IITRI

Research Institute

FACILITY FORM 602

N65-30461

(ACCESSION NUMBER)

(THRU)

63

(PAGES)

1

(CODE)

CR 64218

(NASA CR OR TMX OR AD NUMBER)

15

(CATEGORY)

GPO PRICE $ ________

CFSTI PRICE(S) $ ________

Hard copy (HC) 3.00

Microfiche (MF) .75

ff 653 July 65

Final Report

INVESTIGATION OF SLIP RING ASSEMBLIES

George C. Marshall Space Flight Center
Huntsville, Alabama

Final Report

INVESTIGATION OF SLIP RING ASSEMBLIES

5 March 1964 to 5 May 1965

Contract No. NAS8-5251
Control No. TP3-83367 (1F)
IITRI Project E6000

Prepared by

IIT Research Institute
Technology Center
Chicago, Illinois 60616

for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama 35812
Attn: PR-RDC

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

FINAL REPORT

INVESTIGATION OF SLIP RING ASSEMBLIES

5 March 1964 to 5 May 1965

Contract No. NAS8-5251
Control No. TP3-83367 (1F)
IITRI Project E6000

This report was prepared by IIT Research Institute under Contract No. NAS8-5251, "Investigation of Slip Ring Assemblies," for George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Propulsion and Vehicle Engineering Laboratory, Materials Division of the George C. Marshall Space Flight Center with Mr. J. C. Horton acting as Project Monitor.

FOREWARD

This is the Final Report of IITRI Project E6000, entitled "Investigation of Slip Ring Assemblies." The report covers the period 5 March 1964 to 5 May 1965.

This program was conducted under the technical direction of J. L. Radnik. The project was administered by M. E. Goldberg, Manager, Reliability and Components section. The cooperation of J. C. Horton of the George C. Marshall Space Flight Center is gratefully acknowledged.

Respectfully submitted,
IIT RESEARCH INSTITUTE

O. M. Kuritza

O. M. Kuritza
Research Engineer
Reliability and Components

Approved:

J. L. Radnik

J. L. Radnik
Assistant Manager
Reliability and Components

M E Goldberg

M. E. Goldberg
Manager
Reliability and Components

30461

ABSTRACT

A laboratory investigation of miniature slip ring assemblies was conducted. This investigation was a continuation of the initial program whose objectives were to determine the influence of ring, brush and insulator materials on electrical noise and mechanical wear characteristics. The noise characteristics of experimental and commercial capsules were studied. Extensive run-in tests have demonstrated that destructive galling and erosion effects occur primarily in unlubricated systems which permit high localized temperatures. Surface lubrication with P-38 synthetic oil has been found to be effective in minimizing wear and maintaining low noise levels. Spectrographic analysis of wear debris indicated that the only constituent was gold from the ring and brush surfaces. Microhardness measurements were made on electrodeposits from rhodium, palladium, and platinum modified gold baths, but no significant increase in plate hardness was obtained. Preliminary study of vacuum operation showed that under the conditions of medium vacuum surface lubrication was still effective in minimizing wear deposits.

author

INVESTIGATION OF SLIP RING ASSEMBLIES

I. INTRODUCTION

This report summarizes the results of a laboratory investigation conducted during IITRI Project E6000, "Investigation of Slip Ring Assemblies," for the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama. The program was concerned primarily with the study of noise characteristics of experimental and commercial slip ring capsules, and was a continuation of an earlier program in which the evaluation of appropriate materials for slip ring assemblies was conducted. This evaluation established that electroplated rings of soft gold and two hard gold alloys coupled with brushes of Neyoro 28A exhibited noise levels considerably lower than the presently accepted value of 10 microvolts per milliampere of brush current.

Miniature slip ring assemblies are normally used to transmit electrical information across the axes of inertial platforms in space vehicle guidance systems. Excessive electrical noise at the sliding contact strongly interferes with circuit performance, particularly the null-seeking type of circuit.

The investigation described herein was specifically directed toward problem areas encountered with a commercial 80-ring capsule used in launch vehicles. This capsule is described in Drawing GC-125209, entitled "Specifications for ST-124 Slip

Ring Assemblies," issued by George C. Marshall Space Flight Center, Astrionics Laboratory. The capsule must be capable of complete 360° rotation even though its normal oscillation about a fixed operating point is only about 0.5 minutes of an arc. Its operating life in a launch vehicle is only about two minutes, but qualification and acceptance tests require a total life of about 75 hours. For the laboratory work of this program, experimental capsules were fabricated having the same ring and brush dimensions as the actual capsule in order to simulate the actual operating conditions as closely as possible.

II. PROGRAM OBJECTIVES AND SCOPE

The principal objective of this program was a comprehensive study of noise characteristics of experimental and commercial slip ring assemblies to be based on long term run-in tests. The experimental assemblies were to be fabricated from materials proven during the course of the initial program to exhibit superior noise characteristics. The program was divided in several basic tasks.

The objective of the first task was to verify the vibration, threshold and repeatibility effects of commercial capsules that were demonstrated during the initial program by experimental capsules. As an additional task, the wear debris accumulated during the run-in tests had to be collected and studied to identify the chemical and metallurgical nature of debris deposits so that its sources could be determined and corrective measures specified.

Since it is known that surface lubrication can improve the noise characteristics of sliding contacts, another task had as its objective the evaluation of surface lubrication effects.

The results of the study of precious metal hardening agents carried out during the first year's effort were inconclusive, primarily because of the difficulties that were encountered in obtaining reference plating samples from the bath selected as the vehicle for the additions. Because of the potential merit of this concept, it was decided that further exploratory work would be conducted using the Orotemp 24K bath as the basic bath for additions.

The future requirements of space vehicle systems include satisfactory performance of miniature slip rings in the high vacuum space environment. Since the degrading effect of vacuum environment on the performance of sliding electrical contacts is well known, as a final task of this program, a preliminary study of vacuum operation of slip ring assemblies was to be undertaken.

III. TECHNICAL DISCUSSION

A. Investigation of Noise Characteristics of Experimental Capsules

1. Apparatus and Instrumentation

Apparatus and instrumentation developed during the course of the initial program has been used during this program except for some modifications and improvements. A pneumatically-driven torsion oscillator was used for driving the slip ring capsule in the oscillation mode. The unit was operated from a nitrogen gas cylinder, and the housing portion was pressurized to provide a dry nitrogen protective atmosphere for the capsule. The torsional system was designed to operate at a frequency of about 10 to 12 cps, and peak-to-peak deflections of up to 6° could be obtained. A pneumatic system was selected primarily to avoid noise and pick-up from a motor drive.

For continuous rotation tests, the same apparatus was used except the capsule rotor-inertial cylinder combination was belt driven at 200 rpm by a small synchronous motor. A photograph of the apparatus is shown in Figure 1.

Electrical noise was measured directly across pairs of brushes by sensing the voltage at the ends of the brush leads when a constant d-c current was passed through the brush circuit. The d-c voltage was supplied by an adjustable Heathkit regulated power supply. The voltage drop across two brushes was amplified by a Tektronix Type 122 Low Level Pre-Amplifier and a Keithley Decade Isolation Amplifier and then fed to a

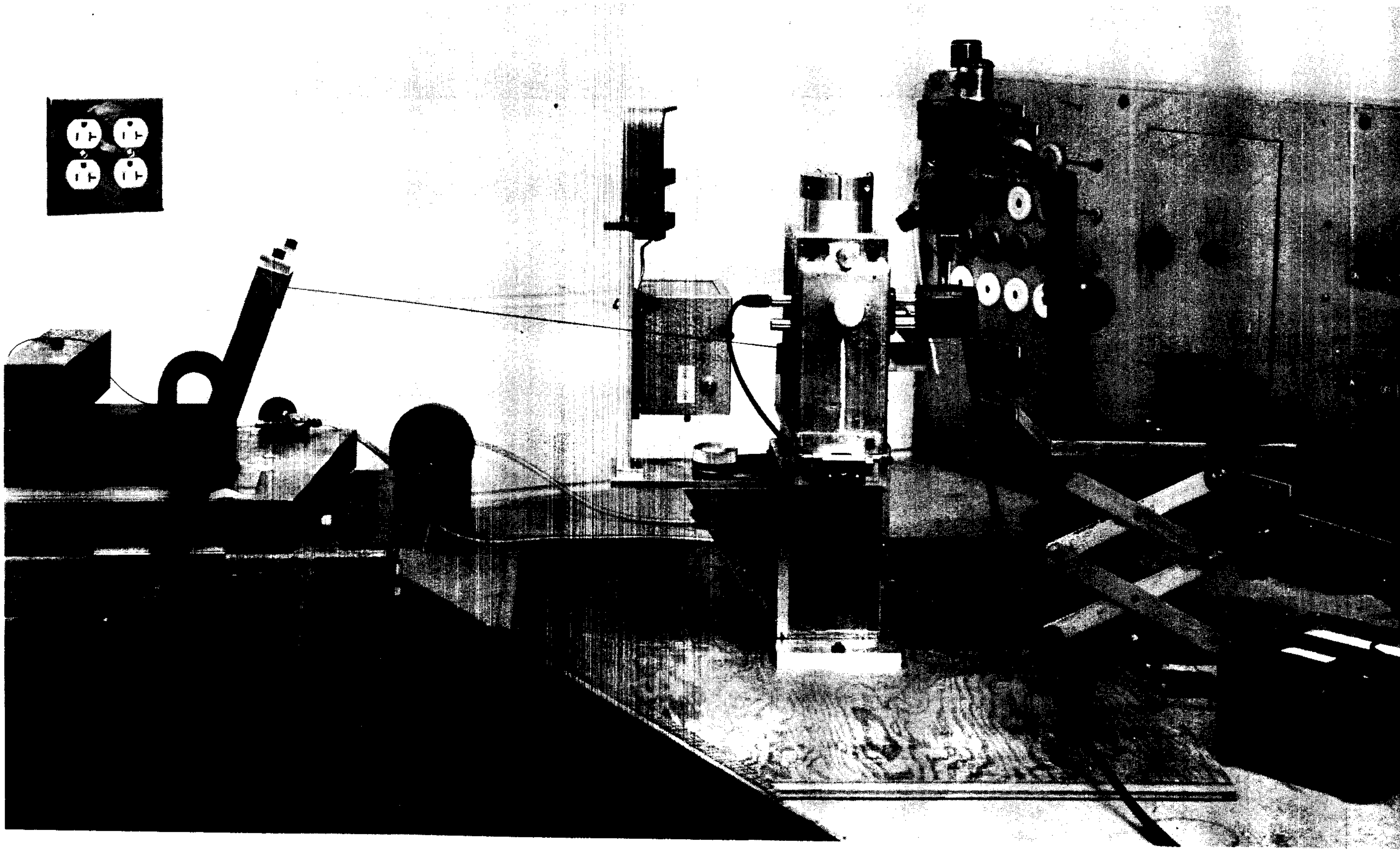


FIGURE 1   APPARATUS USED FOR OSCILLATION AND CONTINUOUS ROTATION RUN-IN TESTS

Tektronix Type 545A oscilloscope and a General Radio Type 1521A Graphic Level Recorder. The use of the GR Graphic Level Recorder permitted determination of the true RMS value of noise while the Tektronix CRO enabled measurements of peak-to-peak noise.

To permit the Materials Division to duplicate the experimental arrangements, detailed engineering drawings have been prepared for the drive assembly and for the experimental capsules. The drawings reflected all of the modifications made during the early work of this extension. They were forwarded to NASA - Marshall under separate cover.

2. Basic Noise Characteristics

Two experimental capsules were used for all of the tests during this program. The first number identifying the capsule indicated the number of the experimental capsule and the second number was the serial number of the rings. Sometimes a third number was used which showed a modification of the rings.

In the investigation of basic noise parameters, noise measurements for both the oscillatory and continuous modes of operation were made with Capsule 1-28-3, a capsule containing soft gold rings and brushes having only one wiper arm. Several differences in noise characteristics were noted, particularly during the oscillatory mode. With oscillation, a clipped noise waveform was obtained with large spikes occurring at times when the rotor started motion in a direction which placed the wiper arm in compression. When the travel was in a direction which placed the wiper in tension, very low noise levels were obtained.

To permit realistic comparison with the conventional brush systems, noise measurements with the single wiper system were made with a brush current of 12.5 ma. In the oscillatory mode, peak-to-peak noise of 75 μv was obtained with Capsule 1-28-3. In the continuous rotation tests, peak-to-peak noise levels of approximately 50 μv were obtained with rotation in either direction. Excellent repeatability of noise waveforms was obtained for rotation in similar directions. Table 1 is a brief comparison of the basic characteristics of the single wiper and conventional double wiper systems.

