which specifies solution annealing and work hardening. The wire size is .006 inches diameter for the smaller assemblies to .009 inches for the largest assemblies. Brushes must be made from this small and relatively soft, highly finished material to the required configuration and tolerance without damaging the brush with scratches, pits, or cuts. (Drawing No. 35629).

4.4.2 Hand Forming

Almost from the inception of the Saturn program at Poly-Scientific, it was recognized that a machine for forming the brushes was necessary for maximum accuracy and duplication. Until a machine could be conceived, designed and built; however, it was necessary to make brushes on simple forming fixtures. (Figure 4.4.1). Brushes were hand formed on the fixtures using polished tools which were gold or mylar coated to avoid marring the surface of the brush. Flatness was checked and corrected if necessary, on a flat plate. Out of flatness was detected by touching the brush lightly on top with a blunt tool as it lay on the place and observing any vertical movement of the brush under 10X magnification. Lack of movement indicates flatness. Back width, parallism of the two legs and uniform radii of the brush were difficult to control with hand forming on fixtures. Brushes produced by this

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FILE: DP1405

35629 02

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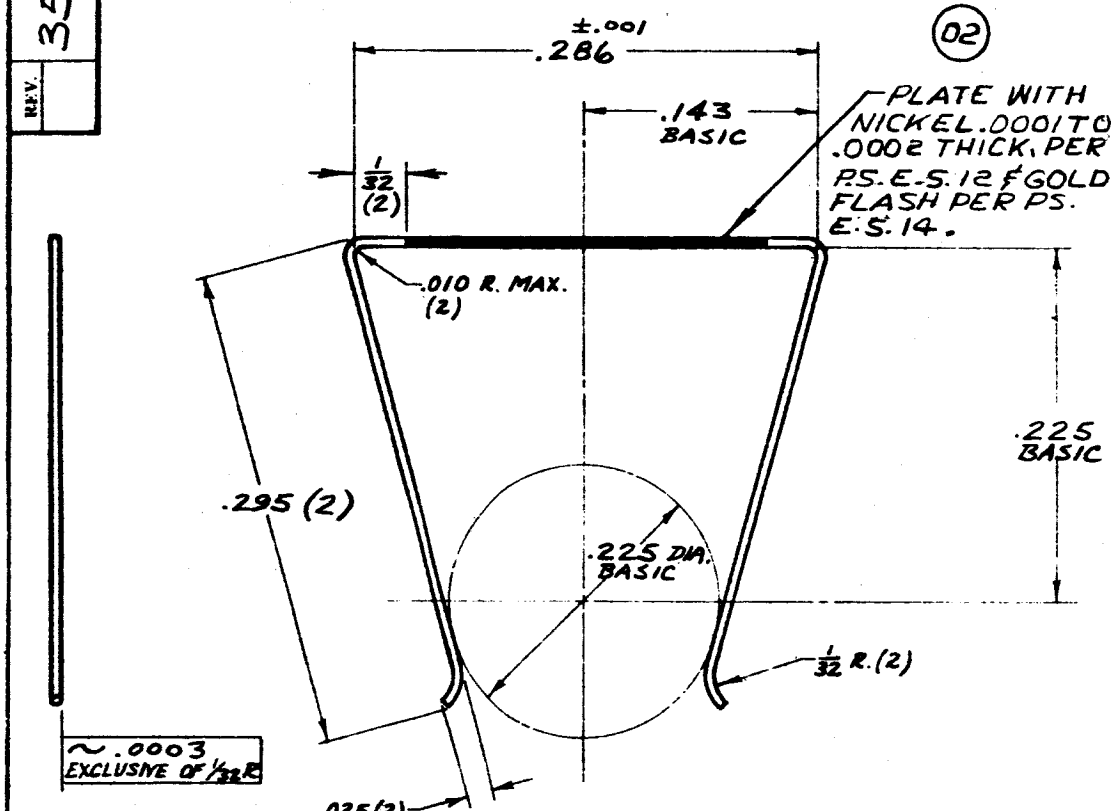
REVISIONS			
SYM.	DESCRIPTION	DATE	APPROVED
01	.0005 -.0007 WAS .00005 -.0002 PER ECO 5889	4-30-64	
02	PER E.C.O. #6370 RL	8-5-64	FG ADW



NOTES:

1. MAT'L. — PER P.S. SPEC. 57-02, TEMPER CWI, .009 DIA.
2. ENTIRE BRUSH MUST BE FREE OF SCRATCHES, PITS, CUTS, & CONTAMINATION.
3. BRUSH FORCE MUST BE 3 1/4 ± 1/2 GM. ON A .266 DIA

35630..	DP1405	80
NEXT ASS'Y.	P.S. FILE	QTY. REQ'D.
APPLICATION		

TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED FG	DATE 11-2-63	BRUSH
DECIMALS ± .005	DRAWN FG	DATE 11-2-63	Poly-Scientific Corporation, BLACKSBURG, VIRGINIA
FRACTIONS ± 1/64	CHECKED	DATE	
ANGLES ± 1/2	APPROVED B. Lindsay	DATE 11-2-63	SCALE: NONE
FED SUPPLY CODE No 99932			DWG SIZE A
			35629 02
			SHEET 1 OF 1

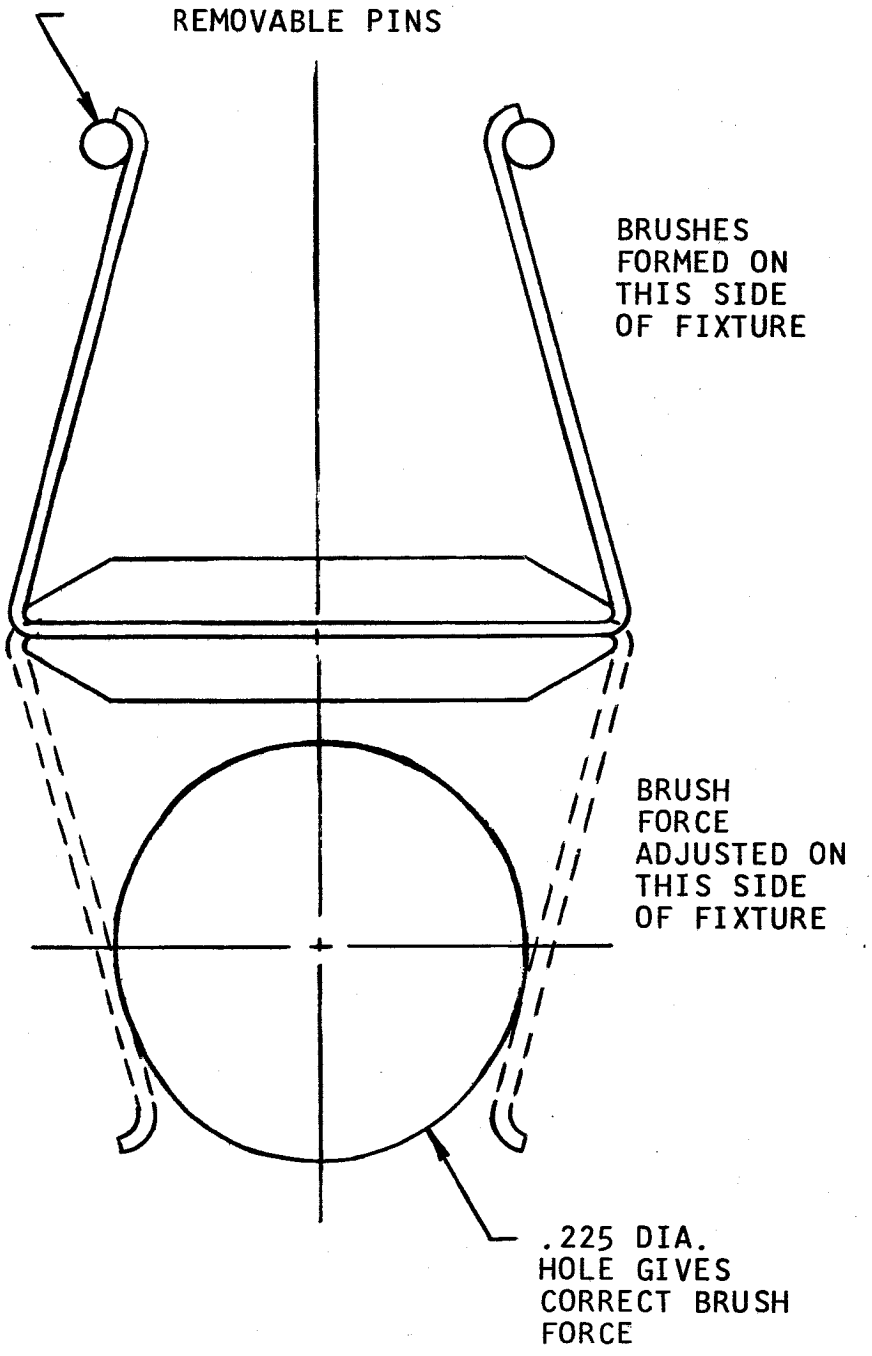


FIG. 4.4.1 - BRUSH FORMING FIXTURE

technique although of satisfactory quality, did not have the exact duplication that was desirable for maximum capsule reliability.

4.4.3 Machine Concept

The consideration of several ideas produced a technique known as stretch forming as the best approach for the mechanization of brush manufacture. Emphasis was placed primarily on repeatibility. Automatic loading and rapid production was not considered in the design of this machine. With the stretch forming technique, as the name implies, the pre-cut brush wire is stretched around a mandrel to obtain the brush configuration. The ends are cut to length while the brush is restrained around the mandrel. The contact surfaces of the brush are never touched by tooling which eliminates any possibility of damage at this most critical area of the brush.

The machine (Fig. 4.4.2 and 4.4.3) basically consists of three (3) ball bearing supported slides each of which is hydraudically controlled. The slide, on which the interchangeable forming mandrels are mounted, lies in the same plane, but moves perpendicularly to the two slides which clamp the ends of the brush wire and which form the curled ends of the brush. Figure 4.4.4 schematically shows the motion and the function of the three slides.

A separate dashpot for each slide governs the power and control needed to form the brushes. The dashpots are filled with hydraulic fluid, the flow of thich is controlled by valves to adjust the backup pressure under the gravity powered pistons. A cable leads from each piston to a sliding arm, (Figure 4.4.3).

Electrical triggering simultaneously releases the two sliding arms designated as "A" and "B" on Figure 4.4.4 when the slide controlling the motion of the forming mandrel is released.

After Saturn brushes are formed, regardless of the forming method, they are mounted on a fixture for deburring the cut ends and for nickel plating across the back of the brush. This plating is applied to prevent amalgamation of the brush material with molten solder when the brushes are soldered to the junction plates of the brush blocks. The brushes are thoroughly

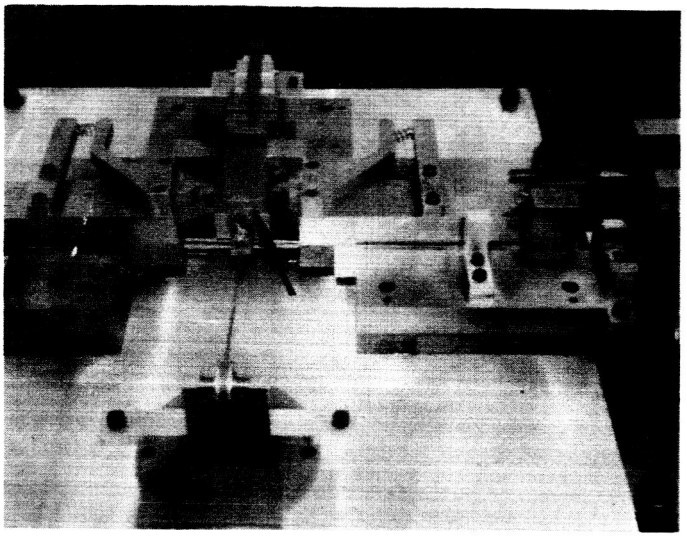


Fig. 4.4.2

Close-Up From Rear of Machine Showing Brush Wire (arrow) After Piston in Dashpot Connected to Back Forming Mandrel has been Released to Apply Forming Pressure to Brush Wire. Note Adjustable Catch Held by Release Mechanism and Adjustable Stop

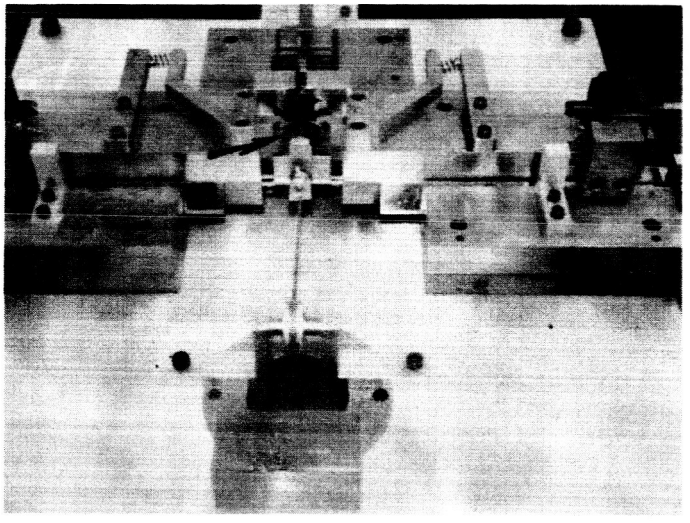


Fig. 4.4.3

Close-Up From Rear of Maching Showing Side Arms Released and Formed Brush (arrow) to be Cut to Size by Cutters (dark components, rear center)

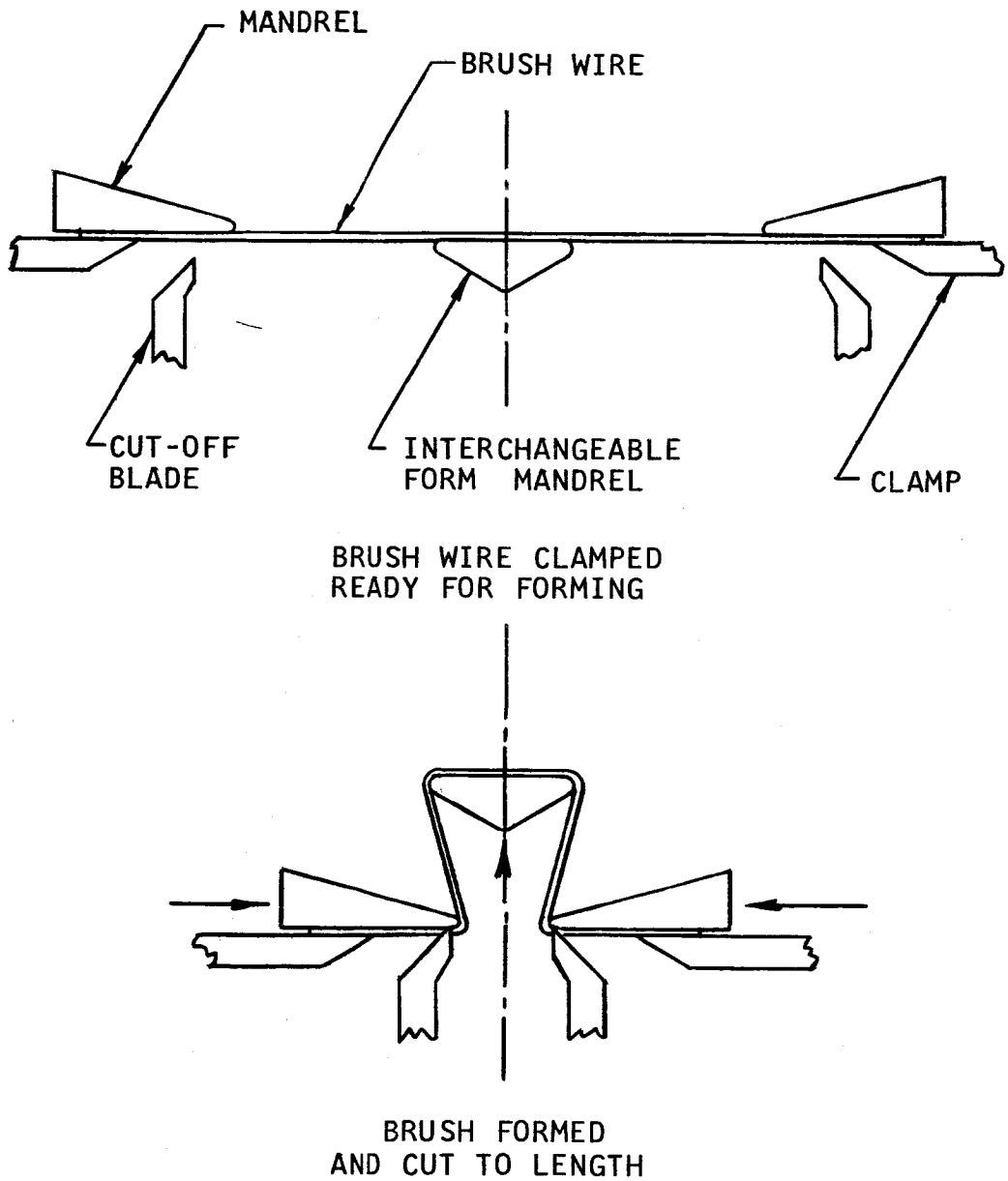


FIG. 4.4.4 - MACHINE SCHEMATIC

cleaned after plating to remove all stop-off lacquer and plating solution. The final operation before inspection is to check and adjust the brushes to the proper setting diameter. This operation is still performed on one side of the hand forming fixture.

The adjustment of a brush is always from a smaller diameter to the correct diameter. If when checked on the fixture, the setting diameter should be too large, the brush legs are sprung in and then reset to the correct diameter. This is to insure that any possibility of brush memory will not cause a relaxation of brush force. The brush machine has largely eliminated the need for this final adjustment.

4.4.4 Conclusion

Brush forming is one of the more critical operations in the manufacture of a capsule. As one member of the sliding contact pair it is essential that each brush be consistently formed and free from any surface imperfection as a result of forming.

A special brush forming machine has been built at Poly-Scientific which forms brushes by the stretch forming technique. The brushes are formed and cut to length with no part of the tooling ever touching the contact area of the brush. The machine has achieved its goal of the updatable accurate formation of brush shape.

4.5 TOOLING

4.5.1 Introduction

The consistently high performance level required of NASA slip ring capsule assemblies, and separates, demand a different tooling philosophy than the one used to tool for conventional parts. The concept of repeatable process reliability provide the key to this philosophy.

The burden of maintaining repeatable process reliability must be shifted from the human operator, regardless of how highly skilled he may be, to the tool or the machine; a mechanism designed and fabricated for a definite purpose, which blindly and unfeelingly will fulfill that purpose with a consistency that no human operator can hope to achieve.

Everything, with the exception of the schedule, must be sacrificed to the concept of repeatable process reliability; design cost, fabrication cost, production speed, and perhaps the most difficult sacrifice of all -- the skill of the exceptional operator.

4.5.2 Slip Ring Molds

The molds used for casting slip ring assemblies utilizing preformed alloy rings fall into two broad general classes -- expendable, whereby a new mold or mold insert is used for each individual slip ring assembly; and permanent molds, which class, of course, needs no elaboration. The concept of both classes is basically the same; i.e., a hollow cylinder divided into two or more sections by a surface on/or parallel to its axis, with shallow grooves provided to retain the preformed ring. The rings with leads attached are held in these grooves, along with any other components such as flanges, bearing seats, etc., positioned in an appropriate manner. The mold is closed and is ready for the plastic casting room technician.

These technicians use the most carefully prescribed processes and calibrated measuring and mixing equipment, and generally have years of experience behind them. Such care is necessary,

as many are the things that can go wrong -- voids, bubbles under the surface, cocked rings, shorts, discontinuities, etc.

4.5.2.1 Expendable Molds - Expendable "one shot" molds and/or mold inserts offer some unique advantages over permanent molds, chief of which is the concept of destroying the mold in order to insure saving the part. The material from which they are made is generally yielding enough so that the width and diameter of the ring retaining grooves can be toleranced to allow a slight interference fit of the ring to the groove. This gain in accuracy of placement of the ring is generally enough to offset the disadvantage of the lower stability of the material than that used for permanent molds.

With the proper removal techniques, the use of release agents can be eliminated, and this is an advantage that needs no elaboration. The "Cerro-Base" alloy molds, discussed below, have the almost unique property of plastic not being able to bond to the mold material.

4.5.2.1.1 Plastic mold inserts - Our other main type of expendable mold consists of a two piece transfer molded plastic insert, resembling a 20-gauge shotgun shell. One half-round section is loaded with the rings and other required components. The other half is closed down over the components, and the whole assembly is loaded into a metallic or plastic mold insert holder in a manner that is similar to loading a breech loading shotgun. The holder is sealed with silastic rubber, with the exception of an opening provided to admit the plastic, and the plastic is cast in the usual manner.

Although the casting plastic bonds the components to the inserts but not to the holder. This presents no particular problem as the mold insert is machined away from the slip ring frontshaft in a conventional manner. What might be described as the most unique advantage of this type of expendable slip ring tooling is that the thermal expansion coefficient of the mold material can be matched to the coefficient of the slip ring to a very close degree. Another, and as yet not satisfactorily explained advantage is that there is no evidence of the mold material degassing and thus causing a more or less honeycomb type of imperfection in the cured plastic.

4.5.2.1.2 Cerro-Base molds - When Phase II began, molds made by casting low melting temperature (255°F) alloy called Cerro-Base had given us our best results when casting high circuit density slip ring assemblies. These molds were considered expendable on the basis of it being more desirable to destroy a relatively inexpensive tool rather than risk damaging a complex and expensive slip ring while unloading the mold. The material used has the added advantage in that, plastic will not adhere to the mold even when no release agent is used.

However, they had one peculiarity that could be a disadvantage; the cast metal was not dimensionally stable with respect to the pattern. While they could be used to make slip rings with reasonably accurate spacing, if too long a period elasped before casting the slip ring, the mold would lengthen; consequently, the pitch would become too great. Instances have been known where a slip ring two (2) inches long would be off dimension at the end ring by as much as .005 to .010 inch. One had to cast the slip ring "on the fly" so to speak.

4.5.2.1.3 Semi-permanent plastic mold - Before the era of pre-formed alloy rings for NASA parts ended, the era of highly filled abrasive plastic was beginning. Although the slip rings could be cast fairly successfully, machining them with single point tools on a lathe was an entirely different matter. Rough machining wasn't too bad as the operator could sometimes make a complete cut across the frontshaft with a carbide tool without having to replace or resharpen the cutting bit a single time. But "V" grooving the rings was somewhat more difficult due to the "V" grooving tool having to cut the side of the saw-toothed plastic barrier at the same time. Even a diamond tool was only good for one slip ring and at its best did none too good a job. Ignoring the inferior quality of the cut, it wasn't deemed an economical operation either at the price of one diamond tool per slip ring.

One fairly obvious solution to the problem was to cast the plastic configuration of the finished slip ring to the correct size and shape. A slight change of the profile of the slip ring was necessary to prevent the "V" grooving tool from having to touch the plastic. Figure 4.5.1a illustrates how this was done; but, as so very often

happens, the solution to one problem only creates another problem; that was, to build a mold that could cast the profile configuration of the plastic barrier all the way around without webs, gates, or obvious mold parting line imperfections. The diameter to length ratio of most slip rings excludes machining the mold as a method of fabrication, as the operator would have to work blind, with very delicate tools, within the limits of a small deep hole.

An external cylindrical profile, with its configuration identical to that of the cast slip ring, can be machined. (The left hand portion of Figure 4.5.1a illustrates this configuration.) We were already accustomed to using machined cylindrical profiles as patterns to cast or mold both the Cerro-Base molds and the plastic mold inserts, but these types of expendable molds were not suitable for casting finished barriers, as both types would have webs in the barriers profile. What was needed was a method of casting a mold, with the material being a thermosetting plastic that would match the thermal coefficient of the slip ring, in which the barrier profile would be uninterrupted for a full 360°.

The concept of how this could be done is shown by Figures 4.5.1a, b, c. The profile pattern of the cast slip ring, hereafter referred to as the mandrel, is supported, within a box shaped container, with its axis in a horizontal plane. The casting plastic material for the mold, containing a built-in release agent, is poured into the box until it reaches a level slightly below the center line of the mandrel. (First casting, Figure 4.5.1b.) The plastic of this first casting is allowed to cure, at least to the point where it could be considered a solid. The whole works is then rotated approximately 90°, and with the axis of the mandrel still horizontal, the second casting is made. (Figure 4.5.1c.) The level of the plastic for this second casting is approximately even with the center line of the mandrel, the only restriction being that it must not encompass more than 180° of the periphery of the mandrel. After the second casting has solidified, the third casting is made, (Figure 4.5.1c) encompassing the remaining periphery of the mandrel. Any necessary final curing of the three castings would then be done. The castings would then be separated from the mandrel and the result would be a three piece mold, with near

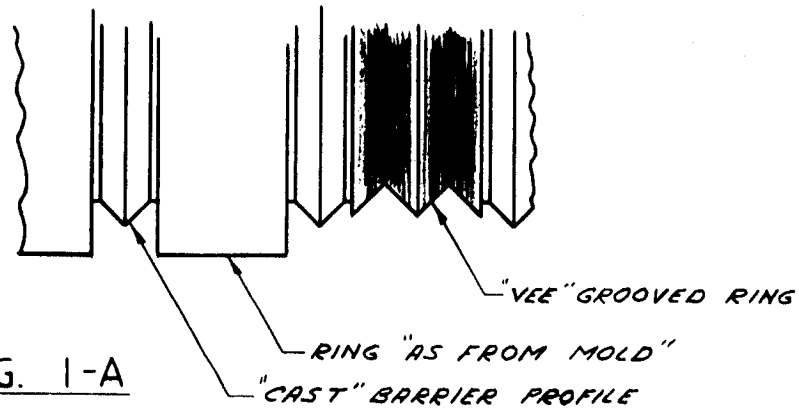


FIG. 1-A

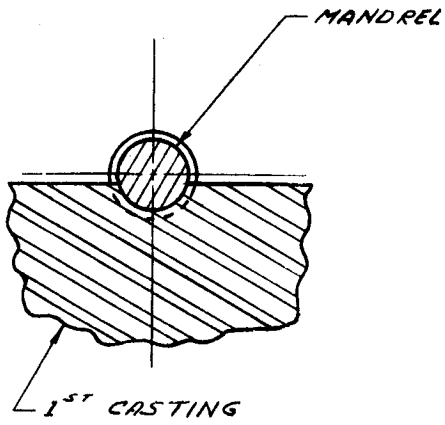


FIG. 1-B

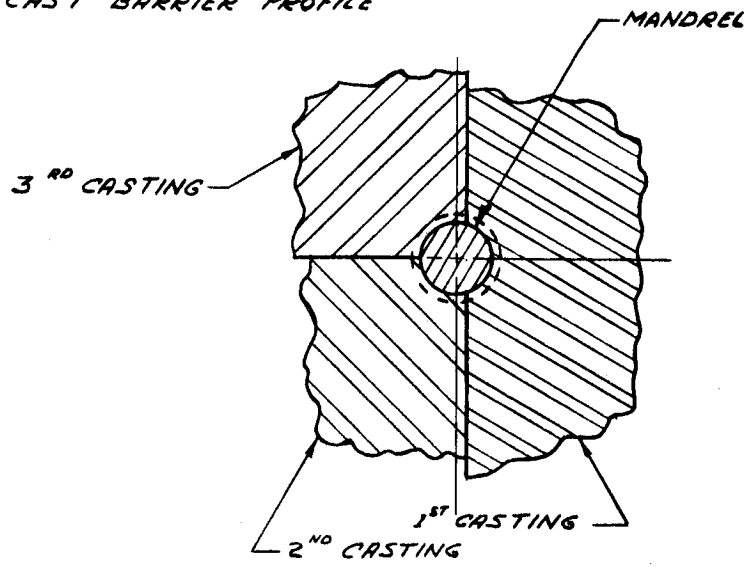


FIG. 1-C

FIGURE 4.5.1 - PLASTIC MOLD

perfectly matched parting lines, whereby the female profile contour of the barriers are uninterrupted for the full 360° of the periphery.

General use support tooling to the specifications of this concept was designed and fabricated. A mandrel, specifically for the DP 1341 was designed, but some machining problems were encountered while trying to make the mandrel. These problems were minor, and could have been eliminated in a very short time and with a slight amount of effort. But time was running out, the work load was heavy, and it was decided to revert to conventional tooling.

A promising line of development was dropped; and unless the project is reactivated, we will never know whether the concept would have worked or not.

4.5.2.2 Permanent Molds - On the face of things, it might seem that permanent molds should give the best results, but such is not always the case. By definition, the permanent mold has to be made from a very durable and inflexible material, usually hardened steel. With such a material, the stresses set up by the curing of the plastic and the difference between the thermal expansion coefficient of the mold and that of the casting often make the part very difficult to remove from the cavity. In spite of the most effective release agents, sometimes the plastic will bond to the mold. In such a case, the assembly will frequently be damaged in unloading. The need for release agents is another disadvantage of the permanent mold.

However, there is one radically different concept for a permanent mold that has received a great deal of thought and "paper" development, but no trials of actual hardware have been made. This concept shows a great deal of promise, as many specific approaches are opened up; some of which would be applicable to certain types or grades of slip rings and some to other types or grades. One of these approaches, known by the rather incredulous title of "Precision Push", is discussed in another portion of this section.

While still in the era of pre-formed rings and "un-machineable" plastic; a fact which had been with us all the time was at last squarely faced.

This fact was that regardless of the class or type of mold used, positioning a ring with a grooved mold was simply not always capable of the precision required. This is a rather broad positive statement and perhaps needs a bit of elaboration.

A very close alignment of the brush to the "V" groove of the slip ring is required for NASA parts. These "V" grooves can be machined into the slip ring to the required degree of precision, but for the slip ring to serve its intended purpose, the functional portion of the "V" groove where the brush rides must be within the metal ring. The center lines of the "V" grooves are dimensioned, toleranced, and machined to within very close limits in reference between any two of the grooves (non-accumulative tolerance). The corresponding edges of any two rings therefore, must be positioned and toleranced so that all "V" grooves will fall within the metal ring. The problem becomes acute when there are two "V" grooves in the same ring. Very often the minimum width of the ring will just barely contain the functional portions of two "V" grooves, leaving very little left over for tolerance stack-up in positioning the ring.

Let's take a look at just what the "state-of-the-art" says that this stack-up is. All tolerances listed are plus or minus.

a) Position of groove in mold - .0005".
b) Tolerance on width of mold groove - .0003".
c) Tolerance on thickness of ring - .0003".
d) Ring flatness - .0003".
e) Contraction and shrinkage allowance ± 25% of nominal .0001 to .001 inch/inch.

If added to the above are a few .0001" readout errors during some intermediate states of the process, the result is that a plus or minus tolerance of .002" per inch of slip ring length is the best that can be guaranteed. One might question the portion of the last statement of "per inch of slip ring length," as being accumulative. This is true; but it doesn't alter the fact of the hardware. Plus or minus .002" per inch of slip ring length is the best that can be guaranteed until the state-of-the-art is improved.

Any state-of-the-art may be improved in two ways: One way is to refine the conventional concept, and the other is to abandon the conventional concept altogether and strike out on a promising, but as yet unexplored path. Generally, the most significant advances are made using the latter method.

4.5.2.2.1 Precision push - The concept of the "Precision Push" method was this type of attempt to advance the state-of-the-art of positioning separate pre-cut rings into a slip ring mold. The concept was based upon the recognition that the fewest operations produces the most reliable product. Rather than accumulate all of the tolerances shown above, if each ring could be precisely located and held at a given position, there could be no stack-up of tolerances.

The concept, in simplest terms, consists of individually loading each ring onto the push device which inserts the ring into a straight bore mold. The diameter of the mold would be a light interference fit for the ring. Thus the pushing device would insert and measure the ring location as it enters. At the exact position the device would retract leaving the ring held by the interference fit.

The details of the concept were extensively thought out with the result that a number of approaches were projected in detail. In effect, the choice of the method and the tooling could be made to develop the precision, reproducability and the degree of automation desired for the apparatus. The process would develop a number of desirable side advantages in precision angular spacing of joints and improved tolerances on ring width and flatness. The most significant advantage is that all tolerance stack-ups prior to loading the mold have been bypassed. The only limits on the accuracy of the positions of the rings in the final slip ring are: the capability of the equipment, and any variations caused by the curing and shrinking of the plastic. A total spread of .0005" per inch of the slip ring length should not be too difficult to achieve.

This concept had been very thoroughly defined and was ready for reduction to drawings when the program concept was changed to the electrodeposited process. This stopped further work on the potentially advantageous "Precision Push" technique.

4.5.2.2.2 Molds for electrodeposited assemblies - A great deal of experience with molds for electrodeposited assemblies prior to their employment on contract parts had pretty well established their general design parameters. Their use on the program only involved certain refinements made necessary by the highly viscous filled plastic, adaptability to the casting machine (discussed under a separate heading), and provisions for retaining the bearing pin so that it could be cast in place. The DP1453 molds for the electrodeposition process will illustrate the state of the art in the early part of 1964.

The first casting mold is illustrated by drawing No. 28855. The flange of the slip ring assembly is positioned by the .3705" diameter and the face of the 1-1/2" diameter counter-bore,(Sht.1,Zone B4), being held down by the mold cap assembly. The .2350" diameter (Sht. 1, Zone B4) is smaller than any of the subsequent diameters, that will be machined on the frontshaft of the slip ring, by an amount that will take care of any possible eccentricity. This is necessary to avoid the chance of machining into any leads. The lead ends are positioned by the .010 x .011 slots which are located on the parting lines of the mold. The bearing pin is secured by the plug (Item 5,Sht. 1, Zone A3) which in turn is retained in the mold body assembly by the .125 wide groove (Sht. 1, Zone A4). Plastic is introduced thru the bottom of the mold, and then traversing sideways thru the 1/16" wide by 3/64" deep slots (Sht. 1, Zone A4)(detail of slot section, Zone C2). An adapter for the casting machine (not shown) fastens to the bottom on the mold body assembly.

The Mold Cap Assembly shown on sheet 2 serves several functions. Item 13 serves to core the counter-bore called out in the final slip ring assembly. Item 12 forms the back contour of the flange, cores the counter-bore for the nameplate and serves as a reservoir for excess plastic which when cured enables the slip ring to be grasped for machining. The whole works is secured to the mold body assembly by screws going thru the strap. (Item 14).

The primary malfunction of this mold was that the filler strained out of the filled plastic and stopped the flow at the junction of the runner and the gate. (Sht. 1, Zone A4). A secondary malfunction was caused by the fact that the plug

(Sht. 1, Item 5 Zone A3) was very difficult to remove from the bearing pin after the plastic had cured. This problem was particularly acute on the assemblies with small delicate frontshafts, as it was not too unusual to break the frontshaft while attempting to remove the plug.

By the middle of June 1965, most, if not all, NASA parts had been redesigned whereby they no longer used a separate center shaft bearing pin, but instead the flange, backshaft, bearing pin, and center shaft functions were all combined into one unit called the slip ring base. As the same time it was necessary to update the first casting molds. This updating pretty well eliminated the malfunctions described above. These refinements are best illustrated by Figures 4.5.2 and 4.5.3.

The runners were enlarged in cross sectional area. Gating was changed from the end gating as used in the first part of the year to side gating with a penthouse cross section. The penthouse gate gives a weak point outside of the cavity area. Adapters to the casting machine were no longer used, the necessary functional diameters being machined into the mold body assembly (Fig. 4.5.2). Figure 4.5.3 illustrates the improvement made to more effectively seal the bearing pin. The diameter that is a close fit on the bearing pin is only .015 inch in length, adequate for giving radial position but not long enough to provide much of a grip on the bearing pin. This section of the plug also contains a counter sink. When this counter sink is filled with silastic and the nut, with only .010 inch clearance in the bore, is screwed down on the bearing pin threads, the threads are very effectively sealed from any plastic.

4.5.3 Brush Block Tooling

4.5.3.1 Brush Block Mold - Phase I, by contributing the Junction Plate, as a component to load in the mold, provided the key to NASA brush blocks. After that, it was merely a matter of straight forward design, some of it rather complex, and the necessity for good accurate tool work. Drawing No. 28809 for the DP1453 is a sample of this design concept.

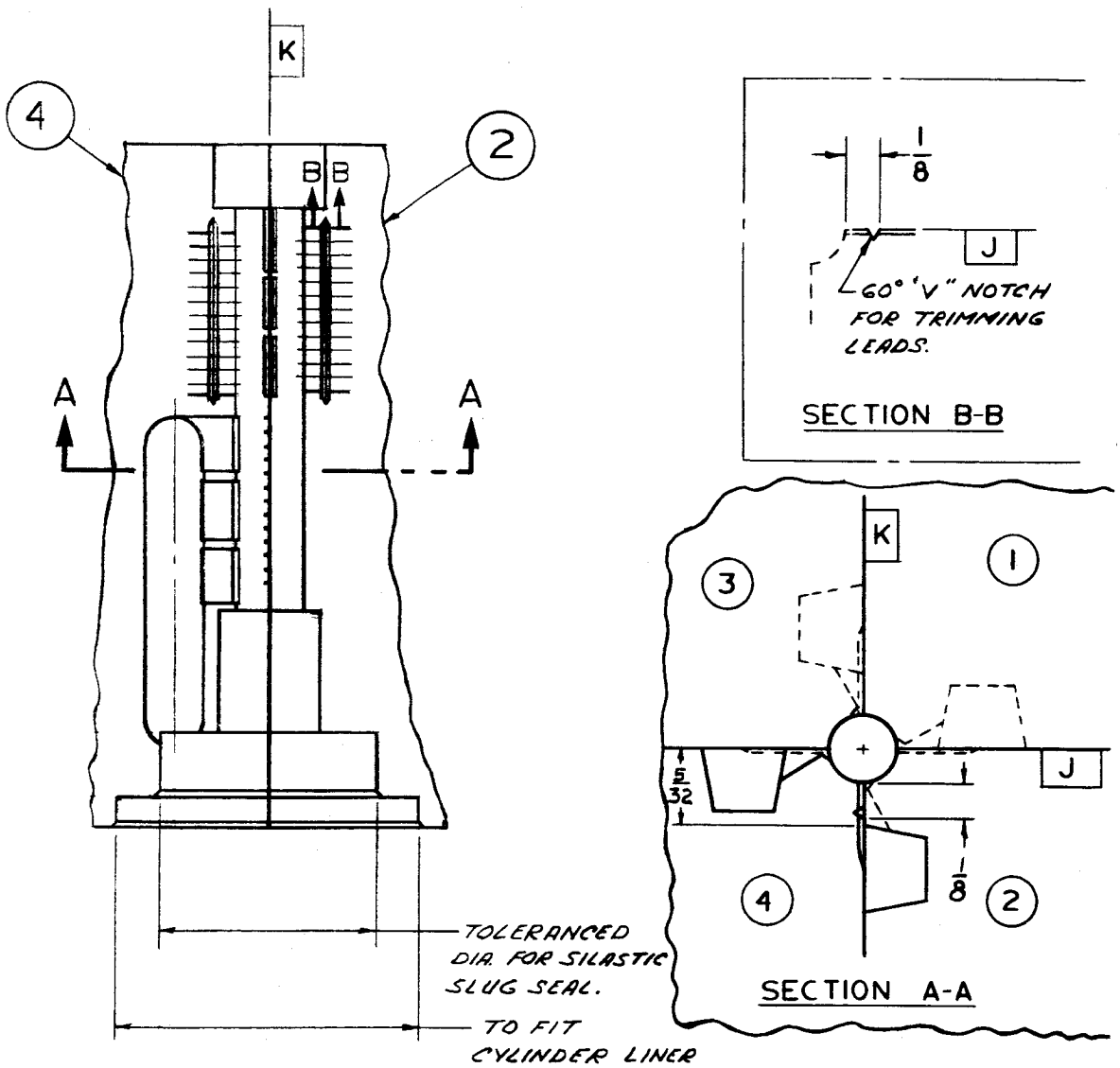


Fig. 4.5.2 - SLIP RING CASTING MOLD

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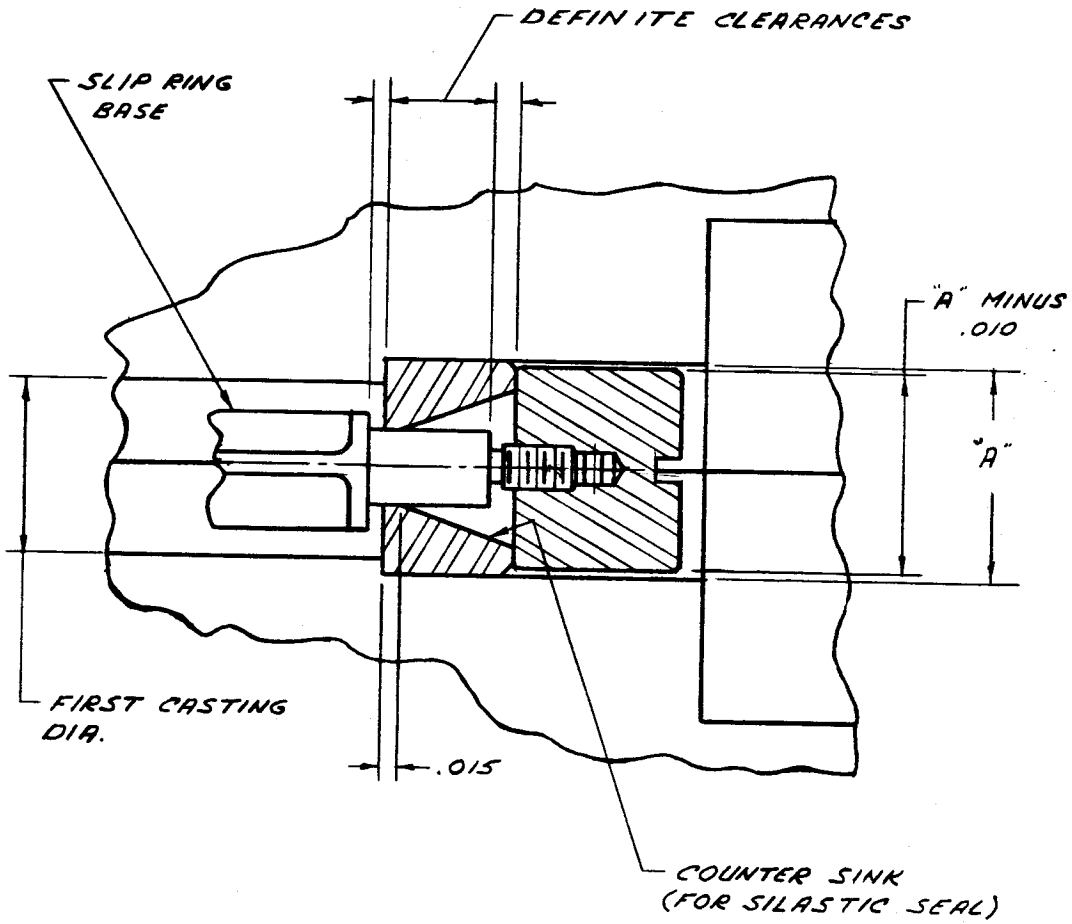


Figure 4.5.3
MOLD PLUG DETAIL

4-27-65

4.5.3.2 Brush Block Machining Fixture - The typical brush block machining fixture is so simple and straight forward that it is hardly worth mentioning. Drawing No. 28980, DP1452, is an example. The basic principle is that of a "vee" block with most of it missing. The angled surfaces of Items 2 and 3 serve to hold the brush block down against the flat surface of Item 1. The excess portion of the Junction Plate, as well as the grooves to receive the brushes, can then be machined. A modified fixture was made in order to use on the Sheffield grinder for the grooving operation.

4.5.3.3 Brush Machine - For a long time we have made our "Noote-Boom" type brushes on a very simple bench fixture, whereby the actuator(s) that formed the brush were merely hand held tools. Drawing No. 33145 for the DP1341 is an example of such a fixture.

The operator bent, twisted, wiggled, rebent, and then finally adjusted the brush by experience. There is no certain way of knowing if any two brushes, much less a whole lot, were identical.

Requests for quotations had been sent to different vendors who have four-slide machines and whose speciality was wire shapes, and the answers were invariably "no quote." Other attempts had been made at designing a gadget, sometimes simple and sometimes complex. The outcome was always the same; we continue to make the brushes on a hand operated fixture, and this we were doing during the initial phases of the NASA program.

A most extensive effort was made to either get someone to make the brushes to the specifications for us, or to design and build us a machine that would be capable of doing the same thing. The vendors refused to accept the orders to the required specifications.

It was determined that Poly-Scientific would develop the brush forming machine under this program. The design objectives were established as:

a) No portion of the tool should touch the brush wire in the intended ring contact area.

b) No subsequent working of the brush wire should be necessary to meet the dimensional specifications of the drawing, and that consistent and repeatable motions of the machine elements will produce consistent and repeatable results with the brush wire being worked exactly the same way and amount for each and every brush.

c) A high machine output would be a desirable design objective, but this objective should in no way conflict with meeting the provisions of objectives "a" and "b".

It was decided that the concept of tension forming offered the best chance of meeting objectives "a" and "b". In tension forming, the brush wire is maintained under a tensile stress less than the elastic limit. The forming is done when the brush is bent beyond the elastic limit.

The tension forming mechanism consists of a male form mounted on a slide which is actuated by a dead weight mechanism. The dead weight mechanism provides the tension maintained on the brush wire during the entire forming operation. The brush wire is held in grips mounted on individual slides which are driven toward the center at a fixed rate. These slides, when moving at right angles to the motion of the male form, cause the brush angles and radii to be precisely formed under the tension load.

The brushes are then cut to length and the only points of tool contact are at the back of the brush and on the outside of the tip radii.

The machine did not operate perfectly the first time it was tried; the production capacity of the machine was only about the same as a hand forming operation. However, the machine was successfully de-bugged, and is now producing good repeatable performance brushes. It has been reported that capsules using brushes made on this machine out-perform capsules using hand made brushes by a substantial margin. This supports the tooling philosophy advocated by NASA on the contract. When operations are done in a more repeatable and consistent manner, the results will be more repeatable and consistent!

The present machine could use some refinements, particularly in the area of coordinating the movements of the slides. Refer to Drawing No. 28804, PS220 for reference to the brush machine itself,

and to Drawing No. 28805, DP1453 for an illustration of a typical male form.

Utilizing the basic principles of this machine and the know-how gained thru fabrication and debugging; there is no reason why a fully automatic, or even partially automated, brush machine could not be designed and fabricated. Preliminary studies have revealed that perhaps its production rate would be on the order of 600 to 800. However, only occasional operator attention would be required, especially if the brush wire stock were in the form of a fairly large coil.

4.5.4 Casting Machine

The obtaining of void free castings of thermosetting plastics has always been a big problem at Poly-Scientific. The causes of voids have been attributed to the batch of plastic containing entrapped gases prior to its introduction into the mold, the incomplete filling of the mold cavity due to entrapped gases in certain reverse configurations of the cavity, bridging of viscous plastic across projections of the cavity or components during too rapid filling of the mold, and to de-gassing of the mold cavity and/or the product components loaded into the mold. It was anticipated that the use of the highly filled plastics would make the problem more severe.

Being aware of the above problem and its probable causes, it was decided that a casting machine should be built having the following functional features:

a) A plate with its major surfaces oriented in a horizontal plane, hereafter referred to as the mold plate. This plate was to have provisions for clamping the mold to its top surface.
b) A heated cylinder with its main mass suspended below the bottom surface of the mold plate, firmly attached to the mold plate, and with a precision bore open at both ends. The volume (displacement) of the cylinder, with the piston fully retracted, was to be three cubic inches or greater.
c) A piston module, with the piston to be a close fit in the bore of the heated cylinder and with an "O" ring seal. The drive mechanism of the piston was to be

able to advance the piston at any selected volume displacement rate between 100 and 2000 cubic micro-inches per second. The piston, or at least its functional head, is to be readily removable from the cylinder for the purpose of cleaning, repair, replacement, etc.

d) A removable cover that can be placed over the mold and provide a vacuum tight seal where it meets the top surface of the mold plate.

e) A vertical shaft system consisting of unbalanced mass(es) attached to the mold plate and capable of imparting to the mold plate and all attachments thereto an approximately circular orbit of approximately 1/8" diameter, with an orbital frequency that will provide a minimum horizontal acceleration of 32 feet per second per second or greater.

The method of operation of the casting machine consists of:

a) The piston is retracted and the cylinder heated to the prescribed temperature. A silastic slug approximately 3/8" thick and an interference fit in the bore of the cylinder is placed on the face of the piston, and a pre-vacuumed mass of plastic is placed in the cylinder on top of the silastic slug.

b) The pre-heated mold is then clamped to the cylinder and mold plate, the cover secured, and the pressure reduced to 3mm, thus evacuating the mold cavity, any components, the plastic, and the cylinder.

c) The vacuum is reduced slightly to just below the ebullition point of the plastic and the piston advanced on rapid travel to the point where the plastic just begins to enter the mold. The rate of travel is then reduced to its pre-selected value, and the orbiting mechanism started.

d) The piston is allowed to advance, filling the mold, until the silastic plug is driven into the counter-bore provided for it in the bottom of the mold, or in the mold adapter plate as the case may be. This effectively removes all plastic from the

cylinder and also seals the bottom of the mold against leakage.

e) The orbiting mechanism is stopped, the vacuum released, the cover removed, the mold placed in an oven for curing, and the machine cleaned and prepared for its next casting operation.

The casting machine, as with all new equipment, required some de-bugging. The Buns-S "O" rings required replacement by teflon rings. The molds would not completely refill and required modification by providing larger runners and gates, etc. The cause of the problem, when it was finally found, was simple and obvious. The mold temperature read-out device was not calibrated and the molds were just too cold to allow the plastic to flow. After this was discovered, practically any mold runner and gate system was effective.

Subsequently, conventional vacuum casting techniques made the casting machine no longer necessary to obtain good castings. The machine concept had proven effective and satisfactory for certain viscous casting operations.

4.5.5 Assembly Fixture

The assembly of a capsule is an operation which has required the skilled hand of the technician to install bearings, insert slip rings and position brushes without damage to performance. The damage to performance can come from cocking or damage of bearings, scratching of ring surfaces, or misalignment of brushes, to mention only a few. These are operations which can be done best only by a skilled technician. Even he, however, is not always exact in every detail, and the same skills cannot be developed in all technicians. It was believed that a well designed assembly fixture could be built which would enable a consistent level of technician performance and would produce at least the minimum required accuracy of assembly, that is to prevent any damage to performance.

At the direction of NASA, Poly-Scientific undertook the design of such an apparatus. This fixture, as designed, has a center post, which by means of an adaptor, mounts the frame of the capsule. A slip ring holding fixture is located on a slide at 12 o'clock (to use the clock reference system).

