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ALTERNATOR INSULATION EVALUATION TESTS

by

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16. Abstract

Tests were conducted to predict remaining electrical insulation life of a 60 KW homopolar inductor alternator following completion of NASA turbo-alternator endurance tests for SNAP-8 Space Electrical Power Systems application.

The insulation quality was established for two alternators following completion of these tests. A step-temperature aging test procedure was developed for insulation life prediction and applied to one of the two alternators. Armature winding insulation life of over 80, 000 hours for an average winding temperature of 248°C was predicted using the developed procedure.

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FOREWORD

The work described herein was conducted by the Aerospace Electrical Systems Programs of the General Electric Company, Erie, Pennsylvania, under NASA Contract NAS3-15691 with Mr. A. William Nice, Power Systems Division, NASA-Lewis Research Center as Project Manager. Measurements and insulation studies were conducted in the Advance Development Laboratory of the Direct Current Motor and Generator Department of the General Electric Company in Erie, Pennsylvania. The work was conducted on hardware developed and manufactured during the period 1964 to 1966 on NASA Contract NAS5-417.

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SUMMARY

Work under NASA Contract NAS3-15691 was conducted to evaluate the quality, determine predicted life and recommend improvements for the armature and field winding electrical insulations of two 60 KW, 120/208 Volts, 400-Hz, 12,000 RPM homopolar inductor alternators. The alternators completed endurance tests in SNAP-8 turbo-alternators accumulating 12,440 and 23,130 hours at rated load.

Electrical measurements were made on the alternators to establish quality as received and under simulated SNAP-8 environmental pressure and altitude. Initial insulation studies were also conducted under high humidity conditions following thermal stabilization. The insulation condition of these alternators as received was considered excellent and suggested a capability for substantially longer life than established by the turbo-alternator endurance tests.

One of the two endurance tested alternator stators was subjected to an increasing step-temperature aging test, starting at 200°C with increments of 25°C for 48-hour periods to 400°C. The armature coils of this stator were isolated to provide approximately 13 groups of 5 armature coils each for insulation measurements. A dielectric breakdown test was applied to each group in turn through the step-temperatures with a criterion of end-life established at 600 Volts dc. The predicted life for each 48 hour period and respective aging temperature was projected from an aging rate slope determined from industry tests on polyimide insulated wire. Using this procedure, total projected armature insulation life for the tested stator was determined to be over 80,000 hours for an average winding temperature of 248°C.

The field insulation life was also projected to be equal to the 80,000 hour armature life, using the same end-life criterion, although the field winding to frame insulations were susceptible to leakage at high temperature and low pressure indicating less margin than the armature winding to frame insulations.

The armature winding insulations appear to be of excellent quality with material and design capabilities substantially in excess of dielectric requirements for a 200°C SNAP-8 operating condition. The field winding to frame insulations do not appear to be dielectrically as strong, and design and material improvements are therefore recommended for future applications.

SECTION I

INTRODUCTION

A. BACKGROUND

A 60 KW inductor alternator was developed by General Electric Company during the mid 1960's for the SNAP-8 Space Electrical Power System under NASA Contract NAS5-417 (ref. 1, 2). The alternator is a three-phase, 120/208 volts 400 Hz, 12000 RPM brushless, solid rotor homopolar type, designed for 10,000 hours minimum life and high reliability. The rating and performance characteristics of this alternator, identified as General Electric Model 2CM391B1, are summarized in Table I.

Several 2CM391B1 alternators constructed under Contract NAS5-417 were assembled into turbo-alternator electrical systems at Aerojet-General Corp. and subjected to endurance tests under NASA Contract NAS3-13458 (ref. 3). The endurance tests were terminated following accumulation of 42,609 hours on 5 alternators with verification of reliable electrical and mechanical performance.

The maximum electrical insulation system life, although expected to meet the required 10,000 hours minimum life at the operating temperatures and environments, was not determined from these endurance tests. Thermal aging test procedures for insulation life prediction have been developed and used by industry for extrapolating life of materials and material systems. IEEE No. 57 and No. 117 are typical procedures (ref. 4, 5). Such procedures are not known to have been applied to the study of the material combinations used in the endurance tested alternator or to determine remaining insulation life of equipment with a previous operational history. Therefore, a determination of remaining insulation life in the existing alternators will provide a firmer basis for alternator insulation life prediction.

B. CONTRACT WORK DESCRIPTION

Two endurance tested alternators were provided by NASA Lewis Research Center for additional insulation system studies using static evaluation methods. These studies are described in NASA Contract NAS3-15691 with objectives as follows:

1. Evaluate the condition of the alternator insulations, as received, to establish effects of the endurance tests.
2. Determine remaining insulation system life by performing accelerated aging tests.
3. Establish relationship of insulation life and operating temperature for future design and application use.
4. Identify failure modes likely to limit insulation life and recommend improvements in insulation materials, application or processing that will lead to longer life potential.

Work under NASA Contract NAS3-15691 was initiated by General Electric in July 1971 with objectives described above. The results of this work are presented in this report.

The stators-in-frame of the two alternators were delivered in July 1971. The alternator serial numbers are 481490 and 481489 and are identified Stator No. 1 and No. 2, respectively, for this study. Endurance test data for Stator No. 1 shows an accumulated operational time of 23,130 hours with an average total armature winding temperature of 205°C and an end turn bus connection temperature of 260°C. The endurance time accumulation for Stator No. 2 is 12,442 hours with operating temperatures approximately equal to Stator No. 1.

Contract work was separated into two tasks and a final report:

Task I - Stator No. 1

1. Non-destructive electrical insulation tests to establish insulation condition.
2. Thermal stabilization.
3. Corona start voltage studies.
4. Effect of humidity.

Task II - Stator No. 2

1. Non-destructive electrical insulation tests.
2. Corona start voltage studies.
3. Effect of humidity.
4. Armature coil isolation.
5. Accelerated aging tests to determine remaining life.
6. Stator sectioning for physical examination.
7. Analysis of data and improvement recommendations.

SECTION II

ALTERNATOR WINDING AND INSULATIONS DESCRIPTION

The wound components consist of an armature winding of double core construction and a field winding positioned between the armature cores and between armature conductors and the alternator frame. The wound components and insulations described throughout this report are depicted and referenced in the cross-sectional view of the alternator. (Figure 1).

A detailed description of the insulating materials and application to this alternator is shown in Tables II and III.

A. FIELD WINDING

The field winding (Figure 1, Item 3) is an epoxy bonded double annular coil wound into a double cavity copper box to provide maximum heat transfer and coil stability. Each coil starts at the bottom of the box with a well insulated joint at the bottom center of the box so as to minimize conductor cross-over and eliminate bulky joints at the coil periphery.

Materials used for insulating the field included fabricated sheet insulations of two thicknesses (Table III, Item 1) cemented to the box sides and bottom with epoxy adhesive. The corners of the box are insulated with three turns of .026" diameter untreated glass cord saturated with epoxy compound. The field coils (Table III, Item 4) were "wet wound" in place using epoxy cement as the "wet winding" compound.

The coil periphery is insulated by placement of two layers of treated glass cloth (Table III, Item 7) around the coil. This operation was followed by winding tin-plate copper wire into the insulation and soldered in place with pure tin solder to provide a heat path (Figure 1, Item 9) from the coil to the alternator frame. The width of the coil periphery insulation exceeded the width of the field such that sides could be folded to contain tin-plated copper wire and solder and maximize field coil insulation reliability. The soldered structure is sized by machining, positioned between the two armature cores and, after armature coil placement, the assembly inserted into the frame (Figure 1, Item 1) providing a line-to-line fit between the oil cooled frame and field coil outer diameter.

B. ARMATURE WINDING

The armature stator is a double core construction (Figure 1, Item 2) with a square bottom semi-closed slot. The armature winding consists of one turn per slot per phase with conductors (Table III, Item 2) inserted into the semi-closed slot from the core end.

The armature slots are insulated with a slot liner (Table III, Item 1) that is continuous and extends through both armature cores with a butt-fold over the top conductor to close the slot. The slot phase separation is achieved by cementing a strip of .016" thick silicone glass laminate to one end of the bottom conductor prior to conductor insertion into the slot.

End turn phase insulation is provided by a wrap-around of impregnated glass cloth (Table III, Item 7) positioned snug between the involute of the armature coil and the slot liner extensions. Coil side phase insulation is provided by sleeving (Table III, Item 6) positioned on formed coils prior to insertion. The sleeving provides sufficient separation between coil sides and is later saturated with epoxy resin to effect dielectric and structural strength for coil support.

The armature slot is closed with a roof-shaped top-stick machined from polyimide sheet. The top-sticks were inserted from each end of the cores and were positioned between the folded slot liner and overhang of the semi-closed slot core such that the top of the stick is essentially flush with the stator bore.

The completed armature winding was impregnated with a pre-heated solventless epoxy compound by vacuum-pressure processing. These techniques were applied to assure optimum slot fill and saturation of glass tapes and sleevings in order to achieve best bond and dielectric strength.

C. BETWEEN CORE STRUCTURE

Following placement of the armature coils, the open area around armature conductors between the two stator areas (Figure 1, Item 8) and field winding was filled with a trowelable-inorganic filled epoxy compound. The space between the folded slot liners in this area and the base was filled with a glass laminate fabricated in place by wet-lay up of three layers .006" thick leno glass weave cloth and the trowelable epoxy to effect a smooth, strong reinforced hoop at the bore.

D. CONNECTIONS

Solid connections (joints) were achieved with Tungsten Inert Gas Weld methods and oxygen-free high conductivity copper (OFHC). The inter-coil connections (Figure 1, Item 6) were protected with a short section of untreated glass sleeving positioned over the joint and filled/bonded with an epoxy compound. All other joints and joint areas were insulated by a double tape system comprised of three thicknesses .0065" thick silicone-glass adhesive tape over the joint plus three layers of .005" thick de-sized glass tape. These tapes provide a rugged and solid joint dielectric system through vacuum impregnation with epoxy during the winding treatment processing.

The phase connections consist of a bus bar arrangement (Figure 1, Item 7) which provides numerous cross-overs and routing of the phase windings. These bars are positioned together to save space. Insulation is provided by placing a strip of .0105" polyimide resin impregnated glass on the bar at adjacent bus bar sides. Each insulation strip is taped in place and then the composite bars also taped together with .005" thick de-sized glass tape.

SECTION III

PRELIMINARY INSULATION EVALUATION

A. INITIAL INSPECTION

A visual and electrical inspection was conducted on Stator No. 1 and No. 2. The stators were in excellent condition. The procedure used and results of this initial inspection are described as follows.

A detailed visual examination was conducted on Stators No. 1 and No. 2 to establish a base line for the "as-received" condition. Notations were coded so that further observations could be made during the test program and degradation changes followed in terms of color, surface cracks and brittleness.

The connection ends of the machines showed that Stator No. 2 had not seen as great a thermal exposure as Stator No. 1 since the resin impregnant and glass tape matrix in Stator No. 2 were much lighter in color. This can be seen in Figures 9, 10, 11 and 12 and was corroborated by the reported endurance test time of 23,130 hours for Stator No. 1 and approximately 12,342 hours for Stator No. 2.

The ML wire and the ML-treated glass cloth in each of the stators appeared to be in excellent condition with no evidence of thermal degradation as determined by flexibility and color change. The epoxy filling compound showed some minor cracks, but the material was firm, rigid and shiny. The end turn windings were solid and rang with a clear sound when tapped. A structure not well bonded has a dull sound when tapped lightly.

The electrical tests to determine the quality of the stators were then initiated. Room temperature insulation resistance values to ground of field, armature and between field and armature windings were consistent and very good. Leakage current versus voltage from zero to the 1000 V dc maximum also showed consistency and high quality. Results of these tests are shown in Table IV.

A stabilization bake for 120 hours at 250°C was then initiated with electrical readings to be taken each 24 hours at temperature. After 24 hours and after 48 hours, no leakage current was detected, up to the 1000 V dc, between field winding and armature coils and between armature coils and frame as measured in the oven at 250°C. No leakage current could be detected between the field winding and frame after the first 24 hours at 250°C. However after 48 hours, leakage current had increased so that only 350 V dc could be imposed on Stator No. 1 and only 200 V dc on Stator No. 2.

The insulation resistance data taken at these intervals indicated that for both stators the field winding-to-frame insulation resistance was the lowest, as shown below.

REF: TABLE V	Insulation Resistance at 500 V dc at 250°C	
Stator No. 1	24 Hours	48 Hours
Field winding-Frame	100, 000 ohms	50, 000 ohms
Armature winding-Frame	2.0 megohms	1.7 megohms
Field to armature windings	1.6 megohms	1.7 megohms
Stator No. 2		
Field winding-Frame	50, 000 ohms	40, 000 ohms
Armature winding-Frame	1.8 megohms	1.6 megohms
Field to armature windings	1.5 megohms	1.5 megohms

After 72 hours and at 250°C, molten solder was observed at the frame bottom of both stators and the test was immediately stopped. (Figure 13).

Examination of the cold stators disclosed that the solder had apparently flowed from between the stator core outside diameter and the frame. Investigation disclosed that during field coil fabrication, a layer of solder had been applied to the coil periphery and machined to provide line-to-line contact between coil and frame thus improving the heat transfer from the coil. The solder is pure tin with a melting point of 232°C. The solder was removed and electrical measurements taken to establish the condition of these stators. These measurements indicated the insulation systems had not deteriorated as a result of the thermal exposure or the solder flow. No leakage current, up to 1000 V dc, was measured at room temperature which corresponded with the measured insulation resistance of infinity (>200 megohms) for all of field-to-frame, armature-to-frame, and field-to-armature winding data.

With NASA Lewis Research Center Project Management approval, testing was reinitiated. The stators were subjected to an additional 15 hours at

250°C with no further evidence of solder flow detected. Electrical readings taken hot also showed high dielectric strength. However, the field winding-to-frame readings were lowest; in the 0.1 megohm range.

The temperature was reduced to 200°C and electrical measurements made after 6 hours and then every 24 hours for the next three days. These readings are consistent, and showed the field winding-to-frame insulation resistance appreciably lower than the armature-to-frame or field-to-armature windings for both stators. After cooling to room temperature, both stators exhibited no detectable leakage current with up to 1000 V dc imposed between field winding-to-frame, armature-to-frame, and field-to-armature winding indicating retention of the "as-received" quality.

Agreement was reached with NASA Lewis Research Center Project Management to proceed with accelerated "aging" temperatures and corona tests up to and, if necessary, above 250°C based on the conclusion that the solder had no damaging effect. It was concluded that most of the solder had flowed from the stator during the 72-hour 250°C stabilizing period. Furthermore, the solder is confined between the channel insulation around the field coil outside diameter and cannot enter the field or armature windings. Also the vapor pressure of pure tin is 10^{-8} mm Hg at 600°C, and therefore solder vapor would not be a deterrent to contract required corona measurements at 8 Torr altitude and 250°C (ref. 6).

B. CORONA STUDY

Corona measurements were taken on Stator No. 1 and No. 2 at voltage stresses not exceeding 700 volts rms, at ambient conditions and at 250°C in 8 Torr pressure. Corona was not detected at ambient conditions but was detected in both stators at voltages less than 700 at the 250°C, 8 Torr condition. The procedure and results of this study are detailed as follows.

Corona start voltage measurements were initiated following thermal stabilization. Measurements were specified for field and armature windings under ambient conditions and at operating pressure and temperature. The test objective was to determine if these stators would encounter corona in service operation and to use corona data as a dielectric tool for evaluating the quality of the insulation system. In keeping with the 1000 V dc voltage limit used in the leakage current measurement, a limit of 700 V ac was used for the corona work, since the peak value of the 700 V ac sine wave corresponds (X 1.4) to the 1000 V dc value. No corona was detected at room temperature (23°C) and ambient atmosphere pressure between field and frame, between armature and frame, and between field and armature windings.

Corona data were obtained at sea level and room temperature and at 8 Torr (100,000 ft. or 30.5 km) and 200°C in an AiResearch vacuum-temperature chamber. 232°C at 93,000 feet (28.4 km) was the maximim temperature-altitude achievable and was limited by outgassing of the stator. It was suspected that outgassing was the result of an oil film in the stator frame cooling passages. Therefore, a decision was reached to "Freon TF" flush and wash both stators and repeat all corona tests. If 250°C could not be achieved, the afore described 24-hour stabilization heat soak would be repeated.

The oil-cooling channels of both stators were flushed and reverse flushed with "Freon TF." The stator windings were also washed by degreaser application in "Freon TF" with care exercised not to apply jet nozzle pressure to the aged insulations. The stators were then dried at 100°C to drive off the "Freon TF". ("Freon TF" is a DuPont tradename).

The corona tests were then repeated. The 8 Torr/250°C condition was achieved and held for approximately 90 minutes prior to measurement of corona. However, equilibrium temperature (250°C) had been reached in the stators for four hours prior to dropping the pressure to 8 Torr. Corona onset voltage for Stator No. 1 dropped from corona free at 700 V ac at sea level/room temperature to approximately 500 volts at 8 Torr/250°C. Stator No. 2 showed lower dielectric quality with a lower corona start voltage of less than 200 volts at 8 Torr/250°C. Repeat measurements were made at this same condition as shown below.

REF. TABLE VIII	Ambient Room Temperature & Pressure	Corona Onset Voltage (V ac)	
Stator No. 1		250°C 8 Torr	250°C 8 Torr
Field winding-Frame	>700 *	400	400
Armature winding-Frame	>700	500	450
Field to armature windings	>700	500	500
Stator No. 2			
Field winding-Frame	>700	<200	<200
Armature winding-Frame	>700	300	300
Field to armature windings	>700	300	300

* No corona detected at 700 V ac (max.imposed)

The corona data verified the earlier indications that the field winding to frame insulation is the weakest component of the insulation system and that Stator No. 1, with over 23,000 hours service exposure, was apparently in better condition than Stator No. 2 with over 12,000 hours service.

It was determined that the isolation of the individual armature coils and the accelerated thermal aging tests would be conducted on a single stator only since the proposed procedure for determining life expectancy was innovative and relatively unproven. In view of the apparently poorer condition of Stator No. 2, this machine was selected for further study while Stator No. 1 was to be retained until the preliminary screening and evaluation tests were completed.

Visual examination disclosed that the connection insulation on Stator No. 2 had darkened as would be expected from exposure to 250°C and to 200°C. The operational test data on Stator No. 1 indicated 200-210°C had been reached in the windings and the end connections of the stator reached 250-260°C. Stator No. 2 had apparently not seen this connection end temperature during test.

Cracks were noted in the A50WB364A filling compound (Table II, Item 13) in both stators but only slightly more than when received. All connections were tight and snug and no loose conductors were found. In several areas, such as glass sleeving, there was a lightening of color as the A50WB363A volatilized and bare glass became exposed. The stators appeared to be in good condition. (Figures 14 and 15).

C. EFFECTS OF HUMIDITY

Electrical measurements were taken on Stator No. 1 and No. 2 in a wet condition following exposure to high humidity. Results of these studies indicated the dielectric quality of Stator No. 1 to be higher than No. 2 with details of the procedure and results described as follows.

Humidity tests were performed to determine the integrity of the insulation systems. The stators were placed in a Tenney environmental cabinet with lead connections made to terminals through a side port in the cabinet. Electrical readings were taken "wet" after an exposure of 56 hours at 100% relative humidity at 23°C. A summary of the results of these tests are shown in the following table.

REF: TABLE X

	Insulation Resistance @ 500 V dc	Leakage Current - microamperes				
Stator No. 1	(in ohms)	200	400	600	800	1000 V dc
Field winding-Frame	400,000	750	1600	F*		
Armature winding-Frame	10,000	850	1650	F*		
Field to armature windings	400,000	600	750	1800	1950	F*
Stator No. 2						
Field winding-Frame	100,000	F*				
Armature winding-Frame	45,000	1950	F*			
Field to armature windings	50,000	750	F*			

* Failure -- leakage current in excess of 2000 microamperes

The wet electrical measurements indicate sensitivity of the system to moisture, but whether due to penetration of the moisture into the insulation or the formation of a conductive wet surface film is not known. It is of interest to note that again the insulation system of Stator No. 1 appears to be in better condition than that of Stator No. 2.

Field winding resistance measurements were made on the "wet" stators to test for the possibility of shorted turns. Stator No. 1 measured 1.529 ohms and Stator No. 2, 1.541 ohms. Compared with the "as-received" dry values of 1.542 ohms for Stator No. 1 and 1.536 ohms for Stator No. 2, the greatest change found, in Stator No. 1, is less than 1% and indicates excellent stability of the winding.

After drying the stators, corona onset voltage measurements were again made at room temperature and ambient atmospheric pressure to see if the humidification exposure had produced any deleterious effects. No corona was detected up to 700 V ac on either stator between field or armature to frame or between field and armature windings.

D. CONNECTION INSULATION STUDY

A careful visual and electrical inspection was made of the end turn phase connection insulations of Stator No. 1 and No. 2. The insulation of both stators was established to be in excellent condition. Results of this study are detailed as follows.

In the final pretest inspection, the lead connections were physically examined and electrical tests made on these insulation components. The insulation was firm though somewhat brittle. Resin had volatilized from the surface glass tapes so that a graying of the black surface was apparent, but no lifting or fraying was noted.

