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Contract NAS 8-5424

DEVELOPMENT OF FLAT FLEXIBLE CONDUCTOR CABLES

February 1965

FINAL REPORT

AEROSPACE GROUP

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

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Report No.

HUGHES AIRCRAFT COMPANY

AEROSPACE GROUP

APPLIED TECHNIQUES DEPARTMENT

Culver City, California

DEVELOPMENT OF THREE TYPES OF FLAT FLEXIBLE CONDUCTORS

by

C. F. Seck

24 February, 1965

Final Report Covering the Period
August 1963 to February 1964

Contract No. NAS 8-5424

George C. Marshall Space Flight Center,
NASA, Huntsville, Alabama

Approved: M. D. Hudson
Manager, Applied Techniques Department

FORWARD

This report was prepared by Hughes Aircraft Company as a required part of NASA Contract #8-5424 Development of three flat flexible cables.

This report covers work from 1 April 1963 through February 1965 and summarized the information contained in thirteen previous Monthly Progress Reports. It also contains information on this program obtained since the Last Monthly Progress Report Thirteen of 17, November 1964.

ABSTRACT

This report describes the development and production of two types of cable in accordance with Part A and Part B of Attachment "A" Contract NAS 8-5424. Approximately ten different cables for each type were designed, constructed and evaluated on the basis of commercially available materials, existing manufacturing equipment, materials compatability, fabrication problems, cable weight, stiffness, dielectric strength, wire spacing tolerances and various other specified requirements. This report describes these various materials as applied to cable construction, methods used for fabrication and evaluation and the factors relating to the selection of the optimum material to best meet the requirements of the contract.

PART A

Work was done on the development of silicone rubber reinforced and unreinforced, TFE Teflon reinforced, filled and unfilled and H-film Teflon bonded cables. The only cable which satisfactorily met the requirements was made of TFE Teflon white pigmented filled. Samples of this cable were submitted and approval was given to proceed with Phase 2.

PART B

Work was done on a combination of insulation materials, shielding, designs and methods of connecting the shield to the ground conductor. The design of the cable which was developed and submitted consisted of Mylar "A" insulation bonded with DuPont polyester adhesive #A6950 loaded with dechlorane and antimony trioxide. Samples of this cable was submitted for preliminary evaluation and were not acceptable primarily because of brittleness and stiffness. Work on Phase 2 was not continued.

INTRODUCTION

The increased number of applications of flexible flat conductor cable in the Electronics Industry has emphasized the need to develop shielded and unshielded cables with high temperature resistance and self extinguishing properties. Materials currently used for the fabrication of high temperature flexible flat conductor cable are limited to approximately 200° C. The low temperature cables are not sufficiently flame retardant to meet the flammability requirements of IPC Specification FC-100A. Materials and fabrication methods for producing shielded cable are quite limited. This investigation approaches the problem of the materials and processes required to fabricate shielded and unshielded cables in accordance with type I and III of IPC - FC - 100A, except the temperature range of the type III cable has been increased from 200° C. to 250° C.

CONTENTS

PART A - PHASE I INVESTIGATION

H-FILM

Because of the exceptional high temperature capability and stability together with high dielectric strength of H-Film, considerable effort was expended to develop a satisfactory H-Film insulated cable. Since H-Film could not be directly heat bonded to itself the problem was one of finding a satisfactory adhesive system.

H-FILM ADHESIVE

Our inquiries were directed to Mr. Courtright of DuPont Marshall Laboratories at Philadelphia who was working with the problem of bonding H-Film. Bond tests made with pyre ML adhesive supplied by DuPont on H-Film gave zero adhesion. Tests were then made with DuPont H-Film adhesive MQ-98 on #116 glass cloth, bare H-Film and on DuPont Pyre MC coated fabric #5510 - .004 thick. The glass cloth coated with 4 to 5 brush applied coatings dried over a hot plate had good appearance but was brittle. Tests with bare H-Film .002 mils thick bonded with MQ-98 adhesive gave only moderate adhesion and were unsatisfactory in appearance in that the adhesive turned green-gray and flowed into a mottled pattern. Test samples of the DuPont #5510 fabric bonded with MQ-98 were excessively brittle with low adhesion of about 1.5 #/in. Glass cloth treated and supplied by DuPont coated by them with their adhesive could not be bonded. Adhesion obtained was zero. H-Film glass fabric flat wire laminate samples .013 to .014 thick fabricated by DuPont with .005 x .062 flat copper conductors supplied by Hughes, were tested for dielectric strength as received. Breakdown values ranged from 900 to1500 VRMS. The samples were excessively brittle and failed when folded flat upon themselves.

H-Film - Silicone Rubber

H-Film coated and bonded with mystic #7000 tape adhesive supplied by Kaminski of Mystic Tape Inc., Glendale, California, gave 1#/in. adhesion which was not satisfactory.

H-FILM EPOXY ADHESIVE

Initial exploratory tests by A.M. Schwider to Hughes, Culver City, Materials Laboratory, with Epoxy Adhesives, indicated the following results:

1) An epoxy based system gave high adhesion.
2) A two part system was used plus an accelerator plus a solvent.
3) The coated film may be stored in refrigeration for several months after evaporating the solvent.
4) Shelf life of the adhesive was 3 to 4 days unrefrigerated.

In as much as it was quite doubtful that the proposed epoxy system would be tough enough to withstand the required flex tests at room temperature no further work was done.

H-FILM TEFLON BONDED

Cable made from H-Film 2 mils thick coated one side with 2 mils of FEP Teflon supplied by DuPont, was submitted to Hughes Qualification Test Laboratory for evaluation according to IDC-FC-100A Specification. Their report showed that:

1) The cable sample failed to meet the sodium hydroxide chemical resistance test with 54% gain in weight together with visible destruction of the H-Film.
2) The cable sample delaminated in the 250° C thermal shock test.

SILICONE RUBBER - GLASS FABRIC REINFORCED

MYSTIC #7000 GLASS TAPE

Pilot samples of 5 conductor cables were fabricated from Mystic #7000 commercial tape made of glass cloth impregnated with pressure sensitive silicone adhesive. Voltage breakdown values obtained with dry cable ranged from 3200 to 5600 VRMS. Voltage breakdown values wet dropped as low as 1200 VRMS, which indicated that the external surface of the glass fabric must be filled with silicone rubber. This design was dropped because the thickness could not be reduced below .022.

which was considered to be excessive.

MYSTIC #7010

Test results of cable made with this tape were similar to those for Mystic #7000. An addition objection to this design was the pressure sensitivity or tackiness of the hygro-phobic silicone rubber coating. This objection could however, have been at least partially overcome by the use of a slip such as powdered talc.

PERMACEL #ES-5215

Cable made of this silicone rubber impregnated glass cloth failed in the glass fabric when bond tested. Bond adhesion between the conductors was near zero although the margin bond was sufficient to tear the glass fabric.

VITON - GLASS FABRIC

Viton impregnated glass cloth was considered as a cable insulation based on available temperature ratings, flexibility electrical and mechanical properties and processing information available. However work with this design was dropped for the same reasons given for Mystic #7000.

SILICONE RUBBER - UNREINFORCED

Five or six commercially available silicone rubber tapes unsupported and supported with backings both, cured and partially cured were procured. None of the materials tested could be collated with satisfactory wrinkle free adhesion in the interface between the conductors.

UNION CARBIDE (Transparent) Y-3487

A specially prepared transparent silicone rubber .010 thick supported on a Mylar Liner was supplied by Union Carbide Company. Preliminary tests yielded a very satisfactory flexible high dielectric strength transparent tough cable. Work was stopped on this design because cable thicknesses below .022 could not be obtained at this stage of development.

PARMACEL #211

Pilot samples of cable for testing were made from this glass cloth tape with silicone rubber pressure sensitive adhesive with the outside surface of the glass cloth filled with varnish. The varnish lacked toughness and failed on fold tests resulting in wet dielectric strength failure as low as 700VRMS. Since a tape with a tough flexible varnish was not commercially available at this time, this design was dropped.

TFE - TEFLON - TFE TEFLON GLASS REINFORCED

One Pass Collation

Several attempts were made to bond TFE Teflon impregnated glass fabric with unsintered TFE Teflon with one pass collation. Trials were made with both unetched and etched glass fabric reinforced Teflon. No bond was obtained between etched glass-Teflon and the unsintered TFE Teflon. The bond obtained between the unetched glass-Teflon and the unsintered TFE Teflon was in the order of .9 pounds per inch of width.

Because TFE Teflon must be thoroughly compacted and in intimate contact at the moment it is brought up to sintering temperature, satisfactory wrinkle free high strength bonds could not be obtained in one pass with the existing collator design with separate heating and squeezing stations.

Two Pass Collation

Cable samples were made with two DODGE-FIBRES INC. TFE-glass (E381-3) .0032 thick covers bonded with a layer each of .004 and .002 unsintered TFE Teflon on each side of the .004 x .040 conductors giving a cable thickness of .017. Tests showed that the TFE - glass had scattered "pin holes" at which dielectric strength failures occurred. Cable samples were then made with the TFE-glass covered with .004 TFE-Teflon unsintered but with only .002 TFE Teflon unsintered between the conductors and the glass-teflon giving the same overall thickness of .017. This cable was pin hole free and somewhat more flexible since the high modulus glass-fabric was closer to the neutral axis. Dielectric strength tests for this construction varied from 4000 to 5000 VRMS.

