NASA CONTRACTOR REPORT

NASA CR-1592



NASA CR-1592

# THERMAL-VACUUM TESTING OF HIGH-TEMPERATURE ELECTRICAL COMPONENTS

*by W. L. Grant and P. E. Kueser*

*Prepared by*
WESTINGHOUSE ELECTRIC CORPORATION
Lima, Ohio
*for Lewis Research Center*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1970

| 1. Report No. NASA CR-1592 | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| 4. Title and Subtitle THERMAL-VACUUM TESTING OF HIGH-TEMPERATURE ELECTRICAL COMPONENTS | | 5. Report Date August 1970 |
| | | 6. Performing Organization Code |
| 7. Author(s) W. L. Grant and P. E. Kueser | | 8. Performing Organization Report No. WAED 67.46E |
| 9. Performing Organization Name and Address Westinghouse Electric Corporation Aerospace Electrical Division Lima, Ohio | | 10. Work Unit No. |
| | | 11. Contract or Grant No. NAS 3-6465 |
| 12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546 | | 13. Type of Report and Period Covered Contractor Report |
| | | 14. Sponsoring Agency Code |
| 15. Supplementary Notes | | |

16. Abstract

The results of a program for the fabrication and subsequent testing of electrically energized components are described. Two test series were conducted in ultra-high vacuum ($10^{-9}$ torr range) and high temperature (1100° or 1300° F). This program demonstrated the suitability and reliability of selected materials for application in advanced high-temperature space and terrestrial electric power systems. Materials compatibility was evaluated using test models in which various materials were applied as they would be in actual advanced high temperature space or terrestrial electric power system components. Two sets of test models were constructed with each set consisting of a three-phase stator, a step-down transformer, and two d-c solenoids. Materials included iron-27 percent cobalt magnetic laminations and forgings, rigid and flexible electrical insulations, and nickel or Inconel clad silver conductors. Two 5000-hour aging tests were conducted at pressures in the $10^{-9}$ torr range with the models' hot spot temperatures at either 1100° or 1300° F. The bore seal containing high purity potassium was included in the 1300° F test. Some material changes, primarily in insulation, potting and conductor cladding, were made between the 1100° and 1300° F test models. The 1100° and 1300° F model stators and solenoids demonstrated both electrical and mechanical materials-compatibility with the high temperatures and ultra-high-vacuums during the two tests. Electrical compatibility of transformer materials was demonstrated in both the 1100° and 1300° F tests, but the primary winding in each transformer shorted because of insufficient mechanical support between turns. The winding interlayer flexible insulations were not rigid enough to suppress relative motion between adjacent turns. Modified design techniques and/or new insulation materials will be required for use in successful high-temperature multilayer transformer windings.

| 17. Key Words (Suggested by Author(s)) | 18. Distribution Statement |
|---|---|
| Electrical components<br>High temperature materials<br>Motors<br>Stators<br>Solenoids<br>Transformers | Unclassified - unlimited<br>1. Heat Resistant Materials<br>2. Electrical Equipment - Testing |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price* |
|---|---|---|---|
| Unclassified | Unclassified | 265 | $3.00 |

*For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151

# PREFACE

The work described herein was done under NASA Contract NAS 3-6465. R. A. Lindberg, Space Power Systems Division, NASA-Lewis Research Center, was the Project Manager for this program.

The Westinghouse Electric Corporation Aerospace Electrical Division (WAED) performed the work reported herein. P. E. Kueser, Manager, Materials Development, WAED, was the Program Manager, and W. L. Grant was the principal investigator.

Contributors and consultants who actively participated on this project were D. M. Pavlovic, E. F. Hammond, D. H. Lane, R. Henderson, W. S. Neff, H. E. Keneipp, J. W. Ogden, R. P. Shumate, and J. W. Toth of WAED.

TABLE OF CONTENTS

TABLE OF CONTENTS - CONCLUDED

## LIST OF FIGURES

LIST OF FIGURES - CONCLUDED

LIST OF TABLES

LIST OF TABLES - CONCLUDED

# SECTION I

## INTRODUCTION AND SUMMARY

This report presents the results of a program for the fabrication and subsequent testing of electrically energized components. Two test series were conducted in ultra-high vacuum ($10^{-9}$ torr range) and high temperature (1100° or 1300° F). This program demonstrated the suitability and reliability of selected materials for application in advanced high-temperature space and terrestrial electric power systems.

Materials compatibility was evaluated using test models in which various materials were applied as they would be in actual advanced high temperature space or terrestrial electric power system components. Two sets of test models were constructed with each set consisting of a three-phase stator, a step-down transformer, and two d-c solenoids. Materials included iron-27 percent cobalt magnetic laminations and forgings, rigid and flexible electrical insulations, and nickel or Inconel clad silver conductors. Two 5000-hour aging tests were conducted at pressures in the $10^{-9}$ torr range with the models' hot spot temperatures at either 1100° or 1300° F. The bore seal containing high purity potassium was included in the 1300° F test. Some material changes, primarily in insulation, potting and conductor cladding, were made between the 1100° and 1300° F test models.

The 1100° and 1300° F model stators and solenoids demonstrated both electrical and mechanical materials-compatibility with the high temperatures and ultra-high-vacuums during the two tests. Electrical compatibility of transformer materials was demonstrated in both the 1100° and 1300° F tests, but the primary winding in each transformer shorted because of insufficient mechanical support between turns. The winding interlayer flexible insulations were not rigid enough to suppress relative motion between adjacent turns. Modified design techniques and/or new insulation materials will be required for use in successful high-temperature multilayer transformer windings.

Two appendixes are included in this report. Appendix A gives procurement and processing information for materials used in this program. Appendix B gives drawings and materials lists for the three component models.

## SECTION II

## MATERIALS COMPATIBILITY AND PERFORMANCE IN A HIGH-TEMPERATURE, HIGH-VACUUM ENVIRONMENT

### A. INTRODUCTION AND TEST FACILITY DETAILS

A previous program which was carried out on Contract NAS3-4162 and discussed earlier in the introduction defined the physical and electrical properties of materials which might be suitable for space electric power systems. In the present program, selected materials from the NAS3-4162 project were combined into test models.

Two sets of models were constructed with each set consisting of a generator or motor type stator, a transformer, and two solenoids. When the first set of models was complete, the assemblies were installed in thermal ultra-high vacuum chambers for a 5000-hour endurance test under vacuum conditions, with a hot-spot temperature of 1100° F. The hot-spot temperature was maintained in part by supplying current to each model (Joule heating) and in part by a heating element in each test chamber. The stator was tested in one chamber and the transformer and two solenoids were tested in a second chamber.

While the first 5000-hour test was being carried out, a second set of models was constructed for test at a 1300° F hot-spot temperature. The basic design of the models was the same for each set, but some material changes were introduced in going from the 1100° F to the 1300° F models. These changes and the overall construction and test procedures will be covered in the detail discussion of each model.

Some details about the test chambers, thermocouple system and "clean" procedures are included in this section because they apply to all model construction and test procedures.

Figure II-1 is a photograph of the two thermal ultra-high vacuum chambers which were used for both phases of the test program. Each chamber is of double wall construction with baffles between the walls to channel cooling water flow. The chamber top cover is also double walled to provide a path for cooling water. The photo also shows the sensing head and magnet for a residual gas analysis mass spectrometer and a sorption roughing pump cart. The residual gas analyzer control console is in the background.

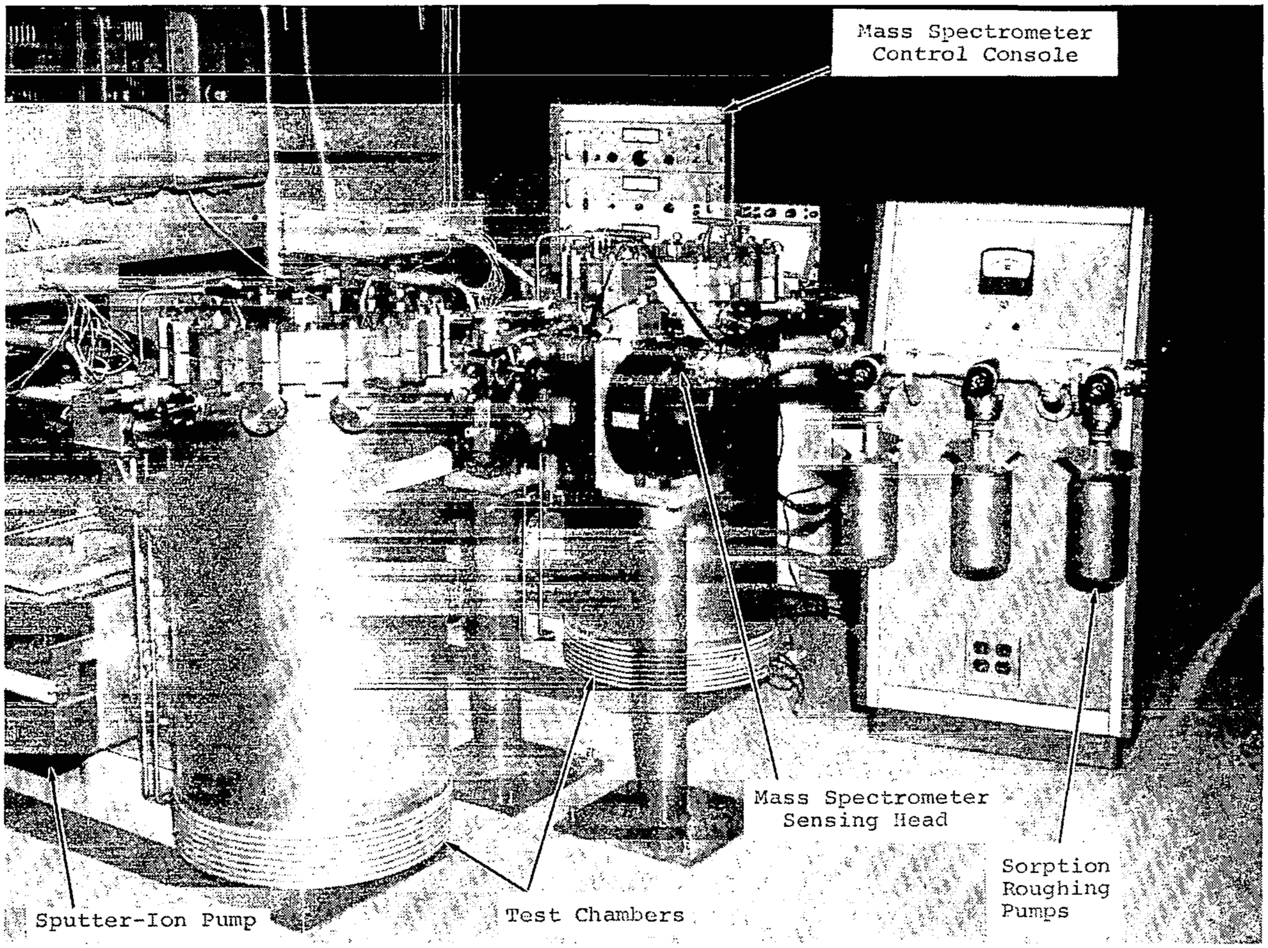



FIGURE II-1. Two Thermal Ultra-High Vacuum Chambers and a Three Element Sorption Roughing Pump Cart

Each chamber is pumped by a 500 liter/second ion pump (visible at the rear of the left chamber) with supplement pumping capacity provided by a titanium sublimation pump. When clean, dry and empty, each chamber is capable of continuous operation with the test zone temperature at 2200° F and at a pressure below $5.0 \times 10^{-9}$ torr.

A special thermocouple system was designed to take advantage of the thermal-vacuum chamber design, and to eliminate thermocouple junctions inside the vacuum chamber. Figure II-2 shows the thermocouple dimensions. The reduced tip diameter version was used in the test models where space was at a premium. The thermocouple wire system was the Platinel II, platinum-rhodium-gold combination available commercially[1]. The wires were encased in an Inconel sheath with $Al_2O_3$ (99%) insulation between the wires and between wires and sheath. The thermocouple junction was isolated from the tip closure and the cold end terminals were vacuum sealed to the sheath.

The thermocouples were installed in the models as they were placed in the test chambers. The test chamber vacuum-to-air feedthroughs included vacuum tight ceramic discs carrying brazed-in hollow Kovar tubes having an inside diameter of 0.040-inch. After the models had been installed in the chambers, each thermocouple was threaded out through a Kovar tube. An induction-brazed, leak-tight joint was formed between each thermocouple and its Kovar tube outside the chamber. Figure II-3 shows the details of the special chamber feedthrough system. This design resulted in a sealed thermocouple system with only the temperature measuring junction located inside the thermal vacuum chamber and continuous conductor with no joints to the external connection outside the chamber.

A stringent cleanliness program was enforced where all the test hardware and the test chambers were concerned. All detail parts received a final cleaning operation before being assembled into the test models. Cleaning procedures included vapor decreasing, ultrasonic cleaning using trichloroethylene and detergent solutions, and ethanol alcohol rinses. All model assembly work was done at a "clean" bench work station, which appears in the background of figure II-4. Filtered air was blown across the work area from the filter bank visible in the photo background. The "clean" bench provided an atmosphere equivalent to or better than a Class 10,000 clean room as defined by Federal Standard No. 209, "Clean Room and Work Station Requirements, Controlled Environment". Particle size in the clean air stream was monitored using a membrane filter as a particle collector. Particle count indicated that the air stream cleanliness was far better than Class 10,000, as it approached Class 100 requirements. The clean bench was moved to the test chamber for installation of the models in the chambers. All personnel were required to wear clean nylon coats, hats, and gloves while handling clean parts and assemblies. Detail parts, subassemblies and assemblies were stored in clean plastic bags between operations.

[1] Manufactured by Engelhard Industries, Inc., Newark, N. J.

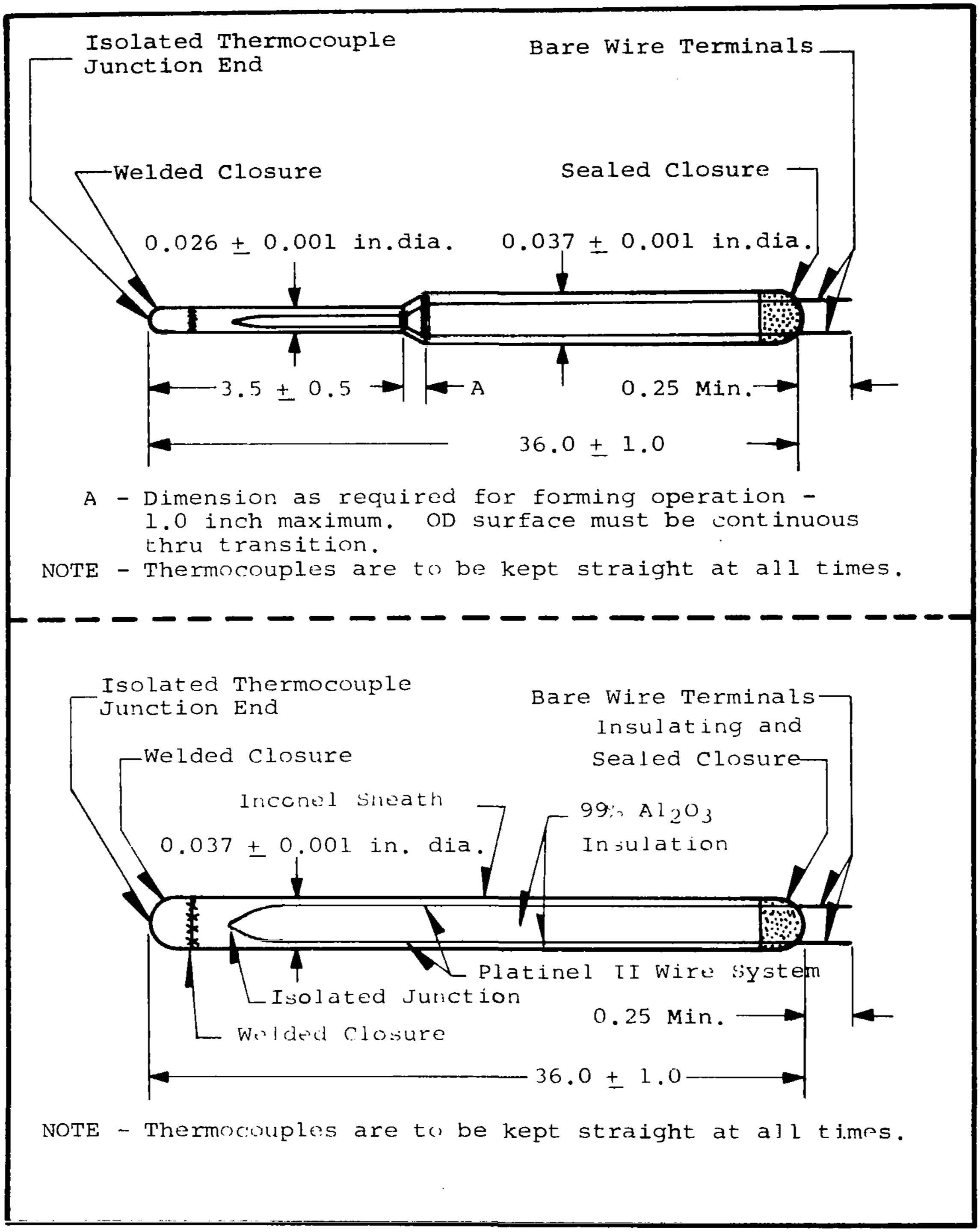



FIGURE II-2. Single and Dual Diameter Sheathed Thermocouples

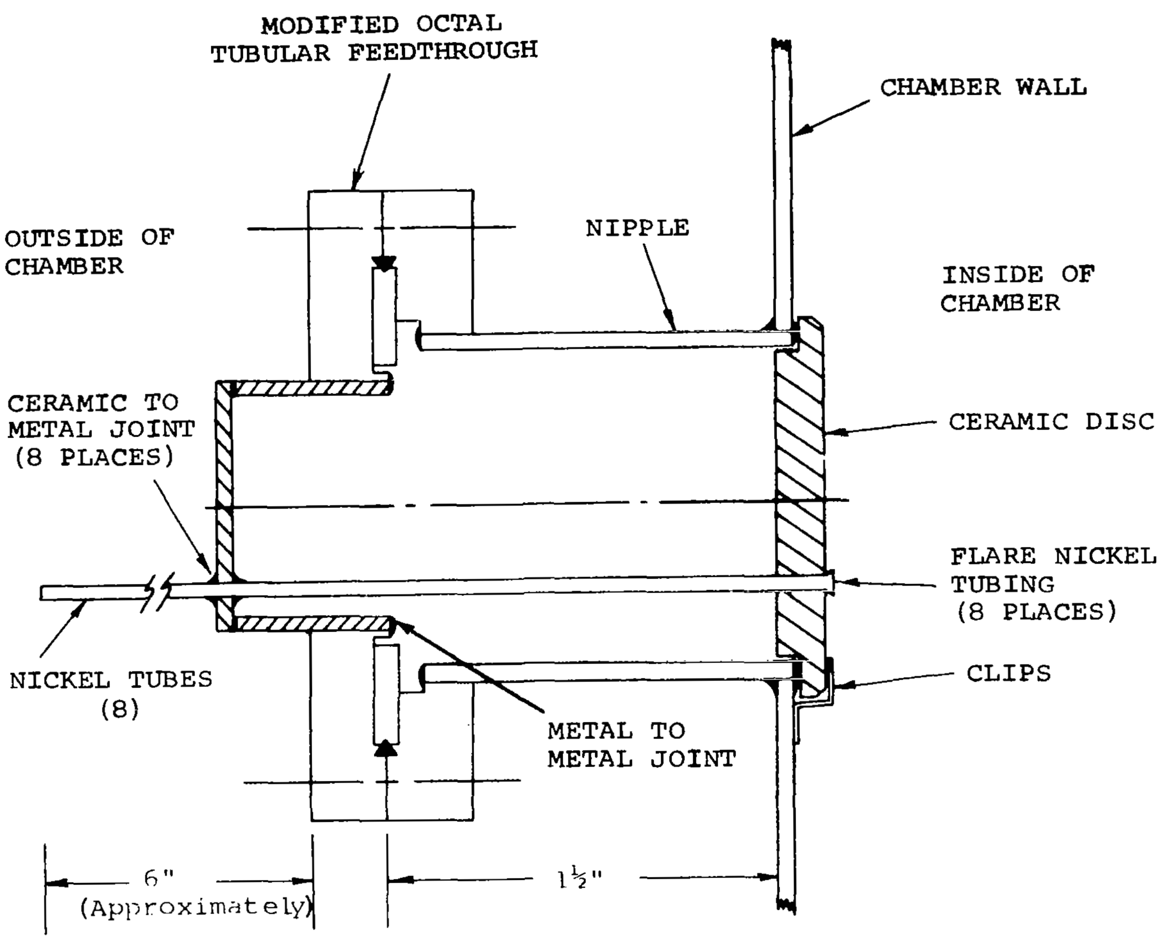



FIGURE II-3. Details of Special Thermocouple Feedthrough Flange on the Vacuum Furnace Chamber

B. STATOR AND BORE SEAL

The following discussion is based on the 1100° F hot-spot temperature stator, with a description of the changes made in going to the 1300° F hot-spot temperature model. A bore seal capsule which was developed as part of this contract (ref. 1) was tested in conjunction with the 1300° F stator model.

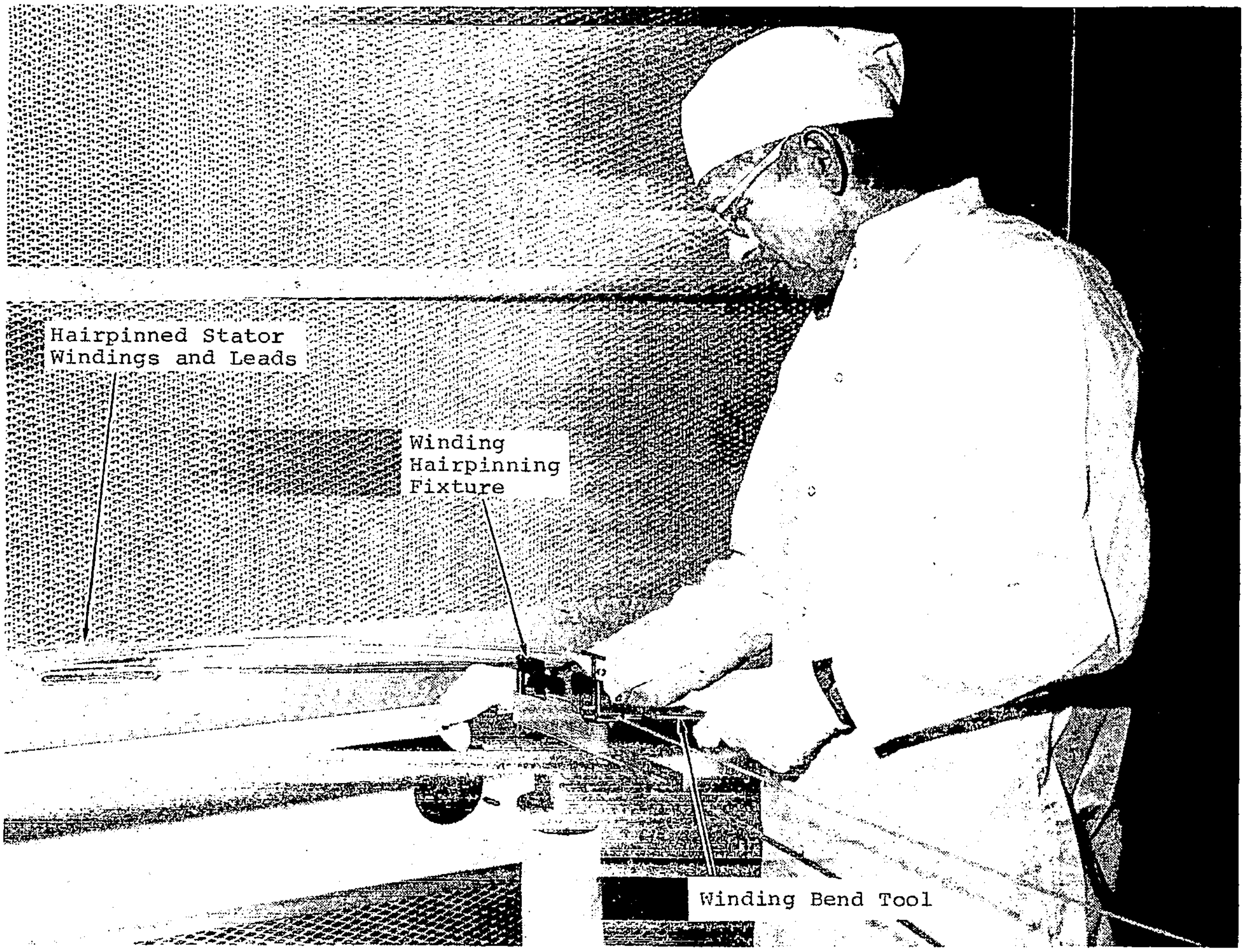



FIGURE II-4. Experimental Technician Forming a Winding with Test Wire in Front of the Clean Bench

1. Stator Physical and Electrical Design and Construction

Figure II-5 is a cutaway view of the stator assembly which shows the primary features of the design. The main frame was made from a Hiperco 27[2] (27% cobalt-iron) alloy forging, and the laminations were held in place in the frame by a retaining ring which was also made from a Hiperco 27 alloy forging. The magnetic stack consisted of Hiperco 27 alloy laminations, 0.008-inch-thick, with a sapphire-like insulation coating of plasma-arc sprayed Linde "A" compound (99.995% $Al_2O_3$). Conductor wire was rectangular 0.091x

[2] Manufactured by Westinghouse Electric Corp., Blairsville, Pa.

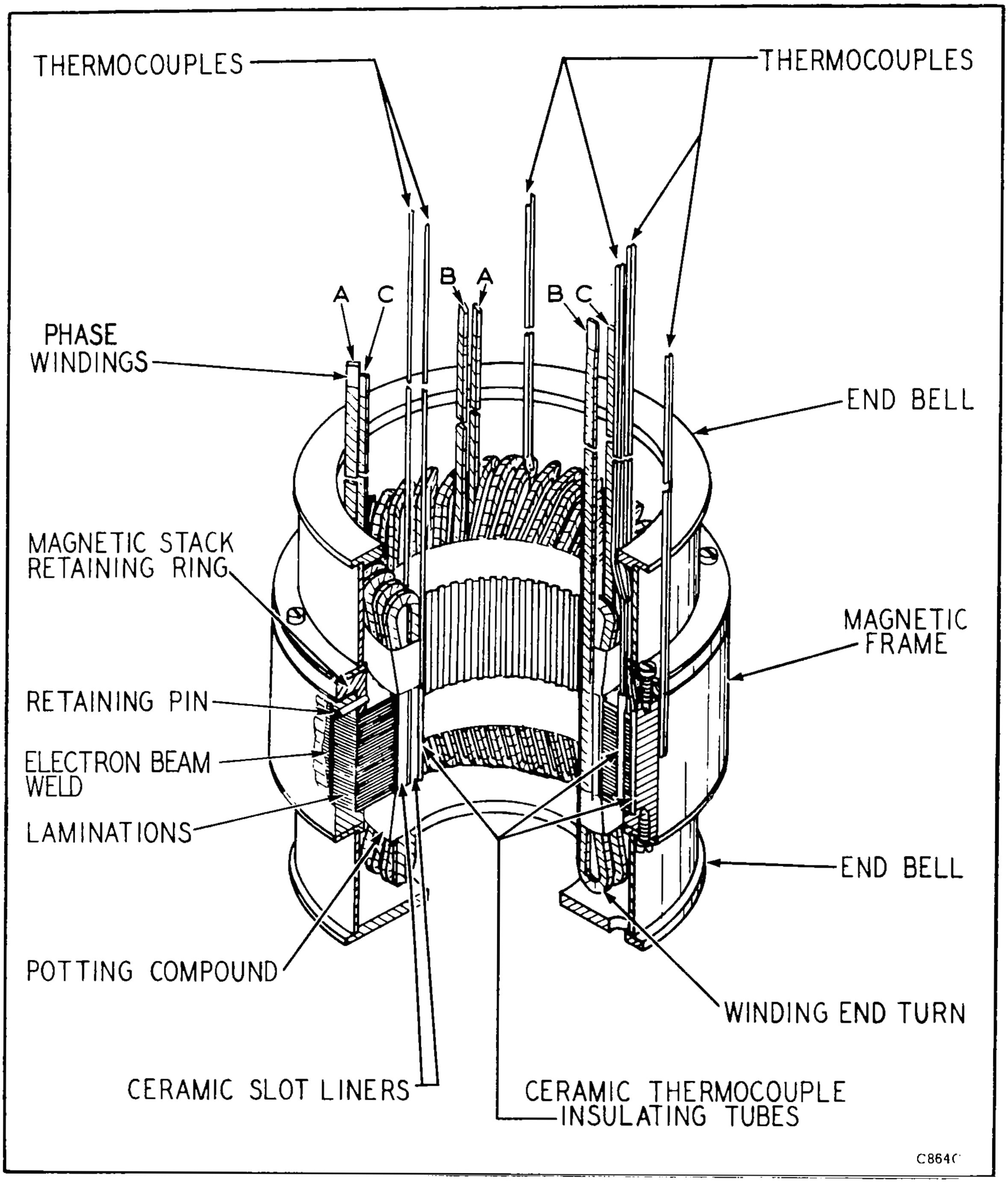



FIGURE II-5. Cutaway View of Stator Without a Bore Seal

0.144 inch nickel-clad silver (20% nickel cross-sectional area) coated with a 0.006-inch-thick layer of Anadur "E"[3] glass, a refractory-oxide-filled glass fiber. Slot insulation was provided by ceramic (99% $Al_2O_3$) U-shaped channels (slot liners), spacers and wedges. W-839[4] (aluminum orthophosphate and zirconium silicate) potting compound was used to fill small voids between the slot liners and the slots, and extended about 3/8-inch beyond the slot-liner ends to provide winding support. Hollow $Al_2O_3$ tubes were used as thermocouple insulators in the slot and stack areas. Two thermocouples were installed in slots in each winding. Additional pairs of thermocouples were located in the stack, between the stack outside diameter of the frame, on the outside diameter of the frame and on winding end turns. (Thermocouple locations are shown in figure II-13). End bells were made from Hastelloy Alloy B, which is a non-magnetic material having a thermal expansion coefficient very similar to that of Hiperco 27 alloy (Fe-27Co). Average thermal expansion coefficient for Hiperco 27 from 72° to 1100° F is $6.14 \times 10^{-6}$ inch/inch-°F, while the coefficient for Hastelloy Alloy B from 72° to 1200° F is $6.7 \times 10^{-6}$ inch/inch-°F.

The lamination stack was representative of one of the two stator stacks of a 15 kVA, 12,000 rpm inductor generator and of the stator for a 12 horsepower, 12,000 rpm induction motor. The laminations had 36 teeth and slots which were proportioned approximately the same as those of an operating generator or motor. The ac stator windings were similar to those in a three phase generator or motor. The winding was divided into three sections of twelve turns each, and the overlapping of the sections was similar to that which occurs between the phases of a generator or motor winding. Thus, it was possible to test the stator with a potential between windings and from winding to ground, the same as in an operating generator.

Rated frequency of the stator for design and test purposes was 400 cps, to insure the availability of a reliable laboratory power supply for endurance testing. However, the stator could have been tested at frequencies up to 1600 cps

---

[3] Special Product of Anaconda Wire and Cable Co., Muskegon, Mich. Zircon potting compound consisting primarily of $SiO_2$ (54.5%), CaO (17.0%), $Al_2O_3$ (14.5%), $B_2O_3$ (8.5%), MgO (4.5%) and other oxides (1.0%).

[4] Product of Westinghouse Research and Development Center, Pittsburgh, Pennsylvania.

if desired. The loss in the stator when current is passed through the winding is the $I^2R$ loss plus a small amount of core loss. At frequencies higher than 400 cps, there would be a slight increase in losses, but at 1600 cps this increase would be less than 10 percent.

The 1300° F hot-spot temperature stator test model design was the same as the 1100° F model except for three materials changes. Nickel-clad silver wire was replaced by Inconel-clad silver wire to obtain greater mechanical strength at 1300° F temperatures. The conductor wire insulation was changed from Anadur "E"[5] glass to Anadur "S" glass[6] to provide increased insulation stability and increased retention of mechanical strength at temperature. The "E" glass, which is a boro-silicate glass fiber, devitrifies and loses strength rapidly at temperatures above 1200° F. "S" glass is composed of over 99% silicon dioxide, which is stable in the temperature range planned for the stator. Presently available encapsulation compounds are not satisfactory for use at 1300° F because of outgassing characteristics and electrical insulation strength. W-839[7] encapsulation compound was replaced by a cement consisting of chopped boron nitride fibers in a colloidal alumina binder, which was developed on the contractors independent program.

Table II-1 is a summary of the materials used in the 1100° F stator and table II-2 summarizes the materials used in the 1300° F model. The "SOURCE" column refers to reports covering work done on Contract NAS3-4162.

2. Stator Assembly

After completion of all shop operations such as machining, punching, welding, plasma-arc spray, and annealing, the detail stator parts were cleaned according to established cleaning procedures. The only material not cleaned was the Anadur coated nickel-clad silver wire and Inconel-clad silver wire. Anadur cleaning was accomplished by the firing process which was also the final cure for the insulation system. The same procedures were applied to both the 1100° F and 1300° F hot-spot temperature models. EDSK 326681 (Appendix B, Page B-9) is an assembly drawing of the stator.

---

[5] Anaconda Wire and Cable Co., op. cit.

[6] Special Product of Anaconda Wire and Cable Co., Muskegon, Mich. consisting primarily of $SiO_2$ (65%), $Al_2O_3$ (25%), MgO (10%) and other oxides (<0.5%).

[7] Westinghouse Research & Development, Pittsburgh, Pa., op. cit.