Aluminum foil was wrapped around the lead and interphase connections and crushed in place to insure good contact. Insulation resistance was measured with a 500 V dc "Megger" between terminal T4, Figure 2, (armature coils) and each foil wrap. A reading of infinity (>200 megohms) was obtained at all positions on both stators. A high potential test voltage of 1000 V ac was then imposed successively on all connections, between the T4 terminal and the aluminum foil without breakdown.

It was concluded at this stage that the insulation system in each of the two stators was in good condition, that the insulation system of Stator No. 1 was somewhat better than that of Stator No. 2, and that the field winding insulation was probably the weakest component in the insulation system.

With this preliminary study phase completed, the evaluation program was initiated.

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SECTION IV

ACCELERATED AGING STUDIES

The objective of the accelerated aging studies was to determine the service life remaining in the insulation system. The approach was to subject the system to gradually increasing temperatures in step increments while measuring the dielectric properties of the system after each such exposure.

High potential or hipot testing of the armature coils in a stator was the parameter chosen for the evaluation. With only two stators available, it was necessary either to use a non-destructive test such as insulation resistance, which does not correlate well with time-to-failure in life testing, or break up the test stator in such a fashion that a large number of test samples are made available. By removal of the end turn section of the stator, the end opposite the connection end, the winding was separated into an assembly of individual armature coils, each capable of being separately high potential tested to failure.

The same procedure could not be applied for the field winding, but a periodic surge test, to check for the initiation of turn-to-turn failure, was incorporated into the test plan.

A. STATOR PREPARATION

A study of the coil configuration indicated isolation of coils could be achieved at the end turns opposite the terminal end of the machine where all "frog-leg" coils are joined. Review of the Connection Diagram revealed opening of these end turns would result in the following open armature coils:

1. 60 sets - "frog-leg" coils (20 coils per each of the 3 phase windings).
2. 3 sets - 4 half "frog-leg" coils tied together per each of 3 phases.
3. 3 sets - 2 half "frog-leg" coils tied together per each of 3 phases.
4. 1 set - 6 half "frog-leg" coils tied together with all phases.
5. Total isolated armature coils for dielectric to frame measurements = 60 + 3 + 3 + 1 = 67.

The method adopted for opening conductors was machining by use of a milling saw cutter. The end turns were cast in 55°C melt, fully-refined petroleum paraffin wax to support conductors and insulations and prevent copper chips from contaminating the windings. To provide additional conductor support for the machining operation, a laminated phenolic cloth ring was inserted between the end turn O.D. and frame I.D. at the cutting area.

An end view of the isolated armature coils is shown in Figure 16.

B. TEST PROCEDURE

The procedure required room temperature high potential tests to failure of five coils. The stator was then heat aged for 48 hours, vibrated for one hour when cool at 1.5 G and then another group of five coils is hipotted to failure at room temperature. This process is continued with the heat aging temperatures increasing in step increments. The dielectric breakdown voltage is measured at room temperature after each thermal cycle so that the values are compared on a consistent basis. Dielectric breakdown at temperature is more meaningful from a service point of view, but correlation between room temperature and elevated temperature failure voltage has not been established for this insulation system.

Data, at temperature, were taken as follows:

1. Connect leads to five adjacent armature coils and monitor leakage current.

2. High potential test to failure, five top coils in five adjacent armature slots at room temperature.

3. Heat age stator in oven for 48 hours with an oxygen concentration in the oven equivalent to that at 100,000 feet. (Based on partial pressures, this was calculated as $\frac{8*}{760}$ x 15.18** = 0.16%. This duplicated the chemistry but not the actual environment. Ozone presence was considered, but was found not to be a factor at this low altitude, 19 statute miles. "Atomic oxygen is the most important constituent in the upper thermosphere"- above 56 statute miles ***). Measure leakage current up to a maximum of 1000 V dc

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* Pressure in Torrs at 100,000 feet. (U. S. Standard Atmosphere).

** Oxygen content of atmosphere at 100,000 feet. (International Critical Tables, Vol. 1, pg. 393.

*** Space Materials Handbook (NASA SP-3051) Rittenhouse & Singletary, Chapter 3, Pg. 18, Paragraph 3 between ground (frame) and each of the five armature coils being monitored. (This is done at various time intervals during the 48 hours at elevated temperature in each cycle.) Measure leakage current between the armature coils and the field winding, and between each pair of armature coils. Measure insulation resistance between field winding and frame and between field coil and armature coils.

4. Cool stator in oven with a low oxygen atmosphere maintained.

5. Mount stator and vibrate at 0.2 mm peak-to-peak amplitude at 60 Hz (1.5 G) for one hour with direction of vibration at right angles to direction of armature coils, at room temperature. (Figure 17).

6. Surge test field winding at 500 V ac peak at room temperature. Compare oscilliscope traces for shorted turns. Measure field conductor resistance.

7. Hipot to failure at room temperature five top coils in five adjacent slots.

8. Visually inspect stator windings.

9. Repeat Steps 3, 4, 5, 6, 7, and 8 for each cycle, increasing the heat aging temperature of Step 3 from an initial 200°C by 25°C for each cycle.

10. Terminate tests when the dielectric breakdown of the test specimens in Step 7 drops below 600 V dc (twice peak value of 208 V ac rating).

The data obtained is summarized in Tables XI, XII, and XIII and Figures 3, 4, 5 and 6. The test was terminated after the 400°C exposure when the dielectric breakdown voltage dropped to an average of 265 V dc, as shown in Table XIII and Figure 3. The appearance of the stator had changed with only clean bare glass and inorganic filler remaining of the stator insulation. (Figures 18 and 19).

SECTION V

METHOD FOR INSULATION LIFE PREDICTION

The analysis of the data and the conversion of aging time at various elevated temperatures to life expectancy at a given temperature has been given much consideration and discussion. Since each of the sample coils was contained in a single stator, aging obviously was cumulative and the problem became one of relating the time-of failure at the various temperatures.

A. AGING RATE FROM DIELECTRIC STUDIES

A relationship between stator insulation time-to-failure and the aging rate of similar insulations was established with the procedure and analysis from published data described as follows.

A procedure for evaluating the data was based on the fact that polyimide resins and polyimide resin treated materials are the basic electrical insulations in this machine. A time-to-failure versus temperature slope could be established for polyimide coated magnet wire either experimentally, if necessary, or from previous test data, if available. These data would involve tests made in air containing 21% oxygen and would therefore include oxidative degradation in addition to the essentially pyrolytic degradation of a low oxygen environment. The results of using such information would be conservative, and therefore usable.

A literature survey was conducted. Data were obtained by private correspondence from the Naval Research Laboratory, Washington, D. C., and publications from the Naval Ships Research and Development Center, Annapolis, Md. These papers were presented at the Conference on Electrical Insulation in October 1967 (ref. 7, 8). Calculations were made from the slopes of the various aging curves given for ML magnet wire to give the temperature incremental change which would produce a doubling or halving of thermal life. Based on 17 sets of data (Table XIV) the arithmetic average was found to be 12.2°C.

An attempt was made to explore the use of thermogravimetric analysis and/or isothermal gravimetric analysis as techniques for establishing a life-temperature relationship(ref. 9,10), but this trial was unsuccessful

B. RELATIONSHIP OF AGING RATES AND STATOR TESTS FOR LIFE PREDICTION

An equivalent insulation life of more than 80,000 hours at 248°C is predicted for the alternator stator windings. The prediction is based upon industry established aging rates for similar insulations and the step-temperature stator aging tests with procedure and analysis described as follows:

Dielectric breakdown was applied at room temperature to each set of five armature coils at room temperature following the temperature exposure of each cycle. The breakdown voltages decreased slowly as the test and the heat aging progressed. Failure, defined as dielectric breakdown at a voltage below 600 V dc with leakage current exceeding 2000 micro-amperes, occurred after the 400° C exposure. These test data are shown in Figure 3. The time-to-failure versus temperature data on polyimide magnet wire was used to integrate thermal exposure times at the various aging temperatures.

The data shown in Table XIV are converted to a 200°C base line by use of the 12.2°C temperature relationship derived from the ML wire information as follows. Using these data and expression shown in Table XIV, an equivalent life of more than 80,000 hours was calculated for 248°C operation.

EQUIVALENT LIFE - HOURS

HOURS	TEMPERATURE	MULTIPLIER	EQUIVALENT at 200°C
48	200	1	48
48	225	4.15	199
48	250	17.2	827
48	275	71	3,431
48	300	297	14,237
48	325	1231	59,086
48	350	5107	245,205
48	375	21195	1,017,600

Cumulative equivalent life at 200°C = summation = 1,340,633

Based on Figure 3, failure occurred after 30 hours at 400°C. Since all of the samples survived the 375°C exposure, this could be considered a lower limit of the life period and a more conservative estimate for insulation system life. On the basis of the 375°C survival, the equivalent 248°C life of this insulation system is over 80,000 hours. Since this time is determined from the aging tests performed on the alternator as received from NASA, previous turbo-alternator operation time (approximately 12,000 hours) could be considered as additional.

The field winding data, taken at room temperature after completion of the final cycle at 400°C (Table XI), indicated that the field winding withstood the thermal exposures better than the armature coils. As shown by the leakage current measurements, the field winding withstood a 1000 V dc high potential test between winding and frame. In addition, the field winding withstood a surge test at 500 V ac peak, which also demonstrated integrity of the field conductor insulation.

Other assumptions made in this prediction of life expectancy are (1) failure will occur in the armature coil insulation system, although this may not be the limiting case since the field winding showed higher leakage to ground when hot than did the armature coil, and (2) the time-to-failure vs. temperature Arrhenius plot continues to be linear above 320°C. The plot is linear in the 240°C to 320°C range and extrapolation is made to 375°C. (Table XIV, Figure 8).

C. LEAKAGE CURRENT MEASUREMENTS

The data from DC leakage current measured, at increasing step-temperatures and increasing voltage levels, was studied as means for life prediction. The procedure and analysis used are described as follows:

Leads were affixed to the field winding terminal (F1), and five armature coils in the stator as well as to the stator frame. These leads were brought out from the oven to permit electrical measurements to be made at temperature during the heat aging. Data from these tests are shown in Table XII.

The leakage current, measured at 200°C between the field winding and the frame, at dc voltages from 200 to 1000 volts shows an increase with voltage as would be expected, as well as an increasing leakage with time of exposure, which is unexpected. The values at 200 V dc continue to rise; the values at 1000 V dc peak at 24 hours. The 17-hour readings show a flattening at the higher voltage, the 24-hour readings are almost linear, but the 48-hour data shows a strong upward slope at the higher voltage, implying a possible fault condition.

At 225°C, the trends shown above are continued, but the leakage current and its rate of change are accelerated. Leakage increases with voltage as well as with time of exposure at temperature and leakage current in excess of 2000 microamperes is reached at 600 V after 48 hours (Figure 6). This value of 2000 microamperes has been selected as the value of leakage current which defines failure. At 250°C and higher, "failure" occurs at 200-400 V dc.

Though this could correspond to an insulation resistance of 0.1 megohms, it appears that the field winding to frame insulation is failing a hot dielectric test of 200-400 V dc at 250°C, though not destructively. Time-to-failure, using the 600 V dc limit, was therefore 48 hours at 200°C plus 48 hours at 225°C or a total equivalent hours at 200°C of 247 hours. If the stabilization period of aging is included in the thermal exposure, the total time to failure at 200°C in this contract study is 2042 hours.

Leakage current measurements made between armature coils and frame were initially conducted with all five coils shorted together. This permitted a single reading to be made, at voltage, to check the quality of the coil-to-frame insulation. This technique is effective providing the leakage current is zero. When leakage developed during the aging program, the bundle of conductors was separated and readings between the individual coils and the frame were then taken.

As shown in Table XII, leakage current became appreciable following the 275°C exposure. Separating the armature coil conductors and checking each one individually showed that one coil had "failed" with leakage current in excess of 2000 microamperes at 600 V dc. All other coils showed zero leakage-to-frame up to 1000 V dc.

There was no change in the data after exposure to 300°C, but increased leakage appeared on another conductor during the 325°C exposure and two more coils failed during the 350°C heat aging. None of the coils showed leakage less than 2000 microamperes at 400 V dc at 375°C, so that these were considered failures at this point. Leakage in excess of 2000 microamperes occurred at 200 V dc on the five armature coils at 400°C.

Based on time to first "failure" (2000 microamperes at 600 V dc) failure of armature coils to frame occurred after the 17-hour exposure to 350°C. If an assumption is made that failure occurred immediately on exposure to 350°C, but that it was not found until the first set of measurements were made at that temperature and after 18 hours, then the equivalent time-to failure at 200°C is 18,742 hours. Previous test or alternator operational time may be added to this equivalent life to obtain total life.

A similar analysis was made using leakage current as a tool to explore degradation of the insulation between conductors. Measurements were taken between each of the five monitored armature coils to alternate coils in the group.

No leakage was observed up through 300°C at voltages to 1000 V dc. At 325°C, the leakage current between conductors began to increase. After 48 hours at 350°C, leakage in excess of 2000 microamperes was found between two pairs of coils at 1000 V dc. Readings taken after 24 hours at 375°C showed numerous coil cross-over "failures" between conductors. Leakage in excess of 2000 microamperes appeared at 200 V. An equivalent time-to-failure at 200°C for shorted armature coils would therefore be determined on survival beyond the 350°C exposure or 323, 033 hours, additional to previous test time.

It should be noted in discussion of "failure", determined by leakage current measurements or by insulation resistance at elevated temperatures, that two factors occur simultaneously, making a quantitative analysis impossible. As temperature increases, electron mobility is increased and materials such as electrical insulations become better conductors with lower electrical resistance. At the same time, the higher temperature produces thermal degradation of the material and pyrolysis coupled with some oxidation occurs. The first effect is essentially reversible so that when a correlation is established, readings taken at one temperature can be related to another temperature. The second effect is irreversible. The degraded material becomes a progressively poorer insulation with lower resistivity until failure occurs.

In determining "failure" time by insulation resistance or leakage current measurements at increasing temperatures, it was not possible to isolate the degradation produced by the heat aging exposures which accelerates the thermal deterioration of the insulation. The failure times are therefore conservative since they contain two effects producing increased leakage; the thermal excitation, not the degradation, may be the predominant factor.

In converting the "failure" time, as obtained in the leakage current or insulation resistance measurements, to equivalent life expectancy at 200°C, a correlation factor was required such as used on the armature dielectric breakdown tests.

D. INSULATION RESISTANCE MEASUREMENTS

Insulation resistance readings were taken on Stator No. 1 at temperatures to 160°C to preclude heat aging from affecting the changes in resistance. These readings showed decreasing resistance with increasing temperature though the slopes of the curves for armature coils to frame, of field winding to frame, and of field winding to armature were slightly different. The average delta factor calculated for these three curves is 11.6, not too dissimilar from the 12.2 derived from the ML wire data which was based on a dielectric breakdown end point. (Figure 7).

The assumption was therefore made that the 12.2 factor should be used and that the slopes of the life expectancy curves were similar even though the curves themselves might be very much apart. This same factor was therefore used to determine cumulative or equivalent life at 200°C for the leakage current and insulation resistance data.

E. FIELD WINDING RESISTANCE

The change in field winding conductor resistance as a function of aging temperature is shown in Table XVII. The increasing divergence between actual and calculated temperature indicates oxidation of the copper has occurred, producing a reduction in conductive copper and a corresponding increase in resistance. The increasing resistance confirms the surge test results; shorted turns did not occur in the field winding. This is also substantiated by the initial room temperature resistance reading of 1.63 ohms compared with the final room temperature resistance reading of 1.721 ohms.

SECTION VI

POST AGING STATOR INSULATION STUDY

A. STATOR SECTION PROCEDURE

Stator No. 2 was prepared for sectioning, following completion of the aging and insulation tests, to visually examine the armature slots and field winding cross-sections for insulation condition, slot fill and bond. Sectioning was accomplished by a radial cut through the connection end armature core at about mid-stack length, so as to permit a view of armature slots, and by an axial cut at center through the major remaining portion of the frame to provide a view of the field winding.

The high temperature aging tests appeared to have removed all organic materials from the tapes, slot liners, coil impregnate and filling materials, and the enamel from the conductors. The winding condition was noted to be dry and frail and was a factor in determining the technique to be used for sectioning. The frame was positioned vertically, with the lead connection end up, and the major portion of the frame material was removed with a milling cutter. It became apparent the bond deteriorated armature core laminations could not be cut radially without possible excessive vibration and damage. To avoid this possible damage, 13/64" dia. adjacent holes were drilled through the stator yoke at the armature conductor positions moving from the bottom through the top of each slot. Following drill-out of the last conductor, the core became delaminated and the connector-end portion of the stator-frame could be lifted from the frame.

Polishing the armature slot sections proved difficult due to looseness of conductors in the slots. Conductors could be readily moved axially in the slot. Combination surface grinding and hand sanding with emery cloth was used to provide as reasonably smooth surface as possible.

The axial cut through the remaining portion of the frame was accomplished with a vertical band saw. The field leads for connection of the field winding to external terminals was contained in one of the axial cut sections. (Opposite section to that shown in Figure 21). The sectioned condition of the field coil was in good condition and was smoothed by hand sanding. Presence of bond material was noted around the field conductors. The tightness of the copper box and insulations that surround and essentially seal the field winding apparently reduced the effects of thermal aging and oxidation and helped retain the polymeric material.

B. ANALYSIS OF STATOR SECTIONS

1. Visual Inspection

Close visual inspection of the sectioned parts of the stator produced the following observations:

a. All exposed glass had been burned free of treating or impregnating resin. This included tapes and sleevings saturated with A50WB363A (Table II, Item 11) and slot tubes impregnated with polyimide resin. The glass was white in color. (Figures 20 and 22).

b. The filling compound, A50WB365A (Table II, Item 13), used to encapsulate the conductors in the stator bore between cores, had disappeared leaving only the white silica filler in a crumbly condition, readily crushable to a fine white powder. Evidence of this loss of binder had also been noted during the vibration testing. (Figure 21).

c. The silicone glass laminate end punchings were essentially intact but could be easily delaminated.

d. The armature conductors were loose in the slot and the surface oxidized.

e. The polyimide slot wedges could be removed from the slot in one piece, but showed evidence of surface checking.

f. The field winding appeared to be in excellent condition with tight conductors. Slight shrinkage voids were noted but the fill was excellent. Examined under 30X magnification, the filling compound appeared somewhat coked and dull, but was hard. (Figure 23).

It was surprising to find that complete combustion of the exposed organic insulation components could occur in the low oxygen concentration of 0.12%. The stator and its included components were aged in an environment with an oxygen content intended to correspond with that of the service environment of 100,000 ft. (30.5 Km) or 0.16%. This environment was maintained by piping pure nitrogen into the oven whose exhaust had been blocked off. A barely cracked valve admitted a trace of air into the oven. Periodic gas chromatographic analyses of the oven atmosphere showed oxygen contents of 0.09%, 0.12%, 0.13% and 0.12%. These values were slightly below the 0.16% sought but readjustment of the settings was felt to be too precarious.

Pyrolysis appeared to have occurred within the field winding box since the epoxy compound was black and slightly porous. Oxygen diffusion apparently did not occur in this enclosed structure. The field winding did show an increase in resistance as a result of the aging, however. (Table 17). The increasing resistance demonstrates that shorted turns did not develop in the field winding. This is confirmed by the initial room temperature resistance reading of 1.63 ohms compared with the final room temperature resistance reading of 1.721 ohms.

2. Electrical Tests

Insulation resistance readings at 500 V dc between frame and field coil conductors taken after sectioning, showed 900 megohms for one section and 80 megohms for the second section. The second section included the lead connection.

The field coil sections were carefully removed from the stator. The first section was removed by applying pressure on one end of the coil assembly, and the second section was removed by extracting the laminated core. Copper oxide scale flaked off the outside of the field winding boxes as they were removed. Insulation resistance between the field winding and copper box remained at the same value as in the frame.

The sectioned ends (Section 1 and 2) were polished and insulation resistance readings shown below were taken between winding and box in the dual box assembly. (Figure 1, Item 3).

Section 1 (no lead)	Box	Winding	IR (megohms)
	1	1	800
	1	2	0.5
	2	2	0.5
	2	1	800
Section 2 (with lead)	Lead to winding 1		900
	Lead to winding 2		0

Section 2 was again sectioned, with separate cuts made on each side of the lead connection. The ends were polished to reduce copper dust and smear. One coil section showed insulation resistance readings of 1000 + megohms between winding and box. The other coil section showed the following:

Box	Coil	Insulation Resistance
1	1	1000 + megohms
1	2	0
2	2	0
2	1	1000 + megohms

The following readings were obtained on the lead section:

Lead - Box 1		1000 megohms
" - Box 2		1000 "
" - Coil 1		1000 "
" - Coil 2		1000 "
Box	Coil	
1	1	0 "
1	2	0 "
2	2	0 "
2	1	0 "

From these analysis, it was concluded the field winding lead area was not contributing to the field insulation weakness. The weakness in the assembly was determined to be in the winding box insulation.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

A. PROJECTED LIFE

A method for determining the insulation life remaining in an inductor alternator was evaluated. The procedure is based on subjecting the wound components to heat aging at successively higher temperature to accelerate insulation degradation.