A heat shrinkage test of one hour at 450° F. showed the cable to be stable. Samples of this cable construction were submitted to NASA in March 1964. NASA reported that this cable construction was not satisfactory because it was too thick, too stiff and too heavy. To reduce weight thickness and stiffness further work could be done with recently available thin section - .0015 thick - TFE-Teflon impregnated glass cloth EX 3-17 made by Taconic Plastic, Petersburg N.Y., by utilizing form rollers to squeeze down the plastic between the conductors, thinner sections of insulation would be required. Also the reduction of the dielectric strength due to mechanical flowing of the plastic in the compaction pass would be obviated. It is further speculated that with a collator having heated rollers a one pass process could be worked out with considerable reduction in cost of labor, and the elimination of the critical bonding of the cable between the first and second passes at which time the unsintered cable is susceptible to cracking when flex or handled resulting in subsequent points of dielectric strength failures.

TFE - TEFLON UNSINTERED UNFILLED

The first two pass collated cable samples made of 4 layers of .004 unsintered TFE Teflon submitted to Hughes Qualification Test Laboratories failed because of:

1) Transverse shrinkage of 1.3% with 1% maximum permissible.
2) Low insulation resistance after humidity test on 9 out of 25 conductors.
3) Dielectric strength below 1500 VRMS on conductors #14 and #10. Analysis of the data and examination of the test samples indicated that these failures except for shrinkage were due to insufficient edge seal and foreign particle inclusions.

During several subsequent tests it was concluded that the low insulation resistance and low dielectric strength were due to a combination of foreign matter inclusions and cracking or fissuring of the plastic.

Efforts to overcome these troubles included:

1) Use of heat cleaned #116 glass cloth as a slip sheet with edges sealed to prevent raveling.
2) Provision for heat shrinkage in wire spacing dimension whenc collated.
3) Use of 7" diameter windup drum between pass 1 & 2.
4) Use of 3" wide raw material to reduce edge side flow and resultant cracking.
5) Use of conductor cable edge stuffers to further reduce edge side flow of plastic.
6) Extra care to preclude foreign matter intorduction into the cable in all steps of the process.
7) Heat shrink treatment of the finished cable.
8) Trimming edge margin after the second (sintering) pass.
9) Increase of plastic thickness from .016 to .020.
10) Use of pigmented (filled) plastic which reduced shrinkage.

It was found that each lot of material had a different heat shrink factor. This fact required that a pilot run of cable be made with each lot of material in order to determine the proper shrinkage factor for that lot in order to control the overall wire spacing within the specified limits of 1.800± .008. The first pilot run of cable was made with two layers of .004 unsintered unfilled TFE Teflon on each side of 10 nickel plated .004 x .040 conductors spaced on .075 centers collated in 2 passes. The first pass was made at 550°F, at 0.7 feet per minute with pressure settings of 170/150 pounds and with 2 silicone - #116 glass cloth slip sheets plus 2 #116 bare glass cloths in contact with the plastic to restrain its flow. The second pass was run at 730° F, 60 pounds pressure, a speed of .7 feet per minute with the 2 glass cloth slip sheets but without the silicone rubber glass cloth slip sheets.

The glass cloth was not removed from the cable between passes. Dielectric strength tests on the first pilot run of narrow cable as collated showed no failures up to 6200 VRMS in 12 tests of 1 minute duration on each side of a 2 foot piece of cable. A similar test made on a full width 25 conductor cable collated as above was then made with the results shown on exhibit A. The reason for the drop in dielectric strength from above 6200 VRMS to an approximate mean value of 4200 was not known.

TFE TEFLON - UNSINTERED - FILLED

An experimental run of cable was made of unsintered TFE "white" pigments filled having .019 total thickness which gave dielectric strength values from 3500 to 6200 VRMS with the mean value around 5500 volts. Refer to reference exhibit B. This result was 5500/4200 or 30% higher than for unfilled TFE Teflon. Because of the superior dielectric strength together with approximately 10% less shrinkage a sample of cable made of 4 layers of .002 + 2 layers of .004 Saunders S-20 TFE Teflon (Hughes DWG AH000256) was collated and submitted to NASA. In a letter of 8 September, NASA reported that Part A, Phase I was complete and that Hughes was to proceed with Phase II. Recently Dodge Fibres Corporation announced that they have developed a cross oriented unsintered TFE Teflon which may simplify the manufacture of this type cable by virtue of its much higher transverse strength which may enable use of less plastic for the same voltage and require less care in handling between the first and second collation passes.

PART A - PHASE II INVESTIGATION

FABRICATION OF HIGH TEMPERATURE CABLE

Discussion

As a result of the effort in Phase I, approximately 1000 feet of 25 conductor TFE Cable was shipped to NASA. This cable was made in varying lengths up to 110 feet. The lengths of each run was limited to about 100 feet because of winding and handling problems. This cable met the requirements of IPC - FC - 100A type III (250° C) with the following exceptions:

1. The minimum pin hole free length was 25 feet instead of 50 feet (Paragraph 3.2.5)
2. The edge margin tolerance was out of limits.
3. Indexing and identification was accomplished by inserting teflon thread in the edge margin.
4. Conductor spacing after High Temperature aging (paragraph 3.3.2) was out of limits.

PROBLEMS

The problems encountered in production of High Temperature Cable were:

1. Long delivery time approaching 2 months was required to obtain the plastic material from one manufacturing lot.
2. Troubles with points of voltage failure varied from a few feet apart to over 100 feet due to the following: a. "pin holes" in the insulation b. foreign matter in the insulation or introduced while collating c. possible piercing of the insulation by the glass slip sheet fibres d. cracks or fissures in the Teflon insulation e. defective nickel plating which flaked off the copper.
3. Control of the margin dimension within the specified tolerance of ± .008. The automatic wire tracking equipment could not be used because of the opacity of the insulation. Manual tracking of the slitters was required.

4. No satisfactory means has been developed for marking or printing cable indentification.
5. Control of the overall wire spacing within the specified tolerance of ± .008. Because of materials variation it was necessary to make a pilot run of cable from each specific lot of material and to conduct a high temperature aging test on the cable in order to obtain the specific shrink factor for that lot.
6. It became necessary to make at least two production runs to fabricate the total of 1000 feet because of the loss due to points of dielectric failure listed in (2).
7. Minimum lengths of 25 feet of flow free cable were supplied instead of the 50 feet specified (paragraph 3.2.5.)

Recommendation and Conclusions

1. Cross oriented unsintered TFE Teflon white pigmented filled very recently made available should be fabricated into cable and tested. This material should be much less subject to fissuring and cracking during fabrication due to winding, flexing and handling.
2. A single pass hot roll process should be investigated in which the Teflon is simultanously compacted and sintered. This arrangement would also permit precise slitting of the margin with fixed slitters.
3. Rigid raw material specifications are required for control of shrinkage, dielectric strength, pin hole frequency, thickness, cleanliness and packaging.
4. Means of marking and identifying Teflon cable should be investigated.
5. Use of a new HT-4 H-Film base high temperature fabric in place of the #116 glass cloth slip sheets both bare and silicone rubber coated should be investigated. Preliminary tests show that this fabric does not fail like the glass

under the heat and pressure required to compact and sinter the Teflon.

6. Means of bonding the cable to structures and repairing points of insulation failure should be developed.
7. In order to economically produce long lengths of flaw free cable it is imparative that the cable be made in a clean room under rigid control with elimination of foreign matter from all sources.
8. Work should be done to find or develop a high temperature adhesive for H-Film.
9. A cable insulated with H-Film should be developed.

PART B - PHASE I INVESTIGATION

APPROACH

The approach to development of a shielded self extinguishing cable included consideration of several basic insulations or combinations thereof such as Kel-F, Teflon, Mylar, H-Film-Teflon bonded, and Mylar with flame retardant adhesives or external coatings. Material for the shield was to be soft copper sheet plain or perforated, expanded metal, fine woven mesh or other feasible approaches.

Because the problem of connecting the shield to the ground conductor appeared to be the most difficult, work was started in this area. In the beginning the idea prevailed that the ground conductor could not lay immediately under the shield in continuous contact therewith. Therefore some means of connecting it to the shield thru the plastic had to be found. The conventional standardized means available at that time was grinding openings thru the main insulation along the cable length and then filling the holes with some kind of conductive material before assembling the shield. Various tests were made using soft solder, conductive rubber pastes, carbon black loaded pastes, silver powder filled plastics, and copper conductor inserts. None of these tests showed that reliable connections could be maintained between the shield and ground conductor when the cable was flexed.

Consideration was then given to welding the shield to the ground conductor through the plastic insulation between them. The conclusion was that this approach would require considerable development, expensive equipment, be costly in production and result in unreliable welds.