TABLE II-1. Stator-Magnetic, Insulation, and Conductor Materials Summary - 1100° F Hot-Spot Model

| Part | Material | Source NAS3-4162 |
|---|---|---|
| Frame | Fe-27Co Forging (Hiperco 27) | NASA-CR-54091 p. 59, 323 |
| Frame Ring | Fe-27Co Forging (Hiperco 27) | |
| Lamirations | Fe-27Co 0.008 mil (Hiperco 27) | |
| Interlaminar Insulation | Plasma-arc sprayed $Al_2O_3$ (Linde A) | NASA-CR-54092 p. 98, 593 |
| Slot Liners | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Spacers | $Al_2O_3$-99.5% | NASA-CR-54092 p. 92, 453 |
| Wedges | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Thermocouple Insulators | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Conductor Insulation | Anadur (Ni-clad silver wire)-1100°F Owens Corning E - Glass fiber double serving overcoated with a proprietary oxide-loaded silicone wire enamel. | NASA-CR-54052 p. 86, 287 |
| Potting Compound | Zircon-type (Aluminum Orthophosphate and Zirconium Silicate)(W-839) | NASA-CR-54092 p. 97, 579 |
| Conductors (Rectangular) (0.091x0.144 inch) | Nickel clad silver - 1100°F (20% Nickel "A" cross-sectional area) | NASA-CR-54092 p. 81, 249 |
| End Bells, Hardware<br>Lamination Plates<br>Spring Pin<br>Thermocouples | Hastelloy Alloy B<br>Hastelloy Alloy B<br>C Res. AMS 5506<br>Inconel 600 Sheath - Platinel II Wire System | |

TABLE II-2. Stator-Magnetic, Insulation, and Conductor Materials Summary - 1300° F Hot-Spot Model

| Part | Material | Source NAS3-4162 |
|---|---|---|
| Frame | Fe-27Co Forging (Hiperco 27) | NASA-CR-54091 p. 59, 323 |
| Frame Ring | Fe-27Co Forging (Hiperco 27) | |
| Laminations | Fe-27Co 0.008 mil (Hiperco 27) | |
| Interlaminar Insulation | Plasma-arc sprayed $Al_2O_3$ (Linde A) | NASA-CR-54092 p. 98, 593 |
| Slot Liners | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Spacers | $Al_2O_3$-99.5% | NASA-CR-54092 p. 92, 453 |
| Wedges | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Thermocouple Insulators | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Conductor Insulation | Anadur (Inconel-clad silver wire) 1300°F Owens Corning S - Glass fiber double serving overcoated with a proprietary oxide-loaded silicone wire enamel. | |
| Potting Compound | Boron Nitride (BN) Fiber Cement | |
| Conductors (Rectangular) (0.091x0.144 inch) | Inconel-clad silver - 1300°F (28% Inconel-600 cross-sectional area) | NASA-CR-54092 p. 81, 249 |
| End Bells, Hardware<br>Lamination Plates<br>Spring Pin<br>Thermocouples | Hastelloy Alloy B<br>Hastelloy Alloy B<br>C Res. AMS 5506<br>Inconel 600 Sheath - Platinel II Wire System | |

After being plasma-arc sprayed on one side with $Al_2O_3$, the magnetic laminations were assembled on a stacking arbor, squeezed with a 500-pound load and secured in place. The measured stack height after compression gave a calculated nominal $Al_2O_3$ layer thickness of 0.000117-inch/lamination.

Figure II-6 shows the stack installed in the frame with the retaining ring in place and the arbor removed (left assembly). The stack on the right side is a practice stack which was used with enamel covered copper wire to develop coil forming techniques. The cleaned tools in the foreground give some idea as to stack size. The stator frame outside diameter is eight inches.

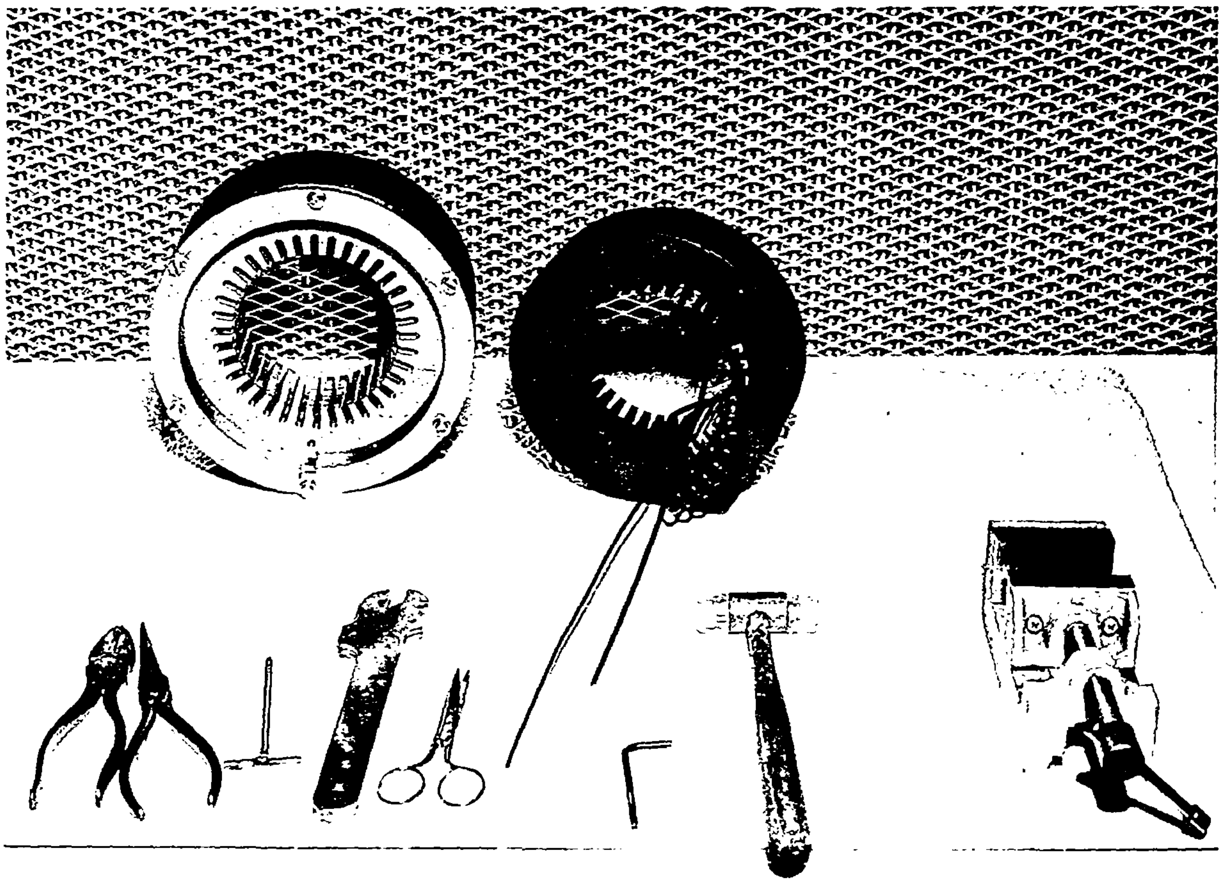


FIGURE II-6. Test Stator Stack and Practice Winding Stator Stack

Figure II-7 shows the test windings installed in the stator prior to the Anadur insulation system bake-out cycle. The slot thermocouple $Al_2O_3$ tubes in one winding are indicated by arrows. Figure II-8 shows the completed stator less thermocouples, sitting on three posts which were used to support the stator on the hearth plate in the thermal vacuum chamber. The stator frame discoloration occurred during the Anadur insulation bake-out period at 1250 $\pm$ 25° F in air. The stator assembled weight less thermocouples was 39.0 pounds.

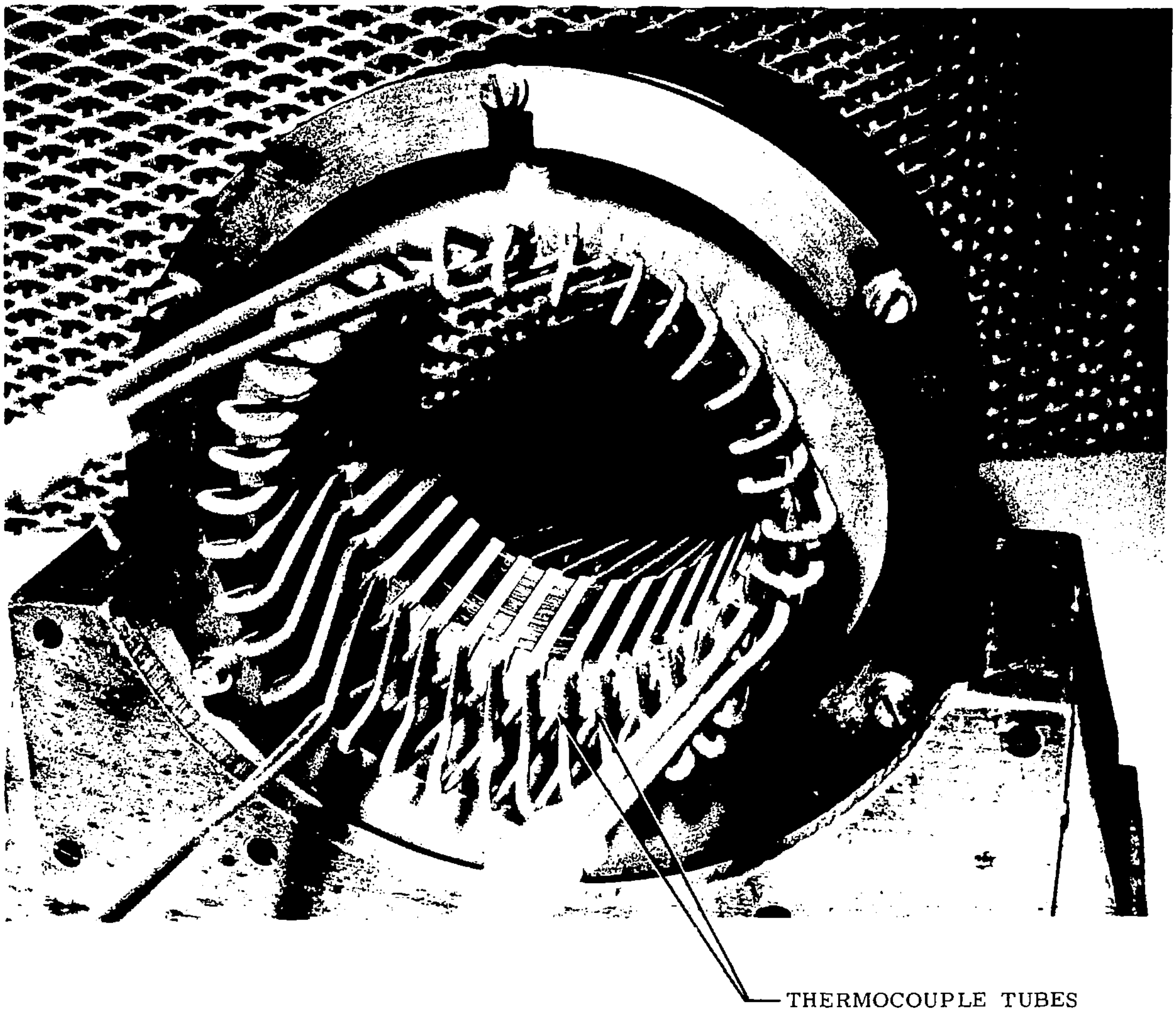



FIGURE II-7. Test Winding Installed in Stator Prior to Conductor Serving Bake-Out

As each stator assembly (1100° and 1300° F models) was completed, it was installed in a liquid-nitrogen-trapped diffusion-pumped vacuum furnace for a preliminary degassing bake-out. After equilibrium furnace temperatures of 1100° and 1300° F respectively were established, each stator assembly was outgassed for 50 hours. In each case the chamber pressure was stable in the $10^{-6}$ torr range before the 50 hours was completed. After the furnace had cooled, the chamber was back-filled with argon. As each stator was removed from the chamber, it was stored in an argon-filled plastic bag containing dessicant envelopes pending installation in a thermal vacuum test chamber.

One construction change was made in the 1300° F model. The laminations in the stack in the 1100° F stator were held in compression in the stator housing by the retaining ring. The laminations stack for the 1300° F model was compressed on a stacking arbor and then electron beam welded in twelve places approximately 30 degrees apart. Figure II-9 shows the stack on the fixture after welding. The welded stack was then held in place as an assembly in the frame by the retaining ring.

### 3. Thermal Vacuum Chamber Installation

The clean bench was positioned in front of the test chamber to supply a filtered air flow across the chambers during stator installation. Figure II-10 is a cutaway drawing of the thermal vacuum chamber which shows a stator installed in the furnace hot zone. Thermocouples were installed in the stator at the clean bench. The stator support posts were bolted to the furnace hearth plate, and the stator was set in place on the posts inside the chamber. The stator winding leads were inserted in short lengths of alumina tubing to insulate them as they passed through the top heat shields. Thermocouples and winding leads were then passed upward through perforations in the top heat shields, and the shields were set in place. The winding leads were brazed to OFHC (oxygen free high conductivity) copper feed-through bus bars inside the chamber, using a bell jar with supporting frame and foil curtains to maintain an argon atmosphere for the brazing operation. Lithobraz BT (72Ag-28Cu) wire was used as the brazing alloy. Thermocouples were passed through the hollow Kovar tubes and induction brazed externally. Shaped glass tubes with feeder tubes were fitted inside a brazing induction coil so argon could be directed across the thermocouple and Kovar tube junction for the brazing operation. Thermocouple and winding lead integrity was verified and the chamber was closed, evacuated and leak checked.

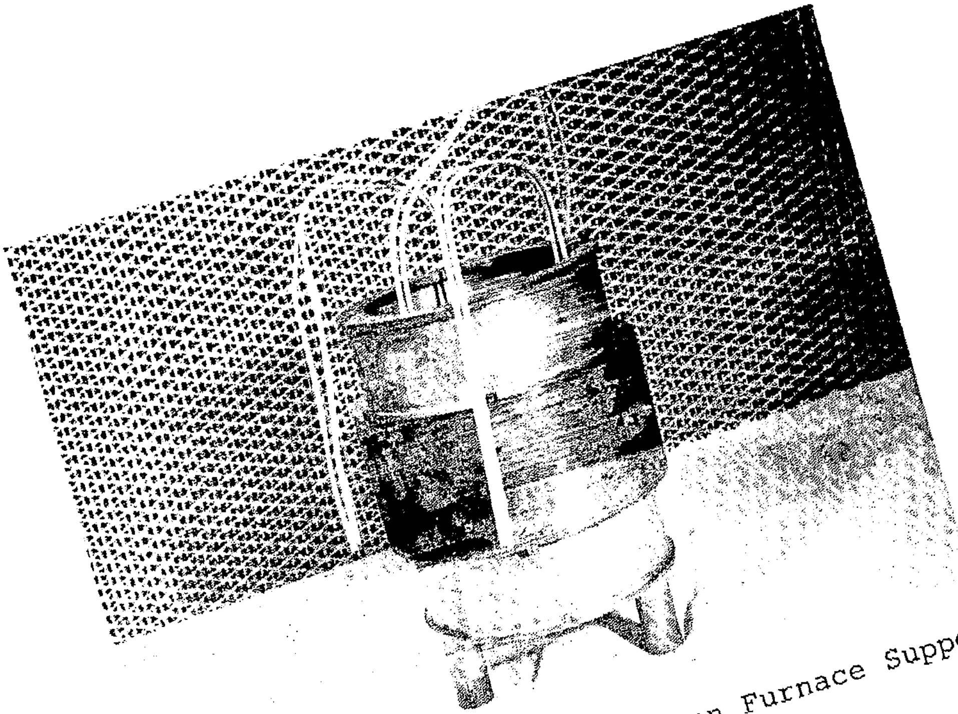
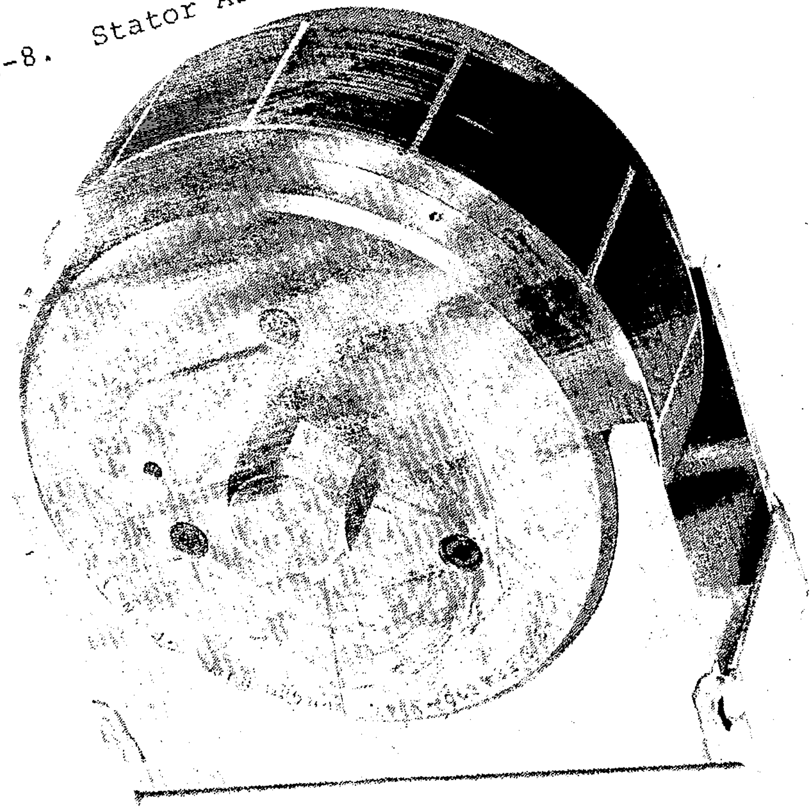


FIGURE II-8. Stator Assembly on Furnace Supports



tor Stack Showing
lds

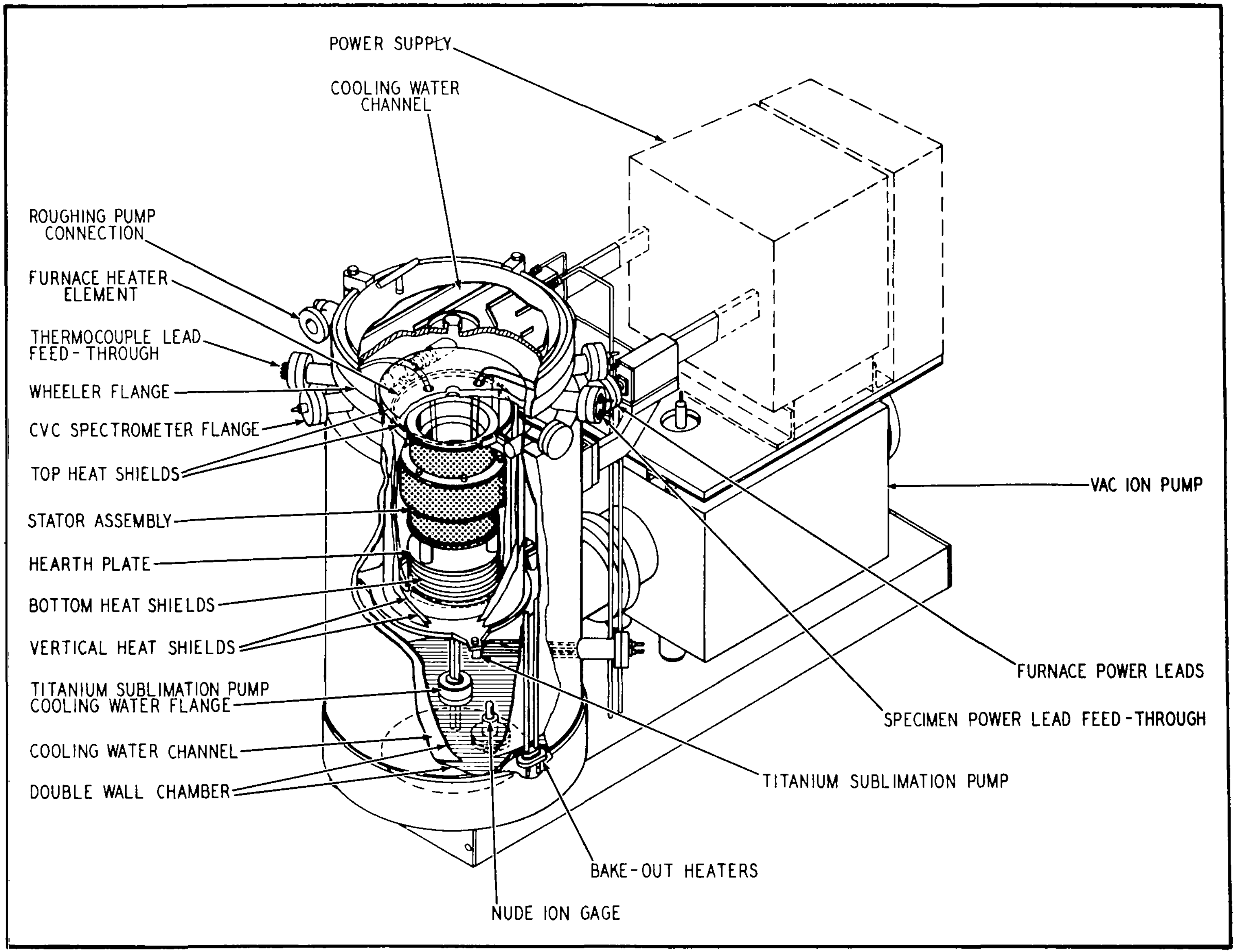



FIGURE II-10. Cutaway View of Vacuum Furnace Showing the Stator Test Specimen Installed

## 4. Stator Test Connections

Figure II-11 is a schematic showing the test method for applying power to the stator windings. Three-phase power from a 400 cps, 292 volt ac line-to-neutral generator was brought into the test area with a 50-amp fuse in each phase. Voltage between phases was 505 volts ac. Two three-phase reactive load banks were connected in phase series with each stator phase outside the test chamber, to simulate the electrical load that normally would be supplied by a conventional generator. Each load bank had multiple taps to permit adjusting each phase current to the desired value. Reactive loads were used rather than resistive loads so that stator winding current densities (amps/square inch) could be maintained at typical generator values without dissipating an excessive amount of heat into the laboratory area.

Thermocouple leads are not shown in the schematic, but they were connected to a multi-point recorder which was set up to sequence readings on a timed cycle basis.

## 5. Stator Test Procedure - 1100° F Hot-Spot Model

After electrical continuity of the winding leads and thermocouples was verified, the thermal vacuum chamber Wheeler flange was installed. The chamber was sorption-pumped to approximately 6 microns and the sputter-ion pump was started. Several titanium sublimation pump bursts were used to bring the chamber pressure down to the $10^{-6}$ torr range as indicated by a Bayard-Alpert type nude ion gauge. Thermocouple brazed joints were leak checked with helium and several joints required additional sealing. The titanium sublimation pump was then cycled, 40 seconds on including warmup time and 85 seconds off, for a nine hour period. System pressure continued to decrease after the leaks were sealed, and when the pressure reached a value of $3 \times 10^{-8}$ torr a 32-hour bake-out at 250° C was started. The minimum cold pressure reached after bake-out was $1.1 \times 10^{-10}$ torr. As mentioned earlier, RGA[8] (residual gas analysis) spectrograms were taken with the chamber under vacuum at ambient temperature and at 1100° and 1500° F before the stator was installed. Additional RGA spectrograms were taken after stator installation at various stages of increasing stator temperature and corresponding chamber pressures.

[8] Consolidated Electrodynamics Corp., model 21-614.

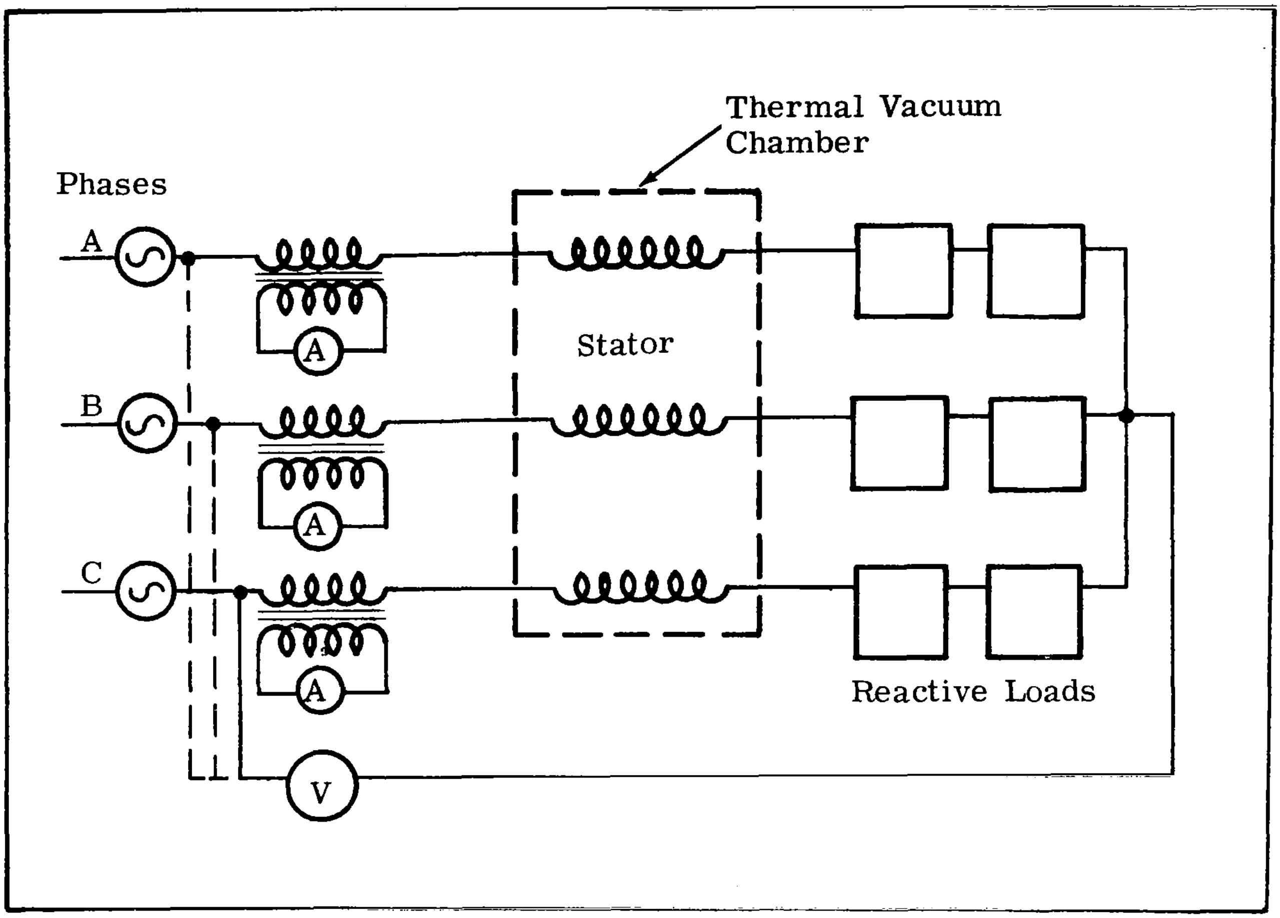



FIGURE II-11. Schematic of Stator Electrical Connections

Bench test static electrical measurements covering conductor resistance, dc insulation resistance, and ac potential electrical leakage had been taken prior to installation of the stator in the chamber. These measurements were repeated at a cold chamber pressure of $1.1 \times 10^{-10}$ torr to provide base line data under high vacuum conditions. Chamber pressure subsequently dropped to a minimum value of $8.2 \times 10^{-11}$ torr before power was supplied to the stator windings.

A current of 31.2 amps was applied to each winding with no furnace heater element power. When the average stator slot temperature reached a near-stable value of 450° F, static electrical tests were repeated. The average slot temperature (4 thermocouples) leveled off at 451° F and a chamber pressure of $4.6 \times 10^{-10}$ torr. With the stator winding current held constant, 400 amperes at 1.0 volt ac was applied to the furnace heater element. This power setting turned out to be at the low end of the automatic temperature controller range, and current fluctuations were troublesome. Furnace power was subsequently increased to 440 amps at 1.4 volts, which improved the controller stability. A set of static electrical readings was taken at a stable average slot liner temperature of 985° F.

The furnace power setting was maintained constant at 616 watts and the stator winding current was increased to 35.6 amperes per phase. In approximately 18 hours, all the stator thermocouples were showing stable readings, with a hot-spot reading of 1040° F. Winding current was increased to 41.2 amperes per phase with furnace power held constant at 616 watts. When the hot-spot temperature (average of 4 slot liner readings) reached 1092° F and was approaching stability, the logging of official endurance time at temperature was initiated. Static electrical measurements were taken when the hot-spot temperature reached 1098° F.

Daily data readings were taken for all thermocouples, phase current and voltage, test chamber pressure, heater element current and voltage, etc. Thermocouple readings were also automatically recorded for 15 minutes out of each test hour on a recorder. Once each week a RGA[9] spectrogram was taken and static electrical readings were measured and recorded.

Titanium sublimation pump (TSP) bursts of 2 minute duration were introduced in the chamber at intervals to determine the effect on chamber base pressure.

6. Stator Data and Discussion - 1100° F Hot-Spot Model

The current passed through the stator windings to duplicate $I^2R$ losses (Joule heating) for the endurance test was 41.2 amperes per phase. This current, divided by a conductor cross-sectional area (silver and nickel) of 0.0123 square inches, resulted in a phase current density of 3350 amperes per square inch. Assuming all current is carried in the silver core, current density would be 4190 amps per square inch. The calculated phase winding $I^2R$ loss at 1100° F was 67.8 watts per phase, or 203.4 watts total for the stator. This value was based on a measured winding resistance value of 0.041 ohms per phase at test temperature.

---

[9] Ibid.

Figure II-12 is a plot of thermal vacuum chamber Bayard-Alpert type nude ion gauge pressure versus endurance test time at test temperature. Chamber total pressure decreased at an almost constant rate for the first 2000 hours, after which pressure reduction continued but at a slower rate. Titanium sublimation pump (TSP) bursts of approximately 2 minutes duration were introduced from time to time. These bursts caused rapid pressure reductions, but until late in the test period the pressure return to the base level was as rapid as the reduction had been. Once the base pressure dropped below approximately $4 \times 10^{-9}$ torr, the TSP burst pressure reductions would hold for several hours before the pressure began a slow recovery to base level. The pressure reductions caused by TSP bursts have been plotted at several points during the test period.

Figure II-13 is a sketch showing representative locations of thermocouples in the stator, with an accompanying tabulation identifying the location. Sixteen thermocouples were installed as the stator was put into the test chamber, but six were rendered useless during installation, primarily because of difficulties in obtaining good brazed joints between the thermocouples and the chamber feedthrough Kovar tubes. Pairs of thermocouples had been installed at each location as a precaution in case of brazing problems, and each sensing location had at least one usable thermocouple.

Table II-3 shows a representative steady-state temperature profile in the stator. This set of data was taken after 1480 hours of endurance tests. A comparison of slot liner and end turn temperatures shows that the end turn temperature was 25° F lower than the slot temperature and at about the same level as the frame outside diameter. The heat flow path was from the conductor volume in the stator slot to the end-turn area, where the heat was radiated to the chamber top and bottom heat shields. Water cooled cold walls were located just outside the heat shields at the top, bottom and sides of the chamber. The temperature gradient from the slot liner to the frame outside diameter was approximately the same as from the slot to the winding end turn.

This temperature pattern suggests that the relatively high radiation emissive power (4th power of absolute temperature - ° R) in the 1100° F operating range can be used to advantage. Heat transfer in high temperature generator and motor designs can be shared between conduction and radiation modes by placing heat sinks where radiation from the end turns can be absorbed. Depending on the absolute operating temperature, radiation may be a more efficient means of winding heat transfer than conductance paths in the stack.

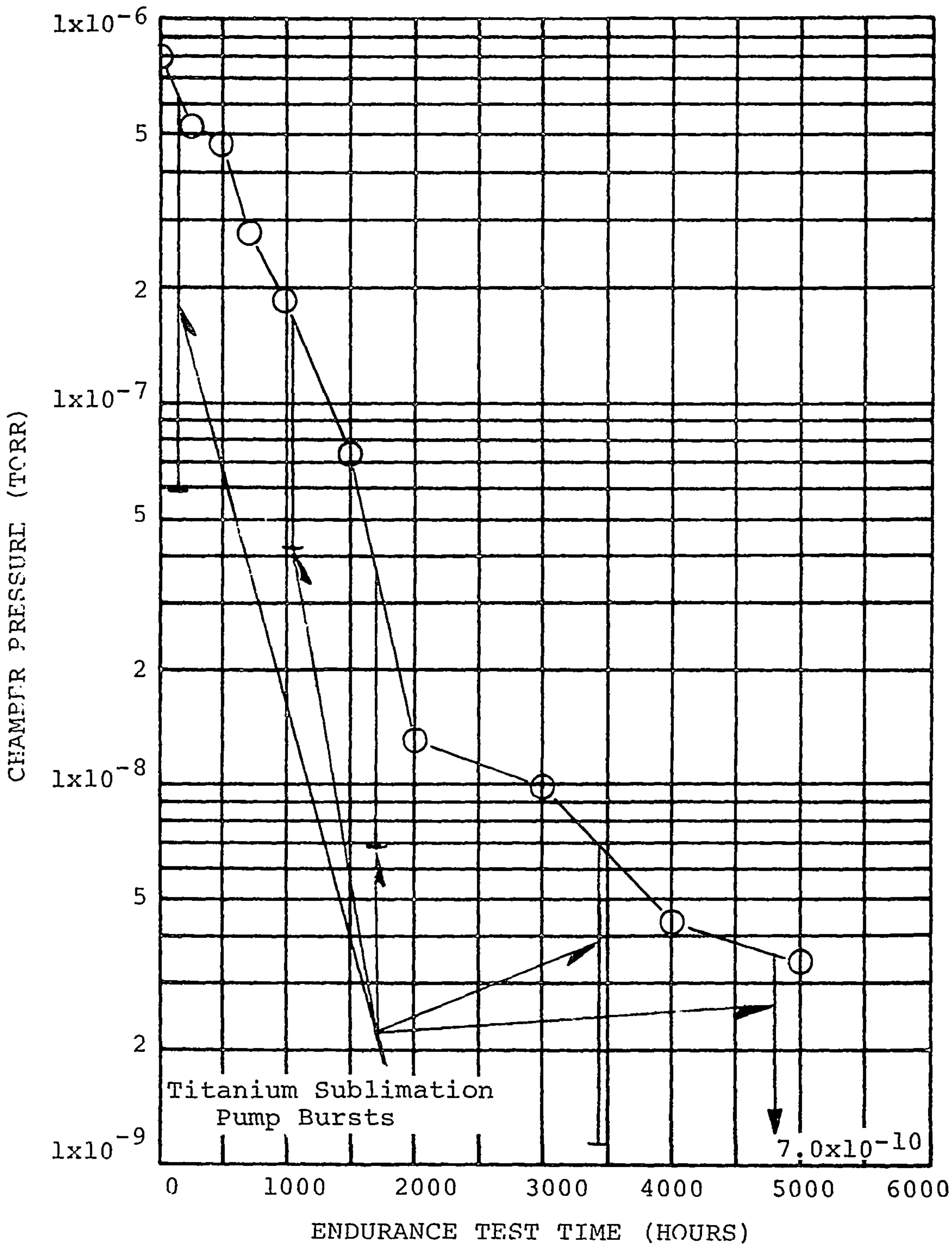
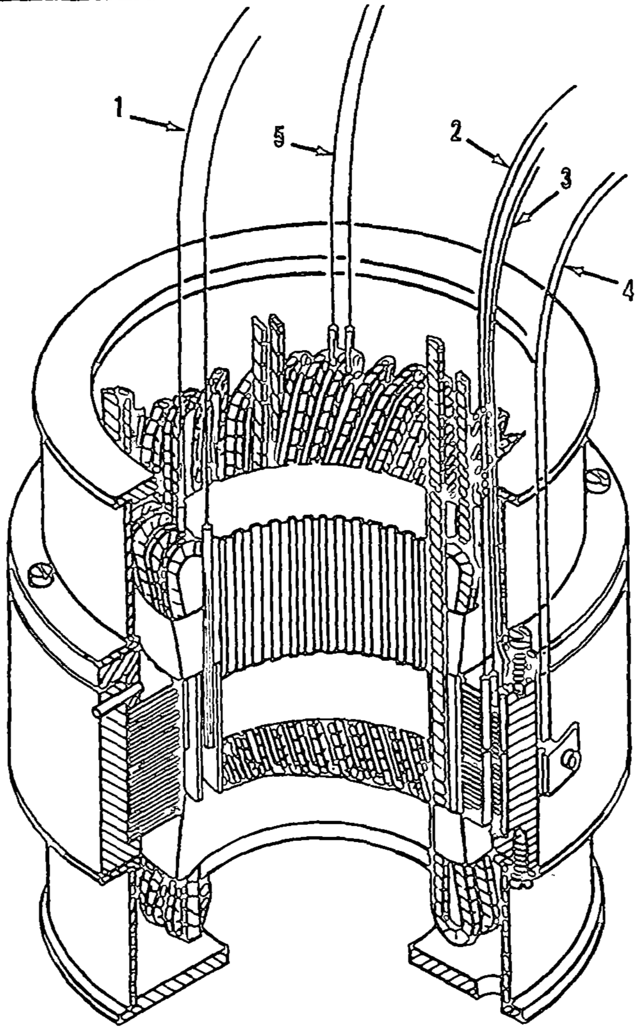



FIGURE II-12. Stator Chamber Pressure Versus Endurance Test Time - 1100° F Model




| Thermocouple Numbers | Quantity Installed | Thermocouple Identification |
|---|---|---|
| 1 | 6 | Slot Liner - 2 per phase. "B" Phase Thermocouple lost during assy. |
| 2 | 2 | Stack Bore Tube |
| 3 | 2 | Lamination - Frame Slot. One lost during assy. |
| 4 | 2 | Frame Outside Diameter One lost during assy. |
| 5 | 4 | "B" and "C" Phase End Turns. "B" phase lost during assy. |

FIGURE II-13. Cutaway Drawing Showing Locations of Stator Thermocouples

TABLE II-3. Representative Stator Temperature Distribution at 1100° F Hot-Spot Test Temperature After 1480 Hours of Endurance Test

| Thermocouple Location | Temperature (°F) |
|---|---|
| Phase "A" Slot Liner | 1103 |
| Phase "A" Slot Liner | 1103 |
| Phase "C" Slot Liner | 1103 |
| Phase "C" Slot Liner | 1103 |
| Mid-Stack Bore | 1080 |
| Mid-Stack Bore | 1083 |
| Lamination OD Slot | 1083 |
| Frame OD | 1080 |
| Phase "C" End Turn | 1078 |
| Phase "C" End Turn | 1078 |

Figure II-14 is a dimensionless plot of conductor resistance versus endurance test time. The effect of temperature on resistance is shown by the temperatures noted on the curve. The time at 870° F amounted to 25 to 30 hours duration when the winding power was temporarily disconnected during the transformer failure investigation discussed later in this report.