TABLE 1

SINGLE AND DOUBLE WIPER BRUSH SYSTEMS

	Single Wiper Capsule 1-28-3 (Noise at 12.5ma)	Double Wiper Capsule 1-1B (Noise at 25 ma)
Average Brush Force-Grams	2.51	2.59
Average Drag Torque-Gram-Cm	2.74	5.12
Average Resistance-Two-Ring Ckt-Ohms	0.577	0.546
Threshold Peak-to-Peak Noise - Oscillation - μv	75	34.8
Threshold Peak-to-Peak Noise - Continuous Rotation - μv	50	34.8

3. High Current Tests

A run-in test of the experimental Capsule 2-38 was conducted to obtain information on the high current performance of the slip-ring system and to establish the effects of the increased heat at the contacting surface. Noise was measured for a brush current of 1 ampere flowing through two brush-ring circuits in series. The initial noise level ranged from 1000 to 1800 μv, and after 70 hours of run-in at 200 rpm, the noise level was 3000 to 4000 μv. Disassembly of Capsule 2-38 revealed very little debris and almost no permanent damage to the brush or ring surfaces. Apparently, the present brush-ring system is capable of safe operation at relatively high currents with almost a linear increase in the noise per unit of brush current.

4. Surface Lubrication

To study the effects of surface lubrication on the noise characteristics, Capsule 1-37 was assembled with a thin coating of P-38 synthetic oil on the ring and brush contacting surfaces. After 335 hours of run-in at 200 rpm with a brush current of 25 ma, no increase in noise level was detected. Inspection of the capsule under the microscope revealed that too little wear debris had accumulated to collect and, therefore, no analysis was attempted. Figure 2 shows the condition of the rings and brushes after the tests. To confirm these results, Capsule 1-39 was coated with P-38 oil and ran-in. After 410 hours no evidence of noise level increase was observed and practically no wear debris was present. The ring and brush contacting surfaces were found to be in excellent mechanical condition. These results conclusively establish that surface lubrication is effective in maintaining low noise level and in minimizing wear. This is analogous to the experience with TV tuners, where it is

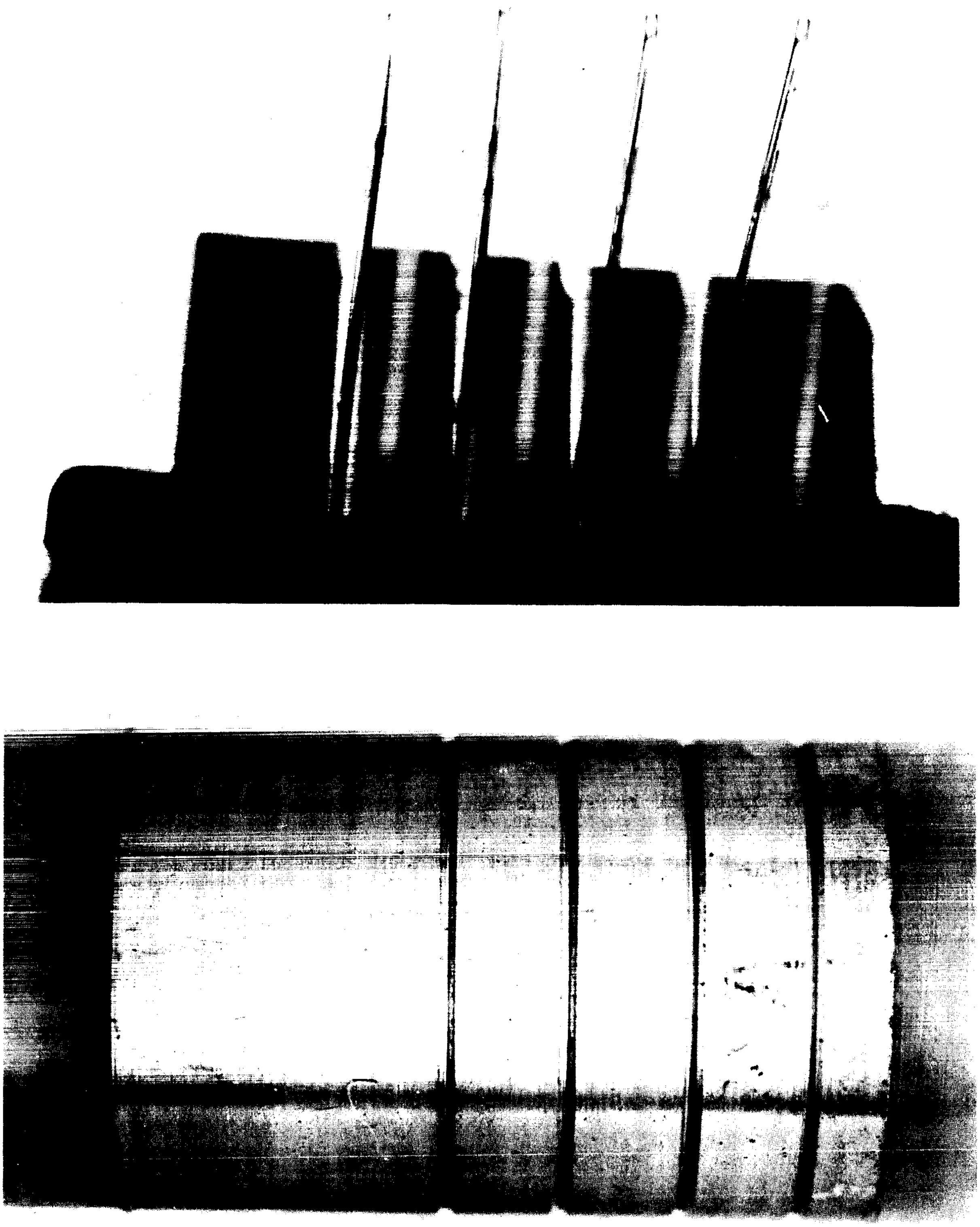


FIGURE 2 PHOTOMACROGRAPHS OF CAPSULE 1-37 AFTER RUN-IN

necessary to use a lubricant on the precious metal alloy of the contact springs to reduce wear of the alloy and give long life.

The effects of surface lubrication with a graphite-oil mixture were evaluated with Capsule 2-40. It was assembled with a thin coating of "Oildag" on the ring and brush contacting surfaces. "Oildag" is the tradename of a colloidal dispersion of graphite in petroleum oil manufactured by the Acheson Colloids Company. It is widely used as a lubricant for sliding contacts, particularly with heavy currents. The run-in test was carried out for 338 hours at 200 rpm with a brush current of 25 ma. The initial noise level was very high (4,000 microvolts peak-to-peak.) During the run-in, the fluctuations of noise were quite pronounced and random, but in general, the noise level decreased with final readings between 200 to 300 μv, peak-to-peak. The rms noise decreased from an initial 53 to 56 db to the final values of 27 and 30 db. No significant difference in the performance of the 80° and 90° grooves was observed. Because of the relatively high noise levels, it was concluded that the graphite-oil mixture is not an effective lubricant for the material system presently used in commercial capsules.

5. <u>80° Versus 90° Grooves</u>

In the original program, a simplified theoretical analysis suggested that there may be some advantage in using 80° grooves in place of 90° grooves. Several of the capsules used in the run-in tests utilized a ring cylinder having two 80° and two

90° grooves. During the tests current was supplied to each pair of grooves for approximately one-half of the total test time with frequent changes from one pair to the other. Although some of the earlier test results indicated some advantage for the 80° grooves, subsequent tests of lubricated capsules have not demonstrated any significant differences between the two systems. It is possible that the differences may have been masked by the beneficial effects of surface lubrication.

B. Investigation of Noise Characteristics of Commercial 80-Ring Capsules

1. Verification of Vibration, Threshold, and Repeatibility Effects

To confirm that noise characteristics obtained with experimental capsules during the original program are representative of general slip ring performance, two commercial ST-124 Slip Ring Assemblies were subjected to laboratory evaluation using the same instrumentation, apparatus, and techniques that were utilized for evaluation of experimental capsules. The torsional drive apparatus was modified to incorporate an aluminum reel between the inertial cylinder and the capsule rotor upon which the unused rotor leads were wound during oscillation and continuous rotation tests. Adjustment of the driving forces was also required to overcome the increased drag-torque of a commercial assembly.

The results of noise measurements with the two commercial capsules are presented in Table 2. The noise levels are considerably below the accepted level of 10 microvolts per milliampere. The fact that low noise levels can be obtained with commercial assemblies is attributed to the low vibration method used for driving the capsule.

TABLE 2

NOISE MEASUREMENTS - COMMERCIAL ASSEMBLIES

	Threshold Noise at 25 ma - 2 rings	
	Oscillation	Continuous Rotation
Assembly A	26 μv, ptp	- - -
Assembly B	34 μv, ptp	34 μv, ptp

Oscillation tests were performed with Commercial Capsule "B" to determine whether the threshold effect is generally applicable. Figure 3 is a plot of peak-to-peak noise at 25 ma versus the peak-to-peak angular amplitude of oscillation at 10 cps. The relationship obtained is practically identical to that obtained for the experimental soft gold rings, and indicates that commercial capsules do exhibit the threshold noise effect.

The noise waveforms for commercial capsules during continuous rotation exhibit the same degree of repeatibility that was demonstrated by experimental capsules. Figure 4 is an oscillogram of noise during rotation at 200 rpm. The upper of each pair of traces is the photo cell output produced by a mask attached to the rotor having 16 equally spaced holes around its circumference. One of the holes was masked and the hole adjacent was half-covered so that position and direction of rotation could be established by the absence of a light

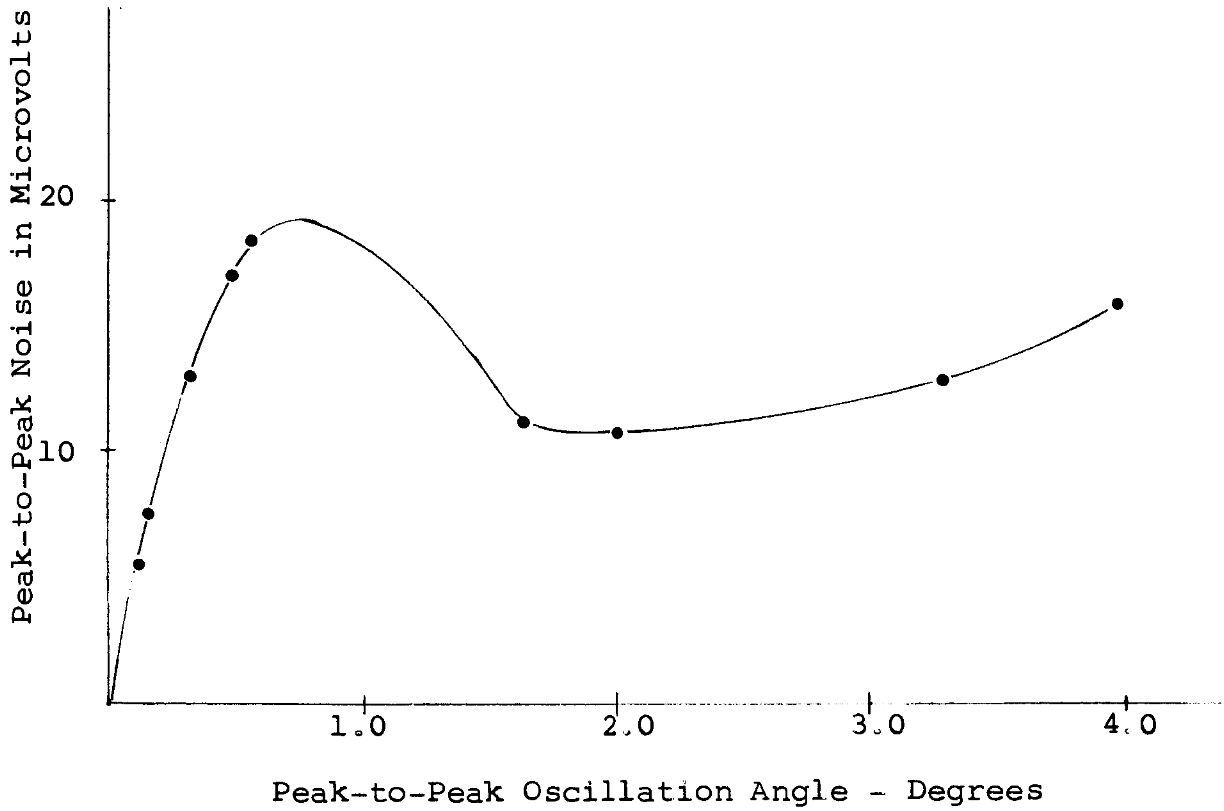


FIGURE 3 THRESHOLD EFFECT-COMMERCIAL CAPSULE "B"

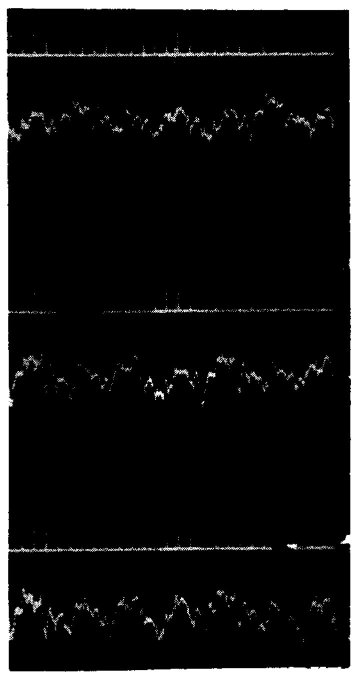


FIG. 4 - NOISE WAVEFORMS DURING ROTATION AT 200 RPM

COMMERCIAL CAPSULE B

pulse, preceded or followed by a pulse of reduced amplititude. An example of noise repeatibility is the noise spike which occurs regularly at the position of the absent light pulse. The regularity of noise waveforms is attributed to the dependence of noise on localized surface imperfections.