It was decided in conference with Mr. Angele of NASA, 9 Jan. 64 to place the ground conductor directly under the shield and in continuous contact therewith at a sacrifice of close dimensional location tolerance of the ground conductor.

MESH SHIELD

The first problem encountered when samples of cable were made with mesh shields was raveling of the woven edge wires of the mesh which caused shorts through the margin and cut-through of the shield cover insulation as well as of the insulation between the conductors and the shield. No satisfactory solution to this problem was found. It was suggested that the mesh be crush cut instead of shear cut along the edges which it was speculated would welde the warp and woof strands together. Another major difficulty with handling the mesh became obvious when it was guided or fed in any operation the edges turned over and subsequently either perforated the plastic shield cover or set up a severe dielectric stress raiser which caused failures at low voltages during electrical inspection.

Four test pieces 6" long were then made with XF506 Teflon cable 1.25 wide shielded with 0.9 wide mesh with folded scallops at 0.5 pitch on each edge of the mesh which in turn was then covered with .002 FEP Teflon / .002 H-Film / .002 FEP Teflon and collated at 530° F / 20 poùnds pressure / with 2 silicone rubber glass cloth slip sheets at 1.7 feet per minute. One test piece failed under dielectric strength test at 1000 VRMS and the second piece at 4000VRMS. The third and fourth test pieces withstood 6000 volts for 1 minute without breakdown. The conclusion was that the upset mesh edges would require crush rolling as the mesh entered the collator. Before these difficulties could be worked out it was decided in conference with Mr. Angele of NASA 9, January 1964, that mesh shielding was too thick, too heavy and too stiff and that we should use .0005 copper perforated strip instead.

EFFECT OF SHIELD ON FLAMMABILITY

Preliminary tests were made to determine effect of perforated .001 copper foil shielding on flammability. It was found that the effect of the shield for similar cables was to increase the required time of exposure to the flame before combustion of the cable would sustain itself.

MESH SHIELD WELDED TO GROUND WIRE

A method of making both a single and double mesh shielded cable having the ground conductor welded to the shields was developed. The shields and the ground conductor were welded together before assembling with the previouslycollated core of the cable. Refer to exhibit C . Cut 1 shows the shields cut to width and welded to the ground conductor at 0.5 intervals. Cut 2 shows the cable core with the edges reference trimmed and split at the right hand edge to enable assembly inside the shield-ground conductor assembly. Cut 3 shows the cable core inserted between the shields and with the right hand edge trim reinserted as a stuffer together with the cover insulation. After collating and splitting the finished cable is shown in cut 4.

Pieces of cable 3 to 5 feet long were satisfactorily made by this process except for the mesh raveling problem previously mentioned. A satisfactory weld jig was built to make long lengths of either single or double mesh welded to the ground conductor. Because of the mesh raveling difficulty no further work was done to work out the problem of assemblies prior to collating.

GROUND SPOTS

Silver Paste

DU PONT #7941

Several tests were run with basic cable made of 7 conductors of .0004 x .040 ni-cu on approximately .075 spacing with conductor ground spots filled with DuPont #7941 conductive silver and then covered with 200 mesh bronze wire .0021 dia callendered to .0035 thick and insulated and bonded to the basic cable with .002 FEP Teflon covers.

The initial dielectric strength tests showed that there was adequate insulation between conductors and the shield for 1500 volts rating. The round spot resistance varied from .02 ohms as collated to about .6 ohms after 10 flexes over a .35 diameter mandrel with about 10% of the spots becoming open or intermittent.

Refer to exhibit D which shows the effects of baking, flexing and repressing on ground spot resistance.

DU PONT #5504A

Ground spot tests with DuPont #5504A conductive silver paste were abandoned when ground spots on XF506 Teflon baked 4 days at 250° F popped off the cable when moderately flexed because of excessive brittleness of the paste and because of practically zero adhesion.

SOFT SOLDER-KESTER #44 OR UNPLATED COPPER CONDUCTORS

Ground spot tests similar to those for DuPont #7941 except filled with Kester #44 .031 diameter soft solder and tinned to the exposed conductor at the root of the spots gave an average resistance of .05 ohms for 50 spots before flexing 10 times over a .30 diameter mandrel with 13 spots open and 4 spots variable after flexing.

Refer to exhibit E.

To facilitate soldering to the conductors the above cable was made of 10 bare copper conductors .0025 x .031 on .050 spacing covered with .0075 FEP A Teflon.

SOFT SOLDER - KESTER #44 ON NICKEL PLATED CONDUCTORS

A second test using Kester #44 solder for ground spots was made on the basic 25 conductor .004 x .040 nickel plated copper conductor cable insulated with .0075 x F506 Teflon. The ground spots were filled with solder with a hot soldering iron and a mesh shield assembled, bonded and covered with .002 FEP A Teflon at a temperature of 520/530° F, a speed of 1.5 feet per minute and a pressure setting of 30#.

Refer to exhibit F.

The results of tests of spot resistances before and after 10 flexes over 0.3 diameter mandrel were tabulated for test pieces #2 through #6.

Results of the test were that:

1. 8 points were open as collated
2. 5 points opened during flexing
3. 3 points became intermittent
4. The average resistance of the balance of the spots increased in sample #2, #5 and #6 while it decreased in samples #3 and #4.

It was not possible to manually control the amount of solder fill in each spot to less than a 100% variation. By the use of shot solder and by mechanizing the spot grinding operation the relation of the volume of solder to the volume of the spot opening may be adequately controlled. Flux was used to facilitate soldering to the conductors. The excess flux had to be removed to prevent interference with the bonding of the mesh over the spots. In order to obtain production quality control this entire procedure would have to be mechanized.

In view of the generally unsatisfactory results no further consideration was given to solder spot ground connections.

INSERTED WIRE SHIELD CONNECTIONS

Because of the unacceptable resistance variations of ground spots filled with conductive pastes or soft solder a series of tests were conducted using .005 x .031 annealled copper wire pieces 0.3 to 0.4 long inserted on-half their length parallel and directly above the conductors into slits in the plastic made with the point of a jewelers tweezers. This operation was easily done manually and could be mechanized. Six 2" wide 25 conductor cable coupons #1 through #6 3" to 4" long were made with every other conductor grounded along a 30° diagonal to the length. The first 4 samples were covered with mesh and 200 A Teflon on one side of the cable and collated.

The remaining two samples #5 & 6 were covered with a laminate of 2/2/2 (.002 A Teflon .002 H-Film / .002 A Teflon) at slightly higher laminating pressure. Sample #5 was shielded and covered one side only and #6 was shielded and covered on both sides. Reference to exhibits G & H shows plots of total circuit resistances as collated and after 2, 10, and 30 flexes over a .38 diameter mandrel except sample #6 which was flexed over a .75 diameter mandrel because of the increased stiffness due to mesh plus H-Film on both sides. Review of the data shows the superior stability of sample #6 - the sample covered with H-Film which maintained higher contact pressure on the inserted ground wire because of the stiffness of the H-Film. Part of this observed higher stability was due to the less severe flexing.

It was noted that there were no connections which became open or intermittent in any of the 6 samples. Sample #6 showed no significant increase in resistance when flexed. The objections to this type of ground connection were:

1. Production would require new automatic equipment.
2. The section discontinuity of the inserted wire would be a source of failure on flex life tests.

OTHER METHODS AND MATERIALS

Only passing consideration was given to the use of conductive rubber and carbon black loaded pastes as ground spot fillers because the basic volume resistivity was at best 2 to 3 orders above that required to give less than say 1 ohm. resistance per spot. Loaded epoxy pastes were not considered because of lack of toughness.

SHIELD - EXPANDED METAL

It was not possible to obtain Exmet #3/0 cut-expanded copper strip thinner than .0023 in any pattern or configuration from Exmet Corporation Corbett-Smith, Los Angeles representative, specialists in this field. Since cable shielded with this material from prior experience was as stiff or stiffer than mesh shielded cable together with the additional disadvantage that the openings would be from 5 to 10 times larger, which would give trouble on flex tests, this material was not considered.

SHIELD - COPPER FOIL PERFORATED

In order to arrive at a satisfactory perforated hole size, pattern and spacing several different cable test coupons were made with standard available and special hand perforated copper foil samples.
Shields with .050 diameter holes on .185 spacing in a hexagonal pattern wrinkled excessively when fabricated into Teflon cable and flexed.
The design decided on was .046 diameter holes .100 apart on a hexagonal pattern having 20% open area with the transverse axis of the holes skewed 5% to give a uniform shield cover tear-back force. Trouble was encountered in obtaining .0005 copper therefore 1/2 ounce or .0007 was used. The first perforating die the vendor built had excessive punch clearance and had to be rebuilt. Considerable difficulties were encountered by the vendor in indexing the feed, guiding and handling the foil web before he could produce satisfactory and acceptable perforated foil and 50 foot minimum lengths accurately wound on cores.

From flex and perforation tests half-hard temper foil was decided upon because hard temper perforated with the least burrs but cracked when flexed in a finished cable assembly and the dead soft copper was difficult to perforate with minimum burrs.