Table II-4 is a tabulation of stator insulation system performance during the course of the test, referred to a slot hot-spot temperature of 1100° F. Values were obtained with 500 volts dc applied between phases and from each phase to ground.

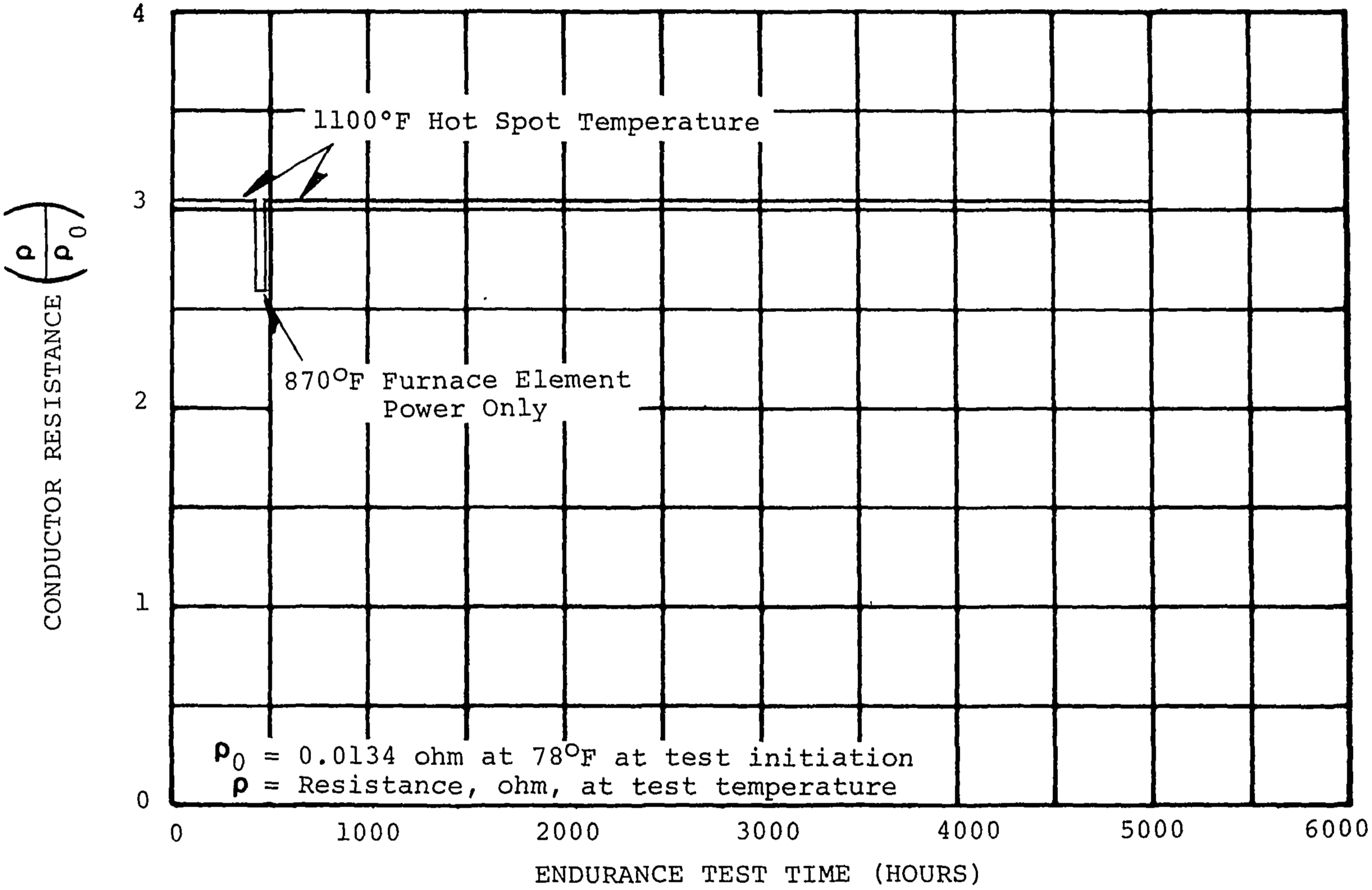



FIGURE II-14. Stator Conductor Resistance Versus Endurance Test Time at Noted Conductor Hot-Spot Temperatures

TABLE II-4. Stator Insulation Performance in Vacuum with Slot (hot-spot) Temperature at 1100° F

| | | | |
|---|---|---|---|
| Endurance Test Time (hours) | 0 | 2500 | 5000 |
| Average Insulation Resistance (ohms) with 500 volts d-c Applied | | | |
| Phase to Phase | $6.8 \times 10^6$ | $6.8 \times 10^6$ | $6.8 \times 10^6$ |
| Phase to Ground | $3.2 \times 10^6$ | $3.2 \times 10^6$ | $3.2 \times 10^6$ |

Note: Stator conductors were rectangular nickel-clad silver wire (0.091 inch by 0.144 inch) with Anadur E glass insulation. Slot insulation consisted of 0.022-inch-thick 99% alumina slot liners and 0.047-inch-thick 99% alumina strips between phases.

Figures II-15 and II-16 are plots of insulation system ac micro-ampere leakage currents with 500 volts ac applied between phases and from each phase to ground. The phase-to-phase values are lower than the phase-to-ground values because the $Al_2O_3$ insulation thickness between phases was 0.047-inch, while the phase-to-ground $Al_2O_3$ insulation was 0.022-inch. No specific reason has been determined for the increase in leakage current at the 2000-hour point. The chamber total pressure level curve also changed slope at the 2000-hour point. There may have been an influence exerted by the materials outgassing rate at that time which affected the ac insulation performance. The increase in leakage current was not detrimental to the test.

In summary, there was no degradation in the performance of the stator electrical insulation system as a result of 5000 hours of testing in a high vacuum environment with a hot-spot temperature of 1100° F.

The 1100° F stator test chamber environment was sampled once each week with a residual gas analyzer (RGA)[10]. (See

[10] Consolidated Electrodynamics Corp., model 21-614, op. cit.

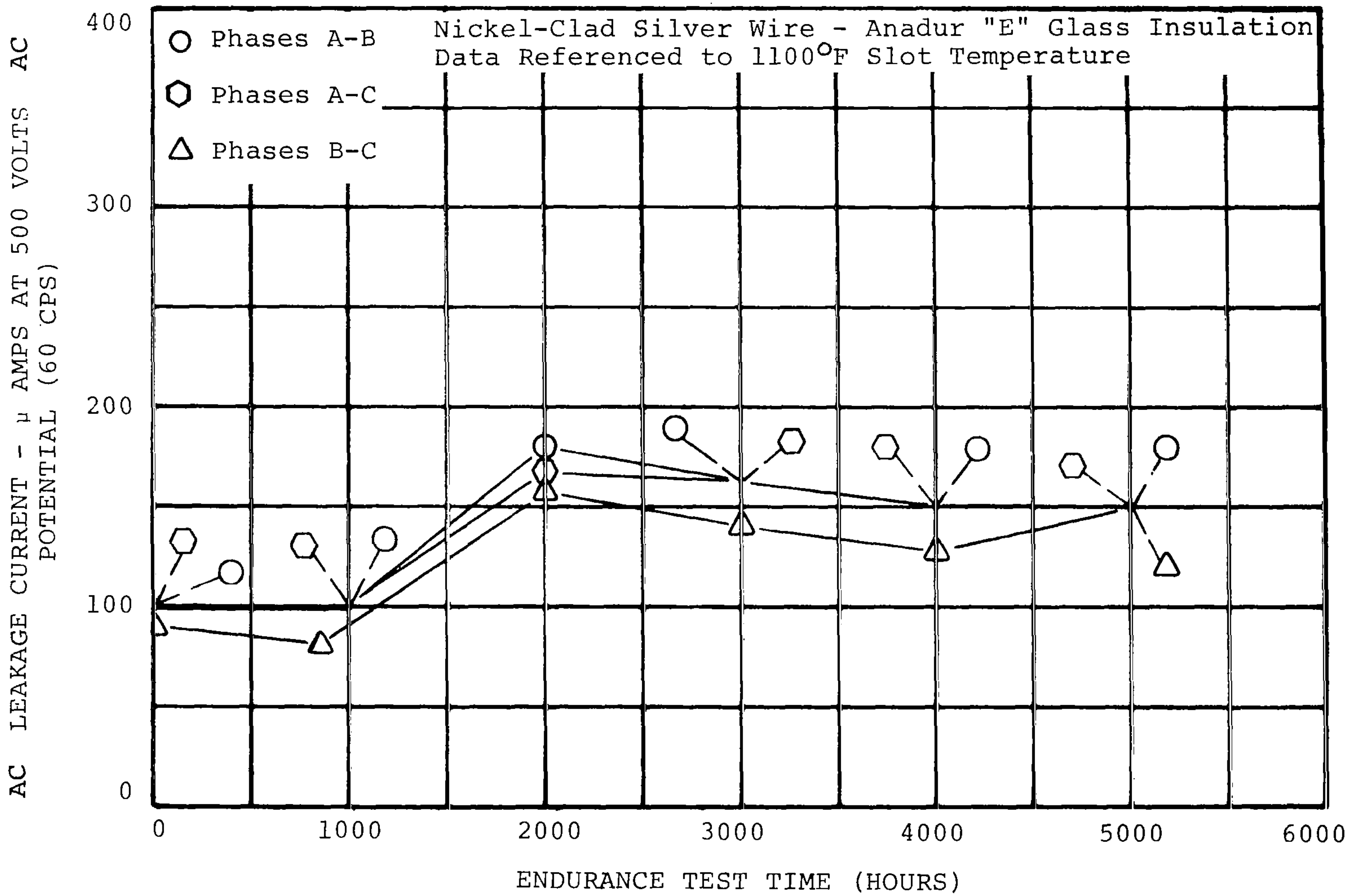



FIGURE II-15. Stator Insulation System Performance, Phase-to-Phase, Versus Endurance Test Time - 1100° F Model

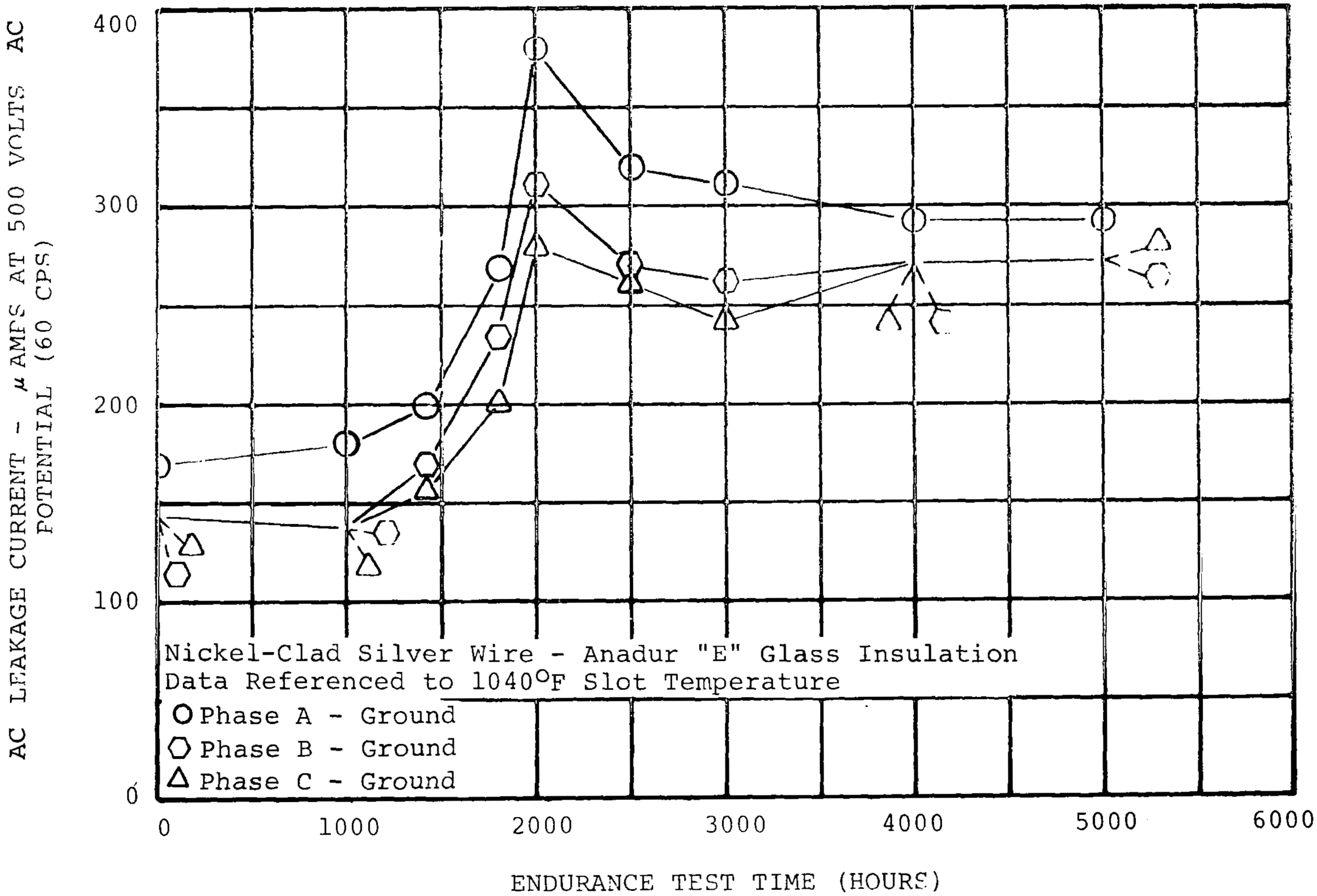



FIGURE II-16. Stator Insulation System Performance, Phase-to-Ground, Versus Endurance Test Time - 1100° F Model figure II-1.) The mass spectrometer sensing head was attached to the test chambers by means of tubes and valves, so that either chamber environment could be scanned with the same set-up. The valves also served to isolate the sensing head if a failed filament had to be replaced. The sensing head was calibrated using A, $N_2$, $CO_2$ and Xe gases. Figure II-17 is a plot showing the trend of the major gas component partial pressures as a function of time. At the beginning of the endurance test, the predominant gases were $N_2$ and CO with a mass/charge (m/e) ratio of 28, followed by $CO_2$ at m/e = 44. Water vapor, hydrogen and argon were present in about equal amounts. The $N_2$ and CO partial pressure increased slightly during the first 500 hours of test, as did the $H_2O$ pressure. The other gas pressures decreased rapidly with time. From the 500-hour point, the $N_2$+CO and $H_2O$ pressures also showed a rapid decrease. The $H_2O$ pressure reversed slope at about 1750 hours, and doubled in magnitude from that point to the end of the test. At the completion of the 5000-hour test, $H_2O$ was the predominant gas in the chamber.

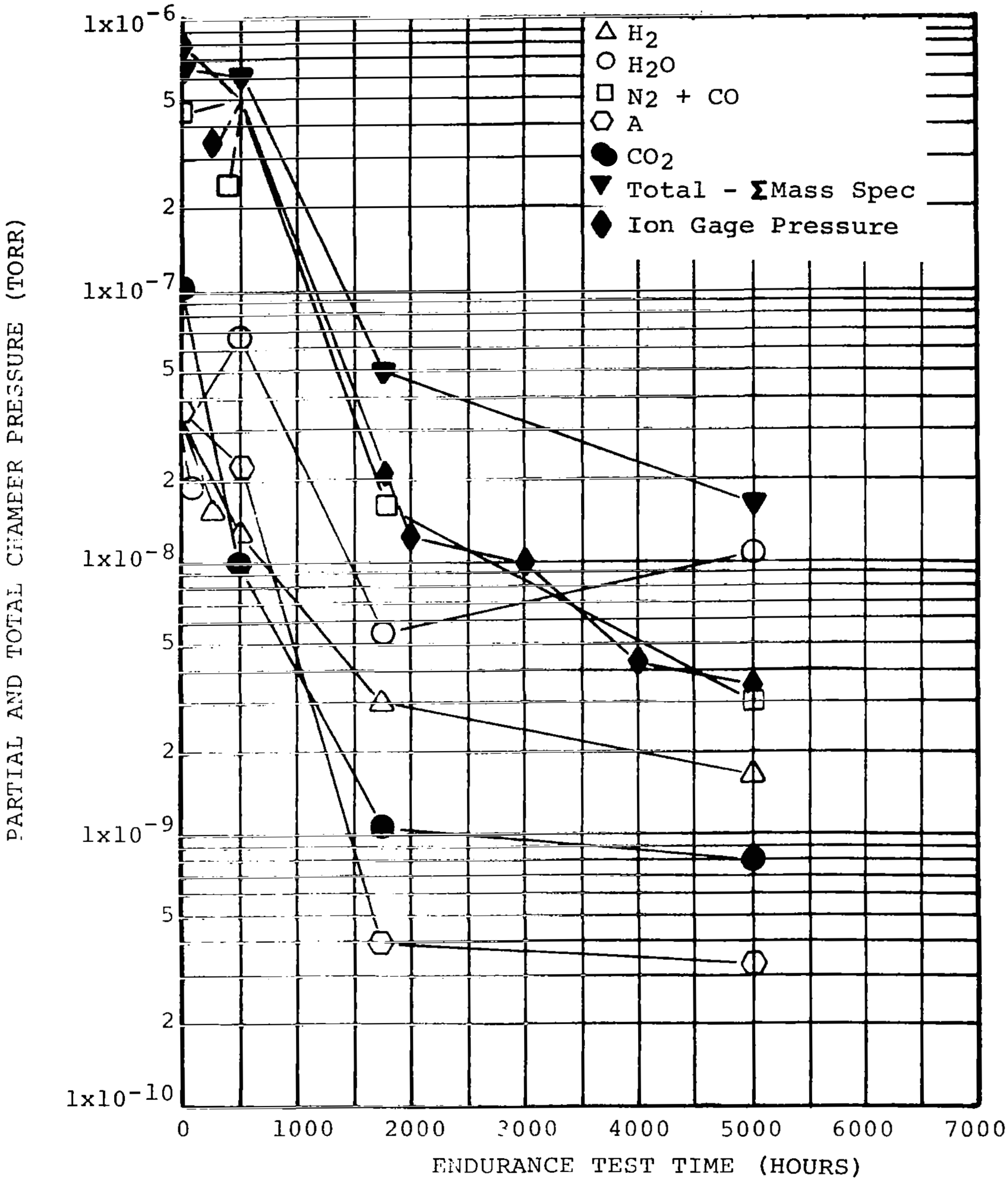
The major outgassing material in the stator, aside from slow-bleeding voids, was the W-839[11] potting compound. Water content in the chamber environment was evidently supported by water extraction from the potting compound as a function of time.

Referring to figure II-12, which is a plot of the chamber nude ion gauge pressure versus endurance test time, the slopes of the partial pressure curves except water vapor have the same general trend as the ion gauge curve. However, the ion gauge pressure is lower than the summation of the partial pressures from the mass spectrometer. This difference in pressure occurred because of relative sensing locations. The ion gauge was located near the bottom of the chamber, in line with the ion pump throat, with a short conductance path to the pump. The RGA sensing head was attached to a feedthrough near the top of the test chamber, with a relatively long conductance path to the ion pump, resulting in a higher total pressure at the sensing head.

## 7. Post-Test Investigation - 1100° F Hot-Spot Stator Model

After completion of the 5000-hour test but before power was removed from the chamber heater element, one of the stator windings was put through a voltage breakdown test. A 60-cps ac high-voltage tester equipped with an arc suppressor was

[11] Westinghouse Research & Development, Pittsburgh, Pa., op. cit.




(Note: Temperature was constant at 1100° F.)

FIGURE II-17. Time-Pressure Plot of Mass Spectrometer Residual Gas Analysis Scans in Chamber No. 1. (Stator) used for the test. With voltage applied from phase A to ground, break-over occurred at 2000 volts. With voltage applied between phases A and B, break-over also occurred at 2000 volts. The A phase slot temperature was 1090° F when these tests were made. Although the arc suppressor prevented development of a full arc, chamber pressure rose from the $10^{-9}$ torr range to the $10^{-7}$ torr range temporarily. Following the high voltage tests the chamber heater element power was shut off in preparation for opening of the chamber.

Figure II-18 is a view of the test chamber and stator taken after completion of the 5000-hour test. Stator winding leads and thermocouple leads have been clipped and the top heat shields have been removed to show the interior of the chamber. The chamber cleanliness and the complete lack of any deposits can be noted by the light reflections on the bright surfaces of the heating element and heat shields.

Figure II-19 is an external view of the stator after removal from the test chamber. Stains on the winding lead ceramic insulating tubes indicate the location of the two chamber top heat shields.

Figure II-20 shows the stator stack, slot wedges, winding end turns and slot-end encapsulating compound. The compound shows some cracks, but these occurred at points where the uncured compound had been grooved during installation to "direct" the formation of cracks.

As part of the post-endurance test investigation the stator was put through a single-axis vibration scan. Figure II-21 is a photograph of the stator and vibration test fixture mounted on the shaker. Arrows and numbers identify the accelerometers used for the test. The No. 1 accelerometer was mounted on the test fixture bed plate and was used to monitor input g's to the assembly. No. 2 was mounted on the top of the end bell, adjacent to the flange away from the frame. No. 3 was a light-weight accelerometer mounted on a winding end turn. No. 4 was mounted on the lamination stack inside diameter and centered axially along the stack. The vibration axis was in the vertical direction. After a preliminary vibration check, the stator was rotated 90 degrees counterclockwise to obtain a better response from the end turn accelerometer. The end bell No. 2 and stack No. 4 accelerometers were moved back 90 degrees to be in the same location as shown in the photograph.

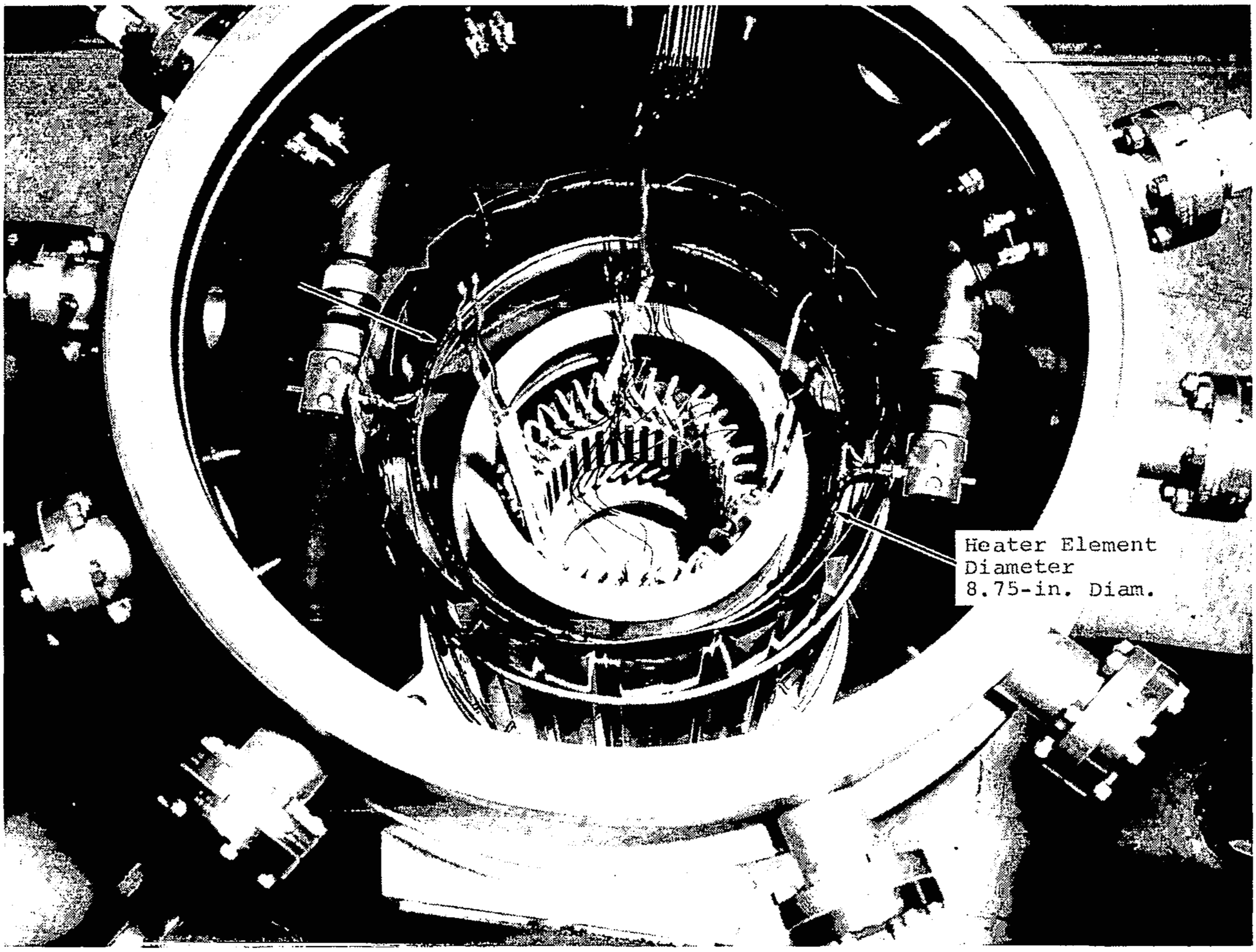



FIGURE II-18. Stator in Test Chamber After Completion of 5000-Hour Test - 1100° F Model

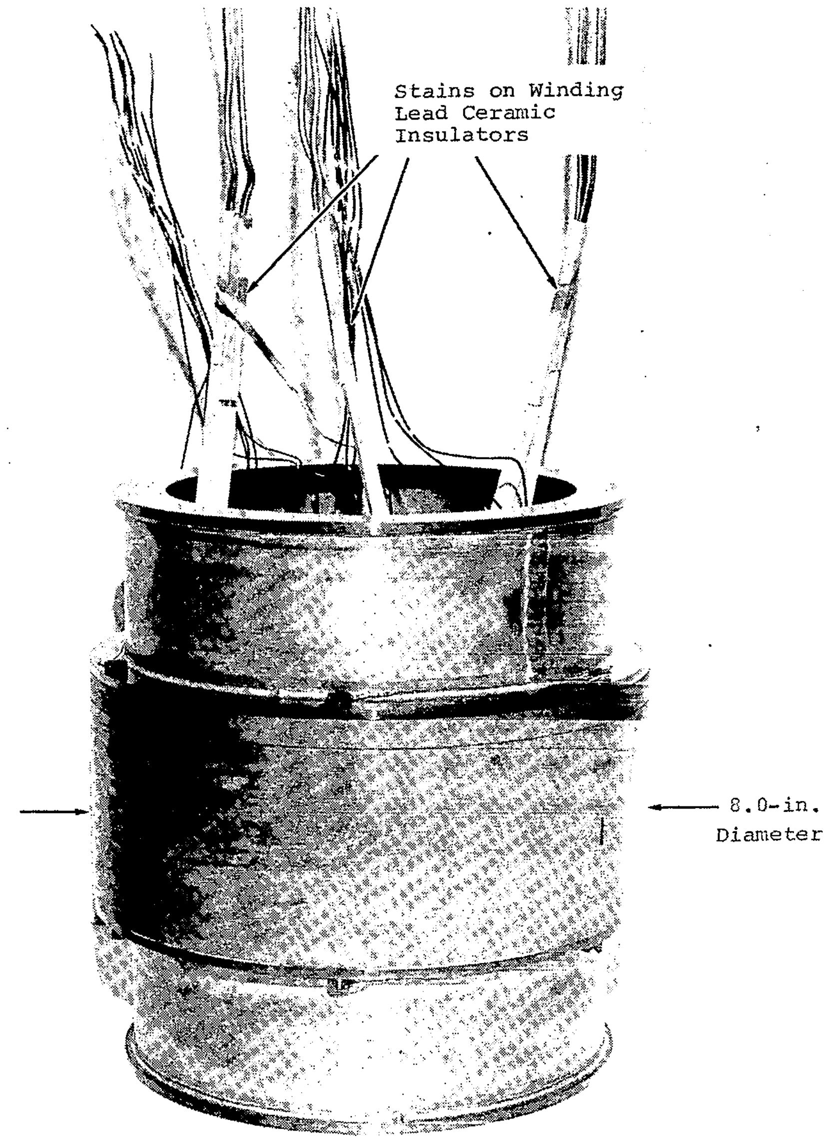



FIGURE II-19. External View of Stator After Removal from Test Chamber - 1100° F Model

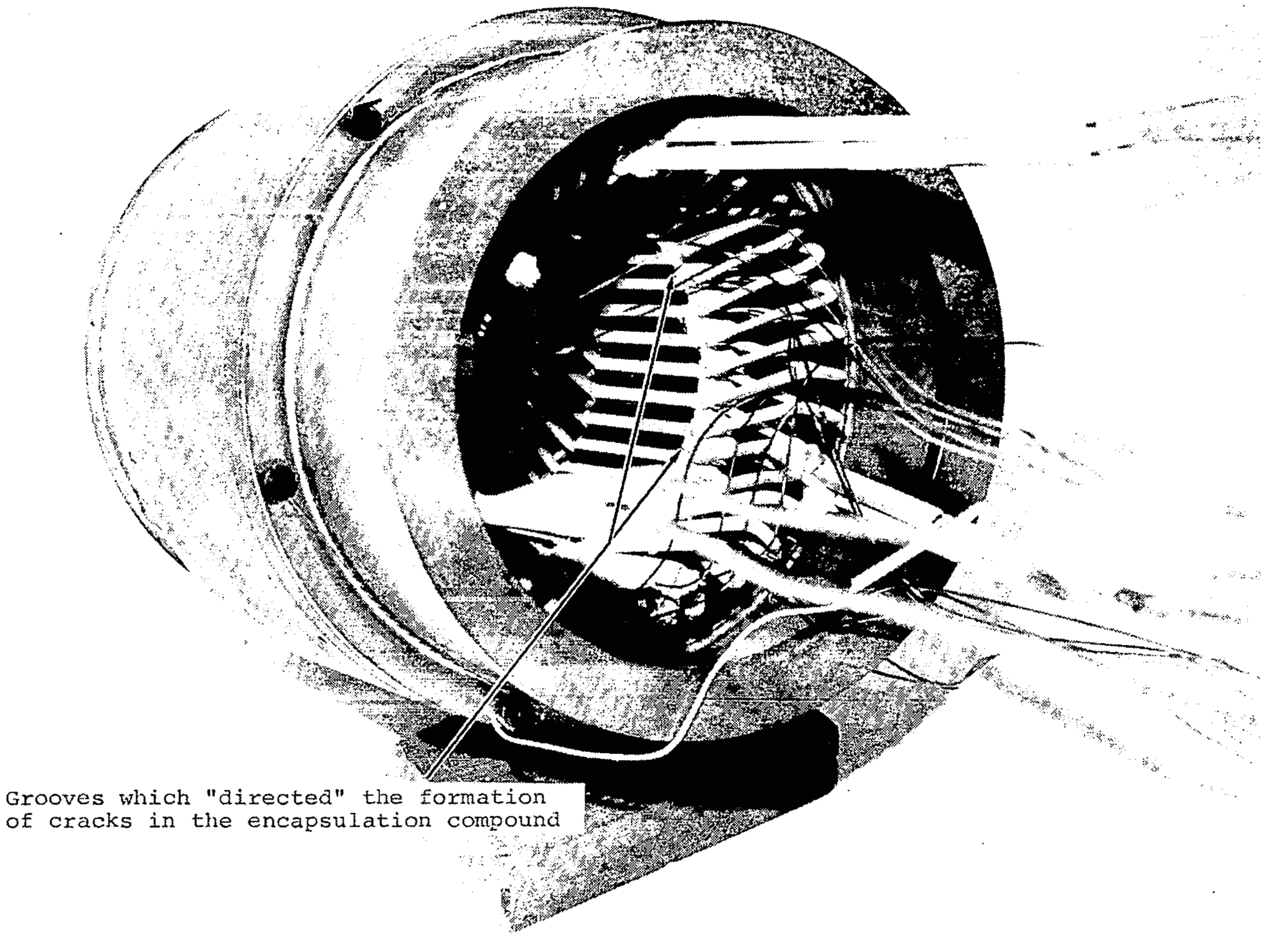



FIGURE II-20. Post-Test View of Stator Showing Stack, Windings, Slot Wedges and Encapsulating Compound - 1100° F Model

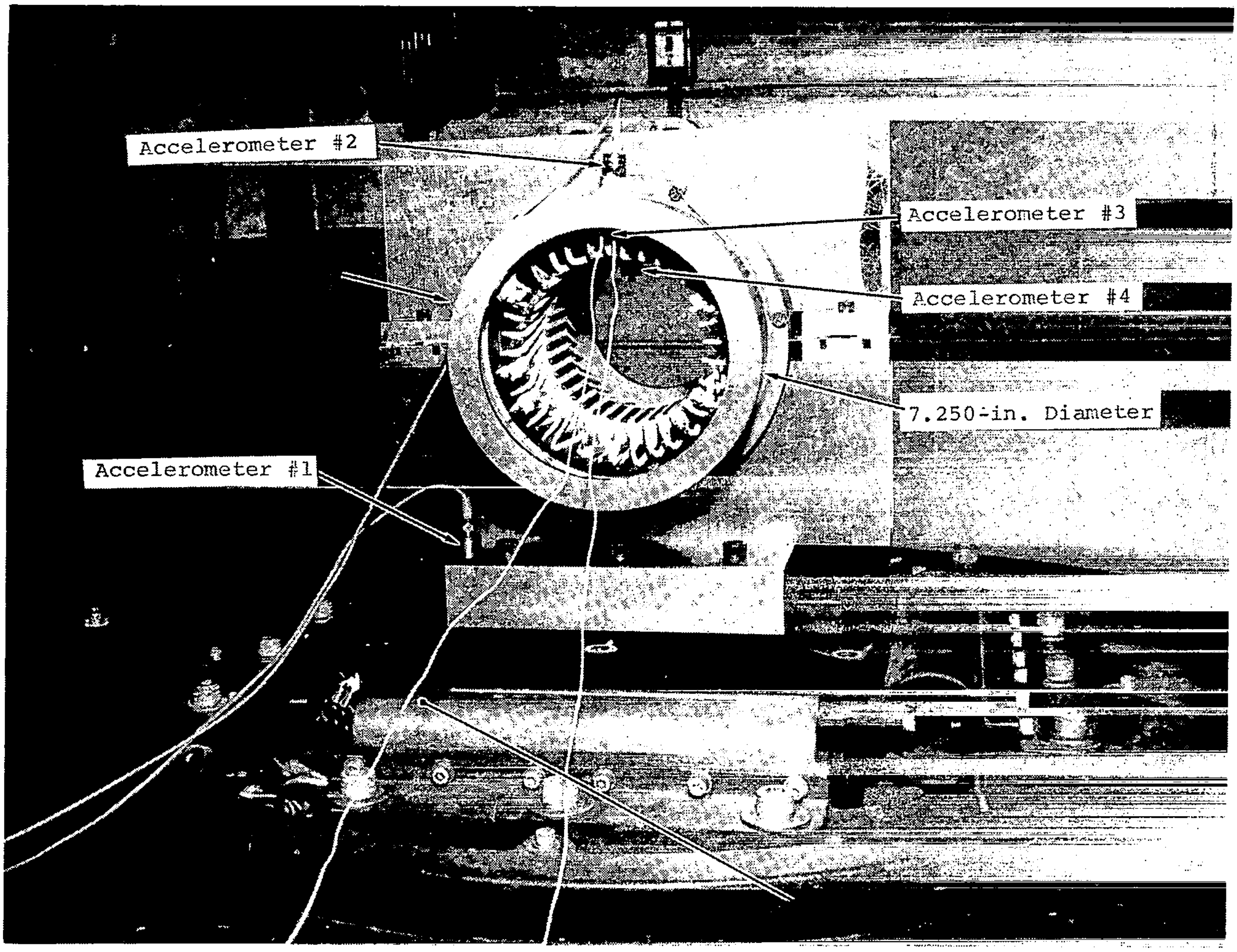



FIGURE II-21. Stator Assembly and Test Fixture Installed on Shaker for Vibration Test - 1100° F Model

A vibration scan was run over the range of 10 to 2,000 cps to locate stator resonant frequencies. The input was held at 5g's as a maximum acceleration, but was reduced when necessary to limit the output to 10g's. The limiting output accelerometer was No. 2, the one attached to the end bell.