The commercial capsules were found to exhibit an "end oscillation" effect similar to that demonstrated by the experimental capsules. This effect occurs at the end of each free rotation test. It was found that the rotor oscillates slightly just before motion stopped. This is believed to be related to the rolling action of the brushes. When the rotation approaches zero velocity, the sliding contact stops and the brushes tend to deflect back toward their equilibrium positions. Because of friction between the brush and the ring, this deflection causes the rotor to oscillate until the neutral positions of the brushes are achieved. Because of the increased drag-torque of an 80-circuit capsule, the end oscillation motion attenuated quite rapidly. However, when external weights were added to the system to increase its moment of inertia, slowly decaying end oscillations were obtained.

2. Run-In Tests

The run-in test of Commercial Capsule "B" was performed at 200 rpm with a ring-brush current of 25 ma. The first evidence of noise increase appeared after 200 hours of operation with peak-to-peak noise spikes of about 200 microvolts. The noise continued to increase rapidly to levels of 2000-3000 microvolts at about 300 hours, and the test was terminated. During the test, the RMS noise level increased from the original 12 db above the one microvolt level to a final value of 50 db.

The commercial 80-circuit capsule assembly was opened to collect the wear debris. It was observed that the wear products were not typical of previous experience with the experimental capsules. A large quantity of about 0.060 grams of wear material was collected and studied under the microscope. The major wear debris in this case was composed of small gold chunks, flakes and slivers of various sizes, almost all comparatively large. A few pieces of epoxy resin were observed and also a few pieces of the welding or soldering alloy used to hold the brushes on the brush block. One of the brushes had broken off at the point at which it was welded to its junction block and a number of the brushes were no longer in contact with the rings. In a few cases, slivers of gold were adhering to one ring which were long enough to touch and possibly short to an adjacent ring. Metallurgical inspection of the capsule indicated that severe galling and erosion had occurred in the grooves. This result was attributed to seizing or a stick-slip phenomena which occurred between the ring and the brush. This was also apparently responsible for the fatigue and subsequent fracture of the brush wiper at the welded junction.

Photomacrographs shown in Figures 5 and 6 were taken after the test with a magnification of 15 times. They show the severe galling and erosion of the rings, and the condition of the brushes with a brush missing. This brush and the wear debris collected from the capsule are shown in Figure 7 which was taken with a magnigication of 8 times. The large amount of debris and the relatively large size of debris particles can be easily seen in this photograph.

3. Lubrication with P-38 Oil

To confirm that the beneficial effects of surface lubrication with P-38 synthetic oil demonstrated with experimental capsules also apply to commercial 80-ring capsules, a run-in test was performed with Commercial Capsule "A" after its contacting surfaces were coated with P-38 oil.

No increase in noise level above the low initial value was detected after 432 hours at 200 rpm. Disassembly of the commercial capsule after the test revealed no debris deposits and no mechanical damage to the rings and brushes. These results were in direct contrast with the run-in results obtained with an unlubricated commercial assembly. During the run-in of Commercial Capsule "B" (unlubricated), noise spikes of 20 μv peak-to-peak were evident after about 200 hours, and noise levels of 2000-3000 μv were measured when the test was terminated after 310 hours. Excessive debris deposits and permanent damage to the rings and brushes were observed when the capsule

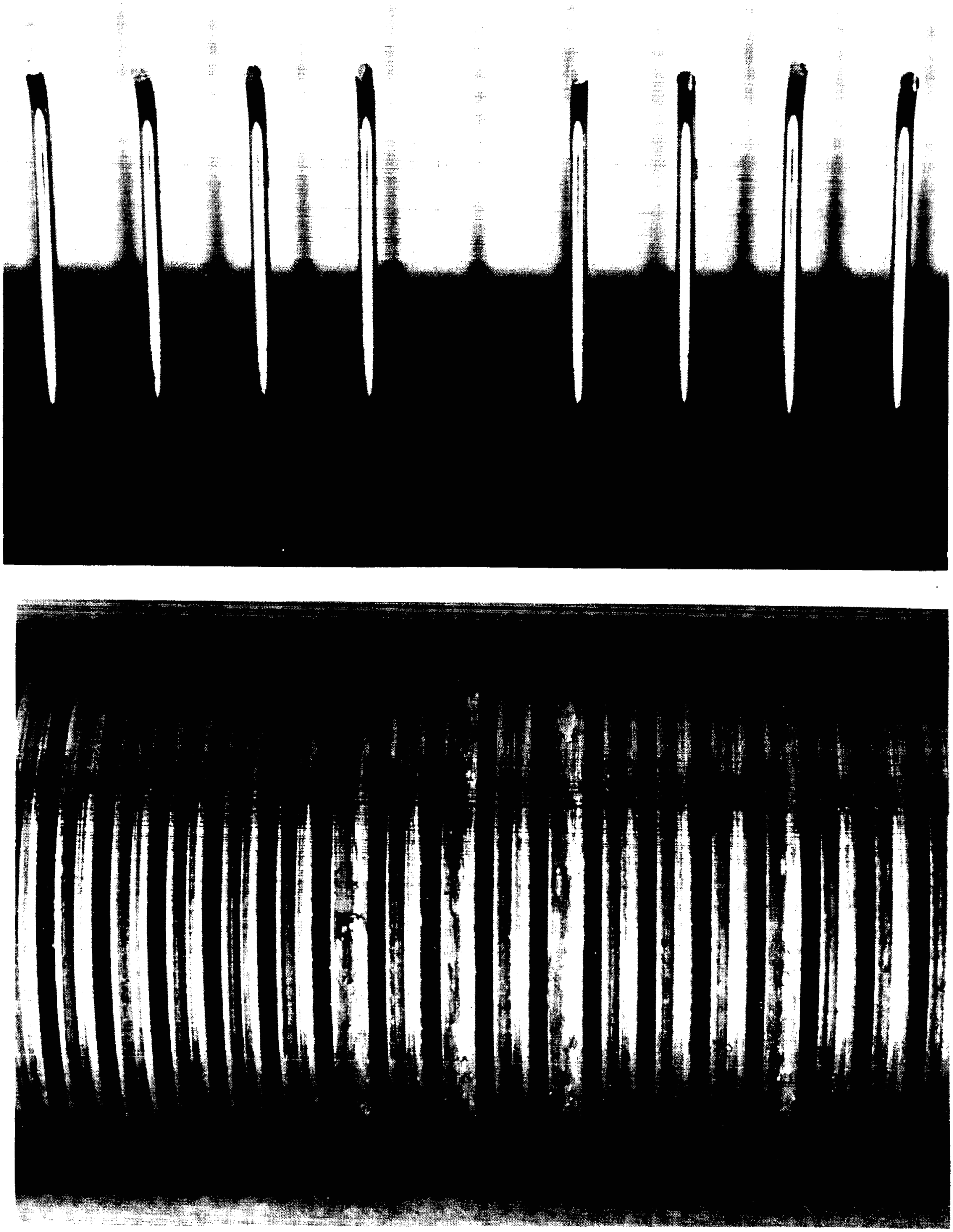


FIGURE 5 PHOTOMACROGRAPH OF COMMERCIAL CAPSULE "B" AFTER RUN-IN

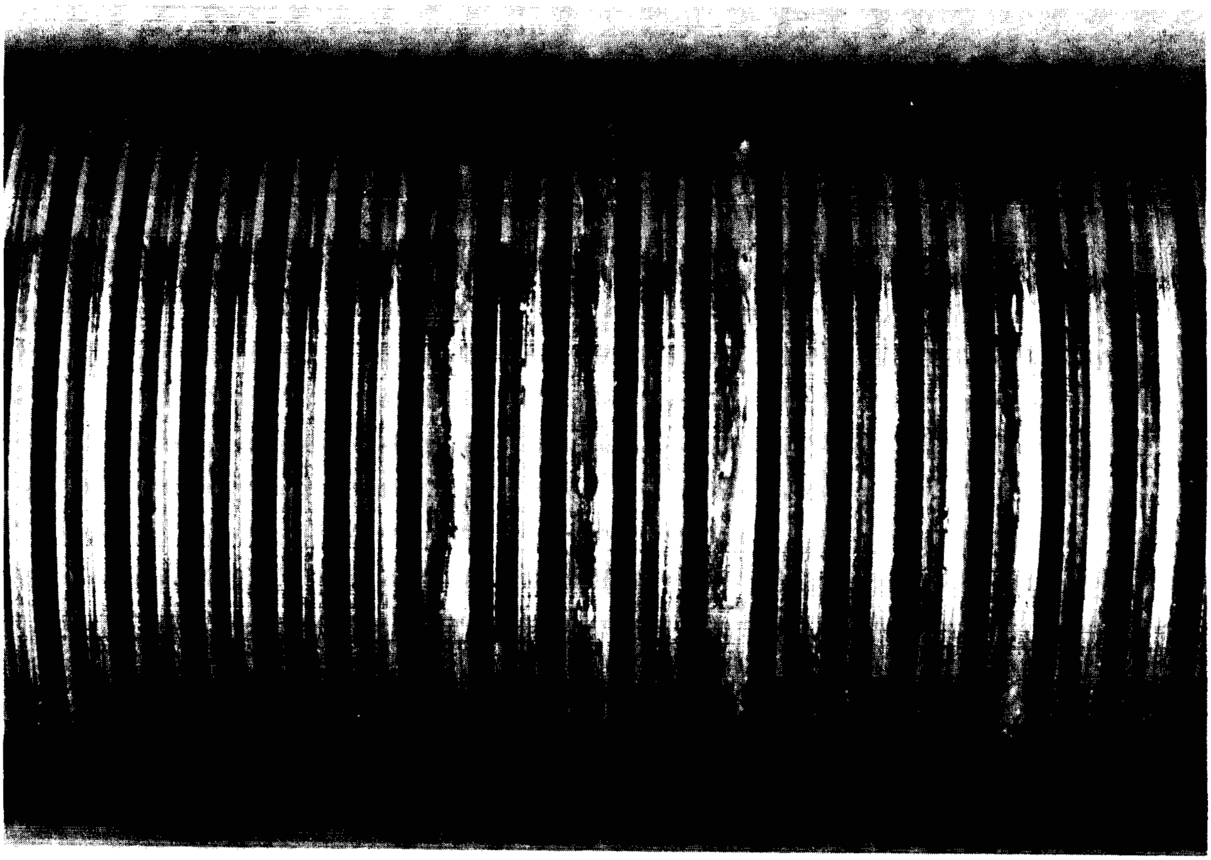


FIGURE 6 PHOTOMACROGRAPH OF COMMERCIAL CAPSULE "B" AFTER RUN-IN

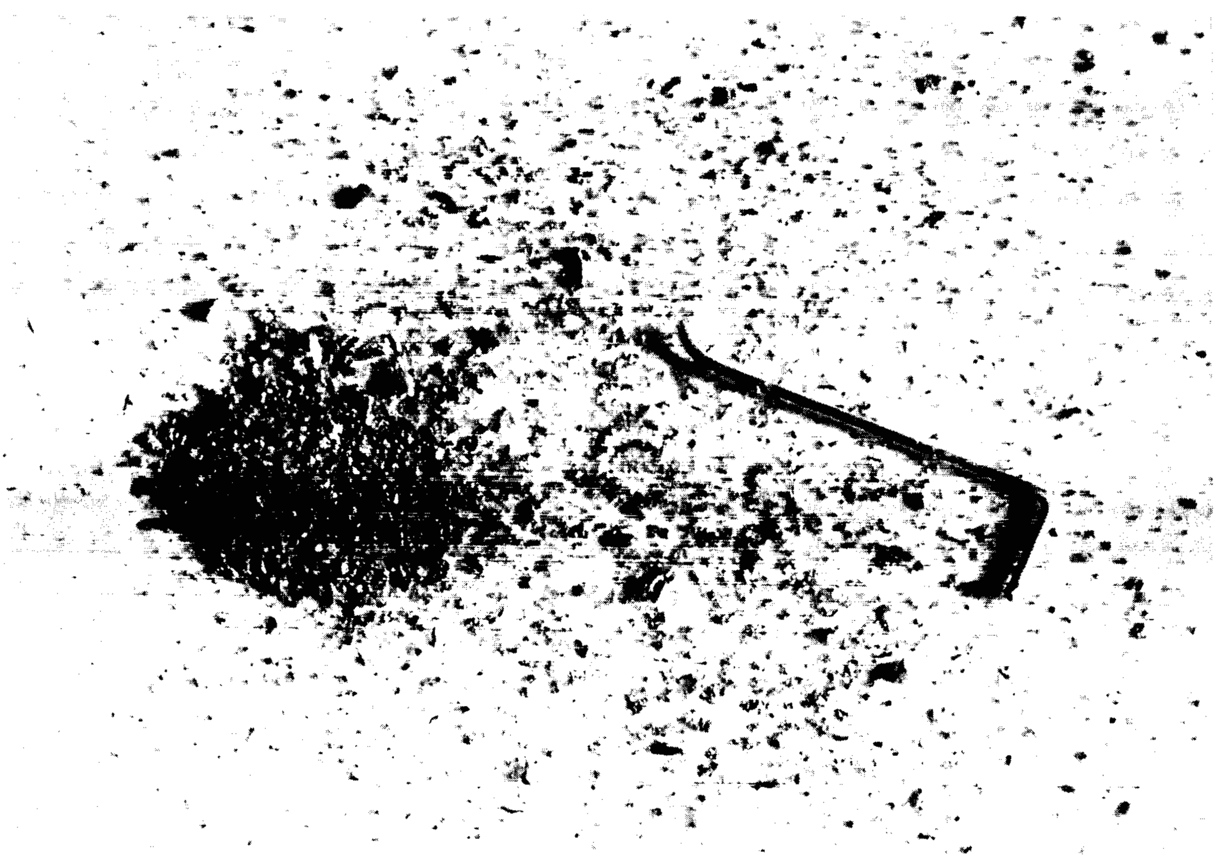


FIGURE 7 WEAR DEBRIS AND A BROKEN OFF BRUSH FROM COMMERCIAL CAPSULE "B"

was disassembled and inspected. These results are similar to those obtained with lubricated and unlubricated experimental capsules.