FLAMMABILITY

Initially proposed means of obtaining self extinguishing plastic constructions included Kel-f, Teflon H-Film, Teflon bonded and specially compounded Mylar or Mylar coated or bonded with specially compounded adhesive.

TEFLON CORE -MYLAR / ADHESIVE COVER

Cable test coupons 1" wide with single shield were made of KF506 FEP Teflon .0075 thick. After collating the cable was sodium etched. The mesh shield was then filled with Schjeldahl GT-200 adhesive. After the solvent evaporated the mesh shield was collated onto the base cable together with Mylar A .002/adhesive .001 (Schjeldahl GT300) at 400° F, 20# pressure at 1 foot per minute.

Flammability tests showed that this construction flamed out in 5, 10 , 15 and 10 seconds on 4 different tests.

A test coupon 1" wide constructed the same as above except shielded both sides was not self extinguishing but continued to burn at a moderate rate after being ignited.

This type of cable presented no problem in construction. The only novel operation was that of filling the mesh with GT-200 Schjeldahl polyester base adhesive. This operation could readily be performed with a small coater unit.

TEFLON CORE - MYLAR / SODIUM META SILICATE / ADHESIVE COVER

Flammability tests were made with cable samples of EX506 FEP Teflon .0075 thick the same as above except that the GT-200 Schjeldahl adhesive was filled with 30 parts by weight per hundred with sodium meta-silicate as recommended by Hughes process chemists. Little if any difference between the sample and the control was noted. Both the sample and the control supported combustion.

KEL-F

Hughes experience with Kel-F cable insulation which is self extinguishing has not been satisfactory to the point where it could be recommended for this application. The major difficulty with existing collating equipment has been orientation particularly where the plastic flows around the conductor edges it becomes brittle and subsequently fractures either during flexing or immediately after collating spontaneously after several weeks in storage. This difficulty can be largely or probably entirely overcome by processing cable in a heated roll collator having thick resilient silicone rubber coverings.

The Hughes Materials Engineers advised that Kel-F could be reoriented after collation by instantaneously raising the temperature above the melt point and then rapidly cooling. Since no simple practical way was visualized for performing such an operation Kel-F was not considered.

MYLAR CORE AND COVER SODIUM SETA-SILICATE (LOADED SHIELD)

A Mylar core cable was made covered with 200 mesh shield on both sides which had been filled with sodium meta-silicate solution, then dried and collated onto the cable core covered and bonded with Mylar .002/.001 adhesive.

Flammability tests of this construction showed little or no effect on burning rate.

ANTIMONY TRIOXIDE

A test sample made the same as above except with the shield saturated with GT200 adhesive loaded with 10% antimony trioxide also supported combustion.

HETRON-ANTIMONY TRIOXIDE

A cable test sample was made of Mylar the same as above shielded both sides with mesh filled with GT200 Schjeldahl polyester adhesive loaded with 20% hetron #93 plus 10% Antimony trioxide and covered both sides with .002 Mylar/.001 adhesive (GT300 Schjeldahl).

Flammability tests on this cable showed a definite reduction in combustibility.

HETRON SODIUM META-SILICATE

A cable test sample was made of Mylar the same as above except that sodium meta-silicate was substituted for the antimony trioxide. The results of the flammability tests were about the same as for Hetron-Antimony trioxide.

None of the foregoing experimental cables designed for self-extinguishing characteristics were satisfactory.

It was concluded that an adhesive loading having a much higher hologen content must be used.

POLYESTER ADHESIVE/DECHLARONE/ANTIMONY TRIOXIDE

Based on the results of the prior tests together with other available information Hughes Materials Chemist prepared a loaded adhesive system consisting of 100, 25 and 12.5 parts by weight of DuPont polyester adhesive #46950 dechlorane and antimony trioxide respectively. Test cables constructed the same as in Mylar core and cover sodium meta-silicate, Antimony Trioxide, Hetron-Antimony Trioxide and Hetron Sodium Meta-Silicate using the dechlorone loaded adhesive flamed out in 2 seconds when flammability tested. Superficial dielectric strength tests gone breakdown values from 4500 to 5500 VRMS/60 cycles. Samples of cable were constructed the same as in the above plus a thin external coating approximately .0005 thick of the loaded polyester adhesive in order to permit more effective bonding of the cable to terminals and structures when used. It was observed that the solids content of Antimony Trioxide gave a general whitish cast to the cable together with streaking in some areas. The addition of solids to the adhesive has initially no effect on insulation resistance, bond strength, dielectric strength, spacing cable stiffness or any other mechanical property. Flex life tests were conducted on a test machine built and operated in accordance with IPC specifications on both the bare Mylar surface and the adhesive coated cables.

The first conductor failure on the bare cable was indicated at 2261 cycles. Wet tests showed that the insulation had not failed. The first conductor failure on the coated cable was indicated at 4436 cycles. Dielectric tests showed that the insulation had failed in 4 places - 2 on each side of the cable. These tests were conducted with a 1.5# weight hung on the bottom of the cables during tests to maintain contact with the 0.5 diameter rollers.

In order to get some idea of the flex life of the bare uninsulated .004 x .040 nickel copper conductors 4 conductors were loaded with 2 ounce weights and simultaneously tested. Failures occurred at 1660, 1702, 1895 and 2049 cycles. This design cable complied with the requirements of the IPC-FC-100A Spec Para 4.6.7 which extrapolated for .004 thick conductors required 750 cycles.

A short production run of full width Mylar cable was made with a perforated copper foil shield, .0008 thick covered with .002 Mylar/.0005 adhesive. The thicknesses of the single and double shielded cables were .015 and .018 respectively. Dielectric strength from conductor to shield on a double shielded cable sample varied from 2000 volts RMS on one edge to 3000 on the other edge with the failure starting in the center of the cable. From this test it was evident that margin stuffers are required of about .002 Mylar .001 adhesive coated both sides to fully seal the margins and thereby considerably improve margin breakdown voltage. Bond strength of the shield cover insulation of .002 Mylar / .0005 adhesive exceeded the strength of the .002 Mylar. Variation in thickness and bond strength of the adhesive was noted. The flame retardant additives interfered with the flow of the adhesive in the vendors stationary knife coating equipment. This trouble can be reduced or eliminated by using a rotary knife coater and/or by use of more finely dispersed dechlorane and antimony trioxide together with better mixing or grinding of the mixture just prior to application.

No trouble was experienced in collating the cable with the doctored adhesive coated Mylar. This construction collated much the same as Schjeldahl GT300 (Mylar coated one side with a polyester thermoset-

Thermoplastic adhesive) which we have used with very satisfactory results for various cable fabrication since August 1962.

ADHESIVE COATING - FORMULATION AND APPLICATION:

The vendor who applied the coating formulation to the Mylar for Hughes was contacted to find out specifically what problems they had with the coating that was supplied and what their recommendations were in order to make the coating material more compatible with their equipment. The report was that; a) the coating as received had a non-uniform dispersion of massive agglomerated solids but had a reasonably satisfactory evaporation rate. However, they advised that the use of drying ovens and a liner in the re-roll should be considered if at all possible, b) the maximum dry coating thickness in a single pass should be no greater than .0007" to assure coating uniformity and that thicker coatings should be built up by multiple passes. The coatings we required were .0005 and .0015 thick) c) the preferred viscosity of the coating formulation should lie in the range of 700 to 3000 centipoises, d) a solids content greater than 30% is preferred in order to be compatible with their coating equipment.

Another coating source was contacted which has had considerable experience in coating DuPont adhesive #46950 onto Mylar in the manufacture of recording tape.

This firm reiterated the coating quality characteristics suggested by the vendor who coated our Mylar. This firm also expressed interest in coating Mylar with our formulation as well as in assisting us in productizing a suitable formulation. In view of the considerable experience of this firm in working with this type of coating system in both the formulation and application to Mylar and in meeting the high quality of recording tape it would appear to be advantageous to work with them.

Coating-Electrical:

The electrical characteristics of the coating were not comprehensively measured during this period. However, certain potential electrical characteristics can be theorized based on the chemical constituents of the coating formulation. Since both dechlorane and Antimony Trioxide, which are good insulators, were added to an adhesive which also is a proven insulator, we can extrapolate that the coating system will be a good insulator and therefore meet the electrical requirements of NAS729. The fact that the dechlorane is dissolved in the adhesive may cause a slight reduction in the overall electrical characteristics. However, initial tests do not so indicate.

STRIPPING

Mechanical

Up to this time no universally satisfactory mechanical stripper has been developed for the hundreds of different design combinations of materials, conductors, plastics, shields etc. Simple flat conductor Teflon insulated cable can be easily stripped by means of an opposed pair of steel blades heated to 700° to 900° F with parallel bands from .030 to .050 wide which close to the conductor thickness. Refer to exhibit I.

Other thermoplastic insulation materials may also be stripped with this type stripper with equal ease once the optimum temperature o for the particular material has been determined.

Grinding

Several attempts have been made to strip simple cable by grinding. Some of the difficulties encountered are loading of the grinding wheel, conductor depth tolerances and holding the cable while stripping.