Based on the criterion of dielectric breakdown at room temperature following heat aging, both field winding and armature coil insulation show outstanding thermal endurance. The life remaining in the armature insulation system is predicted to be more than 80, 000 hours at 248°C.

Based on the criterion of leakage current exceeding 2, 000 microamperes at voltages not less than 600 measured at the heat aging temperatures, the field winding ground insulation has a projected remaining life expectancy at 200°C of 2, 000 hours compared with 18, 700 hours for the armature coils, (Table XII). These values are conservative since the high leakage current may be attributable to thermal excitation rather than thermal degradation. This observation is corroborated for the field winding ground insulation by the insulation resistance readings shown in Figure 5 where the initial 200°C readings are less than 1 megohm, and drop with increasing temperature and aging to 10, 000 ohms at 400°C after 48 hours exposure to 400°C.

Conductor to conductor insulation, phase insulation, and end turn insulation have remaining life expectancy, based on leakage current measurements, of over 300, 000 hours at 200°C.

Field to armature measurements of insulation resistance show an erratic but normal downward trend with increasing temperature. The initial readings at 200°C show insulation resistance greater than 200 megohms. After 48 hours at 400°C, insulation resistance measured 25, 000 ohms. Had this been a smooth curve, the 0.3 megohm limit could have been used to establish time to failure (Figure 4). Analysis of the data in Figures 4 and 5, to compare these slopes with the low temperature (80°C to 160°C) data taken on insulation resistance, was futile because of the erratic position of the data points. A delta factor calculation, based on 200 megohms at 250°C and 25, 000 ohms at 400°C for the field to armature measurements produces a delta factor of 11.5. This was close to the 11.6 factor obtained at the lower temperatures. However, this may be coincidental since the same calculation on the field winding to frame insulation resistance reading produces a delta factor of 31.7. For these calculations the resistance is ratioed in the same manner as time-to-failure for the original calculation.

It should be noted that insulation resistance or the very sensitive leakage current test, although excellent tools for following dielectric changes in an insulation system, are not as precise factors for predicting insulation life as dielectric breakdown. However, the 600 V dc and 2000 microampere limits provide an insulation resistance of 0.3 megohms, a value at which many machines continue to operate.

Surge tests, imposing voltage between turns of the field winding, showed no deterioration of the field conductor insulations during the step exposures through 400°C.

In summary, the armature insulation system appears thermally capable of providing adequate dielectric breakdown protection for the alternator for over 80,000 hours at 248°C. The 600 V dc end point, as related to the 208 V ac (300 V peak) in predicting life, does provide a reduced but conservative estimate.

The alternator insulation system life predictions are based on insulation dielectric performance. It should be noted that change in the insulation system properties during this life could alter thermal or mechanical properties of the alternator such that heat transfer or mechanical integrity could be the limiting performance characteristic for alternator life.

B. INSULATION IMPROVEMENTS

Potential insulation system failure modes were identified by (1) dielectric measurements at aging temperatures, (2) corona onset studies at similated operating pressures, and (3) analysis of the sectioned stator following completion of aging tests. These failure modes were the basis for the following suggested recommendations for improving the alternator insulation system so as to result in longer life potential. The recommendations are listed in order of importance.

1. Improved box insulation for the field winding. The apparent improvement could be an increase in thickness of the same type insulation used for box side and bottom. Additional insulation at the box corners or means to achieve continuous insulation from the box sides and bottom, eliminating a gap and probably current leakage, is also recommended.

2. Increased thickness of the armature slot insulation or change to polyimide film type sheet insulation is recommended to reduce

leakage current at elevated temperature and thereby increase dielectric reliability of the armature winding.

3. An increase in alternator stator cavity pressurization is recommended to increase the corona onset voltage level at hot conditions and provide more margin for operational voltages and switching transients. Pressurization with nitrogen would also reduce oxidation of the winding impregnation, insulation saturants and fillers and thereby reduce void formation and corona foci.

C. RECOMMENDED WORK BEYOND CONTRACT SCOPE

The primary objective for the study herein reported was to establish remaining insulation system life of an endurance tested SNAP-8 alternator stator (Stator No. 2) using an increasing step-temperature aging test procedure. The objective was achieved, resulting in data to predict additional life for a select operating temperature.

An alternate means for insulation life prediction is to establish the end-life of a system for at least each of three accelerated aging temperatures. An Arrhenius plot of these data would provide sufficient data to more precisely predict life-temperature combinations for design and application use. Such data would also provide supporting data and establish confidence for conclusions reported herein.

It is recommended that these additional data be obtained from tests on Stator No. 1, the stator from the alternator subjected to 23,130 hours of turbo-alternator endurance tests. It is further recommended the stator be divided into six armature coil-core sections and each section be subjected to select accelerated temperatures with dielectric tests applied to the coils to achieve end-life and an Arrhenius plot.

From these data, performance and end-life could be predicted for the type insulation system used in the SNAP-8 alternator design.

TABLE I -- SNAP-8 ALTERNATOR RATING AND PERFORMANCE CHARACTERISTICS

General Electric Model: 2CM391B1
Design Specification: Aerojet General Corp. AGC-10175A (31 March 1965) Under NASA Contract NAS5-417
Rating: 80 kVA, 0.75 P.F., 120/208 Volts, 400 Hz, 3 Phase -- 3 Wire, 12000 RPM

Electrical Characteristics:

Wave form, total rms harmonic content, Line-to-line at 1.0 P.F.	2.33%
Efficiency, 80 kVA, 0.75 P.F.	87.5%
Excitation, 80 kVA, 0.75 P.F.	43.3 Volts, 19.6 Amps
Winding symmetry, voltage difference between phases	<1 Volt

Mechanical Characteristics:

Cooling oil	Polyphenyl ether
Oil inlet temperature	96°C
Oil outlet temperature	110°C
Oil inlet pressure	21.9 psia (15.1×10^4 N/M^2)
Oil outlet pressure	8.3 psia (57.2×10^3 N/M^2)
Oil flow	2.84 gpm (1.79×10^{-4} m^3/sec.)

Thermal Characteristics (Rated Load):

Armature end turn winding temperature, hot spot	186°C
Armature bus bar end turn temperature, hot spot	208°C
Field winding temperature, hot spot	162°C

Weight:

Structural	235 Pounds
Electromagnetic	211 Pounds
Total	446 Pounds

Envelope, Max.

Length	21.7"
Diameter, frame	12.2"
Diameter, Over Terminals	16.8"

Design Life: 10,000 hours (3.6×10^6 seconds) continuous, unattended operation at rated load.

Design Environment:

Cavity pressure	0.05 mm Hg (6.66 N/M^2)
Radiation level	5×10^{13} nvt fast neutrons and 10^7 rads (10^5 J/Kg) gamma total dosage.

Sheet No. 1 of 2

TABLE II - ALTERNATOR INSULATIONS AND CONDUCTOR MATERIALS--ARMATURE

Component	MATERIAL DESCRIPTION Size	Composition	General Electric Co. Designation*	SOURCE Commercial Source	Mfg's Designation
1. Slot insulation	.0105"	Aromatic polyimide impregnated and coated glass cloth	A22L16A5	EI DuPont Co., Fairfield, Conn.	#6508-0105
2. Conductor	.125" x .212"	Heavy coated aromatic polyimide insulated rect OFHC copper	B50WB310E	General Electric Co., SAC-Wire Section Schenectady, N. Y.	"HML"
3. Slot phase insulation	.016"	Silicone-glass laminate	A19B22A1	General Electric Co., Coshocton, Ohio	#11556 "Textolite"
4. Insulation end punchings	.020" 3 per end	Silicone-glass laminate	A19B22A1	General Electric Co., Coshocton, Ohio	#11556 "Textolite"
5. Top-sticks	36A227152 .032" thick	Aromatic polyimide	A50WB381A	EI DuPont Co., Wilmington, Delaware	"Vespel"
6. Coil side end turn phase insulation	#3 AWG	Heat cleaned fiber glass sleeving	A50WB304A	Bentley Harris Mfg. Co., Conshohocken, Pa.	"BH Special Treated"
7. Coil top-to-bottom end turn phase insulation	.0105"	Aromatic polyimide impregnated and coated glass cloth	A22L16A5	EI DuPont Co., Fairfield, Conn.	#6508-0105
8. Lead cable - power leads	#8 AWG (3 per phase)	Glass braid, reinforced mica insulated OFHC	B50WB317A8	Rockbestos Wire & Cable Co., New Haven, Conn.	"Mica-Temp"
9. Lead and phase joint insulation	.0065" (3 layers)	Pressure sensitive thermosetting silicone adhesive coated glass cloth tape	A23B5A3	Minnesota Mining and Mfg. Co., Irvington Div.	"Scotch" #69
	Plus - .005" (3 layers)	Heat cleaned fiber glass woven tape	A50WB374A	Hess, Goldsmith & Co., New York, N. Y.	

TABLE II - ALTERNATOR INSULATIONS AND CONDUCTOR MATERIALS--ARMATURE

Component	MATERIAL DESCRIPTION			SOURCE	
	Size	Composition	General Electric Co. Designation	Commercial Source	Mfg's Designation
10. Inter-coil joint insulation	3/8" dia.	Heat cleaned fiber glass sleeving	A50WB304A	Bentley Harris Mfg. Co., Conshohocken, Pa.	"BH Special Treated"
	Plus - Compound	Black, filled thixotropic epoxy Novolac resin compound	A50WB364A	General Electric Co., DCM&G Dept., Erie, Pa.	
11. Winding impregnation	Compound	Thin, clear, unfilled epoxy Novolac resin compound	A50WB363A	General Electric Co., DCM&G Dept., Erie, Pa.	
12. Insulation end punching cement	Compound	Thin, clear, unfilled epoxy Novolac resin compound	A50WB365A	General Electric Co., DCM&G Dept., Erie, Pa.	
13. Fill between stator core sections	Compound	Black, filled thixotropic epoxy Novolac resin compound	A50WB364A	General Electric Co., DCM&G Dept., Erie Pa.	
14. Reinforcement to item #13	.007"	Leno weave, heat cleaned glass cloth tape (3 layers)	A22L14A	Columbia Electric Tape & Mfg. Co. - Philadelphia, Pa.	
15. Bus conductors	.080 x .500	Heavy coated aromatic polyimide insulated rect. OFHC copper	B50WB310E	General Electric Co., SAC Wire Section Schenectady, New York	"HML"
16. Bus insulation	.0105"	Aromatic polyimide impregnated and coated glass cloth	A22L16A5	EI DuPont Co., Fairfield, Conn.	6508-0105
	Plus - .005" (3 layers)	Heat cleaned fiber glass tape	A50WB374A	Hess, Goldsmith & Co.	
17. Lead cable - phase equalizer leads	#12 AWG (one per phase)	Glass braid, reinforced mica insulated OFHC copper stranded cable	B50WB317A12	Rockbestos Wire & Cable Co., New Haven Conn.	"Mica-Temp"

* Revised from designations shown in Report, Reference 1.

TABLE III - ALTERNATOR INSULATIONS AND CONDUCTOR MATERIALS--FIELD

Component	MATERIAL DESCRIPTION			SOURCE	
	Size	Composition	General Electric Co. Designation*	Commercial Source	Mfg's Designation
1. Coil Box Bottom	0055"	Aromatic polyimide impregnated and coated fiber glass cloth	A22L16A2	EI DuPont Co., Fairfield, Conn.	#6507-0055
2. Box corner fill	.026" dia.	Untreated glass cord	A4L1B2	Owens-Corning Fiberglass Corporation	EC9-20
3. Box side lead Insulation		Silicone-glass Laminate	A19B22A1	General Electric Co. Coshocton, Ohio	#11556 Textolite
	Plus - #13 AWG	Aromatic polyimide coated fiber glass sleeving	A50CD307A	Bentley Harris Mfg. Co., Conshohocken, Pa.	"Ben Har 963 ML"
	Plus - #9 AWG	Aromatic polyimide coated fiber glass	A50CD307A	Bentley Harris Mfg. Co., Conshohocken, Pa.	"Ben Ha 963 ML"
4. Conductor	0720" dia.	Heavy coated aromatic polyimide insulated round OFHC copper	B50WB312E	General Electric Co., SAC Wire Section Schenectady, New York	HML
5. Coil box liner cement	Compound	Thin, clear, unfilled epoxy Novolac resin compound	A50WB363A	General Electric Co., DCM&G Dept., Erie, Pa.	
6. Conductor bond	Compound	Black, filled thixotropic epoxy Novolac resin compound	A50WB364A	General Electric Co., DCM&G Dept., Erie, Pa.	
7. Insulation between coil O.D. and copper band	.0055" (2 layers)	Aromatic polyimide impregnated and coated fiber glass cloth	A22L16A2	EI DuPont Co., Fairfield, Conn.	#6507-0055
8. Lead cable - power lead	#12 AWG	Glass braid, reinforced mica insulated OFHC copper stranded cable	B50WB317A12	Rockbestos Wire & Cable Co., New Haven, Conn.	"Mica-Temp"

* Revised from designations shown in Report, Reference 1.

TABLE IV - INITIAL MEASUREMENTS
WINDING RESISTANCE, INSULATION RESISTANCE & DC LEAKAGE

Stator No. 1, S/N 481490

Test Component Position, Measurement	Insulation Resistance, Ohms (Megger @ 500 V dc)	DC Leakage, micro-amperes				
		Volts, dc				
		200	400	600	800	1000
Field Winding, F1 to Frame	∞	*	*	*	*	*
Armature Winding, T4 to Frame	∞	*	*	*	*	*
Armature to Field Windings, T4 to F1	∞	*	*	*	*	*
Field Resistance @ 23°C = 1.542 Ohms						

Stator No. 2, S/N 481489

Field Winding, F1 to Frame	∞	*	*	*	*	*
Armature Winding, T4 to Frame	∞	*	*	*	*	*
Armature to Field Windings, T4 to F1	∞	*	*	*	*	*
Field Resistance @ 23°C = 1.536 Ohms						

* No leakage could be detected.

TABLE V - THERMAL STABILIZATION
WINDING RESISTANCE & INSULATION RESISTANCE

Stator No. 1, S/N 481490

Test Component Position, Measurement	Hours @ 250°C				Hours @ 200°C				@ Room Temperature @ Completion of Test
	24	48	72	87	6	24	48	72	
Field Resistance, Ohms	2.852	2.901	*	3.101	2.682	2.661	2.716	2.657	1.531
Insulation Resistance, Ohms									
Field Winding, F1 to Frame	10×10^4	50×10^3	*	75×10^3	800×10^3	750×10^3	725×10^3	600×10^3	
Armature Winding, T4 to Frame	2 M	1.7 M	*	3.5 M	150 M	150 M	150 M	175 M	
Armature to Field Windings, T4 to F1	1.6 M	1.7 M	*	3.7 M	100 M	100 M	135 M	175 M	

Stator No. 2, S/N 481489

Field Resistance, Ohms	2.794	2.793	*	2.823	2.798	2.619	2.592	2.651	1.542
Insulation Resistance, Ohms									
Field Winding, F1 to Frame	50×10^3	40×10^3	*	100×10^3	1.2 M	1.5 M	1.0 M	1.0 M	
Armature Winding, T4 to Frame	1.8 M	1.6 M	*	2.5 M	150 M	150 M	150 M	150 M	
Armature to Field Windings, T4 to F1	1.5 M	1.5 M	*	3.0 M	100 M	125 M	150 M	150 M	

* Tests terminated - molten solder observed.

TABLE VI - THERMAL STABILIZATION -- LEAKAGE CURRENT AT 250°C

Stator No. 1, S/N 481490

Test Component Position, Measurement	Hours at Temperature	DC Leakage, micro-amperes				
		Volts, dc				
		200	400	600	800	1000
Field Winding, F1 to Frame	24	0	0	0	0	0
	48	F	-	-	-	-
	72	*	-	-	-	-
	Stator cleaned and stabilization at 250°C for 15 hours.					
	87	F	-	-	-	-
Armature Winding, T4 to Frame	24	0	0	0	0	0
	48	0	0	0	0	0
	72	*	-	-	-	-
	Stator cleaned and stabilization at 250°C for 15 hours.					
	87	15	40	65	85	100
Armature to Field Windings, T4 to F1	24	0	0	0	0	0
	48	0	0	0	0	0
	72	*	-	-	-	-
	Stator cleaned and stabilization at 250°C for 15 hours.					
	87	15	40	65	85	100

Stator No. 2, S/N 481489

Test Component Position, Measurement	Hours at Temperature	200	400	600	800	1000
Field Winding, F1 to Frame	24	0	0	0	0	0
	48	F	-	-	-	-
	72	*	-	-	-	-
	Stator cleaned and stabilization at 250°C for 15 hours.					
	87	F	-	-	-	-
Armature Winding, T4 to Frame	24	0	0	0	0	0
	48	0	0	0	0	0
	72	*	-	-	-	-
	Stator cleaned and stabilization at 250°C for 15 hours.					
	87	15	35	50	65	80
Armature to Field Windings, T4 to F1	24	0	0	0	0	0
	48	0	0	0	0	0
	72	*	-	-	-	-
	Stator cleaned and stabilization at 250°C for 15 hours.					
	87	10	20	40	50	55

*Tests terminated - observed molten solder.

F = Failure, leakage current in excess of 2,000 micro-amperes.

TABLE VII - THERMAL STABILIZATION -- LEAKAGE CURRENT AT 200°C

Stator No. 1, S/N 481490

Test Component Position, Measurement	Hours at Temperature	DC Leakage, micro-amperes				
		Volts, dc				
		200	400	600	800	1000
Field Winding, F1 to Frame	6	350	600	800	950	1100
	24	400	450	750	900	1250
	48	375	450	600	750	1100
	72	400	500	650	800	950
Armature Winding, T4 to Frame	6	15	25	35	60	65
	24	4.5	8	15	35	35
	48	3.5	6	7.5	12	12.5
	72	3.0	4.5	8.5	12	13
Armature Field Windings, T4 to F1	6	9	25	70	75	80
	24	1.5	6	6.5	7	7
	48	1.5	4.5	8	8.5	9
	72	1.5	4.5	9	11	13

Stator No. 2, S/N 481489

Field Winding, F1 to Frame	6	750	800	850	1100	1700
	24	200	350	400	500	550
	48	200	250	450	575	600
	72	175	250	400	550	575
Armature Winding, T4 to Frame	6	10	25	30	35	40
	24	2	10	25	30	30
	48	1.5	3	6.5	9	15
	72	1.5	8.5	9.0	12	13
Armature Field Windings, T4 to F1	6	9	15	25	35	40
	24	5	5	10	15	20
	48	8	8.5	9.5	15	25
	72	6	8.5	11	12	15

TABLE VIII - CORONA ONSET VOLTAGE AT TEMPERATURE AND SIMULATED ALTITUDE

Stator No. 1, S/N 481490

Test Component Position, Measurement	Corona Onset Voltage, Volts AC RMS		
	Initial, As Received @23°C and 732 ft (0.22 Km)	At 250°C Simulated Altitude of 100,000 ft (30.5 Km) or 8 Torr	At 250°C (Repeat Test) Simulated Altitude of 100,000 ft. (30.5 Km) or 8 Torr
Field Winding, F1 to Frame	No corona @ 700 *	400	400
Armature Winding, T4 to Frame	No corona @ 700 *	500	450
Armature to Field Windings, T4 to F1	No corona @ 700 *	500	500
Stator No. 2, S/N 481489			
Field Winding, F1 to Frame	No corona @ 700 *	<200	< 200
Armature Winding, T4 to Frame	No corona @ 700 *	300	300
Armature to Field Windings, T4 to F1	No corona @ 700 *	300	300

* To prevent possible damage to the stator, a 700-Volt AC maximum limitation was set on measurements.

TABLE IX - CORONA ONSET VOLTAGE AFTER HUMIDITY EXPOSURE

Test Component Position, Measurement	Corona Onset Voltage, Volts, AC RMS			
	Initial, As Received at 23°C		Dry at 23°C After 56 Hours @ 100% Relative Humidity	
	Stator No. 1, S/N 481490	Stator No. 2, S/N 481489	Stator No. 1, S/N 481490	Stator No. 2, S/N 481489
Field Winding, F1 to Frame	No corona @ 700 *	No corona @ 700 *	No corona @ 700 *	No corona @ 700 *
Armature Winding, T4 to Frame	No corona @ 700 *	No corona @ 700 *	No corona @ 700 *	No corona @ 700 *
Armature to Field Windings, T4 to F1	No corona @ 700 *	No corona @ 700 *	No corona @ 700 *	No corona @ 700 *

* To prevent possible damage to the stators, a 700-Volt AC maximum limitation was set on measurements.

TABLE X - INSULATION RESISTANCE & DC LEAKAGE CURRENT AFTER HUMIDITY EXPOSURE

Stator No. 1, S/N 481490

Test Component Position, Measurement	Values @ Room Temperature After 56 Hours @ 100% Relative Humidity and 23°C					
	Insulation Resistance, Ohms (Megger @ 500 V DC)	DC Leakage, micro-amperes				
		Volts, dc				
		200	400	600	800	1000
Field Winding, F1 to Frame	400 x 10^3	750	1600	F		
Armature Winding, T4 to Frame	10 x 10^3	850	1650	F		
Armature to Field Windings, T4 to F1	400 x 10^3	600	750	1800	1950	F

Stator No. 2, S/N 481489

Test Component Position, Measurement	Insulation Resistance, Ohms (Megger @ 500 V DC)	200	400	600	800	1000
Field Winding, F1 to Frame	100 x 10^3	F				
Armature Winding, T4 to Frame	45 x 10^3	1900 µa	F			
Armature to Field Windings, T4 to F1	50 x 10^3	750 µa	F			

Stator No. 1 Field resistance after exposure = 1.541 ohms @ 24°C.
Stator No. 2 Field resistance after exposure = 1.529 ohms @ 24°C.