Resonant frequencies were found at 900, 1200, 1400 and 1650 cps. The stator was vibrated for 5 minutes at each of the four frequencies with input and responses as shown in table II-5. Maximum response was limited to 10g's acceleration at the No. 2 accelerometer. The end turn accelerometer No. 3 indicated a considerable amount of damping in the end turns. This was a function of basic wire stiffness and end turn length. The stack showed even more damping, the response being in the same range as the input "g" value.

Figure II-22 is a photograph of the stator following completion of the resonant vibration tests. The conductor insulation and potting compound that was shaken loose during the test can be seen lying in the bottom of the end bell. The powdery material is Anadur "E" glass conductor insulation which was shaken free from the surface of the end turns without bothering the basic Anadur integrity. Glass fibers which had not been broken off the windings by handling before the test remained intact after the test. The larger fragments are pieces of W-839 potting compound, primarily from where the compound was used to bind lead extensions together. A few pieces of W-839 broke away at slot ends, but in most areas the compound remained in place even where cracks had formed. When the W-839 broke away from conductor surfaces, it pulled the Anadur to which it was anchored along with it. The end turn alumina tubes which served as thermocouple insulators remained in place on both instrumented windings, and the potting compound which retained them remained intact.

Electrically (room temperature) the stator was not adversely affected by the vibration test. Winding continuity was maintained and conductor resistance was unchanged after the test. As a result of the vibration test, average phase-to-phase dc insulation resistance increased from 83 megohms to $1.21 \times 10^3$ megohms, and average phase-to-ground values increased from 42 megohms to 380 megohms. Average phase-to-phase leakage current decreased from 88 microamps to <1 microamp, and average phase-to-ground values decreased from 130 microamps to 10 microamps. Visual stator inspections made before and after the vibration test did not reveal any notable physical changes resulting from the test which would

TABLE II-5. Stator Resonant Vibration Test Data

| Frequency (cps) | Input Acceleration (g's) #1 (Bed Plate) | Stator Response Acceleration (g's) #2 (End Bell) | #3 (End Turn) | #4 (Stack) |
|---|---|---|---|---|
| 900 | 1.47 | 9.91 | 4.70 | 2.67 |
| 1200 | 2.35 | 9.91 | 4.27 | 1.33 |
| 1400 | 0.91 | 9.91 | 4.27 | 1.06 |
| 1650 | 2.64 | 9.91 | 4.13 | 1.33 |

explain the improvement. However, the conductor was thoroughly annealed as a result of the 5000-hour test at 1100° F, and the relief of initial-assembly wire stresses in conjunction with vibration may have caused the insulation spacing to be more effective than it was before vibration.

After vibration test, the stator was disassembled for a more detailed inspection. Nearly all winding turns were movable in the slot liners, but all slot liners and wedges were intact. The condition of the Anadur in the slot liner area was very good. Abrasion resistance was quite high, both on end turns and on the slot liner sections.

Stator disassembly allowed a closer inspection of the windings than could be made while they were in the stack. All three windings showed small local areas near the lead-end coils where the nickel cladding had been perforated and the silver core had flowed. This was attributed to an incident which happened at approximately the 2900-hour point in the endurance test and which occurred as follows.

Vacuum-tight power leads into the test chamber were provided by copper rods which were sealed to a ceramic disk by a ceramic-to-metal brazed joint. The ceramic disk was then ceramic-to-metal brazed to a vacuum feedthrough flange. Thus, there were two isolated copper rods in each power feedthrough assembly (dual power lead feedthrough). An external stator power lead connector was inadvertently disconnected from a test chamber copper feedthrough rod while power was applied to the stator windings. The resulting arc (estimated at 2000 to 5000 volts) flashed across to the

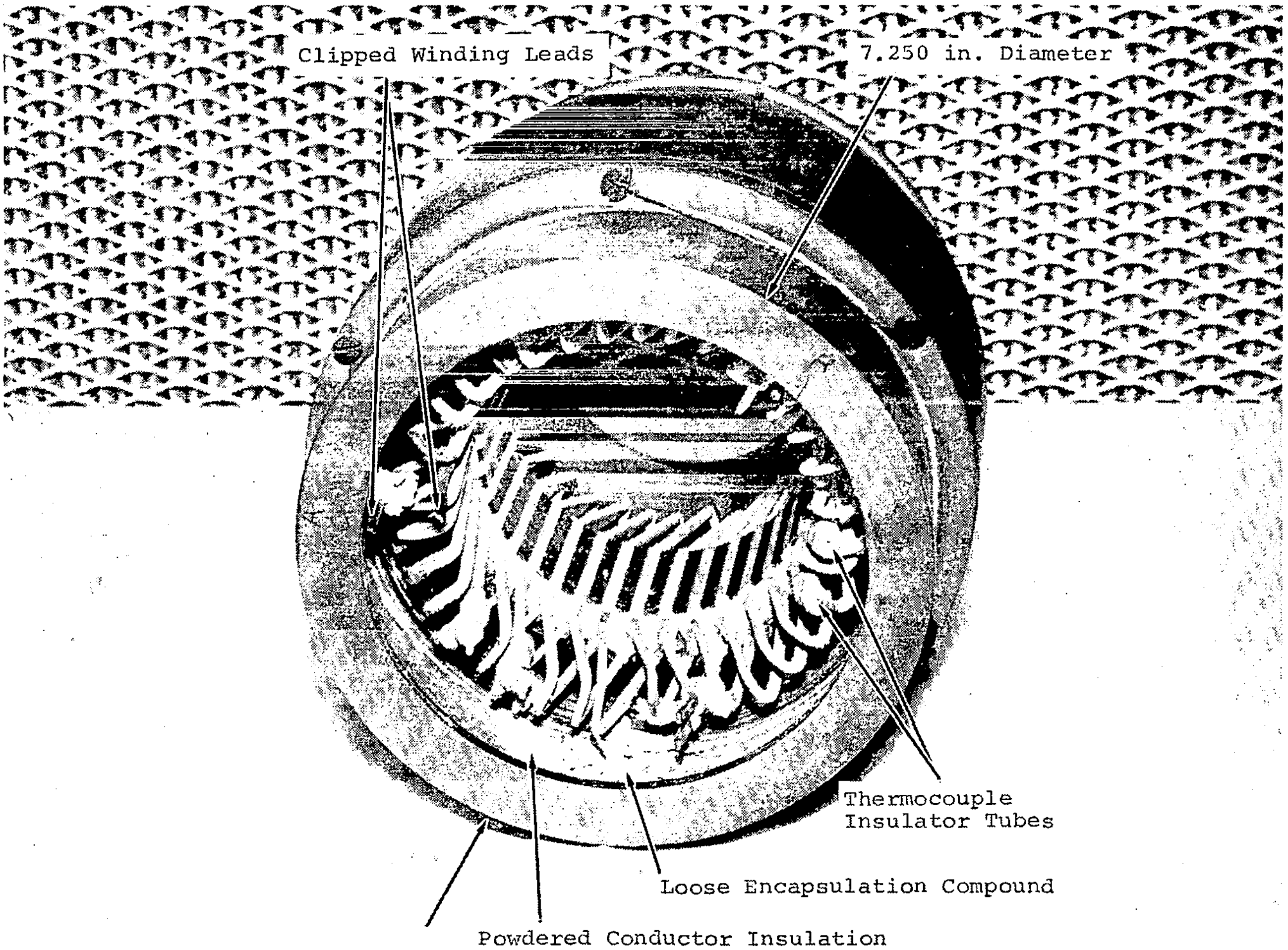



FIGURE II-22. View of Stator Assembly After Completion of the Vibration Test - 1100° F Model adjacent feedthrough rod, generating sufficient heat to melt the copper-to-ceramic brazed joint. Each copper rod was supplying power to a different phase winding so the initial potential between them was 500 volts ac. The test chamber was at a pressure of 9.8x10-9 torr, and vacuum was lost immediately when the seal gave way. The stator slot temperature was 1115° F.

The test chamber was tested for signs of damage caused by the sudden release to ambient pressure, but none could be found. All chamber and control safety interlocks had functioned properly. The chamber top cover was removed and a new power feedthrough was installed, using the same procedure as described earlier to re-braze the stator leads to the feedthrough. The stator could not be inspected physically because that would have required removing the top heat shields and the loss of all thermocouples. The stator was checked electrically and it showed no change in performance compared to original bench test values, so the chamber was closed and restarted. Chamber operation was normal at test temperature and stator electrical performance data at temperature matched previous data, so the test was continued to completion.

When the cladding perforations and silver flows were noted on the windings, the windings were laid out on a table in the same sequence as they had been located in the stack. Inspection indicated that the perforations at each end of each phase winding were adjacent to similar perforations in the respective overlapping windings of the other two phases. The windings do not show signs of cladding perforations in any other areas and the perforations occurred just outside the stack, from 1/8 to 1/4-inch outside the slot-end potting compound, where the phase-to-phase gap was at a minimum.

One perforated conductor section was subjected to a series of metallographic examinations. The first section was taken just outside the perforated area and it showed a normal silver grain structure. Subsequent sections were made by removing a few mils of material at a time, moving into the perforated area, and examining the nickel cladding for signs of flaws. There were no indications of flaws in the cladding, and the silver grain structure did not show signs of melting except at the perforation. Silver had flowed out over the nickel cladding in an area about one-eight inch in diameter and then solidified.

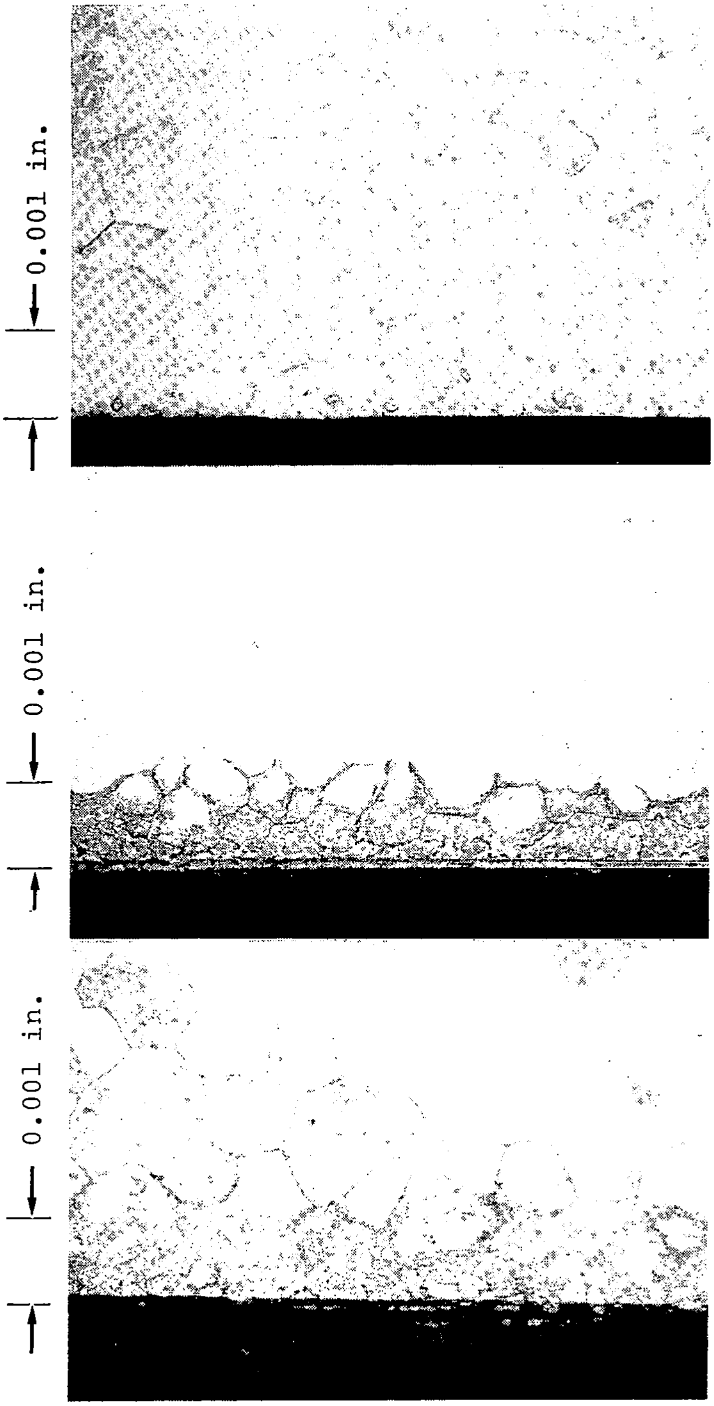
The conclusion reached was that not only had the feedthrough failed due to the load interruption, but the resulting voltage surge (peak value unknown) had also induced arcs between the windings. The current was large enough to cause almost instantaneous melting of the silver and nickel locally, so that the silver was able to breech the nickel cladding and flow to the outside of the conductor. The voltage and current decay was very rapid, so the melting period was very short and solidification occurred quickly. There was no effective change in conductor cross-section, as there was no detectable change in winding resistances before and after the arc.

A winding lead alumina tube (see figure II-19) which had stains in the area where it passed through the chamber top heat shields was given a spectrographic examination. Results showed that the discoloration was silver or compounds of silver in very minute quantities. Chamber pressure at the 1100° F test temperature was greater than the silver vapor pressure. However, the temperature of the silver at the time arcing occurred and the cladding was perforated was above the vaporization temperature. A small quantity of silver was evaporated during the arcing and it stained the ceramic tubes at the heat shields where the ceramic surface was cool enough to condense it.

The stator housing and lamination stack were disassembled for further investigation. The Hiperco 27 alloy laminations (0.008-inch thick) showed considerable brittleness after exposure in vacuum for 5000 hours at 1100° F, as compared with laminations from the same batch which had been on the shelf since pre-test annealing and which were ductile. Metallographic and chemical analyses showed the presence of oxide inclusions in the grain boundaries, indicating that "internal oxidation" took place at test temperature. The oxidation progressed from the lamination surface toward the interior. The oxide, which amounted to 1.2% of the lamination weight, was a complex spinel. Spectrochemical analysis of the oxide layer showed a phosphorus content of approximately 40 percent, with iron, silicon and aluminum as additional major elements.

Figure II-23 shows three micrographs. The first one (a) is a section taken from a stator punching which had not been aged, while the second section (b) is from a lamination which had been aged 5000 hours at temperature in vacuum. Section (c) is the same specimen as (b), but with a Nital etch to bring out the grain structure. The change in surface appearance and penetration of the grain boundaries by oxides can be noted in the second and third views.

The stator laminations were also analyzed for carbon and phosphorus content, in the as-annealed condition, and after




(a)

Nital Etch
Unaged
500X

ASTM Grain Size - 9

(b)

Unetched
Aged 5000
Hours at 1100°F
500X

Oxide Penetration into Lamination Surface

(c)

Nital etch
Aged 5000
Hours at 1100°F
500X

ASTM Grain Size - 8

Oxide Penetration into Lamination Surface

FIGURE II-23. Micrographs of Aged and Unaged Hiperco 27 Stator Lamination Sections - 1100°F Model high-temperature vacuum exposure. The annealed lamination contained 0.011 to 0.012% carbon, while the aged lamination carbon content was reduced to 0.0018%. Phosphorus content in the annealed lamination was 0.002% and in the aged lamination it was 0.012%. The change in phosphorus content was associated with the presence of phosphate-based W-839 potting compound in the stator slots. This coating dissociated at elevated temperature; freeing phosphorus which in turn diffused into the stack and from there into the laminations.

The oxygen penetration extracted carbon, probably as CO, and also formed the other oxides noted before. This concept implies the existence of an oxide layer on the lamination surface to supply oxygen. Internal oxidation has been used in some metal systems; such as silver or copper containing small amounts of aluminum, as a strengthening method. However, oxides in the grain boundaries of Hiperco 27 alloy lower the cohesive strength of the material and cause intergranular embrittlement.

One step in particular in the stator processing prior to high-temperature vacuum exposure may have contributed toward surface oxidation of the laminations. The last step in the cure cycle for the Anadur conductor insulation was a 30 minute bake-out in air at a temperature of 1225° ±25° F. This step was simulated on several samples of heat-treated Hiperco 27 alloy sheet of the same quality as the material used in the stator. These samples displayed no embrittlement after 30 minutes exposure in air at 1100° F; but after a subsequent eight-hour anneal in a neutral protective atmosphere such as argon at this temperature, these samples showed considerable intergranular embrittlement. There was no source for phosphorus present in these tests. The effect of the presence or absence of phosphorus around the laminations is discussed further in the transformer lamination analysis, Section II.C.7.

There was no change in coercive force in the aged laminations indicating that there was no apparent change in the quality of the magnetic properties as a result of aging. Since the unit successfully passed the vibration test with the laminations in their present, less-ductile condition, it is uncertain whether loss of ductility is a problem in the stator design.

8. Stator Test Procedures - 1300° F Hot-Spot Model

The methods and procedures used to install the 1300° F hot-spot stator in the test chamber were the same as those used for the 1100° F model. The only change was the addition of a bore seal capsule, which was supported by a ring in the stator bore so as to be centered radially and axially in the stack and winding assembly.

Figure II-24 is a sketch of the bore seal capsule showing the configuration and dimensions. Figure II-25 shows the stator on its side with the bore seal in position to be installed. The stator sat upright in the test chamber.

After electrical continuity of the winding leads and thermocouples had been verified, the test chamber top cover was installed. The chamber was sorption-pumped to approximately 6 microns and the sputter-ion pump was started. Thermocouple brazed joints were leak-checked with helium, and several required additional brazing operations. Lithobraz BT (72Ag-28Cu) wire was used as the brazing material.

System pressure continued to decrease after leaks had been stopped, and when the nude ion gauge showed a pressure of $3.5 \times 10^{-8}$ torr, a 24-hour system bake-out at 250° C was started. Minimum cold pressure reached after bake-out was $1.6 \times 10^{-9}$ torr.

Bench test static electrical measurements covering conductor resistance, dc insulation resistance and ac potential electrical leakage had been taken prior to installation of the stator in the test chamber. These measurements were repeated after bake-out to provide base line data on stator performance under high vacuum conditions.

Rather than immediately applying current to the stator windings to increase temperature, as had been done with the 1100° F model, the chamber heater element was used to bring the stator temperature up in stages. Electrical performance data were taken for each stage when temperatures throughout the stator were essentially stable. When this operation had been completed, the heater element power was reduced and power was applied to the stator windings. The current in each stator winding was set at 50 amperes and heater element power was adjusted to reach and maintain a 1300° F stator slot hot-spot temperature. Heater element power settled out at 510 amps and 1.8 volts, and the logging of formal endurance time at temperature was initiated.

Basic data, such as readings for thermocouples, phase currents and voltages, heater element performance, etc, were taken each day. Once each week a residual gas analysis

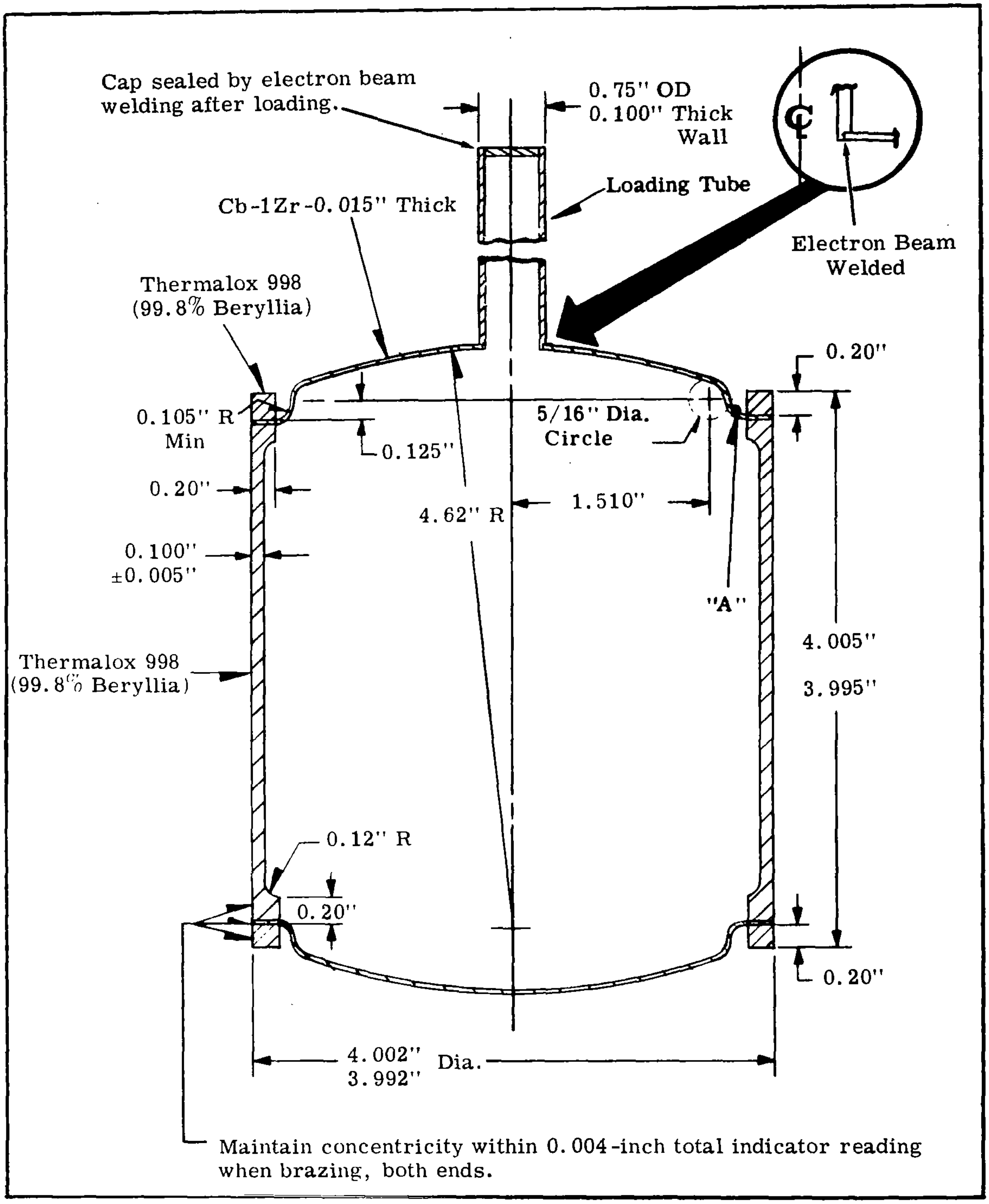



FIGURE II-24. Bore Seal Capsule

FIGURE II-25. Demonstration of the Bore Seal Capsule Fit Inside the Stator Cavity for the 1300° F 5000-Hour Endurance Test. In the Test Chamber the Stator Center Line is Vertical (leads up) and the Capsule sits on a pedestal.

spectrogram was taken and static electrical readings were measured and recorded. Titanium sublimation pump bursts of 2 minutes duration were applied to the chamber at intervals to determine the effect on chamber base pressure.

## 9. Stator Data and Discussion - 1300° F Hot-Spot Model

The $I^2R$ heat loss in each stator winding was caused by a current of 50 amps in each phase. This current, divided by a conductor cross-sectional area (silver and Inconel) of 0.0123 square inches, resulted in a phase current density of 4065 amperes per square inch. Assuming all current is carried in the silver core, current density in the silver would be 5650 amps per square inch. Phase winding resistance was 0.0475 ohms with the slot hot-spot temperature at 1300° F. The calculated phase $I^2R$ loss at temperature was 115 watts per phase, or 345 watts total for the stator. This value compares with a total of 203.4 watts for the 1100° F model, the difference being caused by the higher current level and greater conductor resistance at the higher test temperature.

Figure II-26 is a plot of thermal vacuum chamber nude ion gauge pressure versus endurance test time at test temperature. The chamber pressure decreased at an almost constant rate for the first 1000 hours, then continued to decrease at a slower rate. Even though hot-spot temperature was 200° F higher than the first test, the initial chamber pressure was approximately 1-1/2 decades lower than at the start of the first test. This difference was attributed primarily to the use of boron nitride cement in place of W-839 potting compound in the 1300° F model and their differences in outgassing characteristics. Titanium sublimation pump bursts were again used periodically to determine the effect on chamber base pressure.

Thermocouples were installed in the same locations as in the 1100° F model (see figure II-13). Two thermocouples were damaged beyond repair during the feedthrough brazing operation, and the two lamination outside diameter slot thermocouples could not be installed in the stator because the winding end turns blocked access to the slot.

Table II-6 shows a representative steady-state stator temperature profile taken after 4320 hours of endurance test. The five slot liner thermocouples had a maximum spread of 13° F, which was considered to be good in view of the conductance path from the conductor to each thermocouple sensing tip. The temperature differential between the highest slot temperature and the frame outside diameter

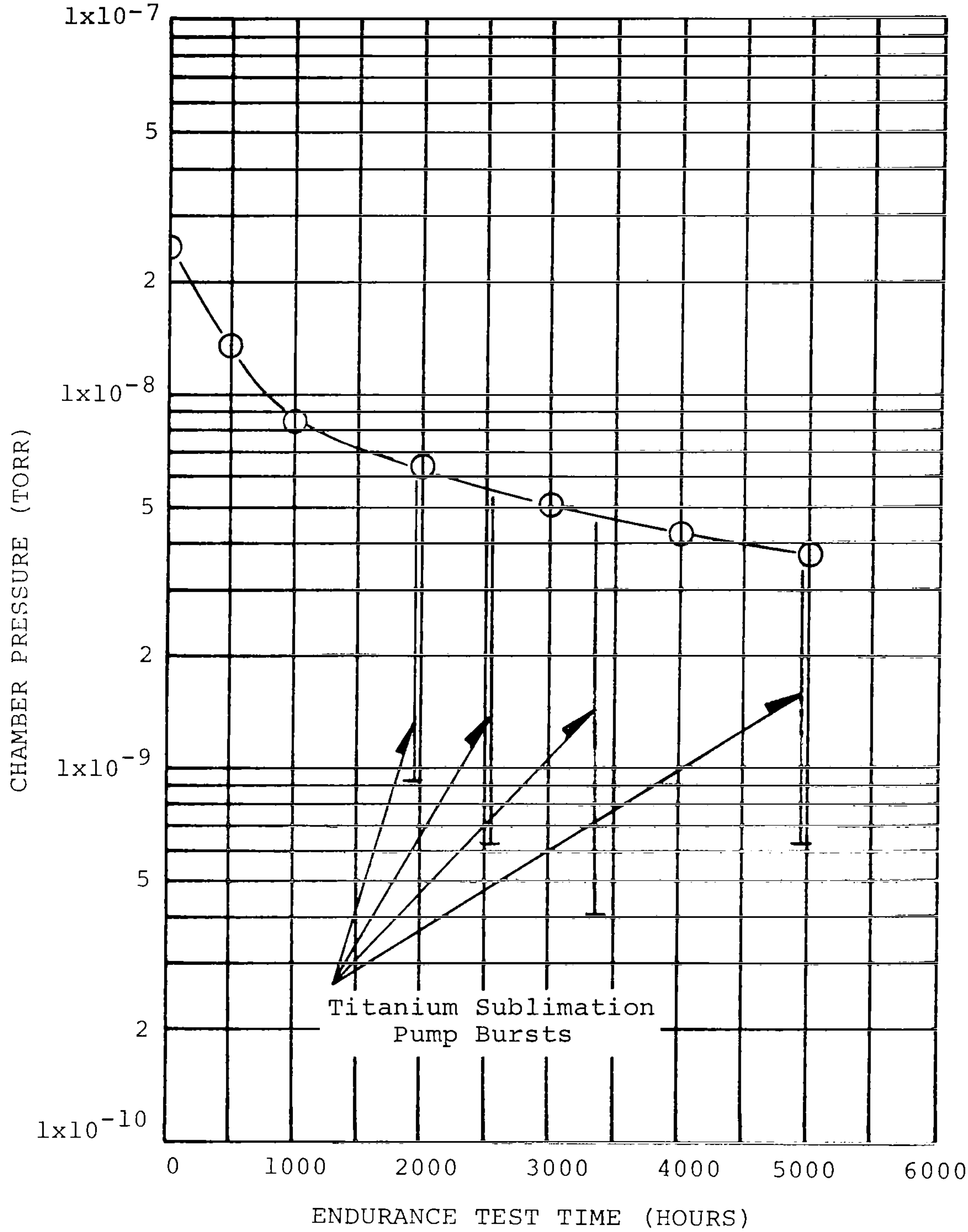



FIGURE II-26. Stator Chamber Pressure Versus Endurance Test Time - 1300° F Model

TABLE II-6. Representative Stator Temperature Distribution at 1300° F Hot-Spot Test Temperature After 4320 Hours of Endurance Test

| Thermocouple Location | Temperature (°F) |
|---|---|
| Phase A Slot Liner | 1287 |
| Phase A Slot Liner | 1297 |
| Phase B Slot Liner | 1300 |
| Phase C Slot Liner | 1287 |
| Phase C Slot Liner | 1290 |
| Mid-stack Bore | 1260 |
| Mid-stack Bore | 1262 |
| Frame OD | 1230 |
| Phase B End Turn | 1239 |
| Phase B End Turn | 1237 |
| Phase C End Turn | 1195 |
| Phase C End Turn | 1205 |

was 70° F, compared with a 23° F differential in the 1100° F model. The highest end turn temperatures (phase B) were 7° and 9° F higher than the frame outside diameter temperature, but the temperature pattern for slots, frame outside diameter and winding end turns was very similar to that shown by the 1100° F model. Phase C end turn temperatures were considerably lower than phase B temperatures. The chopped boron-nitride fiber cement used to anchor alumina thermocouple tubes to end turns was considerably less dense than the W-839 potting compound used on the 1100° F model. This may have resulted in variations in the conductance path from winding to thermocouple tip, depending on how well the boron nitride cement packed around the alumina tubes. The phase C thermocouple tips may also have shifted position a fraction of an inch during installation of the stator in the chamber, resulting in a longer conductive path to the sensing tip.

Figure II-27 is a dimensionless plot of conductor resistance versus endurance test time. Conductor resistance at a hot-spot temperature of 1300° F was constant throughout the test period.