Chemical

The most satisfactory method found for stripping the shielded Mylar cable developed on this contract was to immerse the cable to the depth to be stripped in static or ultrasound agitated tetra-hydrafaron which is a solvent for the polyester adhesive.

If precise control of the stripped area is desired a suitable clamp fixture may be used. Once the shields basic insulation and the conductors have been separated by dissolving the adhesive the termination can be reassemble again as desired using polyester adhesive with heat in a suitable fixture.

RECOMMENDATIONS AND CONCLUSIONS

FLAMMABILITY

The proposed formulation concept is relatively proven in so far as similar formulations are made for coatings on Mylar in the manufacture of recording tape. These formulations with solids content approaching 90% meet the extremely rigid functional requirements including flexibility of the recording tape industry. Based on these known results and conditions there is no question that the requirements of NAS729 can be met except possibly for shrinkage which does not appear to be a problem with heat stable "A" base Mylar.

Further work on this part and phase of the project was stopped the week of 14 October 1964.

Further work should be done to overcome the age brittleness of the flame retardant treated polyester adhesive cable submitted to NASA. Materials other than Mylar which are inherently self-extinguishing such as H-Film with a suitable adhesive should be further investigated as to cost, fabrication techniques, cable thickness, flexability and weight.

SHIELDED CABLE

Further development is required to reduce the cost of shielding. The elongation of the half-hard copper shield should be investigated as soon as commercially etched copper foil strip and an economical etching process is developed.

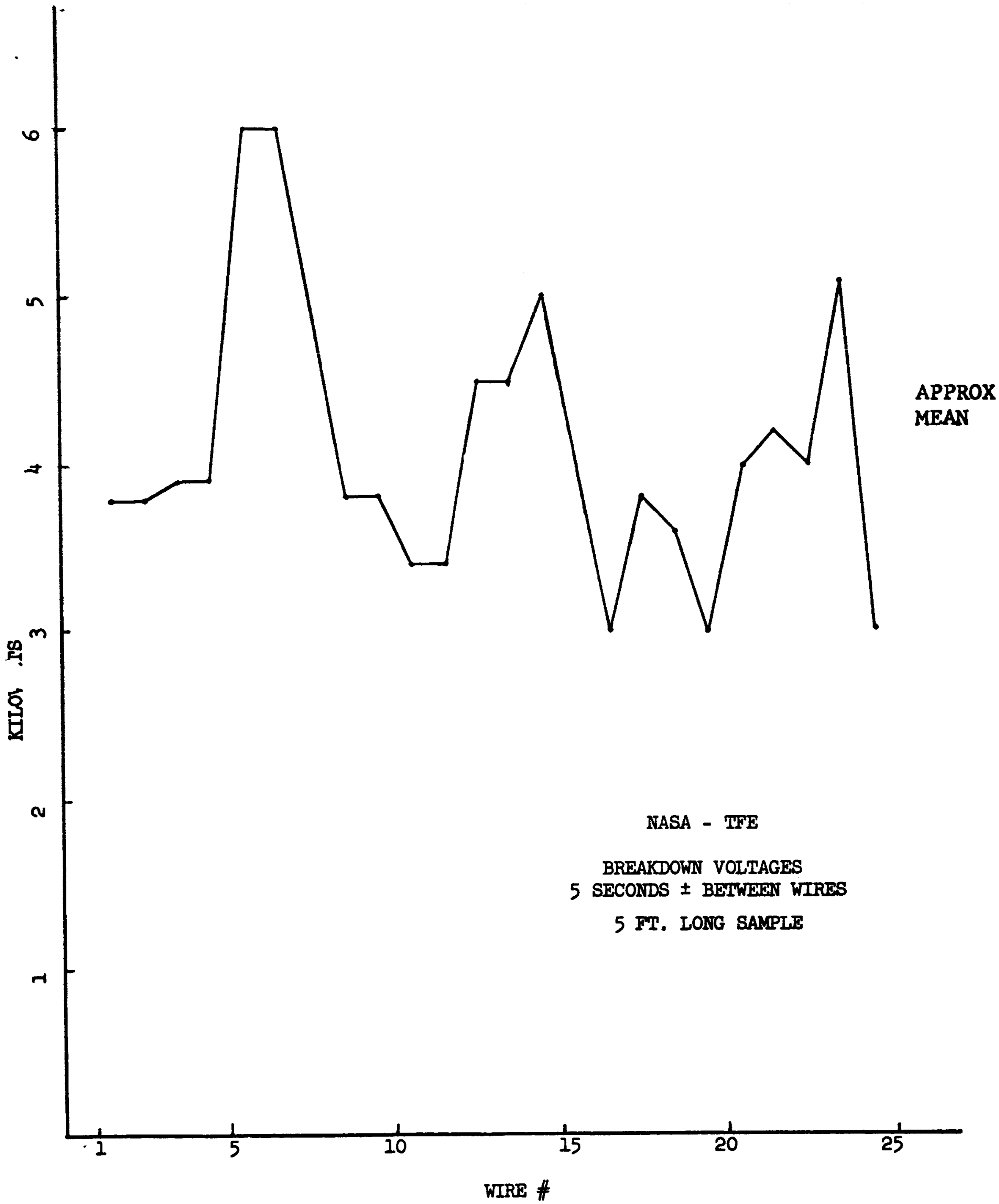

APPROX
MEAN
NASA - TFE
BREAKDOWN VOLTAGES
5 SECONDS ± BETWEEN WIRES
5 FT. LONG SAMPLE
1
2
3
4
5
6
1
5
10
15
20
25
WIRE #

EXHIBIT "A"