This slip ring holder is arranged to be on an axis concentric with the frame. At 9 and 3 o'clock respectively are two slides which support the brush assemblies. The adaptors are adjustable horizontally, vertically, and angularly to correspond to the frame location.

The frame, with bearings, is to be placed in position and the slip ring carefully slid through the bearings with the fixture providing the alignment. The bearing nut is then installed and the end play adjusted and measured. The brush subassemblies would then be aligned to the assembly position and slid approximately into place. A few thousandths of an inch play has been allowed for the final positioning of the brush subassemblies to be achieved by the assembly alignment dowel and operator guidance.

As of the conclusion of the program, the manufacture of the fixture and its first adaptors had not yet been completed, and therefore the actual performance of the system had not been tested. There are some areas that are foreseen as trouble spots. These are particularly in the alignment of the four major components in three dimensions and at precise angles to permit accurate insertion. Small errors of tolerance of a component, an adjustment, or in slide operation at any of a number of points could prevent effective operation of the fixture. In addition, certain capsule assembly design changes will be probably required, particularly on brush assemblies, to provide satisfactory mounting and clamping surfaces. There will undoubtedly be various features requiring debugging and possibly some additional features required before the system performs properly.

It is possible for the device to work, but it will probably require additional effort to make it function with a stability and an accuracy which exceeds the skills of a trained technician.

4.5.6 Summary

During the course of the contract, tool design and construction has been a major portion of the work.

In slip ring mold design the succession of design material, and process changes evolved during the contract have required an equal succession of mold concepts and designs. In addition from the straightforward metal molds designed and used for the electrodeposition process castings, the concepts of the semipermanent plastic molds and of "precision push" developed during the program offer a number of advantages if reduced to practice.

The brush forming machine designed and built successfully for the first time under this contract has proven effective and highly satisfactory.

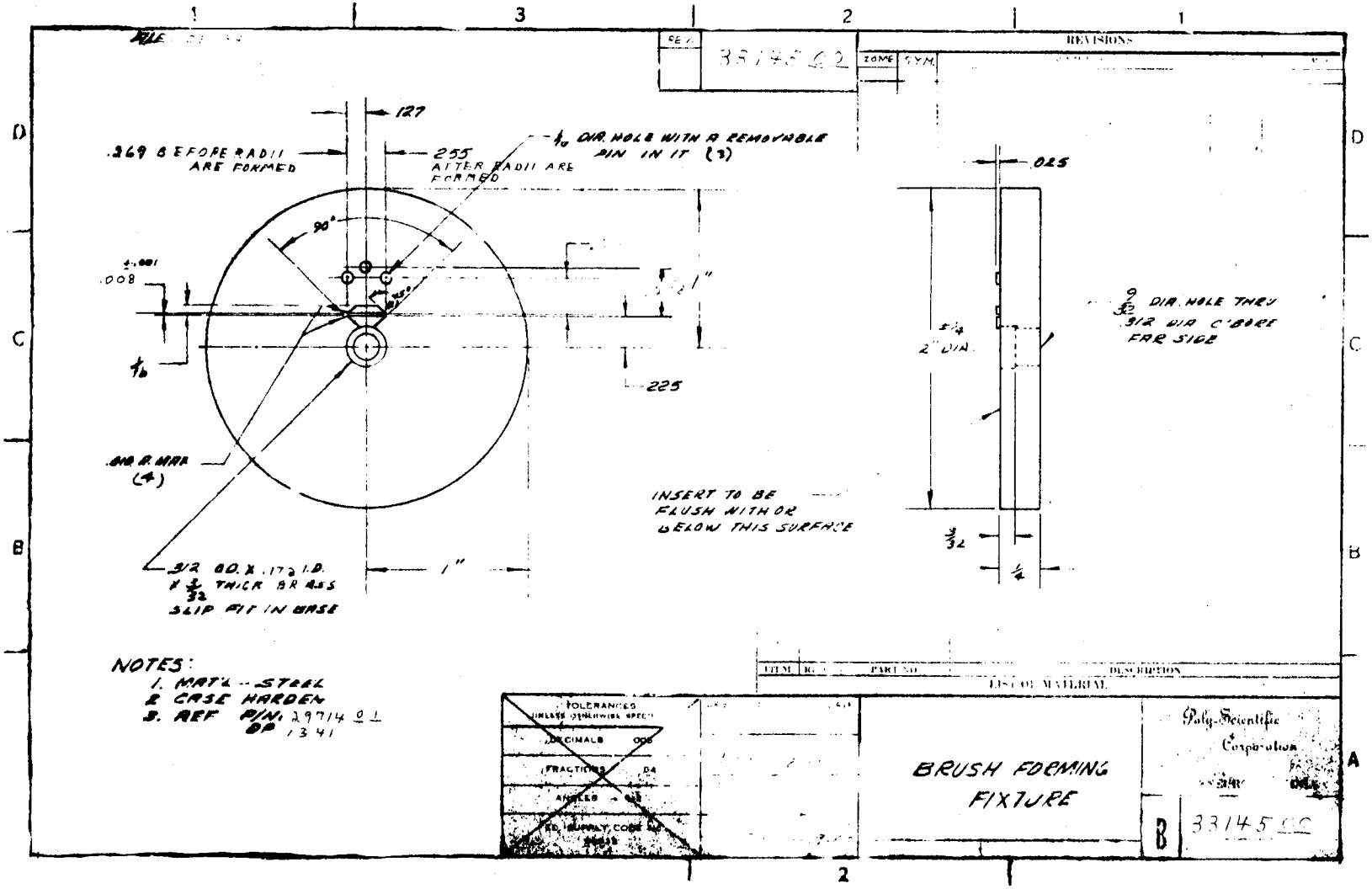
A novel concept of casting viscous plastics has been designed and built into working equipment. The casting machine has proven effective with viscous plastics into narrow crevices.

An assembly fixture has been designed and is being built which is expected will provide an assembly aid to the operators in aligning and assembling the final capsule. In addition many small miscellaneous tools have been constructed to improve the design, processing, and performance of the assemblies.

Tools conceived and developed under this program have made a major contribution to the reliability of the capsule assemblies.

APPENDIX 4.5-I

DRAWINGS


REVISIONS
ZONE
SYM
33145 C2
.127
.369 BEFORE RADII ARE FORMED
.255 AFTER RADII ARE FORMED
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90°
+.001 .008
1/8
.225
.062 R. MAX (4)
3/2 O.D. X .17 I.D. X 5/32 THICK BRASS SLIP FIT IN BASE
1"
INSERT TO BE FLUSH WITH OR BELOW THIS SURFACE
.025
5/4 2" DIA.
9/32 DIA. HOLE THRU 3/2 DIA C'BORE FAR SIDE
3/32
1/4
NOTES:
1. MAT'L -- STEEL
2. CASE HARDEN
3. REF P/N 29714 01 OP 1341
ITEM
QTY
PART NO
DESCRIPTION
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TOLERANCES
DECIMALS
FRACTIONS
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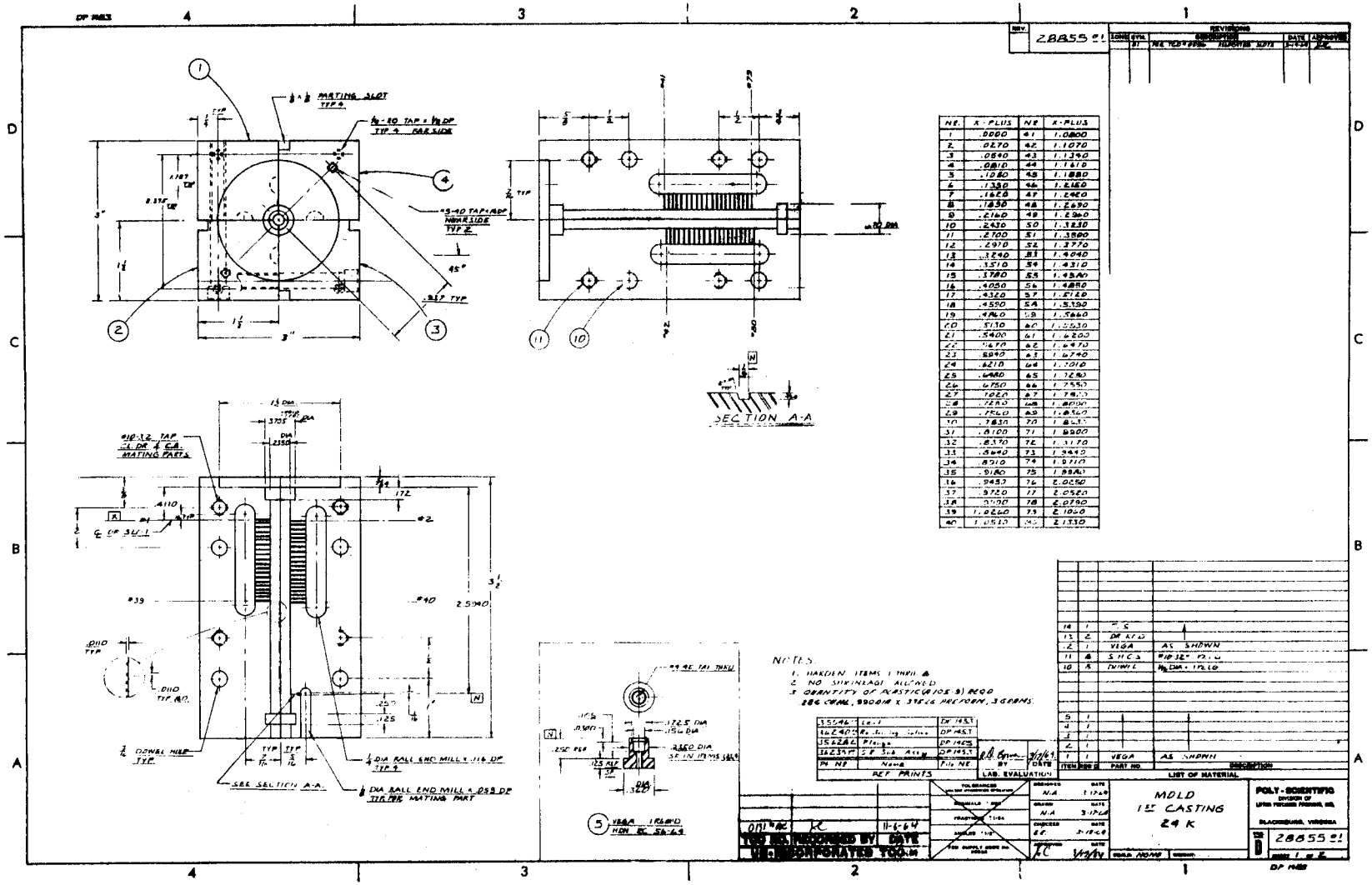
Poly-Scientific Corporation
B
33145 C2



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7	.1620	47	1.2420
8	.1890	48	1.2690
9	.2160	49	1.2960
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28	.7290	68	1.8090
29	.7560	69	1.8360
30	.7830	70	1.8630
31	.8100	71	1.8900
32	.8370	72	1.9170
33	.8640	73	1.9440
34	.8910	74	1.9710
35	.9180	75	1.9980
36	.9450	76	2.0250
37	.9720	77	2.0520
38	.9990	78	2.0790
39	1.0260	79	2.1060
40	1.0530	80	2.1330

NOTES:
1. HARDEN ITEMS 1 THRU 4.
2. NO SHRINKAGE ALLOWED.
3. QUANTITY OF PLASTIC (NOS. 3) REQD
286 CU.IN., 3900 IM x 3.5 FT.LB PRE FOAM, 3.6 GRMS.

ITEM	PART NO	DESCRIPTION
14	1	— S —
13	2	DF 44.0
12	1	VEGA AS SHOWN
11	4	S.H.C.S. #10-32 x 2.00
10	5	DWL PIN 1/8 DIA x 1.10 LG
9	1	
8	1	
7	1	
6	1	
5	1	
4	1	
3	1	
2	1	
1	1	VEGA AS SHOWN

LIST OF MATERIAL

15546	Lock	DP 145.1
16240	Retaining Collar	DP 145.1
15226	Plunger	DP 140.5
16239	S.P. Sub Assy	DP 145.1
IN NF	Name	File NE

REF PRINTS

LAB. EVALUATION

DESIGNED	N.A.	DATE 3-17-69
DRAWN	N.A.	DATE 3-17-69
CHECKED	R.F.	DATE 3-18-69
ENGR	R.C.	DATE 4/7/64

MOLD
1ST CASTING
24 K

POLY-SCIENTIFIC
DIVISION OF
LUTER INDUSTRIES VIRGINIA, INC.
BLACKSBURG, VIRGINIA

SIZE D 28855 S1
SHEET 1 OF 2

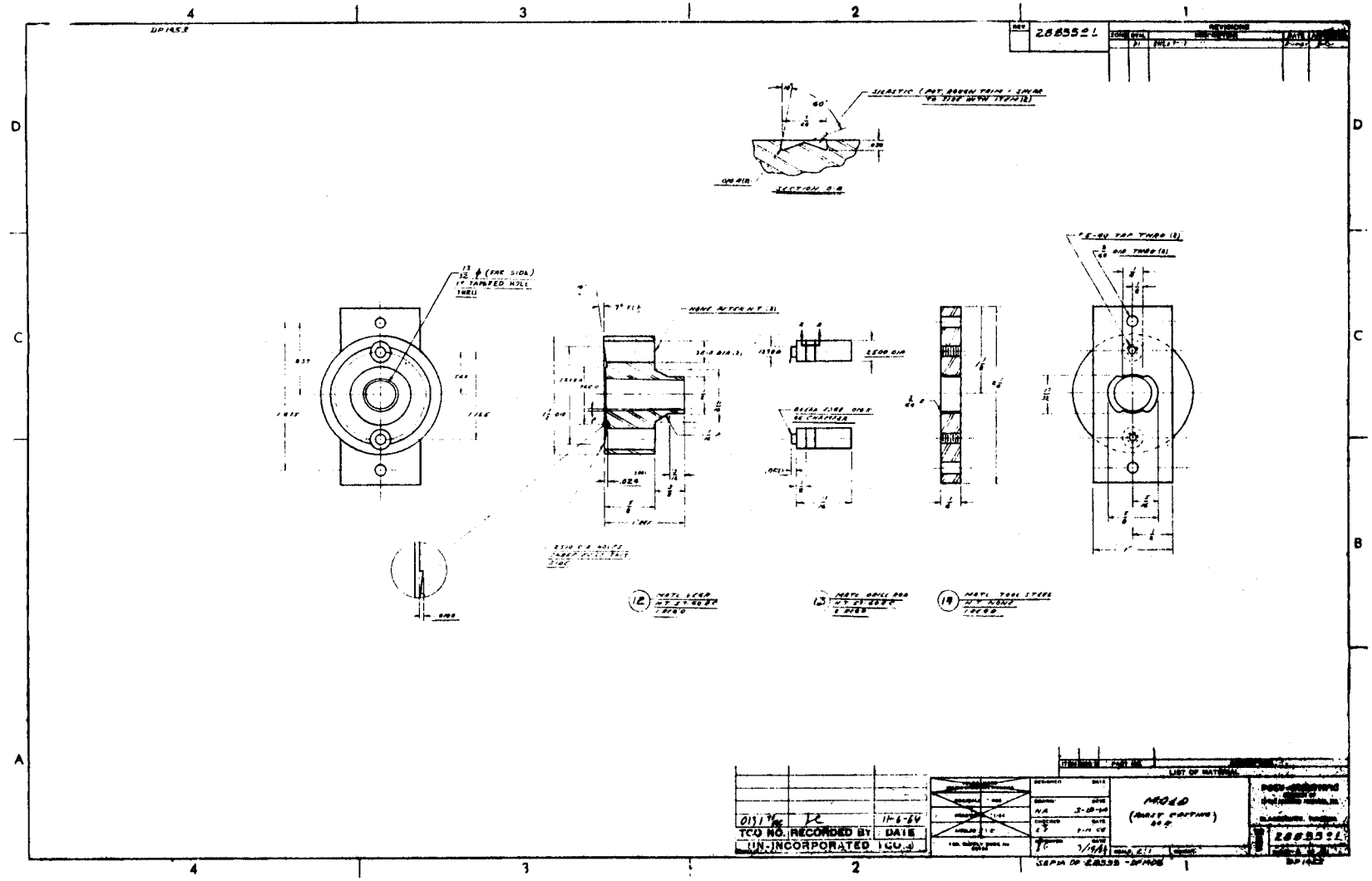
DP 9455

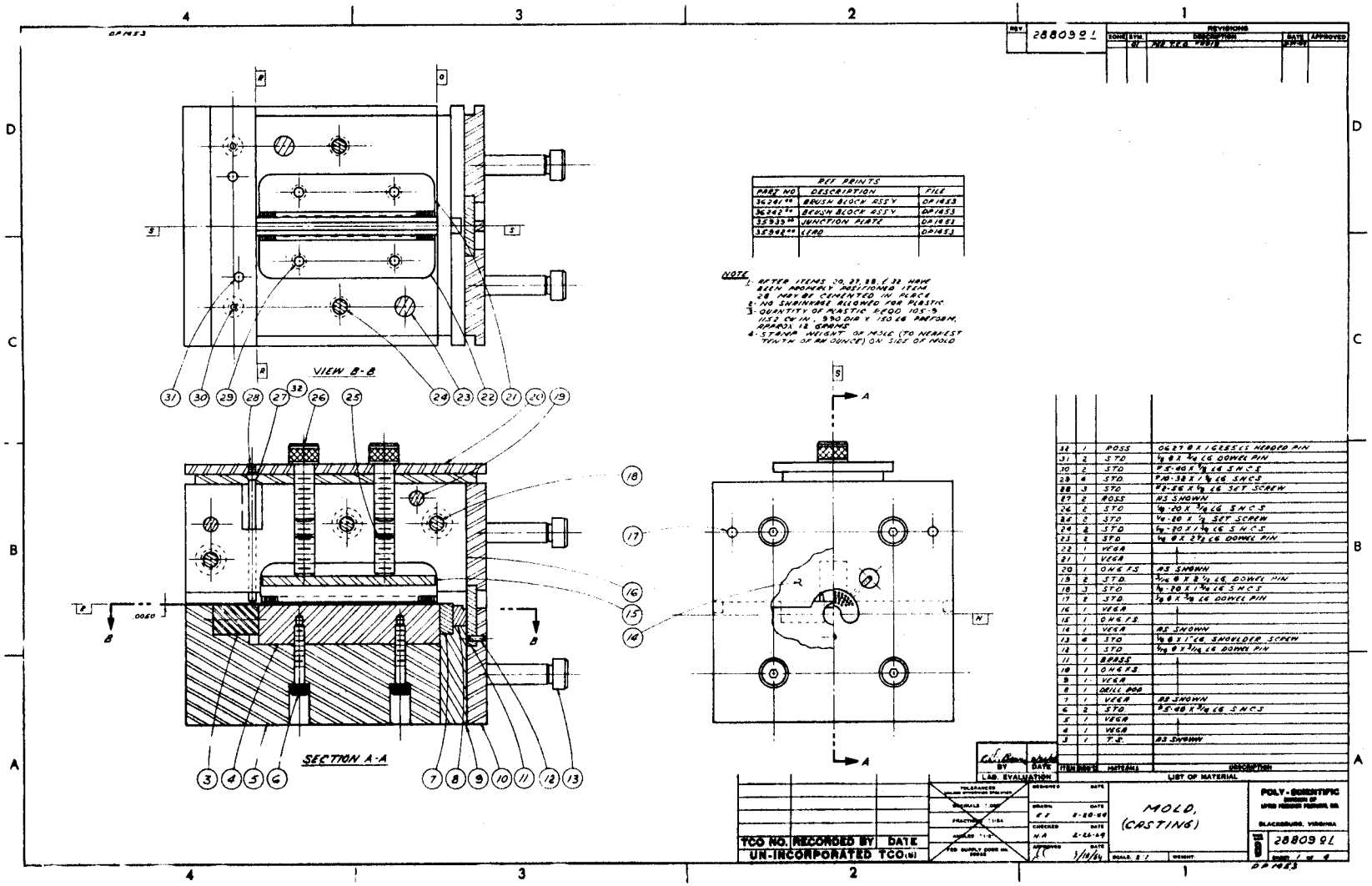
28855 S1

REV.	ZONE	DESCRIPTION	DATE	APPROVED
		PER TCR # 9996 FLUORITE SLOTS	3-17-69	

DP 9453

11-6-64
THIS IS RECORDED BY DATE
INCORPORATES TCO-


4
3
2
1
D
C
B
A
UP 145.8
28855 ☐ L
REVISIONS
SECTION A-A
(12)
(13)
(19)
TCO NO. RECORDED BY
DATE
IN-INCORPORATED
11-6-84
MOLD
(BASE CASTING)
SCALE 2:1
SCALE OF 28838 - SHOWN
28855 ☐ L



REF PRINTS		
PART NO	DESCRIPTION	FILE
34201[19]	BRUSH BLOCK ASSY	DP1653
34202[20]	SENSOR BLOCK ASSY	DP1653
35935[19]	JUNCTION PLATE	DP1651
35948[19]	LEAD	DP1653

NOTE
1. AFTER ITEMS 20, 27, 28, & 32 HAVE BEEN PROPERLY POSITIONED ITEM 28 MAY BE CEMENTED IN PLACE.
2. NO SHRINKAGE ALLOWED FOR PLASTIC
3. QUANTITY OF PLASTIC REQD 105.9 113.2 CU IN - 950 DIA x 150 LG PARTS&M, APPROX 1.8 GRAMS
4. STAMP WEIGHT OF MOLD (TO NEAREST TENTH OF AN OUNCE) ON SIDE OF MOLD

32	1	BOSS	0627 B X 1 GEEDET HEADED PIN
31	2	STD	1/8 Ø X 3/4 LG DOWEL PIN
30	2	STD	PS-#6 X 1/8 LG SNCS
29	4	STD	PM-#8 X 1/8 LG SNCS
28	3	STD	PB-#6 X 1/8 LG SET SCREW
27	2	BOSS	AS SHOWN
26	6	STD	1/4-20 X 3/8 LG SNCS
25	8	STD	1/4-20 X 1/4 SET SCREW
24	2	STD	1/4-20 X 1 1/8 LG SNCS
23	2	STD	1/4 Ø X 2 3/4 LG DOWEL PIN
22	1	VEGA	
21	1	VEGA	
20	1	ONE PS	AS SHOWN
19	2	STD	3/16 Ø X 2 1/2 LG DOWEL PIN
18	3	STD	1/4-20 X 1 3/4 LG SNCS
17	2	STD	1/8 Ø X 3/4 LG DOWEL PIN
16	1	VEGA	
15	1	ONE PS	
14	1	VEGA	AS SHOWN
13	4	STD	1/8 Ø X 1" LG SHOULDER SCREW
12	1	STD	1/16 Ø X 3/16 LG DOWEL PIN
11	1	BRASS	
10	1	ONE PS	
9	1	VEGA	
8	1	DRILL ROD	
7	1	VEGA	AS SHOWN
6	2	STD	PS-#8 X 3/8 LG SNCS
5	1	VEGA	
4	1	VEGA	
3	1	P.P.	AS SHOWN

ITEM NO'S | MATERIAL | DESCRIPTION — LIST OF MATERIAL

LAB. EVALUATION BY DATE

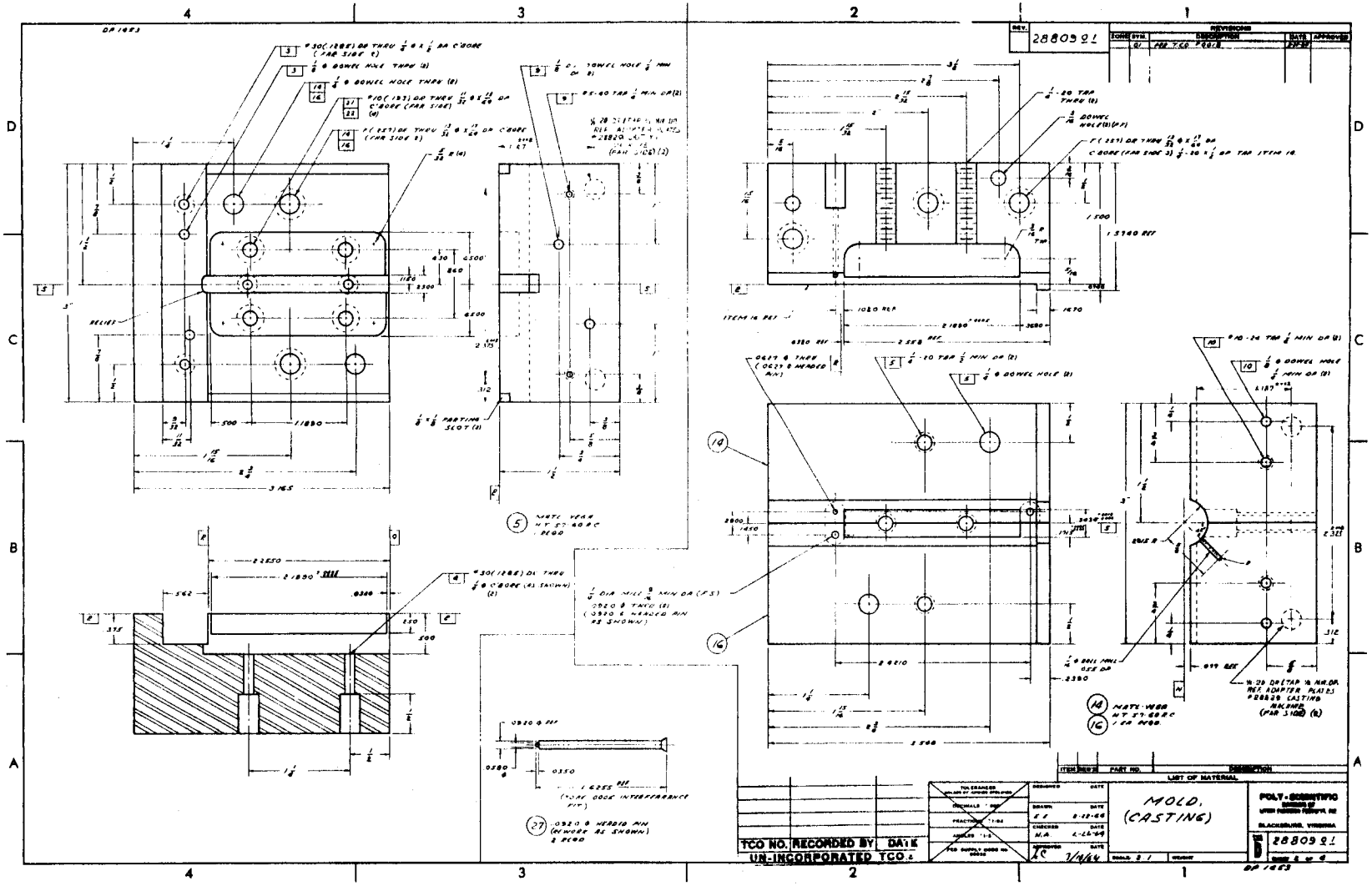
TCO NO. RECORDED BY DATE
UN-INCORPORATED TCO.(S)

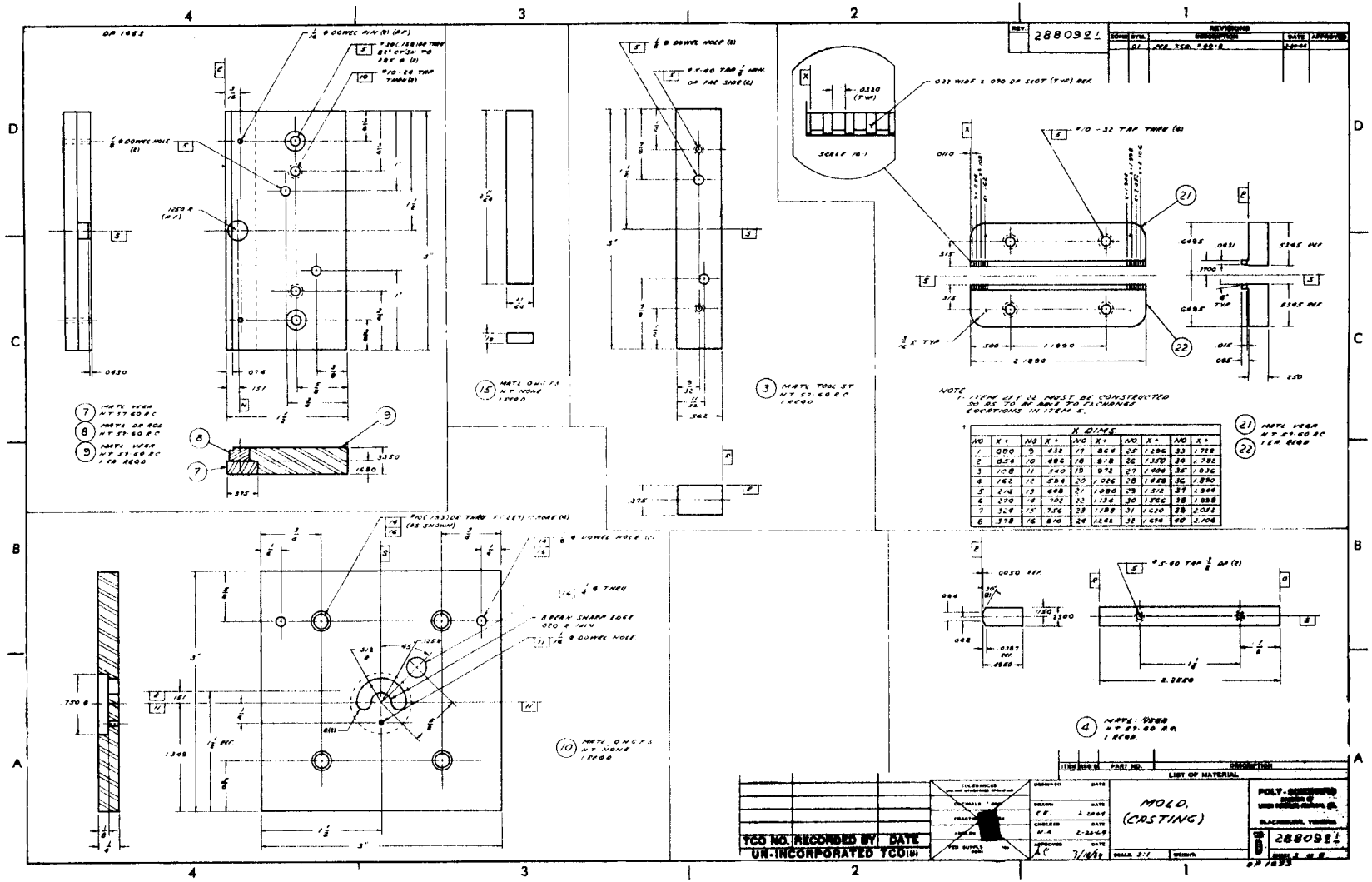
MOLD, (CASTING)

POLY-SCIENTIFIC
BLACKSBURG, VIRGINIA

2880991

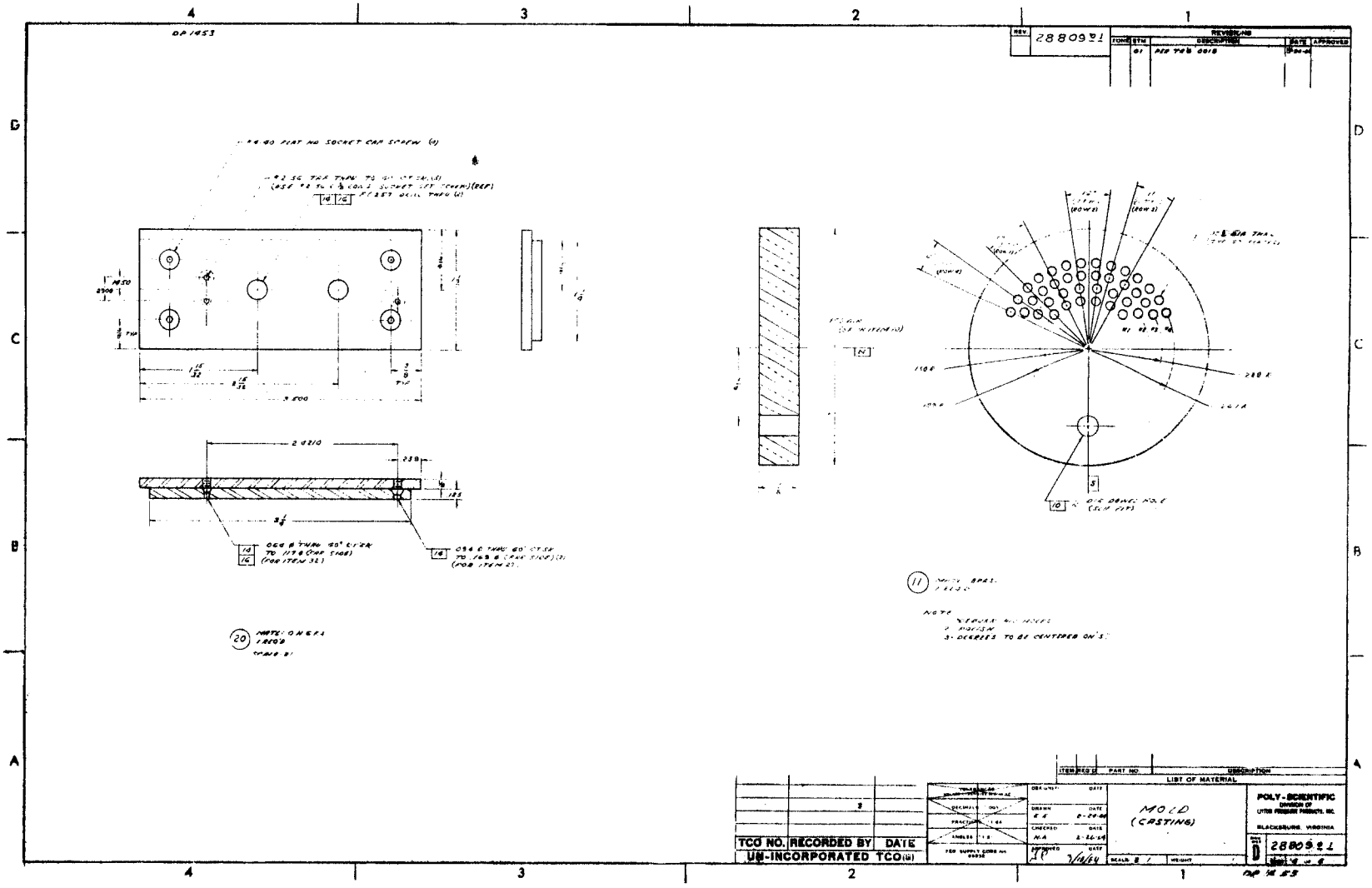
DP1653

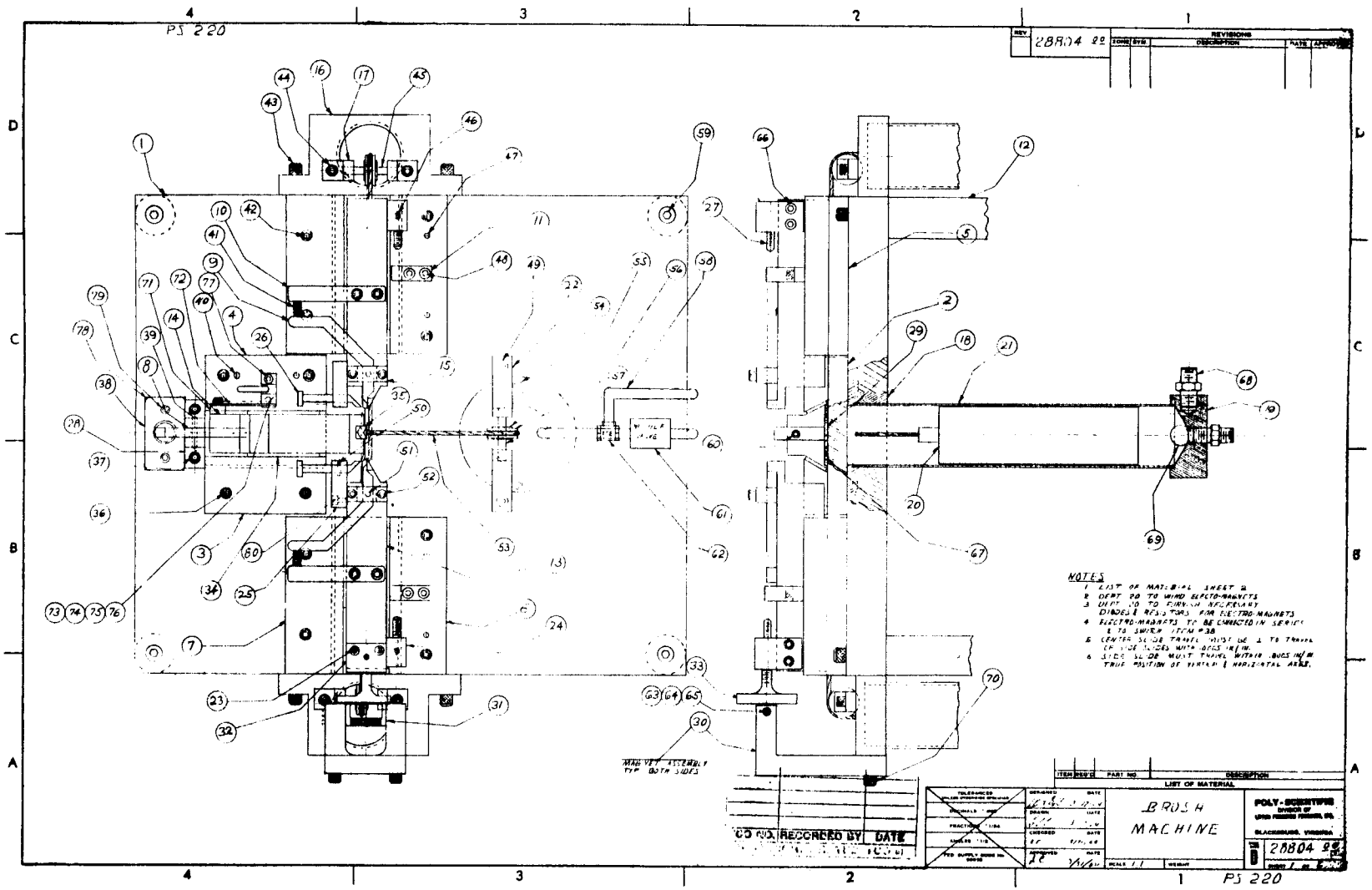

MOLD, (CASTING)
POLY-SCIENTIFIC
28809 91
TCO NO. RECORDED BY DATE
UN-INCORPORATED TCO.
LIST OF MATERIAL



NO	X ±	NO	X ±	NO	X ±	NO	X ±	NO	X ±
1	.000	9	.432	17	.864	25	1.296	33	1.728
2	.054	10	.486	18	.918	26	1.350	34	1.782
3	1/8	11	.540	19	.972	27	1.404	35	1.836
4	.162	12	.594	20	1.026	28	1.458	36	1.890
5	1/4	13	.648	21	1.080	29	1.512	37	1.944
6	.270	14	.702	22	1.134	30	1.566	38	1.998
7	.324	15	.756	23	1.188	31	1.620	39	2.052
8	.378	16	.810	24	1.242	32	1.674	40	2.106

X DIMS


4
3
2
1
D
C
B
A
DP 1453
REVISIONS
DESCRIPTION
DATE
APPROVED
MOLD (CASTING)
POLY-SCIENTIFIC
BLACKSBURG, VIRGINIA
TCO NO. RECORDED BY DATE
UN-INCORPORATED TCO(S)
LIST OF MATERIAL
ITEM
REQ'D
PART NO.
DESCRIPTION


PS 220
REVISIONS
28804 00
NOTES
1 LIST OF MATERIAL SHEET 2
2 DEPT 20 TO WIND ELECTO-MAGNETS
3 DEPT 10 TO FINISH MACHINED PARTS
DIODES & RESISTORS FOR ELECTRO-MAGNETS
4 ELECTRO-MAGNETS TO BE CONNECTED IN SERIES & TO SWITCH ITEM #38
5 CENTER SLIDE TRAVEL MUST BE ⊥ TO TRAVEL OF SIDE SLIDES WITH .005 IN/IN.
6 SIDE SLIDE MUST TRAVEL WITHIN .005 IN/IN TRUE POSITION OF VERTICAL & HORIZONTAL ARMS.
MAG YET ASSEMBLY TYP BOTH SIDES
CO NO. RECORDED BY DATE
LIST OF MATERIAL
ITEM REV'D PART NO. DESCRIPTION
BRUSH MACHINE
POLY-SCIENTIFIC
DIVISION OF
BLACKSBURG, VIRGINIA
28804 00
PS 220

4.6 RELIABILITY CONTROLS DEVELOPMENT

4.6.1 Purpose

The purpose of this section is to describe the development of Reliability Controls on the Saturn Program and to relate information concerning the inspections, tests, and controls developed with this program. It is also the purpose of this section to relate some of the problems encountered and conclusions drawn by Reliability from the development of the program.

The Reliability Division of Poly-Scientific performs all inspections and tests and enforces the requirements of drawings, specifications, and established standards of quality throughout all phases of the manufacturing of Saturn units. With this Division lies the responsibility to prevent, correct, and preclude repetition of discrepancies on the slip rings. In addition, it participates in the initiation, development, and documentation of specifications and processes.

The reliability concept at Poly-Scientific is one which combines the principles of design quality with production quality to ensure that each Saturn unit will function with a high degree of reliability over the specified life span under the specified environmental conditions. To ensure product reliability, the quality of materials used in the manufacture of Saturn units is controlled from the time of order of material by Poly-Scientific until the final unit is shipped to the customer.

Total quality control encompasses the quality of the unit at each step of fabrication. As a means of improving the in-process and subsequently, the final unit quality, Poly-Scientific has embarked on a program of "Zero-Defects" or "Z.D." for short. Through Zero Defects, Poly-Scientific is striving to have the individual assign the same importance to his industrial activities that he, personally, expects of his doctor, dentist, or banker.

4.6.2 Development History

In 1961, Poly-Scientific produced the first capsule assemblies for the Marshall Space Flight Center. These units were built as prototypes in our Model Shop. At that time, the Model Shop procedures were such as to facilitate early delivery of prototype units. Under this concept, documentation was held to a minimum. Marked-up drawings, sketches and verbal instructions were established practice for this concept. Inspection, acceptance, processing, and techniques were left to the experienced judgement of the technicians and the supervising engineer.

Despite the limited documentation, these units represented the highest quality design, and workmanship available to the industry at that time.

Experience gained in the manufacture and test of these units enabled Poly-Scientific and NASA to establish an effective base for development of design, processes, techniques and controls on this program. Knowledge gained from the first phase of the development program conducted by Poly-Scientific for NASA produced an upgrading of design, plastic, processes, documentation and the introduction of Reliability controls in the 1405 series of parts.

Late in 1963, Marshall Space Flight Center began preparing drafts of the required specifications and, after six months of review and communication, effective specifications were produced. GC125355 and its related documents now define the important features of design, materials, process controls, and documentation obtained from these years of development.

In the summer of 1964, Poly-Scientific designed and produced the DP1500 series of Saturn Slip Ring Capsule Assemblies, the first units ever to be produced to the full requirements of the Saturn Program.

4.6.3 Clean Area

Since 1961, capsule slip rings and their components have become more sophisticated. This sophistication has brought with it many requirements, one of which is the demand for better cleanliness standards. To ensure minimum cleanliness and maximum particle contamination, all Saturn units are final assembled and tested under a laminar flow clean bench.

This approach utilizes highly filtered and conditioned air brought into the work space through a filter bank comprising the entire back of the bench. Laminar flow work stations operate on the principle of eliminating dust as soon as it is generated. This is accomplished by air exiting at 100 foot per minute velocity from superinterception filters. The Saturn units are always assembled in "First Air." This is the area between the worker and the bank of HEPA (High Efficiency Particulate Air) filter units. This concept far exceeds the cleanliness requirement specified in the Saturn Slip Ring Specification (GC125355).

It is recognized that, although the atmosphere inside the bench is clean, the air around the work bench may be heavily contaminated. In view of this, strict bench and operator control is maintained in the Saturn work areas. Periodic audits are held to ensure that proper controls are being maintained.

4.6.4 Inspection Plan

An inspection plan has been prepared for parts produced on this program. This inspection plan details the philosophy, organization, procedures, and instructions needed for the assurance of product required for this program. This inspection plan includes such items as manufacturing flow charts, detailed inspection procedures, detailed test procedures, organizational charts, detailed reliability control procedures, and an explanation of the Saturn team concept.

The organizational chart, found in the introduction of the Inspection Plan, shows the organizational relationship of the Reliability Division to all other Poly-Scientific functions. It shows the lines of responsibility descending from the President of Poly-Scientific, through the Division Heads, to the operators and service personnel.

Manufacturing flow charts*show the sequence of operations, processes, inspections and tests performed on each component part. These charts also show how each component or component assembly is integrated into the finished assembly. There is a chart for each slip ring type made for the Saturn Program. (See Figure 4.6.1.)

Inspection procedures are included in Section 2 of the Inspection Plan identical to the inspection instructions issued to the inspectors. Every effort has been made to present these instructions to the inspectors as a practical, workable, inspection tool. Illustrations have been used wherever possible to ensure that each inspector understands the intent of the inspections, therefore ensuring maximum inspection coverage.

The test procedures included in Section 3 list the steps in each test and diagrams of the apparatus used to test Saturn Units.

Sections 4 through 19 relate the methods by which each phase of the Saturn Program is controlled. In these sections are detailed methods for controlling drawing changes, raw materials, traceability, identification, storage, processes, defective material, inspection status, calibration tooling, packaging, shipping and corrective action. Also in these sections are found the methods by which meaningful records, procedures and data are kept on the history of the product.

4.6.5 Process Controls

The following special controls are applicable to each Saturn unit.

* This Inspection Plan has been submitted and accepted by NASA. The plan is not included in this report.

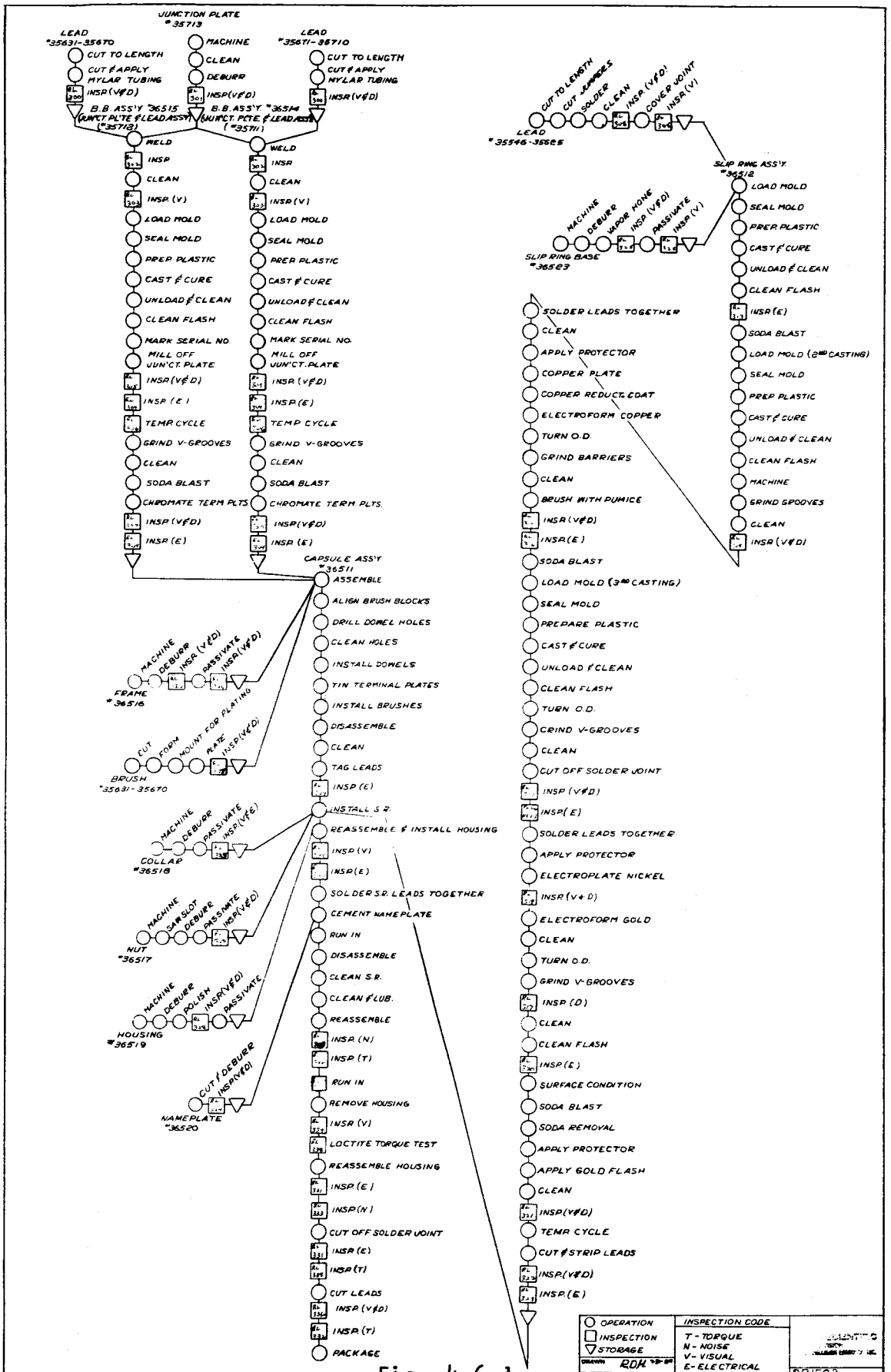

JUNCTION PLATE #35713
LEAD #35631-35670
CUT TO LENGTH
CUT & APPLY MYLAR TUBING
INSP (V&D)
MACHINE
CLEAN
DEBURR
INSP (V&D)
LEAD #35671-38710
CUT TO LENGTH
CUT & APPLY MYLAR TUBING
INSP (V&D)
B.B. ASS'Y #36515 (JUN'CT. PLTE & LEAD ASS'Y #35713)
B.B. ASS'Y #36514 (JUN'CT. PLTE & LEAD ASS'Y #35711)
WELD
INSP
CLEAN
INSP (V)
LOAD MOLD
SEAL MOLD
PREP PLASTIC
CAST & CURE
UNLOAD & CLEAN
CLEAN FLASH
MARK SERIAL NO.
MILL OFF JUN'CT. PLATE
INSP (V&D)
INSP (E)
TEMP CYCLE
GRIND V-GROOVES
CLEAN
SODA BLAST
CHROMATE TERM PLTS.
INSP (V&D)
INSP (E)
CAPSULE ASS'Y #36511
ASSEMBLE
ALIGN BRUSH BLOCKS
DRILL DOWEL HOLES
CLEAN HOLES
INSTALL DOWELS
TIN TERMINAL PLATES
INSTALL BRUSHES
DISASSEMBLE
CLEAN
TAG LEADS
INSP (E)
INSTALL S.R.
REASSEMBLE & INSTALL HOUSING
INSP (V)
INSP (E)
SOLDER S.R. LEADS TOGETHER
CEMENT NAMEPLATE
RUN IN
DISASSEMBLE
CLEAN S.R.
CLEAN & LUB.
REASSEMBLE
INSP (N)
INSP (T)
RUN IN
REMOVE HOUSING
INSP (V)
LOCTITE TORQUE TEST
REASSEMBLE HOUSING
INSP (E)
INSP (N)
CUT OFF SOLDER JOINT
INSP (E)
INSP (T)
CUT LEADS
INSP (V&D)
INSP (T)
PACKAGE
FRAME #36516
MACHINE
DEBURR
INSP (V&D)
PASSIVATE
INSP (V&D)
BRUSH #35631-35670
CUT
FORM
MOUNT FOR PLATING
PLATE
INSP (V&D)
COLLAR #36518
MACHINE
DEBURR
PASSIVATE
INSP (V&E)
NUT #36517
MACHINE
SAW SLOT
DEBURR
PASSIVATE
INSP (V&D)
HOUSING #36519
MACHINE
DEBURR
POLISH
INSP (V&D)
PASSIVATE
NAMEPLATE #36520
CUT / DEBURR
INSP (V&D)
LEAD #35546-35625
CUT TO LENGTH
CUT
SOLDER
CLEAN
INSP (V&D)
COVER JOINT
INSP (V)
SLIP RING BASE #36583
MACHINE
DEBURR
VAPOR HONE
INSP (V&D)
PASSIVATE
INSP (V)
SLIP RING ASS'Y #36512
LOAD MOLD
SEAL MOLD
PREP PLASTIC
CAST & CURE
UNLOAD & CLEAN
CLEAN FLASH
INSP (E)
SODA BLAST
LOAD MOLD (2ND CASTING)
SEAL MOLD
PREP PLASTIC
CAST & CURE
UNLOAD & CLEAN
CLEAN FLASH
MACHINE
GRIND GROOVES
CLEAN
INSP (V&D)
SOLDER LEADS TOGETHER
CLEAN
APPLY PROTECTOR
COPPER PLATE
COPPER REDUCT. COAT
ELECTROFORM COPPER
TURN O.D.
GRIND BARRIERS
CLEAN
BRUSH WITH PUMICE
INSP (V&D)
INSP (E)
SODA BLAST
LOAD MOLD (3RD CASTING)
SEAL MOLD
PREPARE PLASTIC
CAST & CURE
UNLOAD & CLEAN
CLEAN FLASH
TURN O.D.
GRIND V-GROOVES
CLEAN
CUT OFF SOLDER JOINT
INSP (V&D)
INSP (E)
SOLDER LEADS TOGETHER
APPLY PROTECTOR
ELECTROPLATE NICKEL
INSP (V&D)
ELECTROFORM GOLD
CLEAN
TURN O.D.
GRIND V-GROOVES
INSP (D)
CLEAN
CLEAN FLASH
INSP (E)
SURFACE CONDITION
SODA BLAST
SODA REMOVAL
APPLY PROTECTOR
APPLY GOLD FLASH
CLEAN
INSP (V&D)
TEMP CYCLE
CUT & STRIP LEADS
INSP (V&D)
INSP (E)
OPERATION
INSPECTION
STORAGE
DRAWN RDK
CHECKED
INSPECTION CODE
T - TORQUE
N - NOISE
V - VISUAL
E - ELECTRICAL
D - DIMENSIONAL
DP1522
DP1505

Fig. 4.6.1

4.6.5.1 Loctite Retention Test - To ensure that no nut or screw will loosen during operation, each nut or screw used in the assembly of Saturn units is secured with Loctite or a similar compound. After the compound has cured, the nut or screw is tested for retention with a torque wrench or torque screw driver. The torque retention scale is found in P.S. Engineering Specification 156.