F = Failure, leakage current in excess of 2,000 micro-amperes.

TABLE XI - ACCELERATED AGING

INSULATION PROPERTIES - WINDING RESISTANCE, PROOF SURGE AND INSULATION RESISTANCE

Stator No. 2, S/N 481489

Measurement	Test Component Position	Measured Values											
		Cumulative Hours:	0	48	96	144	192	240	288	336	384	432	
		Hour Interval in 48-hour Aging Cycle	Room Temp at Start of Test	200°C	225°C	250°C	275°C	300°C	325°C	350°C	375°C	400°C	Room Temp at Completion of Test
Conductor Resistance, Ohms	Field Winding, F1 to F2	17	1.63	2.634	2.760	2.912	3.050	3.189	3.498	3.561	-	-	1.721
		20		2.615	2.822	2.935	3.046	3.190	3.499	-	-	-	
		24		2.631	2.762	2.938	3.040	3.206	3.495	3.570	3.812	3.953	
		40		2.623	-	2.934	-	3.189	-	3.572	-	3.951	
		48		2.633	2.761	2.936	3.039	3.189	3.496	3.562	3.796	3.952	
Insulation Resistance @ 500 V DC, Ohms	Field Winding, F1 to Frame	17	∞	1M	200×10^3	50×10^3	100×10^3	100×10^3	50×10^3	100×10^3	-	-	50M
		20		1M	200×10^3	50×10^3	125×10^3	100×10^3	75×10^3	-	-	-	
		24		1M	200×10^3	45×10^3	135×10^3	100×10^3	120×10^3	125×10^3	50×10^3	10×10^3	
		40		1M	-	50×10^3	-	125×10^3	-	150×10^3	-	-	
		48		800×10^3	185×10^3	45×10^3	150×10^3	135×10^3	125×10^3	125×10^3	45×10^3	10×10^3	
	Field Winding, F1 to Arm. Conductors (C1-2-3-4-5)	17	∞	∞	∞	200M	200M	100×10^3	2M	1M	-	125×10^3	60M
		20		∞	∞	200M	200M	100×10^3	175×10^3	-	-	-	
		24		∞	250M	200M	10M	100×10^3	175×10^3	900×10^3	200×10^3	25×10^3	
		40		∞	-	200M	-	8M	-	700×10^3	-	25×10^3	
		48		∞	200M	200M	200×10^3	20M	175×10^3	500×10^3	150×10^3	25×10^3	
Repetitive Proof Surge @ 500 V AC, Peak Volts	Field Winding F1 to F2	48	Passed*	Passed*	Passed*	Passed*	Passed*	Passed*	Passed*	Passed*	Passed*	Passed*	Passed*

* No change from start-of-test wave form.

Sheet 1 of 4

TABLE XII - ACCELERATED AGING
DC LEAKAGE CURRENT

Stator No. 2, S/N 481489

Test Component Position, Measurement	Interval in 48-hr. Aging Cycle	DC Leakage, micro-amperes																													
		Initial, Room Temperature					200°C					225°C					250°C					275°C					300°C				
		0 Hours					Cumulative Hours: 48					Cumulative Hours: 96					Cumulative Hours: 144					Cumulative Hours: 192					Cumulative Hours: 240				
		Volts, dc					Volts, dc					Volts, dc					Volts, dc					Volts, dc					Volts, dc				
		200	400	600	800	1000	200	400	600	800	1000	200	400	600	800	1000	200	400	600	800	1000	200	400	600	800	1000	200	400	600	800	1000
Field Winding, F1 to Frame	0	No Leakage																													
	17						80	180	350	500	550	450	940	1350	1750	F	F					F					F				
	20						90	195	360	520	650	550	1100	1350	F		F					F					1850	F			
	24						120	450	580	850	1100	1050	1300	1700	F		F					1600	F				1650	F			
	40						250	300	450	575	700	-	-	-	-	-	F					-					1500	F			
	48						220	350	475	600	850	1000	1500	F			F					1400	F				1850	F			
Armature Coils Tied in Group (C1-2-3-4-5) To Frame	0	No Leakage																													
	17						0	0	0	0	0.5	0	0	0.75	1.0	1.5	0	0	0	0	0.5	15	135	F			F				
	20						0	0	0	0	0.75	0	0	0.5	0.75	1.75	0	0	0	0	0.5	140	225	F			F				
	24						0	0	0	0.75	1.0	0	0	0.25	0.5	1.5	0	0	0	0	0.75	135	F				25	75	F		
	40						0	0	0	0	0.75	-	-	-	-	-	0	0	0	0.5	0.75	-					16	65	150	F	
	48						0	0	0	0	0.5	1.0	2.5	4.5	5.0	6.5	0	0	0	0.5	1	120	.180	F			50	75	125	F	
Armature Coil C2 to Frame*	17	No Leakage					No Leakage					No Leakage					No Leakage					250	1350	F			F				
	20																					-					F				
	24																					175	1650	1800	F		F				
	40																					-									
	48																					1300	1800	F			F				
Armature Coil-to-Coil C1-C2 C1-C3 C1-C4 C1-C5 C2-C3 C2-C4 C2-C5 C3-C4 C3-C5 C4-C5	0 24 40 48	No Leakage					No Leakage					No Leakage					No Leakage					No Leakage					No Leakage				

* As leakage in the tied group became appreciable, individual coils were tested.

F = Failure, leakage current in excess of 2,000 micro-amperes.

TABLE XII - ACCELERATED AGING
DC LEAKAGE CURRENT

Sheet 2 of 4

Test Component Position, Measurement		Interval in 48-hr. Aging Cycle	DC Leakage, micro-amperes																			
			325°C					350°C					375°C					400°C				
			Cumulative Hours: 288					Cumulative Hours: 336					Cumulative Hours: 384					Cumulative Hours: 432				
			Volts, dc					Volts, dc					Volts, dc					Volts, dc				
			200	400	600	800	1000	200	400	600	800	1000	200	400	600	800	1000	200	400	600	800	1000
Field Winding, F1 to Frame		17	F					F					-									
		24	1250	F				1850	F	F			1800	F				F				
		40	-					F					-					F				
		48	1350	F				1500	F	F			1600	F				F				
Armature Coils to Frame	C1	17	65	125	185	300	350	120	180	320	450	520	No Measurements					No Measurements				
	C2		15	50	150	F		40	1750	1750												
	C3		1	3.5	6	9	12	12	18	90	F											
	C4		0.5	1	4	6.5	10	6	10	12	15											
	C5		2.5	5	7.5	9.5	16	16	400	F												
	C1	24	65	85	135	185	185	60	185	350	700	1350	250	F				F				
	C2		15	55	165	F		65	1200	F			1650	F				F				
	C3		2	3.5	6	11	12	8	35	85	F		1275	F				F				
	C4		1.5	2.5	3	4.5	7	3	25	30	80	F	1600	F				F				
	C5		1	6	11	13	15	185	250	F			1100	F				F				
	C1	40	No Measurements					90	160	300	425	F	No Measurements									
	C2							50	F													
	C3							9	40	95	F											
	C4							2	6	12	65	F						F				
	C5							225	650	F												
	C1	48	50	75	135	175	185	165	250	500	1800	F	1375	F				F				
	C2		25	75	185	F		320	F				1800	F				F				
	C3		1.5	4	8	12	15	120	425	F			1600	F				F				
	C4		0.25	0.75	3.5	6	8	250	800	1650	1800	F	1675	F				F				
	C5		0.5	7.5	12	12	16	600	F				1300	F				F				

F = Failure, leakage current in excess of 2,000 micro-amperes.

TABLE XII - ACCELERATED AGING
DC LEAKAGE CURRENT

Test Component Position, Measurement		Interval in 48-hr. Aging Cycle	DC Leakage, micro-amperes																			
			325°C					350°C					375°C					400°C				
			Cumulative Hours: 288					Cumulative Hours: 336					Cumulative Hours: 384					Cumulative Hours: 432				
			Volts, dc					Volts, dc					Volts, dc					Volts, dc				
			200	400	600	800	1000	200	400	600	800	1000	200	400	600	800	1000	200	400	600	800	1000
Armature Coil-to-Coil	C1-C2	17	6	16	50	105	135	20	50	90	130	1800	No Measurements					No Measurements				
	C1-C3		2	4.5	6	9	12	10	15	25	65	125										
	C1-C4		1	2.5	3.5	5	7	1.5	6	10	15	18										
	C1-C5		1.5	3	5	7.5	11	20	35	40	125	250										
	C2-C3		1	3	4.5	6.5	8	6.5	12.5	25	60	85										
	C2-C4		0.5	1.5	2.5	3.5	5	1.5	3	6.5	10	12										
	C2-C5		1.5	2.5	4	5	7.5	25	40	115	135	165										
	C3-C4		0.5	1	1.5	2.5	3	0	0	0.5	1.75	6.5										
	C3-C5		0.75	1.5	2.5	3.5	4.5	0.5	1.5	18	65	90										
	C4-C5		0.5	1	1.5	1.75	2.5	2	5.5	12	15	45										
	C1-C2	24	7.5	15	85	110	135	30	65	85	125	185	275	F				F				
	C1-C3		2	4	9.5	15	20	20	23	40	65	95	300	750	1850	F		F				
	C1-C4		1	4	6	9.5	13	1.5	3.5	6	10.5	20	250	600	F			F				
	C1-C5		1	3	4.5	13	18	15	25	40	165	285	300	F				F				
	C2-C3		1	3.5	8	12	14	5.5	15	35	65	85	F					F				
	C2-C4		0.75	1	4	6	7.5	1.5	3	5.5	11	15	F					F				
	C2-C5		1	2.5	4.5	8	10	20	35	65	85	185	F					F				
	C3-C4		1	1.75	3	4.5	5.5	1.5	2.5	5	8.5	165	F					F				
	C3-C5		1.5	1.75	4	4.5	5	6.5	12	16	25	75	F					F				
	C4-C5		1	1.5	2.5	3.5	4	2.5	15	40	55	60	F					F				
	C1-C2	40	No Measurements					35	65	110	165	250	275	F								
	C1-C3							20	35	60	75	105	300	750	1850	F		F				
	C1-C4							3	5	9	15	35	250	600	F			F				
	C1-C5							35	70	140	350	750	300	F				F				
	C2-C3							7	16	40	65	95	F					F				
	C2-C4							2	4.5	7	12	16	F					F				
	C2-C5							35	75	130	350	500	F					F				
	C3-C4							2	3.5	6	9	F	F					F				
	C3-C5							10	18	60	120	185	F					F				
	C4-C5							3	5	13	35	60	F					F				
	C1-C2	48	8.5	17	65	115	150	65	90	145	375	480	375	F				F				
	C1-C3		1.5	6	8.5	15	20	40	120	350	425	550	350	800	1900	F		F				
	C1-C4		1.0	3	4.5	8	12	4	8.5	125	165	250	300	800	F			F				
	C1-C5		3	4.5	8	12	15	75	120	195	400	F	375	F				F				
	C2-C3		2	4	5.5	8	12	25	85	160	195	350	F					F				
	C2-C4		0.5	1.5	3	4.5	8	6	9	15	65	80	F					F				
	C2-C5		0.5	1.75	4	5.5	8	120	95	225	450	575	F					F				
	C3-C4		0.5	1.5	2	3.5	6	6	25	50	550	F	F					F				
	C3-C5		1	2.5	3	4	6	25	80	165	320	375	F					F				
	C4-C5		1.5	2	3.5	2.5	4	20	65	125	350	700	F					F				

F = Failure, leakage current in excess of 2,000 micro-amperes.

Sheet 4 of 4

TABLE XII - ACCELERATED AGING
DC LEAKAGE CURRENT

Stator No. 2, S/N 481489

Test Component Position		At Room Temperature After Completion of Test				
		DC Leakage, micro-amperes				
		Volts, dc				
		200	400	600	800	1000
Field Winding, F1 to Frame		4.0	7.5	12.5	25	30
Armature Coils to Frame	C1	F				
	C2	F				
	C3	F				
	C4	1650	1800	F		
	C5	F				
Armature Coil-to-Coil	C1-C2	9	45	F		
	C1-C3	275	F			
	C1-C4	350	F			
	C1-C5	25	F			
	C2-C3	F				
	C2-C4	F				
	C2-C5	F				
	C3-C4	F				
	C3-C5	F				
	C4-C5	F				

F = Failure, leakage current in excess of 2,000 micro-amperes.

TABLE XIII - ACCELERATED AGING
ARMATURE COIL DIELECTRIC BREAKDOWN DATA

Stator No. 2, S/N 481489

Test Component Position, Measurement	Circuit or Coil No. *	Dielectric Breakdown @ Room Temperature, Volts dc									
		Room Temp.	200°C	225°C	250°C	275°C	300°C	325°C	350°C	375°C	400°C
		0 Hrs.	48 Hrs	96 Hrs	144 Hrs	192 Hrs	240 Hrs	288 Hrs	336 Hrs	384 Hrs	432 Hrs
Armature Coils to Frame	C1	8 000	6 500	6 900	6 800	6 000	5 000	4 400	2 500	850	250
	C2	11 000	5 800	8 200	7 000	5 500	5 500	3 600	1 800	1 100	350
	C3	8 000	6 000	8 000	8 600	6 000	4 800	4 600	3 500	1 350	<150
	C4	7 700	6 100	7 600	6 000	6 000	5 000	6 000	2 700	1 400	200
	C5	9 000	6 200	8 800	7 000	5 800	5 000	3 500	3 200	1 300	375
	Avg.	8 740	6 120	7 900	7 080	5 860	5 060	4 420	2 740	1 200	265

* C1-2-3-4-5 = separate armature coils or group identity.

After each breakdown completing a cycle, a new set of five armature coils was numbered (C1-2-3-4-5).

TABLE XIV. Life Data on ML Insulated Magnet Wire

The temperature increment "Δ" in °C which would produce a halving of life if the exposure temperature were raised, or a doubling of life expectancy if the exposure temperature were lowered, may be shown by the following algebraic expression:

$$\frac{L_{T_1}}{L_{T_2}} = 2^x$$

$$\text{Where } x = \left[\frac{T_2 - T_1}{\Delta}\right]$$

L_{T_1} = Life expectancy at Temperature 1

L_{T_2} = Life expectancy at Temperature 2

T_1 = Temperature 1

T_2 = Temperature 2

Δ = Temperature increment which changes life factor of 2

The above algebraic expression was used to calculate the Data Source time-to-failure (life) vs. temperature, as follows:

Data Source	Ref Fig. No.	Calculated Δ
IEEE-32C79-63	9	11.6
"	10	11.2
"	11	11.1
"	12	11.5
"	13	11.6
"	14	11.2
"	15	12.1
"	16	11.7
Naval. Res. Lab	1	12.4
"	4	12.0
IEEE-32C79-67	1	13.8
"	2	13.5
"	3	12.9
"	4	10.8
"	5	13.5
"	6	12.3
"	8	14.3
	AVERAGE	12.2

TABLE XV. Test Instrumentation

Test Parameter	Instrument Description
1. Resistance Measurements	Wheatstone Bridge Leeds & Northrup Co. Test Set Mfg S/N 5300
2. Insulation Resistance	Megger Insulation Tester James Biddle Co. Mfg Type No. 500 V dc
3. D. C. Leakage Current	Takk D. C. Leakage Tester Takk Corp., Newark, Ohio Model 86 Ser. 111
4. Corona Detector	G. E. High Voltage Pwr Supply Cat. 153X238. Ser. No. D938553 coupled with an Addison Discharge Scope Detector, Type AC2 Ser. 5651 Addison Electric, London
5. Continuity Measurements	Simpson V-O-M Simpson Electric Co. Chicago, Ill. Model 260
6. Surge Tests	General Electric Pwr Supply coupled with a T186 Textronic Scope
7. Vibration Monitor	Columbia Charge Amplifier Columbia Research Labs Woodlyn, Penna.

All instrumentation was calibrated prior to initiation of tests in accordance with MIL-C-45662.

TABLE XVI. Test Equipment

Function	Equipment Description
1. Humidity Conditioning	Tenney Environmental Chamber Tenney Engineering, Union, N. J. Model 18TR-10025 Ser. 2517
2. Attitude & Corona	Air Research Environmental Chamber
3. Heat Aging	Despatch High Velocity Oven Despatch Oven Co. Minneapolis, Minn. Model V-31SD Ser. 76138
4. Vibration Simulator	MB Vibration Exciter MB Electric Co. New Haven, Conn. Model C25H & C10
Test equipment was calibrated prior to and at termination of tests in accordance with MIL-C-45662.	

TABLE XVII. Field Coil Resistance as a Function of Aging Temperature

Aging Temperature, T_2 - °C	Resistance, R_2 - ohms	Calculated Temperature, T_2 - °C*
200	2.627	---
225	2.776	224.6
250	2.932	250.4
275	3.044	269.0
300	3.193	294.0
325	3.479	343.9
350	3.566	355.3
375	3.804	394.7
400	3.952	419.0
RT_{start}	1.63	
RT_{end}	1.721	

$$* \; T_2 = \frac{R_2}{R_1}(T_1 + 234.5) - 234.5 = \frac{R_2}{2.627}(434.5) - 234.5$$

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FIGURE 1. Cross Section View, Alternator Components and Insulations

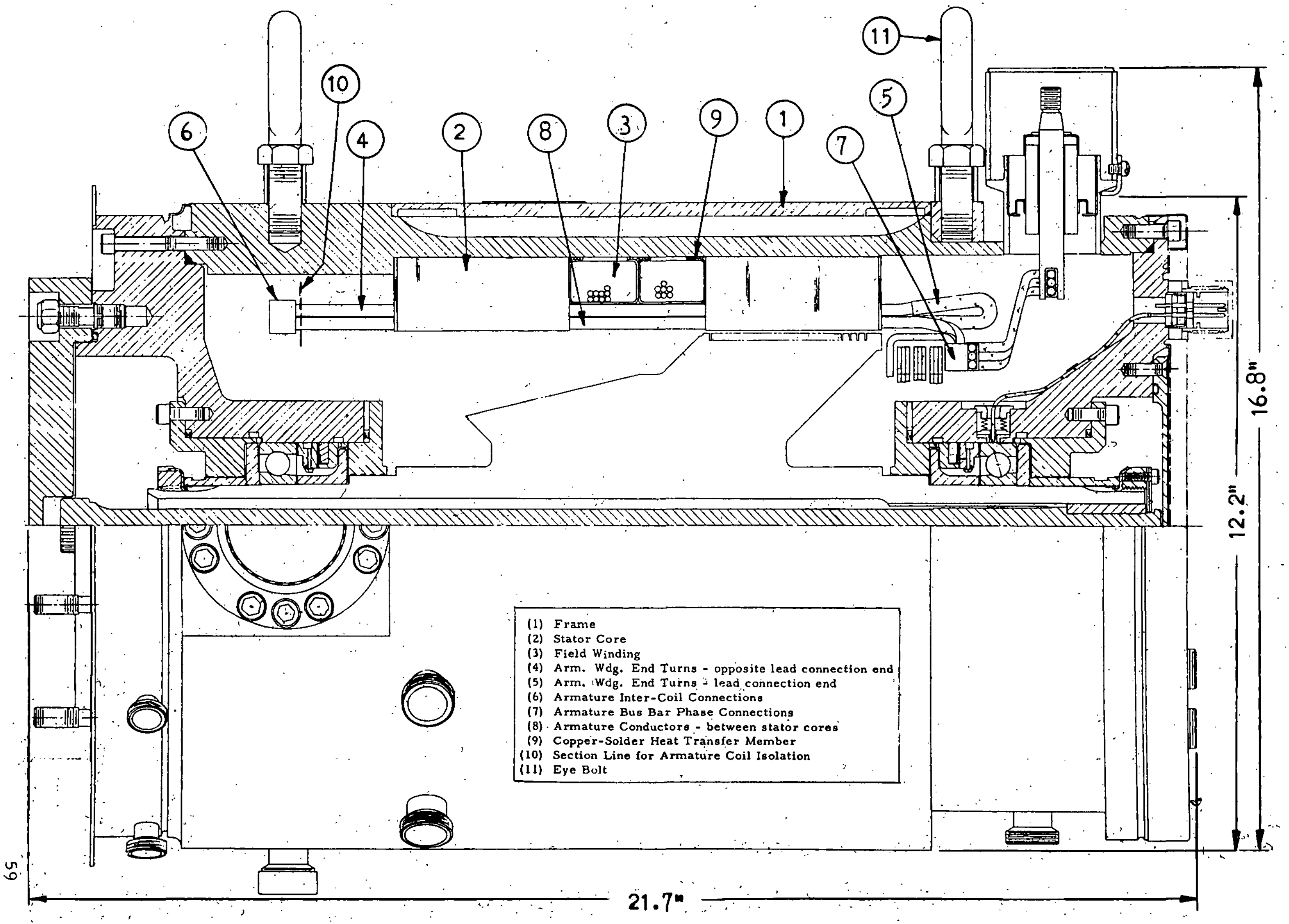
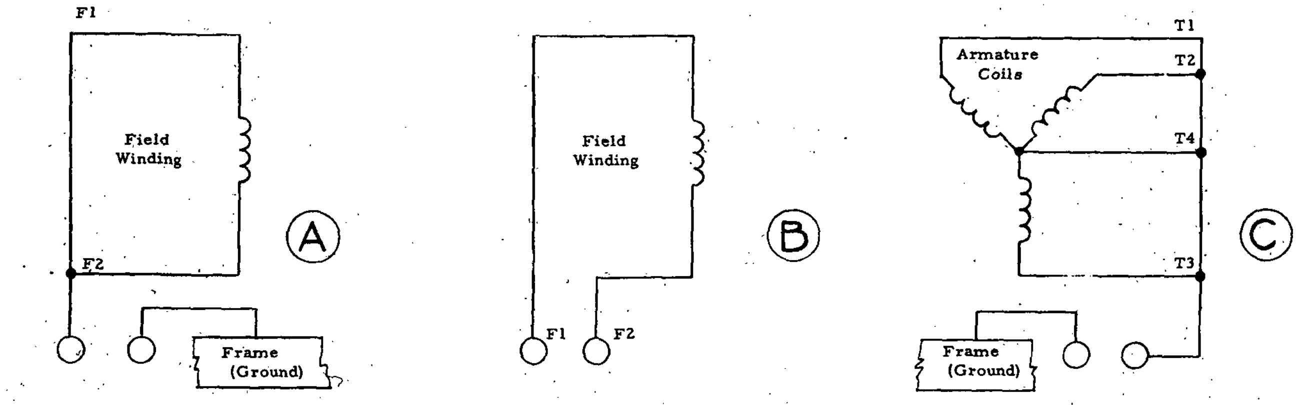