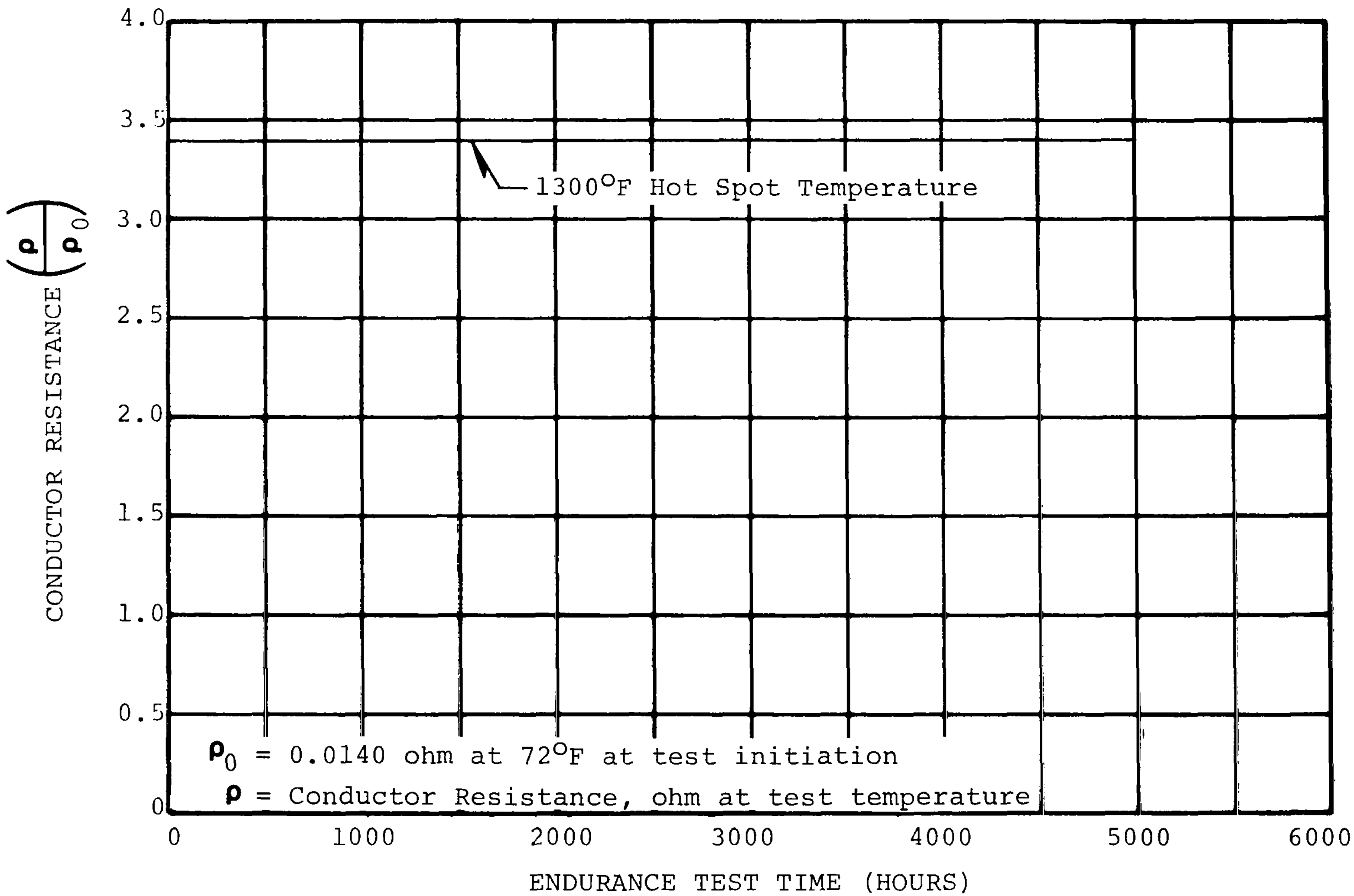



FIGURE II-27. Stator Conductor Average Resistance Versus Endurance Test Time Referenced to a 1300° F Conductor Hot-Spot Temperature

Table II-7 is a tabulation of stator insulation system performance during the course of the test, with the data referred to a slot hot-spot temperature of 1300° F. These values were obtained with 500 volts dc applied between phases and between each phase and ground. There was a definite improvement in insulation performance as a function of test time.

Figures II-28 and II-29 are plots of an ac leakage current across the insulation system with 500 volts ac applied. Figure III-28 is phase-to-phase leakage and figure III-29 is plotted for phase-to-ground leakage. The general reduction of leakage current as a function of test time also shows an improvement in the insulation system performance. This improvement with time in the 1300° F stator insulation performance, as compared to the increased losses noted in the 1100° F stator, was attributed to the use of boron nitride cement in place of W-839 potting compound. The BN cement has a very low outgassing rate at test temperature compared to W-839 potting compound.

As with the 1100° F stator test, the 1300° F stator test chamber environment was sampled once each week with a mass spectrometer. Figure II-30 is a plot showing the trend of the major gas component partial pressures as a function of time. The pattern is similar to that obtained from the 1100° F chamber except that $H_2O$ predominated over $N_2$+CO during the entire test. Initial chamber pressure was also approximately 1-1/2 decades lower than for the 1100° F test,

TABLE II-7. Stator Insulation Performance in Vacuum with Slot (hot-spot) Temperature at 1300° F

| Endurance Test Time (hours) | 0 | 1000 | 2000 | 3000 | 4000 | 5000 |
|---|---|---|---|---|---|---|
| Average Insulation Resistance with 500 volts d-c Applied (ohms) | | | | | | |
| Phase to Phase | $1.5x10^6$ | $3.8x10^6$ | $3.8x10^6$ | $5.0x10^6$ | $5.5x10^6$ | $5.5x10^6$ |
| Phase to Ground | $1.0x10^6$ | $1.9x10^6$ | $2.2x10^6$ | $2.8x10^6$ | $2.8x10^6$ | $2.8x10^6$ |

Note: Stator conductors were rectangular Inconel 600-clad silver wire (0.091 inch by 0.144 inch) with Anadur S glass insulation. Slot insulation consisted of 0.022-inch-thick 99% alumina slot liners and 0.047-inch-thick 99% alumina strips between phases.

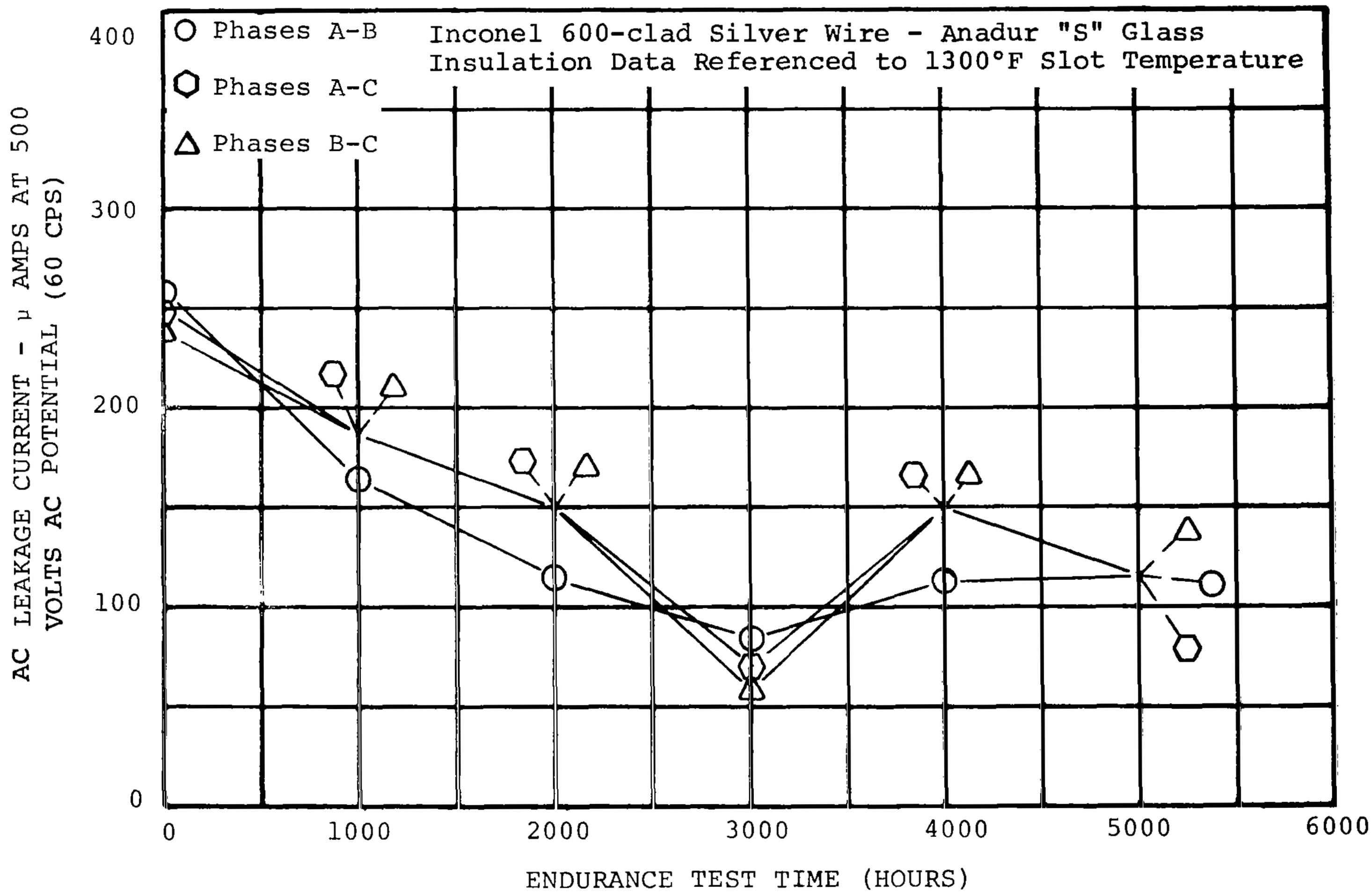



FIGURE II-28. Stator Insulation System Performance, Phase-to-Phase Current Leakage, Versus Endurance Test Time - 1300° F Model

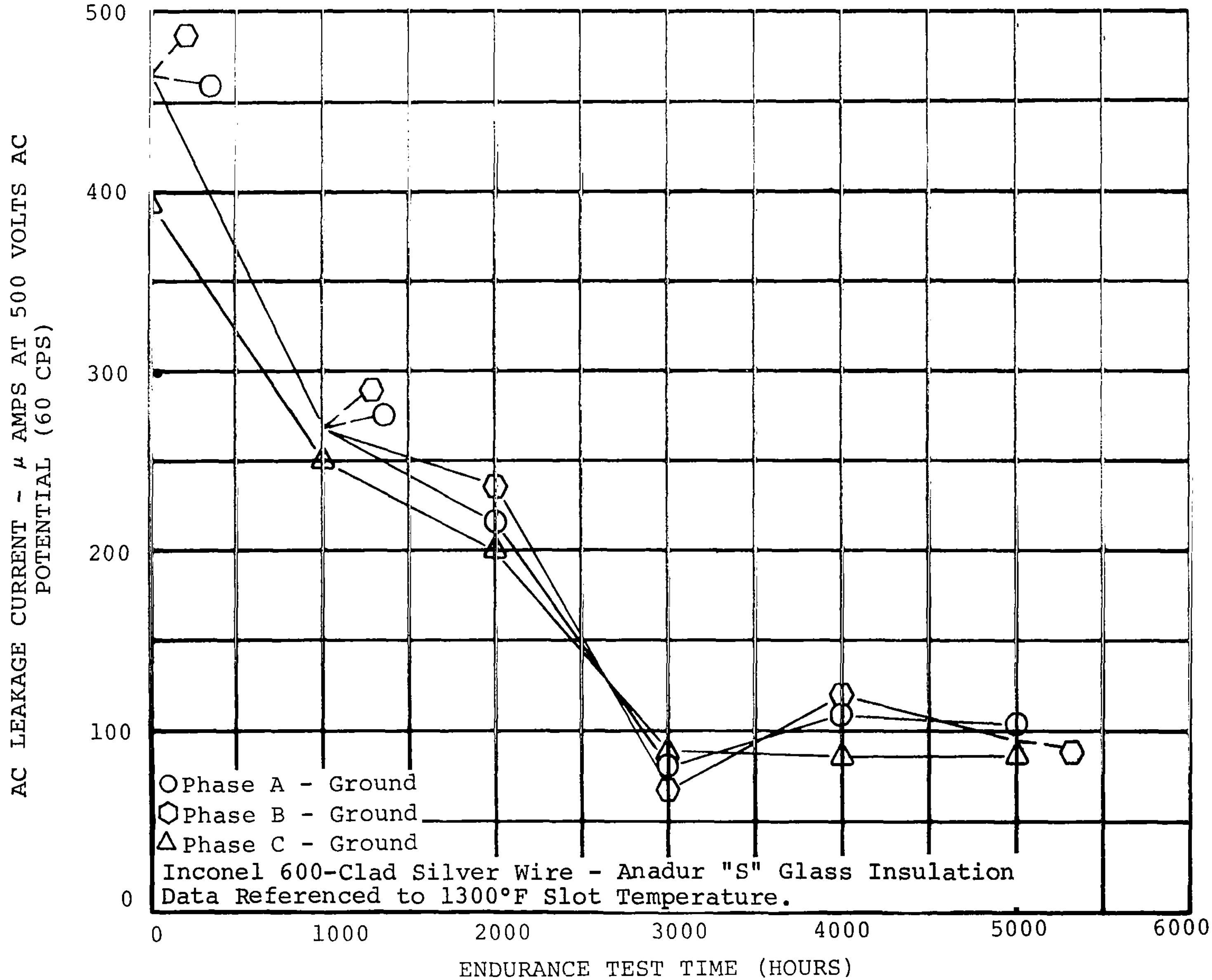
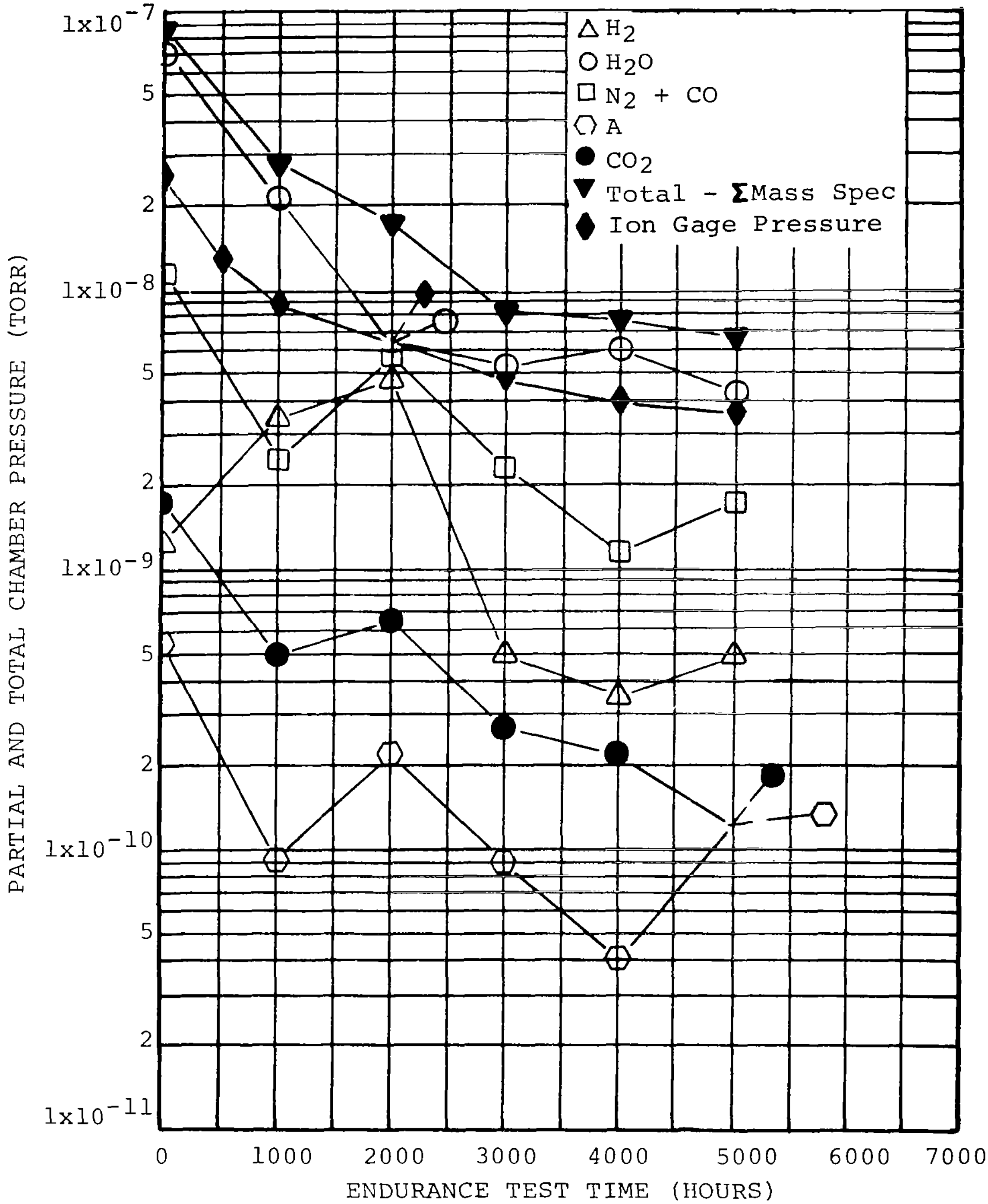



FIGURE II-29. Stator Insulation System Performance, Phase-to-Ground Current Leakage, Versus Endurance Test Time - 1300° F Model




(Note: Temperature was constant at 1300° F).

FIGURE II-30. Time-Pressure Plot of Mass Spectrometer Residual Gas Analysis Scans in Chamber No. 1. (Stator) in spite of a 200° F higher temperature. All the partial pressures showed a rapid reduction for the first 1000 hours. Then all but the $H_2O$ showed a reversal of pressure slope for the next 1000 hours, followed by a tendency to decrease and then level off as testing continued. This pattern was similar to that of the ion gauge total pressure (figure II-22) which had a slowly decreasing slope as total time increased.

The primary materials change between the two tests which affected outgassing was the shift from potting compound (W-839) to a chopped boron nitride fiber cement for anchoring slot liners, wedges, etc. A comparison of partial and total pressures demonstrates that the boron nitride has a higher useful temperature than the potting compound because of its lower contribution to outgassing.

After successful completion of the 5000-hour test, the test chamber and stator model were placed on a stand-by basis, pending a decision to conduct additional endurance testing.

10. Conclusions for 1100° F Stator and Comparison of 1100° and 1300° F Stator Model Performance

a) The magnetic, conducting and insulating materials used in both stators were compatible electrically and mechanically at the two test temperatures.

b) The materials combination used in the 1300° F model demonstrated better insulation characteristics and lower outgassing rates than the 1100° F model materials.

c) Improved insulation system performance in the 1300° F model resulted primarily from the use of boron nitride chopped fiber cement in place of the potting compound. (Zircon bonded by aluminum orthophosphate.)

d) Fe-27Co laminations developed some brittleness as a result of the Anadur "E" glass insulation bake-out cycle (1225 $\pm$ 25° F for 30 minutes in air). However, the brittleness did not affect magnetic coercive force and did not have any effect on vibration test performance.

e) Compounds containing phosphorus should be restricted from use with Fe-27Co laminations in high temperature, high vacuum applications because phosphorus increases the degree of oxygen penetration, which causes embrittlement.

f) A comparison of 1100° and 1300° F model slot-end turn temperature differentials shows that at the higher operating temperatures, some winding heat losses can be radiated from the end turns if a heat sink can be made available.

g) The combination of Anadur "E" glass conductor insulation, alumina slot insulation and W-839 potting compound maintained insulation system integrity during breakdown test with up to 2000 volts ac applied between phases and from phase to ground, at 1100° F in vacuum after 5000 hours test.

h) The 1100° F stator insulation system withstood a one-axis vibration test mechanically and electrically with a 10g maximum response, showing improved insulation performance following the test.

i) No final conclusions can be determined for the 1300° F stator until planned further testing is accomplished and final evaluations and analyses have been completed.

## C. TRANSFORMER

As with the stator, the following discussion will be based on the 1100° F hot-spot transformer design, with a description of the changes made in going to the 1300° F hot-spot temperature model.

### 1. Transformer Physical and Electrical Design and Construction

Figure II-31 is a cutaway view of the transformer which shows the basic design features. The transformer core was made from E-I style Hiperco 27 alloy laminations 0.008-inch-thick, with a coating of plasma-arc sprayed Linde "A" compound ($Al_2O_3$) on one side of each lamination (same as stator laminations). The windings were formed around a ceramic spool (99.5% $Al_2O_3$) which provided insulation between the windings and the center leg of the core. Alumina (99.5%) end plates and channels provided insulation between the winding ends and sides and the laminations. Non-magnetic alloy strips (Hastelloy Alloy "B") were used outside the laminations to provide lamination support. The laminations and support strips were held together by through-studs, ceramic washers and lock nuts. The primary winding was made from No. 20 AWG (0.032 diam) nickel-clad silver wire (20% nickel cross-sectional area) coated with Anadur insulation, and consisted of 174 turns in 5 layers. Flexible

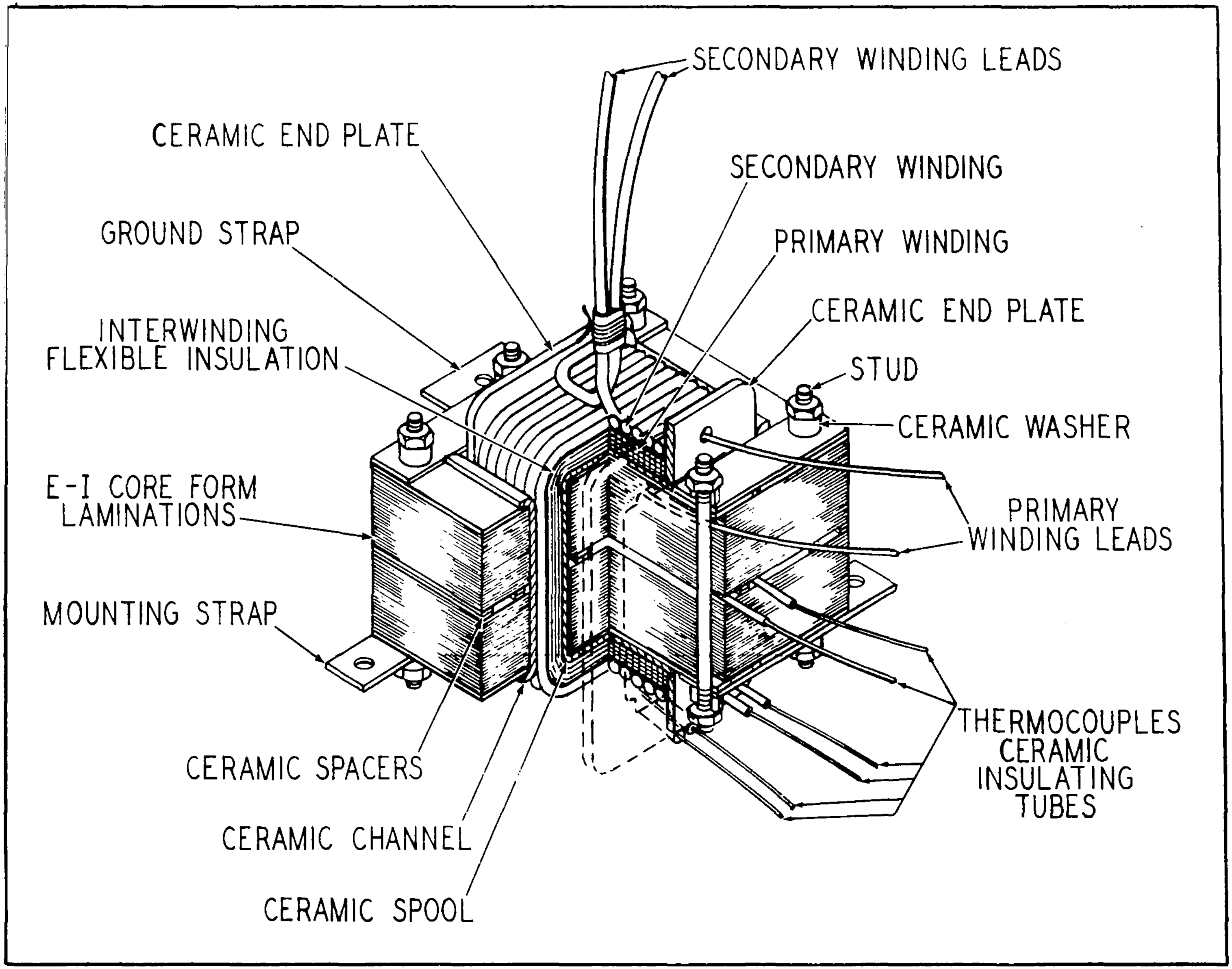



FIGURE II-31. Cutaway View of Transformer insulation (Burnil CM-2[12], a synthetic fluorophlogopite mica paper) 0.010-inch-thick was used to separate the layers. The secondary winding was a single layer 10-turn coil made from the same type wire and insulation but in No. 7 AWG (0.144 diam). Four layers of 0.010-inch-thick Burnil CM-2 were installed between the outermost primary winding layer and the secondary winding. Pairs of thermocouples were installed between the primary winding and ceramic spool and between the primary and secondary windings. The stack was divided into two halves by ceramic strip spacers so that two thermocouples could be buried in ceramic tubes in the center of the core.

Table II-8 is a summary of the materials used in the 1100° F transformer and table II-9 is a summary of the materials used in the 1300° F model. For the 1300° F model the conductor was changed from nickel-clad silver to Inconel-clad silver, and the Anadur was changed from "E" glass to "S" glass. A flexible boron nitride fiber sheet insulation replaced the Burnil CM-2 flexible insulation, and a chopped boron nitride fiber cement replaced the W-839 potting compound. The changes were made to reduce outgassing and increase electrical insulation resistivity.

The transformer design was rated at 1 kVA with 600 volts ac on the primary winding and approximately 30 volts on the secondary winding. This 600-volt ac single-phase design is representative of the technology for a three-phase transformer having the same phase voltage which, when coupled in a wye network with a full wave rectifier system, would provide 1400 volts dc. A frequency of 400 cps was chosen because of the availability of 400 cps power for lab testing, and because Hiperco 27 alloy was available in 0.008-inch thickness only, a thickness best suited for 400 cps. The transformer could have been operated at higher frequencies with little change in losses provided the voltage had been maintained at rated value.

The 1300° F hot-spot temperature transformer physical design was the same as the 1100° F model, but five materials changes were introduced. Nickel-clad silver wire was replaced with Inconel-clad silver wire to obtain greater mechanical strength. Conductor insulation was changed from Anadur "E" glass to "S" glass, for the same reason mentioned in the stator write-up.

[12] Special Product of 3M Company, Chemical Division, St. Paul, Minnesota. Burnil CM-2 is the same as Burnil CM-1 except for the addition of up to 10% ash-free organic sizing to improve handling properties. Sizing was fired out during the conductor insulation bake-out cycle.

## TABLE II-8. Transformer - Magnetic, Insulation and Conductor Materials Summary - 1100° F Hot-Spot Model

| Part | Material | Source-NAS3-4162 |
|---|---|---|
| Laminations | Fe-27Co 0.008-mil thick (Hiperco 27) | NASA-CR-5401 p. 59, 323 |
| Interlaminar Insulation | Plasma-arc sprayed $Al_2O_3$ (Linde A) | NASA-CR-54092 p. 98, 593 |
| Coil Spool | $Al_2O_3$ - 99.5% | NASA-CR-54092 p. 92, 453 |
| Coil End Plates | $Al_2O_3$ - 99.5% | |
| Coil Channels | $Al_2O_3$ - 99.5% | |
| Thermocouple Insulators | $Al_2O_3$ - 99% | NASA-CR-54092 p. 92, 462 |
| Stud Spacer | $Al_2O_3$ - 99% | |
| Lamination Spacer | $Al_2O_3$ - 99% | |
| Flexible Insulation | Burnil CM-2 (Li $Mg_2$ Li $So_4$ $O_{10}$ $F_2$ and Alum. Silicate) | NASA-CR-54092 p. 89, 346 |
| Conductor Insulation | Same as Stator - 1100°F (Anadur E Glass) | NASA-CR-54092 p. 86, 287 |
| Potting Compound | Zircon Type (Aluminum Orthophosphate-Zirconium Silicate) (W-839) | NASA-CR-54092 p. 97, 579 |
| Conductors-Sizes #20 and #7 AWG | Nickel-clad silver - 1100°F | NASA-CR-54092 p. 81, 249 |
| Lamination Support Plates | Hastellov Alloy B | |
| Hardware | Hastelloy Alloy B | |
| Thermocouples | Inconel 600 Sheath - Platinel II Wire System | |

## TABLE II-9. Transformer - Magnetic, Insulation and Conductor Materials Summary - 1300° F Hot-Spot Model

| Part | Material | Source-NAS3-4162 |
|---|---|---|
| Laminations | Fe-27Co 0.008-mil-thick (Hiperco 27) | NASA-CR-54091 p. 59, 323 |
| Interlaminar Insulation | Plasma-arc sprayed $Al_2O_3$ (Linde A) | NASA-CR-54092 p. 98, 593 |
| Coil Spool | $Al_2O_3$ - 99.5% | NASA-CR-54092 p. 92, 453 |
| Coil End Plates | $Al_2O_3$ - 99.5% | |
| Coil Channels | $Al_2O_3$ - 99.5% | |
| Thermocouple Insulators | $Al_2O_3$ - 99% | NASA-CR-54092 p. 92, 462 |
| Stud Spacer | $Al_2O_3$ - 99% | |
| Lamination Spacer | $Al_2O_3$ - 99% | |
| Flexible Insulation | BN Fiber Mat | |
| Conductor Insulation | Same as Stator - 1300°F (Anadur S Glass) | NASA-CR-54092 p. 86, 287 |
| Potting Compound | BN Fiber Cement | |
| Conductors - Sizes #20 and #7 AWG | Inconel 600-clad silver - 1300°F | NASA-CR-54092 p. 81, 249 |
| Lamination Support Plates | Hastelloy Alloy B | |
| Hardware | Hastelloy Alloy B | |
| Thermocouples | Inconel 600 Sheath - Platinel II Wire System | |

Very little encapsulation compound was used in the transformer, but because of outgassing characteristics, the W-839 compound was replaced with the chopped boron nitride fiber cement mentioned previously. This cement was also used in place of Pyroceram cement to hold the alumina spool and end plates together. Pyroceram is a nucleating glass that fuses at approximately 1225° F and changes to a polycrystalline structure at 1400° F. Its use was eliminated because of the possibility of outgassing PbO and ZnO at test temperature.

The Burnil CM-2[13] flexible sheet insulation which was used between winding layers in the 1100° F model did not have adequate electrical insulation capabilities at 1300° F. As an independent program, Westinghouse had developed a flexible sheet insulation made from boron nitride fibers. The material was used to replace the Burnil CM-2 in the 1300° F model.

2. Transformer Assembly

When all fabricating operations had been completed, the transformer parts were cleaned according to prescribed cleaning procedures. The only material not cleaned was the Anadur coated nickel-clad silver wire and Inconel-clad silver wire. The Anadur was cleaned during the firing operation which cured the insulation system.

The first transformer subassembly required was the winding spool. Figure II-32 shows the alumina spool, alumina end plates, alumina thermocouples tubes, and the primary and secondary windings in place.

Figure II-33, which was taken after the Anadur "E" glass insulation bake-out, shows the laminations installed in the winding assembly. The stack consisted of 230 laminations divided into two sections by alumina spacers and thermocouple tubes. Hastelloy Alloy B plates 0.063-inch-thick were used on each side of the stack to provide stiffness; and through-studs, alumina washers, and nuts were used to hold the stack together. The studs were plasma-arc sprayed with alumina insulation and the nuts were welded to the studs after assembly. The weight of laminations built into the stack was 5.75 pounds. Total transformer weight was 8.47 pounds.

After assembly, the transformer was put through an Anadur insulation bake-out, using the same time-temperature schedule as was used for the stator. Following this, a small amount of W-839 potting compound (or boron

[13] 3M Company, _op. cit._

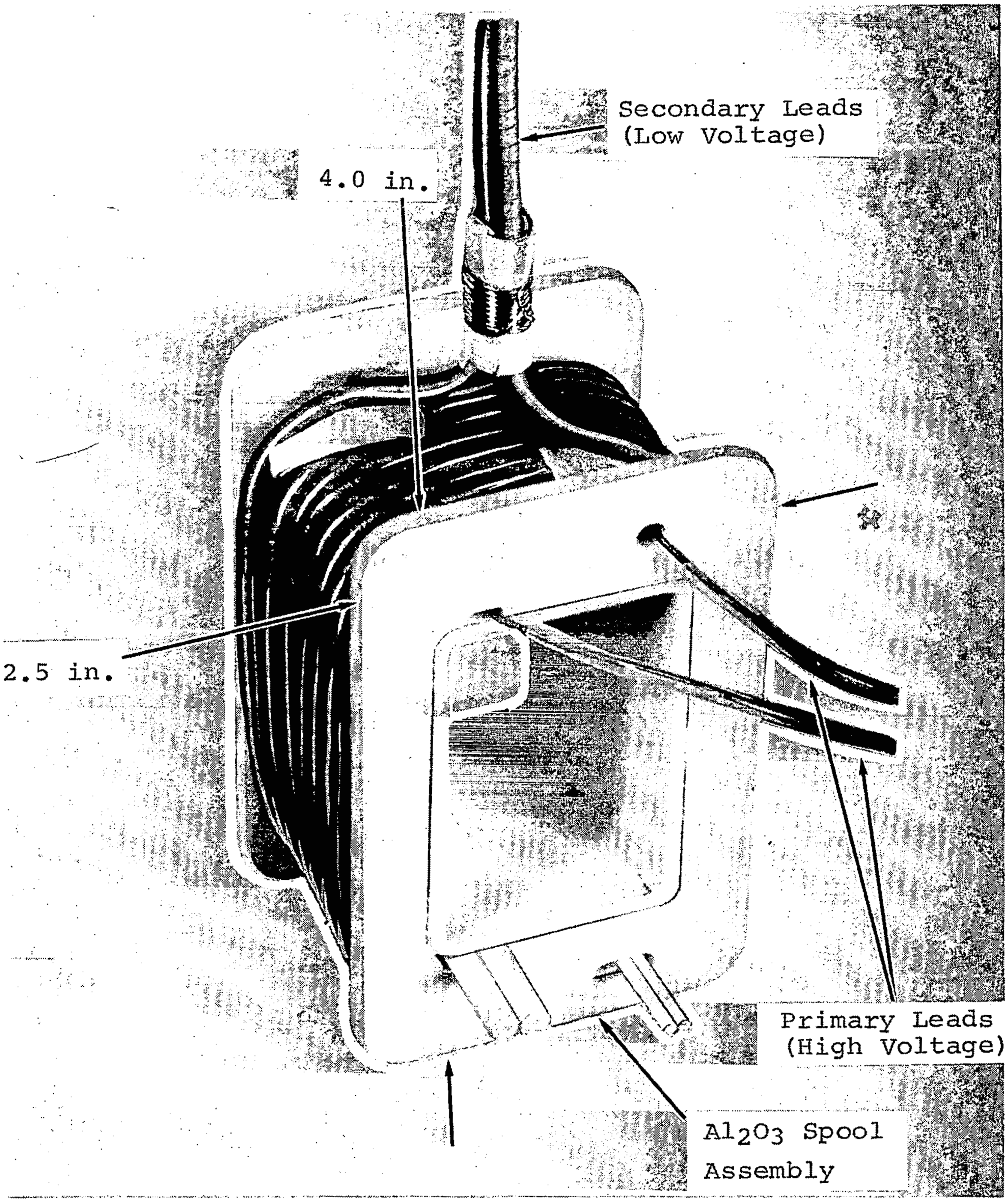



FIGURE II-32. Transformer Spool Assembly and Windings

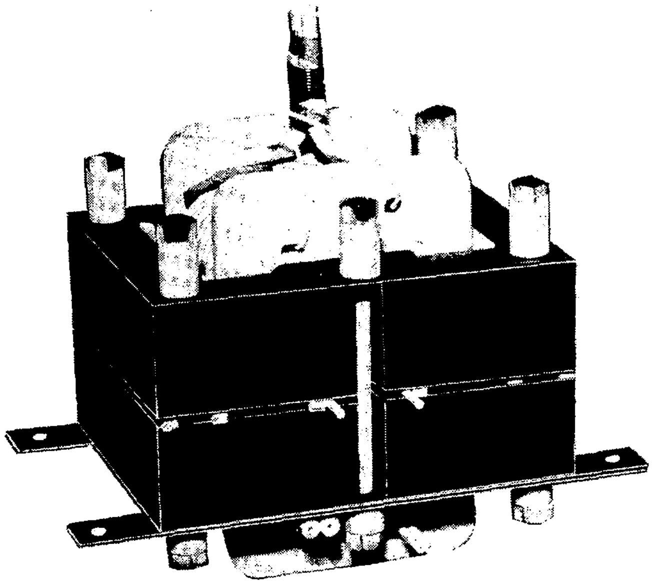


FIGURE II-33. Transformer Assembly After Anadur "E" Glass Insulation Bake-Out - 1100° F Model

nitride fiber cement) was added at the stack midpoint to retain the alumina spacers and thermocouple tubes.