4.6.5.2 Weld Pull Test - The brush block leads are joined to the brush block junction by welding. Each weld joint is inspected under 30 power magnification for open weld, off center weld, cracked weld, deformed weld, metal expulsion, spattering, blow holes, pitts, excessive surface fusion, excessive setdown and insufficient weld which are undesirable characteristics. In addition, samples are tested in each series of welds. The sample lead is welded to a sample junetion plate. There are samples representative of the start of the series and the end of the series. These samples are then mounted in a Hunter Pull Tester and pulled. If the sample fails to withstand 1000 grams of pull along the lie of the lead, the junction plate assembly is rejected. (See Figure 4.6.2.)

4.6.5.3 Ring Pull Test - The purpose of the Ring Pull Test is to test the strength of the bond between the jumper and the plated ring. A dummy slip ring is plated with each lot of production slip rings. The dummy is machined and the rings are cut on each side of the bond. A lead is soldered on the outer surface of the ring, directly over the bond. This sample is then tested in the pull tester. If the plated bond fails to withstand 1000 grams, all the slip rings in that plating lot are rejected. (See Figure 4.6.3.)

4.6.5.4 Process Audits - Periodic audits are held in each area to ensure that processes are being properly executed according to written specifications. This includes such areas as electroforming, matte finishing, plastic casting, plastic curing, brush forming, mold loading, etc.

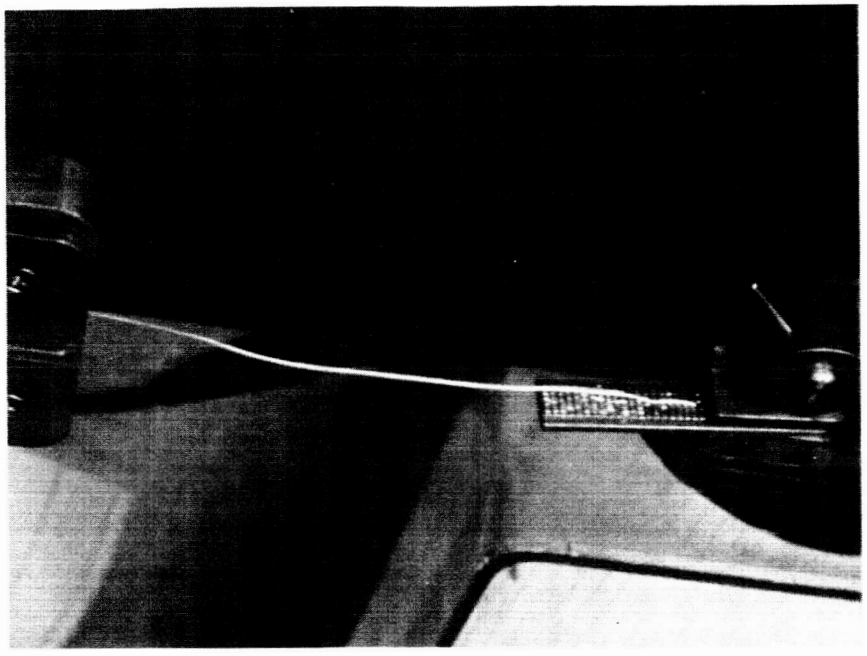


FIG. 4.6.2: WELD PULL TEST

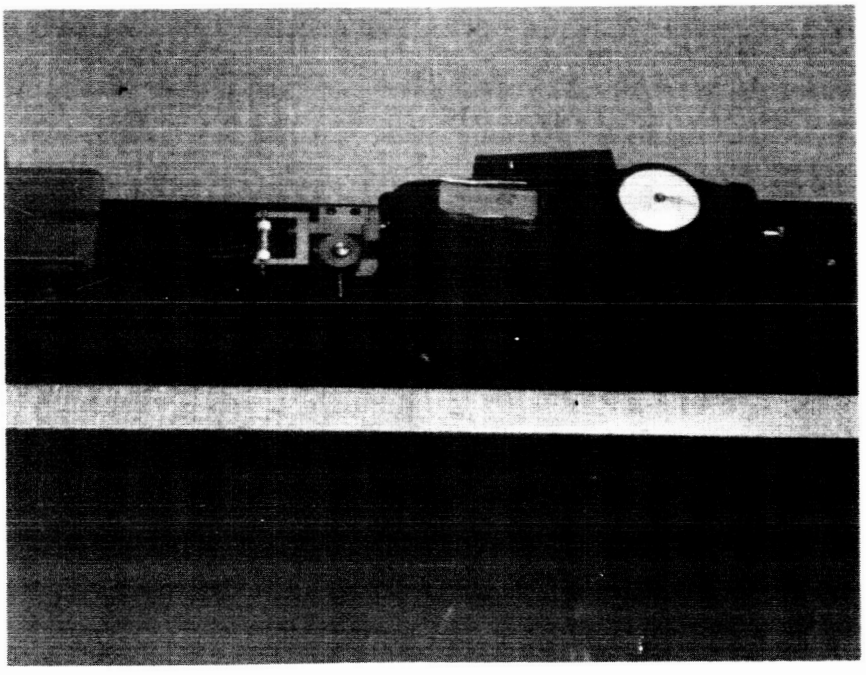


FIG. 4.6.3: RING PULL TEST

4.6.6 Test

The following tests are performed on each unit. Descriptions of procedures and equipment used in tests are in Section 3 of the P.S. Inspection Plan for Saturn Slip Rings.

4.6.6.1 Insulation Resistance - Insulation resistance tests are performed at various stages in the fabrication. In addition to the in-process tests, each slip ring assembly, brush assembly and capsule assembly receives a documented insulation resistance test. The values for each circuit are recorded and shipped in reproducible form with the units. A 10,000 megohm minimum requirement on insulation resistance provides the assurance that the insulation within the subassembly and capsule has been produced to the required standards. It is interesting to note that, during the history of the development of these assemblies, this requirement has been raised by a factor of 100 with respect to the limit initially set by specification.

4.6.6.2 Circuit Resistance - Circuit resistance tests are performed at various in-process stages of manufacture as a double check on the Reliability of the joints of the assembly Each circuit of the slip ring assembly, and each circuit of the brush assembly is provided a documented circuit resistance test. The values for each circuit are recorded and shipped in reproducible form with the unit. The resistance of the circuit of 30 AWG 19 strand copper wire must not exceed 9 milliohms per inch of lead wire. This limitation, which only slightly exceeds the resistance of the lead wire alone, assures the integrity of the lead wire and points within the assembly. (See Figure 4.6.4.)

4.6.6.3 X-Ray - Each Saturn assembly receives a radiographic inspection. The purpose of this inspection is to obtain documentary evidence of proper brush alignment and the degree of parallelism between individual brushes. All radiographic inspections are performed with techniques which are capable of indicating the presence of poor

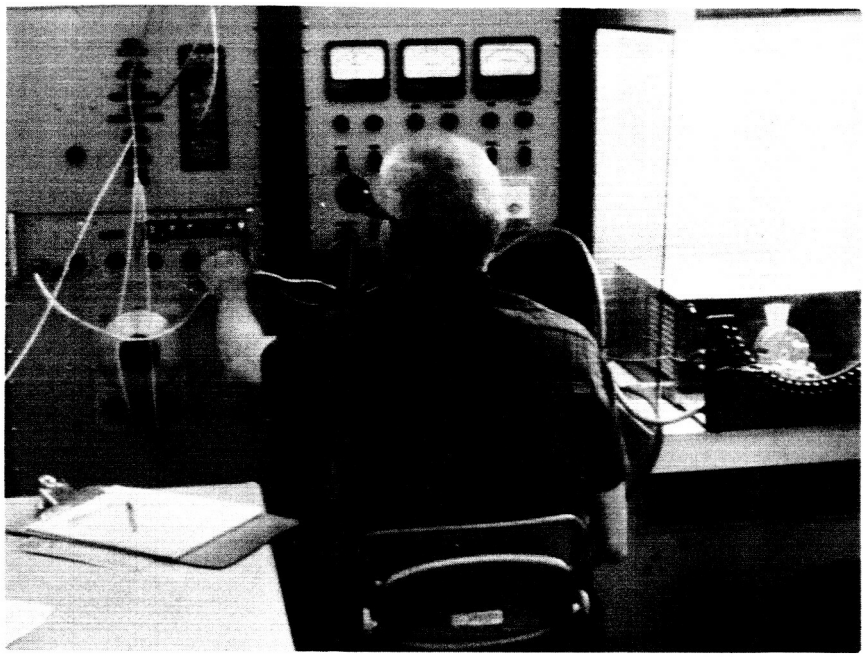


FIG. 4.6.4: CIRCUIT RESISTANCE

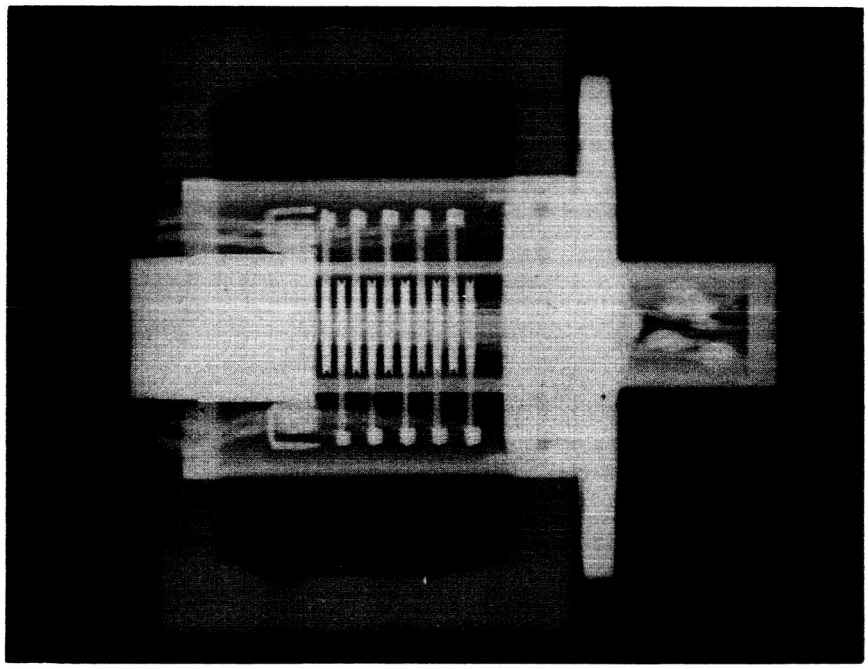


FIG. 4.6.5: X-RAY

assembly methods. Equipment and procedures used in radiographic inspections are found in test procedure RLT 23. A negative showing 3 views of the part is shipped with each unit. The X-ray is an assurance that the unit has been properly fabricated and assembled. (See Figure 4.6.5.)

4.6.6.4 Assurance Test - Each capsule is run in for 2 hours at 100 RPM. The rotor assembly is rotated with respect to the stator assembly for a period of one hour in a clockwise direction and one hour in a counterclockwise direction. Each assembly is then checked for noise and torque to assure satisfactory assembly. Then the capsule is subjected to a 100 hour assurance test at 2 RPM. The direction of rotation is reversed every twelve hours. This is a functional test under continuous rotation. (See Figure 4.6.6.) A 30 power examination of the contact area at the conclusion of the test assures that there has been no contamination or seizure in the contact area during the period of the assurance test.

4.6.6.5 Temperature Cycle - Each brush block assembly and each slip ring assembly are subjected to 3 cycles of the following minimum schedule within a 24 hour period. Heat to $100 \pm 5^{o}C$ for one hour and cool to $-18^{o} \pm 5^{o}C$ for one hour. The rate of heating or cooling does not exceed $5^{o}C$ per minute and the duration at the extremes is not less than one hour. The subassembly is then examined for damage. This stringent cycle provides proof of the structural integrity. (See Figure 4.6.7.)

4.6.6.6 Noise and Torque Tests - Each Saturn assembly receives a noise test (contact resistance variation) and a torque test (breakaway friction). The noise values for each circuit pair are recorded and a reproducible test form is shipped with each unit. The noise test requires that all units have a maximum variation of 10 or 20 (depending on the number of circuits in the unit) milliohms on any circuit. This test is performed after the 100 hour assurance test to verify the reliability of the contacts. The torque test provides assurance of proper breakaway friction and is an additional measure of product

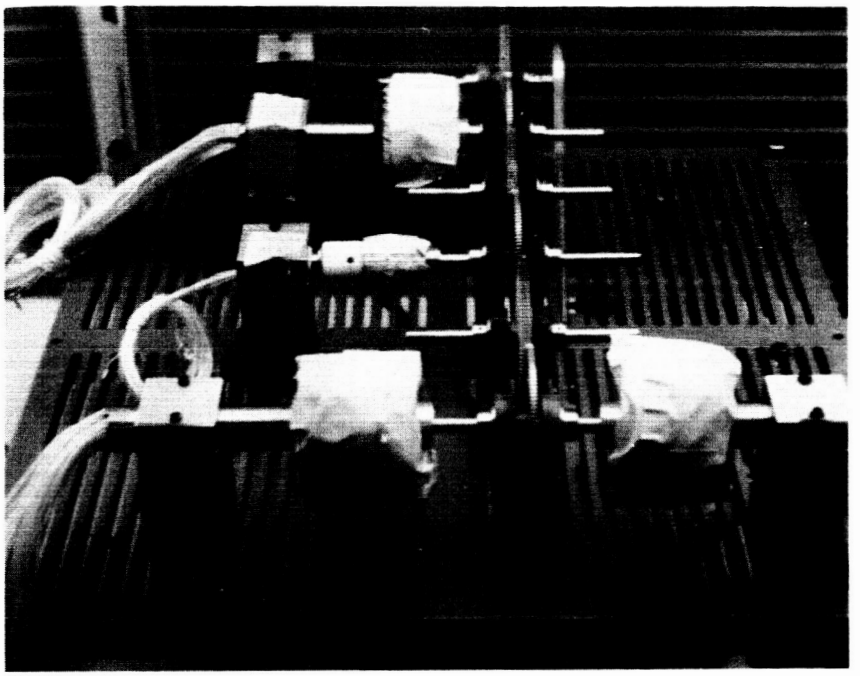


FIG. 4.6.6: ASSURANCE TEST

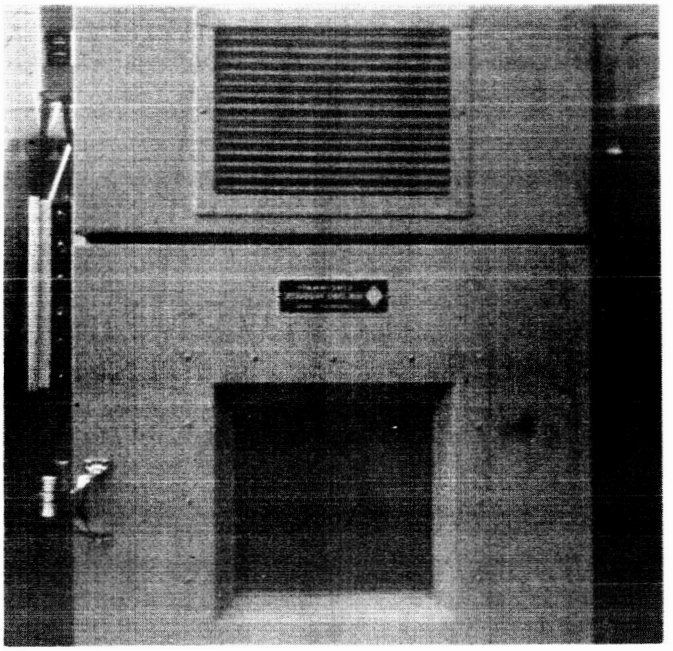


FIG. 4.6.7: TEMPERATURE CYCLE

assurance. Torque test results are recorded on the noise test report which is shipped with the unit.

4.6.6.7 Hipot and Continuity - Each subassembly received hipot and continuity tests at various stages of manufacture. These tests are also performed on the capsule assembly. The hipot test (high potential breakdown) is an assurance that the dielectric material in the unit will withstand high voltage. Continuity tests assure that each circuit is continuous and is also a means of checking proper lead location and proper tagging.

4.6.7 Inspection

4.6.7.1 Microscopic Examination - Each subassembly and each capsule assembly receives a detailed microscopic examination, not only when complete, but also in-process. This gives additional assurance of the quality of all processes of the part.

4.6.7.2 Dimensional - Each subassembly and each capsule assembly receives detailed dimensional inspections at various stages throughout fabrication and manufacture. This is to ensure adherence to drawing dimensions and to ensure interchangeability of parts. The specification (GC125355) requires a maximum misalignment from brush to ring of .002 inch. The grooves locate the brushes. The alignment of brush assembly to the frame is obtained from alignment surfaces on dowels in the brush assembly and frame. Play is removed from between rotor and frame so that the play is a minimum of .0001 inches to a maximum of .0003 inches under 100 gram reversing load. The entire assembly and alignment process is performed in a laminar flow bench. The process is checked microscopically, by X-ray, and optical comparator, if required.

4.6.8 Documentation

The entire manufacturing process for each unit is recorded in detail. (Figure 3 shows a typical flow chart for assemblies

made to the Saturn specification.) Should any repairs be necessary, they are carefully recorded. Each unit and subassembly is carefully controlled and each operation individually signed off by the operator or inspector. Each major process is controlled by a specification or process instruction which is shown on the Planning Master routed with the parts. Critical materials such as lead wire, brush wire, and plastics have traceability maintained to incoming control tests. All planning masters and test documents are in reproducible form. In addition to the test documents shipped with the unit, copies of the planning masters and test reports are sent to Astronautics Laboratory, Marshall Space Flight Center at Huntsville, Alabama. The processes that are in use at P.S. have been developed in conjunction with NASA over the past 3 years and have NASA approval.

4.6.9 Rework Control

Should any rework be required of an assembled capsule, the capsule is disassembled, reworked, cleaned, reassembled and completely acceptance tested, including the 100 hour assurance test. Any rework or repair done to the capsule assembly is completely documented as to the nature of the discrepancy, and the type and extent of repair performed to the unit. This forms part of the documentation package and assures that a total capsule history has been recorded and maintained.

4.6.10 Conclusion

The development of reliability controls has immeasurably increased the reliability of the Saturn unit. Throughout the development program P.S. has seen great improvement in performance reliability. The relative mean time between circuit malfunctions for the now superseded 1400 series has been calculated. On the basis of 5 units tested for a total of 1.2 million circuit hours the mean time between circuit malfunction when

compared to the specification is 4.8×10^4 hours. At 100 milliohms maximum noise, the mean time between malfunction is 1.26×10^6 circuit hours. By way of comparison we find that the original units produced in 1961 at the same 100 milliohm level showed about 700 circuit hours. On this basis it can be seen that the Relative Reliability has been improved by a factor of 2,000 in the past 4 years. The reliability controls developed on the Saturn program offer the maximum assurance that the unit performs in its intended application.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Program Conclusions
by E. W. Glossbrenner, Program Director

5.2 Recommendations
by E. W. Glossbrenner, Program Director

5.1 PROGRAM CONCLUSIONS

5.1.1 General

The total program has been centered around the concept of developing and proving those materials, processes, and designs which offer the greatest reliability to the finished product. This has required a thorough evaluation of all the possible interactions resulting from any decision. This is not easily obtained. A concept may offer significant advantages to a particular problem solution and be totally unacceptable on other considerations. We must conclude that the tremendous improvement of product reliability achieved during the program has been due to the choice of the right materials, properly designed for the application, with the processes and controls to assure repeatability.

5.1.2 Materials

Significant advances were made in the choice of materials for slip ring capsule assemblies whether produced by the cast process or by electrodeposition. It has been found that stainless steel is the best material for all structural members within a capsule assembly. This provides the greatest strength and stiffness for its size.

This choice of structural material was found to be best complimented by the use of highly filler epoxy resins. When the filler is lithium aluminum silicate and high percentages of filler are used, the coefficient of thermal expansion can be closely matched to any or all of the metals necessary in the assembly: gold, copper, stainless steel, and brass. The filled epoxy system has adequate strength to be used effectively with re-inforcement or support. Filled plastics were also found to reduce somewhat the contamination formation on contacts, but they did not eliminate it. Resistance to plating solutions and cleaning agents is excellent with the proper selection of filler.

The ring material found best for the application was pure gold electrodeposited into grooves in the plastic subassembly. Gold, long a problem in electrodeposits of any significant

thickness, was found to be capable of very uniform properties in thicknesses of 15 to 20 mils when properly controlled.

For units produced with wrought rings, the most effective material was found to be 75% Au 22% Ag 3% Ni (E.S. 57), the equivalent to NASA Spec. 10 M 1753. The brush contact material chosen as most reliable was also E.S. 57. This material as a fine wire brush has problems of handling and soldering, but with adequate precautions, has been found more functionally reliable than other metals.

Bearings have been eliminated as a functional problem, during the course of the program. As a result of the repeated failure mode observed with crown retainers, all retainers were specified as ribbon type. There have been as yet no observed failures in slip ring performance modes with ribbon retainers.

Lead wire has been a continuing concern despite some very significant advances. Even the present conductor is not the ultimate since there remains a possibility of copper corrosion. Silver plated copper conductor insulated with clear extruded TFE Teflon, when produced with controls to the latest specification, has eliminated all of the wire failure modes observed with nickel plated Teflon insulated wire originally required. More development remains to be done in the conductor materials.

5.1.3 Processes

Considered collectively, the materials being used as a direct result of the 2-1/2 years of development study contribute significantly to the high reliability of present flight hardware. Few of these material improvements would have resulted in product improvement were it not for the simultaneous developments of process.

Most of the important process development has centered on the contacts themselves as the most important functional features in the capsule. The electrodeposition studies of gold revealed that the character of the gold depended principally on the current density to gold content ratio. This provided the key to other factors to produce consistant deposits with microhardness uniformity never achieved before. The

studies of surface finishing produced a major factor in contact wear performance by introducing the matte finishing concept and developing two processes successfully. These, coupled with a final contact surface material of gold which has been shown most effective in reducing formations of surface films or haze on contact metals, have reduced contact wearout failures to a minor occurrence in the assemblies.

The use of the E.S. 57 as the brush material, known for some time as a good contact material because of its high conductivity and absence of platinum group constituents, has been greatly facilitated by the improvement of forming processes and soldering techniques. The construction of effective brush forming tools to semi-automatically form brushes with precision, has contributed to the uniformity of manufacture, and, hence, reliability. A small, but significant, process for protecting the brush from solder solution, by plating, was introduced during the program.

Probably the most significant structural material contribution of this program was the development of the low expansion plastics. The highly filled plastic could not have been adopted without means to handle them. Two processes were developed for casting with these high viscosity materials: A machine which forced the material into the mold and also a vacuum casting technique. Both have proven effective, but the latter is more economical.

The incorporation of these abrasive plastics could not have been accomplished without the concept and development of form grinding as a process for grooving the plastic. This process avoided tool wear and produced an improvement of ring spacing accuracy previously impossible.

Further development of form grinding processes has made possible the grinding of V-grooves in gold (and brass) with a precision and uniformity also previously impossible.

The studies of various processes relating to lead wire have produced both potential and actual improvements of assemblies. One demonstrated the feasibility of swaging and fusing stranded

silver plated copper conductor to a solid conductor. This approach was found to require both additional silver and an increase in the allowable slip ring space in order to eliminate the jumper wire and its solder joint from the assemblies. The welding techniques were immediately applied to the welding of leads to junction bars. This process is stronger and more consistant than soldering. The welding of rings to leads can be applied directly to any wrought rings used in cast process assemblies or to an alternate process of using rings as a base for the electrodeposition process.

The breakage and damage of lead wire have been virtually eliminated by a combination of techniques. Protective devices for leads at the slip ring flange and on brush assemblies reduced the flexing of the leads in the area adjacent to the exit from the assembly. A protective package has been designed and produced for use with gimbal assemblies which eliminates all lead handling of the slip ring subassembly.

Finally, the overall process for manufacture of the parts has been developed, detailed explicitly, and then refined and improved in a variety of details too numerous to consider in this report. Specific cleaning processes have been formulated, tested, proven, and written for every step in the manufacture. In addition, bearing cleaning and lubrication techniques were developed, using a solvent laid lubricating technique. Numerous other important small processes have been developed and adopted.

5.1.4 Design

Closely interwoven with the development of materials and processes is the development of design. The design of a component is both the master and the slave of materials and processes available. Throughout the many stages of development, each new innovation would affect the specific design and trigger supplementary developments. At present, the design incorporates complimentary concepts of design materials and processes into an assembly of proven reliability for its applications.

The slip ring assembly is supported on a one piece stainless steel cruciform reinforcing member which mounts both ball bearings. This member is surrounded by symmetrically located leads embedded in a low expansion epoxy resin. Surrounding this is a series of gold rings plated on a copper base. These rings which also match the expansion of the plastic are accurately spaced to within .0005 inches tolerance. The rings have V grooves, 90° or less included angle, which are spaced to an equal tolerance.

Brushes contacting in these grooves are aligned to the grooves with tolerances of less than .0015 inches. The brush position is achieved by similar grooves in the junction bars of the brush assembly. This brush assembly design conceived, developed, and improved under the contract is made to be removable for cleaning and adjusting during fabrication. The brush assembly is supported through its entire length by the metal frame. The alignment from brush to ring is maintained by precision ribbon retainer ball bearings between the frame and reinforcing member. The bearings are adjusted to remove all but a few tenths of one thousandth end play and held by a bearing nut and universal washer. The result has been a strong capsule of high continuing level of performance.

5.1.5 Tools and Controls

Much of the improvement of the capsule performance can be attributed to the development of tools and controls to assure that the materials and processes used in the assemblies are consistant in every respect possible. Most of the tools required for this task as well as all of the controls have been established within the framework of this program.

5.1.6 Results

The major result of this cooperative program has been a reliable concept -- a concept of integrated design, materials, processes, and controls which, applied collectively, has led to the fabrication of seven different capsule and matched pair slip ring and brush assembly designs for

various Saturn applications. This concept has been backed by tests at the Marshall Space Flight Center in the most thorough reliability demonstrations ever conducted on slip ring assemblies. These designs are being produced in significant quantities under continuing tight control of the developed processes.

5.2 RECOMMENDATIONS

5.2.1 General

At the conclusion of a program of this breadth and duration, recommendations should be made to incorporate the results of the program. In this case, however, all of the principal conclusions have been translated into working hardware and into effective control specifications. There is still work to be done since reliability improvement is not a goal, but a process, which must continue to eliminate each course of potential failure.

Throughout the report, there have been suggestions made for specific further studies of materials and processes. Each of these facets of the work should be incorporated into a program to further improve the technology.

5.2.2 Major Areas of Future Work

There are some specific far-reaching concepts where supplemental programs of development could lead to significant advances in guidance system manufacture.

5.2.2.1 Capsule Cost - This program has been conducted on the philosophy that performance reliability was the prime objective. This has been achieved. A review of the processes would show that process modifications could be initiated which would have a good possibility of reducing the cost of the assemblies without affecting the reliability of the capsules. Such a move would require a program of complete substantiation before any modifications could be instituted. It is recommended that this type program be arranged as a logical follow-up to the present program.

5.2.2.2 Lead Conductor - It has long been recognized that silver plated copper conductor was subject to corrosion called "red plague." The improvements in lead wire have not completely eliminated the possibility of this corrosion (as discussed in section 2.4). It

is our recommendation that a lead wire conductor development program be established to develop a conductor of a metal or alloy which would have the strength and conductivity requirements and not be subject to corrosion.

5.2.2.3 Inorganic Dielectrics - In the study on contamination, it was reported that the organic materials used within the capsule assembly were the major sources of the contact contamination. A similar conclusion has been reached by other investigators. The work on Phase I indicated that a ceramic assembly was not feasible. This is still true. Recent studies at Poly-Scientific indicate that it is now feasible to develop and produce an assembly with inorganic materials in place of organic materials in locations which most contribute to the contact contamination. Work in this area could lead to a significant improvement of reliability and life of the capsule assembly.

5.2.2.4 Brush Design - Early in the study of performance of the capsule assembly, it was reported that brushes should be of a circular cross section. There is, however, evidence produced from other studies at Poly-Scientific that significant performance improvement could be achieved by other brush designs and shapes. Recently developed methods of brush shaping have resulted in structurally sound brush forms. Some feasibility models have demonstrated lower noise than conventional brushes over more than twice the life. Further development in this area could result in a several times improvement of performance.

5.2.2.5 Small Angle Oscillation - One of the studies of the program was the fabrication of feasibility models of a continuous rotating capsule. The intent here was to eliminate the oscillation of the contact members in a limited area of the ring surface. This concept was shown to be feasible but much too large and complex for a production item. Other concepts which have been studied outside this contract are now available which could absorb all or most of the small angle oscillations, reducing the contact movement to wide angle oscillation or rotation. Several of these features could, with further development, be

proven and adapted to the slip ring capsules for the Saturn guidance system.

5.2.2.6 Gimbal Pivots - It has become apparent, from our discussions with NASA during the program, that the pivots into which the slip ring assemblies are mounted must make use of a variety of standard or semi-standard electro-mechanical components. There have been studies made by Poly-Scientific which would indicate that the pivots could be designed to integrate all such components into a package which would take greater advantage of the space to balance the design of all components. The studies indicate that a reduction of size, improvement of performance, and greater stability could be achieved. It is recommended that a program be established to verify and develop the advantages of this approach.

5.2.3 Suggested Program

The capability of Poly-Scientific, supplemented by good communication and cooperation with the Marshall Space Flight Center, has been proven by the development of reliable capsule assemblies under this contract. This demonstrated teamwork and capability should now be directed to the further improvement of performance of the capsules to achieve a new level of reliability. The concepts suggested above and in other sections of this report project feasible approaches to this goal.

Each of the recommendations sketched above stems from Poly-Scientific's understanding of the role and needs of the slip ring in its application, and would have direct bearing upon the reliability, performance and economy of the system. A detailed program should be established to include these concepts as well as the specific recommendations from the material and process studies. Such a program, established with Poly-Scientific, would certainly result in the same technical achievements as has NAS 8-5091 for the Development of Highly Reliable Capsule Type Slip Ring Assemblies.

6.0 SPECIFICATIONS, PROCESSES, AND INSTRUCTIONS

6.1 Engineering Specifications

Number	Title
19	Stamping and Marking Parts
38	Coin Gold
47	Wire, Lead - Electrical Teflon Insulated Type E and ET
54	Contact Alloy 54
55	Contact Alloy 55
56	Contact Alloy 56
57	Contact Alloy 57
65	Epoxy Formulation P-54
84	Aromatic Amine Cured Epoxy Formulation P-30
115	Mineral Filled Epoxy Formulation, P-41
118	24-K Electroformed Gold
120	Alloy 120
133	Low Viscosity Epoxy Resin
134	Aromatic Amine Cured Epoxy
137	Mineral Filled Epoxy Novalak Formulation
138	Lithium Aluminum Silicate Filler Material
144	Diallyl Iso-Phthalate Molding Compound, Short Glass Filled
149	Thermal Shock Resistant Epoxy Formulation
151	Aromatic-Amine Cured Epoxy Novalak
156	Loctite Sealants and Locquic Primers
161	Mineral Filled Epoxy for A-78-3
167	Aromatic-Amine Cured Epoxy Formulation
191	Lithium Aluminum Silicate Filler for Epoxy Resins
192	Aliphatic Amine Curing Agent
193	Low Viscosity Aliphatic Amine Cured Epoxy Formulation
195	Mineral Filled Aliphatic Amine Cured Epoxy Formulation
199	Mineral Filled Aliphatic Amine Cured Epoxy Formulation
206	Fine Gold Anodes
209	Mineral Filled Aromatic Amine Epoxy Casting Compound
220	DuPont Polyimide Enamel
222	Mineral Filled Epoxy Casting Compound
246	Mineral Filled and Hydride Cured Epoxy Novalak

6.2 Process Instructions

Number	Title
75	Vacuum Casting Procedure for E. S. 209 Plastic (NASA Brush Blocks)
79	Casting Procedures for DP 1500, 1505 and Similar Slip Rings
101	Cleaning Cerrobase or Plastic Mold
102	Cleaning Flash After Casting
103	Final Cleaning of Brush Block Assemblies
106	Cleaning of Stator Assembly after Soldering
123	Cleaning of Rings and Leads and Other Components before Casting
129	Cleaning of Slip Rings after V-Grooving
134	Removal of Plating Residues
143	Removal of Water Soluble Residues
147	Spray Cleaning with Soda Slurry
159	Cleaning Lead Ends after Soldering
161	Lubrication of Bearings by Solvent Application
174	Final Cleaning of NASA Assemblies
175	Cleaning NASA Slip Rings Prior to Final Assembly
176	Preliminary Cleaning for Solder Flux Removal
177	Complementary Cleaning Prior to Final Assembly
601	Copper Reduction Coating for D.P. Parts
602	Copper Electroforming for P/N 35626 or 36512
605	Electroplating Nickel for P/N 35626 and 36512
606	Gold Electroforming for P/N 35626 or 36512
607	Gold Flash for P/N 35626 and 36512
608	Copper Plating Lead Ends of D.P. Parts
617	Flange Protectors for P/N 35626
701	Run-in of N.A.S.A. Capsules
702	100-Hour Run-in of Capsules
800	Preparation of NASA Lead Jumper Assemblies
909	Resistance Welding #30 (19/42) Silver Plated Copper Wire to Yellow Brass Junction Plate (65 Cu 35 Zn) for DP 1405.
950	Pull Strength Test of Brass Junction Plates and 30 AWG (19/42) Silver Plated Stranded Copper Conductor which have been Resistance Welded for NASA Parts

6.3 Reliability Instructions (RL)

Number	Title
300	Visual and Dimensional Inspection of Brush Block after Preparation (Mylar)
303	Junction Plate and Lead Assembly - Visual and Dimensional
304	Electrical Inspection of BB Assembly (Odd and Even)
306	Temperature Cycle - Brush Blocks
307	Brush Block Assembly - Last Visual and Dimensional Inspection
308	Visual and Dimensional Inspection - Lead and HML Assembly
313	Slip Ring Assembly - Electrical Test
314	Sub-Assy. - Visual and Dimensional Inspection after Temperature Cycle
315	Slip Ring Assembly - Visual and Dimensional Inspection after Electroforming Copper and Turn O.D.
316	Slip Ring Assembly - Electrical Inspection after Electroform Copper
317	Slip Ring Assembly - Visual and Dimensional after Final Cure and Machining
318	Slip Ring Assembly - Dimensional Check after Electroplating (Nickel)
319	Slip Ring Assembly - Dimensional Check after Electrodeposit Gold and Turn O.D. of Frontshaft
320	Electrical Inspection after Machining Prior to Surface Treating and Final Plating
321	Slip Ring Assembly - Visual and Dimensional Inspection after Hard Gold Plate, Iridite, and Cleaning
322	Slip Ring Assembly - Last Visual and Dimensional Inspection
323	Slip Ring Assembly - Last Electrical
329	Brush Block (lead wire to brush junction) Elect. Insp.
330	Capsule - Interior Visual Inspection after Installing Housing
332	Capsule - Torque Test (Breakaway Friction) (RLT 16)
333	Capsule - Contact Noise Test
334	Capsule - Visual Inspection after 100 Hour Run-In
336	Capsule - Final Visual and Dimensional Inspection
337	Temperature Cycle - Slip Ring Assembly
338	Locktite Retention Testing of Miniature Screws and Nuts

6.4 Miscellaneous

Method Instruction No.	
200	Load & Cast DP 1405 BB Mold

ENGINEERING SPECIFICATION

PASSIVATION OF CORROSION RESISTANT STEEL

1. SCOPE

   1.1 This Specification defines the procedures to be used by Poly-Scientific Corporation in passivating corrosion resistant steels for use in it's products.

2. SPECIFICATIONS AND REFERENCES

   2.1 Metals Handbook - ASM - Cleveland, 1948, p.p. 584.

   2.2 Metal Finishing Guide Book Directory, 30th edition, 1962, pp. 143.

   2.3 PSC Engineering Specification No. 29, "Electro Cleaning."

   2.4 PSC Engineering Specification No. 31, "Vapor Degreasing."

3. MATERIALS

   3.1 Pickling or descaling solution:

      3.1.1 Nitric acid - 10-15% by volume. Hydrofluoric acid 1-2% by volume. Balance water.

   3.2 Passivation solutions:

      3.2.1 Nitric acid, 25-30% by volume. Balance water.

      3.2.2 Nitric acid, 20-25% by weight. Sodium Dichromate 2% by weight. Balance water.

      3.2.3 Nitric acid, 50-60% by volume. Balance water.

4. PROCEDURE

   4.1 Cleaning

      4.1.1 Parts which have greasy or oily surfaces shall be vapor degreased as per PSC Engineering Specification No. 31 until all traces of grease or oil are removed.

      4.1.2 Parts which have stained, scaled, rusted, or oxidized surfaces shall be pickled in solution (3.1) at 120° to 140°F for 10 to 15 minutes and then hot water rinsed (for 3 minute minimum).

REV.	DATE	CHANGE	CHK.			
02	6/24/63			PREPARED BY	R.W Ellis	11/29/62
				CHECKED BY	[illegible]	11/29/62
				APP. ENG.	[illegible]	11/29/62
				APP. ENG.	[illegible]	12/4/62
				APP. REL.	[illegible]	12/4/62
					SIGNATURE	DATE

TITLE- PASSIVATION OF CORROSION RESIST. STEEL

SPEC. NO. 19 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

4.1.3 All parts shall be electrocleaned as per PSC Engineering Specification No. 29.

4.2 Passivation

4.2.1 The Ferritic or Martensitic types (400 series) shall be held in solution (3.2.2) at 110° to 120°F for 15 to 30 minutes. They shall then be thoroughly hot water rinsed (3 minutes minimum), subsequently cold water rinsed (3 minutes minimum), and dried in still air.

4.2.2 Austenitic grades.

4.2.2.1 The Austenitic grades (300 series) shall be held in solution (3.2.1) at 120° to 140°F for 20 to 30 minutes. They shall then be thoroughly hot water rinsed (3 minutes minimum), subsequently cold water (3 minutes minimum) rinsed and dried in still air.

4.2.2.2 Solution (3.2.3) may be used in place of solution (3.2.1) when specifically called for on applicable process control sheets.

5. INSPECTION

5.1 Examination at 10X shall reveal no surface films, scale, rust or oxidation on acceptable parts.

5.2 Polished surfaces shall not have been etched or dulled by the treatment

REV.	DATE	CHANGE	CHK.	PREPARED BY		
				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE- PASSIVATION OF CORROSION RESIST. STEEL

SPEC. NO. 19 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

COIN GOLD

1. SCOPE

1.1 This specification establishes the requirements for coin gold to be used by Poly-Scientific Corporation in the manufacture of its products.

1.2 All material furnished under this specification must conform to the standards herein described unless otherwise stated in the purchase order.

1.3 This document supersedes all previous documents issued under Poly-Scientific specification No. 38.

2. SPECIFICATION AND REFERENCES

2.1 Bureau of Weapons - OS 12529 - "Description and Requirements Publication for Procurement of Gold, Coin; all forms except Gold Leaf."

2.2 Poly-Scientific Specification No. 9 - "Knoop Hardness Testing".

2.3 Poly-Scientific Specification No. 10- "Stress Corrosion Test for Gold Rings."

3. REQUIREMENTS

3.1 Chemical Composition (by weight)

3.1.1 Nominal composition 90% Gold (Au), 10% Copper (Cu)

3.1.2 Tolerance

Gold (Au)	89.9 to 91.7%
Copper (Cu)	8.3 to 10.1%
Selected Base Metals (Pb, Sb, Bi, Sn, Cd, Ge, Tl, Ga, As)	.01% Max. total
Sulfur	.01% Max.
Total of all impurities	.1% Max.

3.2 Hardness

3.2.1 The criterion for temper designation shall be hardness.

3.2.2 Temper designations.

R.W.ELLIS,Jr. 1/9/63	ENGINEERING SPECIFICATION	TITLE	
W.D.Hensley 1/23/63	Poly-Scientific CORPORATION	COIN GOLD	
Glossbrenner 1/23/63			
G. Gilbert 1/24/63			
W. Cox 1/30/63	BLACKSBURG VIRGINIA	SPEC. NO. 38	REV. 03
	PAGE 1 OF 4		

Temper	Knoop Hardness - 100 gm Load (Average of five Readings)
A (annealed)	120 ± 10%
CW	180 ± 10%

3.3 Workmanship

3.3.1 Surfaces of all material furnished under this specification shall be smooth, clean, and free from scratches, stains, rough spots, slivers, laps, scale, pits, and and other injurious defects within limits consistent with the best possible practice. In no case shall any defect exceed .0005" in depth.

3.3.2 All material shall be free from structural defects, cracks, seams, porosity, inclusions, segregatinn, etc., upon examination of a suitably polished and etched metallurgical sample at 50X.

3.4 Stress corrosion

3.4.1 Material furnished under this specification shall not be susceptible to stress corrosion cracking as defined in Poly-Scientific Specification No. 10.

3.5 Tolerance

3.5.1 Straightness - Rod or tubing shall be furnished in straight lengths with a minimum radius of curvature of 625 in.

3.5.2 Flatness - Strip, sheet, etc., shall be furnished in flat sections with a minimum radius of curvature, in any direction, of 1000 times the material thickness.

3.5.3 Dimensions

3.5.3.1 Rod shall have the required diameter ± .001".

3.5.3.2 Tubing shall have the required inside and outside diameter ± .001".

3.5.3.3 Thickness of sheet shall be as required ± .001".

3.5.3.4 Concentricity of tubing must be maintained within .002" T. I. R.

3.5.3.5 Maximum variation in thickness of sheet, strip, etc., .0005" per inch of width or length.

3.6 Processing

3.6.1 All ingots shall be soaked at 1000° F to 1350° F for 45 to 90 minutes after the initial 50% (minimum) reduction to insure homogeneity.

3.6.2 Annealing is to be accomplished after a minimum of 50% cold reduction.

3.6.3 If scrap is used, only cleaned skeleton scrap may be melted in this material. Turnings, chips or shavings shall not be used.

3.6.4 No sulfurized lubricants are to be used at any stage of processing.

4. INSPECTION AND TESTING

4.1 The vendor shall perform, or have performed, at least these minimum tests to insure conformity to this standard.

4.1.1 Visual inspection at 10X to insure compliance with Para. 3.3.1 of this standard.

4.1.2 Hardness Test - Knoop 100 gram load.

4.1.3 Check of dimensions to insure conformity to Para. 3.5 of this specification.

4.2 Poly-Scientific Corporation shall perform the following tests upon receipt of material furnished to this specification:

4.2.1 Hardness Tests - Knoop 100

4.2.2 Spectrographic Analysis

4.2.3 Dimensional check to insure conformity to Para. 3.5.

4.2.4 Visual Examination (10X)

4.2.5 Microscopic examination (50X) to insure conformity to Para. 3.3.2.

4.2.6 Stress corrosion test (Para. 3.4).

4.3 A spectrographic and/or quantitative analysis by an outside laboratory shall be performed when specified in the purchase order.

4.4 Tensile Tests shall be performed when specified in the purchase order.

5. PACKAGE AND DELIVERY

5.1 The material furnished under this specificatinn shall be packed in such a way as to insure conformity to the standards herein described upon arrival at Poly-Scientific Corporation.

5.2 Packing should be such that danger of damaging upon unpacking is a minimum.

5.3 Deliveries shall be made with due precaution to insure safe, rapid and economic transfer.

6. NOTES

6.1 Orders for this material shall include applicable dimensions and temper designations.

6.2 Intended use - The material defined in this specification is intended for use as low level dynamic electrical contacts of critical application.

ENGINEERING SPECIFICATION

WIRE, LEAD

(Electrical - Teflon Insulation, Type E & ET)

1. SCOPE

This specification establishes the minimum requirements for an ultra-reliable Teflon insulated lead wire, Type E or ET, for use in slip ring assemblies.

2. SPECIFICATIONS, STANDARDS AND REFERENCES

2.1 MIL-W-16878-D - "Wire, electrical, insulated, high temperature, Type E & ET."

2.2 Applicable documents forming a part of and listed on MIL-W-16878-D.

2.3 MIL-STD-104.

3. REQUIREMENTS

3.1 The material described herein shall meet or exceed the minimum requirements of MIL-W-16878-D, Type E & ET, in addition to all other requirements specified herein. In the event of conflict between specifications, this specification shall override.

3.2 Insulation

3.2.1 Material - Unless otherwise specified, the insulation shall be made from virgin TFE (tetrafluoroethylene) fluorocarbon resin. Vendor's records shall identify a particular run of wire with the batch of raw Teflon used.

3.2.2 Processing - The insulation will be either wrapped or extruded as specified on the governing document. In either construction, the concentricity shall be such that the insulation wall thickness, at every point along the wire, shall be not less than 41 percent of the difference between measured diameter over insulation and measured diameter over conductor. The oven temperature profile for each sintering oven shall be known and on record in the vendor's plant.

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REV.	DATE	CHANGE	CHK.			
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				CHECKED BY	[signature]	1/28/65
				APP. ENG.		
				APP. ENG.	[signature]	2/3/65
				APP. REL.	[signature]	2/18/65
					SIGNATURE	DATE

TITLE: WIRE, LEAD

SPEC. NO. 47 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

3.2.3 Quality of Insulation - Over or undersintered insulation shall be cause for rejection.

3.2.3.1 The outer-most winding on a spool of lead wire as received shall be visually examined (10X) for the presence of splits in the insulation occurring parallel to the direction of extrusion. Such occurrence shall be just cause for rejection.

3.2.3.2 Excessive hi-potential failures (more than one per hundred feet) shall necessitate visual examination for splitting insulation in the vicintiy of those failures. In addition, such wire shall meet the following requirements:

3.2.3.2.1 The insulation must be capable of being slipped over a smooth spherical solder joint 2-1/2 times the diameter of the conductor without splitting. In addition, this expanded area of insulation shall not split during or following a three (3) hour subjection to 150°C.

3.2.3.2.2 A thin (1-2 mil) wafer of Teflon shall appear homogeneous throughout its cross-section when viewed as follows:

1. Slice thin sections from the cross-section of a lead,using a razor blade.
2. Place the wafers between two clean glass slides.
3. Mount the slides on the stage of an optical comparator.
4. Focus the mount so that the wafer is displayed on the screen of the comparator.
5. Undersintering is characterized by a darker (more dense) material toward the center of the wafer. A dark line around

REV.	DATE	CHANGE	CHK.	PREPARED BY		
05				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE: WIRE, LEAD

SPEC. NO. 47 | ISSUE

POLY · SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

the periphery of the inner wall is characteristic and is acceptable.