C. Study of Thermal Effects

The seizing phenomenon observed between the ring and the brush of commercial capsules was of great significance since it explained the difference in the type of wear products obtained in commercial and experimental capsules and also the poorer noise characteristics obtained during the run-in tests of commercial capsules. The apparent reason for the seizing effect was thermal in origin, and a major portion of the program was devoted to its study.

1. Explanation of Thermal Effects

It has been hypothesized that the seizing between the ring and the brush in a commercial capsule is a consequence of the high temperatures that are developed at the contact interface. In the commercial capsule with the rings imbedded in the plastic rotor, each ring is thermally isolated, and heat generated at the contact surface cannot be dissipated quickly. In the experimental capsule, on the other hand, the common brass cylinder upon which the rings are plated acts as a heat sink and permits rapid conduction of the heat from the contact surface.

2. Verification of Thermal Effects

To verify that the severe galling and erosion wear are caused by thermal effects which promote seizing between brush and ring, Capsule 2-42 was assembled to simulate the thermal isolation that exists between rings in a commercial assembly. In this special capsule, two independent gold rings were pressed onto a teflon rotor. The rings were interconnected at only one point by a single 2 mil gold wire to avoid good heat conduction paths between the rings while still permitting current flow and noise measurements. The capsule exhibited increased noise after 130 hours of run-in at 200 rpm, and an open circuit developed at approximately 160 hours. Visual inspection upon disassembly of the capsule revealed that one brush and ring had seized causing the ring to rotate on the teflon rotor and to shear off the 2 mil gold wire interconnection between rings. A large amount of wear debris was also present. Figures 8 and 9 show the rings and the brushes after the test. The broken wire and the wear debris can be clearly seen in Figure 8.

The same experiment was repeated with Capsule 1-43, except that this assembly contained four independent rings connected into pairs by separate gold wires. Both pairs of rings exhibited very high noise after about 90 hours of run-in at 200 rpm, and open circuits developed in both pairs at about 96 and 110 hours. Inspection of the disassembled capsule again revealed that the interconnecting wires were sheared off by rotation of the rings relative to the rotor, apparently because of high friction or seizing between brushes and rings. An extremely large amount of black wear debris was found on the lands and in the grooves of the rings. The poor condition of

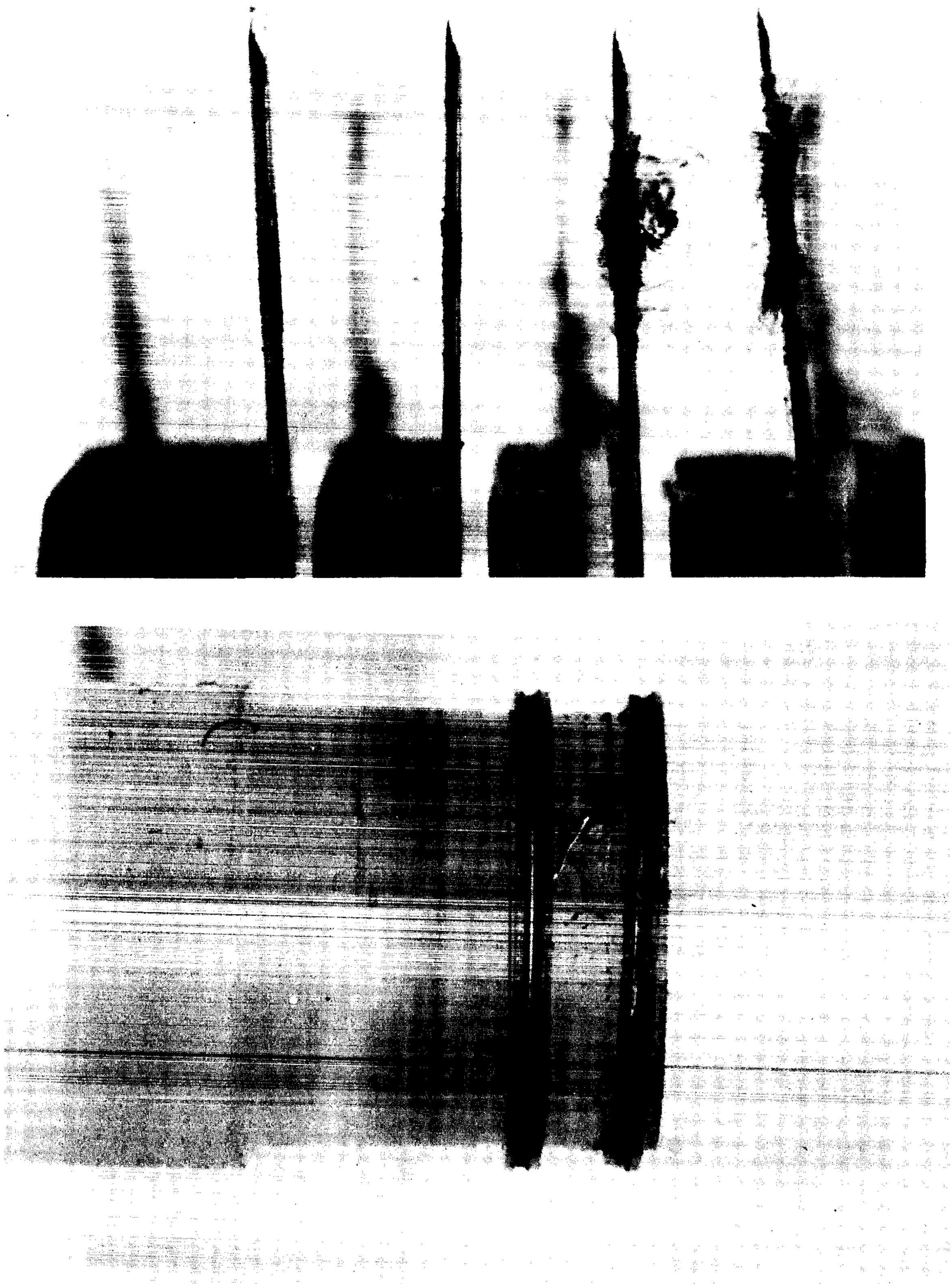


FIGURE 8 PHOTOMACROGRAPH OF CAPSULE 2-42 AFTER RUN-IN

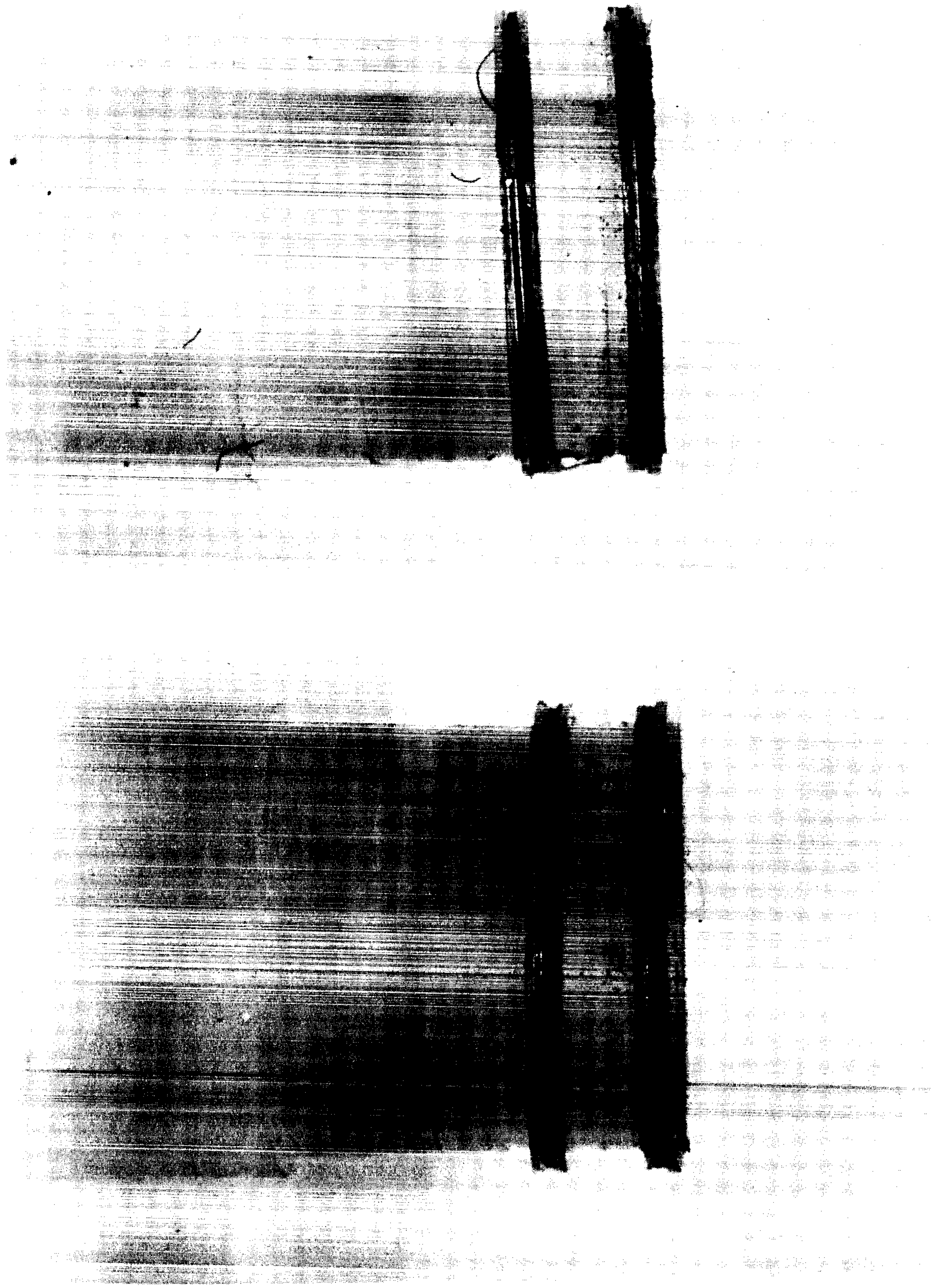


FIGURE 9 PHOTOMACROGRAPH OF CAPSULE 2-42 AFTER RUN-IN

the rings and brushes and the large amount of debris can be seen in Figures 10 and 11.

Experience with Capsules 2-42 and 1-43 indicates quite positively that high friction and/or seizing conditions are developed rapidly in the isolated ring configurations. Seizing between brushes and rings is probably a consequence of cumulative increases in temperature caused by the inter-related effects of friction and heat generation.

3. <u>Thermal Effects and Surface Lubrication</u>

To determine the effectiveness of surface lubrication with the experimental capsules, Capsule 2-44 was assembled with four isolated rings, each coated with P-38 oil. The results of a run-in test of 412 hours of continuous operation indicated again that surface lubrication was effective in maintaining low noise and in preventing destructive effects. This result was identical to that obtained with the commercial capsules.

4. <u>Oscillation Tests</u>

The seizing effects exhibited by unlubricated experimental and commercial capsules have been established during continuous rotation run-in tests. To duplicate these effects during an oscillation run-in test, Capsule 1-45 was oscillated at a fixed stator position with a frequency of 10 to 12 cps and a total displacement angle of 1.0° to 1.2°. After 560 hours of operation only a small increase in noise level was observed.