The transformer assembly less thermocouples was installed in a liquid-nitrogen-trapped diffusion-pumped vacuum furnace for a preliminary degassing bake-out. The two solenoids (section II-D) were put through the same bake-out. After an equilibrium furnace temperature of 1100° F was established, the assemblies were baked for 43 hours. Initial chamber pressure at equilibrium was $4x10^{-6}$ torr and at the end of the bake-out it had decreased to $2.6x10^{-6}$ torr. After cooling, the furnace chamber was back-filled with argon and the assemblies were stored this way until they were installed in the No. 2 thermal vacuum chamber.

3. <u>Thermal Ultra-High Vacuum Chamber Installation</u>

Residual gas analysis scans were taken with the thermal vacuum chamber evacuated and at chamber temperatures of 77°, 1100°, and 1500° F to obtain background data. The chamber was then pressurized to ambient conditions under argon gas preparatory to installing the transformer assembly.

The installation procedure for the transformer was the same as that used for the stator. The clean bench was moved to the chamber to supply filtered air, and after installation of thermocouples, the models were placed in the test chamber. Figure II-34 is a cutaway drawing of the thermal vacuum chamber showing the transformer and solenoids installed in the furnace hot zone. After brazing of model power leads and thermocouples, lead integrity was verified and the chamber was closed, evacuated, and leak checked.

## 4. Transformer Test Connection

Figure II-35 is a schematic showing the connections for applying power to the transformer primary winding and loading the secondary winding. Single phase power from a 400-cps, 292-volt ac line-to-neutral three phase generator was brought into the test area. A variac and a 1:4 step-up transformer were used to provide a 600-volt ac source for the test transformer primary winding. A resistive load bank with multiple series switches was used as an adjustable load for the secondary winding.

## 5. Transformer Test Procedure - 1100° F Hot-Spot Model

After electrical continuity of the thermocouples and winding leads had been checked (transformer and solenoids), the thermal vacuum chamber was closed and sorption pumped. When the pump thermocouple gauge reached 7 to 8 microns pressure, the sputter-ion pump was energized. Several titanium sublimation pump bursts were used to help the pump get started. Thermocouple brazed joints were leak checked and several required additional sealing to form vacuum tight joints.

When chamber pressure reached a value of $8x10^{-7}$ torr, room temperature base line static electrical measurements were made on the transformer and solenoids, and the transformer secondary load bank was adjusted. The titanium sublimation pump was cycled for an hour and when the pressure decreased into the $10^{-8}$ torr range, a 24-hour chamber bake-out at 250° C was started. Cold chamber pressure after the bake-out was $9.3x10^{-10}$ torr.

In an effort to reduce the base pressure, a second 24-hour bake-out cycle was initiated. Cold chamber pressure, after this cycle, reached a value of $4.6x10^{-10}$ torr, and the chamber was judged ready for the application of model test loads and furnace heater power to bring the test models to test temperature.

Bench test electrical measurements covering conductor resistance, dc insulation resistance, and ac potential elec-

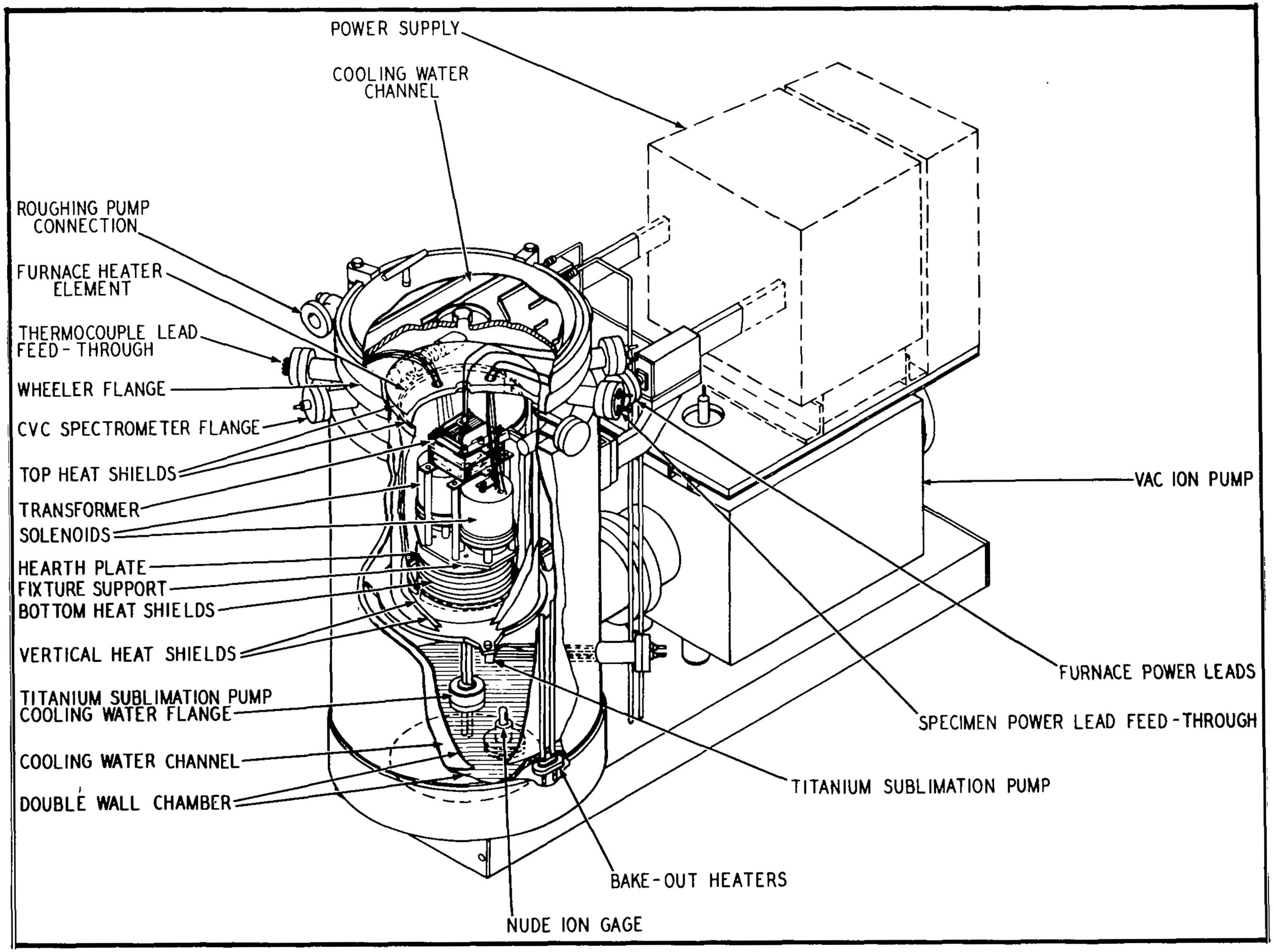



**FIGURE II-34.** Cutaway View of a Vacuum Furnace Showing Installation of a Transformer and Two Solenoids

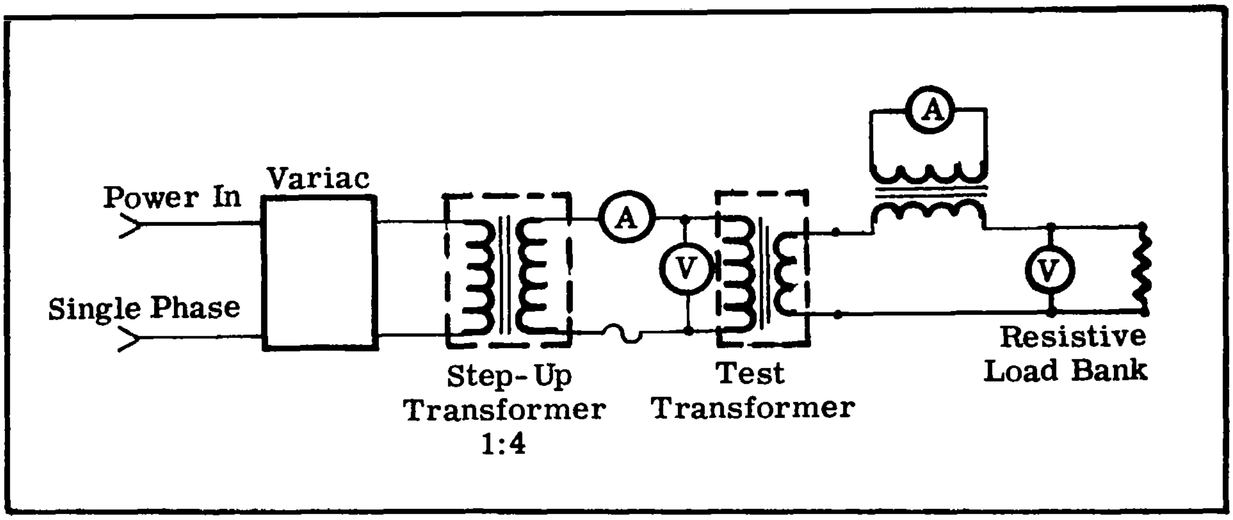



FIGURE II-35. Electrical Test Schematic for the 1 kVA Rated Transformer

trical leakage had been taken prior to installation of the transformer and solenoids in the chamber. As mentioned previously, these measurements were repeated at room temperature under vacuum conditions and they were repeated periodically as the test progressed. Residual gas analysis scans were also taken periodically.

Power was applied to the transformer and to the continuously activated solenoid. Adjustments were made to the solenoid input voltage to hold transformer and solenoid hot-spot temperatures near the same values. Power was then applied to the furnace element in several stages to bring the transformer and solenoid hot-spot temperatures up to 1100° F. When temperatures had reached a stable condition, electrical measurements were taken and official endurance test time was started.

Daily data readings were taken for thermocouples, primary and secondary winding currents and voltages, heater element performance, etc. Thermocouple readings were also recorded for 15 minutes out of each test hour on a multipoint recorder. Once each week a residual gas analysis spectrogram was made of the test chamber atmosphere and static electrical performance readings were measured and recorded. Titanium sublimation pump bursts of 2-minute duration were applied to the chamber at intervals to determine the effect on chamber base pressure.

## 6. Transformer Data and Discussion - 1100° F Hot-Spot Model

The transformer was designed to be a 1 kVA working model. The resistive load banks outside the test chamber were set for a secondary winding load of 29.8 amperes at 29.1 volts. The primary winding input was 1.84 amperes at 600 volts ac, giving an input power of 1104 volt-amps and a load of 867 watts on the secondary winding.

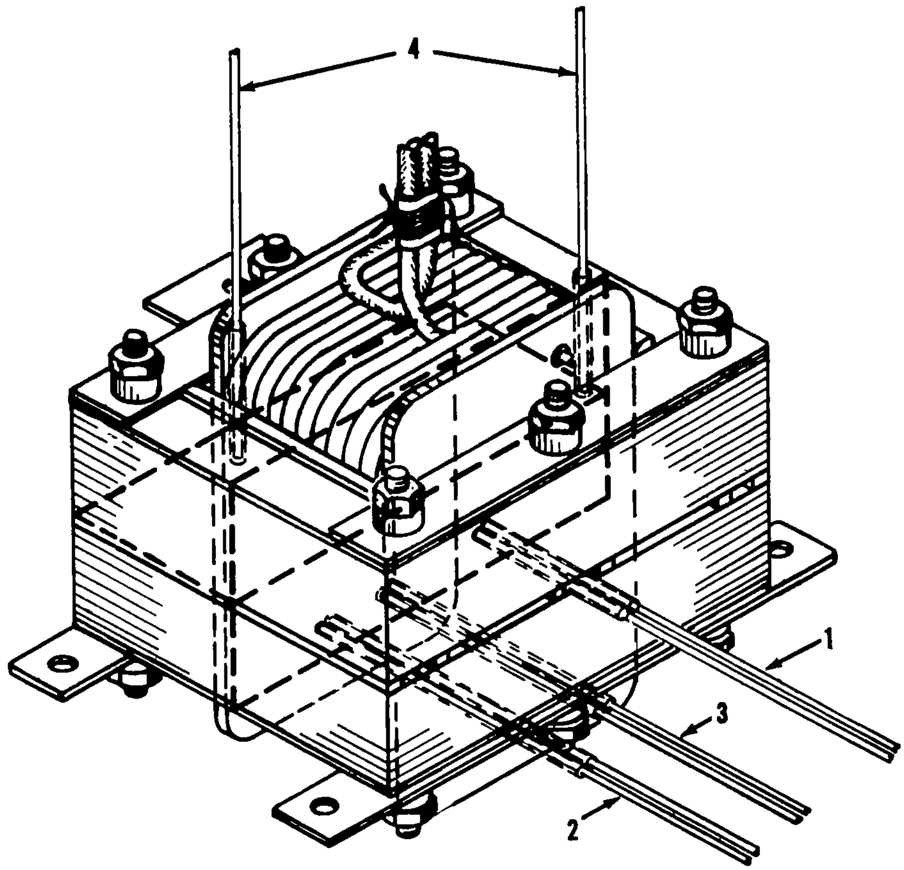
The cross-sectional area (silver and nickel) of the primary winding conductor was 0.00080 square inches, resulting in a current density of 2300 amperes per square inch. Current density in the secondary winding, with a silver-and-nickel cross-sectional area of 0.01625 square inches, was 1830 amperes per square inch. Assuming current is concentrated in the silver core, primary winding current density would be 2875 amps per square inch and secondary winding current density would be 2290 amps per square inch.

Transformer $I^2R$ losses at temperature were 16.4 watts in the primary winding and 15.5 watts in the secondary winding.

Figure II-36 is a sketch showing the location of thermocouples in the transformer with a tabulation identifying each location. Initially the transformer had eight thermocouples, but two were damaged beyond repair during installation in the test chamber. Each thermocouple was installed in an alumina insulator tube.

Table II-10 is a representative tabulation of transformer temperatures taken after 24 hours of endurance testing had been completed. The highest temperature occurred between the primary winding inside diameter and the alumina winding spool. Mid-stack thermocouples showed the next highest temperature.

After approximately 107 hours of endurance testing, the Variac supplying primary winding power and the primary circuit voltmeter were damaged by excessive current. The first analysis was that one or the other had developed a short. These two components were sitting side by side and the metal handle on the voltmeter case might have provided a path to ground through the metal case of the Variac. When power was reapplied to the transformer, however, it was found that the primary winding had developed a layer-to-layer short circuit and would not carry any load. It was assumed that the primary winding insulation system had degraded with time and failed.




| No. | Qty. Installed | Description |
|---|---|---|
| 1 | 2 | Mid-stack |
| 2 | 2 | Primary ID-Spool<br>One lost during assy. |
| 3 | 2 | Primary-Secondary windings |
| 4 | 2 | Secondary OD<br>One lost during assy. |

FIGURE II-36. Transformer Assembly Showing Thermocouple Locations and Junction Positions

TABLE II-10. Representative Transformer Temperature Distribution at 1100° F Hot-Spot Temperature After 24 Hours of Endurance Test

| Thermocouple Location | Temperature (°F) |
|---|---|
| Mid-stack | 1088 |
| Mid-stack | 1088 |
| Primary ID-Spool | 1095 |
| Primary-Secondary Windings | 1083 |
| Primary-Secondary Windings | 1078 |
| Secondary OD | 1062 |

The capabilities of the insulation system materials were reviewed for possible clues to the failure. The Burnil CM-2[14] flexible sheet insulation was composed of synthetic-mica platelets of a complex composition of lithium magnesium silicate. Voltage breakdown as established on Program NAS 3-4162 was 155 volts per mil at 1120° F and 400 cps. Voltage breakdown for the Anadur conductor insulation was 62 volts per mil at 1112° F and 400 cps.

The expected maximum voltage gradient layer-to-layer in the primary winding was 271 volts. The Anadur thickness between two conductors was 0.014-inch, giving a potential breakdown strength of 868 volts between layers at 1100° F. The Burnil CM-2 thickness was 0.010-inch between winding layers, resulting in a potential breakdown strength of 1550 volts at 1100° F. This value is additive to the Anadur strength. Further analysis of the mechanism of failure was postponed until the transformer could be removed from the test chamber.

Electrical performance measurements were taken after the failure, and the results indicated that a 600-volt ac potential from winding-to-ground would continue to provide information on the insulation system performance. The transformer leads were rewired to apply a 600-volt ac potential between each winding and ground and the test was continued to the 5000-hour goal.

[14] 3M Company, op. cit.

Figure II-37 is a plot of transformer-solenoid chamber pressure versus endurance test time. Pressure reduction was quite rapid and steady for the first 1000 hours, followed by an almost constant pressure level for the next 2000 hours. Pressure decrease was steady from the 3000-hour point through 4000 hours, at which time the rate changed sharply. Outgassing from the Burnil CM-2 flexible layer insulation may have been responsible for sustaining the pressure level in the 1000- to 3000-hour period and again in the 4000- to 5000-hour period.

Figure II-38 is a dimensionless plot of the transformer primary and secondary conductor resistance as a function of endurance test time. The effects of the primary winding failure after 107 hours of test are shown as a large reduction in primary winding resistance and a small increase in secondary winding resistance. Neither conductor showed any changes in resistance values at constant temperature from the point of failure through the 5000 hours of test. The reason for the small increase in secondary winding resistance at the time of the failure will be covered in the Post-Test Investigation section.

Table II-11 is a tabulation of transformer insulation system performance during the 5000-hour test. All data are referred to a stabilized (unpowered) transformer temperature of 1030° F. The primary winding failure caused a large reduction in insulation strength between the two windings, but did not have much effect on winding-to-ground performance because a high-purity alumina spool and end plates were used as the ground insulation.

Figure II-39 is a mass spectrogram showing the major gas component partial pressures in the 1100° F transformer and solenoid test chamber. When the test was initiated, the $N_2$+CO components were the predominant gases and the $H_2O$ content was lower than $CO_2$. By the time the 1500-hour point was reached, $H_2O$ had become the predominant gas, which it remained for the balance of the test. The $N_2$+CO combination remained the next most prevalent gas. The water vapor pressure maintained a relatively constant level throughout the test as compared to the stator chamber. In addition to W-839 potting compound, which was used sparingly on the transformer, Burnil CM-2 (synthetic mica) flexible insulation was used as insulation between winding layers. The Burnil CM-2 may have contributed to the $H_2O$ level as a function of time to a greater extent than the potting compound. The $H_2O$ partial pressure level in the transformer chamber was approximately half a decade higher than the stator chamber $H_2O$ partial pressure level during the latter part of the test period.

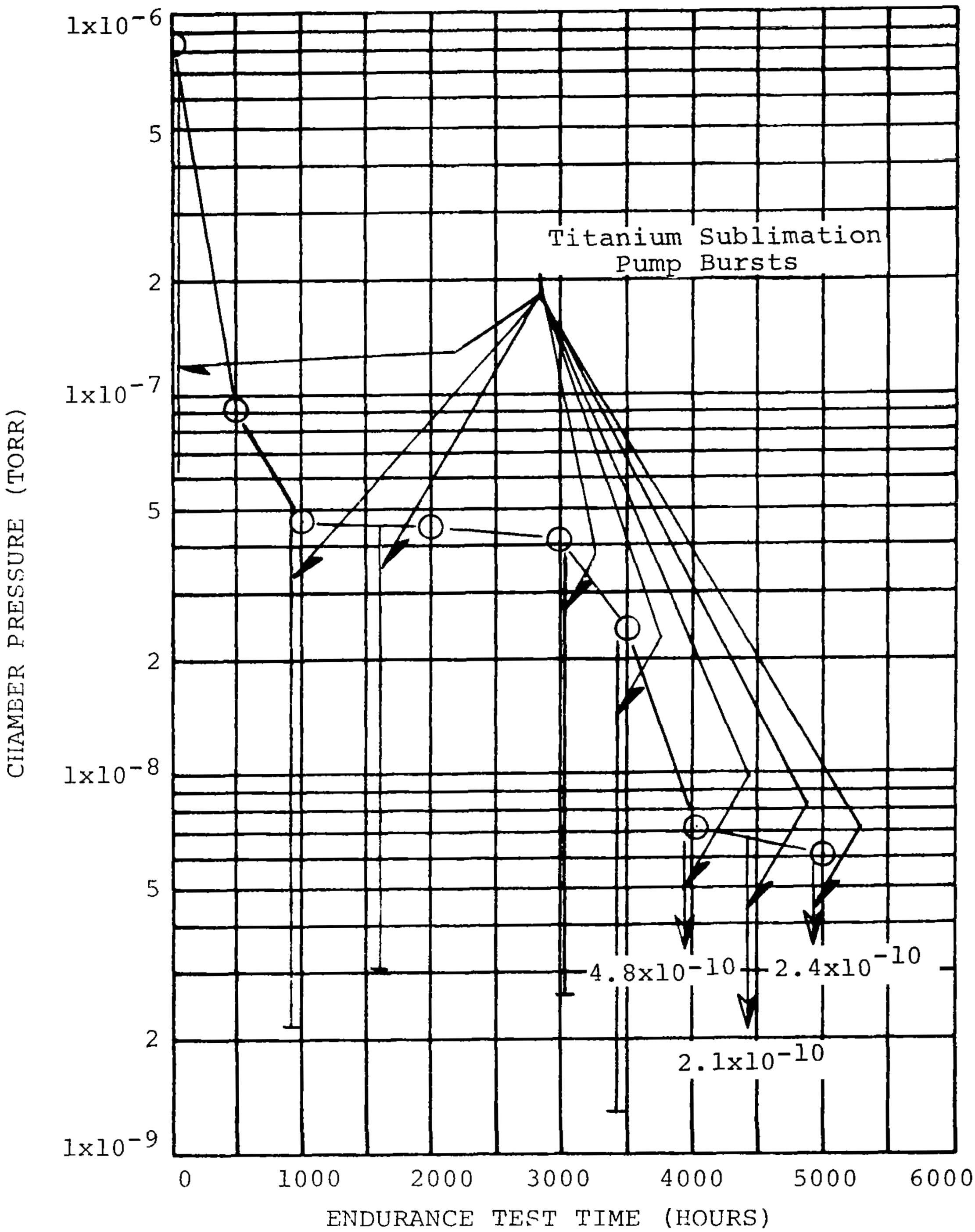



FIGURE II-37. Transformer-Solenoid Chamber Pressure Versus Endurance Test Time - 1100° F Models

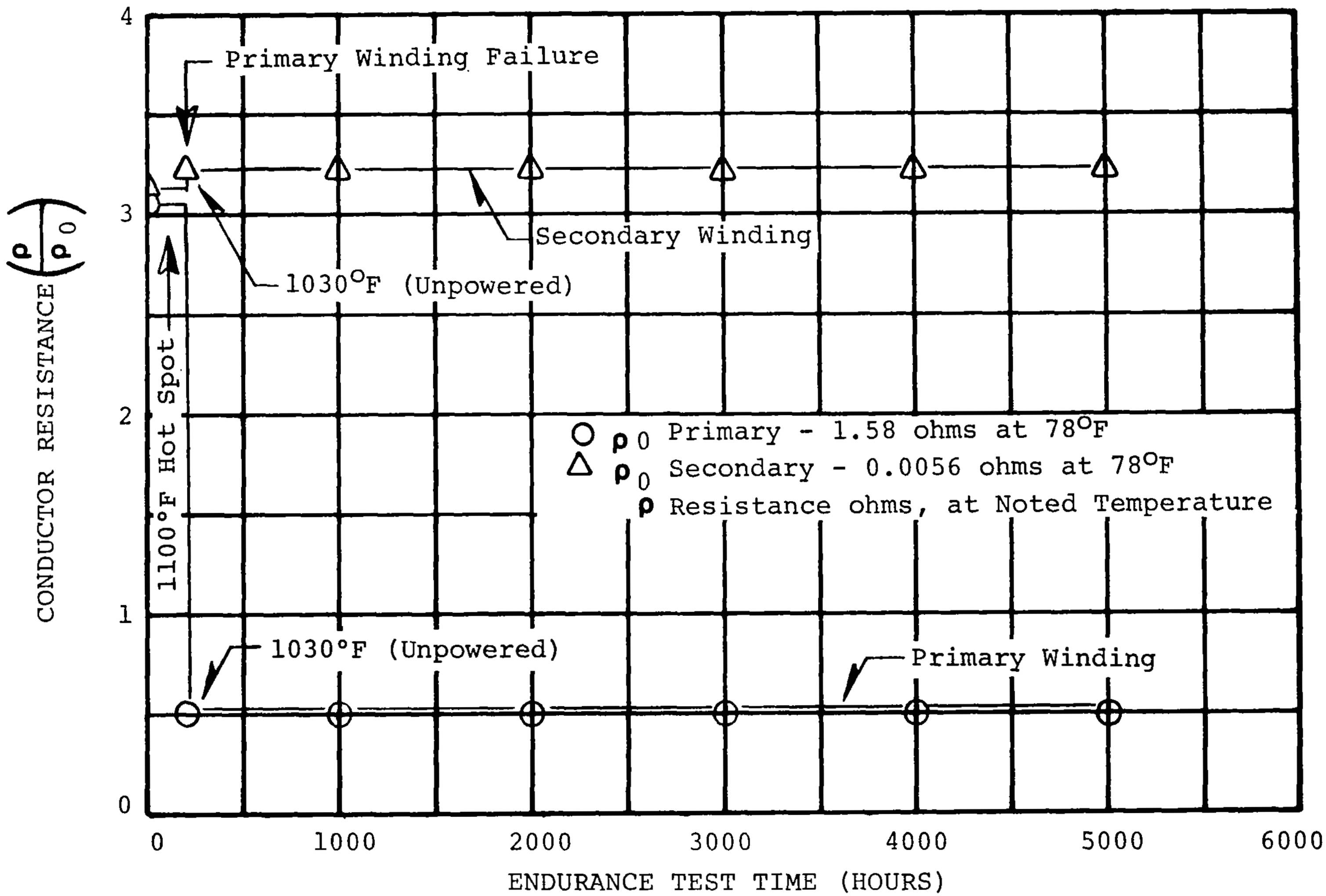
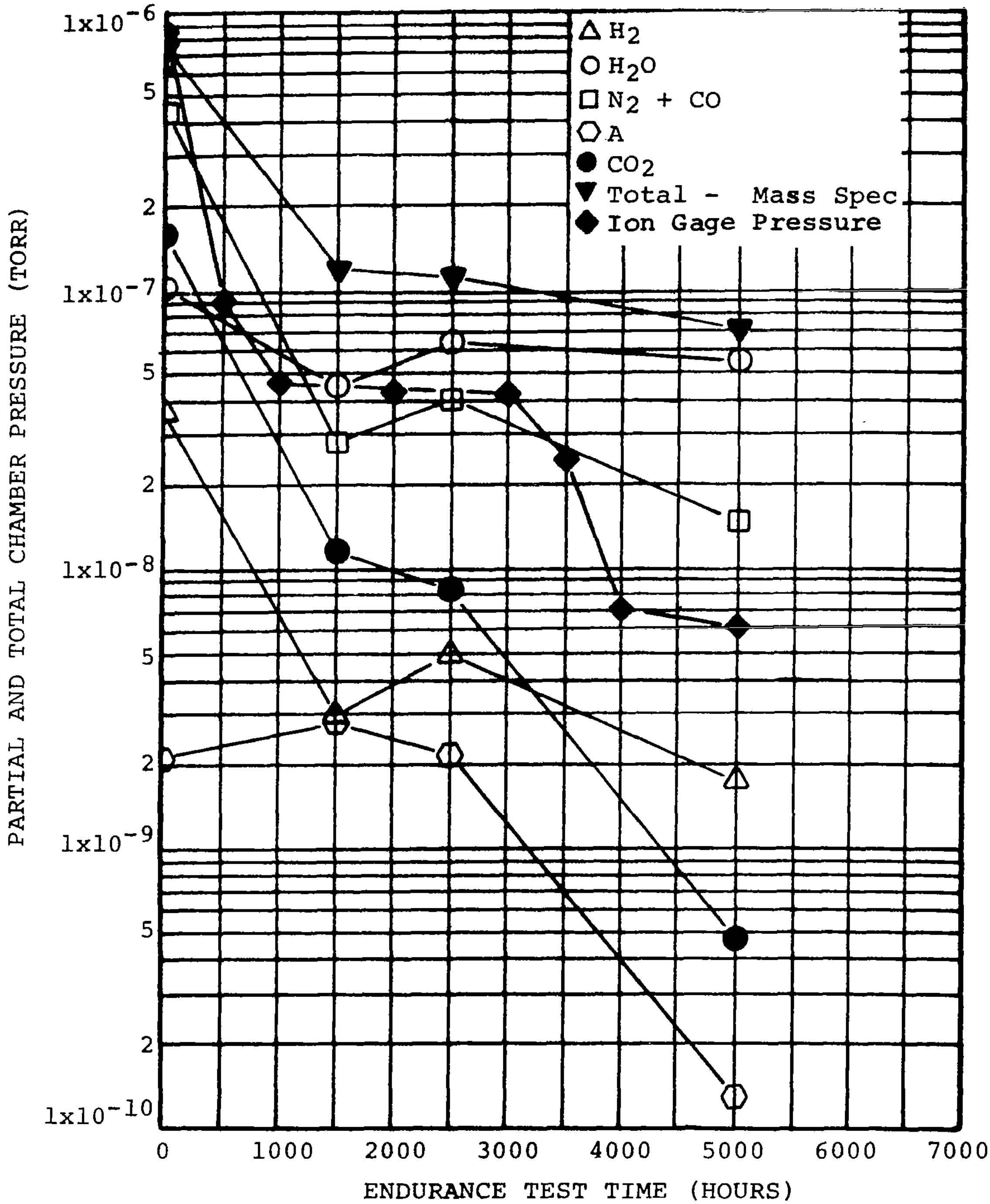



FIGURE II-38. Transformer Winding Resistance Versus Endurance Test Time - 1100° F Model




(Note: Temperature was constant at 1100° F.)

FIGURE II-39. Time-Pressure Plot of Mass Spectrometer Residual Gas Analysis Scans in Chamber No. 2. (Transformer and Solenoids)

TABLE II-11. Transformer Insulation Performance in Vacuum Referenced to a Stabilized (unpowered) Temperature of 1030° F

| Endurance Test Time (hours) | 0 | 200 | 2500 | 5000 |
|---|---|---|---|---|
| Average Insulation Resistance (ohms) with 500-V d-c Applied: | | | | |
| Primary to Secondary[a] | $9x10^6$ | $0.80x10^6$ | $0.83x10^6$ | $0.85x10^6$ |
| Primary to Ground[b] | $17x10^6$ | $15.8x10^6$ | $16.8x10^6$ | $17x10^6$ |
| Secondary to Ground[b] | $15x10^6$ | $14.5x10^6$ | $14.6x10^6$ | $14.7x10^6$ |

(a) Primary winding developed a layer-to-layer short circuit after 107 hours of endurance testing.

(b) Primary Winding - 0.032-inch diameter nickel-clad silver wire with Anadur E glass insulation - 0.010-inch-thick synthetic mica between layers.

Secondary Winding - 0.144-inch diameter nickel-clad silver wire with Anadur E glass insulation; four 0.010-inch-thick layers of synthetic mica insulation between primary and secondary windings.

## 7. Post-Test Investigation - 1100° F Hot-Spot Transformer Model

Figure II-40 shows the transformer and solenoid thermal-vacuum test chamber with the top cover removed after completion of the 5000-hour test. Test model and thermocouple leads are still attached to the chamber feedthroughs. The clean condition of the chamber interior can be noted by the brightness of the light reflections. Figure II-41 shows the transformer and solenoids in the chamber after removal of the top heat shields. Figure II-42 shows the transformer and two solenoids on their support fixture after being removed from the chamber. The model lead ceramic insulators show the same stains at the top heat shield pass-throughs as were noted on the stator insulators. The right hand solenoid has been rotated on the fixture to show a bead of silver sitting on its top surface. The source of this bead is described below.