3.2.3.3 The outer-most winding on a spool of lead wire as received shall be visually examined (10X) for the presence of breaks in the insulation. These breaks occur circumferentially around the insulation. Such a condition indicates an oversintered insulation. Wire suspected to have this condition shall be subjected to the following test:

3.2.3.3.1 Remove a six (6) inch length of wire from each end of a spool of wire. Carefully remove the conductor without damaging the insulation. Elongate the insulation slowly to rupture and observe for a non-uniform necking down of the insulation in spots (as opposed to a gradual thinning) during the elongation process. This condition is indicative of oversintering and is cause for rejection.

3.2.4 Identification

Pigmented TFE teflon (less than 2% pigment) shall be used to achieve a color coding scheme per MIL-STD-104. If circuits in excess of ten (10) are required or if required by other factors, a Teflon color coding tracer shall be extruded into the body of the insulation during and concurrent with the initial extrusion. Inked tracers are not acceptable on extruded wire and are allowed on wrapped Teflon wire only where dictated by necessity. The color coding tracer shall be uniform in width so that its width, as measured, at any point along a one foot length of the wire shall be no less than one-half the maximum width of the tracer within that one foot length of wire.

Show of the base color through the tracer shall be cause for rejection.

The maximum lay of the tracer shall be twenty (20) times the diameter of the completed wire. The lay of the tracer shall be in the same direction as the lay of the outer strands.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
05				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE: WIRE, LEAD

SPEC. NO. 47 | ISSUE

POLY · SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

3.2.5 Cleanness

The insulation shall be free of foreign embedments (except those inherently apparent internally in unpigmented insulation) visible under 10X magnification.

Mixing of foreign (i.e., red pigment in black Teflon lead) colors into the Teflon insulation or tracer is not acceptable.

Questionable wire shall be hi-potential tested per 3.4.1 except at 2400 VAC.

3.2.6 Solvent Resistance

The insulation and coloring pigment shall not be soluble in ketones, alcohol, chlorinated or fluorinated solvents. Following successive five (5) minute ultrasonic generations in each of the above solvents, the insulation shall not peel or form hairs on the Teflon surface.

3.3 Conductor

3.3.1 Stranding - The conductor may be either solid or stranded as specified on the governing document. Individual strands shall not be fused together in a stranded conductor. High strands are not acceptable.

3.3.2 Material - The material shall be soft annealed OFHC copper, silver plated to a minimum thickness of 55 microinches. Unplated strands are not acceptable. No strength members shall be employed.

3.3.3 Conductivity - The conductivity of the conductor material shall not be less than 95% IACS unless otherwise specified in the Purchase Order.

3.3.4 Quality - Any evidence of silver degradation under 45X examination (i.e., a porous non-shiny appearance) shall be cause for rejection. Any evidence of copper through the silver (i.e., a pinkish or red appearance) shall be cause for rejection.

The ASTM Coker Test for silver plate shall not be considered as overriding if the silver surface exhibits evidence of copper exposure.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
05				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE— WIRE, LEAD

SPEC. NO. 47 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

3.4 Completed Wire Performance

3.4.1 Electrical - Type ET wire shall pass a 1500 VAC hi-pot test - Type E, 2200 VAC - one electrode being a sponge wetted with a wetting agent through which the completed wire passes. More than one failure per hundred feet shall necessitate examination per 3.2.3.2 of this specification.

3.4.2 Electrical Testing - The subject wire shall at no point during its manufacture be tested by water immersion.

3.4.3 Shipment - The subject wire shall be received on the appropriate spools (3.4.4) with a minimum of 1/4 inch clearance between the outer wire layer and the spool flange tip. The wire on each spool shall be protected from external contamination by a sealed plastic wrap or bag.

3.4.4 Spool dimension - All spools must be three (3) inches in width with a five (5) inch flange diameter, having a 49/64 center hole, and a 1/4 inch hole for drive key, located 0.750 inches between center lines.

3.5 Bondability

If the insulation is specified as bondable, it must meet the following additional specifications:

3.5.1 The insulation must be bondable with a 25 psi pull-out strength. Wire samples to be tested for bondability shall be potted in an epoxy resin formulation composed of 100 parts Epon 828 or equivalent. Wire sample size shall be approximately eight (8) inches. A one (1) inch section of the wire will be potted in this material with the area of the encapsulation approximately two (2) inches from one end of the wire and four (4) inches from the other. Cure of the epoxy shall be three (3) hours at 90°C. The measure of bondability shall be the pulling force parallel to the axis of the potted wire which is required to move the insulation in the cured epoxy. This force shall be converted to PSI of insulation surface in contact with the epoxy. Measurements shall be made on the test apparatus having a minimum sensitivity of 1/4 lb. Rate of stress shall be nominally constant, from 1 - 5 lb./sec.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
05				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE: WIRE, LEAD

SPEC. NO. 47 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

3.5.2 The color code must be per MIL-STD-104 except a light tan instead of white will be acceptable.

3.5.3 The O.D. of the insulation must be as specified in the governing document after the bonding treatment.

3.5.4 Neither part of the insulation itself nor any substance on the insulation shall flake off in particles visible under 10X magnification.

4. ORDERING INFORMATION

4.1 All orders shall specify that Teflon insulation lead-wire shall conform to the provisions of the latest revision of this specification.

4.2 In addition, the following information shall be included on the Purchase Order:

4.2.1 AWG number

4.2.2 Kind of insulation

4.2.3 Method of applying insulation (wrapped, extruded, etc.).

4.2.4 Insulation O.D.

4.2.5 MIL-W-16878-D type of electrical qualities (E or ET).

4.2.6 Stranding

4.2.7 Strand Size

4.2.8 Kind of conductor

4.2.9 Plating

4.2.10 Bondable, if required

4.2.11 Color Code

REV.	DATE	CHANGE	CHK.	PREPARED BY		
05				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE: WIRE, LEAD

SPEC. NO. 47 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
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BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

CONTACT ALLOY 54

1. SCOPE

1.1 This specification establishes the requirements for 69 gold, 25 silver, 6 platinum alloy to be used by Poly-Scientific Corporation in the manufacture of its products.

1.2 All material furnished under this specification must conform to the standards herein described unless otherwise stated in the purchase order.

1.3 This document supersedes all previous documents issued under Poly-Scientific Specification No. 54.

2. SPECIFICATION AND REFERENCES

2.1 Poly-Scientific Specification No. 9 - "Knoop Hardness Testing."

2.2 Poly-Scientific Specification No. 10 - "Stress Corrosion Test for Gold Ring."

3. REQUIREMENTS

3.1 Chemical Composition (by weight)

3.1.1 Nominal Composition 69% Gold (Au), 25% Silver (Ag), 6% Platinum (Pt).

3.1.2 Tolerance

Gold	68.0 to 70.0%
Silver	24.0 to 25.5%
Platinum	5.8 to 6.5%
Selected Base Metals (Pb, Sb, Bi, Sn, As, Cd, Ge, Tl, Ga)	.01% Max. Total
Sulfur	.01% Max.
Total of all impurities	.1% Max.

3.2 Hardness

3.2.1 The criterion for temper designation shall be hardness.

REV.	DATE	CHANGE	CHK.			
02	6/3/63			PREPARED BY	R.W.Ellis	1-9-63
				CHECKED BY	W.Hensley	1-23-63
				APP. ENG.	Glossbrenner	1-23-63
				APP. ENG.	W.Cox	1-26-63
				APP. REL.	G.Gilbert	1-24-63
					SIGNATURE	DATE

TITLE– CONTACT ALLOY 54

SPEC. NO. 54 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

3.2.2 Temper designations

Temper	Knoop Hardness - 100 gm Load (Average of five Readings)
A (annealed)	90 ± 10%
CW	150 ± 10%

3.3 Mechanical properties in simple tension. These values are for reference purposes only.

Temper	Minimum Ultimate Strength	Minimum elongation in 10 inches
A	40,000 psi	35%
CW	60,000 psi	---

3.4 Workmanship

3.4.1 Surfaces of all material furnished under this specification shall be smooth, clean, and free from scratches, stains, rough spots, slivers, laps, scale, pits, and any other injurious defects within limits consistent with the best possible practice. In no case shall any defect exceed .0005" in depth.

3.4.2 All material shall be free from structural defects, cracks, seams, porosity, inclusions, segregation, etc., upon examination of a suitably polished and etched metallurgical sample at 50X.

3.5 Stress Corrosion

3.5.1 Material furnished under this specification shall not be susceptible to stress corrosion cracking as defined in Poly-Scientific Specification No. 10.

3.6 Tolerance

3.6.1 Straightness - Rod or tubing shall be furnished in straight lengths with a minimum radius of curvature of 625 in.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
02	6/3/63			CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE- CONTACT ALLOY 54

SPEC. NO. 54 | ISSUE

Poly-Scientific CORPORATION BLACKSBURG VIRGINIA

3.6.2 Flatness - Strip, sheet, etc., shall be furnished in flat sections with a minimum radius of curvature, in any direction, of 1000 times the material thickness.

3.6.3 Dimensions

3.6.3.1 Rod shall have the required diameter ± .001".

3.6.3.2 Tubing shall have the required inside and outside diameter ± .001".

3.6.3.3 Thickness of sheet shall be as required ± .001".

3.6.3.4 Concentricity of tubing must be maintained within .002" T.I.R.

3.6.3.5 Maximum variation in thickness of sheet, strip, etc., .0005" per inch of width or length.

3.7 Processing

3.7.1 All ingots are to be soaked at 1200°F to 1400°F for one (1) hour after the initial 50% (minimum) reduction to insure homogeneity.

3.7.2 If scrap is used, only clean skeleton scrap may be melted in this alloy. Turnings, chips, or shavings may not be used.

3.7.3 No sulfurized lubricants may be used at any stage of processing.

4. INSPECTION AND TESTING

4.1 The vendor shall perform, or have performed, at least these minimum tests to insure conformity to this standard.

4.1.1 Visual inspection at 10X to insure compliance with para. 3.4.1 of this standard.

4.1.2 Hardness Test - Knoop 100 gram load.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
				SIGNATURE	DATE	

TITLE— CONTACT ALLOY 54

SPEC. NO. 54 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

4.1.3 Check of dimensions to insure conformity to para. 3.6 of this specification.

4.2 Poly-Scientific Corporation shall perform the following tests upon receipt of material furnished to this specification:

4.2.1 Hardness tests - Knoop 100

4.2.2 Spectrographic Analysis

4.2.3 Dimensional check to insure conformity to para. 3.6

4.2.4 Visual Examination (10X).

4.2.5 Microscopic examination (50X) to insure conformity to para. 3.4.2.

4.2.6 Stress corrosion test (para. 3.5).

4.3 A spectrographic and/or quantitative analysis by an outside laboratory shall be performed when specified in the purchase order.

4.4 Tensile tests shall be performed when specified in the purchase order.

5. PACKAGE AND DELIVERY

5.1 The material furnished under this specification shall be packed in such a way as to insure conformity to the standards herein described upon arrival at Poly-Scientific Corporation.

5.2 Packing should be such that danger of damaging upon unpacking is a minimum.

5.3 Deliveries shall be made with due precaution to insure safe, rapid and economic transfer.

6. NOTES

6.1 Orders for this material shall include applicable dimensions and temper designations.

6.2 Intended use - The material defined in this specification is intended for use as low level dynamic electrical contacts of critical application.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE- CONTACT ALLOY 54

SPEC. NO. 54 | ISSUE

Poly-Scientific CORPORATION BLACKSBURG VIRGINIA

CONTACT ALLOY 55

1. SCOPE

1.1 This specification establishes the requirements for the precipitation hardenable platinum, palladium, gold, silver, copper, zinc alloy to be used by the Poly-Scientific Corporation in the manufacture of its products.

1.2 All material furnished under this specification must conform to the standards herein described unless otherwise stated in the purchase order.

1.3 This document supersedes all previous documents issued under Poly-Scientific Specification No. 55.

2. SPECIFICATION AND REFERENCES

2.1 Poly-Scientific Specification No. 9 - "Knoop Hardness Testing "

2.2 MIL-E-14570-A - "Electrical Contact Alloys, etc.."

3. REQUIREMENTS

3.1 Chemical Composition (by weight)

3.1.1 Nominal composition:

Gold (Au)	10%
Platinum (Pt)	10%
Palladium (Pd)	35%
Silver (Ag)	30%
Copper (Cu)	14%
Zinc (Zn)	1%

3.1.2 Tolerance

Gold (Au)	9.5 to 10.5%
Silver (Ag)	29.0 to 31.0%
Platinum (Pt)	9.5 to 10.5%
Palladium	34.0 to 36.0%
Zinc	.5 to 1.2%
Copper	13.5 to 15.5%
Selected Base Metals (Sb, Pb, Be, Sn, As, Cd, Ge, Tl, Ga)	.02% Max. total
Sulfur	.01% Max.
Total of all impurities	.1% Max.

R.W.Ellis,Jr. 1/9/63 W.D.Hensley - 1/23/63 Glossbrenner- 1/24/63 G.Gilbert - 1/24/63 W.Cox - 1/30/63	ENGINEERING SPECIFICATION Poly-Scientific CORPORATION BLACKSBURG VIRGINIA PAGE 1 OF 4	TITLE CONTACT ALLOY 55 SPEC. NO. 55 REV. 02

3.2 Hardness

3.2.1 The criterion for temper designation shall be hardness.

3.2.2 Temper designations

Temper	Knoop Hardness - 100 gram load (Average of Ten Readings)
A (solution Annealed)	220 ± 15%
HT	360 ± 10%

3.3 Heat Treatment

3.3.1 All material furnished under temper designation "A" shall be capable of precipitation hardening to a hardness consistent with the range defined as "HT" temper in Para. 3.2.2.

3.4 Mechanical properties in simple tension. These values are for reference purposes only.

3.4.1 Wire to 15 mils

Temper	Minimum Ultimate Strength	Minimum Elongation in two (2) inches
A	100,000 psi	18%
HT	155,000 psi	2%

3.4.2 Sheet, rod, tubing

Temper	Minimum Ultimate Strength	Minimum Elongation in two (2) inches
A	100,000 psi	10%
HT	150,000 psi	2%

3.5 Workmanship

3.5.1 Surfaces of all material furnished under this specification shall be smooth, clean and free from scratches, stains, rough spots, slivers, laps, scale, pits, and any other injurious defects within limits consistent with the best possible practice for this alloy. In no case shall any defect exceed .0005" in depth for rod,tubing, sheet, strip, etc., or .0001" in depth for wire.

3.5.2 All material shall be free from structural defects, cracks, seams, porosity, inclusions, segregation, etc., upon examination of a suitably polished and etched metallurgical sample at 50X.

3.6 Tolerance

3.6.1 Straightness

3.6.1.1 Rod or tubing shall be furnished in straight lengths with a minimum radius of curvature of 625 inches.

3.6.1.2 Wire shall be furnished in sections as straight as possible within limits consistent with the best commercial practice.

3.6.2 Flatness - Strip, sheet, etc., shall be furnished in flat sections with a minimum radius of curvature, in any direction, of 1000 times the material thickness.

3.6.3 Dimensions

3.6.3.1 Rod shall have the required diameter ±.001".

3.6.3.2 Tubing shall have the required inside and outside diameter ±.001".

3.6.3.3 Thickness of sheet shall be as required ±.001".

3.6.3.4 Concentricity of tubing must be maintained within .002" T.I.R.

3.6.3.5 Maximum variation in thickness of sheet, strip, etc., .0005" per inch of width or length.

3.6.3.6 Wire up to 15 mils shall have the required diameter ±.0005".

4. INSPECTION AND TESTING

4.1 The vendor shall perform, or have performed, at least these minimum tests to insure conformity to this standard.

4.1.1 Visual inspection at 10X to insure compliance with Para. 3.5.1 of this standard.

4.1.2 Hardness Test - Knoop 100 gram load.

4.1.3 Check of dimensions to insure conformity to Para. 3.6.

4.2 Poly-Scientific Corporation shall perform the following tests upon receipt of material furnished to this specification.

4.2.1 Hardness Tests - Knoop 100

4.2.2 Spectrographic Analysis

4.2.3 Dimensional check to insure conformity to Para. 3.6.

4.2.4 Visual Examination (10X)

4.2.5 Microscopic examination(50X) to insure conformity to Para. 3.5.2.

4.3 A spectrographic and/or quantitative analysis by an outside laboratory shall be performed when specified in the purchase order.

4.4 Tensile Tests shall be performed when specified in the purchase order.

5. PACKAGE AND DELIVERY

5.1 The material furnished under this specification shall be packed in such a way as to insure conformity to the standards herein described upon arrival at Poly-Scientific Corporation.

5.2 Packing should be such that danger of damaging upon unpacking is a minimum.

5.3 Deliveries shall be made with due precaution to insure safe, rapid and economic transfer.

6. NOTES

6.1 Orders for this material shall include applicable dimensions and temper designations.

6.2 Intended use - The material defined in this specification is intended for use as low level dynamic electrical contacts of critical application.

ENGINEERING SPECIFICATION

CONTACT ALLOY 56

1. SCOPE

1.1 This specification establishes the requirements for the precipitation hardenable gold, silver, platinum, copper, zinc alloy to be used by the Poly-Scientific Corporation in the manufacture of its products.

1.2 All material furnished under this specification must conform to the standards herein described unless otherwise stated in the purchase order.

1.3 This document supersedes all previous documents issued under Poly-Scientific Specification No. 56.

2. SPECIFICATION AND REFERENCES

2.1 Poly-Scientific Specification No. 9 - "Knoop Hardness Testing."

3. REQUIREMENTS

3.1 Chemical Composition (by weight)

3.1.1 Nominal composition:

Gold (Au)	71.5%
Silver (Ag)	4.5%
Zinc (Zn)	1.0%
Platinum (Pt)	8.5%
Copper (Cu)	14.5%

3.1.2 Tolerance

Gold (Au)	70.5 to 72.5%
Platinum (Pt)	8.0 to 9.0%
Silver (Ag)	4.0 to 5.0%
Zinc (Zn)	.5 to 1.2%
Copper	13.5 to 15.5%
Selected Base Metals (Sb, Pb, Bi, Sn, As, Cd, Ge, Tl, Ga)	.02% Max. Total
Sulfur	.01% Max.
Total of all impurities	.1% Max.

REV.	DATE	CHANGE	CHK.			
03	6/3/63			PREPARED BY	Ellis	1-22-63
				CHECKED BY	Hensley	1-23-63
				APP. ENG.	Glossbrenner	1-23-63
				APP. ENG.	Cox	1-30-63
				APP. REL.	Gilbert	1-24-63
					SIGNATURE	DATE

TITLE- CONTACT ALLOY 56

SPEC. NO. 56 | ISSUE

Poly-Scientific CORPORATION BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

3.2 Hardness

3.2.1 The criterion for temper designation shall be hardness.

3.2.2 Temper designations

TEMPER	KNOOP HARDNESS - 100 GRAM LOAD (Average of ten readings)
A (solution Annealed)	200 ± 10%
CW (solution Annealed and work hardened)	240 ± 10%
HTA (heat treated from temper A)	320 ± 10%
HTW (heat treated from temper CW)	350 ± 10%

3.3 Heat Treatment

3.3.1 All material furnished under temper designations A or CW must be capable of heat treatment to a hardness consistent with the ranges defined as HTA or HTW in Para. 3.2.2.

3.4 Mechanical Properties in simple tension
These values are for reference purposes only.

3.4.1 Wire to 15 mils

TEMPER	MINIMUM ULTIMATE STRENGTH	MINIMUM ELONGATION IN FIVE (5) INCHES
A	80,000 psi	15%
HTA	130,000 psi	5%
HTW	150,000 psi	2%

3.4.2 Sheet, rod, tubing

TEMPER	MINIMUM ULTIMATE STRENGTH	MINIMUM ELONGATION IN FIVE (5) INCHES
A	75,000 psi	10%
HTA	125,000 psi	4%
HTW	140,000 psi	2%

REV.	DATE	CHANGE	CHK.			
C3	4/3/63			PREPARED BY		
				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE— CONTACT ALLOY 56

SPEC. NO. 56 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

3.5 Workmanship

3.5.1 Surfaces of all material furnished under this specification shall be smooth, clean and free from scratches, stains, rough spots, slivers, laps, scale, pits, and any other injurious defects within limits consistent with the best possible practice for this alloy. In no case shall any defect exceed .0005" in depth for rod, tubing, sheet, strip, etc., or .0001" in depth for wire.

3.5.2 All material shall be free from structural defects, cracks, seams, porosity, inclusions, segregation, etc., upon examination of suitably polished and etched metallurgical sample of 50X.

3.6 Tolerance

3.6.1 Straightness

3.6.1.1 Rod or tubing shall be furnished in straight lengths with a minimum radius of curvature of 625 inches.

3.6.1.2 Wire shall be furnished in sections as straight as possible within limits consistent with the best commercial practice.

3.6.2 Flatness

3.6.2.1 Strip, sheet, etc., shall be furnished in flat sections with a minimum radius of curvature, in any direction, of 1000 times the material thickness.

3.6.3 Dimensions

3.6.3.1 Rod shall have the required diameter ± .001".

3.6.3.2 Tubing shall have the required inside and outside diameter ± .001".

3.6.3.3 Thickness of sheet shall be as required ± .001".

REV.	DATE	CHANGE	CHK.	PREPARED BY		
03	6/3/93			CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE– CONTACT ALLOY 56

SPEC. NO. 56 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

3.6.3.4 Concentricity of tubing must be maintained within .002" T.I.R.

3.6.3.5 Maximum variation in thickness of sheet, strip, etc., .0005" per inch of width or length.

3.6.3.6 Wire up to 15 mils shall have the required diameter ± .0005".

4. INSPECTION AND TESTING

4.1 The vendor shall perform, or have performed, at least these minimum tests to insure conformity to this standard.

4.1.1 Visual inspection at 10X to insure compliance with Para. 3.5.1 of this standard.

4.1.2 Hardness Test - Knoop 100 gram load.

4.1.3 Check of dimensions to insure conformity to Para. 3.6.

4.2 Poly-Scientific Corporation shall perform the following tests upon receipt of material furnished to this specification.

4.2.1 Hardness Tests - Knoop 100

4.2.2 Spectrographic Analysis

4.2.3 Dimensional check to insure conformity to Para. 3.6.

4.2.4 Visual Examination (10X)

4.2.5 Microscopic examination (50X) to insure conformity to Para. 3.5.2.

4.3 A spectrographic and/or quantitative analysis by an outside laboratory shall be performed when specified in the purchase order.

4.4 Tensile tests shall be performed when specified in the purchase order.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE— CONTACT ALLOY 56

SPEC. NO. 56 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

5. PACKAGE AND DELIVERY

5.1 The material furnished under this specification shall be packed in such a way as to insure conformity to the standards herein described upon arrival at Poly-Scientific Corporation.

5.2 Packing should be such that danger of damaging upon unpacking is a minimum.

5.3 Deliveries shall be made with due precaution to insure safe, rapid and economic transfer.

6. NOTES

6.1 Orders for this material shall include applicable dimensions and temper designations.

6.2 Intended use - The material defined in this specification is intended for use as low level dynamic electrical contacts of critical application.

REV.	DATE	CHANGE	CHK.			
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				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE— CONTACT ALLOY 56

SPEC. NO. 56 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

CONTACT ALLOY 57

1. SCOPE

1.1 This specification establishes the requirements for 75% gold, 22% silver, 3% nickel alloy to be used by Poly-Scientific Corporation in the manufacture of its products.

1.2 All material furnished under this specification must conform to the standards herein described unless otherwise stated in the purchase order.

1.3 This document supersedes all previous documents issued under Poly-Scientific Specification No. 57.

2. SPECIFICATIONS & REFERENCES

2.1 Poly-Scientific Specification 9 - "Knoop Hardness Testing."

2.2 Poly-Scientific Specification 10 - "Stress Corrosion Test for Gold Rings."

3. REQUIREMENTS

3.1 Chemical Composition (by weight)

3.1.1 Nominal

75% Gold (Au)
22% Silver (Ag)
3% Nickel (Ni)

3.1.2 Tolerance

Gold (Au)	74.8 to 75.5%
Silver (Ag)	21.5 to 22.5%
Nickel (Ni)	2.9 to 3.5%
Selected Base Metals (Pb, Sb, Bi, Sn, Cd, Ge, Tl, Ga, As)	.01% max. total.
Sulfur	.01% max.
Total of all impurities	.1% max.

REV.	DATE	CHANGE	CHK.			
02	6/3/63			PREPARED BY	Hensley	1-23-63
				CHECKED BY		
				APP. ENG.	Glossbrenner	1-23-63
				APP. ENG.	Cox	1-30-63
				APP. REL.	Gilbert	1-24-63
					SIGNATURE	DATE

TITLE— CONTACT ALLOY 57

SPEC. NO. 57 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

3.2 Hardness

3.2.1 The criterion for temper designation shall be hardness.

3.2.2 Temper Designation

TEMPER	KNOOP HARDNESS - 100g LOAD AVERAGE OF FIVE READINGS
A (Annealed)	100 ± 10%
CW1	140 ± 10%
CW2	180 ± 10%

3.3 Mechanical Properties in Simple Tension
These values are for reference purposes only.

3.3.1 Wire up to .015" dia.

TEMPER	MIN. ULTIMATE STRENGTH	MIN. ELONGATION IN 2"
A	45,000 psi	10%
CW1	80,000 psi	---
CW2	90,000 psi	---

3.3.2 Strip and rod

TEMPER	MIN. ULTIMATE STRENGTH
A	40,000 psi
CW1	75,000 psi
CW2	85,000 psi

3.4 Workmanship

3.4.1 Surfaces of all material furnished under this specification shall be smooth, clean, and free from scratches, stains, rough spots, slivers, laps, scale, pits, and any other injurious defects within limits consistent with the best possible practice. In no case shall any defect exceed .0005" in depth for rod, tubing, strip, sheet, etc., or .0001" in depth for wire.

3.4.2 All material furnished under this specification must be free from seams, inclusions, cracks, segregation, etc., upon examination of a suitably polished and etched metallurgical mount at 50 X.

REV.	DATE	CHANGE	CHK.			
1	6/2/82			PREPARED BY		
				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE: CONTACT ALLOY 57

SPEC. NO. 57 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

3.5 Stress Corrosion

3.5.1 Material furnished under this specification shall not be susceptible to stress corrosion cracking as defined in Poly-Scientific Specification No. 10.

3.6 Tolerance

3.6.1 Straightness - Rod or tubing shall be furnished in straight lengths with a minimum radius of curvature of 625 in.

3.6.2 Flatness - Strip, sheet, etc., shall be furnished in flat sections with a minimum radius of curvature, in any direction, of 1000 times the material thickness.

3.6.3 Dimensions

3.6.3.1 Rod shall have the required diameter ± .001".

3.6.3.2 Tubing shall have the required inside and outside diameter ± .001".

3.6.3.3 Thickness of sheet shall be as required ± .001".

3.6.3.4 Concentricity of tubing must be maintained within .002" T.I.R.

3.6.3.5 Maximum variation in thickness of sheet, strip, etc., .0005" per inch of width or length.

3.6.3.6 Wire up to 15 mils shall have the required diameter ± .0005".

3.7 Processing

3.7.1 If scrap is used, only clean skeleton scrap shall be melted in this alloy.

3.7.2 No sulfurized lubricants are to be used at any stage of processing.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
				CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE— CONTACT ALLOY 57

SPEC. NO. 57 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

4. INSPECTION AND TESTING

4.1 The vendor shall perform, or have performed, at least these minimum tests to insure conformity to this standard.

4.1.1 Visual inspection at 10X to insure compliance with Para. 3.4.1 of this standard.

4.1.2 Hardness Test - Knoop 100 gram load.

4.1.3 Check of dimensions to insure conformity to Para. 3.6 of this specification.

4.2 Poly-Scientific Corporation shall perform the following tests upon receipt of material furnished to this specification:

4.2.1 Hardness tests - Knoop 100

4.2.2 Spectrographic Analysis

4.2.3 Dimensional check to insure conformity to Para. 3.6.

4.2.4 Visual Examination (10X).

4.2.5 Microscopic examination (50X) to insure conformity to Para. 3.4.2.

4.2.6 Stress corrosion test (Para. 3.5)

4.3 A spectrographic and/or quantitative analysis by an outside laboratory shall be performed when specified in the purchase order.

4.4 Tensile tests shall be performed when specified in the purchase order.

5. PACKAGE AND DELIVERY

5.1 The material furnished under this specification shall be packed in such a way as to insure conformity to the standards herein described upon arrival at Poly-Scientific Corporation.

REV.	DATE	CHANGE	CHK.			
02	6/3/63			PREPARED BY		
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				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE– CONTACT ALLOY 57

SPEC. NO. 57 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

5.2 Packing should be such that danger of damaging upon unpacking is a minimum.

5.3 Deliveries shall be made with due precaution to insure safe, rapid and economic transfer.

6. NOTES

6.1 Orders for this material shall include applicable dimensions and temper designations.

6.2 Intended use - The material defined in this specification is intended for use as low level dynamic electrical contacts of critical application.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
02	6/3/63			CHECKED BY		
				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE- CONTACT ALLOY 57

SPEC. NO. 57 | ISSUE

Poly-Scientific CORPORATION

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ENGINEERING SPECIFICATION

ALIPHATIC-AMINE CURED EPOXY FORMULATION
P-54

1. SCOPE.

1.1 This specification defines the components and general properties of the PSC formulation P-54

2. SPECIFICATIONS AND REFERENCES.

2.1 PSC Engineering Specification No. 112, Liquid Epoxy Resin.

2.2 PSC Engineering Specification No. 114, Modified Aliphatic Amine Curing Agent.

2.3 PSC Engineering Specification No. 113, Pigments for Epoxy Formulation.

3. REQUIREMENTS.

3.1 Materials used in this formulation shall be qualified to the appropriate specification given in Section 2.

3.2 Curing agent shall be mixed thoroughly into the liquid epoxy resin in the ratio 25 ± 1 parts curing agent to 100 parts resin. Pigments in amounts less than 1% may be neglected in this measurement.

3.3 Standard cure of P-54 is 30 ± 5 minutes at 90° ± 5°C. Test values for material cured by this cycle shall produce an infusible solid having the following minimum properties.

HDT	90°C	(PSC Test)
Impact	3.0	(PSC Test)
Flexural strength	16.0 in. Hg.	(PSC Test)
Dielectric constant		3.0

3.4 At room temperature this material will have a pot life of less than twenty (20) minutes in 10 gram batches.

3.5 The initial viscosity of this material taken immediately after mixing will be 3,000 - 6,000 cps, at 25°C, increasing steadily with time.

REV.	DATE	CHANGE	CHK.			
0				PREPARED BY	Sindelar	11-30-62
				CHECKED BY	Glossbrenner	11-30-62
				APP. ENG.	Cox	12-4-62
				APP. ENG.		
				APP. REL.	Gilbert	12-4-62
					SIGNATURE	DATE

TITLE- ALIPHATIC-AMINE CURED EPOXY FORM. P-54

SPEC. NO. 65 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
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BLACKSBURG VIRGINIA

3.6 Gel time will be 30 to 40 minutes for a 10 gram batch at room temperature. Gel is defined as the point at which the material is a non-tacky solid.

3.7 Chemical identity of cured material will be determined by comparison with the infra-red spectrum attached to this specification.

4. INSPECTION AND TEST.

4.1 Parts cast or cemented with this formulation should be inspected visually for flaws and dimensional conformance to print. Electrical tests should be made as specified on the engineering drawing.

5. PACKAGE AND STORAGE.

5.1 Components shall be stored unmixed in closed containers of convenient size.

6. NOTES.

6.1 The cure reaction of P-54 is highly exothermic and thus self-accelerating. In general, gel time will be inversely proportional to mass of P-54 mixed.

6.2 In masses of over 20 grams, exotherm may cause "monkeying" or charring and bubbling of the epoxy. Care should be taken to cool or heat-sink when masses exceeding 20 grams are being used.

6.3 Both resin and hardener used in this formulation should be regarded as skin sensitizing. Workers involved in mixing and casting this material should be equipped with goggles, gloves, and aprons and should be required to wear long-sleeved shirts or jackets to minimize the possibility of skin contact. Workers using this formulation as a cement only should be required to be scrupulous in keeping their area free of spilled cement. If skin contact is probable, adequate protective equipment should be provided.

6.4 While this material is less irritating than most aliphatic-amine cured epoxy formulations, rashes resulting from skin contact may frequently occur and sensitivity may increasing with exposure time. Mild cases are usually symptomatically relieved by treatment with Burrow's solution (1% aluminum acetate solution).

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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				APP. ENG.		
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				APP. REL.		
					SIGNATURE	DATE

TITLE: ALIPHATIC-AMINE CURED EPOXY FORM. P-54

SPEC. NO. 65 | ISSUE

POLY · SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
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ENGINEERING SPECIFICATION

6.5 In the event of skin contact with either resin or hardener, skin should be wiped with a clean towel moistened in clean acetone or similar solvent. Skin should then be washed with soap and water. In the case of eye contact, an opthomologist should be consulted immediately.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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				APP. ENG.		
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				APP. REL.		
					SIGNATURE	DATE

TITLE-ALIPHATIC-AMINE CURED EPOXY FORM. P-54

SPEC. NO. 65 | ISSUE

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ENGINEERING SPECIFICATION

AROMATIC-AMINE CURED EPOXY FORMULATION P-30

1. SCOPE

1.1 This specification defines the ingredients and general properties of the epoxy formulation designed at P-30.

2. SPECIFICATIONS AND REFERENCES

2.1 PSC Engineering Specification No. 112, Liquid Epoxy Resin.

2.2 PSC Engineering Specification No. 82, Modified Aromatic Amine.

2.3 PSC Engineering Specification No. 113, Pigments for Epoxy Formulation.

2.4 PSC Laboratory Procedure No. 119, Testing of Thermosetting Resin Formulation.

3. REQUIREMENTS

3.1 Materials used in this formulation must be qualified under the appropriate specification given in Section 2.

3.2 The resin and hardener should be mixed thoroughly in the ratio 20.0 $\pm$ 0.5 parts hardener to 100 parts resin. Pigments present in concentration less than 1% may be neglected in this calculation.

3.3 Color designations of this formulation shall be as follows:

DESIGNATION	COLOR	PIGMENT
Specification 84	Blue	0.06 phr phthalocyanine blue resin paste (E.S. No. 113)
Specification 84-1	Light Blue	0.06 phr phthalocyanine blue resin paste, plus 1.5 phr titanium dioxide resin paste (E.S. No. 113)
Specification 84-2	Amber	None

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REV.	DATE	CHANGE	CHK.			
01	6-28-63			PREPARED BY	Sindelar	11-30-62
				CHECKED BY	Glossbrenner	11-30-62
				APP. ENG.	Cox	12-4-62
				APP. ENG.		
				APP. REL.	Gilbert	12-4-62
					SIGNATURE	DATE

TITLE- AROMATIC-AMINE CURED EPOXY FORMULATION P-30

SPEC. NO. 84 | ISSUE

Poly-Scientific CORPORATION
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3.4 When cured two (2) hours ± 5 minutes at 85° to 90° C and post cured four (4) hours ± 10 minutes at 140° to 160° C this formulation shall produce an infusible material having the following minimum properties:

PROPERTY	PSC TEST VALUE	ASTM TEST VALUES
Heat distortion temp.	145° C	(D648-54T) 140° C
Impact Strength	2 in.	(D256-54T) 0.20 (120D)
Flexural strength	12 in. Hg	(D709-49) 12,000 psi Ult
Tensile strength		(D638-52T) 9,000 psi Ult
Compressive yield		(D695-54) 10,000 psi
Dielectric constant		3.0
Dielectric strength		(D149-55T) 350 v/mil
Arc resistance (.125 sample)		60 seconds

3.5 This material will have a pot life of at least twelve (12) minutes at 90° C in a 50 gram mass. Pot life here is defined as the time interval after normal mixing in which the material is suitable for use in all casting operations.

3.6 Gel time will be less than two (2) hours at 90° C, less than twenty-four (24) hours at 25°C. Gel is defined as the point at which the material is a non-tacky solid.

3.7 Viscosity of the uncured resin-hardener will be less than 1000 cps at 90° C, between 12,000 and 18,000 at 25° C.

3.8 Chemical identity of the cured plastic will be determined as compared to the attached IR spectrum.

4. INSPECTION AND TEST

4.1 Parts cast of P-30 should be inspected visually for flaws and dimensional conformance to print. Electrical tests should be made as specified on the engineering drawing.

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				APP. REL.		
					SIGNATURE	DATE

TITLE: AROMATIC-AMINE CURED EPOXY FORMULATION P-30

SPEC. NO. 84 | ISSUE

Poly-Scientific CORPORATION
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ENGINEERING SPECIFICATION

5. PACKAGING AND STORAGE

5.1 Components shall be stored unmixed in sealed containers of convenient size.

5.2 Curing agent may be maintained at temperatures up to 130° F in order to prevent crystallization or eutectic segregation.

6. NOTES

6.1 Cure time and physical properties of P-30 will vary with the age of the curing agents used. This is attributed to oxidation of curing agent and is accepted as a normal variation in this formulation. This variation will not cause test values to fall below those given in paragraph 3.4. Generally it can be assumed that new or light amber hardener will cure more quickly than the dark brown, aged material.

6.2 Both resin and hardener used in this formulation should be considered as skin sensitizing. Workers handling these materials should be equipped with gloves, aprons, and goggles, and should be required to wear long-sleeved shirts or jackets to minimize possible skin contact.

6.3 Common reaction to the epoxy resin used in this formulation is an irritating rash. Mild cases are usually symptomically relieved by treatment with Burrow's solution (1% aluminum acetate solution).

6.4 Skin contact with amine curing agent produces the same general reaction as the epoxy and also causes dark brown stains which cannot be removed by normal washing.

6.5 Sensitivity to these materials varies among individuals, and usually increases with exposure time. Apparent immunity to any ill effect from skin contact is common on short-time exposure, but sensitivity can be expected to increase with exposure time.

6.6 Vapors from either resin or hardener should be considered as toxic and skin sensitizing, and adequate ventilation should be provided to ensure a minimum of human contact with vapors or their condensation on equipment.

6.7 In the event of skin contact with either resin or hardener, skin should be wiped with a clean towel or cloth moistened in acetone or similar solvent. Skin should then be washed with soap and water, In the case of eye contact an opthomologist should be consulted immediately.

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					SIGNATURE	DATE

TITLE- AROMATIC-AMINE CURED EPOXY FORMULATION P-30

SPEC. NO. 84 | ISSUE

Poly-Scientific CORPORATION
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MINERAL FILLED EPOXY FORMULATION, P-41

1. SCOPE

This specification defines the composition and general properties of the mineral-filled epoxy formulation, P-41.

2. SPECIFICATIONS AND REFERENCES

2.1 Poly-Scientific Engineering Specification No. 112, Liquid Epoxy Resin.

2.2 Poly-Scientific Engineering Specification No. 82, Modified Aromatic-Amine Curing Agent.

2.3 Poly-Scientific Engineering Specification No. 116, Calcium Carbonate Filler for Epoxy Resins.

2.4 Poly-Scientific Engineering Specification No. 113, Pigments for Epoxy Formulations.

2.5 Poly-Scientific Laboratory Procedure No. 119, Testing of Thermosetting Resin Formulations.

3. REQUIREMENTS

3.1 Materials used in this formulation shall be qualified to the appropriate specification given in Section 2.

3.2 Formulation weights for this material are:

Dry Calcium Carbonate	200 ± 5.0
Liquid Epoxy Resin	100 ± 0.0
Modified Aromatic Amine	20 ± 0.5

3.3 This formulation when cured two (2) hours (± 10 minutes) at 90°C (± 5°) and four (4) hours (± 10 minutes) at 150° C (± 5°) will produce a solid, infusible material having the following minimum properties:

PROPERTY	PSC TEST VALUE	ASTM TEST VALUE
Heat distortion temperature	200° C	
Impact strength	0.9 in.	(D256-54T) 0.10 IZOD
Flexural strength	10 in. Hg	(D790-49T) 9,000 psi
Arc resistance		(D495-48T) 45 seconds
Volume resistivity, ohm-cm		(D275-57T) 3.0×10^{15}
Surface resistivity, ohm		(D257-57T) 8.0×10^{16}
Dielectric strength volts/mil		(D149-55T) 325
Specific Gravity	1.75 - 1.80	

3.4 This formulation when cured two (2) hours (± 10 minutes) at 90° C (± 5° C) and four (4) hours (± 10 minutes) at 150° C (± 5° C) shall be insoluble and non-swelling in methylene chloride as determined by Poly-Scientific Laboratory Procedure No. 119.

3.5 This material will have a pot life of at least twelve (12) minutes at 110° C in a 50 gram mass. Pot life is defined as the interval after normal mixing during which the material is suitable for use in all casting operations.

3.6 Gel time will be less than two (2) hours at 90° C, less than twenty-four (24) hours at 25° C. Gel is defined as the point at which the material becomes a non-tacky solid.

3.7 Initial viscosity of the mixed formulation will be at least five (5) poise at 110° C, increasing steadily with time.

3.8 Identification of cured P-41 shall be made both by comparison to the standard spectrum attached to this specification and by a spot test as described in Poly-Scientific Laboratory Procedure No. 117, Rev. 1.

4. **INSPECTION AND TEST**

4.1 Parts cast of this formulation shall be inspected visually for flaws and dimensional conformance to print. Electrical tests shall be made as specified on the engineering drawing.

5. **PACKAGE AND STORAGE**

5.1 Resin and filler shall be pre-mixed and stored in closed containers of convenient size, or stored individually in shipping containers.

5.2 The amine curing agent may be maintained at temperatures up to 130° F to prevent crystallization or eutectic segregation. Shelf storage shall be in closed containers of convenient size.

6. **NOTES**

6.1 The intended use of this material is as a casting formulation where good thermal shock characteristics, low shrinkage, and low cure exotherm are required. The application must, however, be able to tolerate high initial viscosity, and low tensile and impact strength.

6.2 Addition of any ingredient other than those listed here, or alteration of the formulation ratios will change the final properties of this material. In the event of any formulation modification, this specificatinn shall not apply and shall not be referenced in part.

6.3 Cure time and physical properties of this formulation will vary with the age of the hardaner used. This is attributed to the oxidation of an aromatic amine ingredient, and is accepted as a normal variation in this formulation. This variation shall not, however, cause the test values to fall below those given in Para. 3.3 of this specification.

6.4 Both resin and hardener used in this formulation are to be regarded as skin sensitizing, and workers handling these materials shall be equipped with adequate protective equipment to minimize the possibility of skin or eye contact. Vapors from the heated material are to be considered as toxic and skin sensitizing, and adequate ventilation shall be provided to insure a minimum of human contact with the vapors or their condensation on equipment.

ENGINEERING SPECIFICATION

ELECTROFORMED 24 KARAT GOLD

1. SCOPE

1.1 This specification establishes the requirements for Electroformed 24 Karat Gold as used by Poly-Scientific in the manufacture of its products.

1.2 All material furnished to this specification must conform to the standards herein described unless otherwise stated in writing.

2. REFERENCES AND SPECIFICATIONS

2.1 Poly-Scientific Engineering Specification No. 9, "Knoop Hardness Testing".

3. REQUIREMENTS

3.1 Chemical Composition (by weight)

3.1.1 Nominal - 100% Gold

3.1.2 Tolerance

Gold (Au)	99.9% Min.
Base Metals (Pb, Sb, Bi, Sn, Cd, Ge, Tl, Ga, As, Zn)	0.01% Max.

3.2 Hardness (Knoop 100 gm load - Average of 10 readings)

3.2.1 Hardness shall be checked on transverse section of plated rods with the long axis of the Knoop diamond parallel to the radius of the rod. Hardness is not to be checked on curved surfaces or on the outside diameter except when relative, qualitative results are desired. In such cases, the method of obtaining such data shall be included in the test report.

3.2.2 Range - 110 to 140.

3.2.3 Lots in which five (5) or more readings out of ten (10) fall outside the indicated range shall not be acceptable even though average hardness is correct.

3.3 Brittleness

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00				PREPARED BY	[signature]	4/23/64
				CHECKED BY	[signature]	4/23/64
				APP. ENG.	[signature]	4/23/64
				APP. ENG.		
				APP. REL.	[signature]	4/24/64
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TITLE: ELECTROFORMED 24 KARAT GOLD

SPEC. NO. 118 | ISSUE

POLY - SCIENTIFIC
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3.3.1 Material, after removal of base material, if this base material has a coefficient of expansion greater than 37×10^{-6} in./in./°C, furnished to this standard shall be capable of withstanding the thermal shock produced upon immersing a sample from the lot under test, at room temperature, in a bath of mineral oil maintained at 150°C (± 5°), holding for five (5) to seven (7) minutes, and quenching in water at room temperature.

3.3.2 The brittleness test shall be performed on a sample which has been finish machined or ground to the final dimensions of the parts produced in the lot under test. The base material over which the sample is plated shall be the same base material and the plating thickness shall be the same as the applicable production part.

3.3.3 Any sample which, subsequent to this test, exhibits cracking, visible at 10X, shall be cause for rejection of the lot under test.

3.4 Workmanship

3.4.1 All material furnished under this specification shall be free from porosity, cracks, inclusions, segregation, or other injurious defects upon examination, at 50X, of a suitably polished and etched metallurgical sample.

3.4.2 Unless otherwise stated in writing, material produced to this specification shall be capable of attaining a surface finish of four (4) micro inches or better upon grinding or machining. Surfaces shall be clean and free from pits, inclusions or other injurious defects within limits consistent with the best possible practice for this material.

3.5 Tolerance

3.5.1 Plating thickness, after all processing, must be as required ± 0.001" at any point.

3.5.2 Outside diameter of plated rods must be as required ± 0.001".

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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				APP. REL.		
					SIGNATURE	DATE

TITLE: ELECTROFORMED 24 KARAT GOLD

SPEC. NO. 118 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
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ENGINEERING SPECIFICATION

4. INSPECTION AND TESTING

4.1 The following tests shall be performed to ensure conformity to this standard:

4.1.1 Visual inspection (10X)

4.1.2 Hardness Test (Knoop 100 gm. load)

4.1.3 Dimensional Check

4.1.4 Metallographic Examination (Para. 3.5.1)

4.1.5 Spectrographic Analysis

4.1.6 Brittleness Test (Para. 3.3)

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE: ELECTROFORMED 24 KARAT GOLD

SPEC. NO. 118 | ISSUE

POLY - SCIENTIFIC
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ALLOY 120

1. SCOPE

1.1 This specification establishes the requirements for the 85% platinum - 15% iridium alloy to be used by Poly-Scientific Corporation in the manufacture of its products.

1.2 All material furnished under this specification must conform to the standards herein described unless otherwise stated in the purchase order.

2. SPECIFICATIONS AND REFERENCES

2.1 Poly-Scientific Specification No. 9 - "Knoop Hardness Testing".

3. REQUIREMENTS

3.1 Chemical Composition (by weight)

3.1.1 Nominal composition - 85% Platinum
15% Iridium

3.1.2 Tolerance

Platinum	84.5 to 85.5%
Iridium	14.5 to 15.5%
Selected Base Metals (Pb, Sb, Bi, Sn, Cd, Ge, Tl, Ga, As, Zn)	.01% Max. Total
All other impurities	.1% Max. Total

3.2 Hardness

3.2.1 The criterion for temper designation shall be hardness.

3.2.2 Temper designations

Temper	Knoop Hardness - 100 gram load (Average of five readings)
A (annealed)	200 ± 10%
CW	250 ± 10%

R.W. Ellis Jr. 1/22/63
W.D. Hensley 1/23/63
[illegible] 1/24/63
[illegible] 1/24/63
W.C. Cox 1/30/63

ENGINEERING SPECIFICATION

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

TITLE: ALLOY 120

SPEC. NO. 120

REV. 01

3.3 Mechanical Properties in simple tension. These values are for reference purposes only.

Temper	Min. Ultimate Strength	Min. Elongation
A	65,000 psi	------
CW	110,000 psi	------

3.4 Workmanship

3.4.1 Surfaces of all material furnished under this specification shall be smooth, clean, and free from scratches, stains, rough spots, slivers, laps, scale, pits, and any other injurious defects within limits consistent with the best possible practice. In no case shall any defect exceed .0005" in depth for rod, tubing, strip, sheet, etc., or .0001" in depth for wire.

3.4.2 All material shall be free from structural defects, cracks, seams, porosity, inclusions, segregation, etc., upon examination of a suitably polished and etched metallurgical sample at 50X.

3.5 Tolerance

3.5.1 Straightness

3.5.1.1 Rod or tubing shall be furnished in straight lengths with a minimum radius of curvature of 625 inches.

3.5.1.2 Wire shall be furnished in sections as straight as possible within limits consistant with the best commercial practice.

3.5.2 Flatness - Strip, sheet, etc., shall be furnished in flat sections with a minimum radius of curvature, in any direction of 1000 times the material thickness.

3.5.3 Dimensions

3.5.3.1 Rod shall have the required diameter ±.001".

3.5.3.2 Tubing shall have the required inside and outside diameter ± .001".

3.5.3.3 Thickness of sheet shall be as required ±.001".

3.5.3.4 Concentricity of tubing must be maintained within .002" T.I.R.

3.5.3.5 Maximum variation in thickness of sheet, strip, etc., .0005" per inch of width or length.

3.5.3.6 Diameter of wire to 15 mils shall be as required ± .0005".

3.6 Processing

3.6.1 If scrap is used in this alloy, only clean skeleton scrap may be melted. No chips, shavings, or turnings may be used.

3.6.2 Reduction between anneals - 75% maximum.

4. INSPECTION AND TESTING

4.1 The vendor shall perform, or have performed, at least these minimum tests to insure conformity to this standard:

4.1.1 Visual inspection at 10X to insure compliance with Para. 3.4.1.

4.1.2 Hardness Test - Knoop 100 gram load.

4.1.3 Check of dimensions to insure conformity to Para. 3.5 of this specification.

4.2 Poly-Scientific Corporation shall perform the following tests upon receipt of material furnished to this specification.

4.2.1 Hardness Test - (Knoop 100)

4.2.2 Spectrographic Analysis

4.2.3 Dimensional check to insure conformity to Para. 3.5.

4.2.4 Visual Examination 10X.

4.2.5 Microscopic Examination (50X) to insure conformity to Para. 3.4.2.

4.3 A spectrographic and/or quantitative analysis by an outside laboratory shall be performed when specified in the purchase order.

4.4 Tensile tests shall be performed when specified in the purchase order.

5. PACKAGE, STORAGE AND DELIVERY

5.1 The material furnished under this specification shall be packed in such a way as to insure conformity to the standards herein described upon arrival at Poly-Scientific Corporation.

5.2 Packing should be such that danger of damaging upon unpacking is a minimum.

5.3 Deliveries shall be made with due precaution to insure safe, rapid and economic transfer.

6. NOTES

6.1 Orders for this material shall include applicable dimensions and temper designations.

6.2 Intended use - The material defined in this specification is intended for use as low level dynamic electrical contacts of critical application.