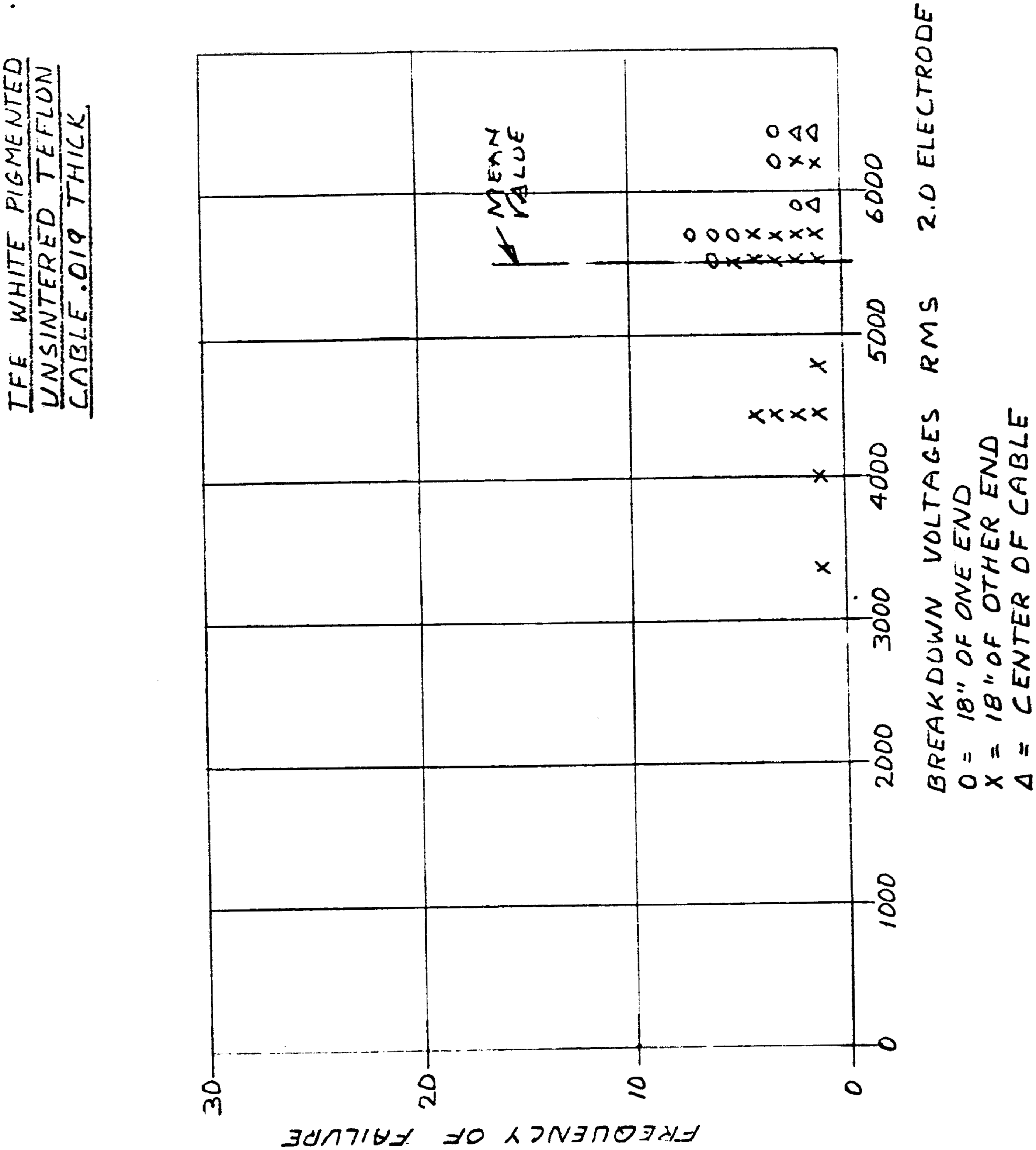
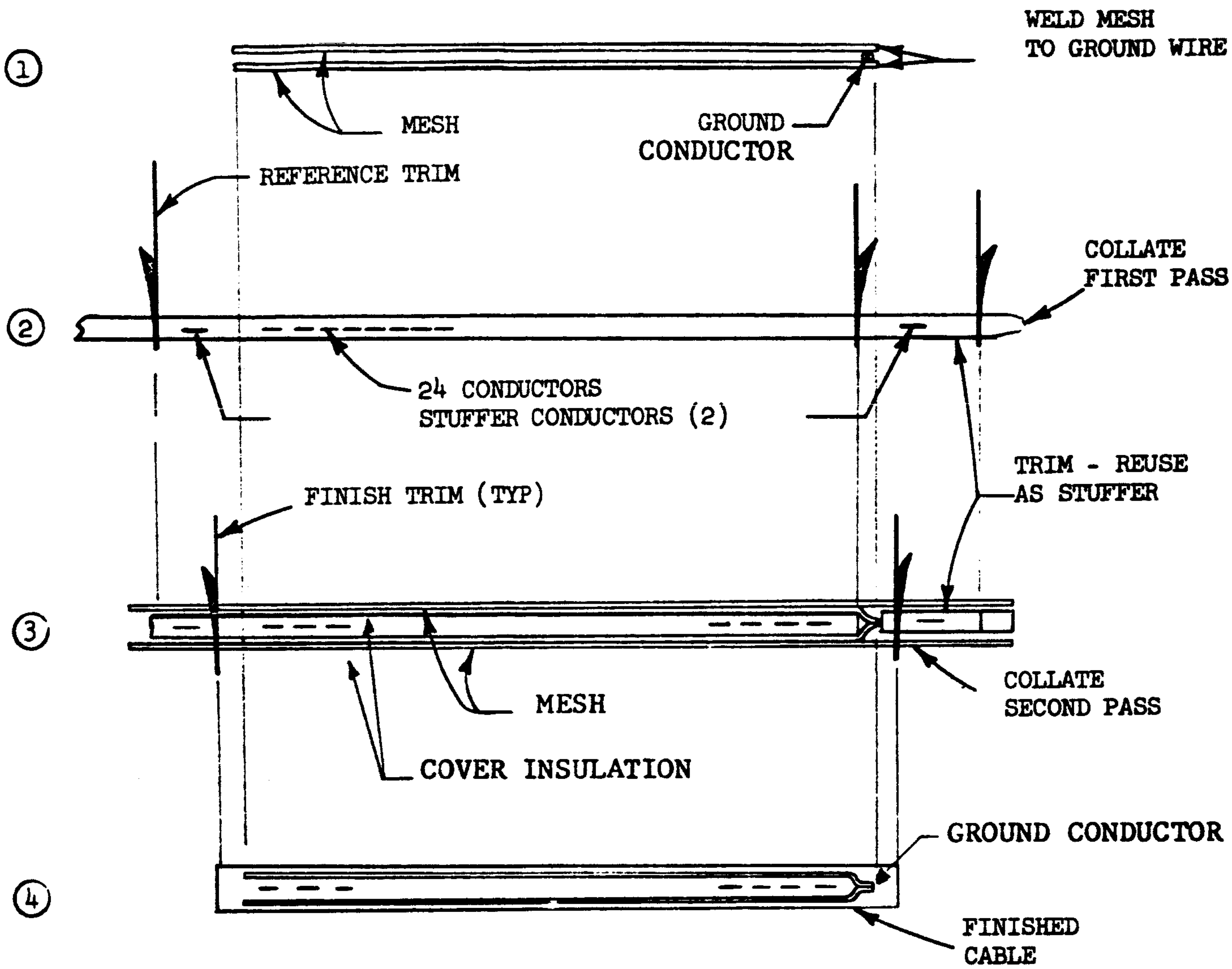
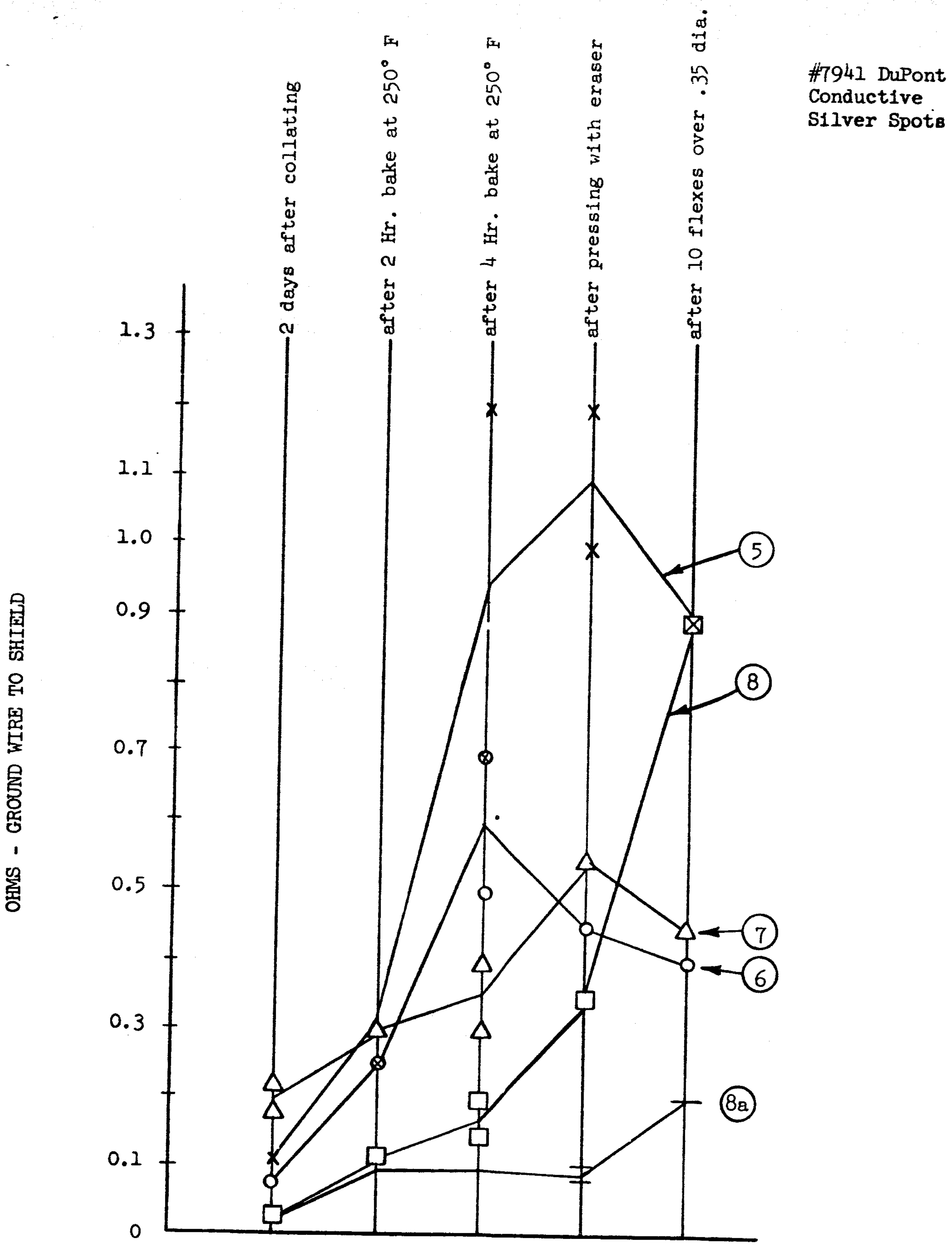

TFE WHITE PIGMENTED
UNSINTERED TEFLON
CABLE .019 THICK
MEAN VALUE
0
1000
2000
3000
4000
5000
6000
BREAKDOWN VOLTAGES RMS 2.0 ELECTRODE
O = 18" OF ONE END
X = 18" OF OTHER END
Δ = CENTER OF CABLE
0
10
20
30
FREQUENCY OF FAILURE

EXHIBIT "B"



1
WELD MESH
TO GROUND WIRE
MESH
GROUND
CONDUCTOR
REFERENCE TRIM
COLLATE
FIRST PASS
2
24 CONDUCTORS
STUFFER CONDUCTORS (2)
TRIM - REUSE
AS STUFFER
FINISH TRIM (TYP)
3
MESH
COLLATE
SECOND PASS
COVER INSULATION
GROUND CONDUCTOR
4
FINISHED
CABLE

EXHIBIT "C"



#7941 DuPont
Conductive
Silver Spots
2 days after collating
after 2 Hr. bake at 250° F
after 4 Hr. bake at 250° F
after pressing with eraser
after 10 flexes over .35 dia.
OHMS - GROUND WIRE TO SHIELD
1.3
1.1
1.0
0.9
0.7
0.5
0.3
0.1
0
5
8
7
6
8a