As discussed previously, the transformer primary winding was assumed to have failed by shorting between layers after

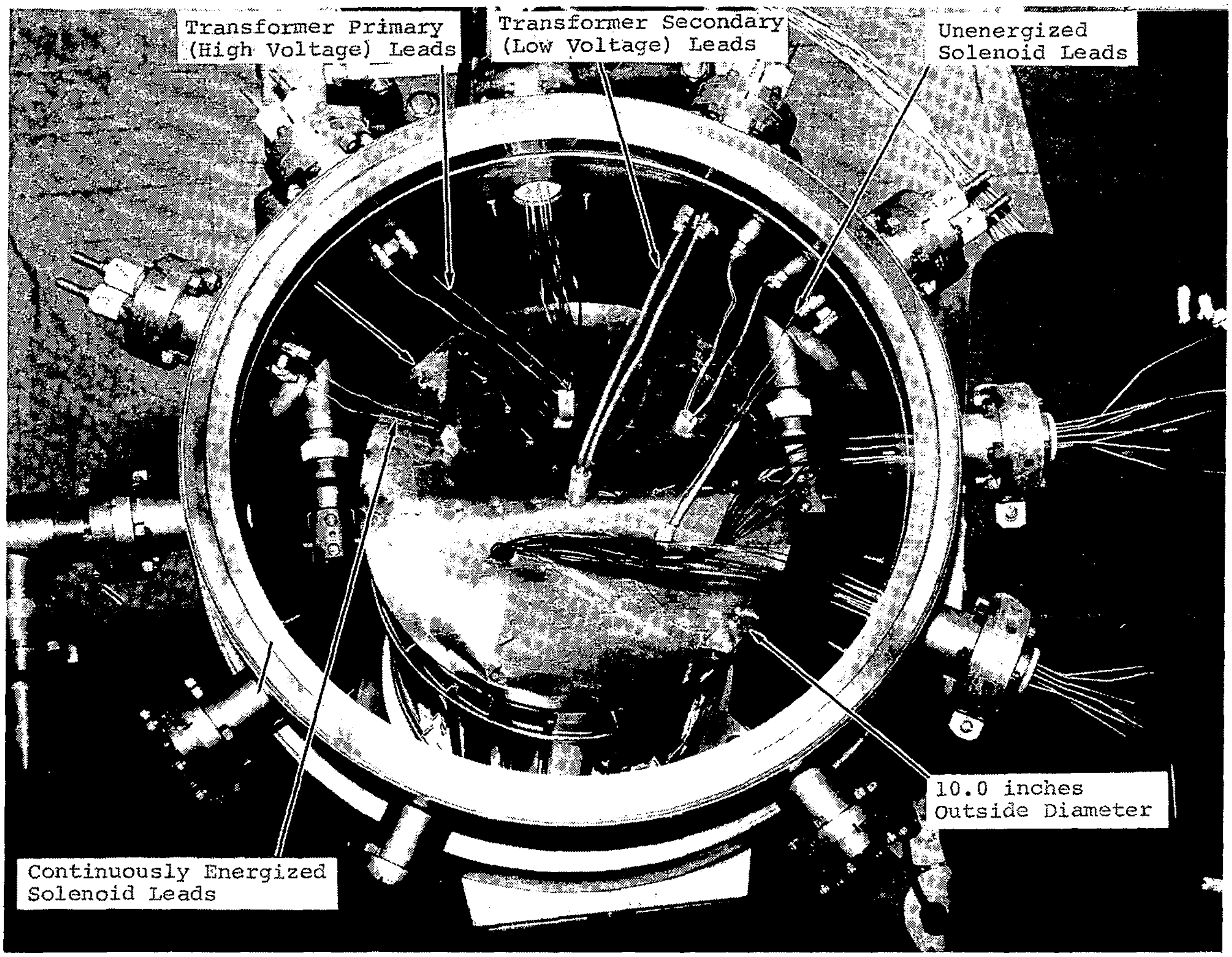



FIGURE II-40. Transformer and Solenoid Test Chamber with Vacuum Chamber Cover Removed - 1100° F Test

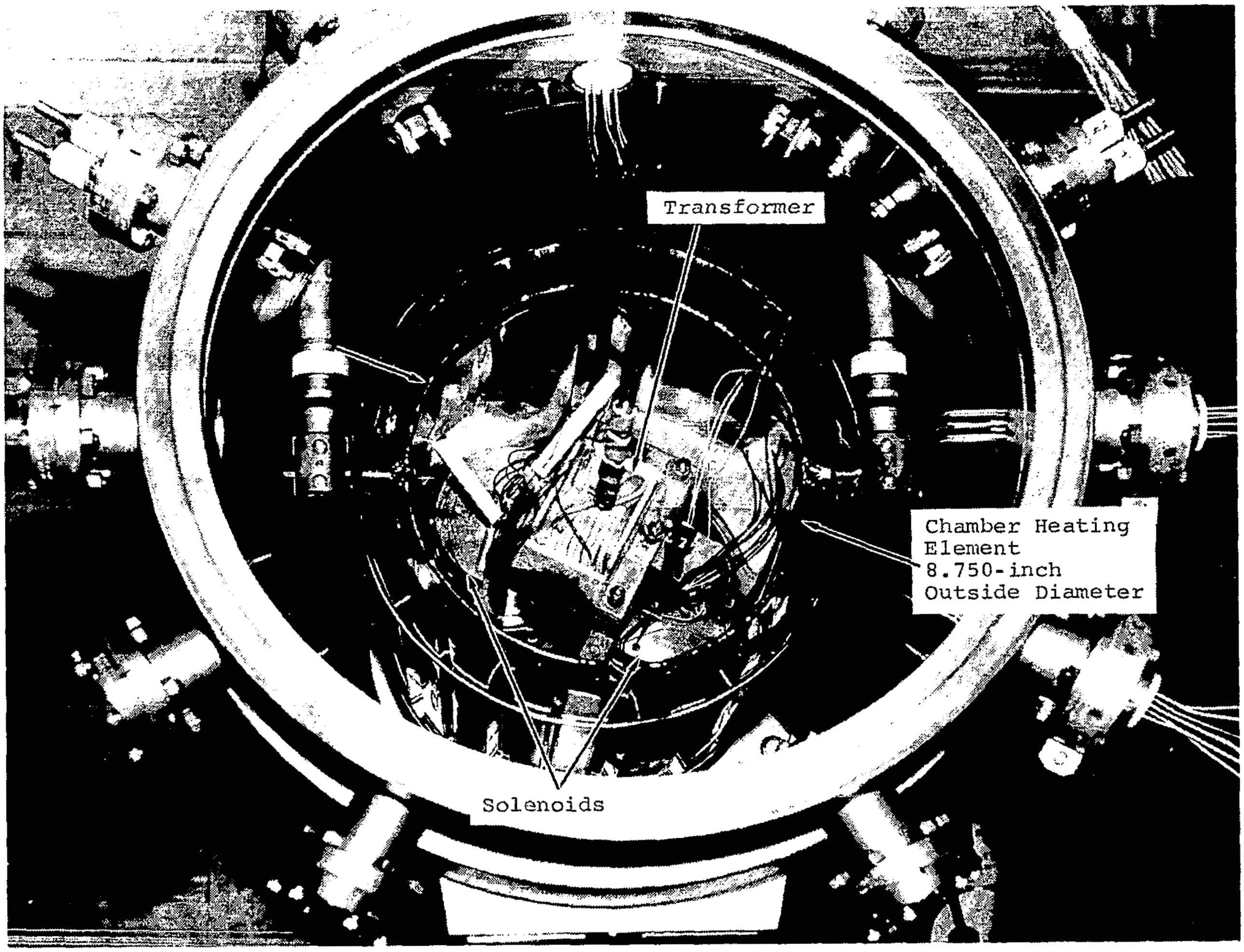



FIGURE II-41. Transformer and Solenoids in Test Chamber with Top Heat Shields Removed - 1100° F Models

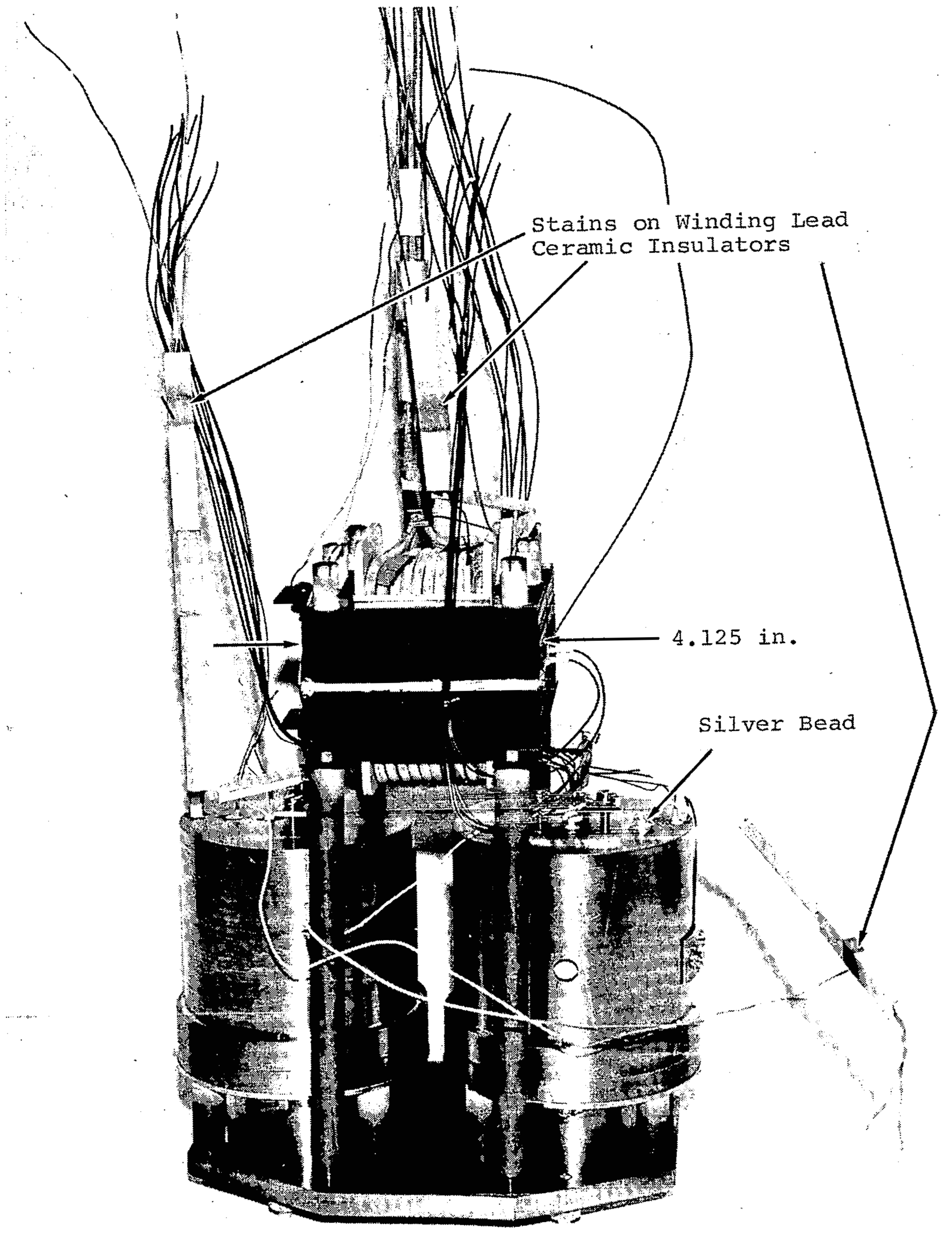



FIGURE II-42. Transformer and Solenoids on Test Support Fixture After Removal From the Test Chamber - 1100° F Models

107 hours of endurance test. The secondary winding showed a slight increase in resistance after the failure, but maintained typical electrical performance otherwise. Thus, it was presumed to be in good condition. Figure II-43 is a close-up of the top of the secondary winding, showing that the furthermost turn has a cross-sectional segment of nickel-clad silver wire completely missing. Part of the Anadur insulation is also missing from the wire. Figure II-44, which is a close-up of the bottom of one side of the transformer, shows a silver flow at the port for the thermocouples installed between the primary and secondary windings. This port was situated over the solenoid in figure II-42, which had the silver bead.

Further analysis of the secondary winding resistance indicated that part of the end turn was open, but it was welded to the adjacent turn in a region that cannot be seen externally. Thus, the lead at that end of the winding was still attached to the winding because of the turn-to-turn weld. The weld resistance was somewhat higher (see figure II-38) than that of the open turn segment, resulting in a slight increase in winding resistance while maintaining electrical continuity.

Figure II-45 shows the primary winding after removal of laminations and the secondary winding and interwinding flexible insulation (Burnil CM-2). The four layers of Burnil CM-2 had been perforated over the hole in the primary winding, but the hole was shaped like a cone with the base at the primary winding side and a 1/16-inch diameter hole in the outer layer at the secondary winding side. The secondary winding was not damaged in this area. The shorted secondary turn was located at the opposite end of the winding (left side of the primary winding in the photo).

The outer primary winding which shows in the photograph had fewer turns than the inner four layers of windings so the turns are spread out. The turns in the inner layers were hand-wound to be as tight as possible. The hole that shows in the winding broadened randomly as it progressed inward through the winding, then decreased in area as it approached the innermost winding. The wire ends around the hole had been fused together by molten silver, and beads of silver can be seen between turns of the outer winding layer. No silver had escaped through the four layers of interwinding Burnil CM-2 insulation so the silver noted on top of the solenoid had to come from the secondary winding. The inner layer of Burnil CM-2 was fused to the winding in the area adjacent to the hole, indicating that a very high temperature occurred locally (greater than 1760° F).

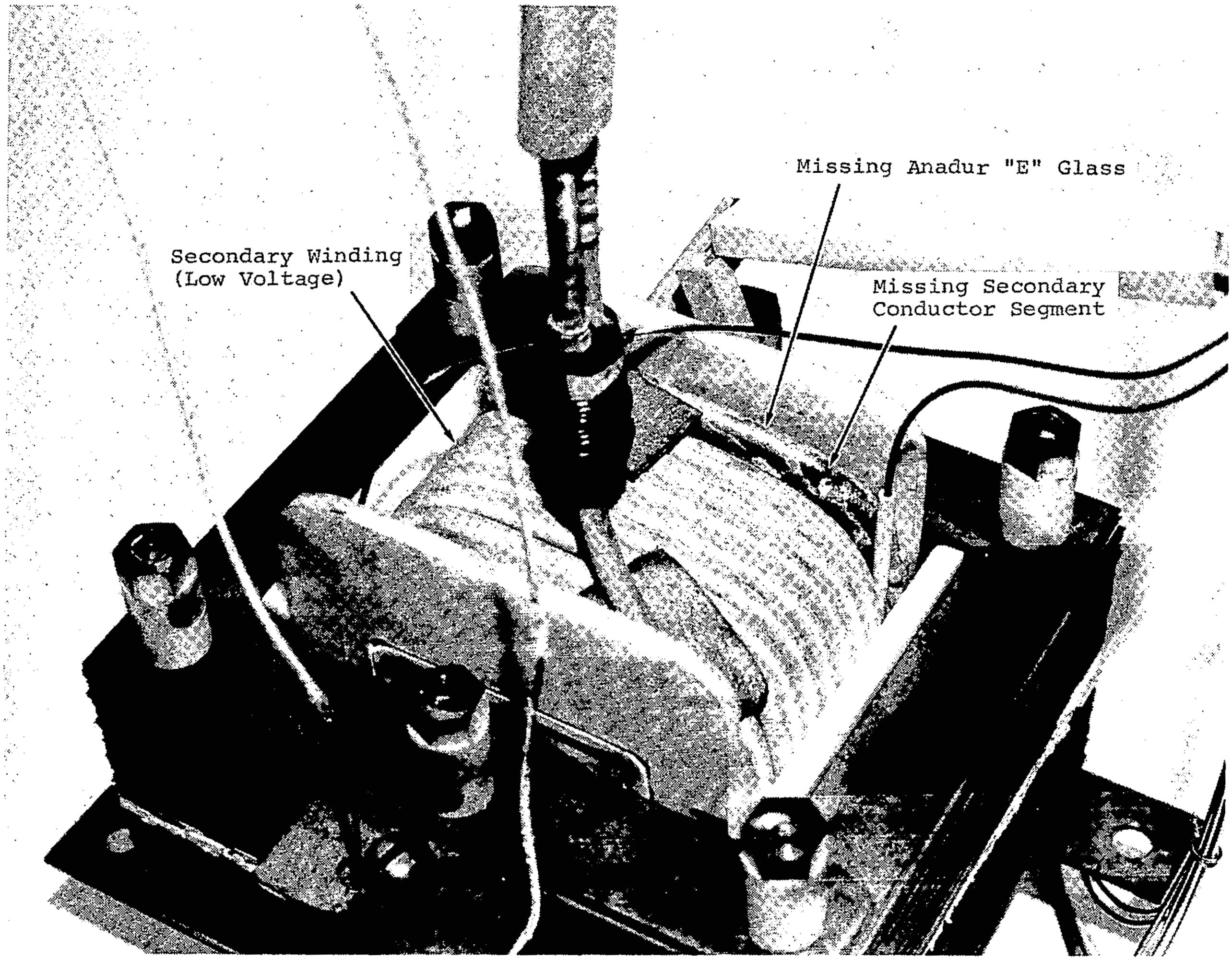



FIGURE II-43. Close-Up of Transformer Secondary Winding

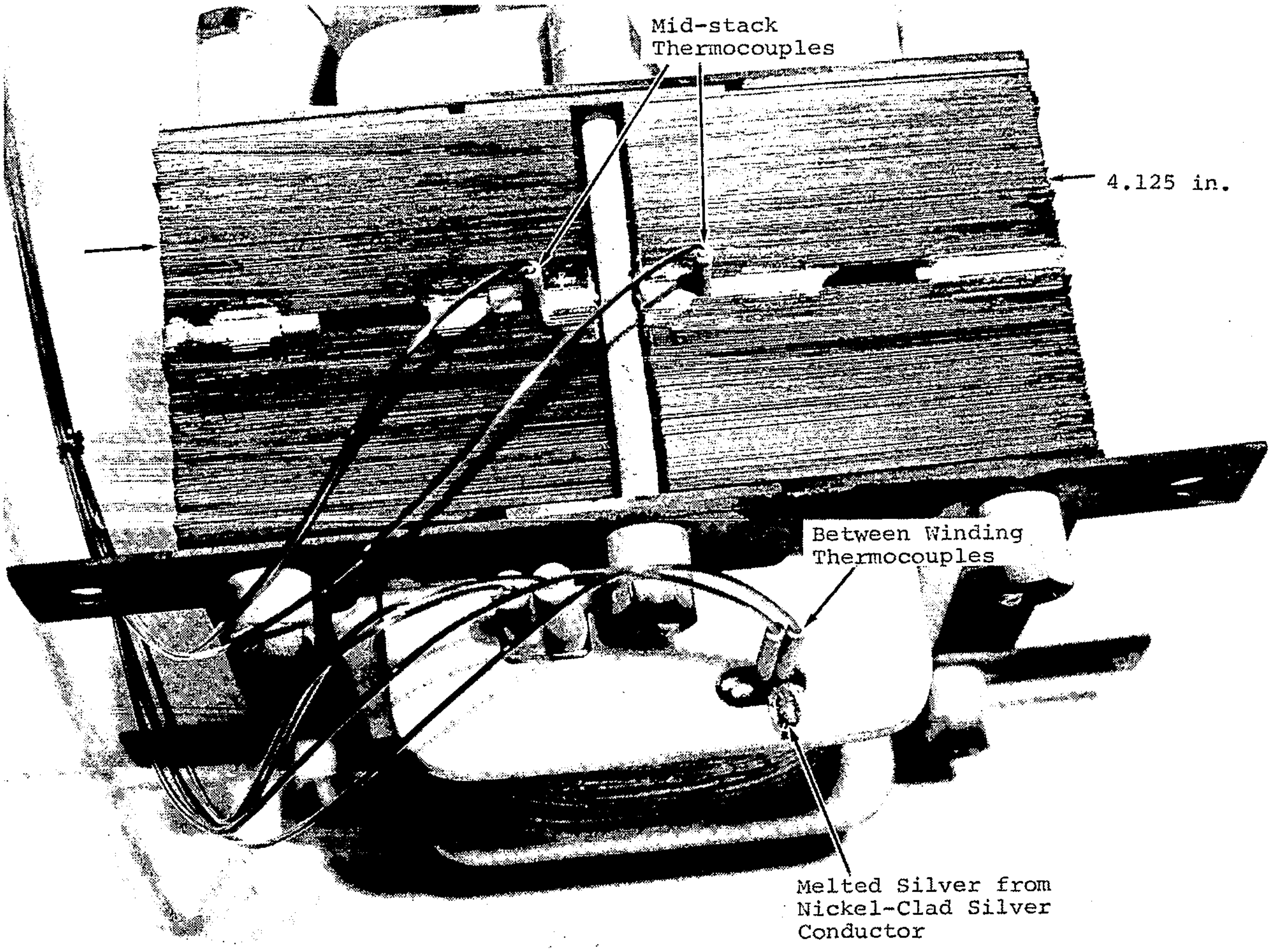



FIGURE II-44. Side View of Transformer - 1100° F Model

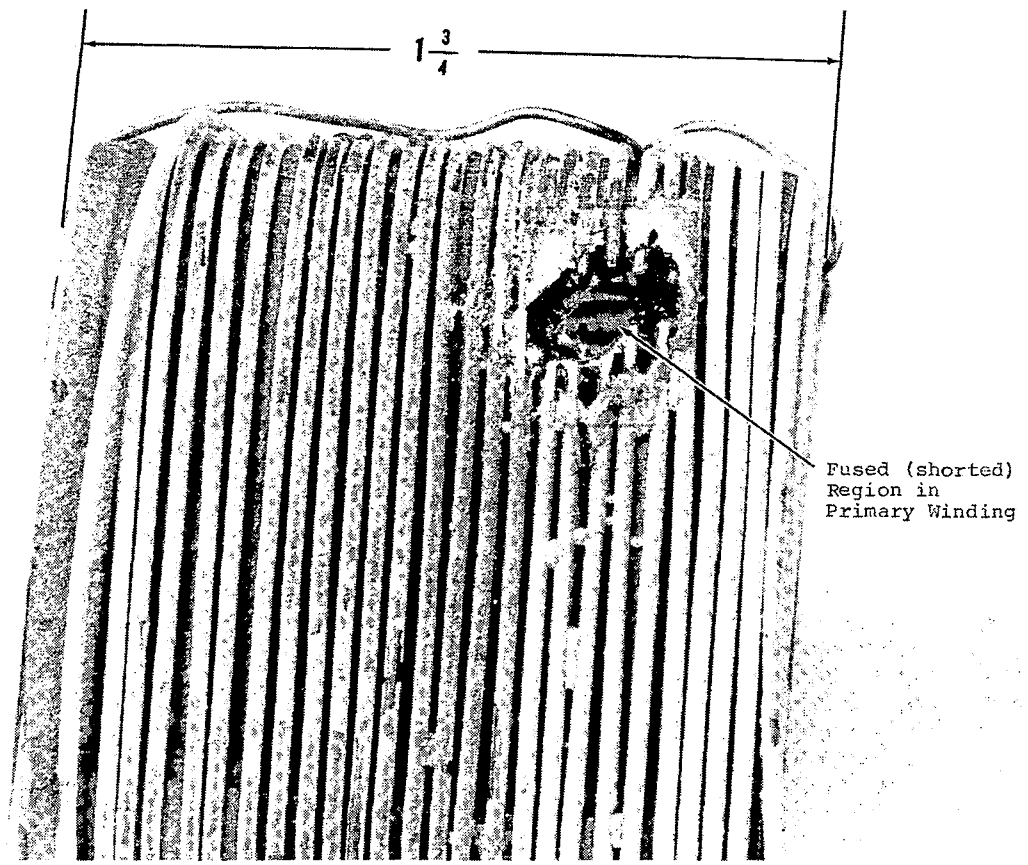



FIGURE II-45. Primary Transformer Winding After Test - 1100° F Model

The primary winding was unwound turn-by-turn to determine the condition of the Anadur and Burnil CM-2 in the inner layers. The outer layer of the winding had been subjected to a considerable amount of handling after transformer disassembly, so the Anadur condition was not considered to be representative. The second layer from the outside had not been disturbed by handling, but as the interlayer flexible insulation was removed, very small flakes (near-powder-size) of Anadur came off the winding. This flaking was a small percentage (3 to 5%) of the total Anadur coating, and it is probable that the Burnil CM-2 held the flakes in place until disassembly. The Anadur near the center of the layer was very hard and brittle compared to the Anadur at the end turns. When the center turns were scuffed with a finger nail, the Anadur continued to come off in very small flakes, while scuffing the end turns resulted in fuzzing and eventual breaking of the glass strands.

The third layer from the outside displayed the same characteristics as the second layer. The Anadur in the fourth layer did not show the flaking spots when the Burnil CM-2 was removed, and it was not as brittle on the center turns as it was in the second and third layers. The fifth (inner) layer did not reveal any Anadur flaking and the center turns of Anadur was far less brittle than in the second and third layers.

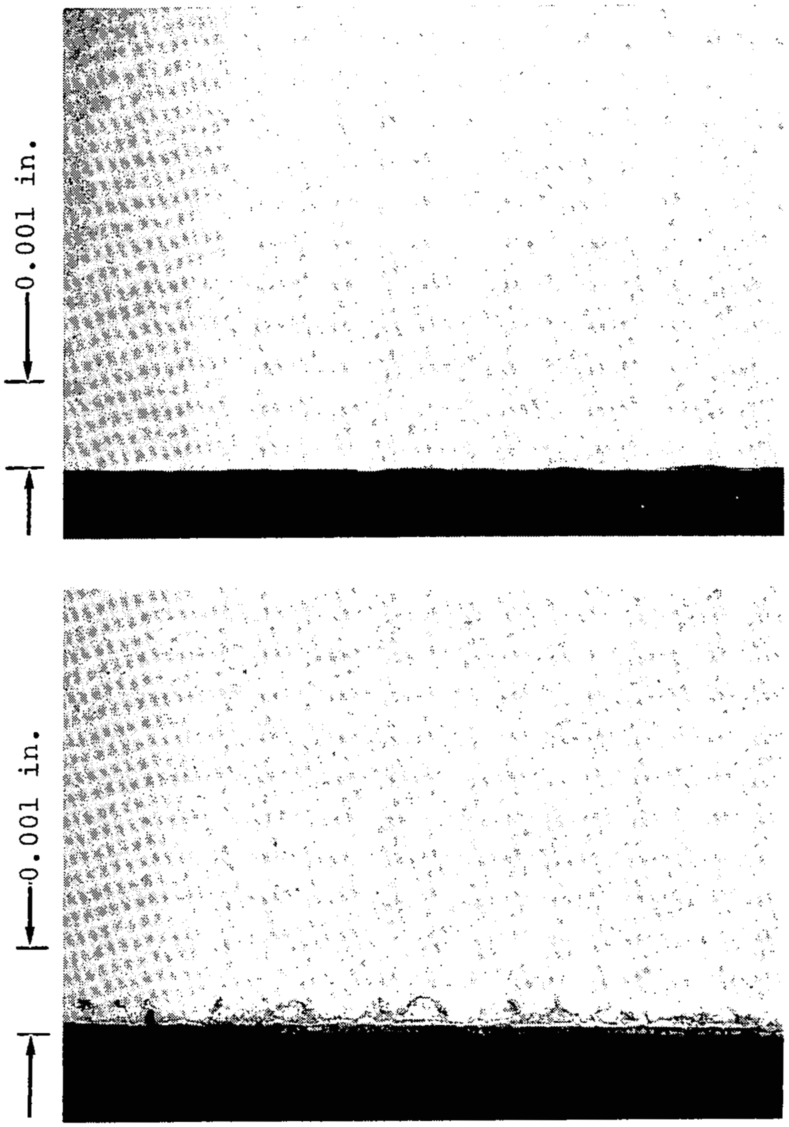
The secondary winding (one layer) did not exhibit any brittleness in the Anadur.

The maximum Anadur temperature in the winding layers was not known, but it would have been higher than any thermocouple readings obtained while the transformer was functioning properly (107 hours). For the balance of the 5000 hours, the various parts of the transformer were at essentially the same temperature, as the only heat supplied was radiated from the energized solenoid and the chamber heating element.

It is assumed that the insulation temperature in the center turns of the interior layers reached a value of at least 1300° F, which was high enough to cause the E-glass component of the Anadur to devitrify and change from an amorphous glassy body to a polycrystalline type of structure. This would account for the Anadur flaking that occurred in the hotter spots in the winding, and provides a rough estimate of the insulation hot-spot temperature in the winding, exclusive of the molten silver area.

Following the failure of the 1300° F transformer primary winding (reference section II.C.9) a design review was held to consider the possible modes of failure in the windings. The results and conclusions of this review are reported in section II.C.9.

Aged and unaged transformer laminations were subjected to metallographic examinations. The aged laminations showed considerable brittleness compared to unaged laminations. Figure II-46 is a comparison of two micrographs; one of an unaged lamination and one of a lamination that has been aged 5000 hours in high-temperature vacuum. Neither specimen has been etched. The unaged lamination is very similar in appearance to the stator unaged lamination (see figure II-23), and there are no apparent surface flaws. The aged lamination shows some evidence of oxidation in surface grain boundaries, but not to as great an extent as in the aged stator laminations.




(a)

Unetched, Unaged

500X

(b)

Unetched, Aged
5000 Hours at 1100°F

500X

Oxide Peneration into Lamination Surface

FIGURE II-46. Micrographs of Unaged and Aged Hiperco 27 Transformer Lamination Sections - 1100° F Model

Both aged and unaged lamination samples were tested for carbon and phosphorus content. The unaged lamination had a carbon content of 0.011 to 0.012% (same range as the unaged stator lamination). The aged lamination had carbon content of 0.0058% which is somewhat higher than that of the aged stator lamination, 0.0018%. The phosphorus content was within the specification limit for this material (<0.005%); it amounted to 0.0028% in the unaged transformer lamination and was only 0.0008% after aging. This is in contrast to a radical change in the phosphorus content between the unaged and aged stator laminations (0.002% and 0.012% respectively). Phosphate-based potting compound was used on the transformer only to anchor the midstack thermocouple tubes and spacers, so only two laminations were directly exposed to it; whereas, each lamination slot in the stator was exposed to it.

The transformer assembly was put through the same Anadur insulation system bake-out as the stator, so there was the same potential source for developing oxide layers on the laminations.

The variations noted in the unaged and aged stator and transformer lamination constituents suggests the following embrittlement mechanism:

a) Internal oxidation takes place forming oxides in the grain boundaries of the Hiperco 27 laminations.

b) The presence of an oxide layer on the lamination surface provides the oxygen source for internal oxidation in a vacuum. The same mechanism is probably responsible for the loss of carbon during high-temperature vacuum exposure.

c) The presence of a phosphorus source (in the stator) considerably increases the extent of internal oxidation, both by its high oxidation potential and probably by leaving a trail of structural imperfections during its diffusion into the alloy.

## 8. Transformer Test Procedure - 1300° F Hot-Spot Model

The methods and procedures used to install the 1300° F hot-spot transformer in the test chamber were the same as those used for the 1100° F model. After electrical continuity of the winding leads and thermocouples had been verified, the test chamber top cover was installed, the chamber was sorption-pumped, and the sputter-ion pump was started.

When chamber pressure had decreased to $2.8 \times 10^{-7}$ torr, the transformer secondary load bank was adjusted. Power was removed from the transformer and the chamber was prepared for a 24-hour bake-out at 250° C. Minimum chamber pressure following bake-out and cooling was $2.6 \times 10^{-10}$ torr.

Bench test static electrical measurements covering conductor resistance, dc insulation resistance, and ac potential electrical leakage had been taken prior to installation of the transformer and solenoids in the test chamber. These measurements were repeated after bake-out to provide base line data on model performance under high-vacuum conditions.

The chamber temperature was brought up in stages using the chamber heater element power only and no power to the models. Electrical performance data were taken at each stage when temperatures throughout the models were essentially stable. When a 1300° F temperature was reached, heater element power was reduced and power was applied to the transformer and the energized solenoid. The transformer was set at 600 volts ac and 1.92 amperes on the primary winding and 32.0 volts ac and 20.8 amperes on the secondary winding. The energized solenoid was set at 24.0 volts dc and 0.55 ampere. Chamber heater element power was adjusted to 500 amperes and 1.6 volts, and the logging of endurance test time was initiated.

Basic data such as thermocouple readings, primary and secondary winding currents and voltages, chamber pressure, heater element performance, etc., were taken daily. Once each week a test chamber residual gas analysis spectrogram was taken and transformer electrical performance readings were measured and recorded. Titanium sublimation pump bursts of 2-minute duration were applied to the chamber at intervals to evaluate the effect on chamber base pressure.

## 9. Transformer Data and Discussion - 1300° F Hot-Spot Model

This transformer was designed to be a 1 kVA working model. In order to obtain a balanced hot-spot temperature with the energized solenoid, the resistive load banks outside the test chamber were set up for a secondary winding load of 20.8 amperes at 32.0 volts. The primary winding input was 1.92 amperes at 600 volts ac, giving an input power of 1150 volt-amperes and an external load of 666 watts on the secondary winding.

The cross-sectional area (Inconel and silver) of the primary winding conductor was 0.00080 square inches, resulting in a current density of 2400 amperes per square inch. Current density in the secondary winding, with an Inconel and silver cross-sectional area of 0.01625 square inches, was 1280 amperes per square inch. Assuming current is concentrated in the silver core, primary and secondary current densities would be 3340 and 1780 amps per square inch respectively.

Transformer $I^2R$ losses at temperature were 23.3 watts in the primary winding and 11.16 watts in the secondary winding.

Thermocouples were installed in the same locations as in the 1100° F model (figure II-36). One primary-secondary winding thermocouple was damaged beyond repair during installation in the chamber. Each thermocouple was installed in an alumina insulator tube.

Table II-12 is a representative tabulation of transformer temperatures taken after 216 hours of endurance testing had been completed. In this model the highest temperature occurred at the thermocouples located at the midstack position rather than between the primary winding inside diameter and winding spool as in the 1100° F model. Magnetic and $I^2R$ losses in the assembly were higher in the 1300° F model. The increase in losses compared to the 1100° F model was caused in part by greater winding resistance at the higher temperature ($I^2R$ losses) and in part by a greater magnetizing current which was required because of a reduction of permeability in the stack at the higher temperature.

TABLE II-12. Representative Transformer Temperature Distribution at 1300° F Hot-Spot Temperature After 216 Hours of Endurance Test

| Thermocouple Location | Temperature (°F) |
|---|---|
| Mid-Stack | 1300 |
| Mid-Stack | 1300 |
| Primary ID-Spool | 1271 |
| Primary ID-Spool | 1294 |
| Primary-Secondary Winding | 1298 |
| Secondary OD | 1230 |
| Secondary OD | 1241 |

The transformer operated normally for 244 endurance test hours, but at that time a failure occurred in the primary winding. Failure was caused by a short in the winding which failed a 2-amp fuse and resulted in an open circuit in the winding. Winding resistance increased from 6.33 ohms at temperature before failure to $5.5 \times 10^5$ ohms.

The primary circuit was re-fused and 600 volts ac was applied. The fuse failed immediately. Application of a variable ac voltage to the winding indicated that an arc was established in the winding at approximately 500 volts ac. These attempts to apply voltage to the winding resulted in an increase of resistance to $1.2 \times 10^6$ ohms. The secondary winding resistance was unchanged by the failure in the primary.

All test data acquired during the 244 endurance test hours were reviewed to see if there was any indication of impending failure. Primary and secondary voltages and currents were constant during the test period. The transformer temperature recording tape did not show any temperature transients until failure occurred, at which time the temperatures began to decrease. The daily transformer temperatures as read by a potentiometer were plotted against time to see if any thermocouple reading showed a change in trend relative to the other readings. Such was not the case.

The conclusion derived from this part of the investigation was that failure in the primary winding occurred too rapidly for any of the thermocouples in the transformer to show a transient condition.

The transformer could not be removed from the test chamber for physical investigation without also stopping the solenoid tests. It was decided to continue the transformer test with 600 volts ac across each winding to ground.

A transformer design review was held to consider possible modes of primary winding failure. Several theories were considered and discarded in favor of the following analysis. Transformer windings have to be well supported to prevent the mechanical forces generated by current flow in a winding from causing conductors to shift position. In many cases a potting compound is used to secure the windings in place. Potting compounds presently available are not satisfactory for use at high temperature in ultrahigh vacuum because of outgassing characteristics. The Inconel-clad silver wire with Anadur insulation which was used in the primary winding was hand-wound to make the windings as tight as possible. The Anadur insulation lost

20 to 40% of its thickness during the final curing process after the winding was formed. The boron nitride flexible insulation used between layers was too soft to prevent all movement of turns within the winding. The resulting lack of "tightness" in the winding allowed relative motion between some turns, and as a random function of time the Anadur layers on two adjacent turns became abraided causing a turn-to-turn short and immediate failure of the winding due to the heat dissipation within the coil.

The foregoing analysis indicates that new conductor insulation materials and new methods of forming transformer windings should be investigated for use in high-temperature, high-vacuum environments.

Figure II-47 is a plot of transformer-solenoid test vacuum chamber pressure versus endurance test time. Pressure reduction was slow but steady for the first 3000 hours, at which point chamber heater element power was reduced to bring the energized solenoid hot-spot temperature from 1335° to 1295° F. This chamber had been operating in the 1330° to 1335° F temperature range since the transformer failure. The temperature reduction had a marked effect on chamber pressure. A comparison of this curve with figure II-36 shows the difference in outgassing characteristics between the 1100° and 1300° F models with the latter model at a lower pressure at the beginning of endurance test. Burnil CM-2 (synthetic mica) was used as flexible insulation between winding layers in the 1100° F model, and flexible boron nitride fiber sheet was used in the 1300° F model. The initial outgassing rate of the boron nitride fiber was much lower than for the Burnil CM-2.

Figure II-48 is a plot of transformer conductor resistance versus endurance test time. The secondary winding resistance had remained unchanged during the test. All data were referred to a constant temperature for comparison purposes. The primary winding resistance was constant at temperature until winding failure. Since then the winding has behaved as a high resistance open circuit. Apparently part of the Inconel-clad silver wire was vaporized at the time of the failure.