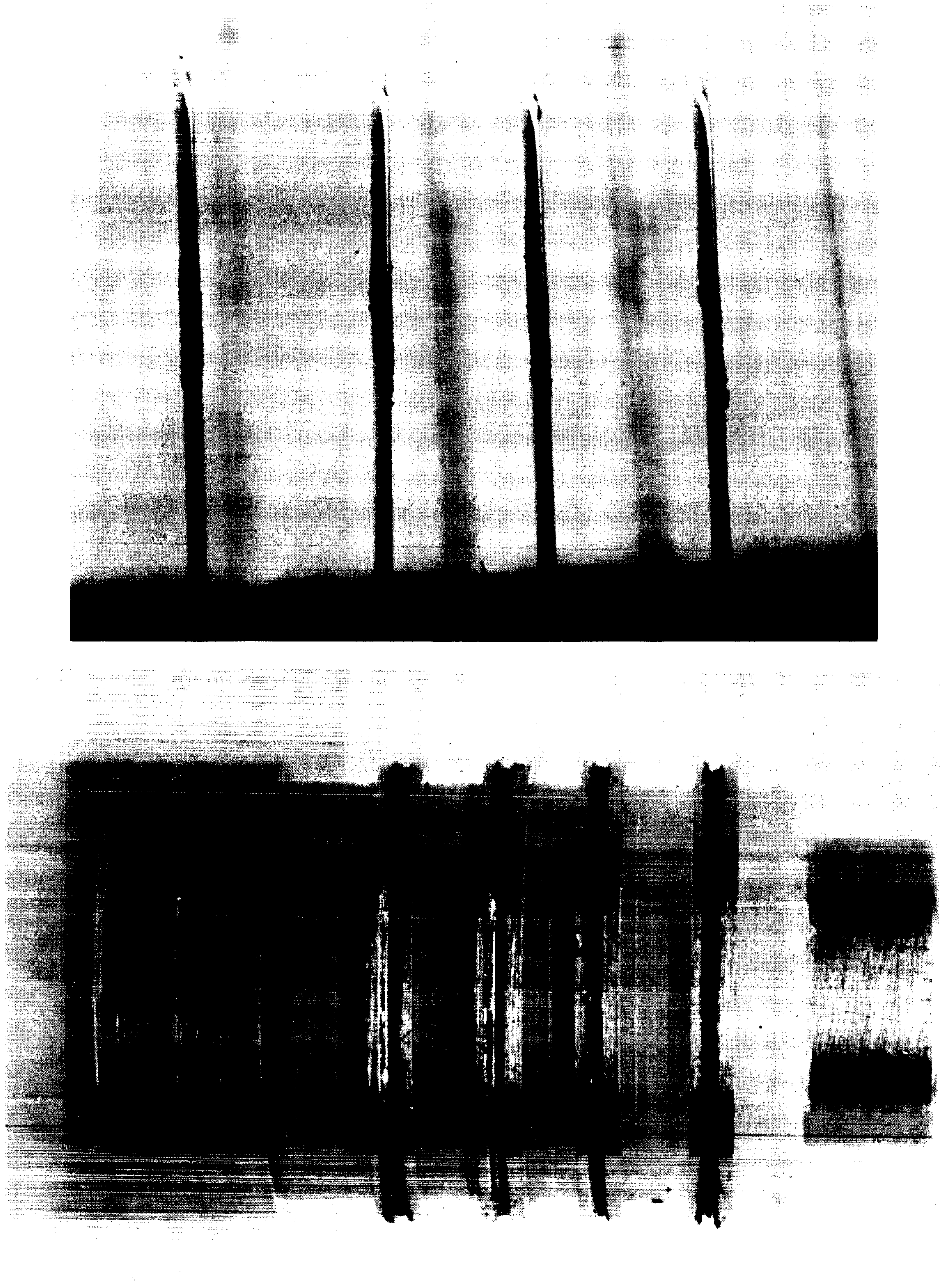
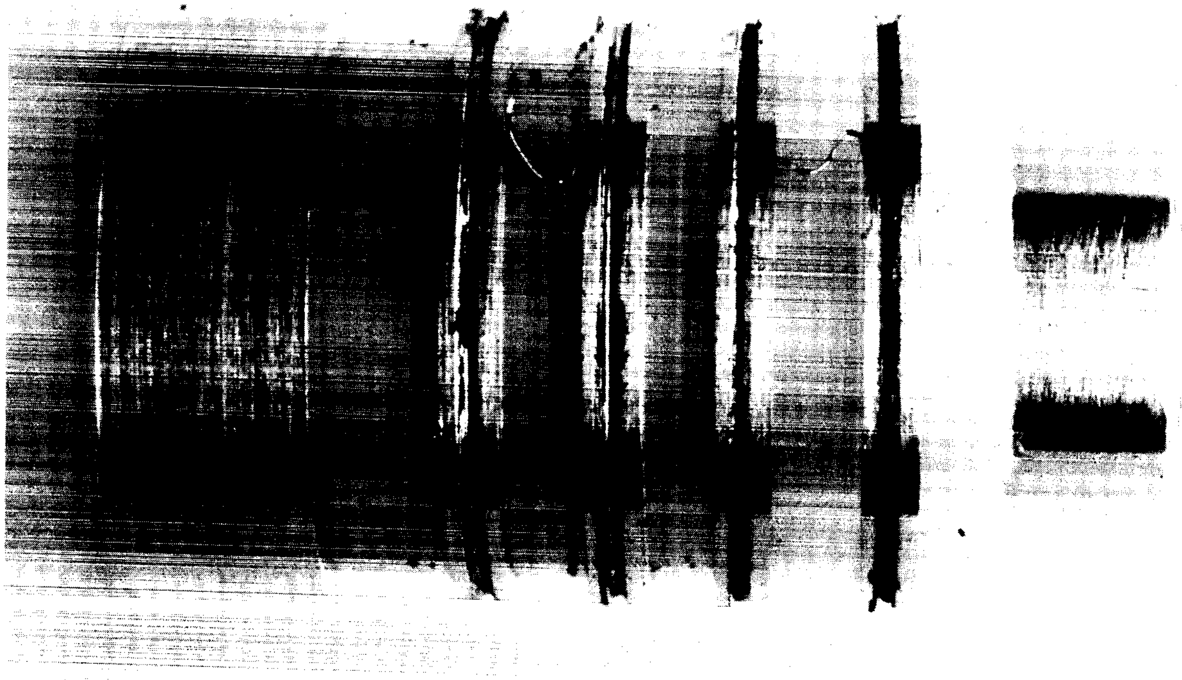


FIGURE 10 PHOTOMACROGRAPH OF CAPSULE 1-43
AFTER RUN-IN



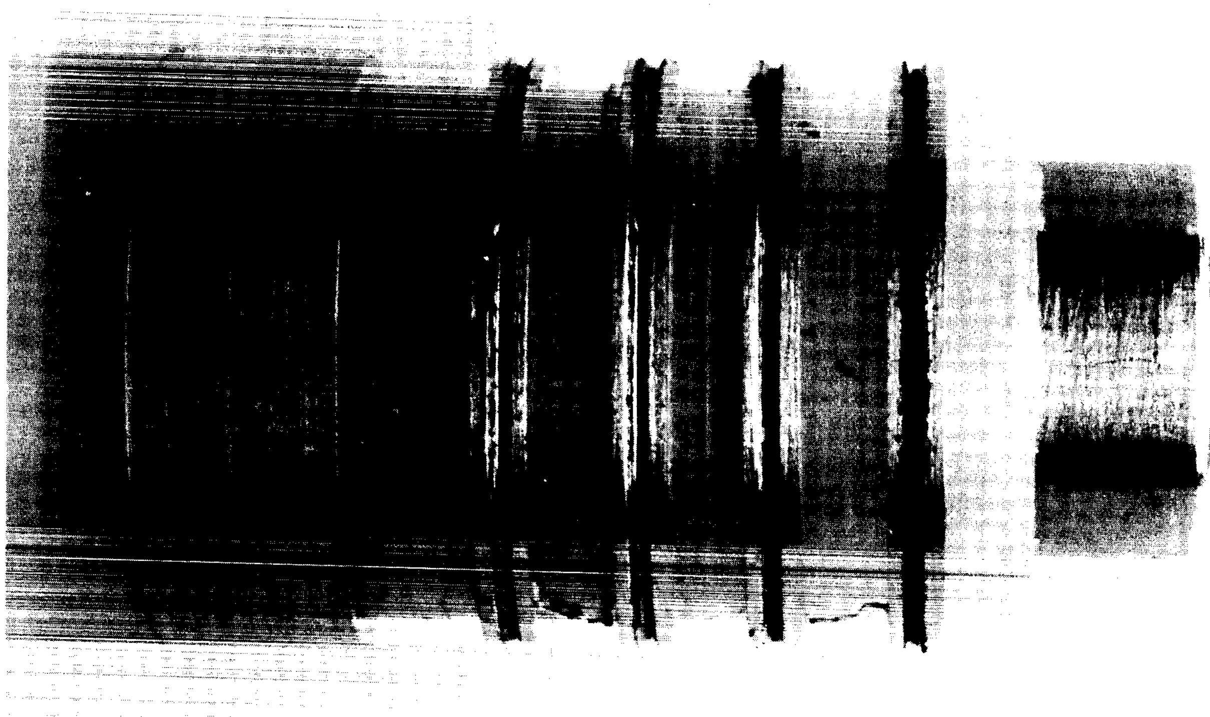


FIGURE 11 PHOTOMACROGRAPH OF CAPSULE 1-43
AFTER RUN-IN

Visual inspection of the slip ring assembly after completion of the test revealed that some debris was assumulated on both sides of the ring-brush areas that were making contact during the oscillation. Apparently this debris was being pushed aside by the sweeping action of the brushes. This was confirmed by the following observation made during the test: moving the stator by a very small amount would result in high noise spike that would rapidly disappear. It was determined in previous tests that noise is related to the speed of rotation. The equivalent speed during the oscillation tests was about 4 rpm as compared with 200 rpm during the continuous-rotation tests. This can explain the low noise and relatively small total amount of debris after the prolonged test of 560 hours. Also the randomness of surface imperfections might be of some significance. In previous tests it was noticed that the debris was not uniformly distributed in the rings and certain areas were completely free of any debris. The random selection of the contact point can, then, be one of the important factors in noise performance during oscillation tests. Photomacrographs of the rings and the brushes taken with a magnification of 15 are shown in Figure 12. Note the presence of wear debris at the points of contact during the oscillation. Based on the limited tests, it might be concluded that the seizing effects could not be duplicated with oscillation run-in tests primarily because of low equivalent speed of rotation.

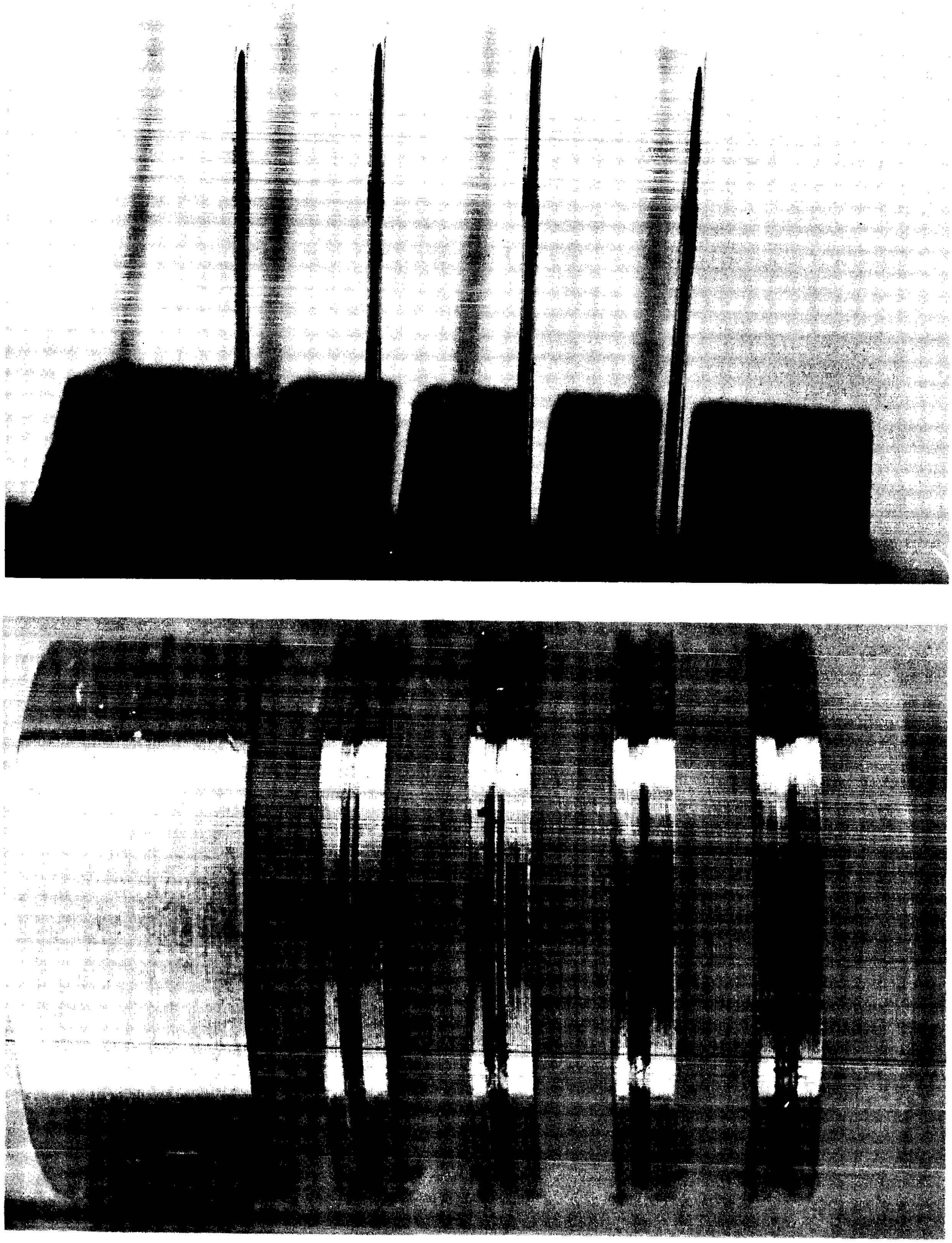


FIGURE 12 PHOTOMACROGRAPH OF CAPSULE 1-45
AFTER RUN-IN

In another oscillation run-in test, Capsule 1-55 was assembled with four isolated rings lubricated with P-38 oil. After 484 hours of operation, a small increase in noise but essentially no wear debris were observed.