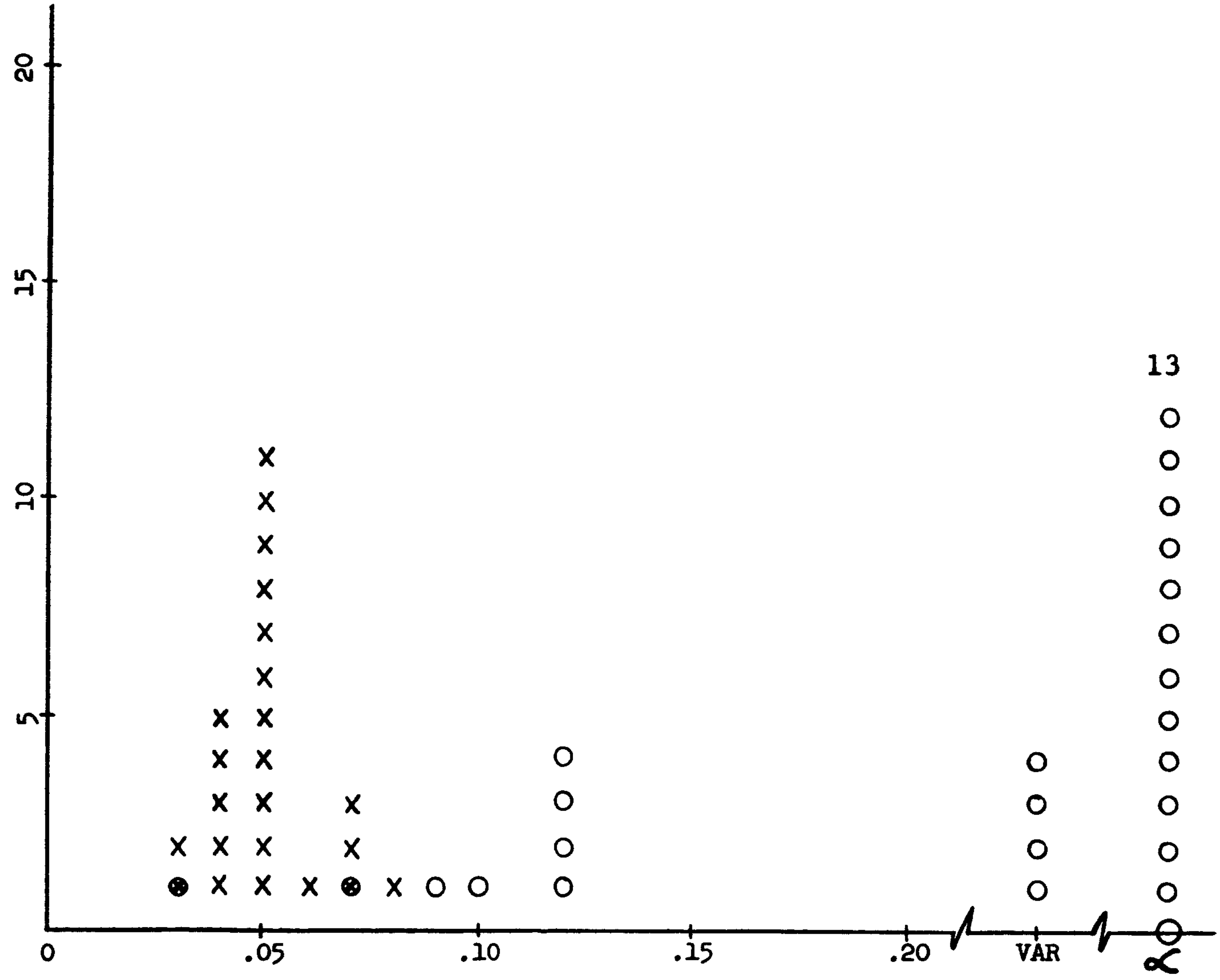
EXHIBIT "D"

GROUND SPOT CONNECTIONS

KESTER #44 (.031Ø) SOLDER

X Resistances as collated

O Resistances after flexing 10 times over pencil (.3Ø)



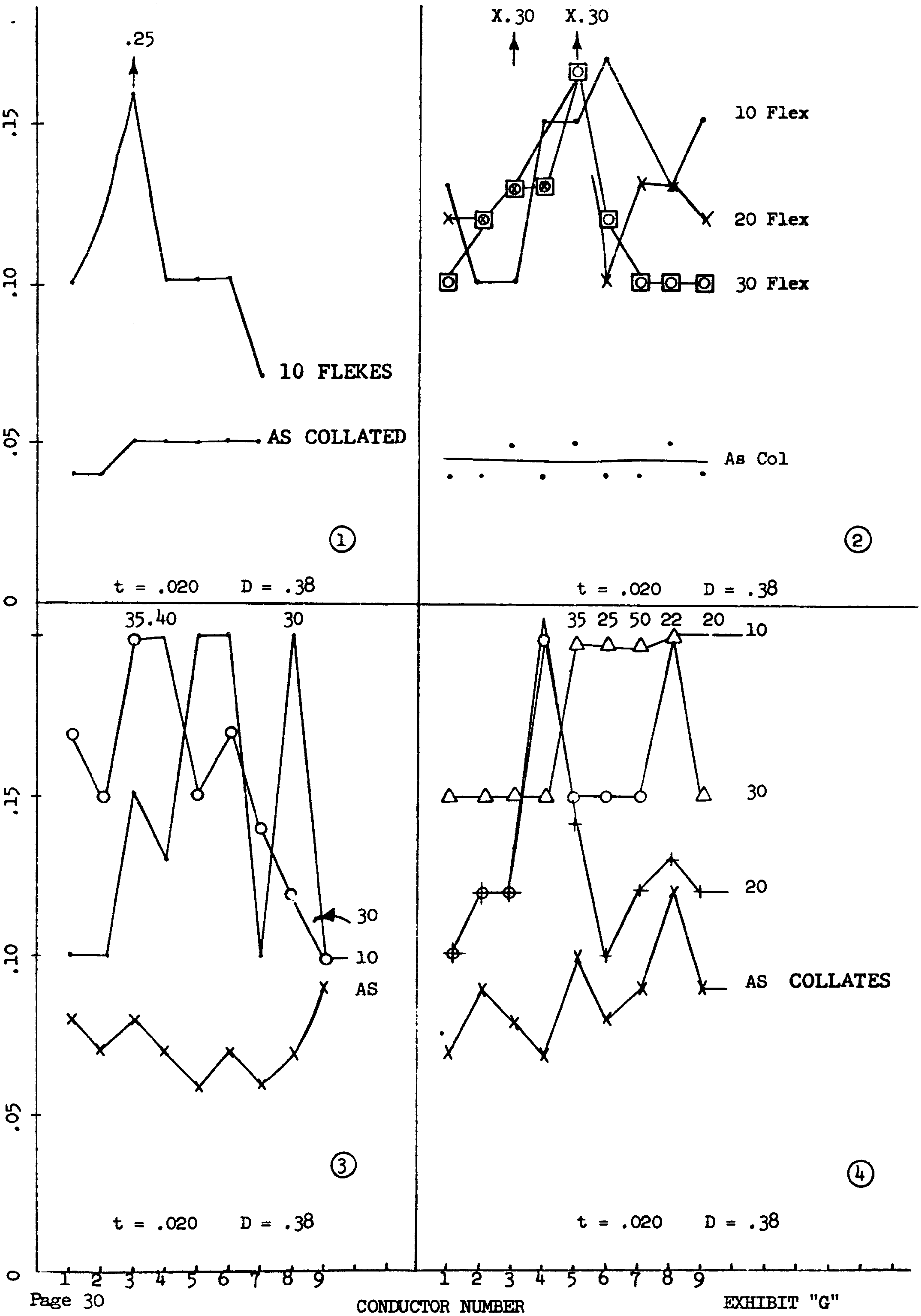
TOTAL CIRCUIT RESISTANCE - OHMS

EXHIBIT "E"