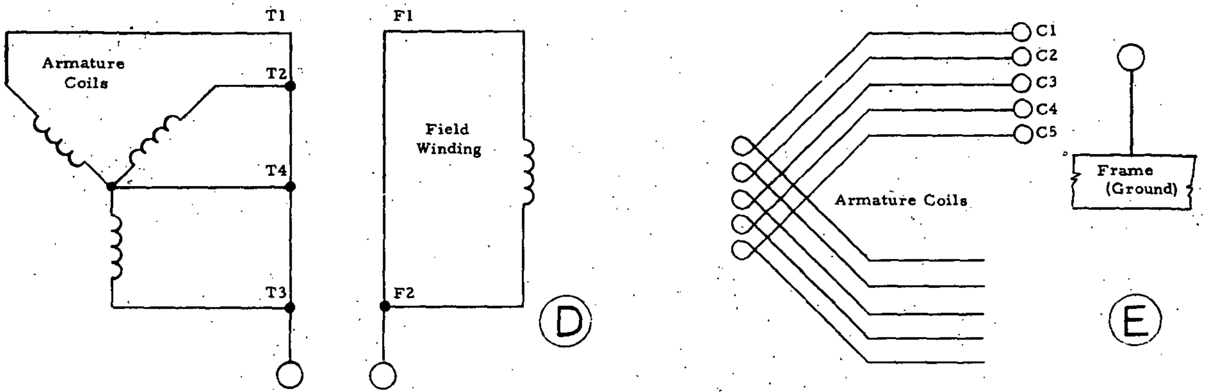
FIGURE 2. Schematic Diagrams



Typical Connection For
Field Winding to Frame Measurements

Typical F1 to F2 Measurements

Typical Armature Winding To
Frame (Ground) Connections



Armature Winding To
Field Winding Measurements

Typical Armature Coil to Frame
(Ground) Test Connections

Measurement	Schematic
Conductor Resistance	B
DC Leakage Current	A, C, D, E
Insulation Resistance	A, C, D
Dielectric Breakdown	E
Surge Test	B
Corona Onset	A, C, D

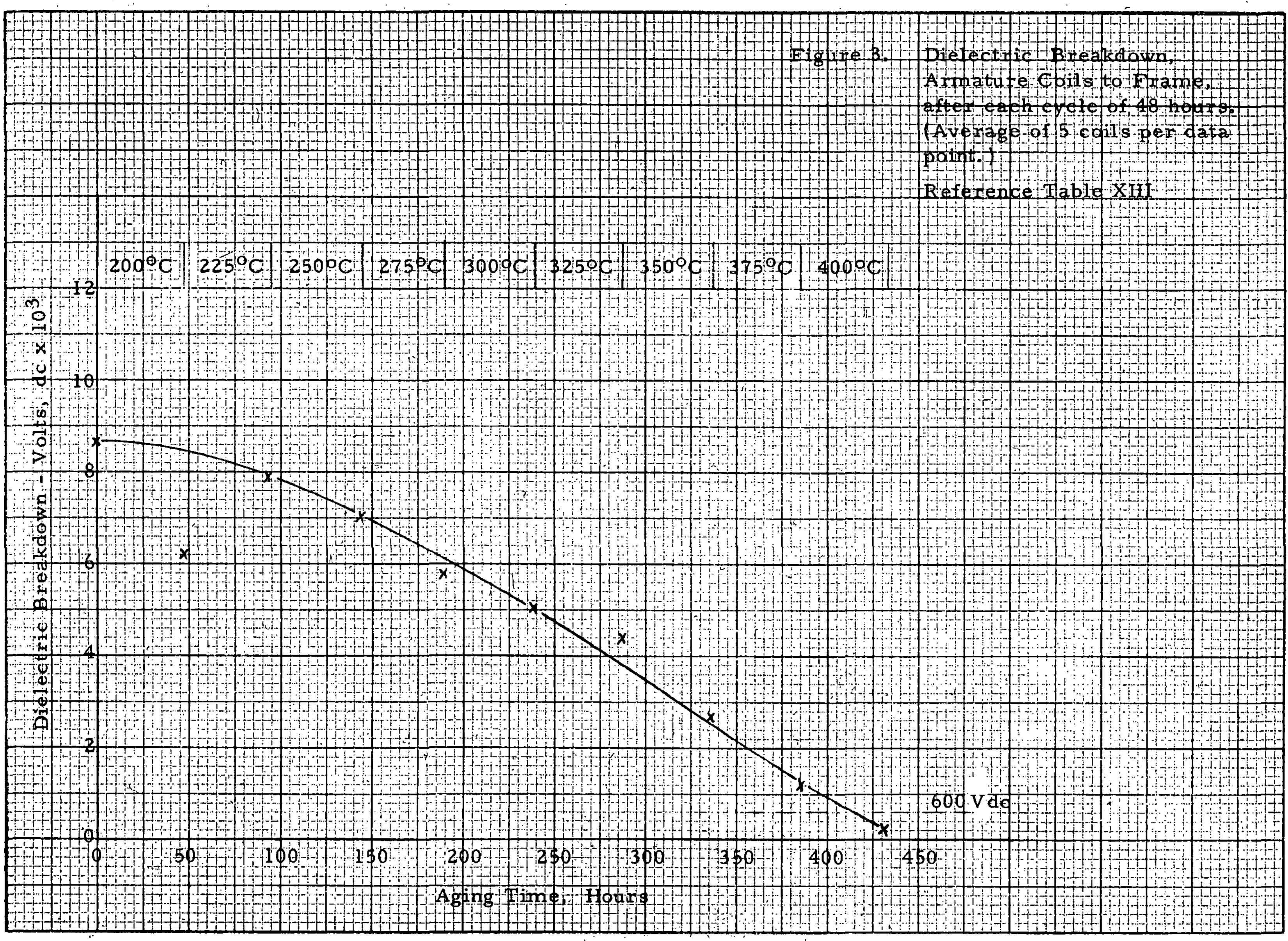


Figure 3. Dielectric Breakdown, Armature Coils to Frame, after each cycle of 48 hours. (Average of 5 coils per data point.)

Reference Table XIII

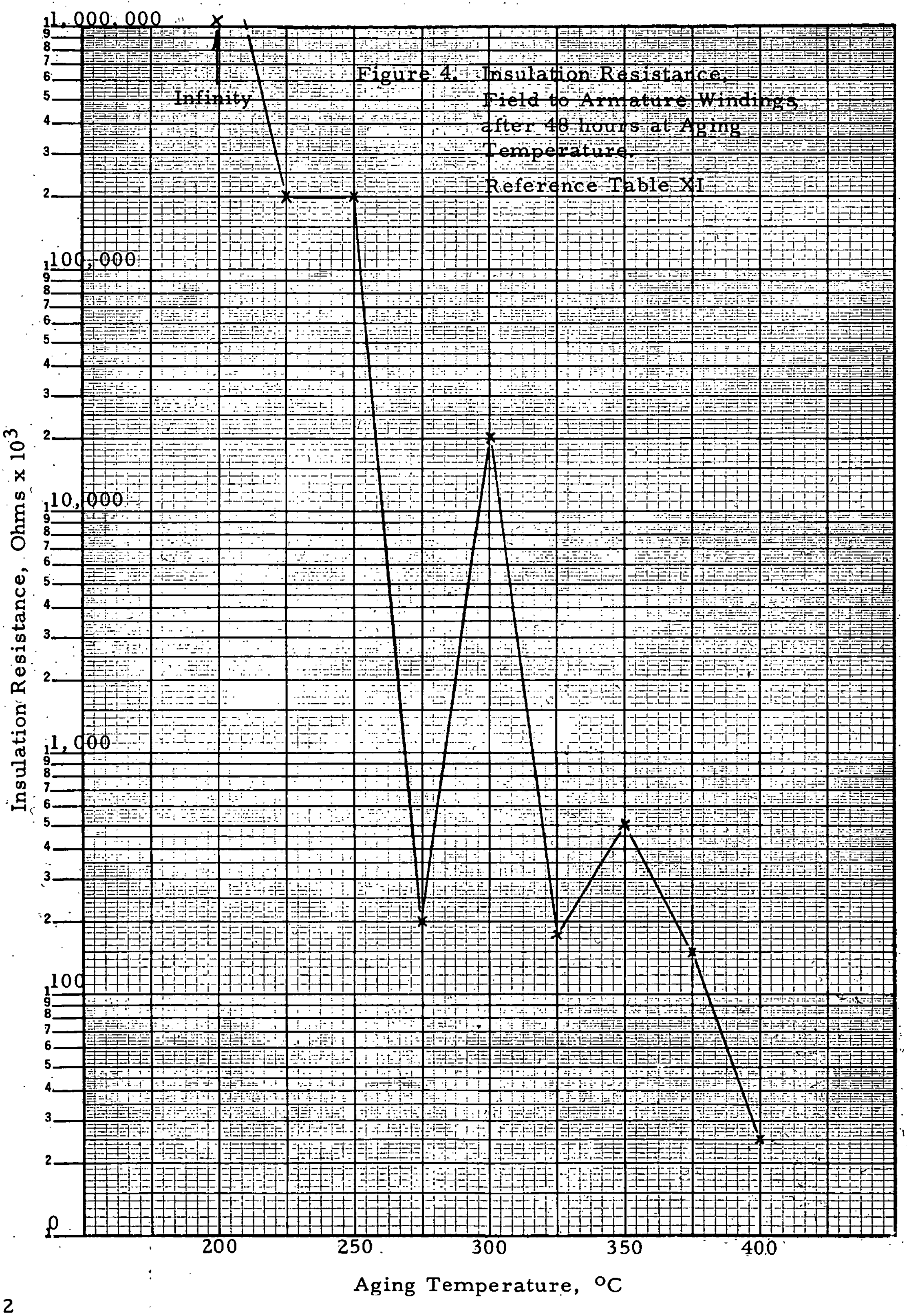


Figure 4. Insulation Resistance, Field to Armature Windings, after 48 hours at Aging Temperature.

Reference Table XI

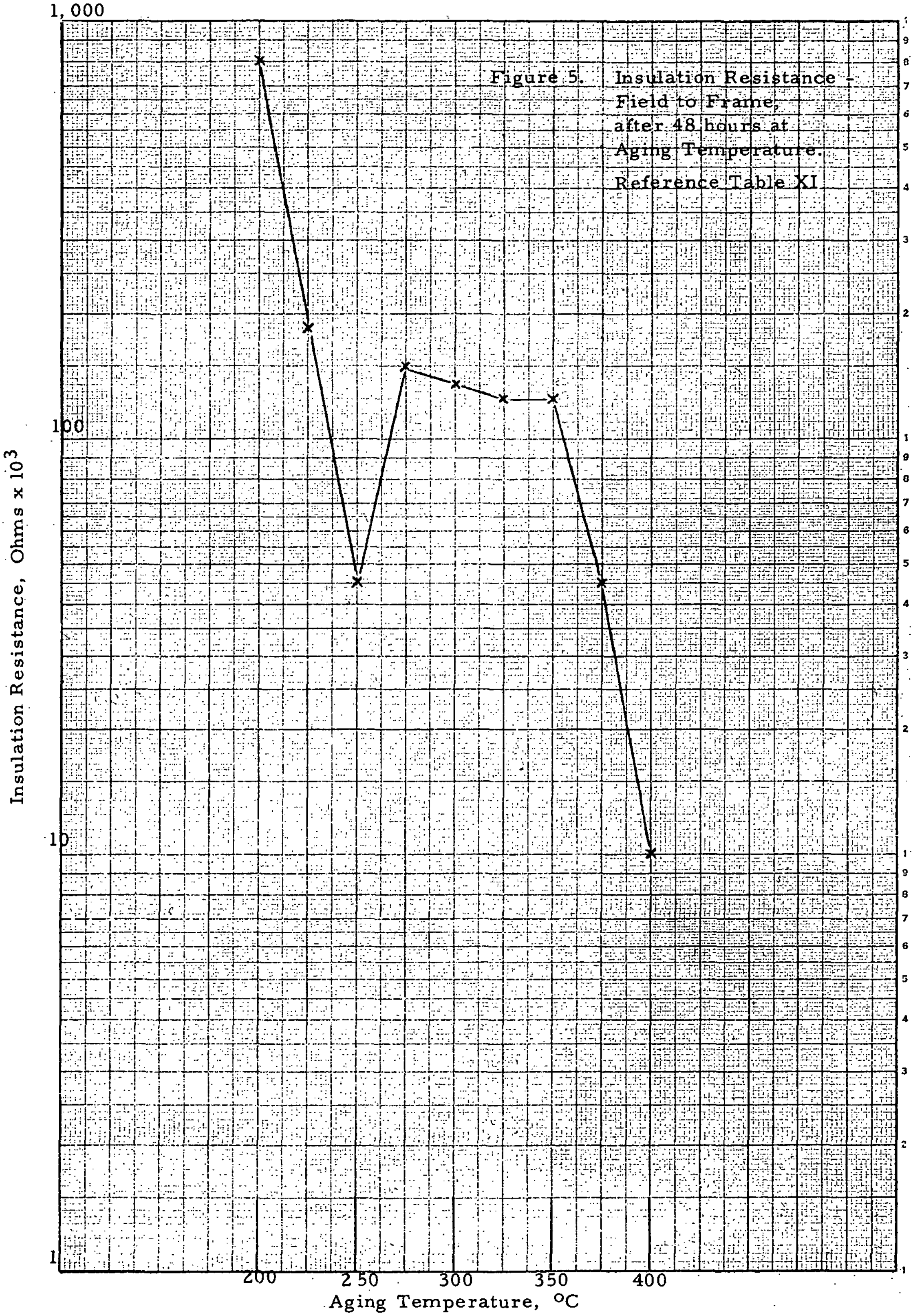


Figure 5. Insulation Resistance - Field to Frame, after 48 hours at Aging Temperature.

Reference Table XI

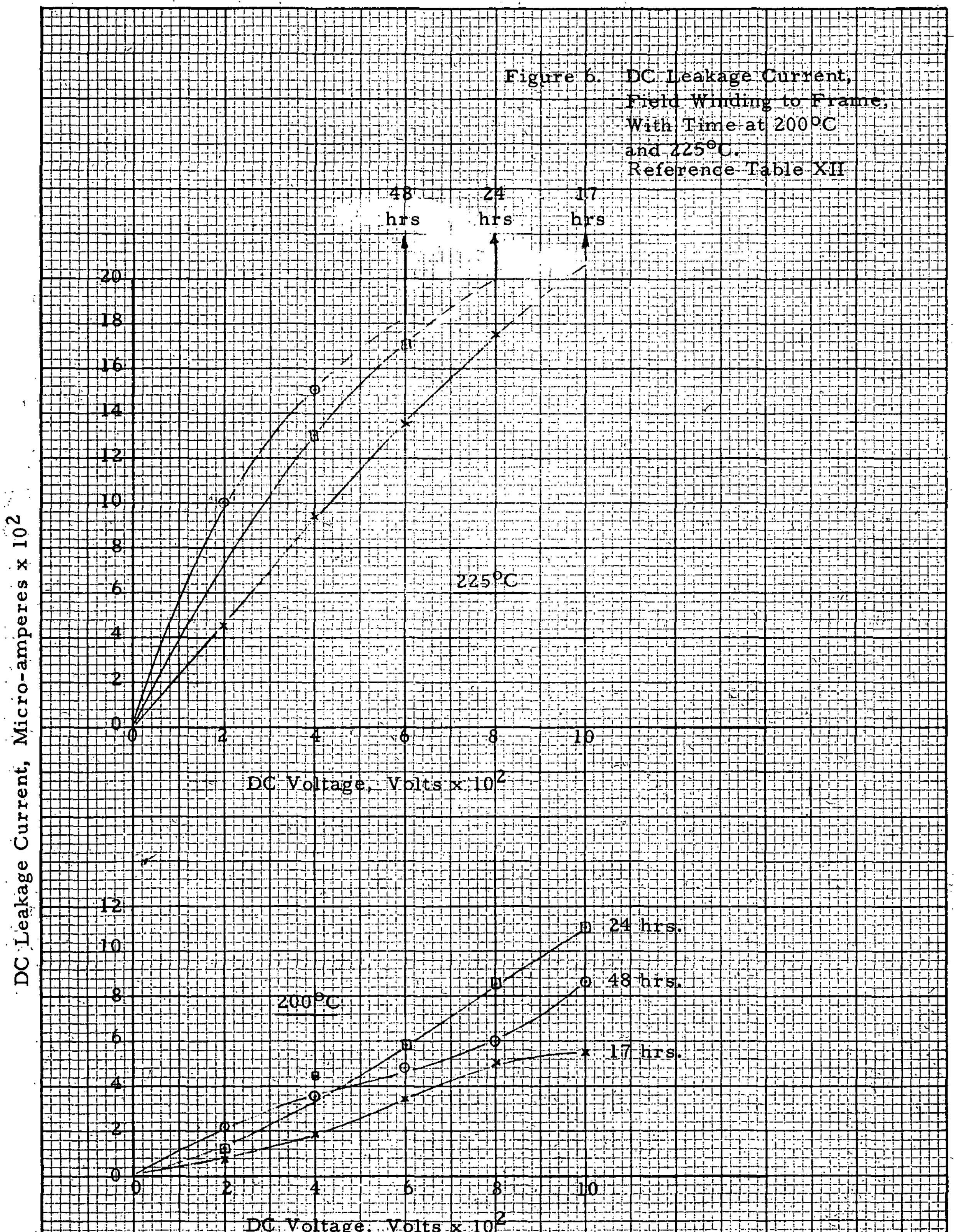


Figure 6. DC Leakage Current, Field Winding to Frame, With Time at 200°C and 225°C. Reference Table XII

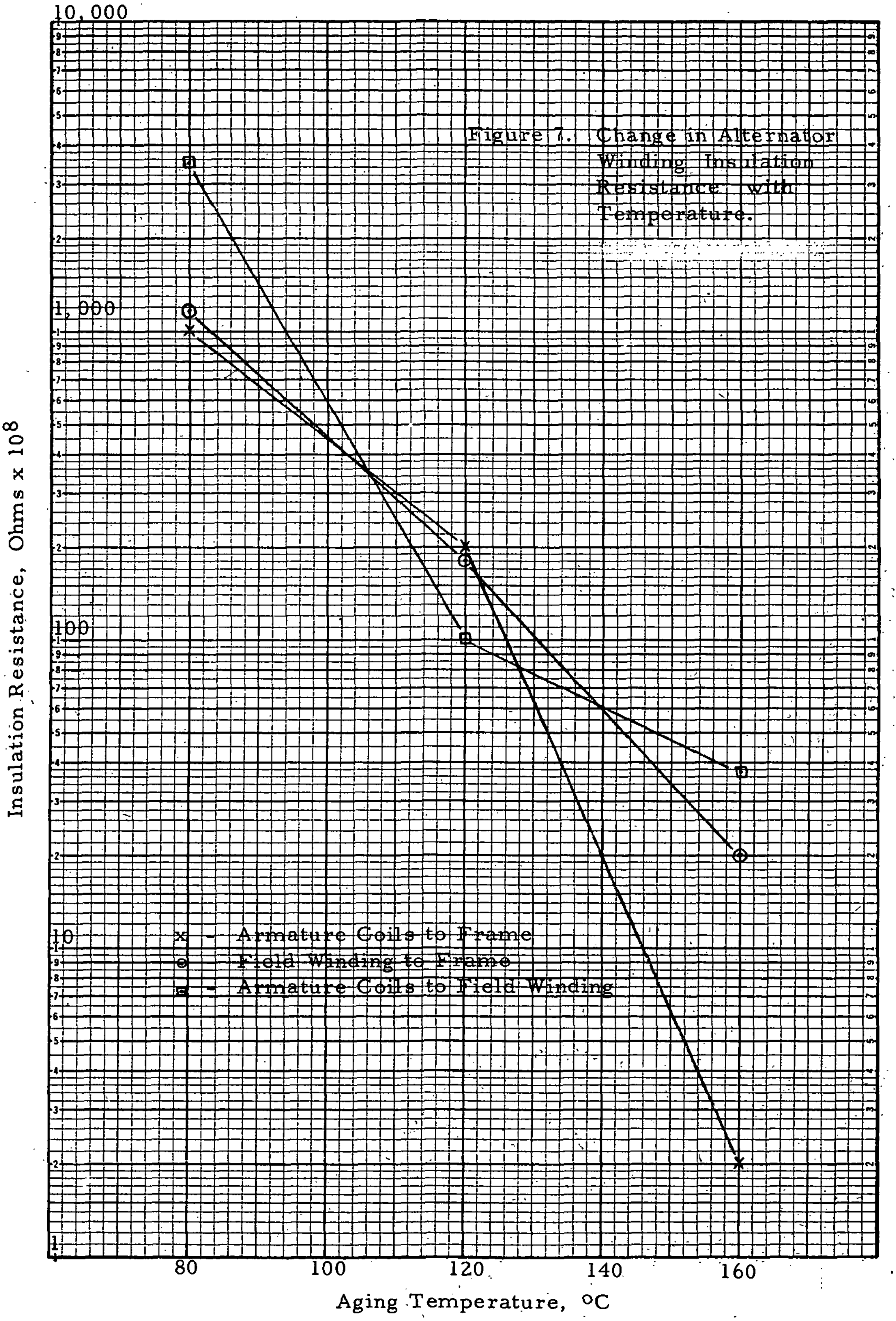


Figure 7. Change in Alternator Winding Insulation Resistance with Temperature.