An oscillation test was performed with Capsule 2-42 to determine if threshold effects exist in thermally isolated capsules. The results, shown in Figure 13, indicate that in general this is true and that the overall noise level is higher than that obtained with commercial or experimental capsules.

D. Vacuum Operation of Slip Ring Assemblies

It is known that a vacuum environment has a degrading effect on the performance of sliding electrical contacts. This degradation generally takes the form of increased friction, wear and electrical noise due to the reduced heat transfer characteristics in a vacuum environment. The thermal effects that lead to severe galling and erosion are aggravated by vacuum. A limited investigation was undertaken with the objective to get a general indication of the performance of the presently used materials in a vacuum environment.

1. Test Set-Up

Test apparatus for vacuum testing of slip ring capsules is shown in Figures 14 and 15. It consisted of a rotary vacuum pump, a synchronous motor with speed reducing gears, a magnetic coupler, and a glass bell jar, used as a vacuum chamber. Two four-pole Cast Alnico V side pole magnets were utilized to drive the slip ring capsule mounted inside of the vacuum chamber.

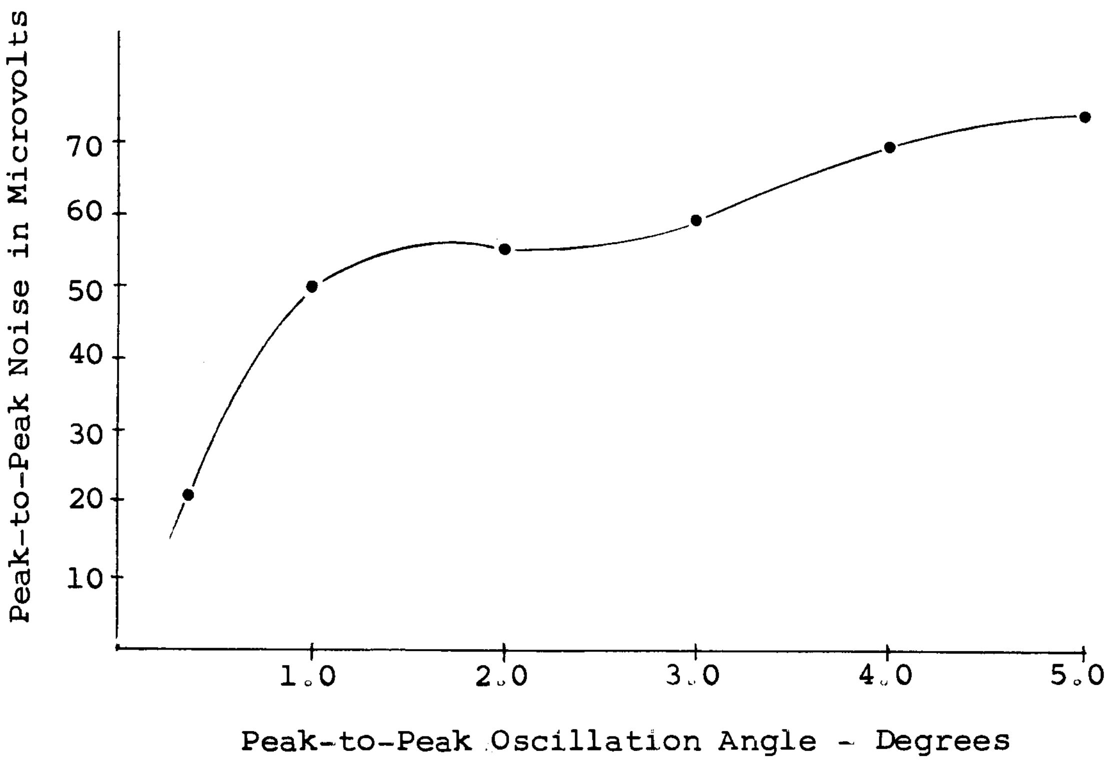


FIGURE 13 THRESHOLD EFFECT, CAPSULE 2-42, THERMAL ISOLATION

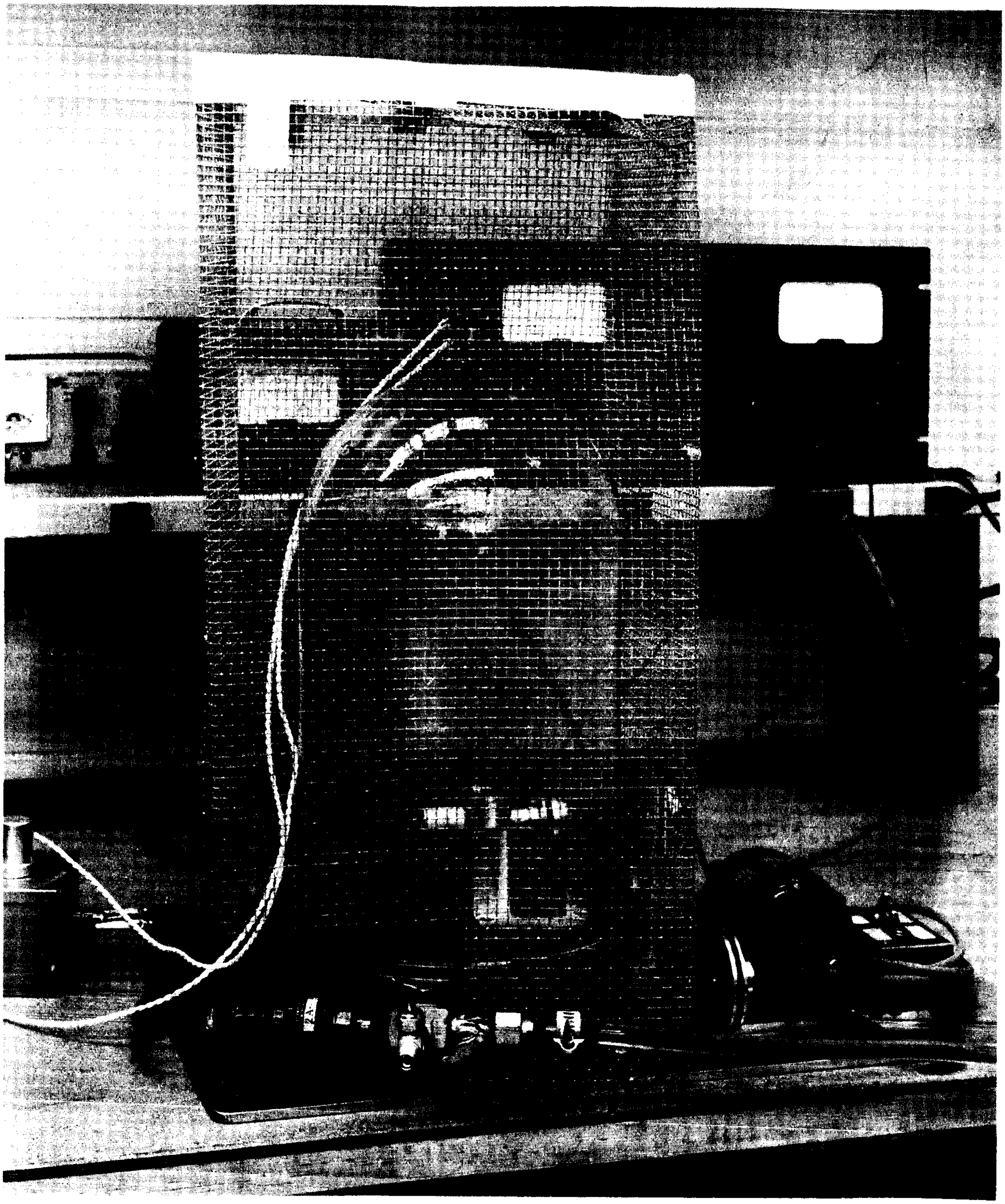


FIGURE 14   VACUUM TEST SET-UP

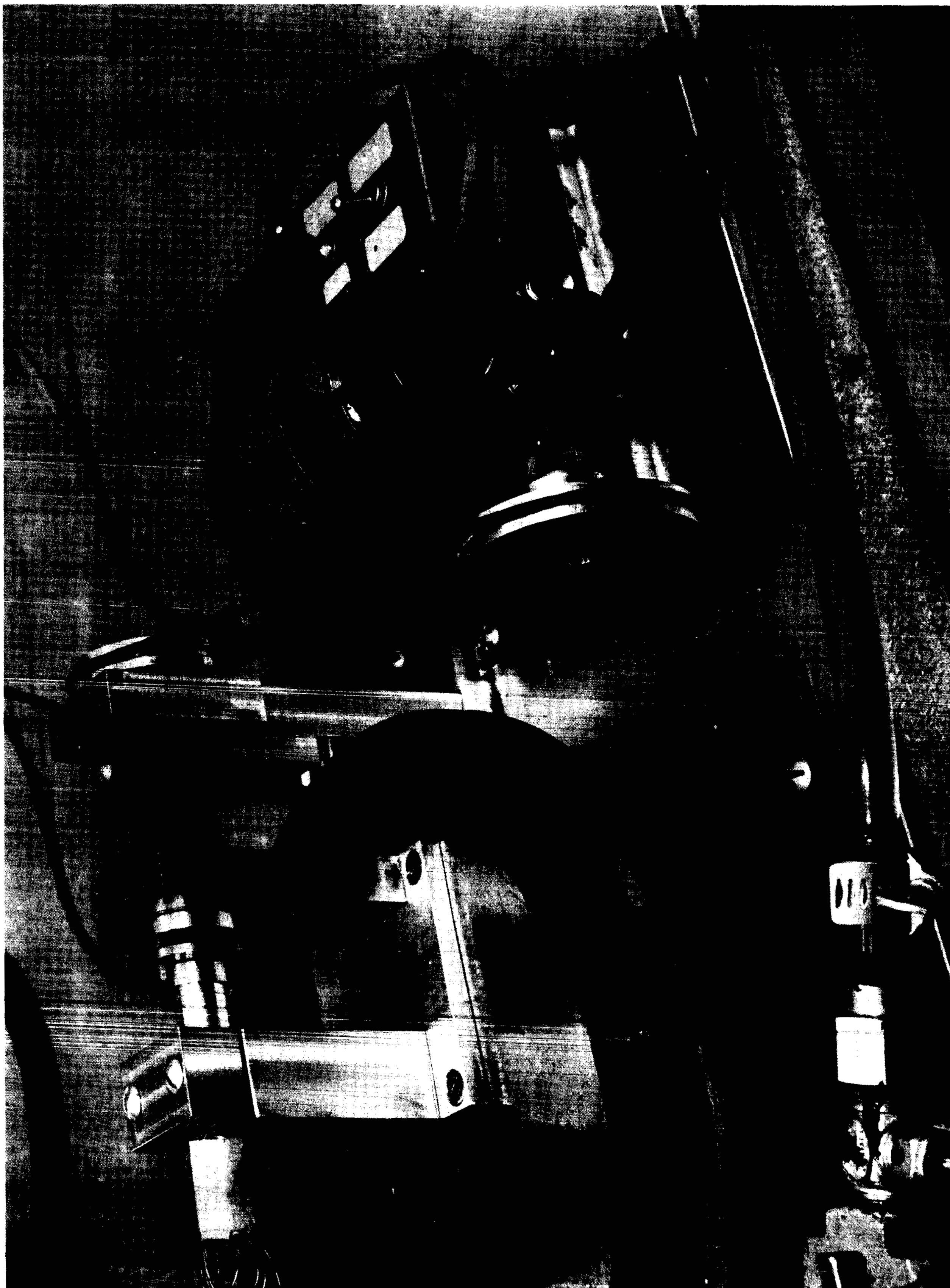


FIGURE 15 CAPSULE DRIVE SYSTEM USED DURING VACUUM TESTS

A close-up of the drive system is shown in Figure 15. Instrumentation used in continuous rotation run-ins in nitrogen atmosphere was also employed for vacuum tests. The capsules were rotated at 200 rpm with a 25 ma brush current. Vacuum obtained in the initial test was 200 microns. Some refinements in the pumping system lowered the vacuum used during subsequent tests to 25 microns.