RESISTANCE BEFORE AND AFTER 10 FLEXES

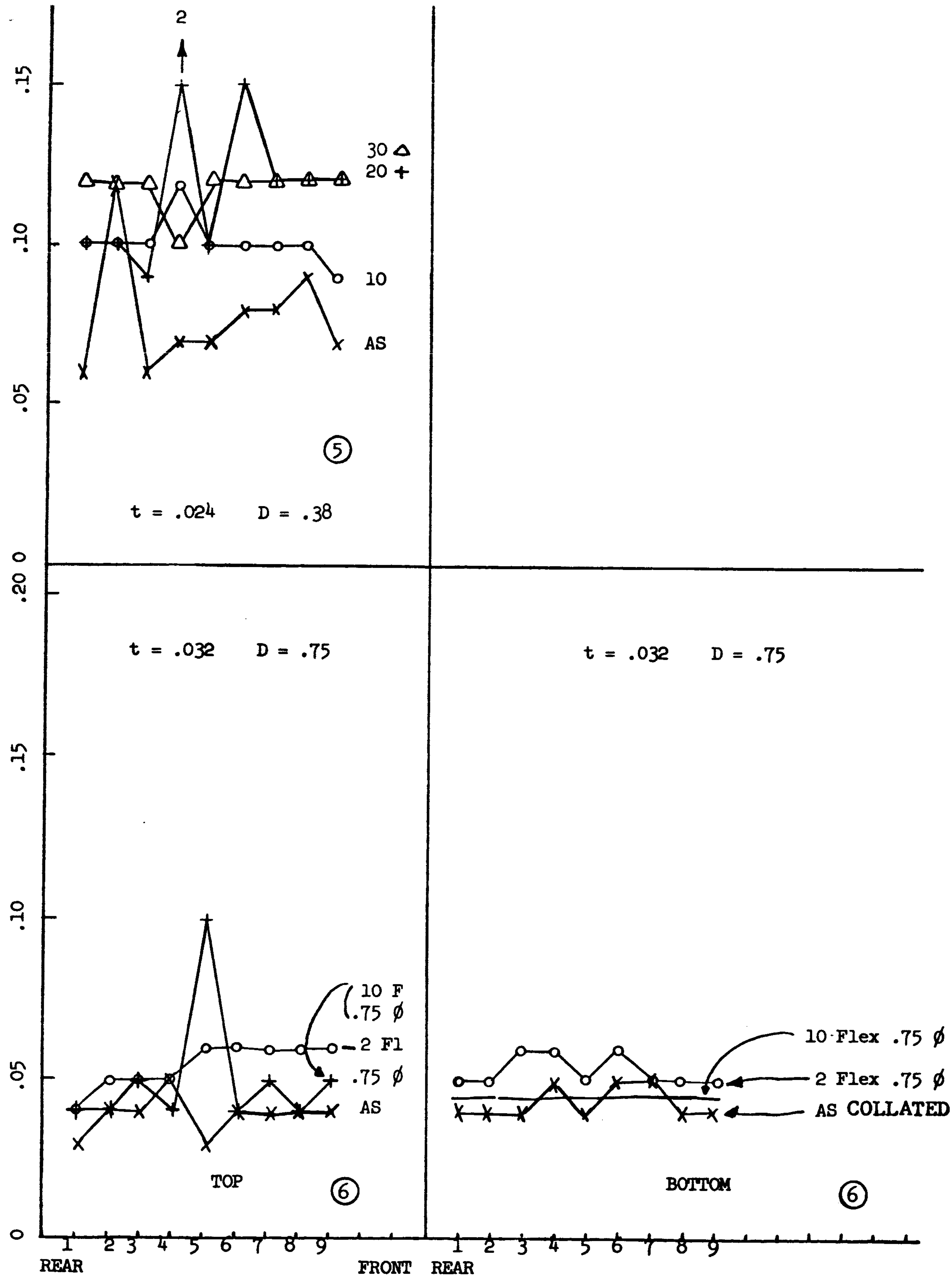
	#2 □ AS COL	AFTER	#3 ○		#4 △		#5 +		#6 ⊗	
1	.05	.12								
2			.05	.10	.05	.04	.03	.06	.05	.05
3	∝	∝								
4			∝	∝			.09	.16	.12	1.0
5	.03	∝								
6			.4	∝			.05	.07	.08	∝
7	.03	.10			-					
8			∝	∝	EXCESSIVE FLOW		.05	.12		
9	.05	.10								
10			.05	∝			.03	.12	.15	∝
11	.03	.05							∝	∝
12			∝	∝			.03	.12		
13	.03	.05								
14			.03	.05	.07	.05	∝	∝	.04	.10
15	.03	.05								
16			.12	.04	.06	.06	.03	INT	-	.05
17	.03	.04								
18			.05	.03	.08	INT	.03	.12	∝	∝
19	.03	.04								
20			.12	.03	.05	INT	∝	∝	.08	.10
21	.03	.04								
22			.05	.03			.04	.07	.05	VAR
23	.03	.05								
24	.02	.05	.07	.03	.03	.02	.02	.05	.05	.06
25										
	.36	.69	.49	.31	.21	.17	.40	.90	.34	1.31

EXHIBIT "F"



.25
10 FLEKES
AS COLLATED
1
t = .020 D = .38
X.30
X.30
10 Flex
20 Flex
30 Flex
As Col
2
t = .020 D = .38
35.40
30
30
10
AS
3
t = .020 D = .38
35 25 50 22 20
10
30
20
AS COLLATES
4
t = .020 D = .38
.15
.10
.05
0
1 2 3 4 5 6 7 8 9
CONDUCTOR NUMBER

EXHIBIT "G"



2
30 △
20 +
10
AS
5
t = .024 D = .38
t = .032 D = .75
t = .032 D = .75
10 F
.75 ø
2 Fl
.75 ø
AS
10 Flex .75 ø
2 Flex .75 ø
AS COLLATED
TOP
6
BOTTOM
6
.15
.10
.05
.20 0
.15
.10
.05
0
1 2 3 4 5 6 7 8 9
REAR
FRONT REAR
1 2 3 4 5 6 7 8 9

EXHIBIT "H"

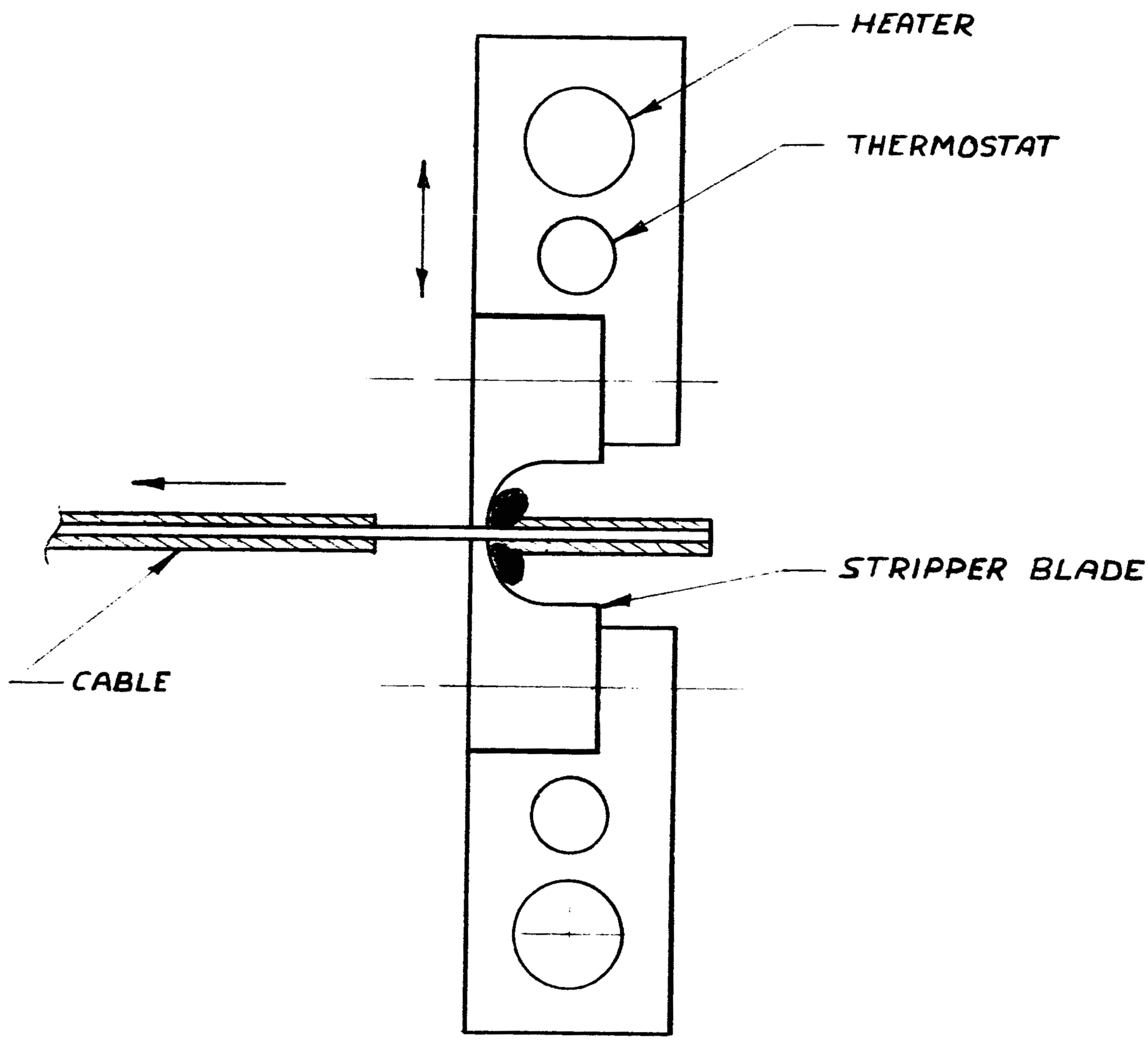


EXHIBIT "I"