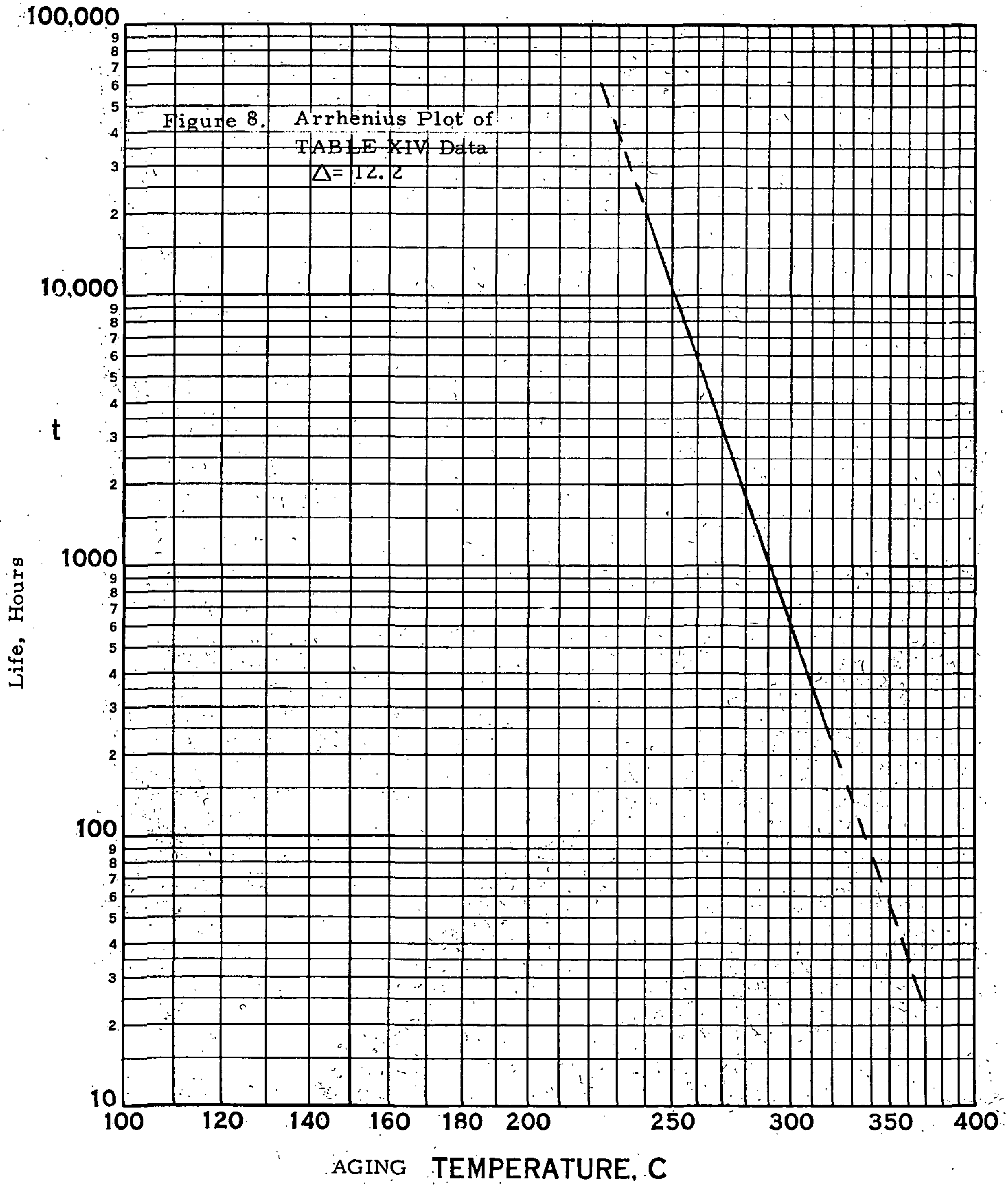


Figure 8. Arrhenius Plot of TABLE XIV Data Δ= 12.2

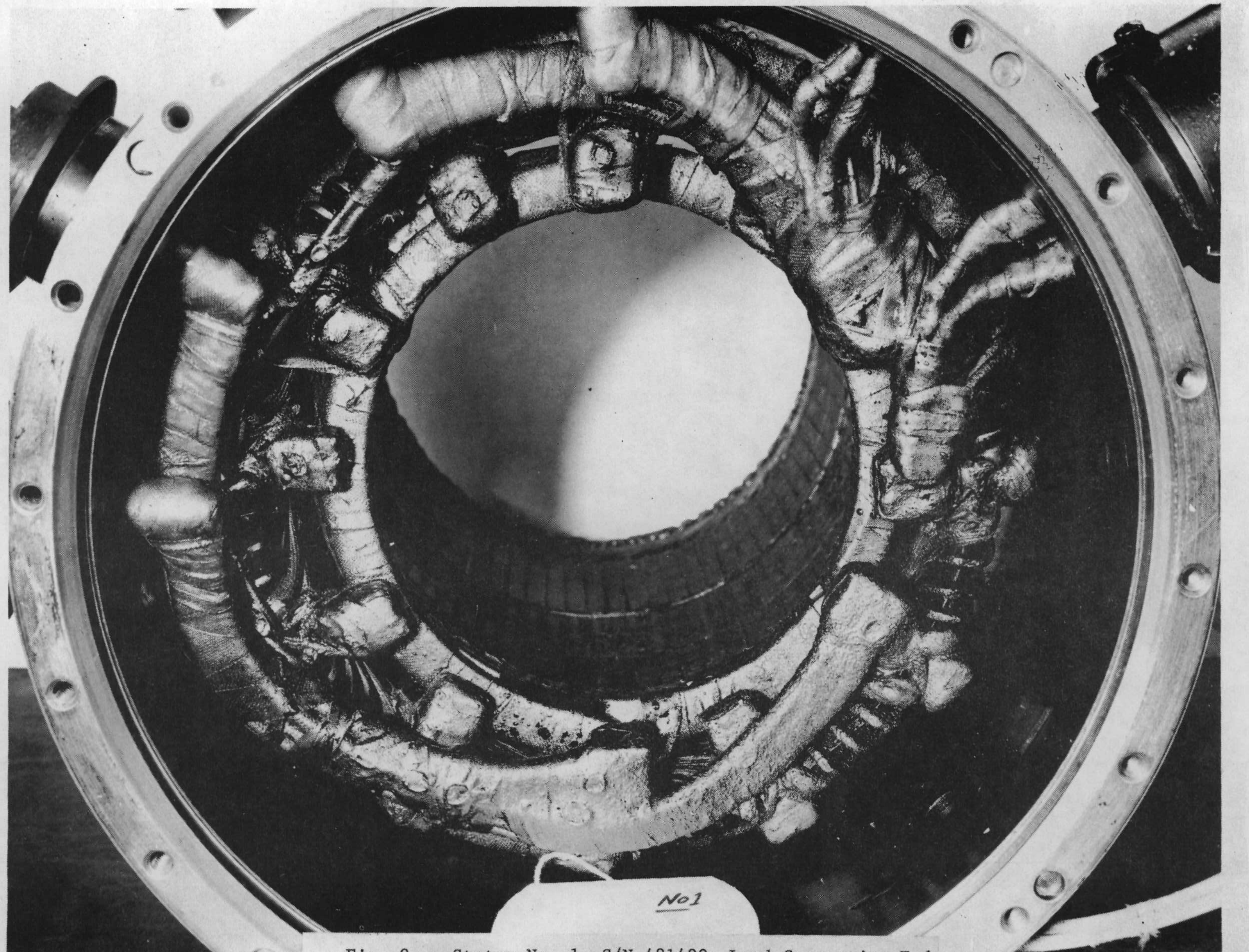


Fig. 9 - Stator No. 1, S/N 481490, Lead Connection End View, As received

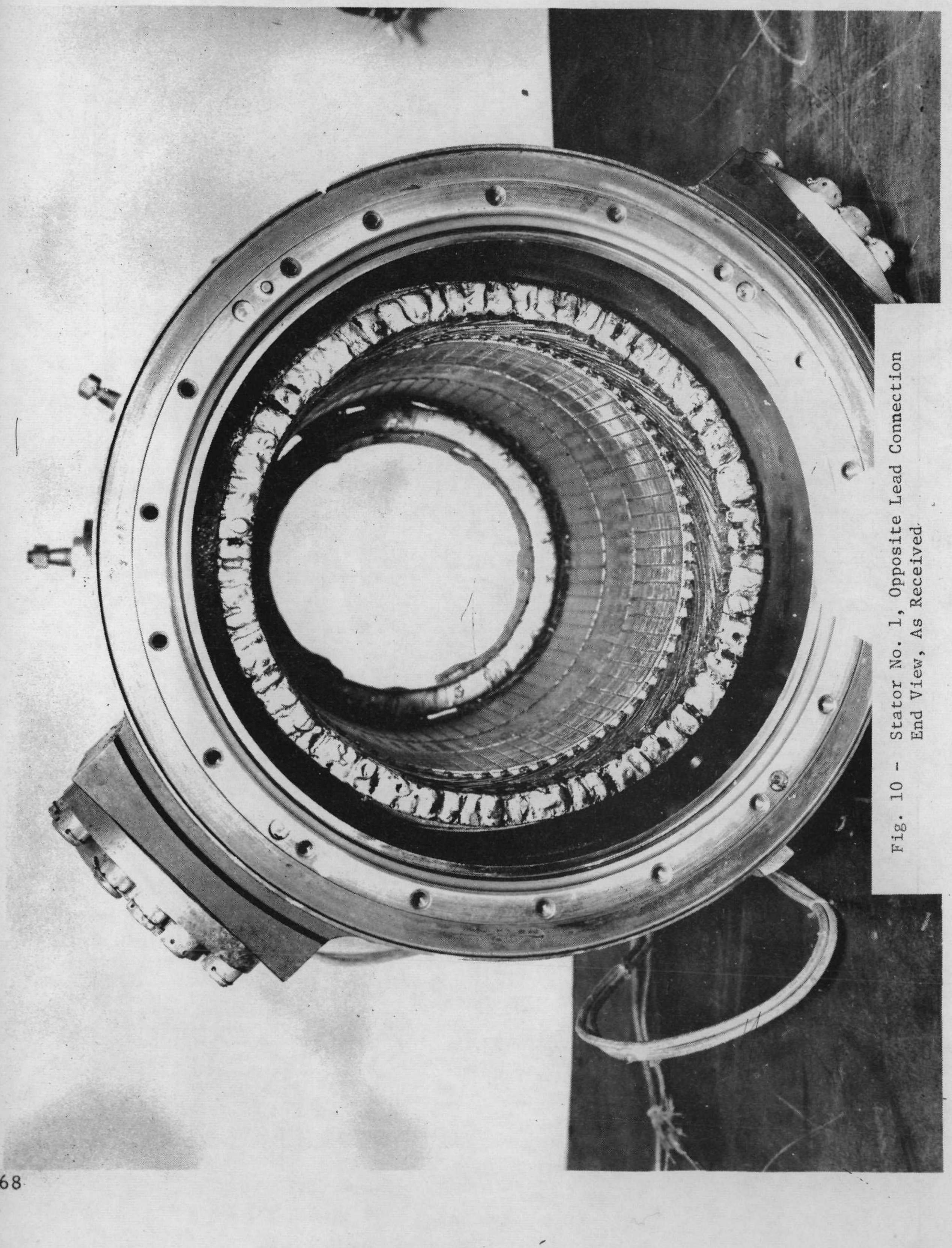


Fig. 10 - Stator No. 1, Opposite Lead Connection End View, As Received

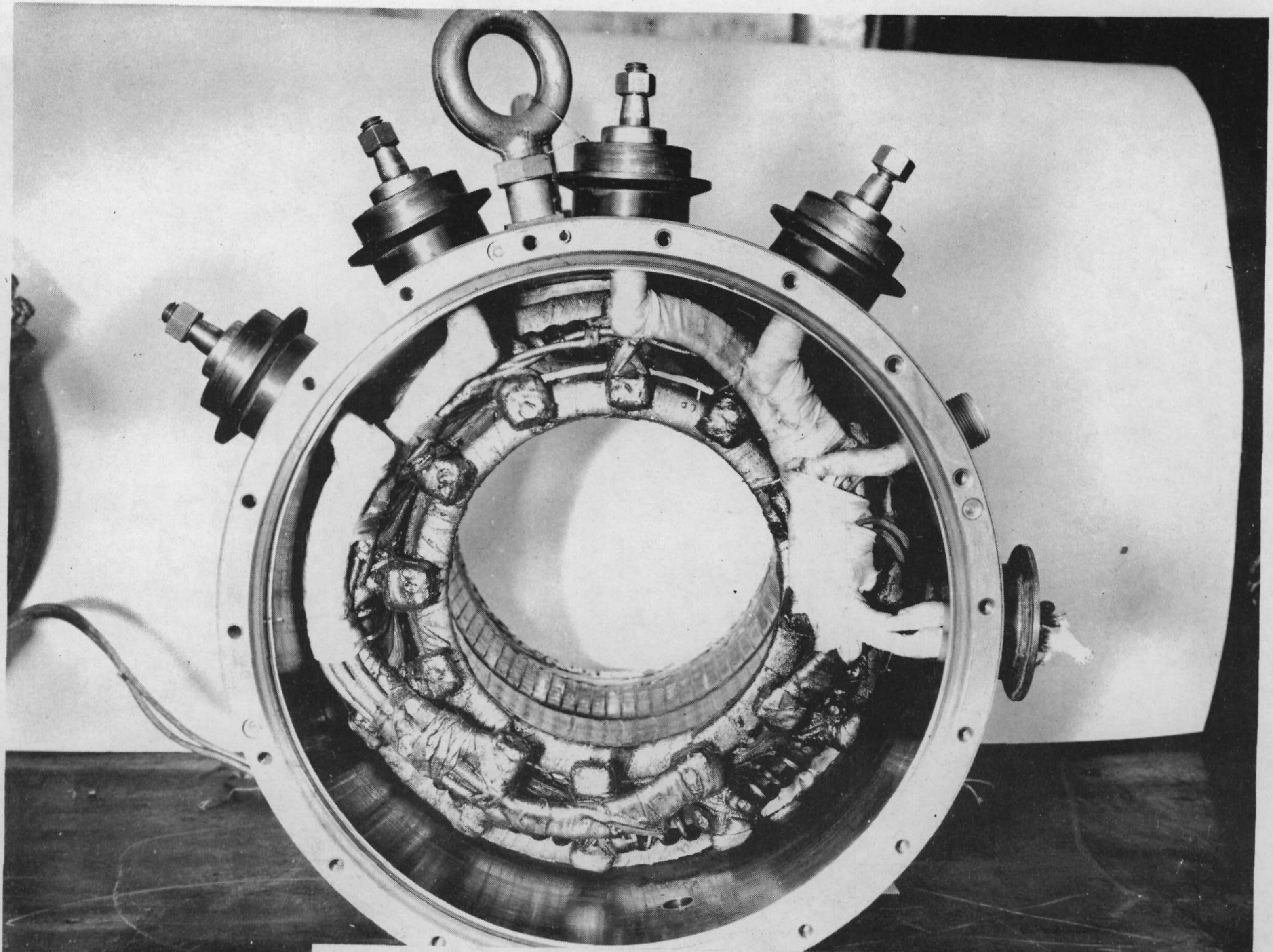


Fig. 11 - Stator No. 2, S/N 481489, Lead Connection End View, As Received

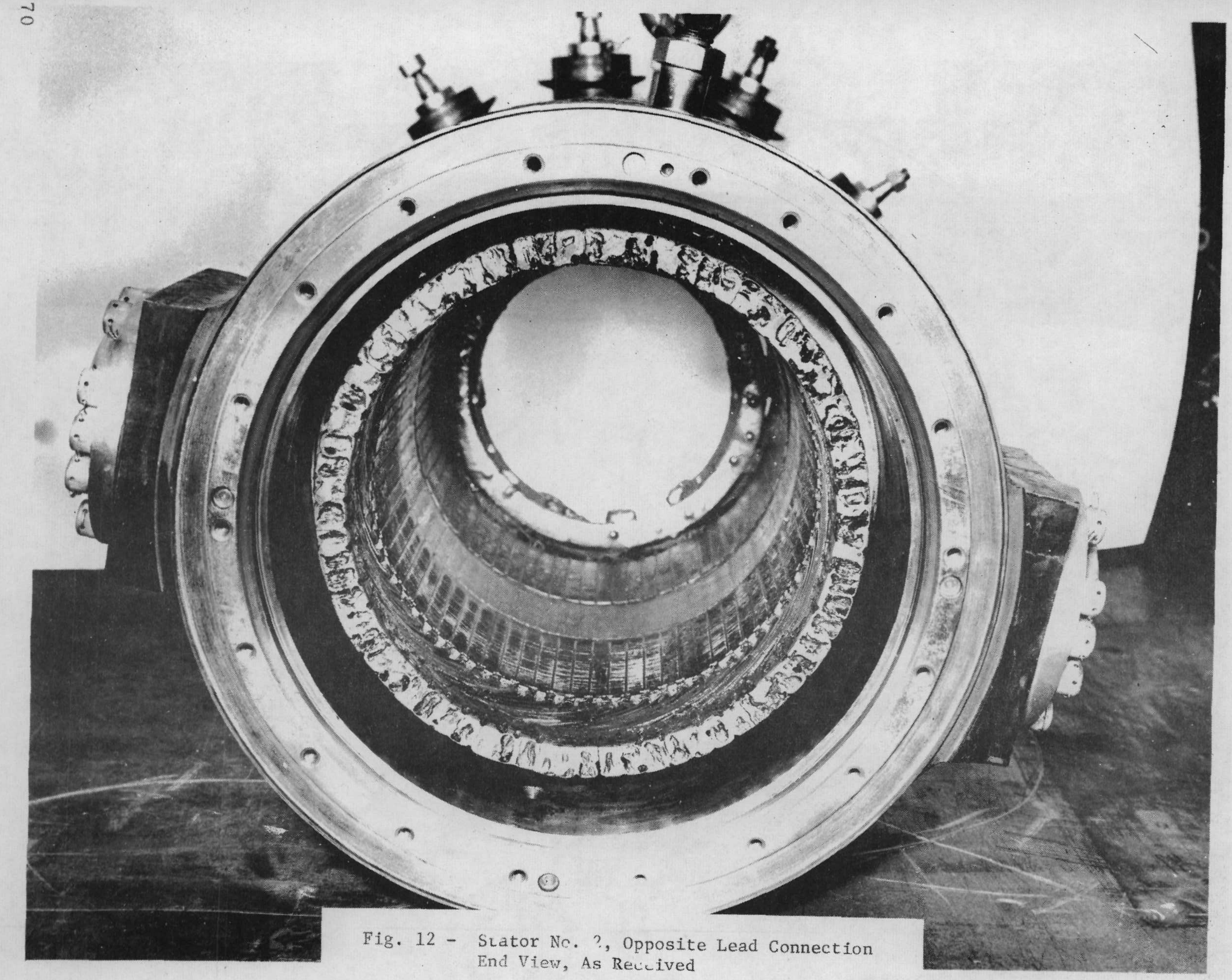


Fig. 12 - Stator No. 2, Opposite Lead Connection End View, As Received

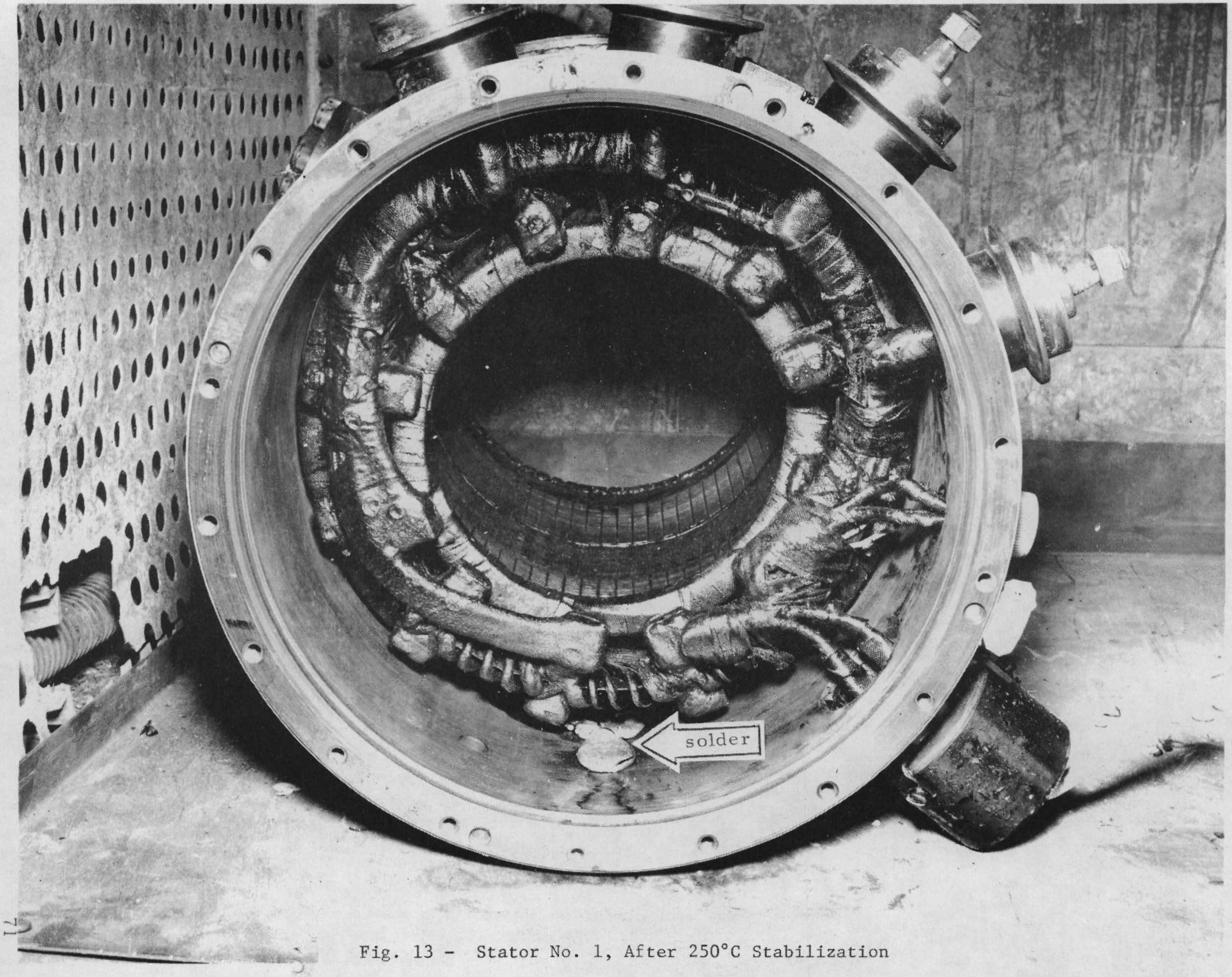


Fig. 13 - Stator No. 1, After 250°C Stabilization