2. Test Results

Experimental Capsule 1-46 was run-in in a vacuum of 250 microns. After a time interval of less than 24 hours, high noise spikes were observed. The average noise level increased from 30 microvolts to 300 microvolts with frequent periodic spikes of up to 2000 microvolts. After 200 hours the test was terminated.

The visual inspection showed that 80° grooves had heavy debris deposits at the bottom of the grooves while the debris in the 90° grooves was concentrated mostly on the groove shoulders. However, the noise performance of both grooves was about equal. Another test was run with Capsule 1-47 which had rings lubricated with P-38 synthetic oil. After 380 hours at a vacuum of 25 microns, no noise level increase was observed and the test was stopped. Visual inspection showed no debris accumulation, due apparently to the fact that the oil film remained intact.

Tests of isolated ring experimental capsules, both unlubricated and lubricated, were undertaken in a vacuum of 25 microns. Unlubricated Capsule 2-56 with four isolated rings was rotated for 284 hours. The noise level remained generally low with occasional noise spikes of up to 400 microvolts. Visual inspection upon completion of the test revealed that a considerable amount of debris was accumulated, mostly on the groove shoulders, but also some at the bottom of 80° grooves. Figures 16 and 17 show the condition of the capsule after the test. Capsule 2-57, with four isolated rings lubricated with P-38 oil was run-in for 240 hours. The results of noise measurements were quite similar to those obtained with the unlubricated Capsule 2-56, however, the lubricated capsule had no visible accumulation of wear deposits at the end of the test. In other words, the effect of lubrication was not so much in noise improvement as in preventing accumulation of wear debris. During the run-in tests of isolated rings in inert atmosphere, it was established that noise and wear are closely interrelated. Apparently this is not necessarily true for vacuum operation. Further tests would be needed to confirm this result. It was also noticed that in vacuum tests the initial noise levels were slightly higher in lubricated thermally isolated capsules than in the unlubricated capsules.

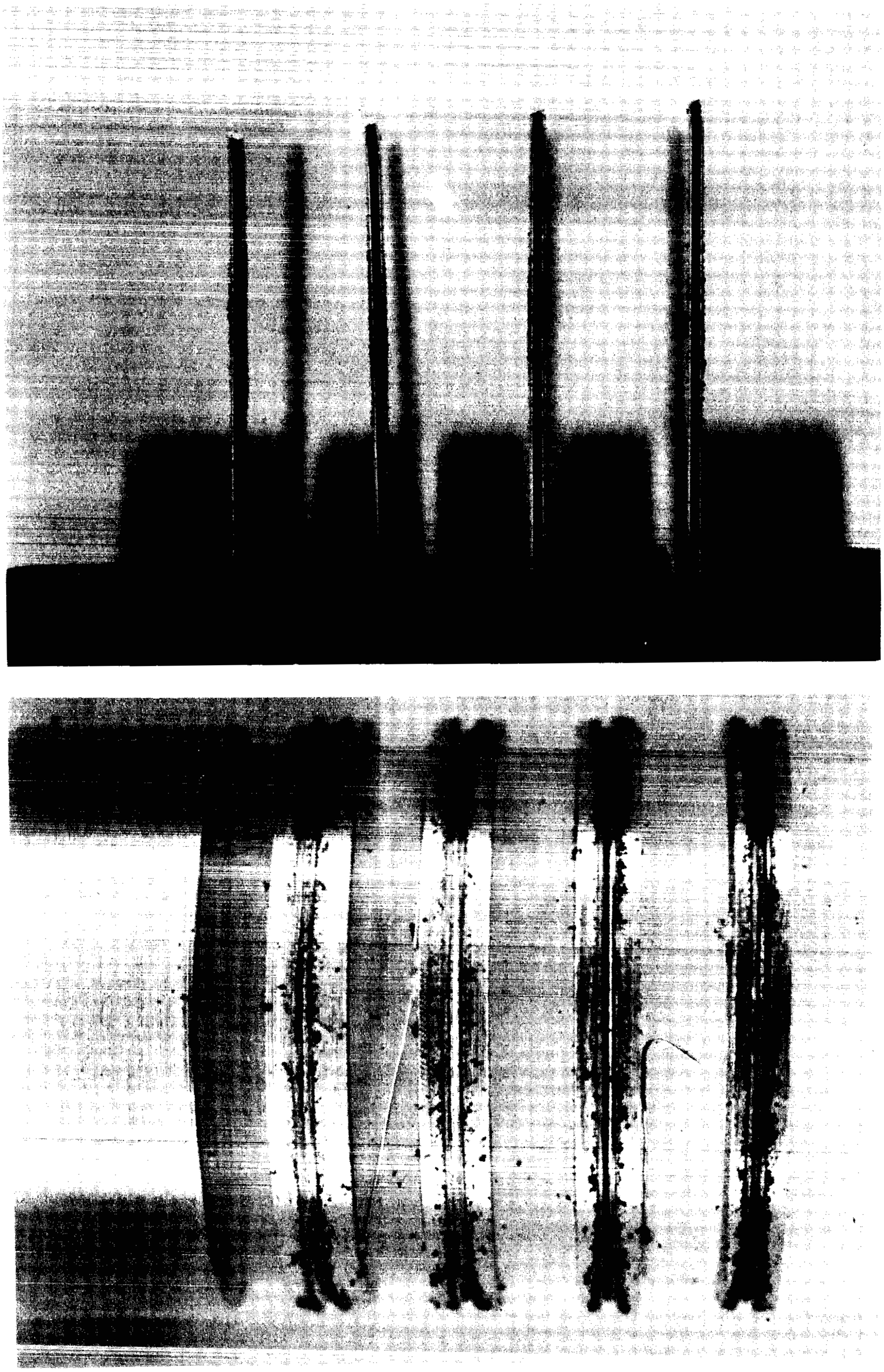


FIGURE 16 PHOTOMACROGRAPH OF CAPSULE 2-56
AFTER RUN-IN

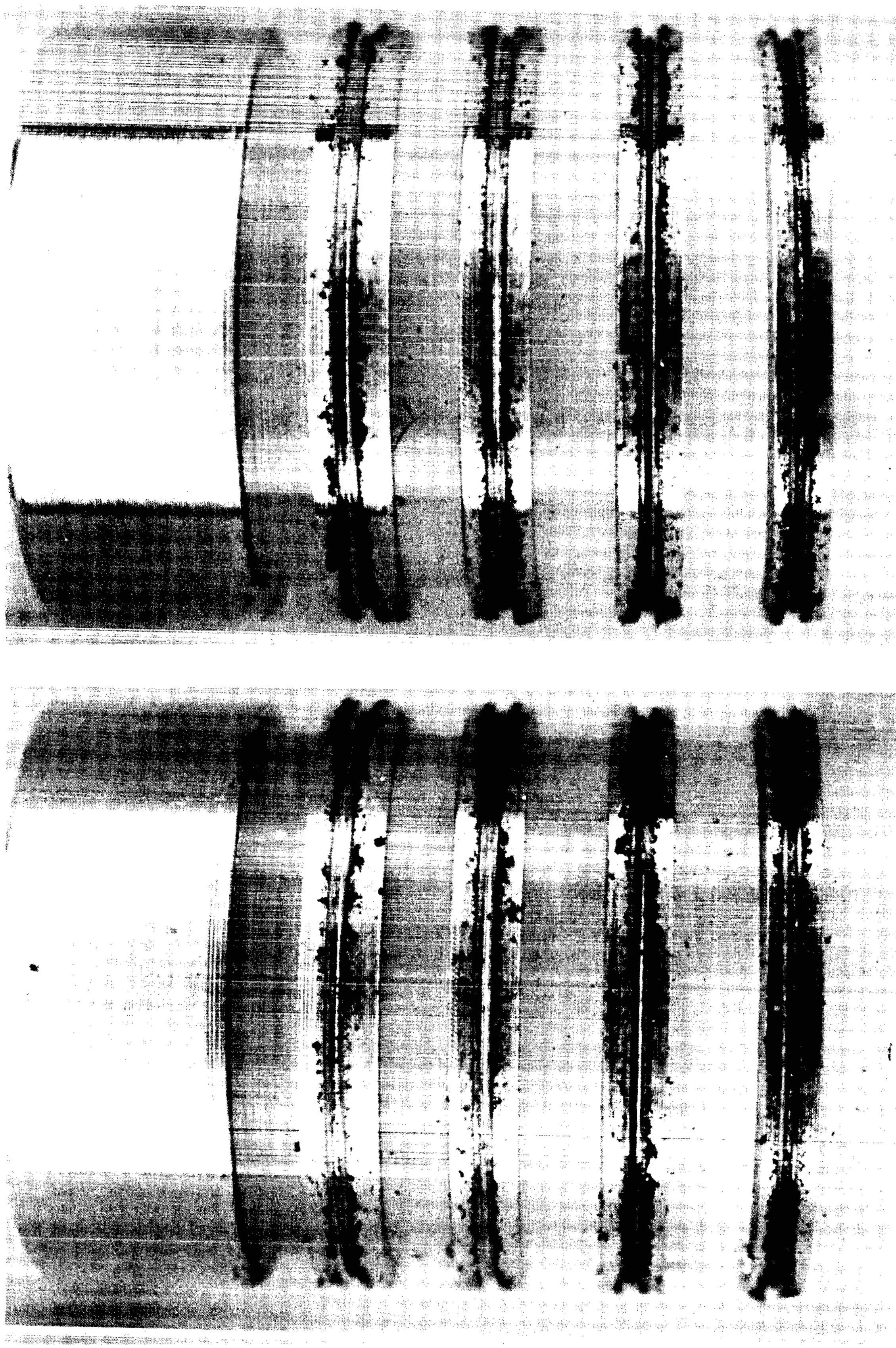


FIGURE 17 PHOTOMACROGRAPH OF CAPSULE 2-57
AFTER RUN-IN

E. Analysis of Wear Debris Deposits

Extended operation of presently designed miniature slip ring capsules is not possible because of the high noise levels that result from accumulation of wear debris deposits during long-term operation. As part of the program, a study has been conducted to identify the chemical and metallurgical nature of the debris deposits in order to determine its sources and take corrective measures.

As the initial step, Capsule C1-28, a capsule containing soft gold rings which had accumulated 40.6 hours of run-in was reconditioned and subjected to a second run-in process. The reconditioned capsule was selected primarily to establish whether the accumulation of debris was a one-time or continuous process.

After 34 hours of run-in at 200 rpm with the reconditioned capsule, excessive noise levels were obtained and the test was terminated. Disassembly of the capsule revealed a relatively large amount of debris, thus indicating that debris accumulation is a continuous process.

The wear debris deposits were extracted with carbon disulfide and the residue taken up in agua regia, and ashed on the carbon electrode for emission analysis. Approximately 0.1 milligram of the sample was present. The strongest lines from this sample were due to gold and calcium; weaker lines were due to aluminum, magnesium and iron.

To establish probable sources of the wear debris deposits, a sample of the P-38 oil used for bearing lubrication was ashed and then analyzed by the emission spectrograph. The strongest lines showed the presence of barium, calcium, strontium, and magnesium. Aluminum and iron were present also, but were much weaker.

Since the ring and brushes are made of gold, its presence in the deposits is expected. The presence of calcium, aluminum, magnesium and iron in the slip ring deposits could be explained by their presence in the oil as established by the analysis of the ash from oil. However, presence of barium and strontium should also then be expected if the oil from the bearings is contributing to the deposits. Because of this inconsistency, further testing of debris samples was required to obtain conclusive evidence on the nature of deposits and the sources of contamination.

Capsule 2-29 was assembled with soft gold rings and a run-in at 200 rpm was conducted. During the run-in, the front bearing became misaligned due to wear of the rotar shaft. After a new bearing was installed, the run-in was continued with Ring #33. After 300 hours of operation, the test was terminated even though the noise level was very low. A small amount of debris was present. Most of it was found at the top of the grooved portion of the rings, but some was also obtained from the bottom of the grooves. The collected debris was sufficient to permit spectrographic analysis. To avoid possible contamination with solvents, the debris was removed in separate portions with the aid of a microprobe using a low power binocular microscope at 27X. Two separate samples of the debris were transferred directly to carbon electrodes for analysis by emission spectrograph. Although the samples were very small, the presence of gold only was detected; all the other trace lines were also indicated in the blank run.

Another portion of the deposit was transferred to a small section of 1/8" copper tubing for attachment to the Bendix time-of-flight mass spectrometer. Since the sample inlet system was not set up for high temperature, the sample was heated to about 500°F using an electric heat gun placed up against the sample tube. No peaks other than normal background were recorded; however, a short burst (about 1 second duration) of hydrocarbons was observed. The highest peak appeared to be in the 120-140 m/e range.

A third sample of debris was left intact on one of the brushes and mounted for analysis by the electron probe. Even though the deposits displayed a black appearance under normal illumination, the typical gold color was observed when light was reflected from the wear particles at the proper angle, and viewed under the microscope.