LOW-VISCOSITY EPOXY RESIN

1. SCOPE

This specification defines the properties of a low-viscosity, high-purity epoxy resin suitable for use in castings and adhesives.

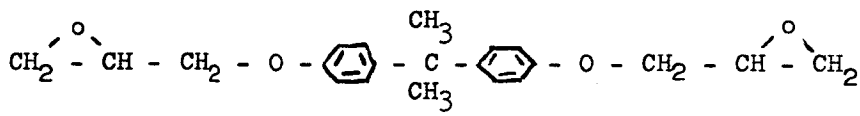
2. SPECIFICATIONS AND REFERENCES

2.1 The Dow Chemical Company Technical Bulletin, "Dow Liquid Epoxy Resins."

2.2 Poly-Scientific Laboratory Procedure No. 122, "Analysis of Epoxy Resins."

3. REQUIREMENTS

3.1 The resin shall be identified chemically by the following idealized formula:



3.2 The chemical identity of this resin shall be established by comparison of its infra-red spectrum with the standard curve attached to this specification. Maximum allowable deviation shall be ± 20% of the standard curve transmission and ± 0.1 micron shift. Both manimum peaks and fine structure shall be reproduced within these limits.

3.3 The resin shall have a viscosity of 6,000 cps ± 500 cps at 25°C. Crystallization is allowable provided the resin will return to the liquid state upon warming to 65 ± 5° C, and does not recrystallize within twelve hours at room temperature (25 ± 5° C).

3.4 The epoxide equivalent of this resin shall be 174 to 179.

3.5 There shall be no evidence of foreign matter in the resin either as received from vendor or upon visual inspection before use.

3.6 The resin shall contain a maximum of 0.40% volatile material as determined upon heating one (1) hour at 150 ± 5° C.

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R. Sindelar 3/22/63
3/22/63
3/25/63
3/29/63

ENGINEERING SPECIFICATION

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

TITLE: LOW-VISCOSITY EPOXY RESIN

SPEC. NO. 133

REV. 0

4. INSPECTION AND TEST

4.1 Poly-Scientific Corporation shall determine conformance to the requirements as set forth in Section 3.

5. PACKAGE, STORAGE, AND DELIVERY

5.1 This material shall be packaged, shipped, and stored in closed containers of convenient size.

5.2 After storage in excess of one (1) year, this material shall be re-inspected to insure conformance with the requirements of Section 3.

5.3 Because of the tendency of this resin to recrystallize at normal room temperature, the resin may be repackaged in smaller containers to facilitate handling and use.

5.4 The resin may be maintained at temperatures up to 65° C to permit easier handling and measuring.

6. NOTES

6.1 The intended use of this material is as an epoxy casting and adhesive resin for use in applications requiring maximum chemical stability and high physical and electrical values.

6.2 This resin and its vapors are to be considered as toxic and skin sensitizing. Workers handling this material shall be equipped with adequate protective clothing and equipment. Ventilation shall be provided to ensure a minimum of human contact with vapors or their condensation on equipment.

7. QUALIFIED PRODUCTS AND VENDORS

7.1 DER 332 Dow Chemical Company

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ENGINEERING SPECIFICATION

AROMATIC - AMINE CURED EPOXY FORMULATION

1. SCOPE

This specification defines the ingredients and general properties of a rigid, chemically stable, high-performance epoxy casting or potting formulation.

2. SPECIFICATIONS AND REFERENCES

2.1 Poly-Scientific Engineering Specification No. 133 - "Low-Viscosity Epoxy Resin."

2.2 Poly-Scientific Engineering Specification No. 82 - "Modified Aromatic Amine."

2.3 Poly-Scientific Engineering Specification No. 113 - "Pigments for Epoxy Formulation."

2.4 Poly-Scientific Laboratory Procedure No. 119 - "Testing of Thermosetting Resin Formulations."

3. REQUIREMENTS

3.1 Materials used in this formulation must be qualified under the appropriate specification given in Section 2.

3.2 The resin and hardener shall be mixed thoroughly in the ratio 21.7 ± 0.5 parts by weight hardener (Engineering Specification No. 82) to 100 parts resin (Engineering Specification No. 133). Pigment present in concentration less than 1% may be neglected in this calculation.

3.3 When cured four (4) hours ± 5 minutes at 60° - 65°C and post cured as indicated below, this formulation shall produce an infusible material having the following minimum properties:

Property	PSC Test Value		Approximate ASTM Equiv.
	Cure A Post Cured 4 Hr. at 120°C	Cure B Post Cured 4 Hr. at 150°C	
Heat Distortion Temp.	140°C	160°C	135° - 155°C
Impact Strength	2 in.	2 in.	0.20 IZOD
Flexural Strength	12 in Hg.	12 in Hg.	12,000 ULT
Dielectric Strength	350 V/MIL	250 V/MIL	350 V/MIL

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0				PREPARED BY	Sindelar	1-29-63
				CHECKED BY	Glossbrenner	1-31-63
				APP. ENG.	Cox	1-8-63
				APP. ENG.		
				APP. REL.	Gilbert	1-6-63
					SIGNATURE	DATE

TITLE: AROMATIC-AMINE CURED EPOXY FORMULATION

SPEC. NO. 134 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

3.4 Cure A shall be the standard post cure schedule.

3.5 This material shall have a pot life of at least 120 minutes at 60°C in a 50 gram mass. Pot life is defined as the time interval after normal mixing in which the material is suitable for use in all casting operations.

3.6 Gel time will be less than four (4) hours at 60°C. Gel time is defined as the time interval after normal mixing and casting required for the material to polymerize to a non-tacky solid.

3.7 Viscosity of the resin-hardener mixture will be less than 1000 cps at 60°C; between 6,000 and 9,000 cps at 25°C.

3.8 Chemical identity of the cured plastic will be determined by comparison of its infra-red spectrum to the standard curve attached to this specification.

4. INSPECTION AND TEST

4.1 Parts cast of this material shall be inspected visually for flaws and dimensional conformance to Engineering Drawing.

5. PACKAGE AND STORAGE

5.1 Components shall be stored unmixed, under cover, in sealed containers of convenient size.

5.2 Both resin and hardener may be maintained at temperatures up to 130°F to prevent crystallization.

6. NOTES

6.1 Cure times and physical properties of this formulation will vary slightly with the age of the curing agent used. This is attributed to oxidation of the amine and is accepted as a normal variation in this formulation. This variation shall not cause values to fall below those given in Para. 3.3.

6.2 Both resin and hardener used in this formulation should be considered as skin sensitizing. Workers handling these materials should be equipped with gloves, aprons, and goggles, and should be required to wear long-sleeved shirts or jackets, to minimize possible skin contact.

ENGINEERING SPECIFICATION

6.3 Sensitivity to these materials varies among individuals, and usually increases with exposure time. Apparent immunity to any ill effect from skin contact is common on short-time exposure, but sensitivity can be expected to increase wtih exposure time.

6.4 In the event of skin contact with either resin or hardener, skin should be wiped with a clean towel or cloth moistened in acetone or similar solvent. Skin should then be washed with soap and water. In the case of eye contact an opthomologist should be consulted immediately.

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TITLE: AROMATIC-AMINE CURED EPOXY FORMULATION

SPEC. NO.	ISSUE
134	

POLY - SCIENTIFIC
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BLACKSBURG VIRGINIA

MINERAL-FILLER EPOXY NOVOLAK FORMULATION

1. SCOPE

This specification defines the ingredients and general properties of a rigid, high heat-resistance potting or encapsulation compound.

2. SPECIFICATIONS AND REFERENCES

2.1 Poly-Scientific Corporation Engineering Specification No. 124 - "Epoxy Novolak Resin".

2.2 Poly-Scientific Corporation Engineering Specification No. 123 - "Nadic Methyl Anhydride Curing Agent for Epoxy Resins."

2.3 Poly-Scientific Corporation Engineering Specification No. 125, "Tris-Amino Phenol Accelerator for Epoxy Formulations".

2.4 Poly-Scientific Corporation Engineering Specification No. 138, "Lithium Aluminum Silicate Filler Material".

2.5 Poly-Scientific Corporation Laboratory Procedure No. 119, "Testing of Thermosetting Resin Formulations".

3. REQUIREMENTS

3.1 Materials used in this formulation shall be qualified under the appropriate specification given in Section 2.

3.2 Processing Base Mix.

3.2.1 The resin and curing agent shall be mixed thoroughly in the ratio 90 ± 0.5 parts by weight curing agent (E. S. No. 123) to 100 parts by weight resin (E. S. No. 124). Mix temperature shall be less than 150° C.

3.2.2 After resin and curing agent have been thoroughly mixed, 175 ± 5 parts by weight filler (E. S. No. 138) shall be added and dispersed evenly.

3.2.3 The above mixture shall be cooled and stored at 0° ± 5° C until needed, or held for immediate use as described in Para. 3.3.

3.2.4 Time interval for mixing procedure shall be less than one (1) hour after addition of curing agent.

3.2.5 Mixture shall be cooled to 25° C within four (4) hours of addition of curing agent, if not mixed for immediate use.

3.2.6 Mixture shall be cooled to 0° ± 5° C within eight (8) hours of addition of curing agent.

3.3 Catalyzing

3.3.1 The above mixture shall be catalyzed by the addition of 0.41 ± 0.02 parts by weight accelerator (E. S. No. 125) to 100 parts by weight of the mixture from Para. 3.2.

3.3.2 Mix temperature upon addition of accelerator shall be less than 115° C.

3.4 When cured two (2) hours ± 5 minutes at 90 ± 5° C and post cured as indicated below, this formulation shall produce an infusible material having the following minimum properties:

PROPERTY	CURE A 4 hours at 150° C	CURE B 4 hours at 150°C +24 hours at 220°C
Heat Distortion Temp.	200° C	250° C
Impact Strength	0.12 (IZOD)	------
Flexural Strength	11,500 PSC (ULT.)	------
Dielectric Strength	350 V/MIL	300 V/MIL

3.5 Cure Schedules

3.5.1 Cure "A" shall be the standard post-cure schedule.

3.5.2 Material cured by post-cure schedule "B" shall be designated as "E. S. No. 137 Cure B".

3.6 Pot and Shelf Life

3.6.1 This material shall have a pot-life of at least twelve (12) minutes at 110° C in masses of less than 100 grams. Pot life is defined as the time interval after normal addition of accelerator in which the material is suitable for use in all casting operations.

3.6.2 The mixture shall have a shelf life of sixty (60) days at 0° ± 5° C, prior to addition of accelerator. Material stored in excess of sixty (60) days at this temperature shall be discarded.

3.6.3 The mixture shall have a shelf life of ten (10) days at 25° C, prior to addition of accelerator. Material stored in excess of 10 days at this temperature shall be discarded.

3.6.4 The mixture shall have an oven life of two (2) hours at 110° ± 5° C, prior to addition of accelerator. Material held in an oven for over two (2) hours at this temperature shall be discarded.

3.7 Gel time for the catalyzed mixture shall be less than two (2) hours at 90° ± 5° C. Gel time is defined as the time interval after normal mixing and casting operations required for the material to polymerize to a non-tacky solid.

3.8 Viscosity

3.8.1 The uncured material shall be a semi-solid at room temperature.

3.8.2 The viscosity of the catalyzed material shall be less than 700 centipoise at 110° C, taken immediately after addition of accelerator, increasing steadily with time.

3.9 Chemical identity of the cured plastic shall be determined by infrared analysis, comparing the infrared spectrum with the Poly-Scientific Laboratory standard curve.

4. INSPECTION AND TEST

4.1 Parts cast of this material shall be inspected visually for flaws and dimensional conformance to the applicable Engineering drawing.

4.2 This formulation when post cured at 150° C turns from an off-white to a light brown color. All castings shall be inspected for this color change with reference to a standard sample.

5. PACKAGE AND STORAGE

5.1 Components shall be stored in closed containers, under cover, protected from moisture and undue exposure to the atmosphere.

6. NOTES

6.1 The mineral filler used in this formulation is highly abrasive and very difficult to machine.

6.2 Resin, curing agent, and accelerator used in this formulation should be considered as toxic and skin sensitizing. Adequate ventilation and protective equipment will be provided in any work area in which this material is to be used.

6.3 Some settling of filler material will occur upon standing, and the mixture of filler with the epoxy system should be stirred before any measurements of it are to be made.

6.4 In the event of skin contact with any of the components of the epoxy system, skin should be wiped with a clean towel or cloth moistened in acetone or similar solvent. Skin should then be washed with soap and water. In the case of eye contact, a physician should be consulted immediately.

ENGINEERING SPECIFICATION

LITHIUM ALUMINUM SILICATE FILLER FOR EPOXY RESINS

1. SCOPE

This specification defines the chemical identity and general physical properties of a grade of lithium aluminum silicate suitable for use as a filler material for epoxy resin formulations.

2. REQUIREMENTS

Materials qualified to this specification shall meet the following limiting physical properties:

Bulk Density (lbs./ cu. ft.)		
	Free Fall	40
	Tapped	57
Particle Size	95% thru 300 mesh.	
True Density (9/cc)	2.37 to 2.40	
Coefficient of Thermal Expansion (in./in./°C.)		
	20 - 100°C	$+0.3 \times 10^{-6}$
	20 - 500°C	$+0.0 \times 10^{-6}$
Color	White	

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3. INSPECTION AND TEST

3.1 After qualification to this specification, vendor's shipments will be inspected visually for debris and color. Chemical identity of the material will be established by Poly-Scientific on one (1) sample of each batch received.

3.2 If either the visual examination or chemical tests on the material indicate that there is a probability of deviation from specification values, a sample will be tested according to the requirements in Section 2. Testing will be discontinued and the material lot rejected when any value does not meet the specification limits.

4. PACKAGE AND STORAGE

4.1 This material shall be stored in shipping containers. Storage shall be under cover, protected from moisture and open flame.

REV.	DATE	CHANGE	CHK.			
				PREPARED BY	R.J. Bowan	12/20/63
				CHECKED BY		
				APP. ENG.	C.D. Jennings	12/23/63
				APP. ENG.	W.C. Gay	1/17/64
				APP. REL.	L. Gilbert	1/24/64
					SIGNATURE	DATE

TITLE— LITHIUM ALUMINUM SILICATE

SPEC. NO. 138 | ISSUE

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BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

5. NOTES

5.1 Although this material can be considered as physiologically innocuous, the fine particle size presents a hazard as airborne dust, and operators using this material should be equipped with respirators to minimize inhalation.

6. QUALIFIED PRODUCTS AND VENDORS

6.1 Lithafrax 2123 - Carorundum
Electronics Division
Latrobe, Pa.

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TITLE- LITHIUM ALUMINUM SILICATE

SPEC. NO. 138 | ISSUE

POLY - SCIENTIFIC
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BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

DIALLYL ISO-PHTHALATE MOLDING COMPOUND, SHORT GLASS FILLED

1. SCOPE

This specification establishes the requirements for molding compound based on diallyl iso-phthalate, reinforced with short glass fibers.

2. SPECIFICATIONS AND REFERENCES

2.1 MIL-M-14F, Type SDG.

2.2 Fed. Std. 406.

2.3 "Diallyl Phthalate Molding Compounds", Acme Resin Corporation, Forest Park, Illinois.

2.4 "Dapon-Diallyl Phthalate Resin for Molding Materials", FMC Corporation, Chemicals & Plastics Division.

3. REQUIREMENTS

3.1 This material shall be based upon the Dapon M diallyl iso-phthalate resin manufactured by FMC Corporation. Catalysts, accelerators, and particulate fillers may be proprietary information.

3.2 Integral release agent, if used, shall be calcium stearate.

3.3 Minimum properties of the molded material shall be as follows:

Property	Value	Test
Specific Gravity	1.75 (Max.)	ASTM D792
Mold Shrinkage	.005 in/in (Max.)	ASTM D551
Tensile Strength	8000 psi	ASTM D638
Compressive Strength	25,000 psi	ASTM D695
Flexural Strength	12,000 psi	ASTM D790
Impact Strength	0.75 (IZOD)	ASTM D256
Arc Resistance	125 Sec.	ASTM D495
Dielectric Strength (Wet) S/T	375 v/mil	ASTM D149
Dielectric Strength (Wet) S/S	350 v/mil	ASTM D149

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00	10-31-63			PREPARED BY	K. Sadler	10/31/63
				CHECKED BY	C. D. Morris	10/31/63
				APP. ENG.	[illegible]	11/6/63
				APP. ENG.		
				APP. REL.	G. Sadler	11/7/63
					SIGNATURE	DATE

TITLE— DIALLYL ISO-PHTHALATE MOLDING COMPOUND

SPEC. NO. 144 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

3.4 Material shall be certifiable under MIL-M-14F as Type SDG.

3.5 Test specimens molded from this material and cured for twelve (12) ± 2 minutes at 310 ± 5°F shall show no evidence of attack after refluxing in chloroform for one (1) hour ± 5 minutes.

3.6 Material shall be supplied as a free-flowing powder.

3.7 Shelf life of the material shall be at least 90 days from date of receipt by P-S. Refrigeration shall not be required, although the compound shall be stored below 90°F.

3.8 Interpretation and designation of molding flow rates may be at the discretion of the vendor, following correlation of test data with Poly-Scientific. After establishing the flow rating, maximum variation from lot to lot shall be ± 10% of the absolute measurement used. Vendor's flow designation shall become a part of the purchase specification, and shall be approved to this specification before purchase is made.

4. INSPECTION AND TEST

4.1 Poly-Scientific shall determine conformance to Para. 3.5, 3.6 on each batch of material received.

4.2 Approval to this specification shall require vendor certification to Para. 3.1 through 3.7.

4.3 Testing of flow rate shall be performed by the P-S Engineering Laboratory in the course of testing per Para. 3.5. Test specimens shall be prepared in a Mesa flow mold at 310°F ± 5°F, 1000 psig. All materials purchased to this specification shall perform within ± 10% of the flow mass of the initial test batch, as established in Para. 3.8.

5. PACKAGE AND STORAGE

5.1 Material shall be packaged in multi-wall bags of not more than 50 lb. capacity.

5.2 Material shall be stored under cover, protected from moisture at temperatures below 90°F.

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00	10-31-63			CHECKED BY		
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				APP. REL.		
					SIGNATURE	DATE

TITLE: DIALLYL ISO-PHTHALATE MOLDING COMPOUND

SPEC. NO. 144 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

6. NOTES

6.1 The intended use of this material is for the manufacture of mold inserts for slip ring assemblies. Under normal curing conditions (150°C) insert dimensions will not change over 0.0003 in/in due to relaxation.

6.2 This material shall be considered to be toxic and skin sensitizing. Workers handling this material shall be provided adequate protective equipment and ventilation to avoid contact with the uncured material, its dust or vapors during cure.

7. APPROVED MATERIALS

7.1 Acme 2-520, 4s flow, Br-2 — Acme Resin Corporation, Forest Park, Ill.

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TITLE— DIALLYL ISOPHTHALATE MOLDING COMPOUND

SPEC. NO. 144 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

THERMAL SHOCK RESISTANT EPOXY FORMULATION

1. SCOPE

This specification defines the ingredients and general properties of a semi-flexible epoxy formulation having good thermal shock resistance.

2. SPECIFICATIONS AND REFERENCES

2.1 Poly-Scientific Corporation Laboratory Specification No. 119, "Testing of Thermosetting Resin Formulations".

3. MATERIALS

3.1 Poly-Scientific Corporation Engineering Specification No. 147, Flexible Epoxy Resin System.

3.2 Poly-Scientific Corporation Engineering Specification No. 150, Methylene Dianiline.

4. REQUIREMENTS

4.1 Materials used in this formulation shall be qualified under the appropriate specification given in Section 2.

4.2 Both resin and hardener shall be preheated to 110° ± 5°C and then mixed thoroughly in the ratio 21.6 ± 0.5 parts hardener (Engineering Specification No. 150) to 100 parts resin (Engineering Specification No. 147) by weight. Pigments present in concentration less than one percent may be neglected in this calculation.

4.3 When cured four (4) hours ± five (5) minutes at 60° ± 5°C and post cured four (4) hours ± five (5) minutes at 120° ± 5°C, this formulation shall produce an infusible material having the following minimum properties:

Property	PSC Test Value	Approximate ASTM Equivalent
Heat Distortion Temperature	95°C	85°C
Flexural Strength	16" Hg	16,000 psi
Impact Strength	3"	0.25 Izod

4.4 This mixture will have a pot life of at least twelve (12) minutes at 90°C in a 50 gram mass.

4.5 Gel time will be less than four (4) hours at 60°C; less than twenty-four (24) hours at 25°C

4.6 Viscosity of the uncured resin-hardener mix will be less than 1,000 cps at 90°C; between 15,000 and 25,000 cps at 25°C.

R. Sandelin 3/27/63
3/28/63
3/28/63
4/2/63

ENGINEERING SPECIFICATION

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

TITLE: THERMAL SHOCK RESISTANT EPOXY FORMULATION

SPEC. NO. 149 | REV. 0

4.7 Chemical identity of the cured plastic will be determined by infra-red analysis and comparison to the standard spectrum attached to this specification.

5. INSPECTION AND TEST

5.1 Parts cast with this formulation shall be inspected visually for flaws and dimensional conformance to the appropriate engineering drawing. Electrical tests shall be made as specified on the engineering drawing.

6. PACKAGE AND STORAGE

6.1 Resin and hardener shall be stored unmixed in sealed containers of convenient size.

7. NOTES

7.1 The intended use of this formulation is as a thermal-shock resistant casting compound. The material is less rigid than most epoxy formulations, and in the case runout is an important consideration a reinforcing member must be used.

7.2 Both resin and hardener used in this formulation shall be considered to be toxic and skin sensitizing, and workers handling these materials shall be equipped with adequate protection to minimize possible skin contact. Adequate ventilation shall be provided to avoid contact with vapors or their condensation on equipment.

7.3 In the event of accidental contact, the affected area should be wiped with a towel moistened in acetone or similar clean solvent, then washed thoroughly with soap and water. In the event of eye contact, a physician should be consulted immediately.

AROMATIC-AMINE CURED EPOXY NOVOLAK

1. SCOPE

This specification defines the ingredients and general properties of a rigid, high heat-resistance, unfilled epoxy casting formulations.

2. SPECIFICATIONS AND REFERENCES

2.1 The Dow Chemical Company Technical Bulletin, DOW EPOXY NOVOLAK, D.E.N. 438.

2.2 Poly-Scientific Corporation Engineering Laboratory Report, "Epoxy Plastics as Structural and Dielectric Elements in Miniature Slip Ring Assemblies", by R. Sindelar - February 6, 1963.

3. MATERIALS

3.1 Poly-Scientific Corporation Engineering Specification No. 124, "Epoxy Novolak Resin".

3.2 Poly-Scientific Corporation Engineering Specification No. 150, "Methylene Dianiline".

4. REQUIREMENTS

4.1 Materials used in this formulation shall be qualified under the appropriate specification given in Section 3.

4.2 Both resin and hardener shall be preheated to $110^{\circ} \pm 5^{\circ}C$ and then mixed thoroughly in the ratio 26.8 ± 0.5 parts hardener (Engineering Specification No. 150) to 100 parts resin (Engineering Specification No. 124) by weight. Pigments present in concentration less than 1% may be neglected in this calculation.

4.3 When cured 4 hours ± five minutes at $60^{\circ} \pm 5^{\circ}C$ and post-cured 4 hours ± 5 minutes at 120°C, this formulation shall produce an infusible solid having the following minimum properties:

Property	PSC Test Value	Approximate ASTM Equivalent
Heat Distortion Temp.	165° C	160° C
Impact Strength	3"	0.25 IZOD
Flexural Strength	14" Hg	14,000 psi
Dielectric Constant, 60 cps		3.7
Dissipation Factor, 60 cps		0.002

R. Sindelar 3/27/63
3/27/63
5/28/63

ENGINEERING SPECIFICATION

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

TITLE: AROMATIC-AMINE CURED EPOXY NOVOLAK

SPEC. NO. 151 | REV. 0

4.4 This formulation will have a pot life of at least ten minutes at 90°C in a 50 gram mass.

4.5 Gel time will be less than three (3) hours at 60° ± 5° C; less than twelve (12) hours at 30° ± 5° C.

4.6 Viscosity of the mixture will be less than 2,000 cps at 90°C. Material will be a semi-solid at temperatures below 30°C.

4.7 Chemical identity of the cured material shall be established by infra-red analysis and comparison to the standard spectrum attached to this specification.

5. INSPECTION AND TEST

5.1 Parts cast with this formulation shall be inspected visually for flaws and dimensional conformance to the appropriate engineering drawing.

6. PACKAGE AND STORAGE

6.1 Resin and hardener shall be stored unmixed in sealed containers of convenient size.

6.2 To facilitate handling, the resin shall be maintained at 60° ± 5°C in production areas. Material held at this temperature in excess of seventy-two (72) hours shall be discarded. Normal shelf storage shall be at room temperature.

7. NOTES

7.1 The intended use of this formulation is as a casting compound for applications requiring high rigidity and excellent thermal and chemical stability.

7.2 Both resin and hardener shall be considered as toxic and skin sensitizing, and workers handling these materials shall be equipped with adequate protection to minimize possible skin contact. Adequate ventilation shall be provided to avoid contact with vapors or their condensation on equipment.

7.3 In the event of accidental contact, affected area should be wiped with a towel moistened in acetone or similar clean solvent, then washed thoroughly with soap and water. In the event of eye contact a physician should be consulted immediately.

ENGINEERING SPECIFICATION

LOCTITE SEALANTS AND LOCQUIC PRIMERS

1. SCOPE

This specification defines the properties of a polyester material which, when used on catalytic metals or in conjunction with prescribed primers, cures to act as a sealant or retaining adhesive.

2. SPECIFICATIONS AND REFERENCES

2.1 General Specification "Locking, retaining, and sealing compounds; single-component, self-curing." Prepared by American Sealants Co.

2.2 MIL-S-22473A

2.3 MIL-S-22473B

2.4 MIL-S-40083

3. REQUIREMENTS

3.1 The materials, Loctite Sealant and Locquic primers shall conform to MIL-S-22473A, MIL-S-22473B, and MIL-S-40083.

3.2 Sealant Grades

3.2.1 Various grades of sealant shall be identified by the following colors and physical properties:

Grade	Color Code	Relative Torque	Viscosity (Centipoise)	"Running" Shear Strength psi
AA (15-1)	Green	15	10-15	1150-1500
A (10-1)	Red	10	10-15	750-1000
D (10-4)	Orange	10	40-50	750-1000
AV (10-10)	Red	10	100-150	750-1000
B (7-2)	Yellow	7	20-30	525-700
C (4-10)	Blue	4	10-15	300-400
CV (4-10)	Blue	4	100-150	300-400
E (2-1)	Purple	2	10-15	150-200
EV (2-10)	Purple	2	100-150	150-200
H (1-1)	Brown	1	10-15	75-100
HV (1-10)	Brown	1	100-150	75-100

REV.	DATE	CHANGE	CHK.			
00	7-22-63			PREPARED BY	Sindelar	8-8-63
				CHECKED BY	Morris	8-12-63
				APP. ENG.		
				APP. ENG.	Cox	8-15-63
				APP. REL.	Gilbert	8-14-63
					SIGNATURE	DATE

TITLE— LOCTITE SEALANTS AND LOCQUIC PRIMERS

SPEC. NO. 156 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

3.22 Grades - Q (blue) and N (green) activate inert surfaces such as cadmium, zinc, and gold platings; passivated stainless steel; anodized aluminum; and thermosetting plastics. Q provides maximum curing speed on active base metal surfaces.

3.2.3 Degreasing - Both primers serve as mild degreasing agents and will dissolve light oil films. Particularly greasy parts should be brushed or cleaned with regular solvents before application of primer.

3.3 Temperature Resistance

3.3.1 Operating Temperature Range: -65° to 300°F.

3.3.1.1 Hot Strength

Relative Strength Percentages (%)

	-65°F	100°F	200°F	300°F	400°F
Low Viscosities	140	100	90	40	30
High Viscosities	190	100	70	20	12

3.3.1.2 Recovery - Upon cooling, full room temperature strength will be restored.

3.3.1.3 Decomposition - The sealant decomposes at 650°F.

3.3.1.4 Heat Ageing -

Satisfactory Service Life at Various Temperatures

	75°F	175°F	200°F	250°F	300°F
Life	Infinite	20 yrs	7-1/2 yrs	1-1/2 yrs	100 days

3.4 Chemical Resistance

3.4.1 Liquid State - Soluble in trichlorethylene and most degreasing solvents. Insoluble but readily dispersible in water.

3.5 Electrical Characteristics

3.5.1 Effect on Threaded Electrical Connections - the sealant shall not harm conductivity where securing connections from loosening under vibration.

3.6 Material Compatibility

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				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE- LOCTITE SEALANTS AND LOCQUIC PRIMERS

SPEC. NO. 156 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

3.6.1 Sealer shall harden to the above properties, without primer, in the presence of steel, copper alloys, aluminum, magnesium, chrome and nickel alloys.

3.6.2 Neither sealer or primer shall attack gum rubber, polyethylene, polypropylene, saran, nylon, teflon, Delrin, hardened epoxy, alkyd or polyester, phenolics, melamine or urea plastics.

3.6.3 Sealer shall harden in contact with inert surfaces such as cadmium, zinc, gold, passivated stainless steel, anodized aluminum, and thermosetting plastics, when these materials have been treated with either grade of primer. Use of primer shall not reduce any property of the sealant by more than 25%.

3.7 Sealant Curing Speed - Curing shall take place as scheduled below.

Parts Unprimed		LOCQUIC Primed		
	Max. Required		Max. Required Curing Time	
Temperature	Curing Time	Temperature	Grade Q	Grade N
75°F	12 hrs.	75°F	40 min.	2 hrs.
150°F	1-1/2 hrs.	40°F	12 hrs.	48 hrs.
212°F	10 min.	10°F	72 hrs.	10 days

3.8 Shelf Life - Material shall meet the above specifications after storage in shipping container for 1 year at 40° - 80°F.

4. INSPECTION AND TEST

4.1 The material shall be inspected visually for color conformance to para. 3.2.1.

4.2 Vendor shall certify conformance to this specification, with certification to accompany each lot of material.

5. PACKAGE, STORAGE, AND DELIVERY

5.1 LOCTITE Sealant - The sealant shall be furnished in the following polyethylene squeeze bottle sizes:

10cc (1/3 fl. oz.)
50cc (1-2/3 fl.oz.)
250cc (8-1/3 fl. oz.)

NOTE: 10cc and 50cc bottles shall incorporate a dispenser nozzle.

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				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE- LOCTITE SEALANTS AND LOCQUIC PRIMERS

SPEC. NO. 156 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

5.1.1 Air Space - Bottles are oversize to provide air space which must be maintained above the liquid level to prevent the sealant from curing until applied.

5.2 LOCQUIC Primer - LOCQUIC Primer shall be available ready-to-use, concentrated, and in spray cans per the following schedule:

	Grade N (green)		Grade Q (blue)	
	Concentrate	Ready-to Use	Concentrate	Ready-to Use
4 oz. glass bottle	X	X	X	X
6 oz. aerosol spray can		X		X
1 gallon can	X	X	X	X

6. NOTES

6.1 Selection of Grade of Sealer - By selecting from six (6) strengths of LOCTITE Sealant it is possible to obtain varying degrees of locking torque for screws from a mild drag to a lock exceeding the torsional strength.

6.1.1 Engagement Ratio - equals the engaged length of the screw divided by the screw diameter.

6.1.2 Holding Power - A percentage of the screw torsional strength.

6.1.3 Holding Power versus Engagement Ratio

(See Table 1 and Table 2 attached to this specification)

6.2 Finish Sensitivity - sealant holding power is reduced on parts smoother than a 32 micro inch finish. Use rougher parts for full holding power.

7. QUALIFIED VENDORS AND MATERIALS

7.1 American Sealants Company - Loctite Sealers
Locquic Primers

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				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE— LOCTITE SEALANTS AND LOCQUIC PRIMERS

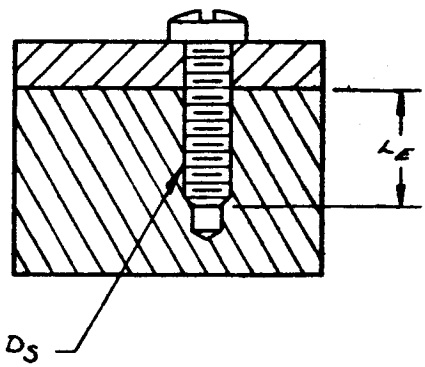
SPEC. NO. 156 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

TABLE 1

To find engagement ratio:
Divide engaged length of threads (L_e) by the screw diameter (d_s). Use this number to find correct column in table.



GUIDE FOR SELECTION OF PROPER GRADE OF LOCTITE SEALANT FOR USE ON SCREWS

Application	Engagement Ratio				
	0.5	1.0	1.5	2.5	5.0
Nuts on steel screws	A or D	B	C	—	—
Steel screws in tapped holes	A or D	B	C	C	E
Steel studs	AA	A or D	A or D	C	C
Steel adjustment screws	A or D	C	E	H	H
Adjustment nuts on steel screws	A or D	C	E	—	—
Nuts on aluminum or brass screws	A or D	C	C	—	—
Aluminum or brass screws in tapped holes	A or D	C	C	E	H
Aluminum or brass adjustment screws	C	E	E	H	—
Adjustment nuts on aluminum or brass screws	C	E	E	—	—

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TITLE— LOCTITE SEALANTS AND LOCQUIC PRIMERS

SPEC. NO 156 | ISSUE

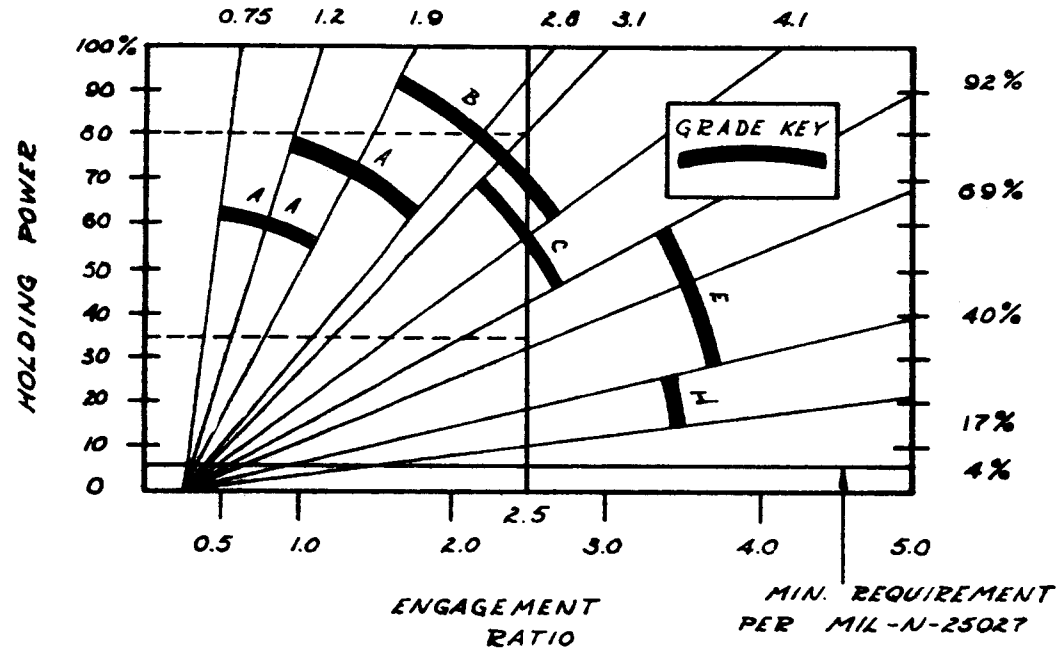
Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

TABLE 2

GRADE SELECTOR CHART — MILD STEEL

(For aluminum or brass screws, use next lower grade strength.)



Draw vertical line up from point on horizontal axis representing this engagement ratio. Intercepts of vertical ine with each grade sector define range of torque required to remove screw as of % to the torsional strength of the screw, or Holding Power. For highly stressed screws use a grade which will apply a holding power not exceeding 100%. For screws that must remain readily adjustable use the grade which will apply a holding power of 5-15%.

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				APP. REL.		
					SIGNATURE	DATE

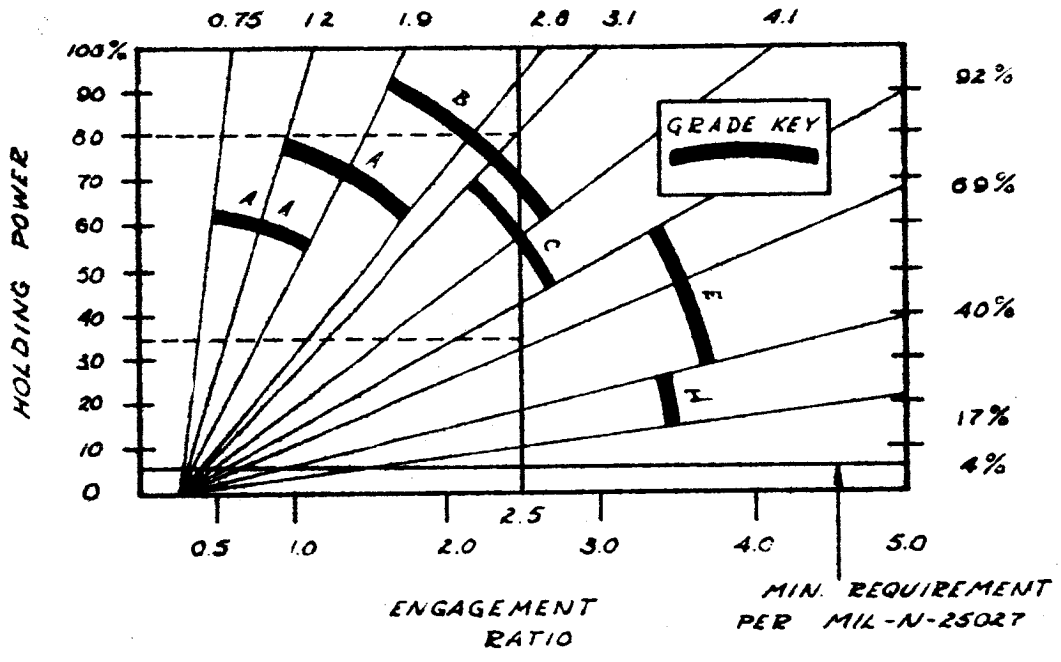
TITLE— LOCTITE SEALANTS AND LOCQUIC PRIMERS

SPEC. NO. 156 | ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION



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SPEC NO | ISSUE

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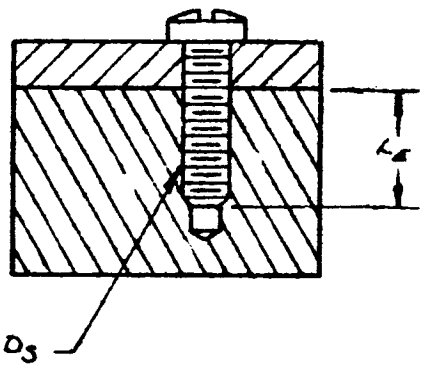

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TITLE

SPEC. NO ISSUE

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ENGINEERING SPECIFICATION

MINERAL FILLED EPOXY FORMULATION, A-78-3

1. **SCOPE**

This specification defines the composition and general properties of the mineral-filled epoxy formulation, A-78-3.

2. **SPECIFICATIONS AND REFERENCES**

2.1 Poly-Scientific Engineering Specification No. 133, "Liquid Epoxy Resin".

2.2 Poly-Scientific Engineering Specification No. 82, "Modified Aromatic-Amine Curing Agent".

2.3 Poly-Scientific Engineering Specification No. 116, "Calcium Carbonate Filler For Epoxy Resins".

2.4 Poly-Scientific Engineering Specification No. 113, "Pigments for Epoxy Formulations".

2.5 Poly-Scientific Laboratory Procedure No. 119, "Testing of Thermosetting Resin Formulations".

3. REQUIREMENTS

3.1 Materials in this formulation shall be qualified to the appropriate specification in Section 2.

3.2 Formulation weights for this material are:

Dry Calcium Carbonate	200 ± 5.0
Liquid Epoxy Resin	100 ± 0.0
Modified Aromatic Amine	21.7 ± 0.5

3.3 This formulation when cured two (2) hours (± 10 minutes) at 90°C (± 5°C) and four (4) hours (± 10 minutes) at 150°C (± 5°C) will produce a solid, infusible material having the following minimum properties:

Property	PS Test Value	ASTM Test Value
Heat Distortion Temperature	200°C	
Impact Strength	0.9 In.	(D256-54T) 0.10 Izod
Flexural Strength	10 in. Hg	(D790-49T) 9000 psi

REV.	DATE	CHANGE	CHK.			
00	9-23-63			PREPARED BY	R.D. Bowen 9/30/63	
				CHECKED BY	C.D. Morris 9/30/63	
				APP. ENG.		
				APP. ENG.	10/9/63	
				APP. REL.	9/30/63	
					SIGNATURE	DATE

TITLE— MINERAL FILLED EPOXY FORMULATION, A-78-3

SPEC. NO. 161 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

Property	PS Test Value	ASTM Test Value
Arc Resistance		(D495-48T) 45 seconds
Volume Resistidity, Ohm-Cm		(D275-57T) 3.0×10^{15}
Surface Resistivity, Ohm		(D257-57T) 8.0×10^{16}
Dielectric Strength Volts/Mil		(D149-55T) 325
Specific Gravity	1.75-1.80	

3.4 This formulation when cured two (2) hours (± 10 minutes) at 90°C (± 5°C) and four (4) hours (± 10 minutes) at 150°C (± 5°C) shall be insoluble and non-swelling in Methylene Chloride as determined by Poly-Scientific Laboratory Procedure No. 119.

3.5 This material will have a pot life of at least twelve (12) minutes at 110°C, in a 50 gram mass. Pot life is defined as the interval after normal mixing during which the material is suitable for use in all casting operations.

3.6 Gel time will be less than two (2) hours at 90°C, less than twenty-four (24) hours at 25°C. Gel is defined as the point at which the material becomes a non-tacky solid.

3.7 Initial viscosity of the mixed formulation will be at least five (5) poise at 110°C, increasing steadily with time.

3.8 Identification of cured A-78-3 shall be made both by comparison to the standard spectrum attached to this specification and by a spot test as described in Poly-Scientific Laboratory Procedure No. 117, Rev. 1.

4. INSPECTION AND TEST

4.1 Parts cast with this formulation shall be inspected visually for flaws and dimensional conformance to print. Electrical tests shall be made as specified on the Engineering Drawing.

5. PACKAGE AND STORAGE

5.1 Resin and filler shall be pre-mixed and stored in closed containers of convenient size, or stored individually in shipping containers.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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				APP. ENG.		
				APP. ENG.		
				APP. REL.		
					SIGNATURE	DATE

TITLE- MINERAL FILLED EPOXY FORMULATION, A-78-3

SPEC. NO. 161 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

5.2 The amine curing agent may be maintained at temperatures up to 130°F to prevent crystallization or eutectic segregation. Shelf storage shall be in closed containers of convenient size.

6. **NOTES**

6.1 The intended use of this material is as a casting formulation where good thermal shock characteristics, low shrinkage, and low cure exotherm are required. The application must, however, be able to tolerate a fairly high initial viscosity and low tensile and impact strength.

6.2 Addition of any ingredient other than those listed here, or alteration of the formulation ratios will change the final properties of this material. In the event of any formulation modification, this specification shall not apply and shall not be referenced in part.

6.3 Cure time and physical properties of this formulation will vary with the age of the hardener used. This is attributed to the oxidation of an aromatic amine ingredient, and is accepted as a normal variation in this formulation. This variation shall not, however, cause the test values to fall below those given in Para. 3.3 of this specification.

6.4 Both resin and hardener used in this formulation are to be regarded as skin sensitizing, and workers handling these materials shall be equipped with adequate protective equipment to minimize the possibility of skin or eye contact. Vapors from the heated material are to be considered as toxic and skin sensitizing, and adequate ventilation shall be provided to insure a minimum of human contact with the vapors or their condensation on equipment.

6.5 This formulation may be used interchangeably with PSC Engineering Specification No. 115, where lower viscosity is required. Practically, viscosity is the only difference between these formulations.

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TITLE— MINERAL FILLED EPOXY FORMULATION, A-78-3

SPEC. NO. 161 | ISSUE

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

AROMATIC-AMINE CURED EPOXY FORMULATION

1. SCOPE

This specification defines the ingredients and general properties of a rigid, chemically stable epoxy casting or potting formulation.

2. SPECIFICATION AND REFERENCES

2.1 Poly-Scientific Engineering Specification No. 133, "Low Viscosity Epoxy Resin".

2.2 Poly-Scientific Engineering Specification No. 150, "Methylene Dianiline".

2.3 Poly-Scientific Engineering Specification No. 113, "Pigments for Epoxy Formulation".

2.4 Poly-Scientific Laboratory Procedure No. 119, "Testing of Thermosetting Resin Formulations".

3. REQUIREMENTS

3.1 Materials used in this formulation must be qualified under the appropriate specification given in Section 2.

3.2 The resin and hardener shall be mixed thoroughly in the ratio 27 ± 0.5 parts by weight hardener (Engineering Specification No. 150) to 100 parts resin (Engineering Specification No. 133). Pigment less than 1% may be neglected in this calculation.

3.3 When cured two (2) hours ± five (5) minutes at 85°C to 95°C and postcured four (4) hours ± five (5) minutes at 150°C. This formulation shall produce an infusible material having the following minimum properties:

Property	ASTM Test Value
Heat Distortion Temperature	160°C
Impact Strength	0.5 IZOD
Flexural Strength	12,000
Dielectric Strength	350 V/Mil.

3.4 This material shall have a pot life of at least 120 minutes at 60°C in a 50 gram mass.

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00	10-14-63			PREPARED BY	R.D. Bowen	
				CHECKED BY	C.D. Morris	10/16/63
				APP. ENG.	W.E. Cook	10/30/63
				APP. ENG.		
				APP. REL.	G. Gallant	10/30/63
					SIGNATURE	DATE

TITLE: AROMATIC-AMINE CURED EPOXY FORMULATION

SPEC. NO.	ISSUE
167	

Poly-Scientific CORPORATION
BLACKSBURG VIRGINIA

3.5 Gel time will be less than two (2) hours at 90°C.

3.6 Viscosity of the resin-hardener mixture will be less than 500 cps at 90°C, between 5,000 and 6,000 cps at 25°C.

3.7 Chemical identity of the cured plastic will be determined by comparison of its infrared spectrum to the standard curve attached to this specification.

4. INSPECTION AND TEST

4.1 Parts cast of this material shall be inspected visually for flaws and dimensional conformance to Engineering Drawing.

5. PACKAGE AND STORAGE

5.1 Components shall be stored unmixed, under cover, in sealed containers of convenient size.

6. NOTES

6.1 Both resin and hardener used in this formulation should be considered as skin sensitizing. Workers handling these materials should be equipped with gloves, aprons, and goggles, and should be required to wear long-sleeved shirts or jackets, to minimize possible skin contact.

6.2 Sensitivity to these materials varies among individuals, and usually increases with exposure time. Apparent immunity to any ill effect from skin contact is common on short-time exposure, but sensitivity can be expected to increase with exposure time.

6.3 In the event of skin contact with either resin or hardener, skin should be wiped with a clean towel or cloth moistened in acetone or similar solvent. Skin should then be washed with soap and water. In case of eye contact an opthomologist should be consulted immediately.

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00	10-14-63			PREPARED BY	R.D. Bowen	
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				APP. REL.		
					SIGNATURE	DATE

TITLE- AROMATIC-AMINE CURED EPOXY FORMULATION

SPEC. NO. 167 ISSUE

Poly-Scientific CORPORATION

BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

LITHIUM ALUMINUM SILICATE FILLER FOR EPOXY RESINS

1. SCOPE

This specification defines the chemical identity and general physical properties of a grade of Lithium Aluminum Silicate suitable for use as a filler material for epoxy resin formulations.

2. REQUIREMENTS

Materials qualified to this specification shall meet the following limiting physical properties:

Color	Tan
Particle size	95% - 325 mesh
Bulk density (lbs./cu. ft.)	Free fall 40
	Tapped 59
True density (g/cc.)	2.37 to 2.40
Thermal Stability	to 2300°F
Coefficient of Thermal expansion (in./in./°C.)	20 - 100°C -0.5×10^{-6}
	20 - 500°C $+0.2 \times 10^{-6}$

3. INSPECTION AND TEST

3.1 After qualification to this specification, vendors' shipments will be inspected visually for debris and color. Chemical identity of the material will be established by Poly-Scientific on one (1) sample of each batch received.

3.2 If either the visual examination or chemical tests on the material indicate that there is a probability of deviation from specification values, a sample will be tested according to the requirements in Section 2. Testing will be discontinued and the material lot rejecaed when any value does not meet the specification limits.

4. PACKAGE AND STORAGE

This material shall be stored in shipping containers. Storage shall be under cover, protected from moisture and open flame.

5. NOTES

5.1 Although this material can be considered as physiologically innocuous, the fine particle size presents a hazard as airborne dust, and operators using this material should be equipped with respirators to minimize inhalation.

REV.	DATE	CHANGE	CHK.		SIGNATURE	DATE
				PREPARED BY	C. VanGorgier	2/4/64
				CHECKED BY	R.D. Brown	2/4/64
				APP. ENG.	C.D. Morris	2/6/64
				APP. ENG.	[signature]	2/18/64
				APP. REL.	[signature]	2/7/64

TITLE: LITHIUM ALUMINUM SILICATE FILLER

SPEC. NO. 191 | ISSUE

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DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

6. QUALIFIED PRODUCTS AND VENDORS

6.1 Lithafrax 2121

Carborundum
Electronics Division
Latrobe, Pa.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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				APP. ENG.		
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TITLE— LITHIUM ALUMINUM SILICATE FILLER

SPEC. NO. 191 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

ALIPHATIC AMINE CURING AGENT

1. SCOPE

This specification defines the properties and general chemical identity of an aliphatic polyamine used as a curing agent for epoxy resins.

2. SPECIFICATIONS AND REFERENCES

Shell Chemical Company Bulletin SP-23-A.

3. REQUIREMENTS

3.1 The chemical identity of this material shall be established by comparison to the standard infra-red spectrum attached to this specification. Maximum allowable variations from this standard shall be ± 20% of the standard curve transmission and ± 0.1 micron shift. Both maximum peaks and fine structure shall be reproduced within these limits.

3.2 There sahll be no trace of crystallization or haze in this material as received from the vendor or after standing at 25 °C for six (6) months in a closed container.

3.3 The material shall be between a water clear and a pale amber liquid with a viscosity of not more than 200 cps at 25 °C.