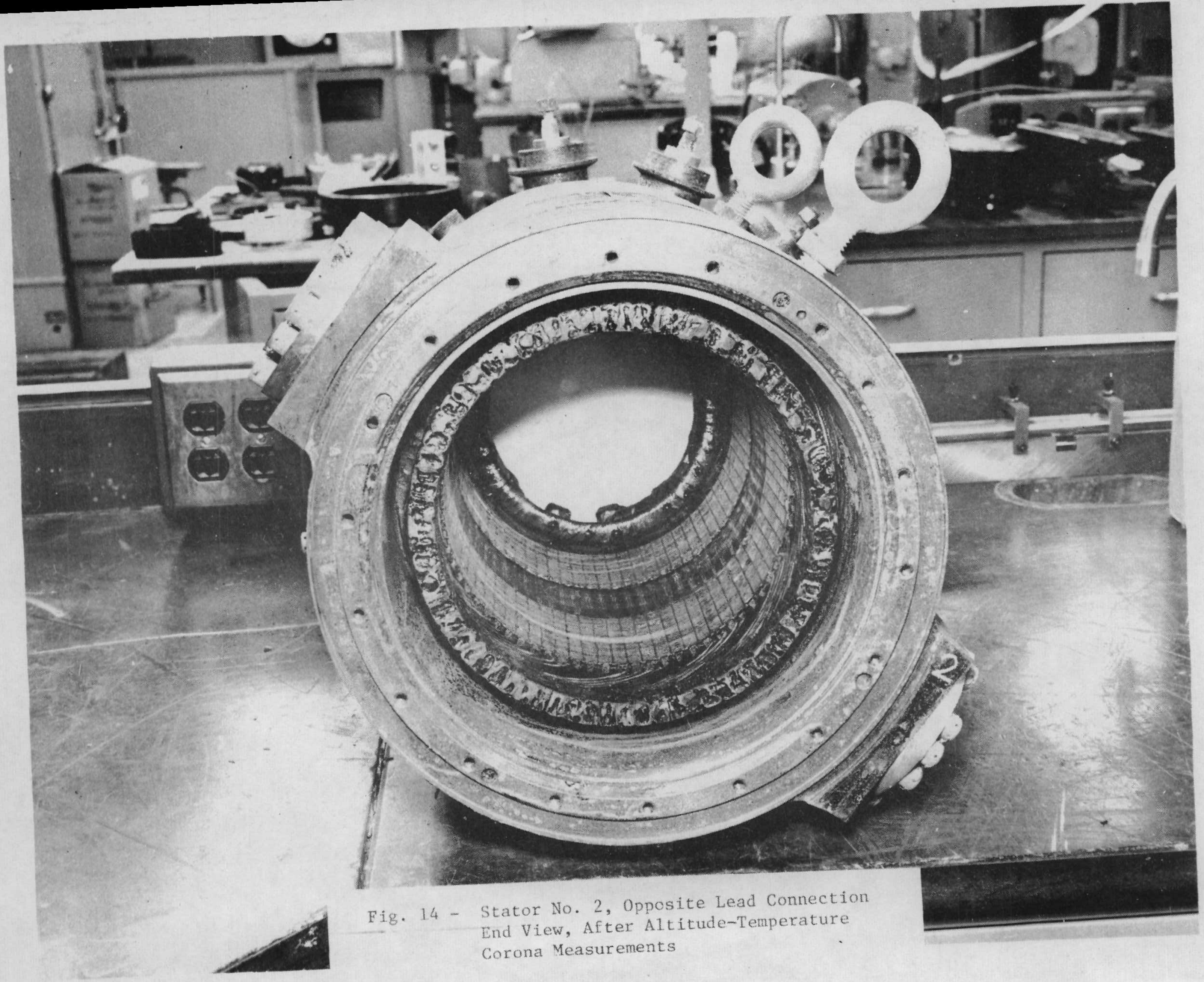


Fig. 14 - Stator No. 2, Opposite Lead Connection End View, After Altitude-Temperature Corona Measurements

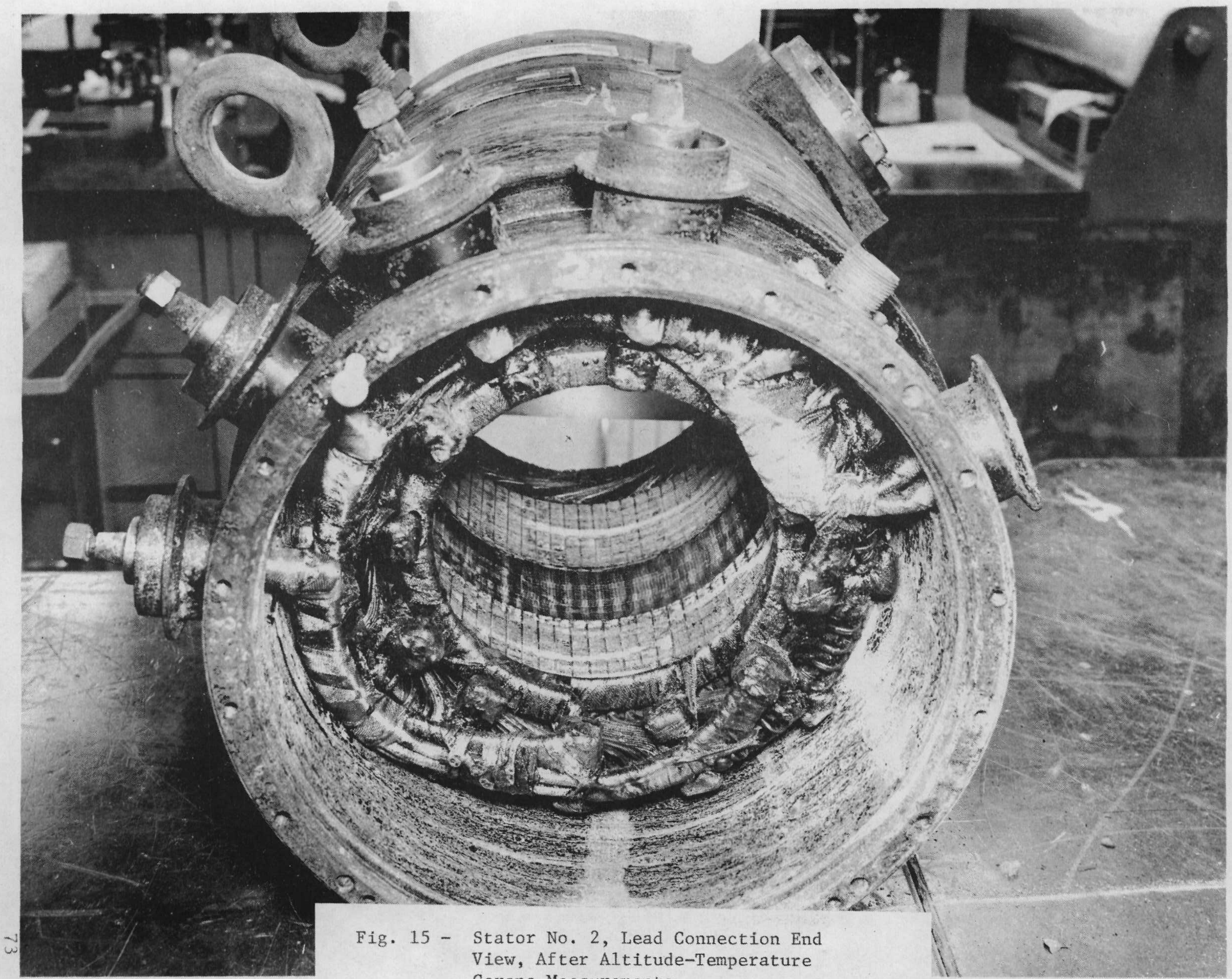


Fig. 15 - Stator No. 2, Lead Connection End View, After Altitude-Temperature Corona Measurements

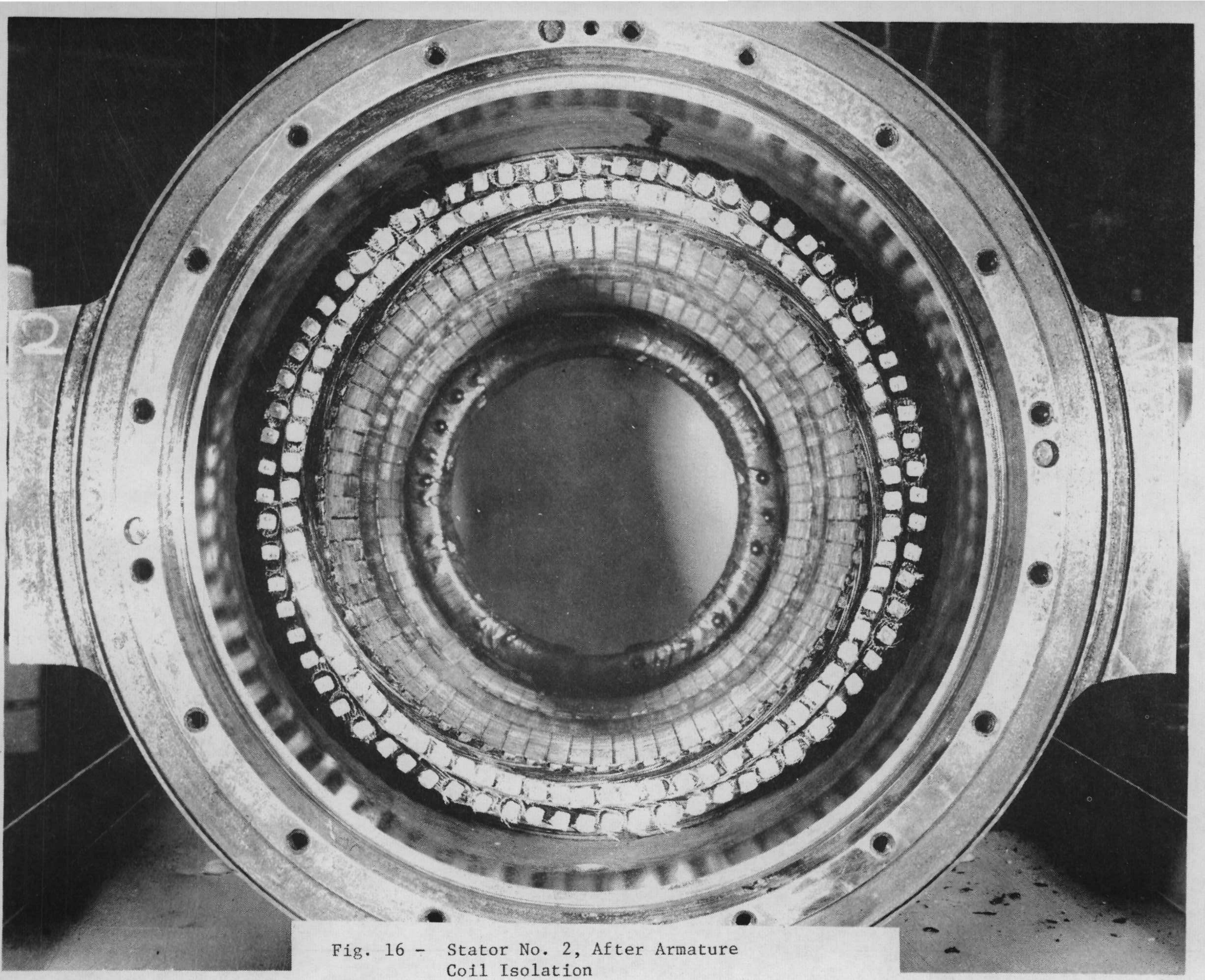


Fig. 16 - Stator No. 2, After Armature Coil Isolation

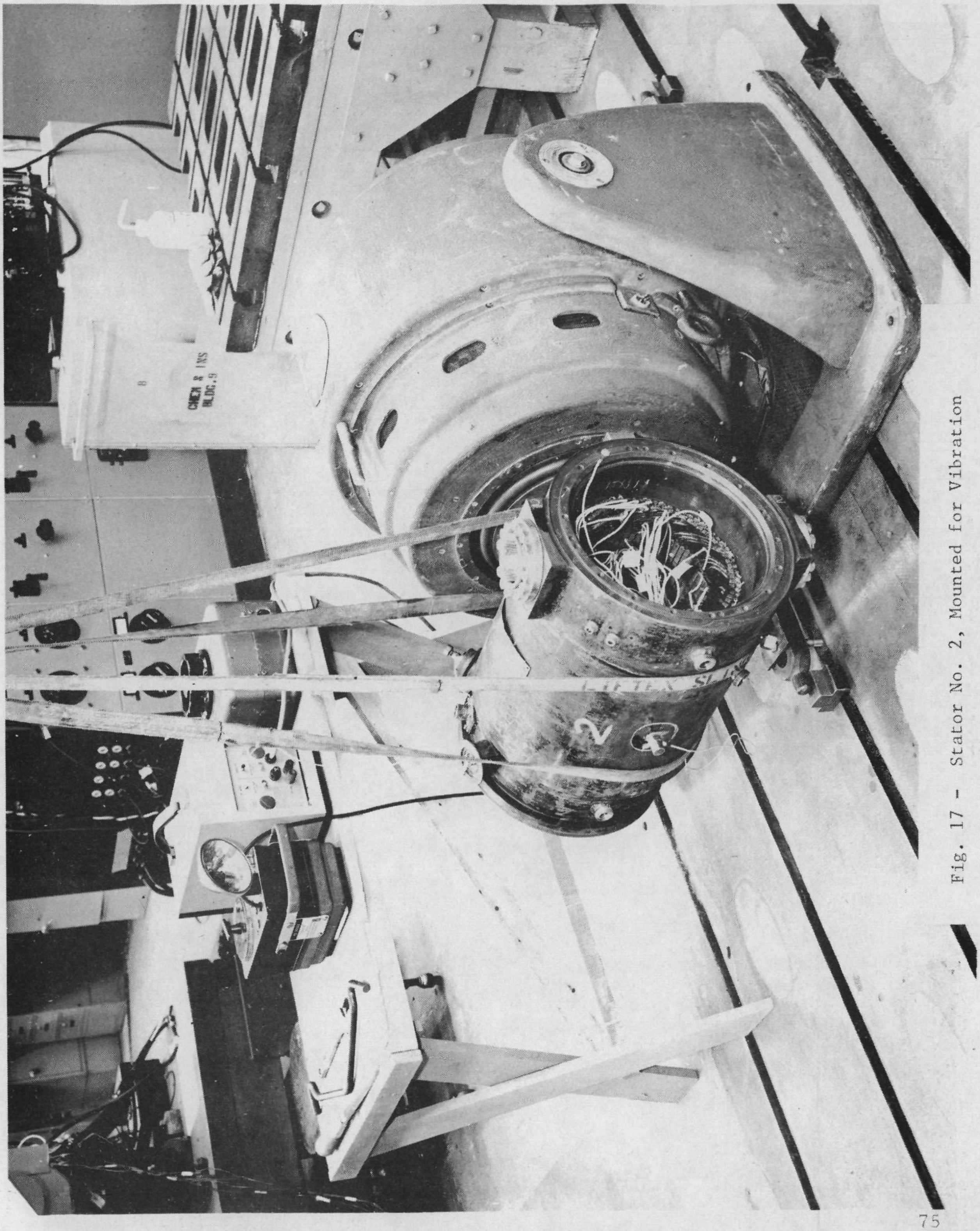


Fig. 17 - Stator No. 2, Mounted for Vibration

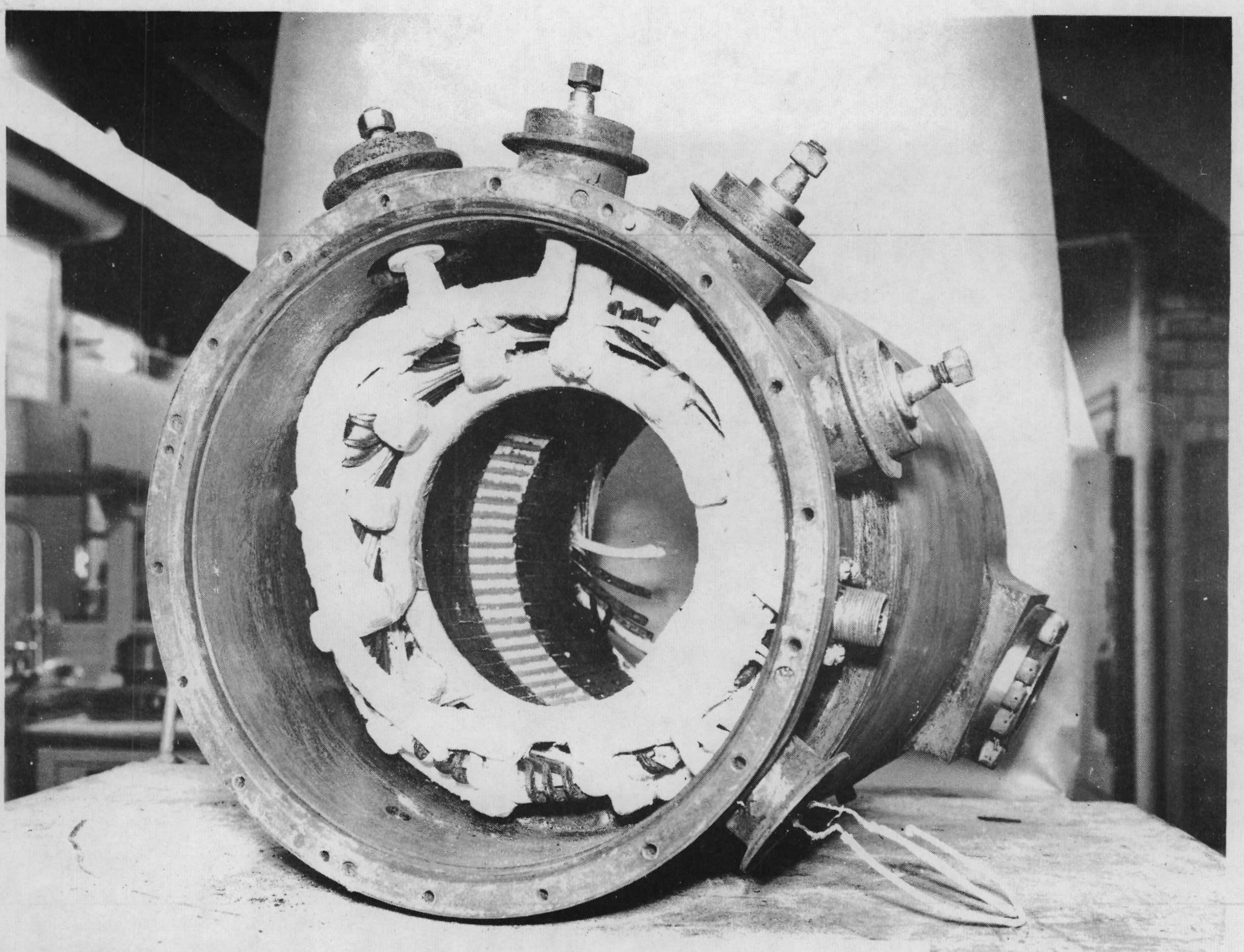


Fig. 18 - Stator No. 2, Lead Connection End View, After Thermal Accelerated Aging