The trace constituents of calcium, aluminum, magnesium, and iron observed previously were apparently due to contamination of the electrode system and/or the solvent extraction step and not due to the bearing lubrication or other sources within the capsule.

In one additional test, the carbon disulfide extract was evaporated to about 0.2 ml and then injected into a gas chromatograph operated at 300°C. No evidence of any organics or oil was obtained.

F. Effect of Precious Metal Hardening Agents in Gold Electroplating Baths

The results of the study of precious metal hardening agents carried out during the first year's effort were inconclusive, primarily because of the difficulties that were encountered in obtaining reference plating samples from the bath selected as the vehicle for the additions (Oroverge Bath). Because of the potential merit of this concept, it was decided that further exploratory work would be conducted using the Orotemp 24K formulations as the basic bath for additions. This bath was selected on the basis of its known good plating behavior in earlier work. Five ring cylinders were plated from this bath. They were used as references for comparison with different metal hardening agents.

A series of experiments was carried out involving the hardening of electrodeposited gold by precious metal ion additions of rhodium, palladium, and platinum to the basic gold bath. Rhodium and palladium both belong to the low atomic weight family of precious metals (Ru, Rh, and Pd) whereas platinum belongs to the high group (Os, Ir, and Pt).

1. Rhodium - Treated Gold Bath

Specimens were plated from a conventional neutral pH gold bath (Orotemp 24) with progressively increasing amounts of rhodium ion present. The rhodium additions were prepared from rhodium chloride ($RhCl_3 \cdot 3H_2O$) dissolved in water. Since it is not possible to predict the amount of rhodium that will codeposit under a given set of operating conditions, four levels of addition ion concentration were arbitrarily selected. These were Rh/Au ion ratios of 0.0000 (no rhodium ion), .0001, .001, and .01. Specimens were plated at a current density of 5 amperes per square foot on a rotating mandrel utilizing an inert anode.

The microhardness determinations on electrodeposits from the rhodium - treated Orotemp 24K gold bath are summarized in Table 3.

TABLE 3

MICROHARDNESS DATA ON Au-Rh-ELECTRODEPOSITS

Ring No.	Rh/Au Ion Ratio in Bath	Range of Hardness in Deposit	
		VHN_{25g}*	VHN_{15g}
44	0.0000	102-116	97-101
45	0.0001	100-118	89-105
46	0.001	91-101	83-93
47	0.01	59-91	76-87

* VHN_{25g} - Vickers Hardness Number, 25 gram indentor load.

The specimens were mounted in Bakelite holders and polished metallographically. Microhardness determinations were conducted on the polished gold surfaces using an Ernst Leitz Durimet machine. This device utilizes a square base pyramid diamond indentor which is provided with a variable loading feature. Hardness values were taken at two indentor load levels, 15 and 25 grams. Referring to the table, it is immediately apparent that an unexpected trend in hardness was found. Whereas the rhodium level in the bath increased, the hardness exhibited a significant decrease. It can be seen that there is some variation in hardness from spot to spot in the deposits also.

2. <u>Palladium - Treated Gold Bath</u>

Massive electrodeposits were prepared from gold bath formulations containing palladium/gold ion ratios of 0.0000, 0.0001, 0.001, and 0.01. Plating was carried out at a current density of 5 amperes per square foot and at a bath temperature of about 55°C. The specimens were rotated at about 400 rpm during plating.

Microhardness measurements were made on the deposits using standard metallographic mounting and polishing techniques in conjunction with a Ernst Leitz Durimet microhardness device. Hardness values were taken at four points (90° positions) around the circumference of the specimen at about the center of the 16 mil thick deposit. The experimental results are presented in Table 4. The results indicate that there is no significant change in hardness with the addition of palladium up to a concentration of 0.01. This is in contrast to the general decrease in hardness that was effected by additions of rhodium.

TABLE 4

MICROHARDNESS DATA ON Au-Pd ELECTRODEPOSITS

Ring No.	Pd/Au Ion Ratio in Bath	VHN^{*}_{15g} 0°	90°	180°	270°
48	0.0000	70.2	63.7	71.0	61.3
49	0.0001	73.2	74.7	67.5	64.9
50	0.001	64.3	67.5	68.2	64.9
51	0.01	69.5	64.3	78.7	79.5

*Vickers Hardness Number, 15 gram indentor load.

3. Platinum - Treated Gold Bath

Massive gold electro-deposits were made from a 24K gold plating bath which had been modified by platinum ion additions. It was reasoned that the possible co-deposition of platinum with the gold would result in plates of improved wear resistance and higher hardness. Platinum ion in the form of chloroplatinic acid (37.5% Pt) was added to a proprietary 24K neutral gold plating bath. Two Pt/Au ion ratios were investigated, .001 and .01. Leaded brass sleeves were plated from the baths to a thickness of approximately 15 thousandths of an inch at a current density of 5 amperes per square foot. Results of microhardness determinations on polished specimens of the deposits are shown in the table. A Leitz Durimet microhardness tester operated with an indentor load of 15 grams was employed for the measurements. The hardness measurements were made at four positions around the circumference of the plated sleeve. A comparison of the hardnesses of Rings 59 and 60 with Ring No. 48 (no addition) indicates that Pt/Au ion ratios up to .01 exert no hardening effect on the deposits obtained from a commercial 24K gold bath.

TABLE 5

MICROHARDNESS DATA ON Au-Pt ELECTRODEPOSITS

Ring No.	Pt/Au Ion Ratio in Bath	VHN^{*}_{15g} 0°	90°	180°	270°
48	0.000	70.2	63.7	71.0	61.3
59	0.001	54.5	48.3	52.6	47.5
60	0.01	70.2	50.8	68.8	52.6

* Vickers Hardness Number, 15 gram indentor load.

IV. TABULATION OF DATA

Table 6 summarizes the run-in tests, identifying the capsule and the objective of each test. Tables 7, 8, 9, and 10 give the tabulated results of all tests giving the capsule number, test conditions, and noise measurements taken at an indicated time during the test.

TABLE 6

RUN-IN TESTS

CAPSULE	OBJECTIVE
1-28	Effects of reconditioning
2-33	Collection of wear debris
1-37	Effects of P-38 oil lubrication
2-38	High current effects
Commercial, "B"	Collection of wear debris
1-39	Repeat of P-38 oil lubrication
2-40	Lubrication with graphite-oil
Commercial, "A"	Effects of P-38 oil lubrication
2-42	Effects of thermal isolation, unlubricated
1-43	Repeat of thermal isolation, unlubricated
2-44	Effects of thermal isolation, lubricated with P-38
1-45	Oscillation test; effects of thermal isolation, unlubricated

TABLE 6 (Continued)

CAPSULE	OBJECTIVE
1-46	Effects of vacuum, unlubricated
1-47	Effects of vacuum, lubricated with P-38
1-55	Oscillation test; effects of thermal isolation, lubricated with P-38
2-56	Effects of vacuum and thermal isolation, unlubricated
2-57	Effects of vacuum and thermal isolation, lubricated with P-38

TABLE 7

RUN-IN CHARACTERISTICS - COMMERCIAL CAPSULES

Capsule	Test Conditions	Time, Hours	Peak-to-peak Noise, μv	RMS Noise db (1)
"B"	(2)	0	40	12
		200	200	24
		310	2000 - 3000	50
"A"	P-38 Oil	0	40	10
	(2)	432	40	10

(1) db values taken with reference to 1 μv level

(2) with a current of 25 ma

All tests at 200 rpm

TABLE 8

RUN-IN CHARACTERISTICS - EXPERIMENTAL CAPSULES

Capsule	Test Conditions	Time Hours	80° Grooves Peak-to-Peak Noise, μv	80° Grooves RMS Noise db(1)	90° Grooves Peak-to-Peak Noise, μv	90° Grooves RMS Noise db (1)
2-33	(2)	0	45	14.5	35	15.5
		300	70	18.0	80	20.0
1-37	P-38 Oil (2)	0	40	11	40	11
		335	50	12	50	12
2-38	(3)	0	1000-1800	43	1000-2000	43
		71	3000-4000	47	3000-3900	49
1-39	P-38 Oil (2)	0	50	11	50	11
		410	60	12	60	12
2-40	"Oildag," (2)	0	4000	53	4000	56
		132	3000	50	1000	39
		338	300	30	200	27

(1) db values taken with reference to 1 μv level

(2) with a current of 25 ma for approximately one half time

(3) with a current of 1 ampere through both brush-ring circuits in series

All tests at 200 rpm

TABLE 9

THERMAL ISOLATION TESTS - INERT GAS ATMOSPHERE

Capsule	Test Conditions	Time, Hours	Peak-to-Peak Noise, μv		RMS Noise, db (1)	
2-42	(2)	0	60		13	
		130	150		16	
		163	-	open	-	
1-43	(2)	0	80		17	
		96	6000		50	
		110	-	open	-	
			Ring #1	Ring #2	Ring #1	Ring #2
2-44	P-38 Oil, (3)	0	60	40	11	10
		412	60	50	12	10
1-45	Oscillation (3), (4)	0	60	50	12	17
			560	120	19	18
1-55	Oscillation (4) P-38 Oil	0	50		15	
		484	130		17	

(1) db values taken with reference to 1 μv level

(2) with a current of 25 ma

(3) with a current of 25 ma for approximately on half time

(4) frequency: 10-12 cps, total displacement: 1.0° to 1.2°
nonoscillatory tests at 200 rpm

TABLE 10

VACUUM TESTS

Capsule	Vacuum, Microns	Test Conditions	Time, Hours	80° Grooves Peak-to-Peak Noise, μv	80° Grooves RMS Noise db (1)	90° Grooves Peak-to-Peak Noise, μv	90° Grooves RMS Noise db (1)
1-46	250	(2)	0	30	11	80	16
			24	300-2000	25	300-500	24
			200	300	23	300	24
1-47	25	P-38 Oil, (2)	0	90	17	60	15
			24	60	13	50	12
			384	80	17	80	16
2-56	25	Thermal Isolation, (2)	0	30	10	30	11
			172	200	20	400	22
			284	60	14	250	21
2-57	25	Thermal Isolation, P-38 Oil (2)	0	80	17	80	16
			160	200	22	300	24
			240	100	20	100	19

(1) db values taken with reference to 1 μv level

(2) with a current of 25 ma for approximately one half time

All tests at 200 rpm

V. SUMMARY AND CONCLUSIONS

The results of the experimental investigation conducted during this program can be summarized as follows:

A. Laboratory evaluation has demonstrated that commercial 80-circuit slip ring assemblies exhibit the same vibration, threshold and repeatibility effects that were demonstrated by experimental capsules.

B. Spectrographic analyses of wear debris indicated that the only constituent of the debris was gold from the ring surface.

C. Nature of wear deposits accumulated during run-ins of commercial capsules is different from those of experimental capsules. The reason for that was found to be the thermal isolation of rings in commercial capsules. This thermal effect causes seizing between ring and brush and results in severe galling and erosion.

D. Surface lubrication with P-38 synthetic oil has been found to be effective in maintaining low noise levels and in minimizing wear of ring and brush surfaces operating in inert atmosphere.

E. Electrodeposits from rhodium, palladium, and platinum modified gold baths using precious metal ion/gold bath ion ratios of up to 0.01 did not result in any significant increase in plate hardness.

F. Thermal effects could not be duplicated in oscillation tests of isolated rings. This was apparently due to the low rotational velocity used during the tests.

G. Preliminary study of vacuum operation conducted at medium vacuum levels indicated that surface lubrication with P-38 synthetic oil was beneficial in minimizing wear products accumulation.

VI. RECOMMENDATIONS

The investigation of slip ring performance in vacuum carried out during this program was limited. The ultimate use of slip ring assemblies in high vacuum of space requires a further comprehensive study. Therefore, it is recommended that the following activities be pursued in order to clearly define the problems of high vacuum operation, and to evaluate corrective measures.

A. Different capsule materials and design techniques should be evaluated in an intermediate-to-high vacuum environment. The effects of out-gassing of dielectric base materials and the proper lubrication techniques should be carefully studied.

B. The study of the effects of electroplating should be carried out. The prime variables to be considered are: plating current density, bath composition and temperature, and hardening agents. Present work on hardening agents included precious metal ion/gold bath ion ratios of up to 0.01. This ratio should be increased to 0.1 or higher.

C. Studies in an inert atmosphere should be continued to a limited extent, mainly for screening of different materials and lubricants.

VII. CONTRIBUTING PERSONNEL AND LOGBOOKS

Significant contributions to the over-all effort of this program were made by the following IITRI staff members:

Spectrographic Analysis of Wear Debris	-	H. J. O'Neill, Research Chemist
Precious Metal Hardening Agents	-	W. H. Graft, Research Metallurgist
Laboratory Evaluation	-	D. E. Richardson, Senior Electronic Engineer, and O. M. Kuritza, Research Engineer
Capsule and Apparatus Fabrication	-	M. Holzer, Jr., Model Maker
Technical Direction	-	J. L. Radnik

The detailed laboratory data is contained in IITRI Logbooks C14622, C14635, C14942, and C15698.