4. INSPECTION AND TEST

4.1 Poly-Scientific shall determine conformance to the requirements set forth in Section 3.

4.2 After storage in excess of six (6) months, the material shall be reinspected to ensure conformance to the requirements in Section 3.

5. PACKAGE AND STORAGE

This material shall be packaged and stored in sealed containers of convenient size.

6. NOTES

6.1 The intended use of this material is as a highly reactive curing agent for epoxy resins to be used where short cure times are desirable and where maximum heat resistance is not required.

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REV.	DATE	CHANGE	CHK.		SIGNATURE	DATE
				PREPARED BY	C. VanHouzen	2/4/64
				CHECKED BY	R.W. Bowen	2-4-64
				APP. ENG.	C.D. Morris	2-6-64
				APP. ENG.	[signature]	2-8-64
				APP. REL.	[signature]	2-7-64

TITLE: ALIPHATIC AMINE CURING AGENT

SPEC. NO. 192 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

6.2 This material is toxic and skin sensitizing; therefore, care should be exercised to avoid contact with skin. Workers handling this material shall be equipped with adequate protective equipment to ensure a minimum of contact with this hardener.

7. QUALIFIED PRODUCTS AND VENDORS

Triethylenetetramine(TETA)	Shell Chemical Company
	Miller-Stephenson Chemical Co.
	Dow Chemical Company

REV.	DATE	CHANGE	CHK.			
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TITLE: ALIPHATIC AMINE CURING AGENT

SPEC. NO. 192 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

LOW VISCOSITY ALIPHATIC AMINE CURED EPOXY FORMULATION

1. SCOPE

This specification defines the ingredients and general properties of a rigid epoxy casting, potting or cementing formulation.

2. SPECIFICATION AND REFERENCES

2.1 Poly-Scientific Engineering Specification No. 133, "Low Viscosity Epoxy Resin".

2.2 Poly-Scientific Engineering Specification No. 192, "Triethylenetetramine".

3. REQUIREMENTS

3.1 Material used in this formulation must be qualified under the appropriate specification given in Section 2.

3.2 The resin and hardener shall be mixed thoroughly in the ratio 14 (± 0.2) parts by weight E. S. 192 hardener to 100 parts by weight E. S. 133 resin.

3.3 When cured one (1) hour (± 5 min.) at 60°C (± 5°C) and one (1) hour (± 5 min.) at 90°C (± 5°C), this material shall produce an infusible material having the following minimum properties:

Property	ASTM Test Value
Heat Distortion Temperature	90°C
Impact Strength	0.25 Izod
Flexural Strength	10,000 PSI
Dielectric Strength	350 V/mil.

3.4 This material shall have a pot life of at least 20 minutes at 25°C in a 50 gram mass.

3.5 Gel time will be less than one (1) hour at 60°C.

3.6 Viscosity of the resin-hardener mixture will be less than 2000 cps at 25°C.

3.7 Chemical identity of the cured plastic will be determined by comparison of its infrared spectrum to the standard curve attached to this specification.

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REV.	DATE	CHANGE	CHK.			
				PREPARED BY	R. W. Brown	2/5/64.
				CHECKED BY	C. D. Morris	2/6/64
				APP. ENG.		
				APP. ENG.		2-8-64
				APP. REL.		2-7-64
					SIGNATURE	DATE

TITLE LOW VISCOSITY ALIPHATIC AMINE CURED EPOXY FORMULA.

SPEC. NO.	ISSUE
193	

POLY - SCIENTIFIC
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LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

4. INSPECTION AND TEST

4.1 Parts cast of this material shall be inspected visually for flaws and dimensional conformance to Engineering Drawing.

5. PACKAGE AND STORAGE

5.1 Components shall be stored unmixed in sealed containers of convenient size.

6. NOTES

6.1 Both resin and hardener used in this formulation are skin sensitizing. Workers handling these materials should be equipped with gloves, aprons, goggles, and should be required to wear long-sleeved shirts or jackets to minimize possible skin contact.

6.2 In the event of skin contact with either resin or hardener, skin should be wiped with a clean towel or cloth moistened in acetone or similar solvent. Skin should then be wahsed with soap and water. In case of eye contact an ophthalmologist should be consulted immediately.

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TITLE-LOW VISCOSITY ALIPHATIC AMINE CURED EPOXY FORMULAT.

SPEC. NO.	ISSUE
193	

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

MINERAL FILLED, ALIPHATIC AMINE CURED EPOXY FORMULATION

1. **SCOPE**

This specification defines the ingredients and general properties of a highly filled casting, potting or cementing formulation.

2. **SPECIFICATION AND REFERENCES**

2.1 Poly-Scientific Engineering Specification No. 133, "Low Viscosity Epoxy Resin."

2.2 Poly-Scientific Engineering Specification No. 192, "Triethylenetetramine".

2.3 Poly-Scientific Engineering Specification No. 191, "Lithium Aluminum Silicate."

3. **REQUIREMENTS**

3.1 Material used in this formulation must be qualified under the appropriate specification given in Section 2.

3.2 The resin, hardener, filler shall be mixed thoroughly in the following proportions:

E. S. 133 Resin	100 ± 2 parts
E. S. 192 Hardener	14 ± 0.2 parts
E. S. 191 Filler	200 ± 5 parts

3.3 When cured one (1) hour (± 5 minutes) at 60°C (± 5°C) and One (1) hour (± 5 minutes) at 90°C (± 5°c), this material shall produce an infusible material having the following minimum properties:

Property	ASTM Test Value
Heat Distortion Temperature	120°C
Impact Strength	0.15 IZOD
Flexural Strength	8000 PSI
Dielectric Strength	350 V/MIL.

3.4 This material shall have a pot life of at least 60 minutes at 25°C in a 30 gram mass.

3.5 Gel time will be less than one (1) hour at 60°C/

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REV.	DATE	CHANGE	CHK.			
00				PREPARED BY	R.L. Bowen	2-21-64
				CHECKED BY	C.D. Morris	2-24-64
				APP. ENG.		2-25-64
				APP. ENG.		
				APP. REL.		2-29-64
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TITLE: MINERAL FILLED, ALIPHATIC AMINE FORMULATION

SPEC. NO. 195 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

3.6 The completed mix will be thixotropic at 25 °C.

3.7 Chemical identity of the cured plastic will be determined by comparison of its infrared spectrum to the standard curve attached to this specification.

4. INSPECTION AND TEST

4.1 Parts cast of this material shall be inspected visually for flaws and dimensional conformance to Engineering Drawing.

5. PACKAGE AND STORAGE

5.1 Components shall be stored unmixed in sealed containers of convenient size.

6. NOTES

6.1 Both resin and hardener used in this formulation are skin sensitizing. Workers handling these materials should be equipped with gloves, aprons, goggles, and should be required to wear long-sleeved shirts or jackets to minimize contact.

6.2 In the event of skin contact with either resin or hardener, skin should be wiped with a clean towel or cloth moistened in Acetone or similar solvent. Skin should then be washed with soap and water. In case of eye contact, an optomologist should be consulted immediately.

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TITLE: MINERAL FILLED, ALIPHATIC AMINE FORMULATION

SPEC. NO. 195 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

MINERAL FILLED, ALIPHATIC AMINE CURED EPOXY FORMULATION

1. SCOPE

This specification defines the ingredients and general properties of a moderately filled casting, potting and cementing formulation.

2. SPECIFICATIONS AND REFERENCES

2.1 Poly-Scientific Engineering Specification No. 133, "Low Viscosity Epoxy Resin".

2.2 Poly-Scientific Engineering Specification No. 192, "Triethylenetetramine".

2.3 Poly-Scientific Engineering Specification No. 191, "Lithium Aluminum Silicate".

3. REQUIREMENTS

3.1 Material used in this formulation must be qualified under the appropriate specification given in Section 2.

3.2 The resin, hardener, filler shall be mixed thoroughly in the following proportions:

E. S. 133 Resin	100 (± 2) parts
E. S. 192 Hardener	14 (± 0.2) parts
E. S. 191 Filler	150 (± 5) parts

3.3 When cured one (1) hour (± 5 minutes) at 60°C (± 5°C) and one (1) hour (± 5 minutes) at 90°C (± 5°C), this material shall produce an infusible material having the following minimum properties:

Property	ASTM Test Value
Heat Distortion Temperature	120°C
Impact Strength	0.15 IZOD
Flexural Strength	8,000 PSI
Dielectric Strength	350 V/MIL.

3.4 This material shall have a pot life of at least sixty (60) minutes at 25°C in a thirty (30) gram mass.

3.5 Gel time will be less than one (1) hour at 60°C.

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REV.	DATE	CHANGE	CHK.			
				PREPARED BY	C. N. Brown	3/3/64
				CHECKED BY		
				APP. ENG.	C. DiDomizio	3/8/64
				APP. ENG.	W. Lagi	3/11/64
				APP. REL.	S. Gubbi	4/2/64
					SIGNATURE	DATE

TITLE-ALIPHATIC AMINE CURED EPOXY FORMULATION

SPEC. NO.	ISSUE
199	

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

3.6 Chemical identity of the cured plastic will be determined by comparison of its infrared spectrum to the standard curve attached to this specification.

4. INSPECTION AND TEST

4.1 Parts cast of this material shall be inspected visually for flaws and dimensional conformance to Engineering Drawing.

5. PACKAGE AND STORAGE

5.1 Components shall be stored unmixed in sealed containers of convenient size.

6. NOTES

6.1 Both resin and hardener used in this formulation are skin sensitizing. Workers handling these materials should be equipped with gloves, aprons, goggles, and should be required to wear long-sleeved shirts or jackets to minimize contact.

6.2 In the event of skin contact with either resin or hardener, skin should be wiper with a clean towel or cloth moistened in Acetone or similar solvent. Skin should then be washed with soap and water. In case of eye contact, an ophthalmologist should be consulted immediately.

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TITLE- ALIPHATIC AMINE CURED EPOXY FORMULATION

SPEC. NO. 199 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

FINE GOLD ANODES

1. SCOPE

1.1 This specification establishes the requirements for fine gold to be used by Poly-Scientific as anodes in the electroplating and/or electroforming of its products in potassium gold cyanide solutions.

1.2 All material furnished under this specification must conform to the standards herein described unless otherwise authorized by the Engineering Laboratory Manager and so stated in the Purchase Order.

2. SPECIFICATIONS AND REFERENCES

2.1 Poly-Scientific Engineering Specification No. 9, "Knoop Hardness Testing".

3. REQUIREMENTS

3.1 Chemical composition (by weight)

3.1.1 Nominal composition - Pure Gold.

3.1.2 Tolerance - Gold 99.90% min.

Selected base metals (Ag, Pb, Sb, Bi, Sn, Cd, Ge, Tl, Ga, As, Fe)	0.01% max., total
Sulfur	0.01% max.

3.2 Hardness

3.2.1 The hardness, determined as KHN under 100 gram load (average of five readings), shall not exceed 60.

3.3 Workmanship

3.3.1 Surfaces of all material furnished under this specification shall be smooth, clean and free from scratches, stains, rough spots, slivers, laps, scale, pits, and any other injurious defects within limits consistent with the best possible practice. In no case shall any defect exceed .005" in depth.

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REV.	DATE	CHANGE	CHK.			
00				PREPARED BY	[signature]	4-14-64
				CHECKED BY	[signature]	4-16-64
				APP. ENG.	[signature]	4/17/64
				APP	[signature]	4/17/64
				APP. REL.		
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TITLE— FINE GOLD ANODES

SPEC. NO. 206 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

3.3.2 All material shall have been cut parallel to the direction of rolling.

3.3.3 All material shall be free from structural defects, cracks, seams, porosity, inclusions, segregation, etc., upon examination of a suitably polished and/or etched metallurgical sample at 50X.

3.4 Tolerance

3.4.1 Dimensions

3.4.1.1 Width and length of sheet shall be as required ±.010".

3.4.1.2 Maximum variation in thickness of sheet, .010" per inch of width or length.

4. INSPECTION AND TESTING

4.1 The vendor shall perform, or have performed, at least these minimum tests to ensure conformity to this standard.

4.1.1 Visual inspection at 10X to ensure compliance with Para. 3.3.1 and 3.3.2 of this standard.

4.1.2 Hardness Test - Knoop 100 gram load.

4.1.3 Check of dimensions to ensure conformity to Para. 3.4 of this specification.

4.2 Poly-Scientific shall perform the following tests upon receipt of material furnished to this specification:

4.2.1 Hardness Tests - Knoop 100

4.2.2 Spectrographic Analysis

4.2.3 Dimensional check to ensure conformity to Para. 3.4

4.2.4 Visual Examination (10X)

4.2.5 Microscopic examination (50X) to ensure conformity to Para. 3.3.3.

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TITLE— FINE GOLD ANODES

SPEC. NO. 206 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

5. PACKAGE AND DELIVERY

5.1 The material furnished under this specification shall be packed in such a way as to ensure conformity to the standards herein described upon arrival at Poly-Scientific Division, Litton Precision Products, Inc.

5.2 Packing should be such that danger of damaging upon unpacking is a minimum.

5.3 Deliveries shall be made with due precaution to ensure safe, rapid and economic transfer.

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TITLE— FINE GOLD ANODES

SPEC. NO. 206 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

MINERAL FILLED, AROMATIC AMINE CURED EPOXY CASTING COMPOUND

1. SCOPE

This specification defines the ingredients and general properties of a mineral filled epoxy casting formulation.

2. SPECIFICATIONS AND REFERENCES

2.1 Poly-Scientific Engineering Specification No. 133, "Low-Viscosity Epoxy Resin".

2.2 Poly-Scientific Engineering Specification No. 191, "Lithium Aluminum Silicate Filler for Epoxy Resins".

2.3 Poly-Scientific Engineering Specification No. 212, "Aromatic Amine Hardener for Epoxy Resins".

3. REQUIREMENTS

3.1 Materials used in this formulation shall be qualified to the appropriate specification given in Section 2.

3.2 Formulation weights for this material are:

E. S. 133 Resin	100 parts
E. S. 191 Filler	400 parts
E. S. 212 Hardener	30 parts

3.3 This formulation when cured eight (8) hours (± 5 minutes) at 120°C (± 5°C) and four (4) hours (± 5 minutes) at 150°C (± 5°C) will produce a solid, infusible material having the following minimum properties:

Property	P-S Test Value
Heat Distortion Temperature	200°C
Flexural Strength	15.0 in. Hg.
Impact Strength	1.3 in.
Coefficient of Thermal Expansion	13.4 in./in./°C x 10^{-6}

3.4 This material will have a pot life of at least thirty (30) minutes at 150°C, in a 50 gram mass.

3.5 Gel time will be less than eight (8) hours at 120°C.

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REV.	DATE	CHANGE	CHK.			
00				PREPARED BY	R.D. Bourn	4/20/64
				CHECKED BY	C.D. Morris	4/22/64
				APP. ENG.		
				APP. ENG.	[illegible]	4/23/64
				APP. REL.	[illegible]	[illegible]
					SIGNATURE	DATE

TITLE: MINERAL FILLED ---- CASTING COMPOUND

SPEC. NO. 209 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

3.6 Identification of the cured E. S. 209 plastic shall be made by comparison to the Infrared Spectrum attached to this specification.

4. INSPECTION AND TEST

4.1 Parts cast with this formulation shall be inspected visually for flaws and dimensional conformance to print.

5. PACKAGE AND STORAGE

5.1 Resin and filler shall be pre-mixed and stored in closed containers of convenient size. Pre-mixed material shall be stored at 60°C (± 5°C) to prevent resin crystalization.

6. NOTES

6.1 The intended use of this material is as a casting formulation where good thermal shock characteristics, low shrinkage and low cure exotherm are required. The application must, however, be able to tolerate high initial viscosity.

6.2 Addition of any ingredient other than those listed here, or alteration of the formulation ratios will change the final properties of this material. In the event of any formulation modification, this specification shall not apply and shall not be referenced in part.

6.3 Both resin and hardener used in this formulation are to be regarded as skin sensitizing and workers handling these materials shall be equipped with adequate protective equipment to minimize the possibility of skin or eye contact. Vapors from the heated material are to be considered as toxic and skin sensitizing, and adequate ventilation shall be provided to ensure a minimum of human contact with the vapors or their condensation on equipment.

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TITLE- MINERAL FILLED --- CASTING COMPOUND

SPEC. NO.	ISSUE
209	

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

AROMATIC AMINE HARDENER FOR EPOXY RESINS

1. SCOPE

This specification establishes the requirements for a purified grade of diaminodiphenylsulfone suitable for use as a curing agent for epoxy resins.

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2. SPECIFICATIONS AND REFERENCES

2.1 Epoxy Resins, Lee-Neville

3. REQUIREMENTS

3.1 The material shall be a light tan, fine powder.

3.2 The material shall be free from any dirt or foreign matter.

3.3 Material shall be completely miscible with DER-332, E. S. 133, at 120°C.

3.4 Infrared analysis shall produce a spectrum substantially identical to the standard attached to this specification.

4. INSPECTION AND TEST

4.1 Poly-Scientific shall determine conformance to Para. 3.4 on each lot of material received.

4.2 After one (1) years storage, material shall be retested per Para. 3.4

5. PACKAGE AND STORAGE

5.1 The material shall be packaged in closed containers of convenient size.

5.2 Material shall be stored inside, protected from moisture.

6. NOTES

6.1 This material shall be considered to be toxic and skin sensitizing. Workers handling this material shall be provided sufficient protective equipment and ventilation to eliminate human contact with the solid material or vapors given off when heated. Contaminated skin should be washed immediately with soap and water. In case of eye contact, eyes should be flushed with flowing water for at least fifteen (15) minutes - then medical attention received immediately.

REV.	DATE	CHANGE	CHK.			
00				PREPARED BY	R.D. Brown	4/20/64
				CHECKED BY	C.D. Morris	4/22/64
				APP. ENG.		
				APP. ENG.	[signature]	4/23/64
				APP. REL.	[signature]	4/23/64
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TITLE AROMATIC AMINE HARDENER FOR EPOXY RESINS

SPEC. NO. 212 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

7. QUALIFIED PRODUCTS AND VENDORS

7.1 Diaminodiphenylsulfone — Polychemical Laboratories, Inc.

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TITLE— AROMATIC AMINE HARDENER FOR EPOXY RESIN

SPEC. NO. 212 | ISSUE

POLY - SCIENTIFIC
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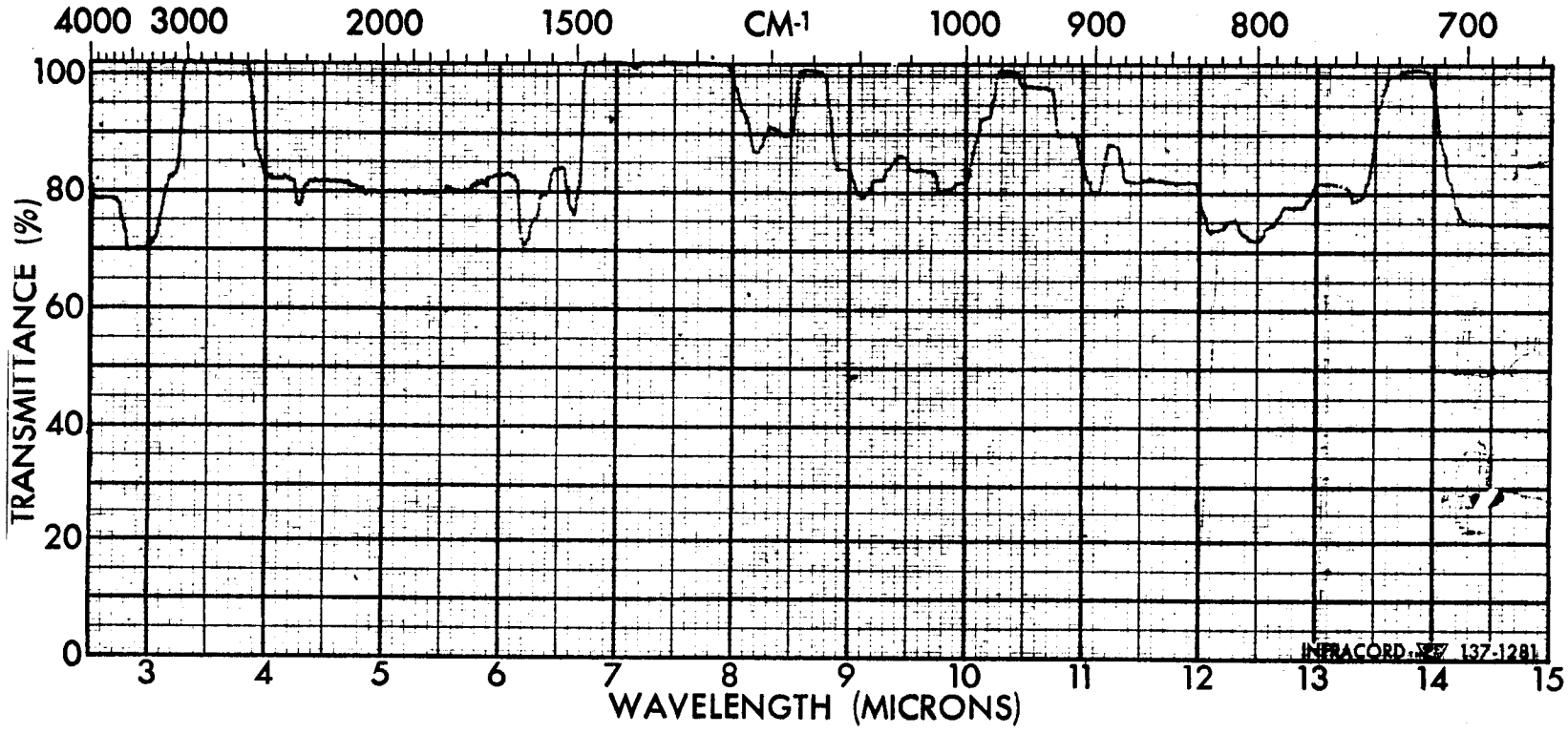
BLACKSBURG VIRGINIA



SPECTRUM NO.	ORIGIN Lab	LEGEND	REMARKS
SAMPLE 4-56		1.	
	PURITY Std Cast	2.	
	PHASE Liquid	DATE 3-27-65	
	THICKNESS 0.1mm	OPERATOR	

SPECTRUM NO. SAMPLE

THE PERKIN-ELMER CORPORATION, NORWALK, CONN.

ENGINEERING SPECIFICATION

DUPONT POLYIMIDE ENAMEL

1. SCOPE

This specification establishes the requirements for an insulating varnish suitable for coating splines, flanges and other metal components in Poly-Scientific products for electrical insulating purposes.

2. SPECIFICATIONS AND REFERENCES

"Pyre-M.L." Varnish (RK 692) Bulletin No. 1 (Revision No. 2).

3. REQUIREMENTS

3.1 The chemical composition of the material may be a proprietary formulation of the vendor, except that in the event of any changes ; in material or composition Poly-Scientific shall be notified of the change.

3.2 Properties of the material shall be:

Solids Content	11.5 to 12.5%
Viscosity (Poises at 25°C)	6 to 10
Tensile Strength (25°C)	15,000 PSI
Dielectric Constant (25°C - 1000 CPS)	3.5
Dielectric Strength	4,000 V/Mil.

3.3 This material when properly applied and baked shall produce an insoluble and infusible material that is stable up to a temperature of 300°C.

3.4 The material as received shall be free of any foreign matter.

3.5 The chemical identity of this material shall be established by comparison of its infrared spectrum with the standard curve attached to this specification.

4. INSPECTION AND TEST

4.1 Poly-Scientific shall test conformace to Para. 3.2, 3.4, and 3.5.

REV.	DATE	CHANGE	CHK.			
00				PREPARED BY	R.D. Bowen	8/10/64
				CHECKED BY	C.D. Morris	8/10/64
				APP. ENG.		
				APP. ENG.	W.B. Coy	8/28/64
				APP. REL.	L. Gilbert	8/17/64
					SIGNATURE	DATE

TITLE: DUPONT POLYIMIDE ENAMEL

SPEC. NO. 220 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
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BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

5. PACKAGE AND STORAGE

5.1 The material shall be packaged and stored in closed containers of convenient size that will ensure protection from moisture and airborne matter.

5.2 The material shall be stored below 4°C (40°F).

6. NOTES

6.1 This material is to be regarded as toxic and skin sensitizing. Workers handling this material shall be provided with adequate ventilation, equipment and protective clothing to eliminate contact with either the material or its vapors.

6.2 In the event of accidental skin contact, flush affected area with water immediately. In the event of eye contact, flush with clear water and obtain medical attention immediately.

7. QUALIFIED PRODUCTS AND VENDORS

Pyre - M.L. RK-692 — E. I. DuPont De Nemours & Co. Inc.
Fabrics & Finishes Department
Wilmington 98, Delaware

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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TITLE- DUPONT POLYIMIDE ENAMEL

SPEC. NO. 220 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

MINERAL FILLED EPOXY CASTING COMPOUND

1. SCOPE

This specification defines the ingredients and general properties of a moderately filled casting, potting and cementing formulation.

2. SPECIFICATIONS AND REFERENCES

2.1 Poly-Scientific Engineering Specification No. 133, "Low Viscosity Epoxy Resin".

2.2 Poly-Scientific Engineering Specification No. 192, "Triethylenetetramine".

2.3 Poly-Scientific Engineering Specification No. 138, "Lithium Aluminum Silicate".

3. REQUIREMENTS

3.1 Material used in this formulation must be qualified under the appropriate specification given in Section 2.

3.2 The resin, hardener, filler shall be mixed thoroughly in the following proportions:

E. S. 133 Resin	100 (± 2) parts
E. S. 192 Hardener	14 (± 0.2) parts
E. S. 138 Filler	150 (± 5) parts

3.3 When cured one (1) hour (± 5 minutes) at 90°C (± 5°C), this material shall produce an infusible material having the following minimum properties:

Property	ASTM Test Value
Heat Distortion Temperature	120°C
Impact Strength	0.15 IZOD
Flexural Strength	8,000 PSI
Dielectric Strength	350 V/MIL

3.4 This material shall have a pot life of at least sixty (60) minutes at 25°C in a thirty (30) gram mass.

3.5 Gel time will be less than one (1) hour at 90°C.

3.6 Chemical identity of the cured plastic will be determined by comparison of its Infrared Spectrum to the standard curve attached to this specification.

REV.	DATE	CHANGE	CHK.			
				PREPARED BY	R.D. Bowen	6/18/64
				CHECKED BY	C.D. Morris	6/19/64
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				APP. ENG.	[illegible]	6/23/64
				APP. REL.	[illegible]	6/22/64
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TITLE-MINERAL FILLED EPOXY CASTING COMPOUND

SPEC. NO. 222 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

4. INSPECTION AND TEST

4.1 Parts cast with this material shall be inspected visually for flaws and dimensional conformance to Engineering Drawing.

5. PACKAGE AND STORAGE

5.1 Components shall be stored unmixed in sealed containers of convenient size.

6. NOTES

6.1 Both resin and hardener used in this formulation are skin sensitizing. Workers handling these materials shall be equipped with gloves, aprons, goggles, and should be required to wear long-sleeved shirts or jackets to minimize contact.

6.2 In the event of skin contact with either resin or hardener, skin should be wiped with a clean towel or cloth moistened in Acetone or similar solvent. Skin should then be washed with soap and water. In case of eye contact, an ophthalmologist should be consulted immediately.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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TITLE- MINERAL FILLED EPOXY CASTING COMPOUND

SPEC. NO. 222 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

MINERAL FILLED, ANHYDRIDE CURED EPOXY NOVOLAK

1. SCOPE

This specification defines the ingredients and general properties of a rigid, highly heat resistant potting and encapsulating compound.

2. SPECIFICATIONS AND REFERENCES

2.1 Poly-Scientific Engineering Specification No. 124, "Epoxy Novolak Resin."

2.2 Poly-Scientific Engineering Specification No. 123, "Nadic Methyl Anhydride Curing Agent for Epoxy Resins."

2.3 Poly-Scientific Engineering Specification No. 125, "Tris-Amino Phenol Accelerator for Epoxy Formulations."

2.4 Poly-Scientific Engineering Specification No. 138, "Lithium Aluminum Silicate Filler Material."

3. REQUIREMENTS

3.1 Materials used in this formulation shall be qualified under the appropriate specification given in Section 2.

3.2 Processing base mix:

3.2.1 E.S. 124 resin and E.S. 123 curing agent shall be mixed thoroughly in the ratio 90 (± 0.5) parts by weight curing agent to 100 parts by weight resin. Mix temperature shall be less than 150°C.

3.2.2 After resin and curing agent have been thoroughly mixed, 300 (± 1) parts by weight E.S. 138 filler shall be added and dispersed evenly.

3.2.3 The above mixture shall be cooled and stored at 0°C (± 5°) until needed or held for immediate use as described in Para. 3.3.

3.2.4 The time interval for mixing procedure shall be less than one (1) hour after addition of curing agent.

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REV.	DATE	CHANGE	CHK.			
00				PREPARED BY	R.L. Bates	11/13/64.
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				APP. ENG.		11/21/64
				APP. REL.		11/20/64
					SIGNATURE	DATE

TITLE: MINERAL FILLED, ANHYDRIDE CURED EPOXY NOVOLAK

SPEC. NO. 246 | ISSUE

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

3.2.5 Mixture shall be cooled to 25°C within four (4) hours of addition of curing agent if not mixed for immediate use.

3.3 Catalyzing

3.3.1 The above mixture shall be catalyzed by the addition of 0.18 (± 0.02) parts by weight E. S. 125 accelerator to 100 parts by weight of the mixture from Para. 3.2.

3.3.2 Mix temperature upon addition of E.S. 125 accelerator shall be less than 120°C.

3.4 When cured four (4) hours (± 5 minutes) at 90°C (± 5°C) and eight (8) hours (± 5 minutes) at 150°C (+ 10 - 0°C), this formulation shall produce an infusible material having the following minimum properties:

Property	ASTM Value
Heat Distortion Temperature	200°C +
Flexural Strength	9,000 PSI (Ult.)
Impact Strength	0.10 (IZOD)
Dielectric Strength	300 V/Mil

3.5 Pot and Shelf Life

3.6.1 The catalyzed mixture shall have a pot life of at least twelve (12) minutes at 110°C in masses of less than 100 grams.

3.6.2 The mixture shall have shelf life of sixty (60) days at 0°C (± 5°) prior to addition of accelerator. Material stored in excess of ten (10) days shall be discarded.

3.6 Gel time for the catalyzed mixture shall be less than four (4) hours at 90°C (± 5°).

3.7 Chemical identity of the cured plastic shall be determined by comparing the infrared spectrum with the standard P-S Laboratory curve.

4. INSPECTION AND TEST

4.1 Parts cast with this material shall be inspected visually for flaws and dimensional conformance to print.

REV.	DATE	CHANGE	CHK.	PREPARED BY		
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TITLE MINERAL FILLED, ANHYDRIDE CURED EPOXY NOVOLAK

SPEC. NO.	ISSUE
246	

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

ENGINEERING SPECIFICATION

5. PACKAGE AND STORAGE

5.1 Components shall be stored in closed containers, protected from moisture and undue exposure to the atmosphere.

6. NOTES

6.1 The mineral filler used in this formulation is highly abrasive and very difficult to machine.

6.2 Resin, curing agent and accelerator used in this formulation shall be considered toxic and skin sensitizing. Adequate protective equipment and ventilation will be provided in any work area in which this material is to be used.

6.3 In the even of skin contact with any of the components of the epoxy system, skin should be wiped with a clean towel or cloth moistened in Acetone or similar solvent. Skin should then be washed with soap and water. In the case of eye contact, a physician should be consulted immediately.

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TITLE MINERAL FILLED, ANHYDRIDE CURED EPOXY NOVOLAK

SPEC. NO.	ISSUE
246	

POLY - SCIENTIFIC
DIVISION OF
LITTON PRECISION PRODUCTS, INC.
BLACKSBURG VIRGINIA

TITLE: VACUUM CASTING PROCEDURE FOR E.S. 209 PLASTIC (N.A.S.A. BRUSH BLOCKS)

TOOLS AND EQUIPMENT:

Glass Beaker

Glass Stirring Rod

Forced Air Ovens

Thermometer

Balance

Hot Plate

Surface Pyrometer

Evacuating Apparatus

OPERATION STEPS:

1. Preheat mold 90 (± 5) minutes at 160°C (± 5°C) in a forced air oven.
2. Preheat BPM E. S. 209 weighed in a glass beaker 10 to 20 minutes at 160°C (± 5°) in a forced air oven.
3. Remove BPM E. S. 209 from oven and place on hot plate preheated to 200°C (± 20°C).
4. Add E. S. 212 hardener to BPM E. S. 209 in the following proportions:

BPM E. S. 209	E. S.212 Hardener
25 grams	1.5 grams
50 grams	3.0 grams
75 grams	4.5 grams
100 grams	6.0 grams
200 grams	12.0 grams

5. Begin stirring very slowly with glass stirring rod until E.S. 212 has melted and begins to go into solution then stir more vigorously. Stir until mix is of a free flowing, homogeneous consistancy. Total mixing time is 2 to 4 minutes.
6. Place mold on vacuum pad.
7. Pour a sufficinet amount of plastic into mold reservoir.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	PROCESS INSTRUCTION NO.
		1-14-65	02	75

TITLE:	VACUUM CASTING PROCEDURE FOR E. S. 209 PLASTIC (N.A.S.A. BRUSH BLOCKS)

OPERATION STEPS CONTINUED:

8. Place Bell jar over mold and evacuate as per the following:

   a) Bring plastic to boil and breakdown.
   b) Boil one (1) minute (± 5 seconds).
   c) Turn OFF pump and release vacuum rapidly.
   d) Bring plastic to boil.
   e) Boil 10 to 15 seconds.
   f) Turn OFF pump and release vacuum rapidly.
   g) Repeat steps d, e, and f nine (9) more times.

9. Remove from vacuum pad, place in a forced air oven preheated to 120°C and cure for eight (8) hours (± 5 minutes) at 120°C (± 5°C).

10. Remove from 120°C oven, place in a forced air oven preheated to 150°C and cure four (4) hours (± 5 minutes) at 150°C (± 5°C).

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE 1-14-65	REV. 02	PROCESS INSTRUCTION NO. 75

TITLE: CASTING PROCEDURES FOR DP 1500, 1505 AND SIMILAR SLIP RINGS

TOOLS AND EQUIPMENT:

Glass Stirring Rod

Glass Beaker

Ovens

Thermometers

Balance

Hot Plate

Evacuating Apparatus

MATERIALS:

BPM E.S. 218 Plastic

E. S. 212 Hardener

OPERATION STEPS:

FIRST CASTING

1. Preheat mold two (2) hours (± 5 minutes) at 150°C (+10 -0°) on a one (1) inch thick, one square foot aluminum plate in a forced air oven.

2. Mix E. S. 218 plastic as per the following:

   a) In a suitable size glass beaker, place 100 (± 2) parts BPM E. S. 218 plastic.

   b) Place beaker containing BPM E. S. 218 plastic into a forced air oven preheated to 150°C (+ 10 -0°). Material is to remain in oven for 15 to 30 minutes.

   c) Remove beaker from oven and place on hot plate that has been preheated to 200°C (± 20°).

   d) Add 6 (± 0.02) parts E. S. 212 hardener to BPM E.S. 218 plastic.

   e) Begin stirring slowly with glass stirring rod until E.S. 212 begins to go into solution, then stir more vigorously. Stir until mix is homogeneous. (Total stirring time is 2 to 3 minutes.)

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS,INC.	ENGINEER	DATE	REV.	PROCESS INSTRUCTION NO.
	[illegible]	11/20/64	00	79

TITLE: CASTING PROCEDURES FOR DP 1500, 1505 AND SIMILAR SLIP RINGS

OPERATION STEPS CONTINUED:

3. Remove mold from oven and place on vacuum pad.

4. Pour an adequate amount of E.S. 218 plastic into mold reservoir and evacuate as per the following:
   a) Bring plastic to boil
   b) Boil 2 minutes (± 5 seconds).
   c) Release vacuum rapidly
   d) Bring plastic to boil
   e) Boil 30 (± 5) seconds.
   f) Release vacuum rapidly.
   g) Repeat d, e, and f three (3) more times, releasing vacuum slowly the last time.

5. Cure eight (8) hours (± 5 minutes) at 120°C (± 5°) and four (4) hours (± 5)minutes at 150°C (± 5°) in forced air ovens.

   NOTE: After mold has had a minimum of eight (8) hours at 120°C, remove mold cap and check flange to see if it is adequately filled with plastic. If flange has not filled, replace cap, reseal, place reservoir over open mold cap, preheat and recast as before. Cure four (4) hours (± 5 minutes) at 150°C (± 5°).

SECOND CASTING

1. Preheat mold two (2) hours (± 5 minutes) at 150°C (+10 -0°) on a one (1) inch thick, one square foot aluminum plate in a forced air oven.

2. Mix E. S. 218 plastic as per first casting, Step 2.

3. Remove mold from oven and place on vacuum pad.

4. Pour an adequate amount of E.S. 218 plastic into mold reservoir and evacuate as per the following:
   a) Bring plastic to boil
   b) Boil one (1) minute (± 5 seconds).
   c) Release vacuum rapidly.
   d) Bring plastic to boil.
   e) Boil 30 (± 5) seconds.
   f) Release Vacuum rapidly.
   g) Repeat d, e, and f three (3) more times, releasing vacuum slowly the last time.

5. Cure eight (8) hours (± 5 minutes) at 120°C (± 5°) and four (4) hours (± 5 minutes) at 150°C (± 5°) in forced air ovens.

TITLE: CASTING PROCEDURES FOR DP 1500, 1505,AND SIMILAR SLIP RINGS

OPERATION STEPS CONTINUED:

THIRD CASTING

Follow Second Casting Procedure

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS,INC.	ENGINEER	DATE	REV. 00 PROCESS INSTRUCTION NO. 79

TITLE:	CLEANING CERROBASE OR PLASTIC MOLD

TOOL & EQUIPMENT:

Generator -	Ultrasonic ("Sontegrator" Model G-40Cl-P) and tank ("Sontegrator", Model T-401, or equivalent).
Hood -	Exhaust with capacity to move two (2) cubic FPM per linear inch of work space.
Sprayer -	(Baker or equivalent) connected to a supply of clean dry compressed air.
Beakers -	Pyrex, low form, with spout.
Nitrogen Cylinder -	

OPERATION STEPS:

1. Fill spray bottle with fresh filtered "Chlorothene" (E. S. No. 101).
2. Spray part thoroughly with "Chlorothene (E. S. No. 101) under exhaust hood for 20 - 30 seconds.
3. Fill 600 ml beaker 1/2 full with fresh filtered "Chlorothene" (E. S. No. 101) for complete immersion. Place beaker in tank (have 3/4 to 1-1/4 inches of distilled water plus 8 to 10 drops of "L.O.C." solution in tank). Immerse part in beaker; ultrasonically generate for one (1) munite minimum.
4. Remove part from solvent while generator is still in operation; place on clean industrial wiper or blast dry with nitrogen.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER JEW	DATE 12/10/13	REV. 00	PROCESS INSTRUCTION NO. 101

TITLE: CLEANING FLASH AFTER CASTING

TOOL & EQUIPMENT

Brass Tool or Orangewood Stick

Sprayer - (Baker or equivalent) connected to a supply of clean dry compressed air.

Hood - Exhaust with capacity to move two (2) cubic FPM per linear inch of work space.

Generator - Ultrasonic ("Sonteyrator", Model G-40Cl-P) and tank ("Sontegrator", Model T-401, or equivalent).

Nitrogen Cylinder -

Beakers - Pyrex, low form, with spout.

OPERATION STEPS

1. Using a brass tool or orangewood stick, scrape mold to remove excess plastic.
2. Spray mold with "Chlorothene" (E. S. 101) for 30 - 40 seconds under an exhaust hood.
3. Immerse part in a clean beaker containing fresh "Chlorothene" (E.S. 101) and ultrasonically generate 30 to 40 seconds.
4. Remove part and allow to air dry in a clean area or ablast dry with nitrogen.

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	PROCESS INSTR. NO.
			00	102

TITLE: FINAL CLEANING OF BRUSH BLOCK ASSEMBLIES

TOOLS AND EQUIPMENT

Hood - Exhaust with capacity to move two (2) cubic FPM per linear inch of work space.

Tongs or Tweezers -Length of tongs six (6) to nine (9) inches - Tweezers four (4) to nine (9) inches with blunt points.

Sprayer - (Baker or equivalent) connected to a supply of clean dry compressed air.

Clean Work Area - Per P-S E. S. No. 90

Generator- Ultrasonic ("Sontegrator", Model G-40Cl-P) and tank ("Sontegrator", Model T-401, or equivalent).

Beakers - Pyrex, Griffin, with spout.

SOLVENTS

Trichloroethane - ("Chlorothene", per P-S E. S. No. 101)

"L.O.C" - One (1) tablespoon (0.5 liquid oz.) of "L.O.C.", liquid organic cleaning concentration, low sudsing (Amway Products Inc., or equivalent) dissolved in a quart or 1000 ml of warm (30-40°C) water, per P-S E. S. No. 88.

Water - Distilled or deionized, per P-S E. S. No. 88.

Ethylene glycol monoethyl ether - ("Cellosolve", per P-S E. S. No. 105).

Trifluorotrichloroethane - (Freon, per P-S E. S. No. 85).

OPERATION STEPS - (Read entire procedure before beginning this operation.)

1. Spray part under an exhaust hood with "L.O.C." solution (1/2 oz. "L.O.C." to 1 quart of distilled water, E. S. 88), rotating and moving part from side to side so as to expose all surfaces to the spray, 1 - 2 min.

2. Holding the part with a pair of clean tongs or clean blunt tweezers, soak immediately in a clean beaker containing distilled water (E.S. 88) held at a temperature between 80° and 90°C, for fifteen (15 to twenty (20) seconds, carefully swishing part for agitation. Beaker shall contain enough solvent for easy immersion without risk of striking part on bottom of beaker.

POLY-SCIENTIFIC DIVISION Litton Precision Products, Inc.	ENGINEER Jw	DATE 11-1-63	REV. 00	PROCESS INSTRUCTION NO. 103

TITLE: FINAL CLEANING OF BRUSH BLOCK ASSEMBLIES

OPERATION STEPS CONTINUED:

3. Repeat step No. 2 in a second beaker.

4. Holding the part with a pair of clean tongs or clean blunt tweezers soak immediately in a clean beaker containing Cellosolve (E. S. 105) for fifteen (15) to twenty (20) seconds, carefully swishing part for agitation. Beaker shall contain enough solvent for easy immersion without risk of striking bottom of beaker with part.

5. Holding as in steps 2 through 4, immediately immerse part in a clean beaker containing Chlorothene (E. S. 101) and ultrasonically generate for 60 - 70 seconds.

6. Repeat step 5 in fresh Chlorothene (E. S. 101).

7. Remove part from solvent and immediately immerse in a clean beaker containing "Freon" (E. S. 85) and ultrasonically generate for 30 - 40 seconds.

8. Remove part from solvent and place on a fresh industrial wiper to air dry in a clean work area, per P-S E. S. No. 90.

9. Change all solvents every five (5) parts or more often if they become visible contaminated.

10. Retain all used "Freon" in used solvent can for reclamation.

	ENGINEER	DATE	REV.	PROCESS INSTR. NO.
	JW			103

TITLE: CLEANING OF STATOR ASSEMBLY AFTER SOLDERING

TOOLS AND EQUIPMENT:

Beakers -	Pyrex, low form, capacity 250 ml.
Generator -	Ultrasonic, and tank.
Tongs -	Pick up, nickel plated, with stirrup jaws.
Wipers -	Industrial (Scott No. 590).

SOLVENTS:

Alcohol -	Isopropyl (P-S E. S. No. 184).
"Chlorothene" -	Per P-S E. S. No. 101.

OPERATION STEPS:

1. Carefully place the assembly with leads UP in a 250 ml. beaker containing 1-1/2 to 2 inches of isopropyl alcohol. Place beaker in generator tank and generate for 60-70 seconds. Change alcohol every two (2) or three (3) parts or every part if visibly contaminated.

2. Using a pair of tongs, carefully remove assembly from alcohol while generator is still in operation and place gently in a 250 ml. beaker containing 1-1/2 to 2 inches of "Chlorothene". Do not bind leads. Place beaker in generator tank and generate for 30 to 40 seconds. Change "Chlorothene" for every part.

3. Using tongs, carefully remove the assembly from beaker while generator is still in operation and place on a fresh industrial wiper to air dry.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER Cam	DATE	REV. 00	PROCESS INSTRUCTION NO. 106

TITLE: CLEANING OF RINGS AND LEADS AND OTHER COMPONENTS BEFORE CASTING

TOOLS & EQUIPMENT:

Generator -	Ultrasonic ("Sontegrator", Model G-40Cl-P) and tank ("Sontegrator", Model T-401), or equivalent.
	The generator tank shall contain 3.4 to 1-1/4 inches of distilled water plus 8 to 10 drops of "L.O.C." solution. (1/2 oz. "L.O.C." to one (1) quart distilled water.)
Beakers -	Pyrex, (or Nalgene) low form, with spout, capacity 400 to 600 ml.
Cover Glasses -	for beakers.
Containers -	Metal, glass or plastic with vapor tight cover, capacity one (1) to five (5) gallons, labelled "USED FREON".
Industrial Wipers -	"Scott" No. 590.

SOLVENTS:

Trifluorotrichloroethane - "Freon", or equivalent, per P-S E. S. No. 85.

Water -	Distilled or deionized, per P-S E. S. No. 88.
"L.O.C." -	Liquid organic cleaner (Amway Products Inc.), or equivalent.

OPERATION STEPS:

PROCEDURE FOR RINGS AND LEADS

(Do not touch rings at any time during or after process.)

1. Use a clean beaker, fill 1/2 full with "Freon" (P-S E. S. No. 85) and place in generator tank. Turn ON power and adjust for maximum agitation. Immerse one (1) to two (2) inches of ring and lead assemblies, into solvent, do not allow components to strike bottom or sides of beaker. Ultrasonically generate for 20 - 30 seconds.
2. While generator is still in operation, remove units from solvent and place on a clean industrial wiper. Keep beaker covered with a clean watch glass when not in use.
3. Change solvent every 100 - 150 ring and lead assemblies.
4. Empty all used "Freon" in "USED FREON" can for reclamation.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	PROCESS INSTRUCTION NO.
		10-14-64	01	123

TITLE: CLEANING OF RINGS AND LEADS AND OTHER COMPONENTS BEFORE CASTING

OPERATION STEPS CONTINUED:

PROCEDURE FOR OTHER COMPONENTS

1. Using clean tweezers, place components in a separate beaker of "Freon". Use fresh solvent for every 10 sets or more often if visible contaminated. Keep beaker covered with a clean watch glass when not in use.

2. Ultrasonically generate for one (1) minute minimum.

3. While generator is still in operation, remove components from the solvent with tweezers and place in a clean area to air dry. Empty all used "Freon" in reclamation can.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV. 01	PROCESS INSTRUCTION NO. 123

TITLE: CLEANING OF SLIP RINGS AFTER "V" GROOVING

TOOLS & EQUIPMENT:

Generator -	Ultrasonic ("Sontegrator", Model G-40C1-P) and tank (Sontegrator", Model T-401) or equivalent.
Beakers -	Pyrex, high form or low form, capacity sufficient to contain part without risk of binding leads.
Wipers -	Industrial, ("Scott" No. 590).
Vacuum System -	Pyrex desiccator, vacuum pump, rubber hose, and 2-way valve.

SOLVENTS:

Trichloroethane - "Chlorothene" per P-S E. S. No. 101.

Trifluorotrichloroethane - "Freon" per P-S E. S. No. 85.

OPERATION STEPS: (Read entire procedure before beginning this process.)

1. Set-up for cleaning -
   a) Two (2) clean 600 ml beakers, containing sufficient fresh filtered "Chlorothene" (E. S. No. 101) to cover part. One shall be heated to 40° to 50°C.
   b) One (1) clean beaker containing fresh filtered "Freon" (E. S. No. 85).
2. Place part in a clean beaker containing "Chlorothene" and ultrasonically generate for two (2) minutes minimum. Change solvent every part.
3. While generator is still in operation, remove part from solvent and immediately place in second beaker of hot "Chlorothene" heated to 40° to 50°C. Generate a minimum of one (1) minute.
4. Place beaker in vacuum desiccator and vacuum extract four (4) cycles. Bring solvent to a rolling boil and hold for one (1) minute each cycle. Use fresh solvent for each part.
5. Remove part from "Chlorothene" and immediately place in a clean beaker containing "Freon" (E.S. No. 85). Place beaker in vacuum desiccator and vacuum extract four (4) boiling cycles of one (1) minute each. Change solvent for every part.
6. Remove part from solvent and place on a fresh industrial wiper to air dry.

NOTE: Retain all used "Freon" in used solvent can for reclamation.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV. 01	PROCESS INSTRUCTION NO. 129

TITLE: REMOVAL OF PLATING RESIDUES

TOOLS AND EQUIPMENT:

Beakers -	"Pyrex", low form, 600 ml.
Vacuum System -	Desiccator, pump, rubber hose, two-way valve.
Oven -	Vacuum, temperature capacity to 90°C.
Wipers -	Industrial, (Scott No. 590).
Containers -	Plastic, box or bag.

SOLVENTS:

Water -	Distilled or deionized (P-S E. S. No. 88).

OPERATION STEPS:

1. Place the slip ring assembly in a clean beaker containing enough distilled or deionized water to completely cover part.
2. Place beaker in vacuum desiccator and vacuum extract four (4) boiling cycles of one (1) minute each.
3. Remove beaker, transfer assembly to a fresh industrial wiper inside vacuum desiccator, and vacuum dry for five (5) minutes.
4. Remove assembly from desiccator and place on a fresh industrial wiper inside vacuum oven, maintained at a temperature between 85° and 90°C.
5. Close oven door, turn on vacuum, and leave for 30 - 40 minutes.
6. Remove assembly from oven, allow to cool to below 45°C, then place in a clean plastic container.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV. 00	PROCESS INSTRUCTION NO. 134

TITLE: REMOVAL OF WATER SOLUBLE RESIDUES

TOOLS & EQUIPMENT:

Tanks -	Two (2) metal or plastic
Beakers -	Pyrex, low form, capacity sufficient to contain parts without risk of binding leads.
Vacuum System -	Desiccator or Bell jar, with valve, connected to pump.
Hoses -	Two (2) rubber, with nozzle, connected to hot and cold water lines at tanks.
Containers -	Clean, lint free, for assemblies only.
Oven -	Vacuum, capacity for 70°C, and 3 mm Hg vacuum.
Microscope -	Zoom Type, capacity 30X.
Compressed Air -	Filtered and dried.
or Nitrogen Cylinder -	With connecting hose and nozzle.