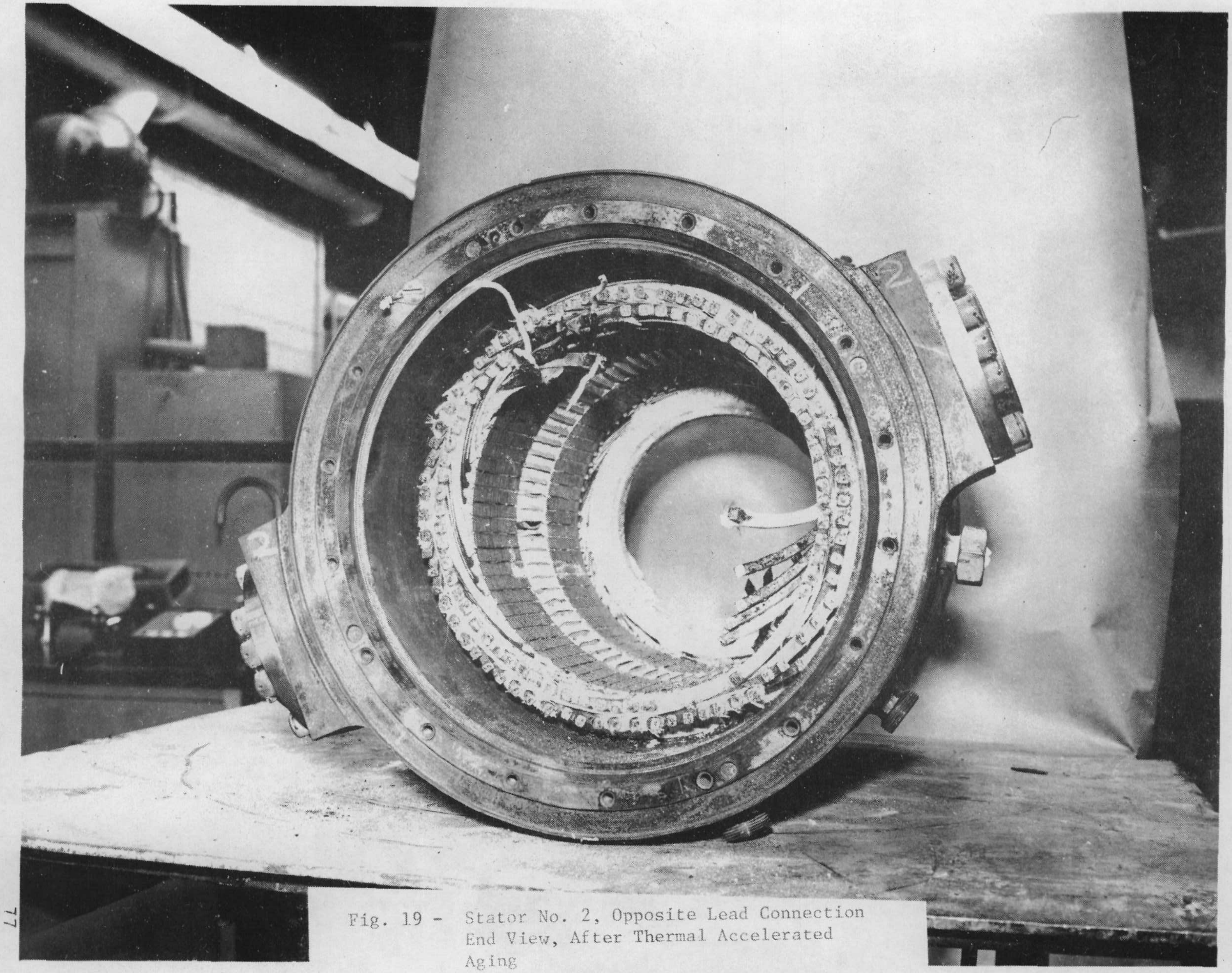


Fig. 19 - Stator No. 2, Opposite Lead Connection End View, After Thermal Accelerated Aging

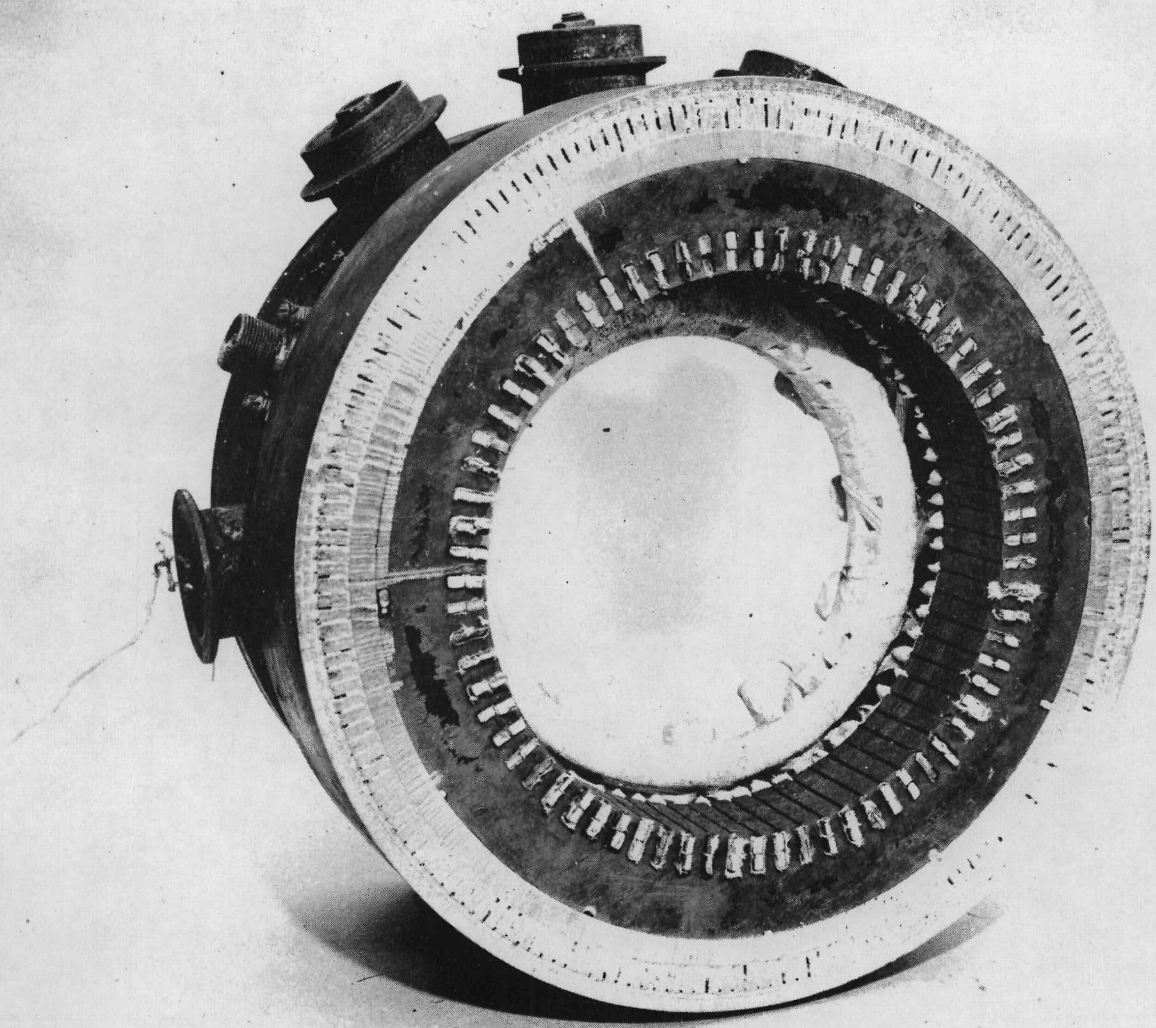


Fig. 20 - Stator No. 2, Mid-Stator Core Section, Lead Connection End, After Thermal Accelerated Aging

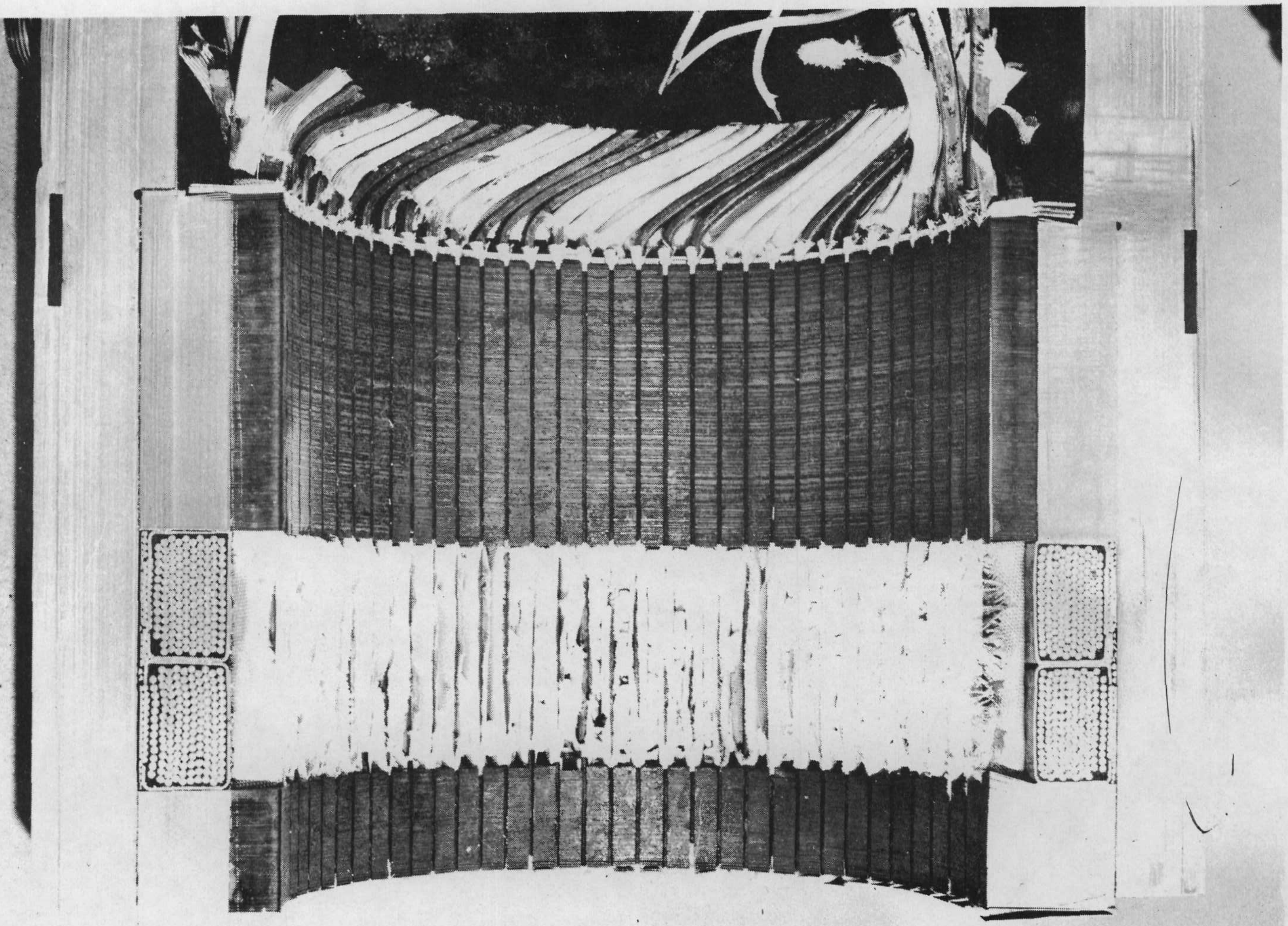


Fig. 21 - Stator No. 2, Axial Stator-Field Section, After Thermal Accelerated Aging

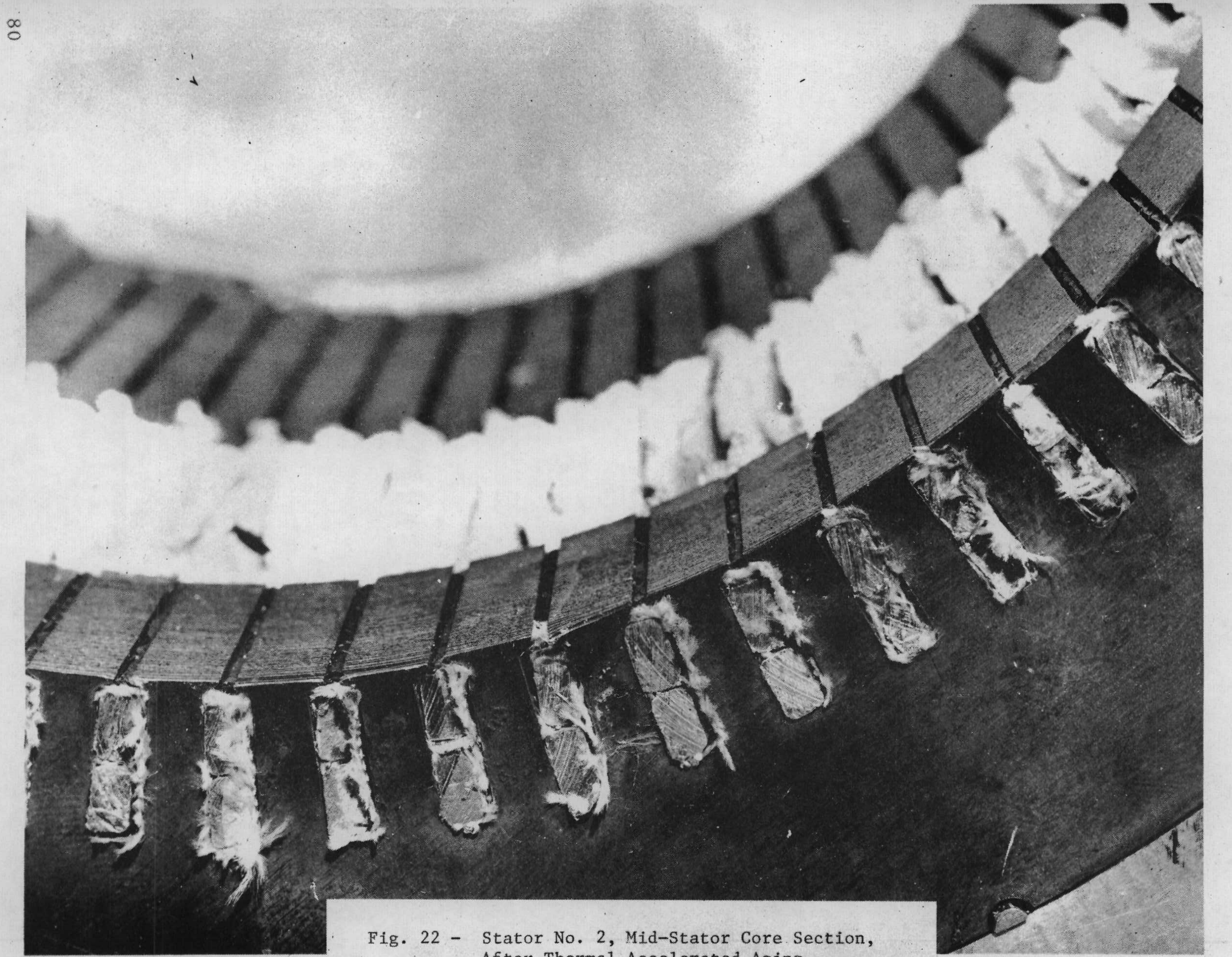


Fig. 22 - Stator No. 2, Mid-Stator Core Section, After Thermal Accelerated Aging

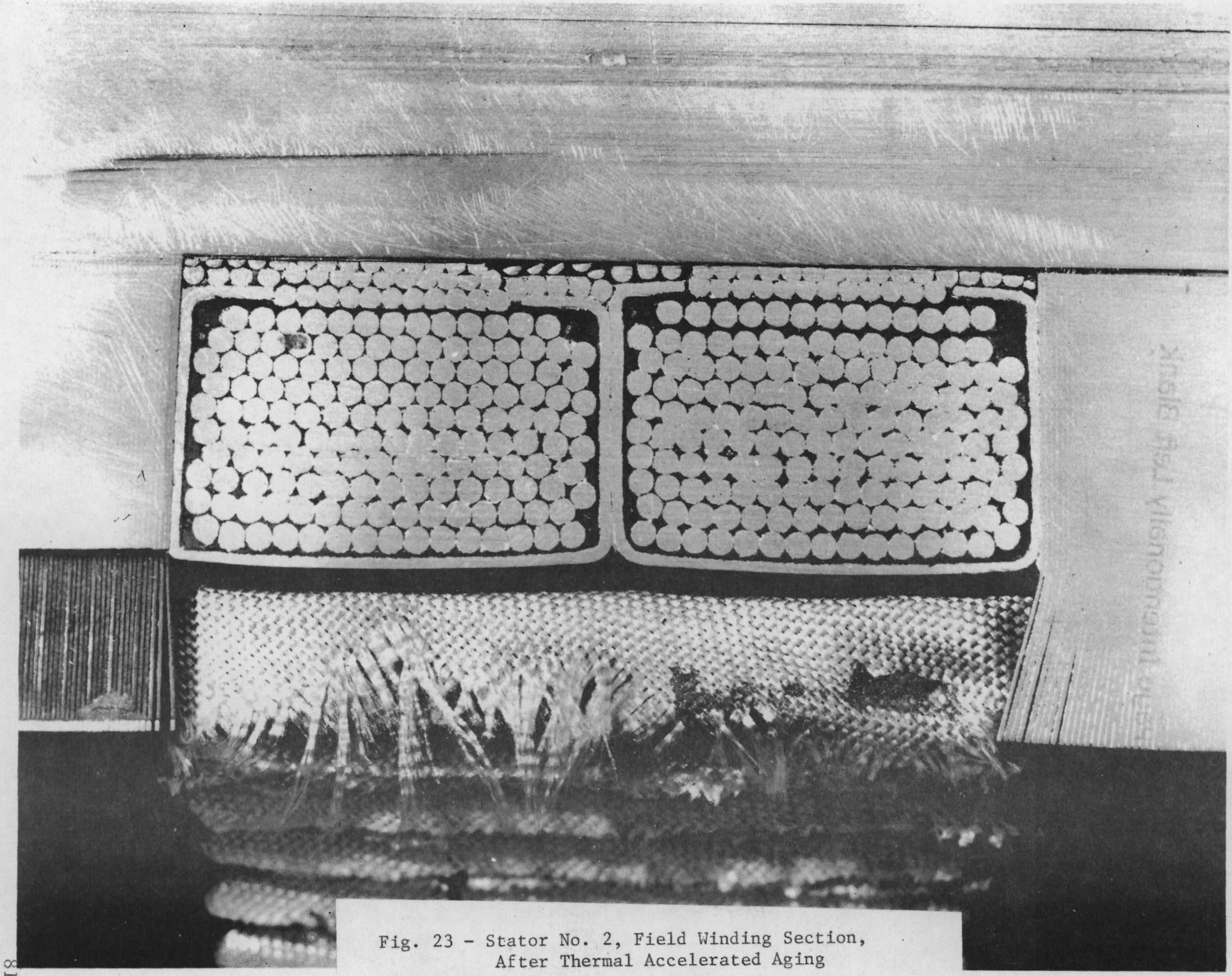


Fig. 23 - Stator No. 2, Field Winding Section, After Thermal Accelerated Aging

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