SOLUTIONS:

Water -	Hot (50-60°C), and cold, in adjoining tanks, with jet spray.
Water -	Distilled or deionized (P-S E. S. No. 88).

OPERATION STEPS:

NOTE: When cleaning a capsule, rotate the slip ring occasionally during water rinses.

1. Place the assembly in a vacuum oven at a temperature of 70°C for 20 to 25 minutes.
2. Remove from oven and jet rinse in hot water for 20 to 30 seconds.
3. Jet rinse in cold water for 20 to 30 seconds.
4. Immerse assembly in a beaker of tap water, place beaker in a vacuum desiccator or under a Bell jar and vacuum until water boils for 30 to 40 seconds.
5. Remove from water and blast dry with nitrogen or filtered compressed air.
6. Repeat steps 1 through 5.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER WM.	DATE 2-22-67	REV 02	PROCESS INSTRUCTION NO. 143

TITLE:

REMOVAL OF WATER SOLUBLE RESIDUES

OPERATION STEPS CONTINUED:

7. Remove assembly from oven and inspect under 10X and 30X. If salts exudate is present repeat again steps 1 through 5 and reinspect (step 7).

8. When free of all salts residues place assembly in a beaker of distilled water and vacuum until water boils for 30 to 40 seconds.

9. Remove assembly from water, blast dry with nitrogen, or compressed air and return to vacuum oven for 60 to 90 minutes.

10. Remove assembly from oven and place in a clean lint free container for transit.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER WHH.	DATE 2-22-64	REV 02	PROCESS INSTRUCTION NO 143

TITLE: SPRAY CLEANING WITH SODA SLURRY

TOOLS AND EQUIPMENT:

Sprayer -	Connected to a supply of clean compressed air.
Tanks -	Two (2), metal or plastic.
Beakers -	Pyrex, low form, capacity sufficient to contain parts without risk of binding leads.
Hoses -	Two (2), rubber, with nozzle, connected to hot and cold water lines at tanks.
Containers -	Clean, lint free, for assemblies only.

SOLUTIONS:

Sodium Bicarbonate -	($NaHCO_3$), slurry, two (2) pounds to one (1) gallon of water.
Water -	Hot (50° to 60°C), and cold, in adjoining tanks, with jet spray.
Water -	Distilled or deionized (P-S E.S. No. 88).

OPERATION STEPS:

1. Hold the assembly or component one (1) to three (3) inches from sprayer nozzle and spray thoroughly with sodium bicarbonate (soda) slurry. Rotate or turn the part to insure that all surfaces (except leads) are exposed to the spray.
2. Jet rinse with hot water for one (1) minute minimum.
3. Jet rinse with cold water for one (1) minute minimum.
4. Immediately rinse in fresh distilled water for 10 to 20 seconds.
5. If soda removal process (P.I. 143) is called for, proceed immediately with same. If not, place the part in a clean, lint free container for transit.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV	PROCESS INSTRUCTION NO.
	WH	7-28-64	01	147

TITLE: CLEANING LEAD ENDS AFTER SOLDERING

TOOLS & EQUIPMENT:

Beakers -	"Pyrex" or Nalgene, low form, capacity 250 ml.
Generator -	Ultrasonic ("Sontegrator", Model G-40C1-P) and tank ("Sontegrator", Model T-401) or equivalent. The tank shall contain 3/4 to 1-1/2 inches of distilled water and 8 to 10 drops of "L.O.C." solution.
Sprayer -	"Baker", or equivalent, connected to a supply of clean dry compressed air.

SOLVENTS:

Isopropyl Alcohol - P-S E. S. No. 184.

Liquid Organic Cleaner ("L.O.C.") solution - 1/2 oz. "L.O.C." concentrate to one quart of distilled water (P-S E.S. No. 88).

Distilled Water - P-S E. S. No. 88.

OPERATION STEPS:

1. Place a beaker containing about two (2) inches of isopropyl alcohol in the ultrasonic generator tank.
2. Immerse two (2) to three (3) inches of the soldered lead ends in the alcohol.
3. Generate for one (1) to two (2) minutes.
4. Remove leads from solvent and spray soldered tips with isopropyl alcohol for 60 - 70 seconds.
5. Air dry in a clean area.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV. 00	PROCESS INSTRUCTION NO. 159

TITLE: LUBRICATION OF BEARINGS BY SOLVENT APPLICATION

TOOLS AND EQUIPMENT:

Sprayer -	"Baker" or equivalent, connected to a supply of clean, dry air.
Forceps -	Bearing ("Baker" or equivalent); or tweezers, plastic tipped.
Plate or dish -	Glass
Vacuum S stem-	Desiccator, pump, motor, rubber connecting hose, and two-way valve.
Beakers -	"Pyrex" low form, with spout. Capacity 250 ml max.
Syringe -	Hypodermic, glass, capacity 5 cc. and needle.
Generator -	Ultrasonic ("Sontegrator, Model G-40Cl-P) and tank ("Sontegrator," Model T-401) or equivalent. Tank to contain 1/2 inch to 1 inch distilled water, plus 8 to 10 drops of"L.O.C." solution (1/2 oz. "L.O.C." to 1 qt. of distilled water).
Clean Bench -	"Whitfield", "Farr" or equivalent).
Wipers -	Industrial (Scott No. 590 or equivalent).
Can -	Metal or glass with vapor tight cover, labelled "USED FREON".

SOLVENTS:

"Freon" -	Per P-S E.S. No. 85
Isopropyl Alcohol -	Per P-S E.S. No. 184.
Oil -	Bearing (ESSO Univis P-38).

OPERATION STEPS:

NOTES: a) Handle bearings with clean forceps or plastic tipped tweezers only.

b) Perform steps 6 through 9 on a laminar flow clean bench.

1. Spray the bearing thoroughly with "Freon" for 30 to 40 seconds.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	PROCESS INSTRUCTION NO. 161
		12-17-64	01	

TITLE: LUBRICATION OF BEARINGS BY SOLVENT APPLICATION

OPERATION STEPS CONTINUED:

2. Immediately rinse in a small beaker of isopropyl alcohol for 10 to 20 seconds.

3. Rinse in a beaker of "Freon" for 10 to 20 seconds.

4. Place bearing in vacuum desiccator on a fresh industrial wiper and vacuum dry for five (5) minutes.

5. Slowly release the vacuum.

6. Measure 100 ml of "Freon" in a clean 250 ml beaker. Using a hypodermic syringe and needle add one half (1/2) cc of P-38 bearing oil.

7. Place the beakerin an ultrasonic generator tank and generator until oil is evenly dispersed in the "Freon".

8. Remove bearing from desiccator and immerse in the solvent mixture and generate for 50 to 60 seconds.

9. Remove bearing and place on a clean glass plate or dish on clean bench to air dry while awaiting assembly. Do not dry with nitrogen or compressed air.

10. Empty all used "Freon" into reclamation can.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	PROCESS INSTRUCTION NO. 161
		12-17-64	01	

TITLE: FINAL CLEANING OF N.A.S.A. ASSEMBLIES

TOOLS AND EQUIPMENT:

Generator -	Ultrasonic ("Sontegrator, Model G-40Cl-P) and tank ("Sontegrator," Model T-401) or equivalent. Tank to contain one (1) inch to 1-1/2 inches distilled water, plus 8 to 10 drops of "L.O.C." solution (1/2 oz. "L.O.C." to 1 qt. of distilled water).
Desiccator -	Vacuum, Pyrex, with "T" sleeve, inside diameter 200 to 250 mm.
Vacuum System -	Vacuum pump and hose capable of 2 mm Hg or less.
Beakers -	Pyrex, Griffin, with spout, capacity sufficient for complete immersion of assembly without risk of binding leads.
Clean Bench -	Laminar flow.
Microscope -	Capacity, 30X magnification.
Wipers -	Industrial (Scott No. 590, or equivalent).
Cans -	Two, metal, with vapor tight cover; one (1) labelled "USED FREON", one (1) labelled "USED CHLOROTHENE".

SOLVENTS:

Rosin Residue Remover - AP-20, per P-S E.S. No. 102.

Trichloroethane - "Chlorothene," per P-S E.S. No. 101.

Trifluorotrichloroethane - "Freon" per P-S E.S. No. 85.

OPERATION STEPS:

NOTE: a) Read entire process and prepare solvents before beginning.
b) Do not allow assemblies to dry between solvents.

1. Place the assemoly in a beaker containing enough AP-20 to completely cover the part and ultrasonically generate for 60 - 70 seconds.
2. Transfer the beaker to vacuum desiccator and vacuum extract for three (3) to five (5) minutes.
3. Immediately repeat steps 1 and 2 using clean beakers and fresh solvent.
4. Transfer the assembly directly to a beaker of Chlorothene heated to 60°C to 70°C.
5. Place the beaker in an ultrasonic generator tank and generate for 60 to 70 seconds.
6. Transfer the beaker to the vacuum desiccator and vacuum extract three (3) to five (5) minutes.
7. Transfer the assembly directly to a beaker of "Freon" and ultrasonically generate for 60 - 70 seconds.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER cgm	DATE 3-24-65	REV. 01	PROCESS INSTRUCTION NO. 174

TITLE: FINAL CLEANING OF N.A.S.A. ASSEMBLIES

OPERATION STEPS CONTINUED:

8. Remove the capsule from "Freon" beaker, and allow to air dry while slowly rotating the slip ring 10 to 15 revolutions.

   NOTE: Empty all used "Freon" into reclamation can.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE 3-24-65	REV. 01	PROCESS INSTRUCTION NO. 174

TITLE: CLEANING N.A.S.A. SLIP RINGS PRIOR TO FINAL ASSEMBLY

TOOLS AND EQUIPMENT:

Generator -	Ultrasonic ("Sontegrator, Model G-40Cl-P) and tank ("Sontegrator," Model T-401) or equivalent. Tank to contain 1 inch to 1-1/2 inches distilled water, plus 8 to 10 drops of "L.O.C." solution (1/2 oz. "L.O.C." to 1 qt. of distilled water).
Beakers -	Pyrex, Griffin, with spout, capacity sufficient for complete immersion of assembly without risk of binding leads.
Clean Bench -	Laminar flow.
Microscope -	Capacity, 30X magnification.
Wipers -	Industrial (Scott No. 590, or equivalent).
Cans -	Two (2) metal, with vapor tight cover; one (1) labelled "USED FREON", one (1) labelled "USED CHLOROTHENE".

SOLVENTS:

Trichloroethane - "Chlorothene," per P-S E.S. No. 101.

Trifluorotrichloroethane - "Freon" per P-S E. S. No. 85.

OPERATION STEPS:

NOTE: a) Read entire process before beginning.

b) Perform steps 2 through 5 on a laminar flow clean bench.

c) Do not touch critical surfaces of the slip ring at any time.

1. Place the assembly in a beaker containing enough Chlorothene for complete immersion of the slip ring.

2. Place the beaker in an ultrasonic generator tank and generate for one (1) to two (2) minutes.

3. Transfer the assembly directly to a beaker of "Freon" (on clean bench) and generate for 50 to 60 seconds.

4. With the generator still in operation, remove the assembly from the "Freon" and inspect under 30X magnification. If an contamination is observed, repeat steps 1 through 4.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	PROCESS INSTRUCTION NO. 175
		12-17-64	00	

TITLE:	CLEANING N.A.S.A. SLIP RINGS PRIOR TO FINAL ASSEMBLY

OPERATION STEPS CONTINUED:

If slip ring is clean, place on a fresh industrial wiper to await assembly. Do not use container.

5. Empty used "Freon" and used Chlorothene into respective reclamation cans.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	PROCESS INSTRUCTION NO. 175
		2-17-64	00	

TITLE: PRELIMINARY CLEANING FOR SOLDER FLUX REMOVAL

TOOLS AND EQUIPMENT:

Beaker -	Pyrex, with spout; capacity sufficient to contain assembly without risk of binding any leads present.
Generator -	Ultrasonic ("Sontegrator," Model G-40Cl-P) and tank ("Sontegrator," Model T-401), or equivalent. Tank to contain 1 to 1-1/2 inches of distilled water, plus 8 to 10 drops of "L.O.C." solution (1/2 oz. "L.O.C." to 1 qt. of distilled water).

SOLVENTS:

Chlorothene -	Per P-S E.S. No. 101.

OPERATION STEPS:

1. Fill a clean beaker with enough chlorothene for complete and easy immersion of the part to be cleaned. Use fresh solvent for every part.
2. Place the assembly in the beaker of chlorothene. Use care not to strike critical surfaces on the sides or on bottom of the beaker.
3. Place the beaker in an ultrasonic generator tank and generate for one (1) to two (2) minutes.
4. Remove the assembly and return it to work station. Do not dry with compressed air or nitrogen.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	PROCESS INSTRUCTION NO. 176
		12-17-64	00	

TITLE: COMPLEMENTARY CLEANING PRIOR TO FINAL ASSEMBLY

TOOLS AND EQUIPMENT:

Generator -	Ultrasonic ("Sontegrator, Model G-40C1-P) and tank ("Sontegrator," Model T-401) or equivalent. Tank to contain 1/2 inch to 1 inch distilled water, plus 8 to 10 drops of "L.O.C." solution (1/2 oz."L.O.C." to 1 qt. of distilled water).
Wipers -	Industrial (Scott No. 590 or equivalent).
Can -	Metal or glass with vapor tight cover, labelled "USED FREON".
Clean Bench -	Laminar flow ("Farr", "Whitfield", or equivalent.
Gloves - or Finger Cots -	Nylon(Victor, or equivalent). Rubber
Tweezers -	With blunt tips.
Beakers -	Pyrex, low form, with spout.

SOLVENTS:

"Freon" -	Per P-S E.S. No. 85

OPERATION STEPS:

Note: a) Perform the entire process on a laminar-flow clean bench. Clean slip ring and brush block assemblies first, other components last.

b) Wear nylon gloves or finger cots. Tweezers may be used for small, non-contact components.

1. Fill a clean beaker with enough "Freon" for complete immersion of the parts.

2. Place the assembly or components in the "Freon" and ultrasonically generate for one (1) to two (2) minutes. Do not let critical surfaces strike the sides or bottom of the beaker.

3. With the generator still in operation, transfer the part to a fresh industrial wiper. Do not dry with compressed air or nitrogen.

Note: Do not remove any component from the clean bench before completion of final assembly.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	PROCESS INSTRUCTION NO.
		12-22-64	00	177

TITLE: COPPER REDUCTION COATING FOR D.P. PARTS

TOOLS AND EQUIPMENT:

1. Water, distilled or deionized, per P-S Engineering Specification No. 88.
2. Six (6) beakers, Pyrex, 400 ml., Griffin low form with spout.
3. Pumice, powdered, Grade FFF.
4. Brush, Nylon bristles with more than half less than 0.010" diameter (Colgate, or equivalent).
5. Slip ring sub-assembly, with flange protectors and copper plated .003" bump.
6. Sensitizer solution: Stannous chloride ($SnCl_2$) 10 grams and hydrochloric acid (36 - 38% HCl by weight) 40 ml., dissolved in enough distilled or deionized water to make 1,000 ml.
7. Catalyst activator solution: Palladium Chloride ($PdCl_2$) one (1) gram and hydrochloric acid (36-38% HCl by weight) 10 ml. dissolved in enough distilled or deionized water to make one (1) gallon.
8. Copper reduction solution A: copper sulfate ($CuSO_4 \cdot 5\ H_2O$) 29 grams and formaldehyde (37% HCHO by weight) 166 grams dissolved in enough distilled or deionized water to make 1,000 ml.
9. Copper reduction solution B: Sodium potassium titrate ($NaKC_4H_4O_6$) 140 grams and sodium hydroxide (NaOH) 40 grams dissolved in enough distilled or deionized water to make 1,000 ml.
10. Graduated cylinder measuring 0 - 250 ml., subdivisions 1.0 ml..
11. Nitrogen tank with pressure gage, air hose and nozzle attached.

OPERATION STEPS:

1. Scrub the entire front shaft with pumice, applied with the nylon brush, which has been previously wet with tap water. Rinse in flowing hot (50-60°C) tap water and brush alternately until the surfaces are thoroughly clean with no "water breaks".
2. Rinse the front shaft in warm (35-45°C) tap water for 20-30 seconds, then generate in fresh distilled or deionized water for at least one (1) minute.
3. Immerse the front shaft in the sensitizer solution at room temperature (70-80°F) for 2 - 3 minutes.
4. Rinse in flowing tap water for 1 - 2 minutes.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	PROCESS INSTRUCTION NO.
		11-30-64	02	601

TITLE: COPPER REDUCTION COATING FOR D.P. PARTS

OPERATION STEPS CONTINUED:

5. Immerse the front shaft in the catalyst activator solution at room temperature for 3 - 5 minutes.

6. Rinse in flowing tap water for 2 - 3 minutes.

7. Rinse in fresh distilled or deionized water for 20 - 30 seconds.

8. Mix 200 ml. of copper reduction solution A with 200 ml. of copper reduction solution B in a clean 400 ml. beaker.

9. Immerse the front shaft in these mixed solutions at room temperature for fifteen (15) minutes, or until the entire part is covered with an even, adherent coating of copper. Hand agitate at first to remove air bubbles from grooves.

10. Rinse in flowing tap water for 10 - 15 seconds.

11. Rinse in fresh distilled or deionized water for at least fifteen (15) seconds.

12. Go immediately to copper fluoborate bath after distilled or deionized rinse. Electroform copper in accordance to Process Instruction covering part.

13. Do not allow tap water or any solutions to dry upon the front shaft or contact the flange and leads, at any time.

14. The mixed copper reduction solutions can be used until the copper is all precipitated — approximately twenty-four (24) hours.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC	ENGINEER	DATE 12-1-64	REV. 02	PROCESS INSTRUCTION NO. 601

TITLE: COPPER ELECTROFORMING FOR P/N 35626 OR 36512

TOOLS AND EQUIPMENT:

1. Fluoboric acid solution: HBF_4 (48-50%) 100 ml. dissolved in 900 ml. of distilled or deionized water.
2. Bright dip solution: Sulfuric acid (98% minimum H_2SO_4) 256 ml., nitric acid (69% min. HNO_3) 128 ml., hydrochloric acid (3.6% min. HCl) 0.5 ml. and distilled or deionized water 1.5 ml.
3. Water, distilled deionized, per Poly-Scientific E.S. No. 88.
4. Three (3) beakers, Pyrex, 600 ml., Griffin low form with spout.
5. Slip ring sub-assembly, P/N (as stated in Title) with reduced copper coating and flange protectors intact.
6. Plating solution: Copper fluoborate [$Cu(BF_4)_2$] 225 grams dissolved in enough distilled or deionized water to make 1,000 ml.
7. Two (2) copper anodes 1" x 2" x 3", rolled-annealed or electrolytic, 99.9% by weight.
8. Power supply 6-volt battery.
9. Ammeter 0 - 1,800 milliamperes.
10. Rheostat, 100 ohm x 1 amp. capacity.
11. Support bars and clamps, stainless steel, Type 303, for positioning anodes and slip ring sub-assembly in the plating bath.
12. Electrical connect eight (8) No. 45, Cadmium-plated alligator clips attached to sufficient test prod wire (Type 8899, 0.144" O.D. with 0.45 rubber insulation to connect battery, rheostat, ammeter, anodes and the part to be electroplated.
13. Activated carbon, which has been generated in "Freon" (per Poly-Scientific E.S. No. 85) for three (3) minutes, filtered onto a membrane (Gelman GM-6) then dried at 95°C ($\pm$ 5°) for three (3) hours.
14. Stop-off lacquer (Michigan Chrome and Chemical Company, "Microstrip" or equivalent).
15. Brush, camel's hair, 1/8" dia., 5/8" long bristle portion (Torrington 66, No. 5, or equivalent) for applying stop-off.
16. One (1) X-Acto knife and blades #11.
17. One (1) plastic container (5-1/2" x 4" x 11-1/2") Styrene plastic, or equivalent.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS,INC.	ENGINEER	DATE 12-4-64	REV. 03	PROCESS INSTRUCTION NO. 602

TITLE: COPPER ELECTROFORMING FOR P/N 35626 OR 36512

TOOLS AND EQUIPMENT CONTINUED:

18. Pumice, powdered, Grade FFF.

19. Brush, nylon bristles of which more than half are less than 0.010" inch diameter.

20. Nitrogen tank with pressure gage, air hose and nozzle attached.

OPERATION STEPS:

1. Connect the positive side of the battery to the two (2) anodes with electrical connectors.

2. Pour 2.5 liters of the plating solution into the plastic container at room temperature (70-80°F).

3. Position anodes in the copper fluoborate, 180° apart, 1/8" from sides of the container parallel.

4. Connect the slip ring leads to the negative side of the ammeter. Connect the ammeter to the negative side of the battery through the rheostat.

5. The front shaft of the slip ring assembly must be clean. Do not handle an area that is to be electroplated.

6. Position the front shaft in the center of the plating solution, equidistant from the anodes. The flange protectors, applies to the part, per Process Instruction No. 617, must be intact.

7. Gradually raise the amperage to 200 ma (± 2) over a period of 50-60 seconds and plate for fifteen (15) minutes.

8. Reduce the amperage to zero while removing the front shaft from the plating solution.

9. Remove connectors and immerse the front shaft in a 600 ml. beaker, containing 450 ml. of distilled or deionized water (drag-out) for 10-20 seconds.

10. Rinse the front shaft in flowing tap water for 20-30 seconds.

11. Immerse the front shaft in fresh distilled or deionized water at least two (2) minutes.

12. Dry front shaft with nitrogen blast.

13. Apply stop-off to the bearing pin and around the outside portion of the flange protector adjacent to the front shaft. Allow to air dry, 20-30 minutes.

TITLE: COPPER ELECTROFORMING FOR P/N 35626 OR 36512

OPERATION STEPS CONTINUED:

14. Scrape copper reduction from top and side surfaces of plated copper bump following Process Instruction No. 660.

15. Scrub lightly the copper-plated areas of the slip ring front shaft with pumice, applied with the nylon brush, which has been previous wet with tap water. Rinse in flowing hot (50-60°C) tap water.

16. Rinse part in warm (35-45°C) tap water for 20-30 seconds, then immerse in fresh distilled or deionized water for at least one (1) minute.

17. Immerse in fluoboric acid solution for 30-60 seconds, rinse with tap water and immerse in distilled or deionized water for 20-30 seconds.

18. Connect the slip ring lead to the negative side of the ammeter; connect the ammeter to the negative side of the battery through the rheostat.

19. Position the front shaft in the plating solution, equidistant from the anodes. Manually agitate the solution with the front shaft for 50-60 seconds while adjusting the amperage to 257 ($\pm$ 2) (10 a.s.f.).

20. Plate until grooves are closed, then reduce the amperage to zero, while removing the front shaft from the plating solution.

21. Remove the connector and immerse the front shaft in a 600 ml. beaker, containing 450 ml. of distilled or deionized water (drag-out) for 10-20 seconds.

22. Rinse the front shaft in flowing tap water for 20-30 seconds.

23. Immerse the front shaft in fresh distilled or deionized water for at least two (2) minutes and nitrogen dry.

24. Remove the anodes from the plating solution, disconnect and store in drag-out beaker until further use.

TITLE: ELECTROPLATING NICKEL FOR P/N 35626 AND 36512

TOOLS AND EQUIPMENT:

1. One (1) beaker, Pyrex, 1000 ml., Griffin low form with spout.
2. Two (2) beakers, Pyrex, 600 ml., Griffin low form with spout.
3. Wet soda blast equipment, soda bicarbonate - 2 lbs. per gal. u.s.p., stainless steel tank with 1/4 H.P. motor and stainless steel propeller attached, sand blaster gun with hose attached to line pressure, 80 psi, and hood.
4. Heater, capable of maintaining 1000 ml., of plating solution at 58°C ($\pm$ 2).
5. Slip ring sub-assembly, copper-plated and grooved with flange protectors intact.
6. One (1) nickel anode, approximately 6" x 2" x 1", 99.9% minimum Ni, rolled and depolarized, enclosed in a Dynel anode bag.
7. Stirrer, magnetic with Teflon bar, or equivalent.
8. Plating solution: Nickel sulfamate [$Ni(SO_3NH_2]_2$] 450 grams, boric acid (H_3BO_3) 30 grams, Barrett anti-pitting agent (or equivalent) 0.375 gram, and Barrett stress reducer (or equivalent) 1.875 grams dissolved in enough distilled or deionized water to make 1000 ml.
9. Power Supply, 6-volt battery.
10. Ammeter, 0 - 500 milliamperes.
11. Rheostat, 0 - 100 ohm capacity.
12. Electrical connectors, seven (7) No. 45, Cadmium-plated alligator clips attached to sufficient test prod wire (Type 8899, 0.144" O.D. with 0.045" rubber insulation) to connect battery, rheostat, ammeter, anode and the part to be electroplated.
13. Support bars and clamps, stainless steel, Type 303, for positioning anode and slip ring assembly in the plating bath.
14. Pumice, powdered, Grade FFF.
15. Brush, nylon, bristles with more than half, less than 0.010" diameter (Colgate, or equivalent).
16. Ultrasonic generator ("diSontegrator" Model G-40Cl, or equivalent).
17. Nitrogen tank with pressure gage, air hose and nozzle attached.

TITLE: ELECTROPLATING NICKEL FOR P/N 35626 AND 36512

TOOLS AND EQUIPMENT CONTINUED:

18. Fluoboric acid solution: HBF_4 (48-50%) 100 ml. dissolved in 900 ml. of distilled or deionized water.

OPERATION STEPS:

1. Apply flange protectors as written in Process Instruction No. 617.
2. Wet soda blast copper plated areas of the slip ring front shaft with soda bicarbonate. Rinse in flowing warm (20-30°C) tap water and nitrogen dry.
3. Attach electrical connector to the anode, connecting it to the positive side of the battery.
4. Pour 800 ml. of the plating solution into a 1000 ml. beaker.
5. Stir solution mildly while heating to 58°C (± 2°) and during plating.
6. Position the anode in the plating solution about 1/8" from an inside surface of the beaker.
7. Electroetch part in fluoboric acid solution at 3.0 volts until copper turns dark or bright in appearance with hand agitation.
8. Immediately rinse in flowing tap water for 10-15 seconds, then rinse with hand agitation in a beaker of distilled or deionized water for 15-20 seconds, then immediately go to nickel bath.
9. Connect the slip ring leads to the negative side of the ammeter; connect the ammeter to the negative side of the battery through the rheostat.
10. Adjust the temperature of the plating solution to 58°C (±2°) and maintain throughout the plating.
11. Position the front shaft in the plating solution, equidistant from the anode and the side of the beaker.
12. Front shaft of the assembly must be clean. Do not handle with the bare hands any surfaces which are to be electroplated.
13. Adjust the amperage to 363 ma (± 2 ma) (50 a.s.f.).
14. Plate for nine (9) minutes.
15. Reduce the amperage to zero while removing the front shaft from the plating solution.

TITLE: ELECTROPLATING NICKEL FOR P/N 35626 AND 36512

OPERATION STEPS CONTINUED:

16. Remove the connector and immerse the front shaft in the 600 ml. beaker, containing 400 ml. of distilled or deionized water (drag-out) for 10-20 seconds.

17. Rinse the front shaft in flowing tap water for 20-30 seconds.

18. Visually inspect the front shaft, using 10X-45X for imperfections.

19. Immerse the front shaft in fresh distilled or deionized water until ready for gold electroforming.

20. Remove the anode from the plating solution, disconnect and store in the drag-out beaker.

21. Do not allow tap water or plating solution to dry upon the assembly at any time.

22. Maintain the flange protectors intact so as to prevent any solutions from contacting the flange, leads or the inside surfaces of the protectors, which must be kept dry.

23. Maintain the plating solution:

    a) At a temperature between 56 and 60°C.
    b) With nickel (Ni) content between 9 and 10 oz./gal.
    c) With a boric acid content between 3.5 and 4.0 oz./gal.
    d) With an anti-pit content between 0.04 and 0.05 oz./gal.
    e) At a pH, at 80°F, between 3.5 and 4.5.
    f) With the stress reducer concentration between 0.2 and 0.3 oz./gal.
    g) Free of particulate contaimination: filter as necessary through two (2) fiberglass filters (Gelman Type E, or equivalent).

24. Do not let slip ring dry between nickel and gold electroforming. Inspect nickel in step 18 while still wet.

TITLE: GOLD ELECTROFORMING FOR P/N 35626 OR 36512

TOOLS AND EQUIPMENT:

1. Water bath at 35°C (±1°).
2. Four (4) gold anodes, 1/16" x 1/2" x 4", KHN 40-80, (60 max.) Au 99.9% by weight, cut parallel to the direction of rolling.
3. Water, distilled or deionized, P-S Engineering Specification No. 88.
4. Plating solution: Potassium gold cyanide [$KAu(CN)_2$] 122.4 grams, potassium cyanide (KCN) 52.5 grams dissolved in enought distilled or deionized water to make 1,000 ml.
5. Beakers, four (4) Pyrex, 600 ml. Griffin low form with spout.
6. Power supply, 6-volt battery.
7. Ammeter, DC, 0-100 milliamperes.
8. Electrical connectors: Nine (9) No. 45, Cadmium-plated alligator clips attached to sufficient test prod wire (Type 8899, 0.144" O.D. with 0.045" rubber insulation) to connect battery, rheostat, ammeter, anodes and the part to be electroplated.
9. Rheostat, 100 ohm x 1 amp. capacity.
10. Rods, stainless steel, type 303, 0.55" dia. (± 0.05") x 12" long, support bars.
11. Support bar clamps.
12. Support blocks, aluminum, 3/4" x 4" x 4".
13. Pumice, powdered, Grade FFF.
14. Brush, nylon bristles with more than half less than 0.010" diameter (Colgate, or equivalent).
15. Hydrochloric acid solution: HCl (35-37%) 500 ml. dissolved in 500 ml. of distilled or deionized water.
16. Ultrasonic generator ("diSontegrator" Model G-40Cl, or equivalent).
17. Slip ring assembly with nickel plate, per Process Instruction No. 605, and flange protectors intact.
18. Activated carbon, which has been generated in "Freon" (Per P-S E. S. No. 85) for three (3) minutes, filtered onto a membrane filter (Gelman GM-6), then dried at 95°C (±5°) or three (3) hours.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE 3-1-65	REV. 06	PROCESS INSTRUCTION NO. 606

TITLE: GOLD ELECTROFORMING FOR P/N 35626 OR 36512

TOOLS AND EQUIPMENT CONTINUED:

19. Gold Strike Bath: Potassium gold cyanide [$KAu(CN)_2$] 6.1 grams, potassium cyanide (KCN) 75.0 grams dissolved in enough distilled or deionized water to make 1,000 ml.

OPERATION STEPS:

1. Remove nickel electroformed slip ring from beaker of distilled or deionized water and hand agitate in hydrochloric acid 50% for 30-45 seconds.
2. Rinse in flowing warm (35-45°C) tap water for 45-60 seconds.
3. Generate the front shaft in fresh distilled or deionized water for at least one (1) minute.
4. Place a 600 ml. beaker, containing 400 ml. of plating solution, upon a support block within the water bath at 35°C (± 1°).
5. Attach electrical connectors to the two (2) anodes, connecting them to the positive side of the battery.
6. Position the anodes in the plating solution, 180° apart, a parallel to and 1/8" from the sides of the beaker.
7. Gold strike slip ring in strike solution at 120.0 ma (± 0.2) or raise current until part gases, hand agitate for 20-30 seconds.
8. Remove slip ring from strike bath, go straight to plating bath with current on.
9. Connect the slip ring leads to the negative side of the ammeter. Connect the ammeter tothe negative side of the battery through the rheostat.
10. Position the slip ring front shaft in the center of the plating solution, equidistant from the anodes.
11. Adjust amperage from 15 to 62.0 ma (± 0.2) 10.0 a.s.f. over 5 - 10 minutes.
12. After plating for five (5) hours, raise amperage to 68.0 ma.
13. After plating for another five (5) hours, or until gold is above barriers, remove the front shaft from the plating solution then reduce the amperage to zero.
14. Remove the connector and immerse the front shaft in a 600 ml. beaker, containing 450 ml. of distilled or deionized water (drag-out), for 10-20 seconds.

TITLE: GOLD ELECTROFORMING FOR P/N 35626 OR 36512

OPERATION STEPS CONTINUED:

15. Rinse the front shaft in flowing tap water for 20-30 seconds.

16. Immerse the front shaft in fresh distilled or deionized water for at least two (2) minutes.

17. Visually inspect the front shaft for dark areas; if any detected, pumice a plated area and rinse for fifteen (15) seconds; immerse in distilled or deionized water for one (1) minute.

18. Remove the anodes from the plating solution, disconnect and rinse in the drag-out beaker for 10-15 seconds.

19. Store the anodes in a beaker of fresh distilled or deionized water when not in use.

20. Replace anodes periodically to minimize flaking and breaking while in use. Remove all gold particles and pieces of broken anodes from the plating solution as soon as possible.

21. Do not allow tap water, hydrochloric acid solution or plating solution to dry upon the front shaft at any time.

22. Maintain the plating solution:

    a) At a temperature between 34 and 36°C.

    b) Within 0.5 troy oz./gal. of Au content, 1.0 oz./gal. of free KCN and the K_2CO_3 content below 4.0 oz./gal.

    c) Free of contamination: filter as necessary through activated carbon, supported by two (2) fiberglass filters (Gelman Type E) in a stainless steel funnel.

23. Do not handle with bare hands the surfaces of the slip ring assembly which are to be plated.

24. Do not allow any solutions to contact the flange, leads, or inside of the flange protector, which must be kept intact and dry.

25. Maintain strike bath:

    a) At room temperature 70°F ($\pm$ 3°).

    b) Within 0.2 troy oz./gal. of Au content, 1.0 oz./gal. of free KCN and the K_2CO_3 content below 4.0 oz./gal.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC	ENGINEER	DATE 3-1-65	REV. 06	PROCESS INSTRUCTION NO. 606

TITLE: GOLD FLASH FOR P/N 35626 AND 36512

TOOLS AND EQUIPMENT:

1. Slip ring assembly with grooved gold rings and flange protectors intact; surfaced conditioned to E. S. 89. Soda blast-wet and soda removed.
2. Pumice, powdered, Grade FFF.
3. Water, distilled or deionized, per P-S E. S. No. 88.
4. Two (2) anodes, Platinum (99.9% Pt by weight) 9/16" (± 1/32") wide, 2 (± 1/16") long, 0.006" thick. Stainless steel may be used if platinum is not available.
5. Plating solution: 20 dwg./gal. of Au (Technic "OROTHERM" HT or equivalent).
6. Heater, electric, capable of maintaining 400 ml. of plating solution at 60°C (± 1°).
7. Three (3) beakers, Pyrex, 600 ml., Griffin low form with spout.
8. Power Supply, 6-volt battery.
9. Ammeter, DC, 0-100 milliamperes.
10. Electrical connectors: Nine (9) No. 45, Cadmium-plated alligator clips attached to sufficient test prod wire (Type 8899, 0.144" O.D. with 0.045" rubber insulation) to connect battery, rheostat, ammeter, anodes and the part to be electroplated.
11. Rheostat, 100 ohm x 1 amp. capacity.
12. Support bars and clamps, stainless steel, Type 303, for positioning anodes and slip ring assembly in the plating bath.
13. Fluoboric acid solution: HBF_4 (48-50%) 100 ml. dissolved in 900 ml. of distilled or deionized water.
14. Detergent ("Alconox", or equivalent).
15. Brush, Nylon bristles with more than half less than 0.010" diameter.
16. Ultrasonic generation ("diSontegrator" Model G-40C1, or equivalent).
17. Two (2) bags, Polyethylene, 4" wide, 8" long, 0.002" (± 0.001") thickness.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE 12-10-64	REV. 01	PROCESS INSTRUCTION NO. 607

TITLE: GOLD FLASH FOR P/N 35626 AND 36512

OPERATION STEPS:

1. Rinse front shaft in flowing hot (50-60°C) tap water and brush with Nylon brush lightly to remove any foreign matter and a surface with no "water breaks" must result.
2. Rinse the front shaft in warm (35-45°C) tap water for 20-30 seconds.
3. Immerse in the fluoboric acid solution for one (1) minute.
4. Rinse in flowing warm (35-45°C) tap water for 20-30 seconds.
5. Immerse the front shaft in fresh distilled or deionized water and generate in ultrasonic generator for one (1) minute. Leave slip ring in distilled water until ready for plating.
6. Pour 400 ml. of the plating solution into a 600 ml. beaker.
7. Heat plating solution to 60°C (± 1°) and maintain this during plating.
8. Attach electrical connector to the two (2) anodes, connecting them to the positive side of the battery.
9. Position the anodes in the plating solution, 180° apart, parallel to and 1/8" from the sides of the beaker.
10. Connect the slip ring leads to the negative side of the ammeter. Connect the ammeter to the negative side of the battery through the rheostat.
11. Position the slip ring front shaft in the center of the plating solution, equidistant from the anodes.
12. Adjust the amperage to 47 ma (± 2) (4 a.s.f.). Agitate with hand to move gas bubbles.
13. Plate for 62 minutes, or a minimum of 0.0004" thickness.
14. Reduce the amperage to zero while removing the front shaft from the plating solution.
15. Remove the connector and immediately rinse the front shaft in flowing hot (50-60°C) tap water for 20-30 seconds.
16. Brush slip ring lightly with Alconox to remove dark spots and rinse in warm (35-45°C) tap water for one (1) minute.
17. Immerse the front shaft in fresh distilled or deionized water for at least two (2) minutes.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE 12-10-64	REV. 01	PROCESS INSTRUCTION NO. 607

TITLE: GOLD FLASH FOR P/N 36526 AND 36512

OPERATION STEPS CONTINUED:

18. Remove the anodes, disconnect and store in distilled or deionized water until further use.

19. Do not allow tap water, HBF_4 solution or plating solution to dry upon the assembly at any time.

20. Do not handle with bare hands the surfaces of the front shaft which are to be plated.

21. Do not allow any solutions to contact the flange, leads or the inside of the flange protectors, which must be kept intact and dry.

22. Slip ring should be kept in plastic bag before and after electroforming.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS,INC.	ENGINEER	DATE 12-10-64	REV. 01	PROCESS INSTRUCTION NO. 607

TITLE: COPPER PLATING LEAD ENDS OF D. P. PARTS

TOOLS & EQUIPMENT:

1. Water, distilled or deionized, per P-S E. S. No. 88.
2. Soda blast equipment.
3. Fluoboric acid (10% solution): HBF_4 (48-50%) 200 ml. dissolved in 800 ml. of distilled or deionized water.
4. Slip ring sub-assembly, P/N 35545, with flange protectors intact.
5. Two (2) copper anodes 1/8" x 2" x 3", rolled and annealed or electrolytic, 99.9% by weight.
6. Two (2) cathode thieves, copper, 1/8" x 1" x 2-1/2".
7. Plating solution: copper fluoborate [$Cu(BF_4)_2$] 225 grams dissolved in enough distilled or deionized water to make 1,000 ml.
8. Power supply, 6-volt battery.
9. Ammeter, DC, 0 - 500 milliamperes.
10. Electrical connectors, eight (8) No. 45, cadmium-plated alligator clips attached to sufficient test prod wire (Type 8899, 0.144" O.D. with 0.045" rubber insulation) to connect battery, rheostat, ammeter, anodes, thieves and the part to be electroplated.
11. Rheostat, 100 ohm x 1 amp. capacity.
12. Support bars and clamps, stainless steel, Type 303, for positioning anodes, thieves and part in plating bath.
13. Three (3) beakers, Pyrex, 600 ml., Griffin low form with spout.
14. Bright dip solution: Sulfuric acid (98% minimum H_2SO_4) 256 ml., nitric acid (69% minimum HNO_3) 128 ml., hydrochloric acid (36% minimum HCl) 0.5 ml., and distilled or deionized water 1.5 ml.

OPERATION STEPS:

1. Soda blast for 1 - 2 minutes. Jet rinse with cold tap water for a minimum of one (1) minute.
2. Electroetch in 10% fluoboric acid solution at 9 - 10 volts for 5 - 10 seconds with hand agitation. The surfaces must be thoroughly clean with no "water breaks". The lead ends must appear bright and free of corrosion under 45X magnification.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV. 04	PROCESS INSTRUCTION NO. 608

TITLE: COPPER PLATING LEAD ENDS OF D. P. PARTS

OPERATION STEPS CONTINUED:

3. Rinse front shaft in tap water for 20-30 seconds, then immerse in fresh distilled or deionized water for at least one (1) minute.

4. Attach electrical connectors to the two (2) anodes, connecting them to the positive side of the battery.

5. Pour 400 ml of the plating solution into a 600 ml beaker at room temperature (70-80°F).

6. Position the anodes in the plating solution, 180° apart, parallel to and 1/8" from the sides of the beaker.

7. Connect the slip ring leads and the cathode thieves to the negative side of the ammeter, connect the ammeter to the negative side of the battery through the rheostat. Ensure a good connection to the thief cathode.

8. Position the slip ring front shaft in the center of the plating solution, equidistant from the anodes.

9. Position the cathode thieves equidistant from the front shaft and the anodes.

10. Adjust amperage to 400 ma (± 2) (10 a.s.f.).

11. Plate for sixty (60) minutes, or until the lead ends are completely covered with an adherent "bump" of copper at least 0.001" thick.

12. Remove the connector, reduce amperage to zero, and immerse the front shaft in a 600 ml beaker containing 450 ml of water (drag-out) for 10-20 seconds.

13. Rinse the front shaft in flowing tap water for 20-30 seconds.

14. Visually inspect front shaft, before soaking (in step 15), using 10X to 45X, for imperfections or discolorations around the lead ends. Carefully test bonding of copper plate to the lead ends. All must be securely bonded. Top of plated copper should be scraped cleaned with an X-Acto knife with care exercised to not sever connection on sides to reduction coating.

15. Immerse the front shaft in the fresh distilled or deionized water until ready for copper reduction in accordance with Process Instruction No. 601.

16. Remove the anodes and the cathode thieves from the plating solution, disconnect and store in the drag-out beaker until further use.

TITLE: COPPER PLATING LEAD ENDS OF D. P. PARTS

OPERATION STEPS CONTINUED:

17. Do not allow tap water, fluoboric acid, or plating solution to dry upon the front shaft, or contact the flange and leads, at any time.

18. Do not handle with the bare hands any surfaces which are to be plated.

19. Remove any discolorations from lead ends by immersing the front shaft in bright dip solution for two (2) seconds, rinsing immediately in flowing tap water for 10-15 seconds, immersing in the bright dip again for two (2) seconds, rinsing immediately in flowing tap water for 10-15 seconds, then immersing in fresh distilled or deionized water for at least two (2) minutes.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV. 04	PROCESS INSTRUCTION NO. 608

TITLE: FLANGE PROTECTORS FOR P/N 35626 (SUB-ASSEMBLY P/N 35545)

TOOLS AND EQUIPMENT:

1. Bag, polyethylene, 4" wide, 8" long, 0.002 (± 0.001) inch thickness.
2. Cap, polyethylene, 2-1/2" (± 1/32") I.D., 2-9/16" (± 1/32") O.D., 1/32" - 1/8" thick ("CAPLUG™ 2-1/2 SC, or equivalent).
3. Stop-off lacquer (Michigan Chrome and Chemical Co., "Microstrip," or equivalent).
4. Brush, camel's hair, 1/8" diameter 5/8' long bristle portion (Torrington 66, No. 5, or equivalent) for applying stop-off.
5. Cork borer, size No. 3(O.D. 5/16"), or equivalent.

OPERATION STEPS:

1. Place closed end of plastic bag inside plastic cap. Position so that the cork borer can be used to cut a neat hole through the center of the bottom portion of the cap and an area of the bag, 1/4" to 1/2" from any seams or the closed end of the bag.
2. Carefully push the front shaft through these holes, fitting the bag and cap snugly against the flange. The flange and the leads should be enclosed by the bag. The flange must be inside the cap, thus separated from the front shaft.
3. Apply stop-off to the bearing pin and around the outside portion of the cap adjacent to the front shaft. Air dry for thirty (30) minutes. The flange and the leads exiting from it must be sealed water tight to prevent contamination from the solution, which will be used in cleaning and plating the front shaft.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER W. Starkey	DATE	REV.	PROCESS INSTRUCTION NO. 617

TITLE: RUN-IN OF N.A.S.A. CAPSULES

TOOLS AND EQUIPMENT:

1. Run-in fixture consisting of timer, transformer, variable speed drive motor, belt drive to hollow tube equipped with fixed lathe chucks at one end and slip ring lead holder at other end.
2. Assembled capsule.

OPERATION STEPS:

1. Position slip ring leads inside the hollow shaft of fixture until the capsule housing can be chucked onto.
2. Chuck the capsule into place leaving approximately 1/4" between the flange and the face of the chucks.
3. If the slip ring leads are sufficiently long to extend out of the opposite end of the fixture tube, wrap the leads in the lead holder provided at the end of the fixture tube.
4. Flip the reversing switch to "clockwise (CW)" position.
5. Set the timer to 60 minutes.
6. Flip the power switch to "ON" after turning the speed selector to 0 rpm.
7. Allow 30 seconds for warm-up.
8. Turn the speed selector to 100 rpm.
9. When the timer buzzer goes off, turn the speed selector to 0 rpm.
10. Flip the reversing switch to "counter-clockwise (CCW)" position.
11. Re-set the timer to 60 minutes.
12. Turn the power selector to 100 rpm.
13. When the timer buzzer goes off, turn the speed selector to 0 rpm.
14. Flip the power switch to "OFF".
15. Disengage the slip ring leads from their holder.
16. Remove the capsule from the fixture.
17. Place the capsule in a clean plastic container.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER M. Hensley 10-7-64	DATE 0-7-64	REV. 01	PROCESS INSTRUCTION NO. 701

TITLE: 100 HOUR RUN-IN OF CAPSULES

EQUIPMENT:

1. Run-in fixture with 5 rpm drive.
2. Assembled capsule (housing not secured) ready for final acceptance testing.

OPERATION STEPS:

1. Position the capsule in the run-in fixture in such a manner so as to drive the slip ring end (flange).
   a) In the general fixture a wooden or aluminum spool is provided to drive the slip ring. Bring the slip ring flange flush with this spool so that the slip ring leads can be positioned into the spool slots and the leads carefully wrapped about the spool. Masking tape is used to secure the leads to the spool.
2. Begin the rotation (5 rpm) by starting the drive motor.
3. Reverse the direction of rotation once every eight (8) hours (no less often than once every 12 hours).
4. Upon completion of 100 hours run-in time, remove the capsule from the run-in fixture.
5. Remove the housing so that the capsule interior may be observed.
6. Examine the interior under a 20X microscope for evidence of wear or contamination.
7. Decide on the basis of the forgoing examination whether the capsule has successfully met the 100 hour run-in requirement.
   a) Any evidence of seizure or contamination shall be cause for rejection.
8. If the capsule fails this examination:
   a) Reclean per P.I. No. 136.
   b) Perform qualification tests (noise and torque).
   c) Re-cycle through 100 hour run-in test if capsule passes qualification tests as directed in 8-b above.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER PRR	DATE 12/19/63	REV. 00	PROCESS INSTRUCTION NO. 702

TITLE: PREPARATION OF N.A.S.A. LEAD JUMPER ASSEMBLIES

TOOLS AND EQUIPMENT:

1. Mylar heat-shrink tubing (0.030 I.D. before shrinking).
2. AWG 30 - 19/42 Teflon (Clear TFE) insulated (max. O.D. of 0.030 inch) leads cut to length per applicable print.
3. AWG 30 HML insulated magnet wire cut to print specified length and stripped chemically.
4. Heat stripper capable of stripping TFE extruded Teflon from 30 AWG lead wire.
5. Miscellaneous hand tools:

   Soldering iron
   Solder and flux
   Holding fixture (i.e., mounted spring loaded long nose pliers)
   X-Acto knife with sharp blade
   Diagonal cutters
6. 600 ml beakers
7. Chlorothene per E. S. No. 101.

OPERATION STEPS:

1. Heat strip approximately 1/4 inch from one end of each Teflon insulated lead. (Apply only enough tip pressure to cut through the insulation then release tip pressure and remove the 1/4 inch sleeve by hand. Do not apply direct tip pressure to the conductor.)
2. Cut exposed 1/4 inch length of conductor off back to within approximately 0.050 inch of the Teflon insulation using diagonal cutters.
3. Cut exposed 1/4 inch stripped and tinned portion of HML jumper off back to within approximately 0.050 inch of the HML insulation using diagonal side cutters.
4. Position the Teflon lead vertically in the holding fixture so that the stripped portion is topmost and is approximately 1/8 inch above plier jaws.
5. Apply one drop of flux to the exposed conductor by using a tooth-pick.
6. Position the stripped portion of the jumper adjacent to and parallel with the stripped portion of the Teflon insulated lead.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER P.L.R.	DATE 11-9-64	REV. 00	PROCESS INSTRUCTION NO. 800

TITLE:	PREPARATION OF N.A.S.A. LEAD JUMPER ASSEMBLIES

OPERATION STEPS CONTINUED:

7. Touch the clean tinned portion of a hot soldering iron to the end of a solder wire to secure a small amount of solder on the tip. Then touch this hot tip to the exposed and tinned magnet wire until the solder flows to encircle both exposed conductors, approximately 2 seconds).

8. Drop each junction, as completed, into a 600 ml beaker of Chlorothene (2/3 full). After completing each set rinse set through 600 ml beaker of fresh chlorothene for 30 seconds using ultrasonic generator.

9. Visually inspect (10X minimum) for good solder joint and for proper spacing between HML and Teflon (0.075 inch or less).

10. Using X-acto knife and a metal scale marked in tenths, pre-cut mylar tubing to approximately 0.20 inches.

11. Work flared Teflon (incurred during heat stripping) down and toward jumper lightly with fingernails. This is necessary to give clearance for mylar tubing.

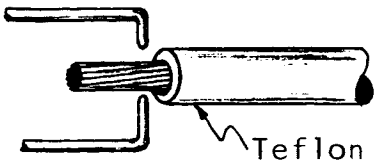
12. Slip pre-cut tubing up jumper and over solder joint to insulate both exposed conductors. Position so that excess tubing is divided equally over Teflon and HML insulations.

13. Place prepared lead jumper assemblies in a 120°C oven for five (5) minutes minimum.

14. Inspect (10X minimum) completed assemblies for insufficient coverage of bare conductor and for rupture of the tubing exposing the bare conductor and/or solder joint.

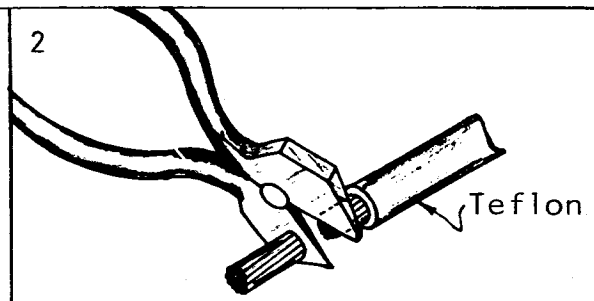
    NOTE: If insufficient coverage of bare conductor is observed, carefully axially slit the mylar and pull off with needle nose pliers. Begin with Step 12 and reprocess to get an acceptable lead.

1



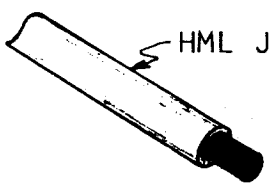
Heat strip approximately 1/4 inch of Teflon.

2



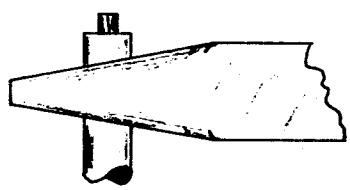
Cut conductor to within approximately 0.050 inch of the Teflon.

3



Cut pre-stripped (in Chemical Department) end of jumper to within approximately 0.050 inch of the HML.

4



Position Teflon lead in spring loaded long-nose pliers.

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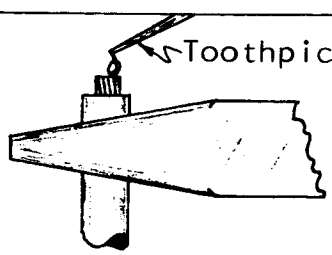
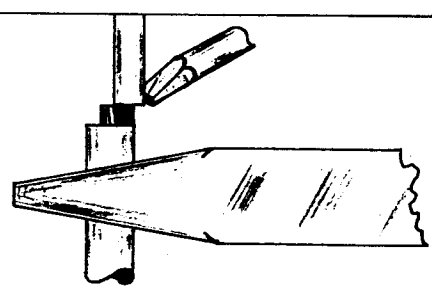


Apply drop of flux to the conductor.

6

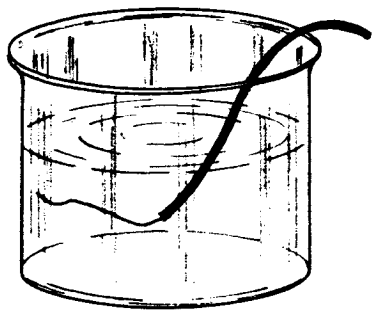


Position stripped portion of jumper against stripped portion of lead and apply hot tip with solder.

PREPARATION OF NASA LEAD-JUMPER ASSEMBLIES
P.I. 800

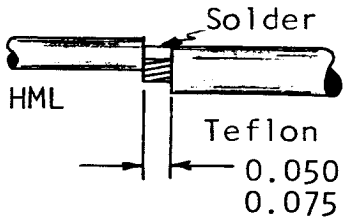
(continued)

7



Rinse in chlorothene for thirty (30) seconds minimum per set.

8



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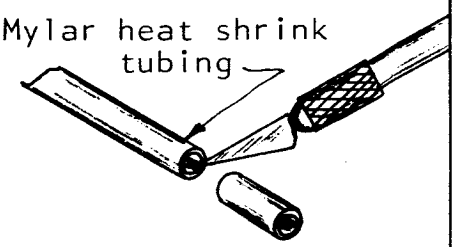
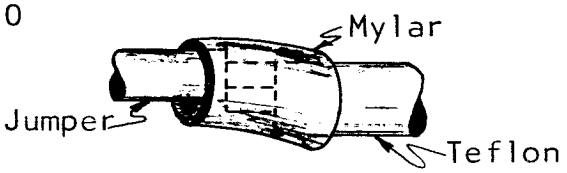


Cut tubing to 0.200 inch with sharp X-Acto knife and metal scale (hundredths).

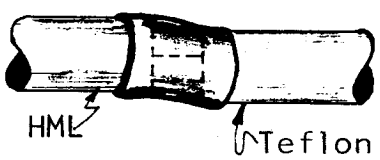
10



Slip tubing over jumper, solder joint, and Teflon so that all exposed conductor is covered and excess tubing is positioned equally on either side.

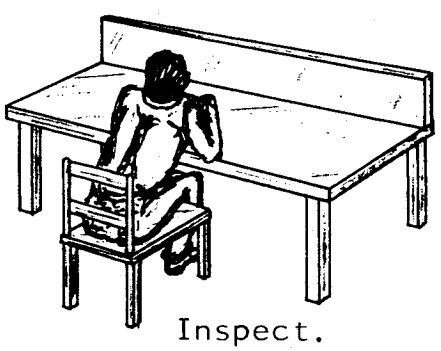
(*) Note.

11



Place in 120°C oven for five (5) minutes minimum and remove.

12



Inspect.

PREPARATION OF NASA LEAD-JUMPER ASSEMBLIES
P.I. 800

(*) Work flared Teflon at area of heat strip down (forward) with fingernails.

TITLE: RESISTANCE WELDING #30 (19/42) SILVER PLATED COPPER WIRE TO YELLOW BRASS JUNCTION PLATE (65 Cu - 35 Zn) FOR DP 1405

TOOLS AND EQUIPMENT:

Power Supply - Capable of 100 watt-seconds and a discharge time of 4-5 milliseconds only. (Unitek Model 1045 or equivalent).

Weld Head - Capable of 4 oz. to 15 lbs. (Weldmatic - 1032 or 1101, or equivalent).

Electrodes - Per drawing E-1 and E-2 (attached).

Microscope - 10X magnification.

Knife - "X-Acto"

Finger Cots - Latex Tissue Finger Cots (Richmond Surgical Supply Co., or equivalent).

Ultrasonic Generator and Tank - with 1/2 to 1 inch distilled water in tank.

Power Leads - 9-1/2" standard length only.

Solvents - Filtered isopropyl alcohol. "Freon" (E. S. No. 85).

OPERATION STEPS:

1. Set-up weld head with electrodes number E-1 and E-2 (drawings enclosed) and align per Figure 2.
2. Set pressure on weld head to 120 ± 10 ounces (7.5 ± 1/2 lbs.) with spring scale or force gage.
3. Attach negative lead from power supply to top electrode. Attach positive lead to bottom electrode.
4. Turn on power supply and allow to warm-up (about 30 seconds) then set to 90 (± 5) watt-seconds. Trip switch to "set-up" then back to correct range to see if reading repeats. If not, refer to trouble shooting section below.
5. Obtain parts to be welded.
6. Place one (1) junction plate on top of table on bottom electrode with long axis of plate pointing toward operator.
7. Hold junction plate in left hand and a lead to be welded in the right hand.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV. 00	PROCESS INSTRUCTION NO. 909

TITLE: RESISTANCE WELDING #30 (19/42) SILVER PLATED COPPER WIRE TO YELLOW BRASS JUNCTION PLATE (65 Cu - 35 Zn) FOR DP 1405

OPERATION STEPS CONTINUED:

8. Place bare end of lead on top of first section (fartherest from operator) of the junction plate.
9. Be sure to check print for even and odd plates and correct alignment of weld joints.
10. When alignment is correct with print, bring down top electrode with foot pedal and make sure top electrode covers lead correctly.
11. Continue to press on foot pedal until welder "trips". Weld is complete.
12. Repeat steps #7 through #11 for remaining leads, staggering in groups of five (5).
13. Re-dress electrodes at least once per 25 welds by scraping bearing surfaces on each electrode with an "X-Acto" knife until surfaces show normal metallic lustre.
14. Replace electrodes every twenty (20) parts.

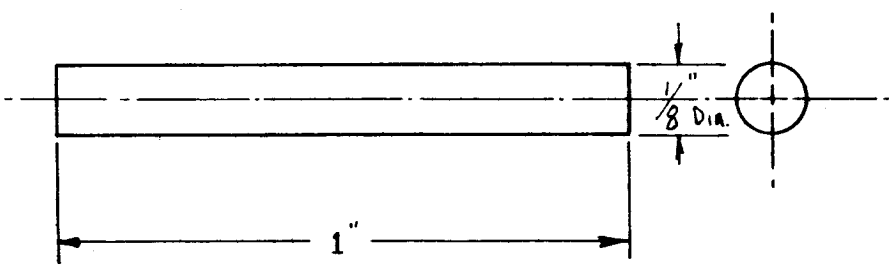
TROUBLE SHOOTING:

1.	No weld on set-up:	(1) Check power setting. (2) Check switch for "weld". (3) Check lead to weld head. (4) Check electrode alignment. (5) After checks and still no weld, notify Supervisor.
2.	Visual appearance shows poor weld.	(1) Check power setting. (2) Check electrodes for dirt. (3) If all appears correct, call Supervisor.
3.	After explosion (spattering)	(1) Change electrodes. (2) If explosion repeats with new electrodes, notify Supervisor.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV. 00	PROCESS INSTRUCTION NO. 909

REVISIONS			
SYM.	DESCRIPTION	DATE	APPROVED

REV.



MATERIAL: $\frac{1}{8}$" DIA. RWMA # 2 ROD

NO. REQ'D: _____

NEXT ASS'Y	P.S. FILE	QTY. REQ'D.

APPLICATION

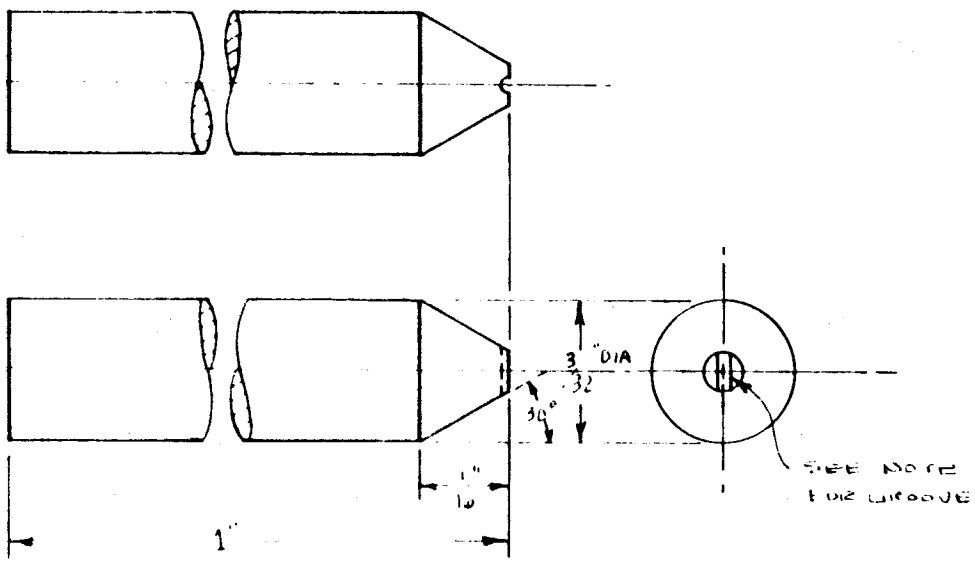
TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED R.E. Livingston	DATE	DP-1405, EG-1416, AND EG.-1417 Bottom Electrode	POLY - SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC. BLACKSBURG, VIRGINIA
DECIMALS ± .005	DRAWN S.M. Caldwell	DATE 12/17		
FRACTIONS ± 1/64	CHECKED	DATE		
ANGLES ± 1/2°				
FED. SUPPLY CODE NO. 99932	APPROVED	DATE	SCALE: 4:1	DWG. SIZE A

E - 1-P.I.909

SHEET OF

REVISIONS			
SYM.	DESCRIPTION	DATE	APPROVED

KEY



MATERIAL: .125" DIA PLATINUM

NOTE: FOR GROOVE .008" DIA, 0.005" DEEP - EG-1417
.008" DIA, 0.005" DEEP - EG-1416
0.010" DIA, 0.001" DEEP - DP-1405
.125" DIA, 0.006" DEEP ±.001 -.000

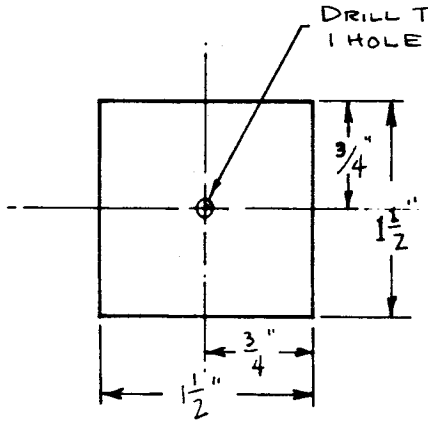
NEXT ASS'Y	P.S. FILE	QTY. REQ'D.

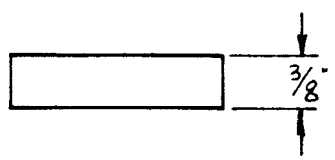
APPLICATION

TOLERANCED UNLESS OTHERWISE SPECIFIED	DESIGNED C.E Livingston DATE	DP-1405, EG-1416, AND EG-1417 TOP ELECTRODE	POLY - SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC BLACKSBURG, VIRGINIA
DECIMALS ± .000	DRAWN S.M. Caldwell 10-11 DATE		
FRACTIONS ± 1/64	CHECKED DATE		
ANGLES ± 1°	APPROVED DATE	SCALE: 10:1	DWG SIZE A
FED SUPPLY CODE NO 88932			E-2-P.I. 909
			SHEET OF

REVISIONS			
SYM.	DESCRIPTION	DATE	APPROVED

REV.





MATERIAL: 3/8" TK. STOCK PHENOLIC OR PLASTIC

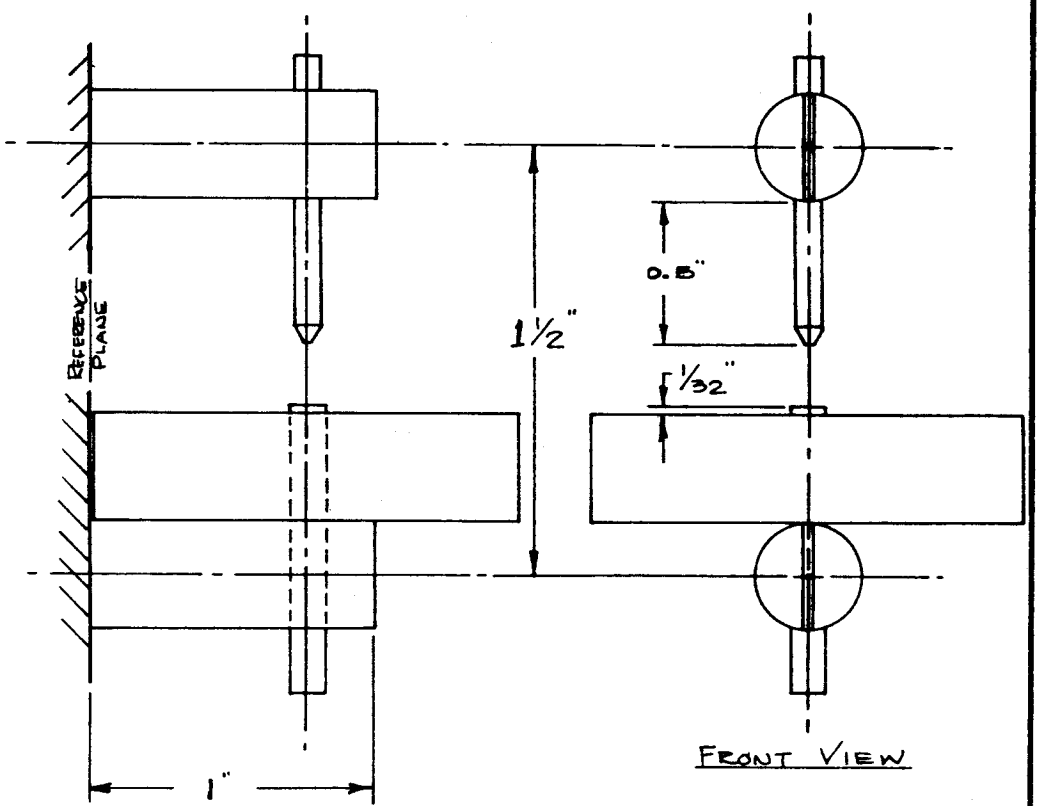
NEXT ASS'Y	P.S. FILE	QTY. REQ'D.

APPLICATION

TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED R.E. Livingston DATE	DP-1405, EG-1416 AND EG-1417 BOTTOM ELECTRODE TABLE	POLY - SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC. BLACKSBURG, VIRGINIA
DECIMALS ± .005	DRAWN S.M. Caldwell 12/17 DATE		
FRACTIONS ± 1/64	CHECKED DATE		
ANGLES ± 1/2°			
FED. SUPPLY CODE NO. 99932	APPROVED DATE	SCALE: FULL	DWG. SIZE A
			FIG. 1-P.I. 909
			SHEET OF

REVISIONS			
SYM.	DESCRIPTION	DATE	APPROVED

REV.



FRONT VIEW

NEXT ASS'Y	P.S. FILE	QTY. REQ'D.

APPLICATION

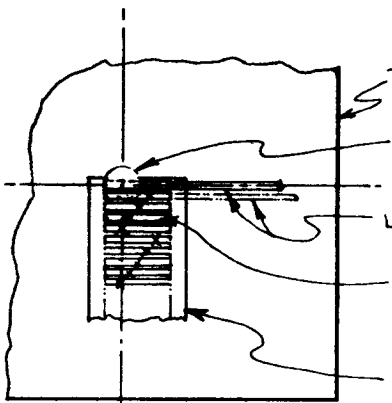
TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED R.E. Livingston DATE	DP-1405, EG-1416, AND EG-141T ELECTRODE POSITIONING	POLY - SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC. BLACKSBURG, VIRGINIA
DECIMALS ± .005	DRAWN S.M. Caldwell DATE 12/18		
RACTIONS ± 1/64	CHECKED DATE		
ANGLES ± 1/2°			
FED. SUPPLY CODE NO. 99932	APPROVED DATE	SCALE: 2:1	DWG. SIZE A

FIG-2
P.I. 909

SHEET OF

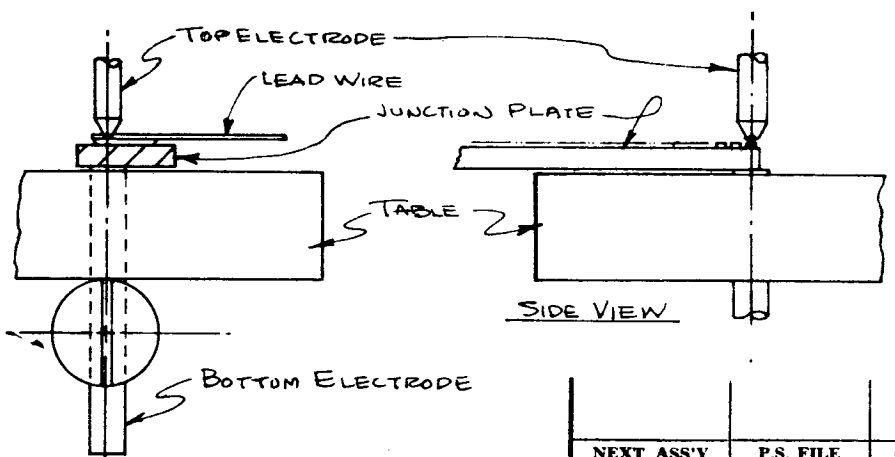
REVISIONS			
SYM.	DESCRIPTION	DATE	APPROVED

REV.



PLAN VIEW

NOTE:
LINE UP THE JUNCTION PLATE SUCH THAT THE WELDS ARE MADE AT THE "X" POINTS ONLY.



FRONT VIEW

NEXT ASS'Y	P.S. FILE	QTY. REQ'D.
APPLICATION		

TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED R.E. Livingston	DATE	DP-1405 ORIENTATION OF PARTS FOR WELDING
DECIMALS ± .005	DRAWN S.M. Caldwell	DATE 12/18	POLY - SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC. BLACKSBURG, VIRGINIA
FRACTIONS ± 1/64	CHECKED	DATE	
ANGLES ± 1/2°			
FED. SUPPLY CODE NO. 99932	APPROVED	DATE	SCALE: 2:1

DWG. SIZE A

FIG. 3 - P.I. 909

SHEET OF

TITLE: PULL STRENGTH TEST OF BRASS JUNCTION PLATES AND 30 AWG (19/42) SILVER PLATED STRANDED COPPER CONDUCTOR WHICH HAVE BEEN RESISTANCE WELDED FOR N.A.S.A. PARTS

OOLS AND EQUIPMENT:

1. Vise- small table vise as shown in Fig. 1.
2. Spring Scale - capable of 2000 grams, as shown in Fig. 1.
3. Clamp for attaching lead wire to spring scale.

OPERATION STEPS:

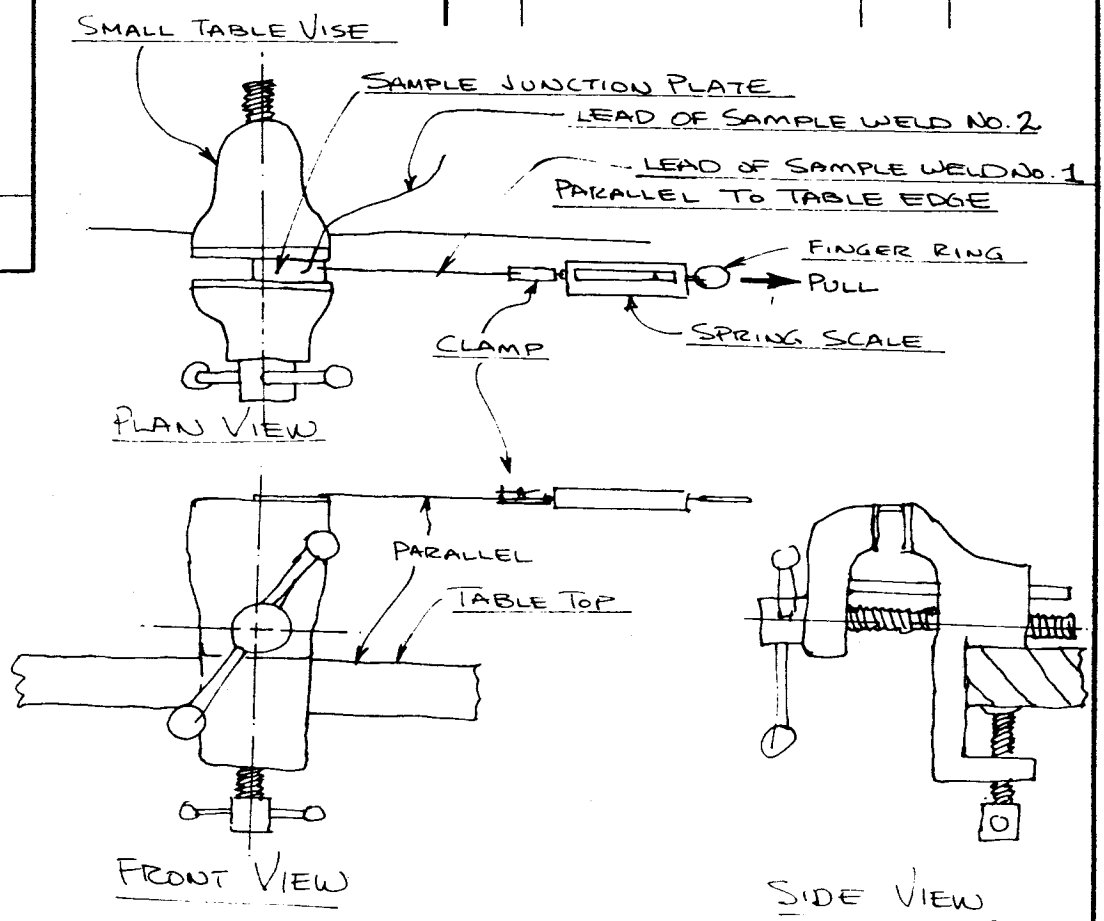
1. Set up vise as shown in Fig. 1.
2. Place sample junction plate in vise as shown in Fig. 1, and Fig. 2.
3. Snap spring scale onto lead as shown in Fig. 1.
4. Hook thumb in ring of spring scale and tighten lead. Align lead parallel to junction plate.
5. Pull slow and steady without jerky motion at a uniform rate until the lead breaks.
6. Record the following data: -

Date of Weld	P/N	Prod. Plate No.	Sample Weld No.	Did Joint Test 1000 g. Yes - No.	Breaking Strength of Joint, Grams	Visual Inspection Remarks

7. Remove the broken lead from the spring scale and throw lead away.
8. Repeat procedure for remaining weld samples and record data.
9. Remove sample junction plate from vise and return to welding operator along with the visually inspected production junction plate.

REVISIONS			
SYM.	DESCRIPTION	DATE	APPROVED

REV.



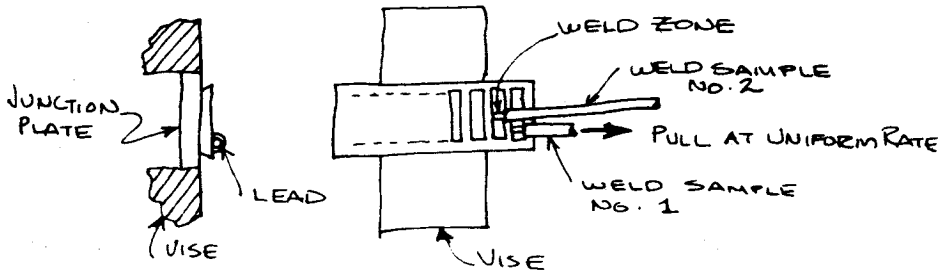
NEXT ASS'Y	P.S. FILE	QTY. REQ'D.

APPLICATION

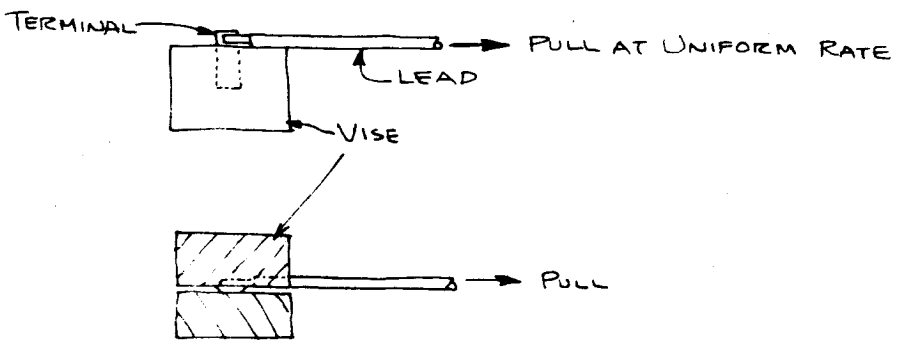
TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED Caldwell, S.M. 4/13	PULL TEST SET-UP FOR WELDED N.A.S.A. PARTS IN MODEL SHOP	POLY - SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS INC BLACKSBURG, VIRGINIA
DECIMALS ± .005	DRAWN Caldwell, S.M. 4/14		
RACTIONS ± 1/64	CHECKED		
ANGLES ± 1 2'	APPROVED 4-30-64	SCALE: NONE	DWG SIZE A
FED. SUPPLY CODE NO 99932			FIG. 1-P.I.950
			SHEET OF

REVISIONS			
SYM.	DESCRIPTION	DATE	APPROVED

REV.



METHOD OF PULL TESTING JUNCTION PLATE - LEAD WELD



METHOD OF PULL TESTING TERMINAL AND LEAD

NEXT ASSY	P.S. FILE	QTY. REQ'D.
APPLICATION		

TOLERANCES UNLESS OTHERWISE SPECIFIED	DESIGNED DATE Caldwell S.M. 4/10	ORIENTATION OF PARTS DURING PULL TEST	POLY - SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS INC. BLACKSBURG, VIRGINIA
DECIMALS ± .005	DRAWN DATE Caldwell, S.M. 4/20		
FRACTIONS ± 1/64	CHECKED DATE		
ANGLES ± 1,2°		SCALE: None	DWG SIZE A
FED. SUPPLY CODE NO 99932	APPROVED DATE 9-30-69		FIG. 2-P.I.950
			SHEET OF

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 300	SECTION 2
		REVISION 01
SUBJECT Visual and Dim. Inspection of Brush Block after preparation(Mylar)		DATE ISSUED 4-17-64

Visual: Inspect leads for cuts, nicks, splits, and/or any undesirable characteristics that would tend to affect the quality of the finished part. Check lead per pertinent print to insure correct number of strands, type insulation, mylar installation, and/or other design factors. Unless otherwise specified, the inspection is to be performed under 10X (microscope).

Dim: Check dimensions per pertinent print. Check lead length, mylar tubing length and all dimensions critical to the assy. of the part. Use scale, micrometer, calipers and/or other equipment as required to obtain accurate readings. It is the inspector's responsibility to insure that his/her equipment has been calibrated.

Insp.

Level: 100%

Visual: Inspect assembly for any obvious defects that might tend to affect the quality of the finished part. Check leads for insulation defects (cuts, nicks, splits, etc.). Check for damage conductor. Inspect weld joints closely for welding defects (burns, separations). Check for burrs, nicks, scratches, or any other defects of the junction plate. Use 10X (microscope) unless otherwise specified by print or Q.C.

Dim.: Check dimensions per pertinent print utalizing measuring equipment as necessary to obtain accurate readings. It is the inspector's responsibility to insure that his/her equipment is calibrated.

Inspection Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 304	SECTION 2
		REVISION 00
SUBJECT Electrical Inspection of BB Assembly (odd & even)		DATE ISSUED 7-13-64

Insulation Resistance:	Check insulation resistance per specification to insure that no damage has occurred during machining operations.
Equipment:	Megohmmeter, Switching Fixture
Inspection level:	100%
Circuit Resistance:	Check circuit resistance per RLT 15
Equipment:	Per RLT 15
Inspection level:	100%

SUBJECT: Temperature Cycle - Brush Blocks

Temperature Cycle -

1. Preheat oven to +100° C (212° F)
2. Place part in preheated oven for 90 minutes minimum
3. Remove from oven and allow assembly to stand at room temperature for 30 minutes minimum.
4. Reduce chamber temperature and hold at -18° C (0°F)
5. Place assembly in precooled chamber for 90 minutes minimum.
6. Remove the assembly from chamber and let stand for 30 minutes minimum.
7. This completes one cycle. This sequence (Steps 2-6) must be repeated 2 additional times (a total of 3 cycles).

Equipment -

1. Chamber capable of attaining temperature reductions to -18° C.
2. An oven separate from the above mentioned chamber and capable of attaining temperatures of 100° C. (212°F)

Inspection Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 307	SECTION 2
		REVISION 01
SUBJECT Brush Block Assy. - Last Visual and Dimensional Inspection		DATE ISSUED 11-27-64

Visual - Inspect for any material failure that might have occurred during temperature cycling. Use 30X microscope to inspect for cracks. Use 10X microscope to inspect for all other characteristics.

Inspect for plastic defects. Check for chips, voids, cracks, airbubbles, flaking, excess plastic flash or any other obvious plastic defects. Check leads for defects that might have occurred during casting or machining. Inspect for burrs, per P.-S Burr Class indicated on print. Inspect for imbedded foreign matter or any other obvious defects that might affect the quality of the finished part.

Dim. - Check all dimensions per pertinent print. Use comparator, micrometer, calipers, and/or scale as needed to insure accurate readings. It is the inspector's responsibility to insure that his/her equipment has been calibrated.

Inspection Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 308	SECTION 2 REVISION 00
SUBJECT Visual and Dimensional Inspection - Lead and HML Assembly		DATE ISSUED 7-20-64

Visual: Inspect lead for conformance to pertinent print. Insure that conductor has correct number of strands and correct insulation has been used. Inspect for splits in the insulation. If splits or heavy stress marks are noted in the insulation, notify the Process Control Co-ordinator. Inspect for foreign contamination and imbedments. Use 10X microscope. Inspect for broken strands. Do not flex, bend, or kink leads. Check for tarnish or unusual conditions in the conductor.

Dim: Check lead length. Check all dimensions per pertinent print. Use scale, micrometer, and/or calipers as necessary to insure accurate readings. It is the inspector's responsibility to insure that his/her equipment has been calibrated.

Insp. Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 313	SECTION 2
		REVISION 00
SUBJECT Slip Ring Assembly -- Electrical Test		DATE ISSUED 4-17-64

INSULATION RESISTANCE - Check Insulation Resistance per RLT 17
Minimum Insulation Resistance 10,000 megs.

EQUIPMENT - Megohmmeter, Switching Fixture

INSPECTION LEVEL - 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 314	SECTION 2
		REVISION 00
SUBJECT Sub-Assy. Visual and Dimensional Inspection after Temperature Cycle.		DATE ISSUED 4-17-64

Vis: Check part configuration to pertinent print. Check plastic for defects. (voids, airbubbles, imbedded material, cracks, chips, excessive flash) Check leads for damage to the conductor and/or insulation. Inspect for burrs per P-S Burr Class indicated on print. Check for sharp edges. Inspect part for any material defects which might have occured as a result of Temperature Cycle. Check for foreign matter.

Dim: Check all dimensions per pertinent print. Check Concentricity requirements.

Equip: 30X microscope for visual. Comparator, micrometer, calipers, fixtures, and/or other measuring equipment as necessary.

Insp.
Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 315	SECTION 2 REVISION 00
SUBJECT: Slip Ring Assy. - Vis. and Dim. Inspection after Electroforming Copper and Turn O. D.		DATE ISSUED 7-20-64

Visual: Inspect for lead damage. Check solder joints for workmanship. Check for solder flux. Check grooves for any copper that has imbedded in the barrier. Check for plastic in the copper. Check grooves and barriers for voids in the plastic.

Dim: Check dimensions per print. Check and record on the Planning Master the correct dimension of the frontshaft at the copper. This check is to be used in calculating the thickness of the nickle plate. Take three representative readings along the frontshaft and record highest to four decimal places.

Equip: Comparator (50X)

Insp. Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 316	SECTION 2 REVISION 00
SUBJECT Slip Ring Assy. - Electrical Inspection After Electroform Copper		DATE ISSUED 4-17-64

Circuit Resistance - Test per Reliaiblity Test Procedure 15.
(RLT 15).

Inspection Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 317	SECTION 2 REVISION 00
SUBJECT: SLIP RING ASSEMBLY - VISUAL AND DIMENSIONAL AFTER FINAL CURE AND MACHINING		DATE ISSUED 4-17-64

Visual: This inspection is for any defects that might have incurred as a result of curing or machining. Check for lead damage (cuts, nicks, splits, etc.). Inspect plastic for any defects such as airbubbles, voids, chips, excessive flash, etc. Check the front shaft of the assembly for machining defects. Check plating for defects or damage. Check for burrs

Dim: Check dimensions per print. Be especially critical of those dimensions that were machined just prior to this inspection. The Planning Master should indicate what machining operations preceded this inspection.

Equip: Use 20X for visual inspection. Use comparator, micrometer, calipers, scale, and/or other fixtures and equipment as specified by Quality Control.

Insp:

Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 318	SECTION 2
		REVISION 00
SUBJECT: SLIP RING ASSEMBLY - DIMENSIONAL CHECK AFTER ELECTROPLATING (NICKLE)		DATE ISSUED 4-17-64

Visual: Inspect quality of plating. Check for metal wicking up sides of barrier. Check for voids or airbubbles in barriers. Check for pits, voids, or seams in the nickle.

Dim: The purpose of this inspection is to check the dimensions of the nickle plating to determine thickness. Consult the Planning Master to obtain the dimensions after nickle plating. Subtract the copper plate dimension from the nickle plate dimension. Divide the difference by two to obtain the thickness of the nickle plate. Check three places (both ends and middle) on frontshaft to obtain representative readings. Record both the plate thickness and the frontshaft dimension on the Planning Master.

Equip: Comparator, 50X lens, holding fixtures.

Insp. Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 319	SECTION 2 REVISION 00
SUBJECT Slip Ring Assembly - Dimensional Check after Electro deposit Gold and turn O.D of frontshaft		DATE ISSUED 4-17-64

Visual: Inspect quality of plating. Check for pits, holes, or seams in the gold. Check for gold that has failed to clean up in machining. Use 10X and 30X as required.

Dim: The purpose of this inspection is to check the dimensions of the gold plating to determine thickness. Consult the Planning Master to obtain the dimensions of the frontshaft after nickle plate. Check the dimensions of the frontshaft after electro depositing gold and turning the outside diameter. Subtract the frontshaft dimension after nickle plate from the frontshaft dimension after gold plate. Divide the difference by two to obtain the plating thickness of the gold. Check three places on the frontshaft (both ends and middle) to get representative readings. Record the dimension of the frontshaft and the plating thickness of the gold in four decimal places on the planning master.

Equip: Comparator, 50X lens, holding fixtures.

Insp. Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 320	SECTION 2
		REVISION 00
SUBJECT ELECTRICAL INSPECTION AFTER MACHINING PRIOR TO SURFACE TREATING AND FINAL PLATING		DATE ISSUED 4-17-64

Circuit Resistance: Check circuit resistance per Reliability Test Procedure 15 (RLT 15). Record circuit resistance readings on the reproducable copy of the test report furnished by Reliability. Use black ink only on this report. The reproducable copy shall be shipped with the unit. A copy will be retained for file.

Equip: Use equipment call out in RLT 15.

Insp.
Level: 100%.

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 321	SECTION 2 REVISION 00
SUBJECT: SLIP RING ASSEMBLY -VISUAL AND DIMENSIONAL INSPECTION AFTER HARD GOLD PLATE, IRIDITE, AND CLEANING		DATE ISSUED 4-17-64

Visual: Check for any conditions that might affect the quality of the finished part. Check for lead damage which might have occurred during processing. Inspect metal for nicks, scratches, or burrs. (P-S Burr Class per print). Check the quality of plating and iridite coat. Burr Class will determine the magnification under which the part is inspected.

Dim: The purpose of this dimensional inspection is to determine the thickness of the Hard Gold Plate. Consult the Planning Master for the dimensions of the frontshaft after electrodepositing gold. Check this dimension after Hard Gold Plate. Subtract the results of the electro-deposited gold frontshaft inspection from the results of the Hard Gold Plate frontshaft inspection. Divide the differences by two to obtain the thickness of the hard gold.
Record the results of the thickness check in four decimal places on the Planning Master.

Equip: Comparator, 50X lens, holding fixtures.

Insp. Level: 100%.

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 322	SECTION 2
		REVISION 00
SUBJECT: Slip Ring Assembly - Last Visual and Dimensional Inspection		DATE ISSUED 4-17-64

Visual - Check part configuration per pertinent print. Check for conditions that might affect the quality of the finished part. Check for burrs, nicks, cuts, scratches, and/or any other obvious defects. Check to see that all sharp edges have been broken. Check lead exits.

Dim. - Check all dimensions per print
Use micrometer, calipers, scale, and/or any other equipment that will insure accurate measurements. It is the inspector's responsibility to insure that his/her instruments have been calibrated.

Insp. Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL323	SECTION 2
		REVISION 02
SUBJECT SLIP RING ASSEMBLY-LAST ELECTRICAL		DATE ISSUED 8-18-64

Insulation Resistance:	1. Check insulation resistance per RLT17
	2. Check color code
	3. Check lead exits
	4. Record actual I.R. readings on test report
Equipment:	Megohmmeter, switching fixture
Insp. level:	100%

GC 125355 Spec. Limit 10,000 megohms

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 329	SECTION 2
		REVISION 00
SUBJECT Brush Block (lead wire to brush junction) Elect. Insp.		DATE ISSUED 7-20-64

Circuit Resistance- A lead wire to brush circuit resistance measurement shall be made and recorded. A reproducable copy of the record shall be shipped with the unit. The connection or measuring points shall be between the end of the lead wire and the back side of the brush where it is soldered to the junction bar. Extreme care shall be used to insure that no damage is done to the brush or solder joint. The value of circuit resistance shall be .009 x lead length (in.) + .000 -.050 ohms. Failure of any circuit to meet the above requirements will constitute a rejection of the entire sub-assembly. Test shall be conducted per RLT 15.

Equipment: Per RLT 15

Inspection Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 330	SECTION 2 REVISION 01
SUBJECT Capsule - Interior Visual Inspection after installing Housing		DATE ISSUED 4-17-64

Visual - Slip housing back far enough to expose all brushes. Check brush alignment. Check for solder flux. Slide housing back in place and check for lead damage.

Equip: Inspect visually under 30X microscope.

Insp. Level: 100%

Torque Test - Test in accordance with Relaibility Test Procedure 16. (RLT)

Record findings on Noise Test Report.

Noise Test - Test for Contact Noise per Reliability Test Procedure 16.

(RLT) Record all readings on Noise Test Reports. Use equipment indicated in RLT 16

Insp. Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 334	SECTION 2 REVISION 00
SUBJECT Capsule - Visual Inspection after 100 Hour Run In		DATE ISSUED 4-17-64

Visual - Inspect under 30X stereo microscope for any loose particles or film within the capsule other than contact material. Check for any local wear track roughness exceeding that of the ring matte finish and/or an indication of non equidimensional wear product.

Insp. Level: 100%

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 336	SECTION 2
		REVISION 00
SUBJECT Capsule - Final Visual and Dimensional Inspection		DATE ISSUED

Visual - Inspect part configuration per pertinent print. Inspect for burrs. Check for lead damage and cleanliness. Check lead tags. Check serial numbers against accompanying documents. Make sure that all documentation is in order and signed off. Inspect for any conditions that are contrary to the high standards set for Saturn V.

Dim. - Check all dimensions per pertinent print. Record all dimensions on Inspection Check Sheet. Insure that all spaces have been filled out on check sheet. Use equipment as necessary to insure accurate measurements. It is the inspector's responsibility to insure that his/her equipment has been calibrated.

100% INSP

POLY-SCIENTIFIC DIVISION OF LITTON PRECISION PRODUCTS, INC.	RL 337	SECTION 2
		REVISION 00
SUBJECT: Temperature Cycle - Slip Ring Assembly		DATE ISSUED 4-17-64

Temperature Cycle - 1. Heat unit to ≠ 100° C (212° F) for 1 hour minimum.

2. Reduce unit temperature and hold at -18° C (0° F) for 1 hour minimum.

3. This completes one cycle. This sequence (Steps 1 and 2) must be repeated 2 additional times (A total of 3 cycles).

Equipment - Sub-Zero temperature chamber

100% on all parts

Scope - This Inspection Instruction defines the equipment, procedure and requirements for retention testing of all miniature screws and nuts used on production assemblies that have been secured with Locktite or P-S Epoxy Formulation .

Equipment -

1. Torque screwdriver.
2. Special screwdriver tips as necessary. NOTE: Screwdriver tips should include a retaining ring for applicable head diameters.

Preparation -

1. Retention tests may be performed as soon as Locktite has been properly cured.
2. Select proper torque measuring instrument compatible with test requirements per Table I.
3. Select proper tip to fit head of screw. Screwdriver blade width should be 90 $\pm$ 10% of the fastener slot width.

Procedure -

1. Carefully place the screw adapter on head of fastener to be tested. Make sure tip of measuring device is fully seated and does not receive interference from any other part of the assembly.
2. Hold axis of measuring instrument perpendicular to the plane of the screw head applying only enough pressure to maintain full tip engagement.

Procedure - (Cont.)

3. Slowly apply torque in the direction tending to loosen the fastener. Torque should be increased in one smooth operation while maintaining alignment and pressure and remove only after torque has reduced to zero.

Failure Procedure -

1. If a fastener exhibits any tendency to loosen or if any damage to the fastener or assembly is evidenced as a result of this test, the item shall be rejected and properly tagged and returned for rework.

100% TEST

Thread Size	Locktite Grade E
00-90	1.0 oz. in.
4-40	10.0 oz. in.

TABLE I

TORQUE RETENTION VALUES FOR THREADED FASTENERS SEALED WITH LOCKTITE

	Torque Values for all Nuts & for Thread Engagement Ratios less than 2.5		Torque Test Values for all Fasteners with a thread engagement Ratio of 2.5 or more	
Thread Size	Locktite Grade C, E, H	Locktite Grade A, AA, B, D,	Grd. E C, E, H	Grade A, AA, B,D
0000-160	.1 in. oz.	.2 in. oz.	.2 in. oz.	.3 in. oz.
000-120	.75 "	1.5 "	1.5 "	2.0 "
00-90	1.0 "	2.0 "	1.5 "	3.0 "
0-80	1.5 "	3.0 "	2.5 "	5.0 "
2-56	2.5 "	5.0 "	5.0 "	10.0 "
3-48	8.0 "	1 in. lb.	12.0 "	1.5 in. lb.
4-40	10.0 "	1.5 "	1.2 in. lb.	2.5 "
5-40	1.0 in. lb.	2.0 "	2.0 "	4.0 "
6-32	1.5 "	3.0 "	3.0 "	6.0 "
8-32	2.5 "	5.0 "	5.0 "	10.0 "
10-32	5.0 "	10.0 "	10.0 "	20.0 "
1/4-20	10.0 "	20.0 "	20.0 "	40.0 "

NOTE: Engagement Ratio = $\frac{\text{Length of Thread Engagement}}{\text{Thread Diameter (O.D.)}}$

TITLE: LOAD & CAST DP 1405 BB MOLD	FINAL ASS'Y. NO. DP 1405	DRAWING NO.

EQUIPMENT:	MATERIAL:

PROCESS:

Make silastic mold by using Pattern per SK 1. Load junction plate into silastic mold & cast with E.S. 137 plastic. Grind plastic to .110 ±.002 per SK 2. Pick off areas approximately .040 long per SK 3 for weld joint. Soda blast surface for good bond. Weld leads to junction plate.

Load junction plate into mold. Thread leads thru holes per lead exit pattern of BB Ass'y. After all leads are loaded, spray fine frayed teflon hairs from around lead exit area with chlorothene. Tie mylar insulated leads into tight bundle, two places with nylon cord per SK 4. Cut .007 thick x 1/2 wide fiberglass ribbon to 3" long. Load into mold half containing teeth or core plate so that the teeth protrude thru the ribbon. Close mold slip (1) strip of fiberglass .009 x .040 x 3" impregnated with P-54 into mold between the teeth & outside corners of mold. Make reservoir per SK 5. Seal mold & install reservoir for tip casting per SK 6. Preheat mold 1 hr. ±5 min. at 120°C.

Mix DEN & NMA together using heat gun, place mixture in 120°C oven for 5 min. Remove mold from oven & put into tip casting chamber leaving reservoir accessible, mix hardner with resin and pour into reservoir. Check rubber seal of vacuum chamber. Push mold into chamber & attach cover. Vacuum (2) min. in horizontal position. Raise chamber slowly to vertical position. Vacuum (1) min., release vacuum quickly. Pull vacuum (15) sec. & drop quickly 5-7 times. Vacuum (1) min. & release slowly last time.

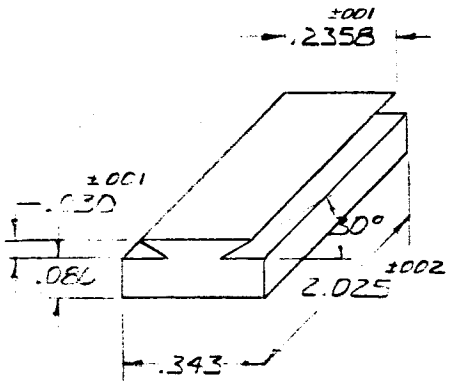
UNLOAD MOLD

Remove silastic from mold & from around lead exit cluster.

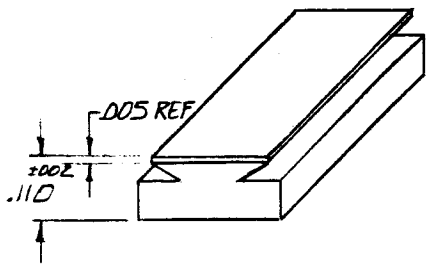
Pull lead spacer plate out about 2" from mold. Pull each lead thru spacer plate individually. Use jack screw against junction plate to break open mold. Remove top half of mold. Place mold upside down on "V" block under arbor press. Insert dowel & press. Remove brush block.

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	METHOD INSTRUCTION No. 200
	mlh	5-1-64		

TITLE: LOAD & CAST DP 1405 BB MOLD



SK-1



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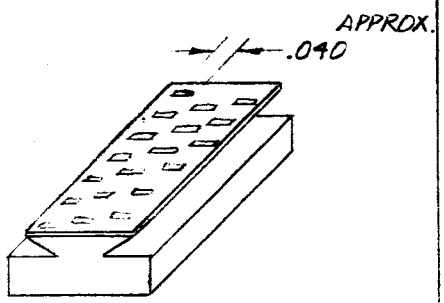
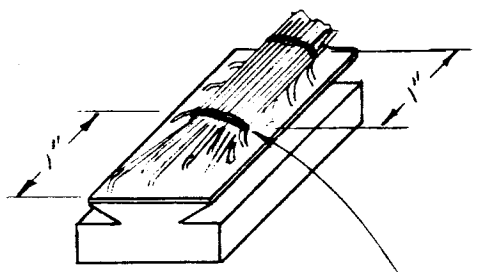


SLOTS STAGGERED

SK-3

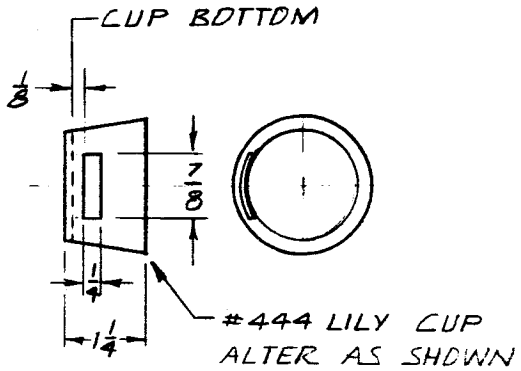


NYLON BONDED FINISH
CSB-15 LEFT Z TWIST
CORD

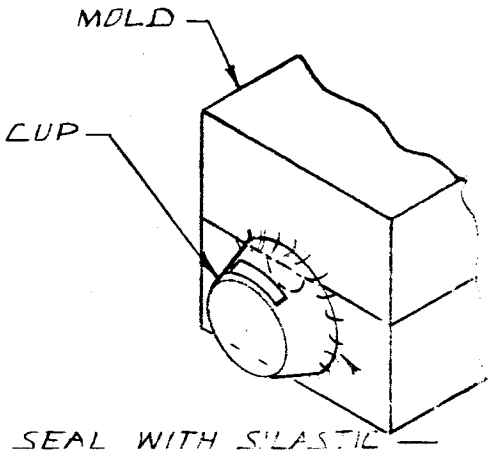
SK-4

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER	DATE	REV.	METHOD INSTRUCTION NO. 200
	[illegible] 5-1-[illegible]			

TITLE: LOAD & CAST DP 1405 BB MOLD



SK-5



SK-6

POLY-SCIENTIFIC DIVISION LITTON PRECISION PRODUCTS, INC.	ENGINEER WMJ 5-1-84	DATE	REV.	METHOD INSTRUCTION NO. 200