Table II-13 is a tabulation of 1300° F transformer insulation system performance for the 5000 hours of endurance test. The data has been corrected to a temperature of 1250° F. The primary winding failure did not affect the boron nitride fiber sheet insulation between the primary and secondary windings, as noted by a slow increase in insulation resistance performance as the test progressed.

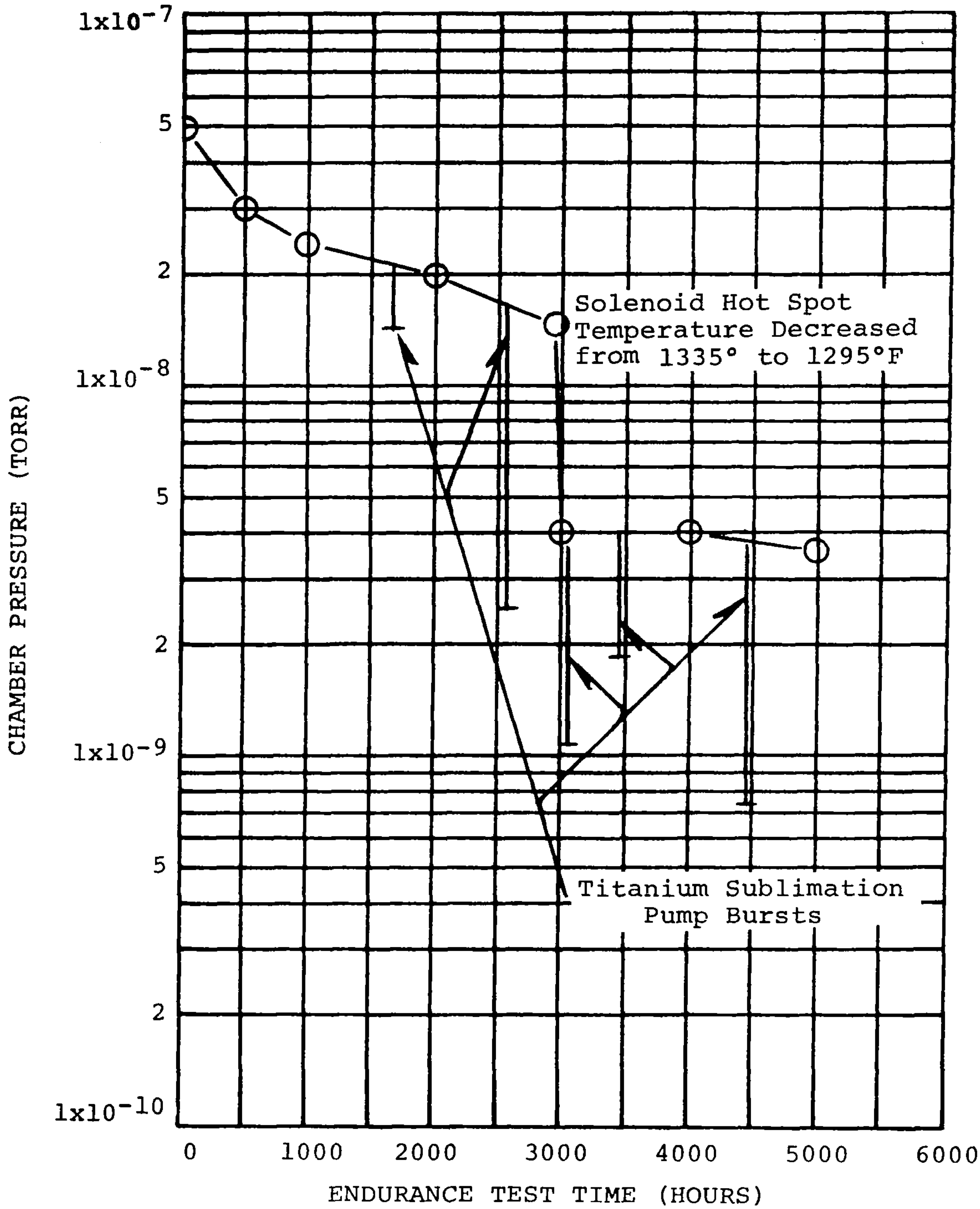



FIGURE II-47. Transformer-Solenoid Chamber Pressure Versus Endurance Test Time in Chamber No. 2 - 1300° F Models

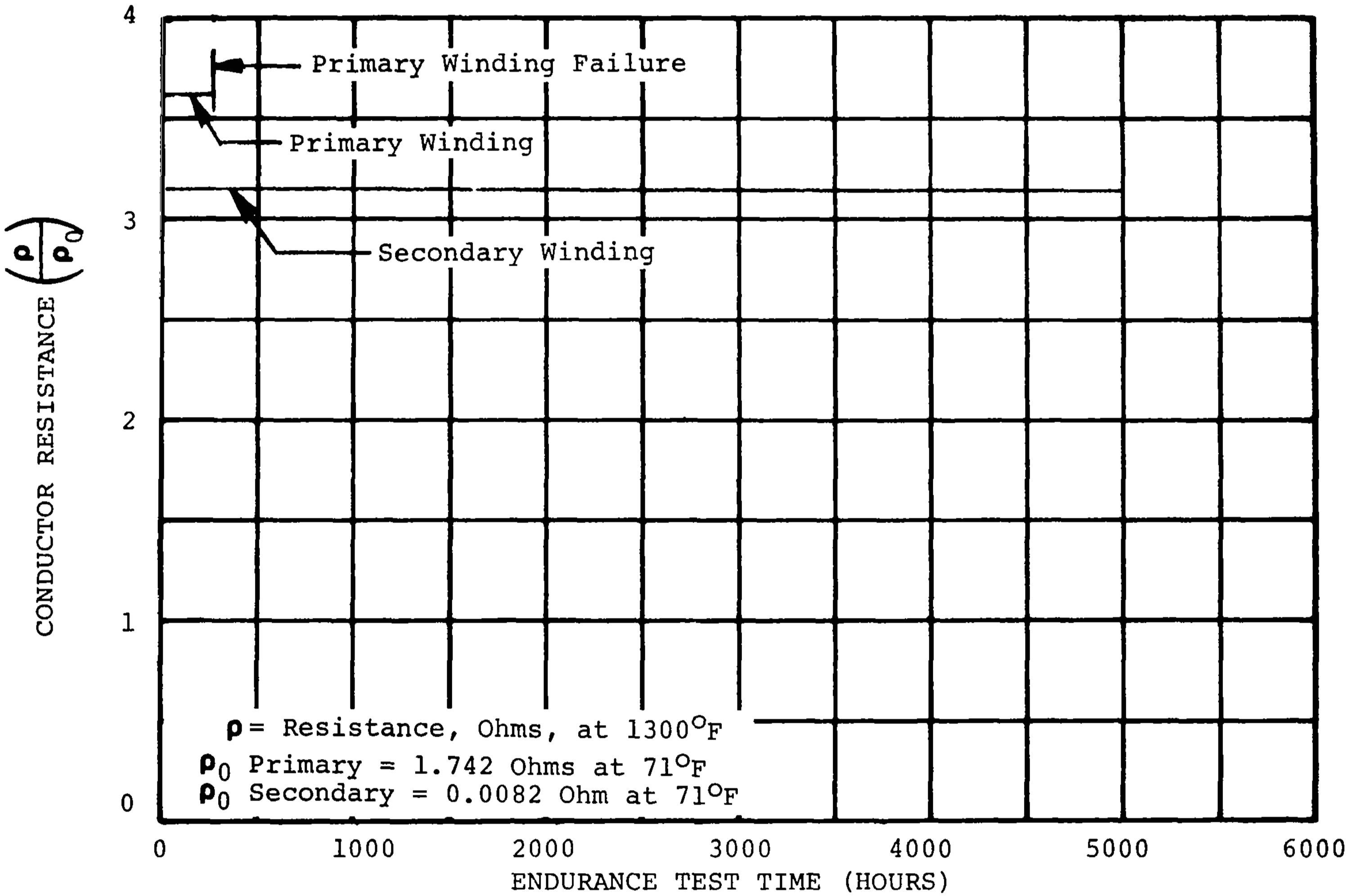



FIGURE II-48. Transformer Conductor Winding Resistance Versus Endurance Test Time - Referred to 1300° F Temperature

TABLE II-13. Transformer Insulation Performance in Vacuum Referenced to a Stabilized (unpowered) Temperature of 1250° F

| Endurance Test Time (hours) | 0 | 250 | 2500 | 5000 |
|---|---|---|---|---|
| Average Insulation Resistance (ohms) with 500 volts d-c applied | | | | |
| Primary to Secondary[a] | $1.1x10^7$ | $2.3x10^7$ | $3.0x10^7$ | $3.2x10^7$ |
| Primary to Ground[b] | $1.0x10^7$ | $2.3x10^7$ | $3.4x10^6$ | $4.5x10^6$ |
| Secondary to Ground[b] | $8.7x10^6$ | $6.8x10^6$ | $2.2x10^7$ | $7.8x10^6$ |

(a) Primary winding developed a turn-to-turn short circuit after 244 hours of endurance testing.

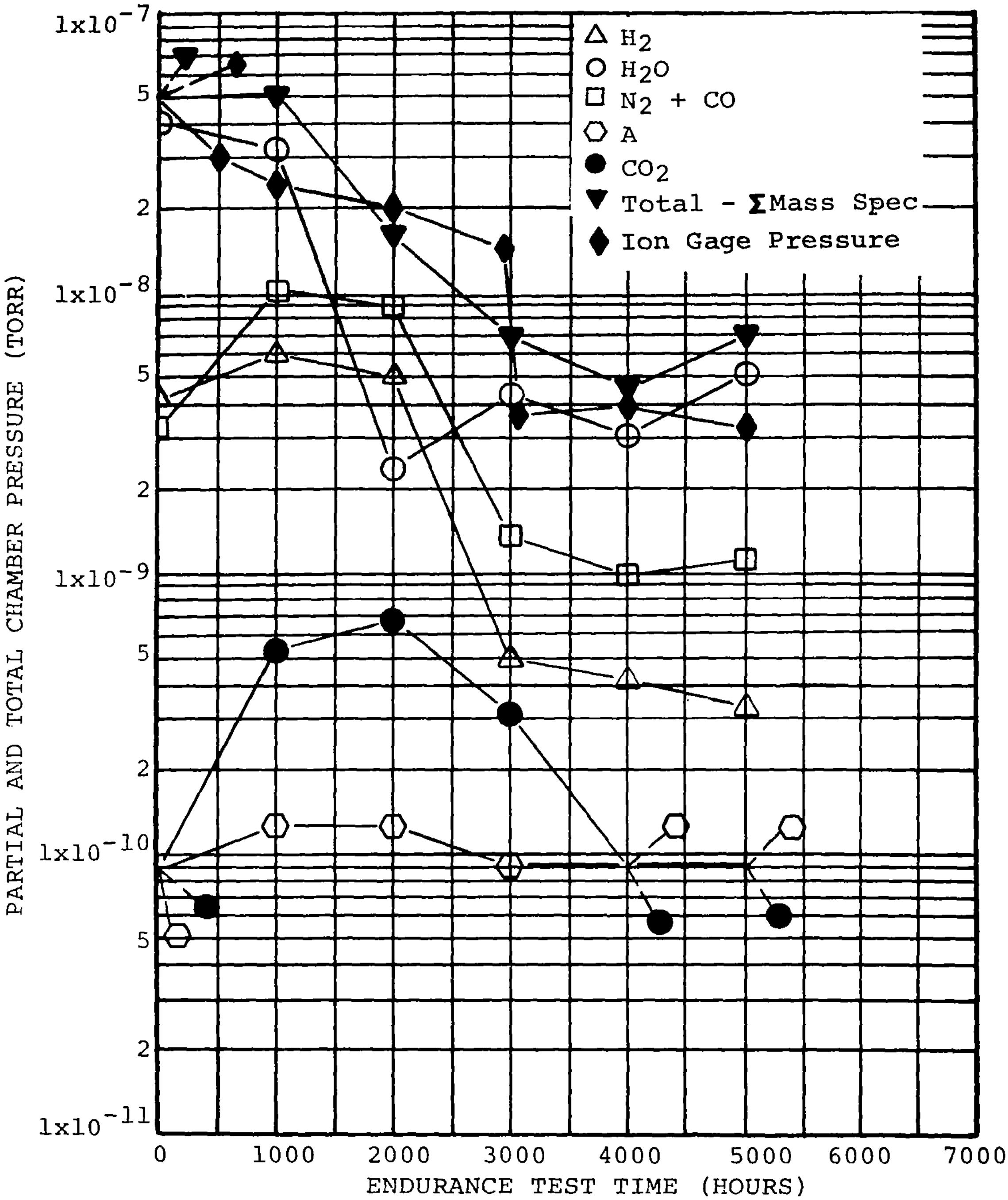
(b) Primary winding - 0.032-inch diameter Inconel-clad silver wire with Anadur S glass insulation - 0.010-inch-thick flexible boron nitride fiber sheet between layers.

Secondary Winding - 0.144-inch diameter Inconel-clad silver wire with Anadur S glass insulation - 0.040-inch-thick layer of flexible boron nitride fiber sheet insulation between primary and secondary windings.

However, the insulation to ground ($Al_2O_3$ spool and end plates) performance was erratic as a function of time. This behavior was charged to random migration of silver from the apparent rupture in the primary winding at the time failure occurred.

Figure II-49 is a mass spectrometer plot of residual gases for the 1300° F transformer and solenoid test chamber. The component pattern is very similar to that for the 1300° F stator, with water vapor being the predominant gas for most of the test period. The 5000-hour partial pressure levels for each of the gases involved were nearly equal in both the 1100° and 1300° F tests. (See figure II-38 for 1100° F partial pressure levels.) The 1300° F transformer had boron nitride fiber mat as flexible insulation, and a chopped boron nitride fiber cement was used in place of W-839 potting compound in the transformer and solenoids. Thus, the same materials were used in both 1300° F test chambers.

After completion of the 5000-hour test, the test chamber and model were put on a standby basis, pending a decision to conduct additional endurance testing.




Note: Temperature was constant at 1300° F

FIGURE II-49. Time-Pressure Plot of Mass Spectrometer Residual Gas Analysis Scans in Chamber No. 2 - 1300° F (Transformer and Solenoids)

10. Conclusions for 1100° F Transformer and Comparison of 1100° and 1300° F Transformer Model Performance

a) Materials used in both models were compatible electrically, but mechanically the primary wire insulation system was not satisfactory. Mechanical winding support is required to oppose mechanical forces induced between turns by a current flow. The normal loss of conductor Anadur insulation during the post-winding bake-out cycle caused a reduction in winding support, allowing turn-to-turn motion which resulted in insulation failure. Modified design techniques and/or new insulation materials will be required to develop high temperature multilayer transformer windings which are not subject to shorting because of mechanical stresses.

b) Both transformer models demonstrated a useful load-carrying capability prior to primary winding insulation failures.

c) Flexible boron nitride sheet insulation and boron nitride chopped fiber cement installed in the 1300° F model displayed a lower outgassing characteristic than the combination of synthetic mica flexible insulation and potting compound (zircon bonded by alumina orthophosphate) used in the 1100° F model.

d) The 1100° F transformer laminations developed some embrittlement in high temperature vacuum, the same as the stator laminations, but the degree was not as great as in the stator because there was very little potting compound present to provide a source for phosphorus.

D. SOLENOID

As with the stators and transformers, the following discussion will be based on the 1100° F hot-spot solenoid design, with a description of the changes made in going to the 1300° F models.

1. Solenoid Physical and Electrical Design and Construction

Figure II-50 is a cutaway drawing of the solenoid showing the configuration and construction. The magnetic housing, cover and plunger were made from Hiperco 27 alloy forged material. The coil was wound on an alumina (99%) spool

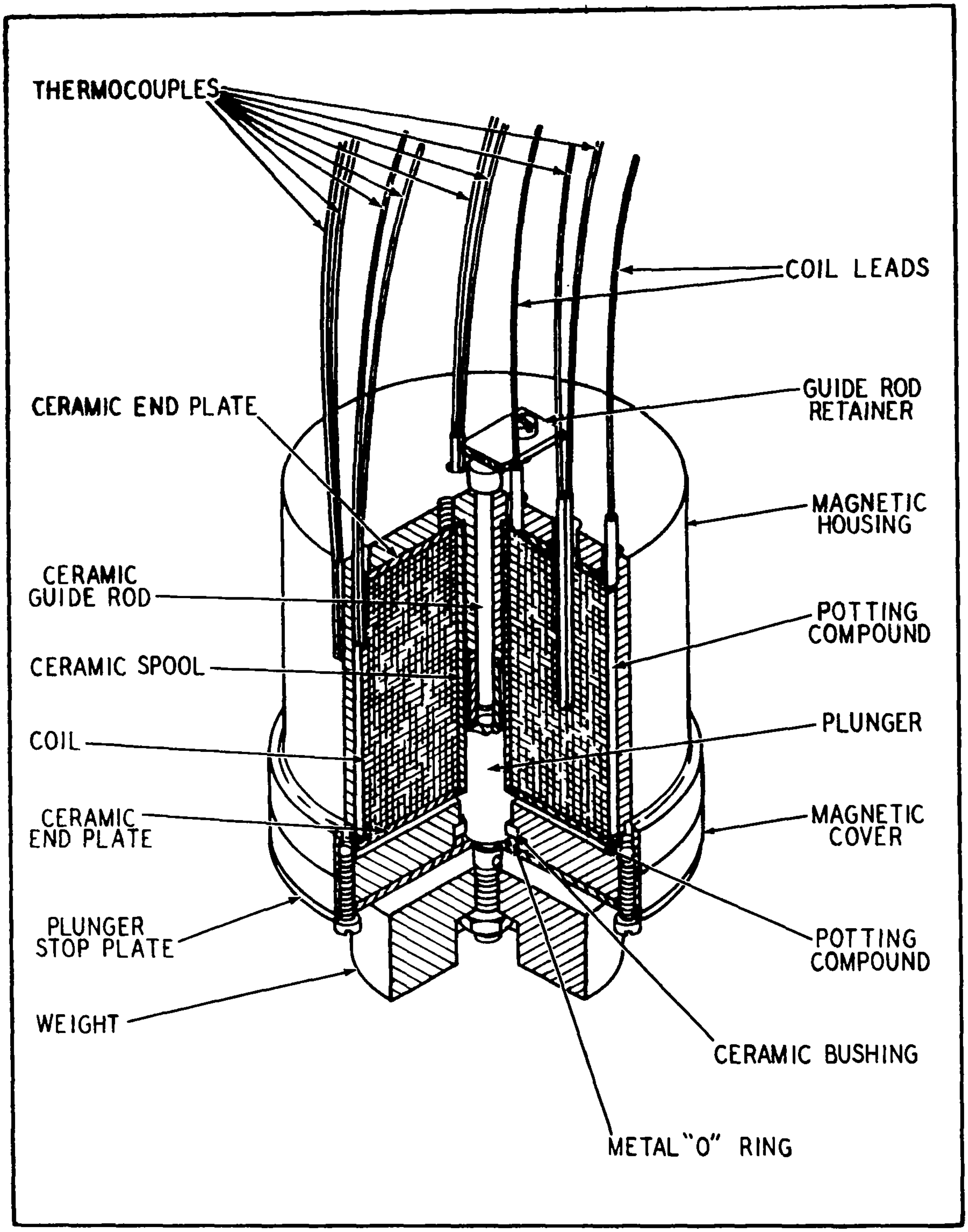



FIGURE II-50. Cutaway View of Solenoid

which provided insulation between the winding and the plunger and housing center core. Alumina (99.5%) end plates insulated the sides of the winding from the housing and cover. Bearing surfaces for the plunger consisted of an alumina (99.5%) guide rod at one end of the plunger and an alumina (99.5%) bushing at the opposite end. A weight of three pounds was suspended on the plunger, and when the solenoid was activated, the weight was lifted approximately 0.050 inch and held in that position. Table II-14 is a summary of the materials used in the 1100° F model and Table II-15 is a summary of the materials used in the 1300° F model. The changes involved replacing nickel-clad silver wire with Inconel-clad silver wire, Anadur "S" glass in place of "E" glass, and a chopped boron nitride fiber cement in place of W-839 potting compound. The reasons for the changes were the same as those listed for the stator.

The winding was formed from 1860 turns of No. 20 AWG (0.032-inch diam) nickel-clad or Inconel-clad silver wire. The same wires were used for the transformer primary winding. Electrically, the solenoid design was rated at 1530 ampere-turns with 28 volts dc applied to the winding at a winding temperature of 1100° F. The 1300° F model was rated at 1048 ampere turns with 28 volts dc applied.

Pairs of thermocouples were installed between the winding inside diameter and ceramic spool, at the radial mid-winding point, between the winding outside diameter and the housing, and on the housing outside diameter. All except the housing outside diameter thermocouples were installed in alumina (99%) tubes. Refer to figure II-57 for further thermocouple identification.

2. Solenoid Assembly

Two solenoids were manufactured for test at each test temperature (1100° F and 1300° F). When all shop fabricating operations had been completed, the solenoid parts were cleaned according to prescribed cleaning procedures. The only material not cleaned was the Anadur coated nickel-clad and Inconel-clad silver wire. The Anadur insulation was cleaned by the firing operation which was the final stage of the insulation cure cycle.

The solenoid windings were formed on a winding arbor which was mounted on a level winding machine, but the machine spindle was turned by hand and the wire was guided by hand. Figure II-51 shows a completed winding on the winding arbor. Alumina thermocouple tubes can be seen protruding

## TABLE II-14. Solenoid - Magnetic, Insulation and Conductor Materials Summary - 1100° F Hot-Spot Model

| Part | Material | Source-NAS3-4162 |
|---|---|---|
| Housing | Fe-27Co - Forging (Hiperco 27) | NASA-CR-54091 p. 59, 323 |
| End Bell | Fe-27Co - Forging (Hiperco 27) | |
| Plunger | Fe-27Co - Forging (Hiperco 27) | |
| Plunger Bushing | $Al_2O_3$ - 99.5% | NASA-CR-54092 p. 92, 453 |
| Plunger Guide Rod | $Al_2O_3$ - 99.5% | |
| Coil End Plates | $Al_2O_3$ - 99.5% | |
| Coil Spool | $Al_2O_3$ - 99% | NASA-CR-54092 p. 92, 462 |
| Coil Lead Insulators | $Al_2O_3$ - 99% | |
| Thermocouple Insulators | $Al_2O_3$ - 99% | |
| Conductor Insulation | Same as Stator - 1100°F (Anadur E Glass) | NASA-CR-54092 p. 86, 287 |
| Potting Compound | Zircon-type (aluminum orthophosphate-zirconium silicate) (W-839) | NASA-CR-54092 p. 7, 579 |
| Conductors-Size #20 AWG Wire | Nickel-clad silver - 1100°F | NASA-CR-54092 p. 81, 249 |
| End Plates, Hardware<br>Weight<br>Thermocouples<br>Metal "O" Ring | Hastelloy Alloy B<br>Mallory 1000<br>Inconel 600 Sheath-Platinell II<br>Wire System 321 SS | |

## TABLE II-15. Solenoid - Magnetic, Insulation and Conductor Materials Summary - 1300° F Hot-Spot Model

| Part | Material | Source-NASA3-4162 |
|---|---|---|
| Housing | Fe-27Co - Forging (Hiperco 27) | NASA-CR-54091 p. 59, 323 |
| End Bell | Fe-27Co - Forging (Hiperco 27) | |
| Plunger | Fe-27Co - Forging (Hiperco 27) | |
| Plunger Bushing | $Al_2O_3$ - 99.5% | NASA-CR-54092 p. 92, 453 |
| Plunger Guide Rod | $Al_2O_3$ - 99.5% | |
| Coil End Plates | $Al_2O_3$ - 99.5% | |
| Coil Spool | $Al_2O_3$ - 99% | NASA-CR-54092 p. 92, 462 |
| Coil Lead Insulators | $Al_2O_3$ - 99% | |
| Thermocouple Insulators | $Al_2O_3$ - 99% | |
| Conductor Insulation | Same as Stator-1300°F (Anadur S Glass) | NASA-CR-54092 p. 86, 287 |
| Potting Compound | BN Fiber Cement | |
| Conductors - Size #20 Wire | Inconel 600-clad silver - 1300°F | NASA-CR-54092 p. 81, 249 |
| End Plates, Hardware<br>Weight<br>Thermocouples<br>Metal "O" Ring | Hastelloy Alloy B<br>Mallory 1000<br>Inconel 600 Sheath-Platinell II<br>Wire System 321 SS | |

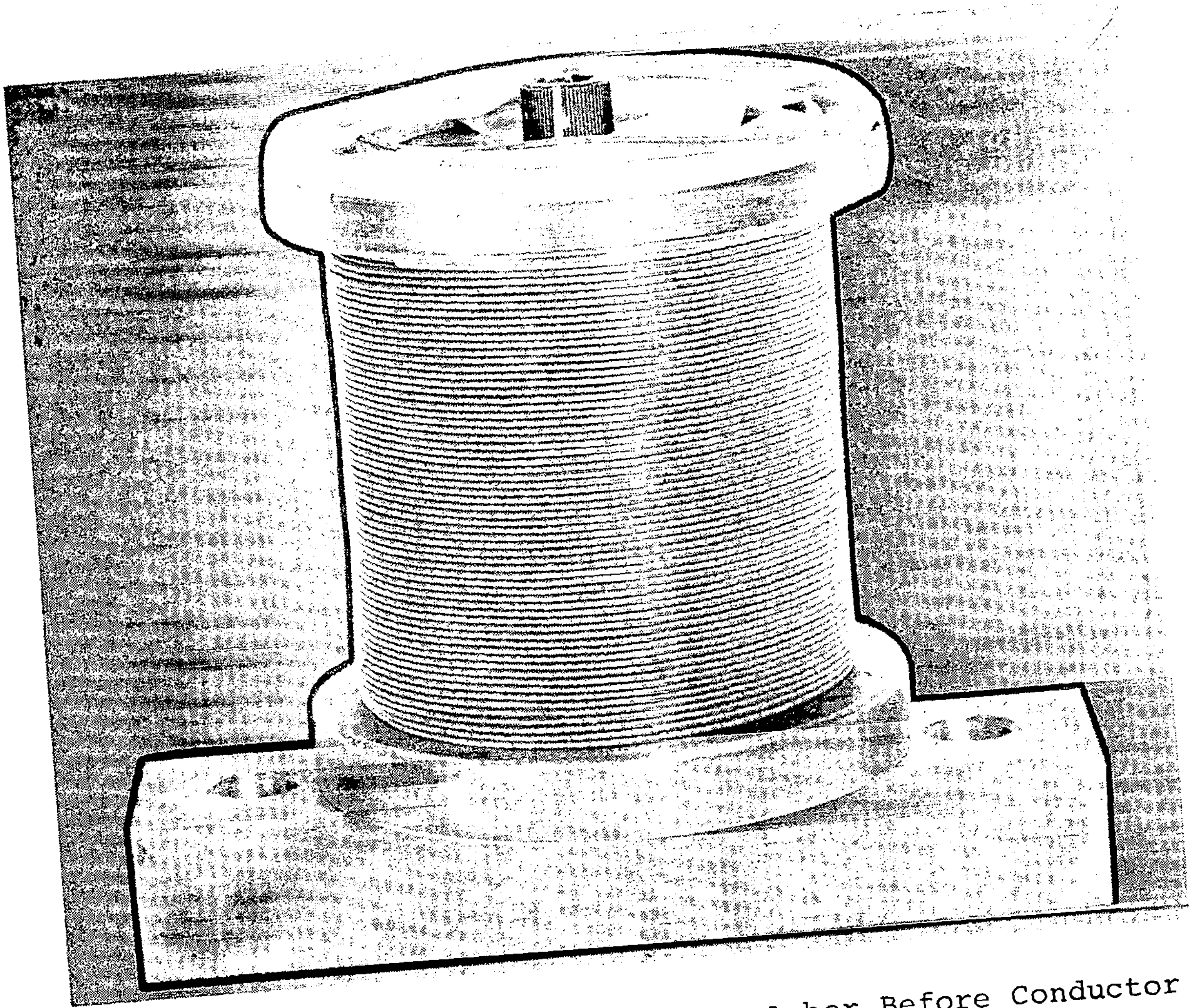


FIGURE II-51. Solenoid Winding on Arbor Before Conductor Serving Bake-Out

through the top arbor plate in Figure II-52, which shows one winding on the arbor after the Anadur insulation bake-out cycle. The other winding has been removed from the arbor and the alumina end plates have been installed and are held in place with W-839 potting compound. The weight of the winding as shown was 4.0 pounds. The fragility of the Anadur conductor insulation after bake-out can be seen by noting the bare spots on the lead wires.

Figure II-53 is an exploded view of a solenoid housing, plunger and weight assembly. The completed winding assembly shown in figure II-52 fits over the center post inside the housing, which also serves as a stop for the plunger. The end of the post had been plasma-arc sprayed

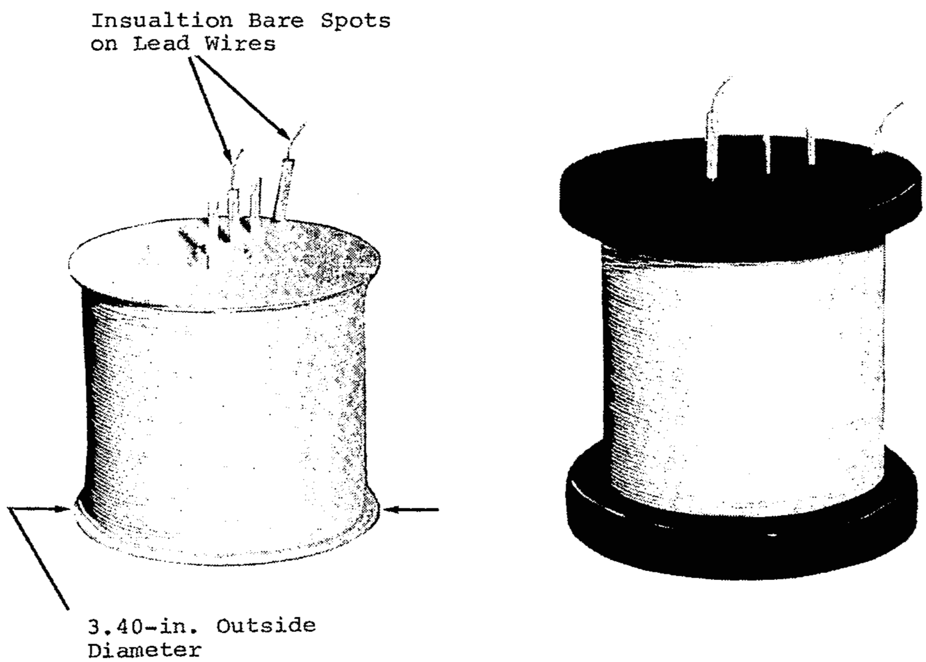



FIGURE II-52. Solenoid Winding Assembly and Solenoid Winding on Arbor After Conductor Serving Bake-Out

with high-purity alumina (>99%) to prevent "cold welding" between the plunger and post. Holes for the thermocouple tubes and lead wires can be seen in the bottom of the housing. The end bell shows the counterbore for the alumina bushing and metal O-ring. The end plate acted as a stop for the plunger when the solenoid was not energized. The alumina guide rod fitted the hole in the housing center post and extended beyond it to provide a bearing guide for a close tolerance hole drilled in the plunger. The opposite end of the plunger rides in the alumina bushing, which acted as a second bearing for the plunger. The metal O-ring was used as a semi-flexible ring to load the bushing at low temperatures and compensate for differential thermal expansion at high temperatures. The end of the plunger which rested against the end plate was coated with plasma-arc sprayed alumina to prevent cold welding with the end plate. Both the plunger and weight were threaded, and a lock nut (not shown) was added after the weight is installed.

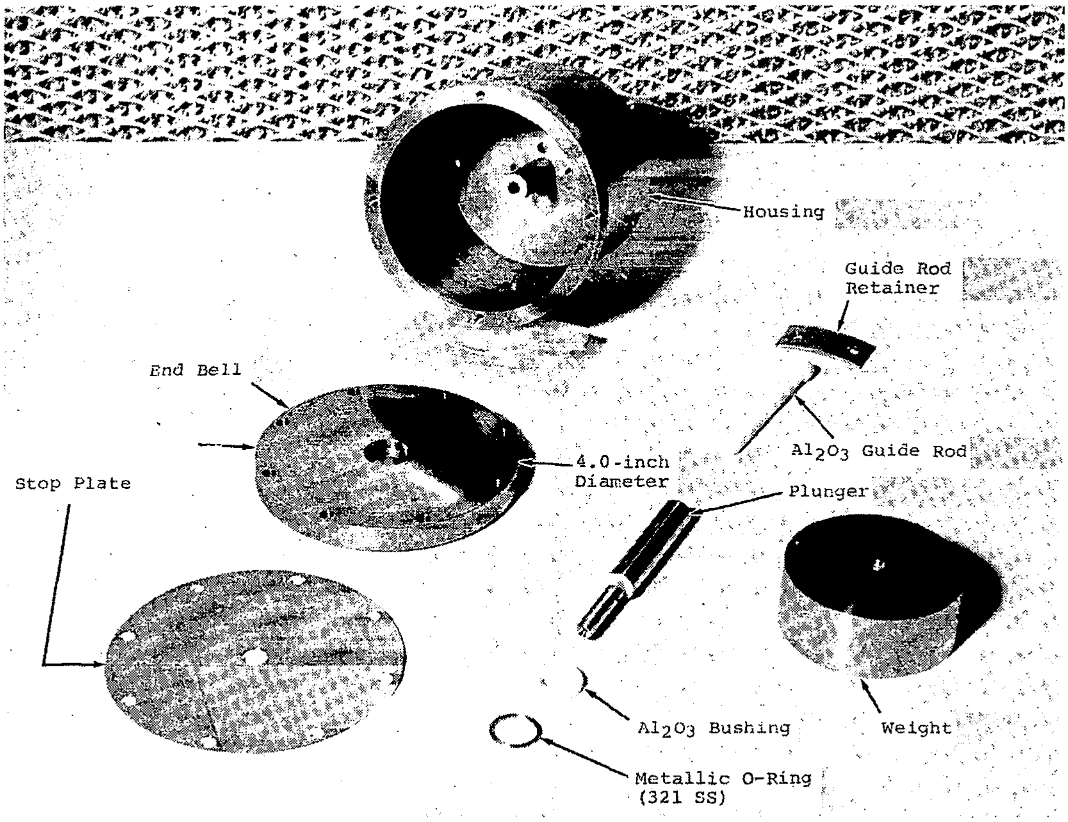



FIGURE II-53. Exploded View of Solenoid Parts Less Winding Assembly - 1100° F Model

Before the installation of the winding assembly into the housing, four axial strips of W-839 potting compound were added to help keep the windings in place. After installation, four radial strips of potting compound were added to the alumina winding end plate adjacent to the end bell, to take up the axial slack with the end bell in place. The end bell was installed and this portion of the solenoid assembly was given a potting compound bake-out. Then the plunger and bearing system was installed and the end plate was added. The last part to be added to the assembly was the weight.

Figure II-54 shows both solenoids complete, except for thermocouples, just before being put through a 43-hour outgassing bake-out with the transformer.

One potential problem occurred with the solenoids, as well as with the stator and transformer. The threads in threaded

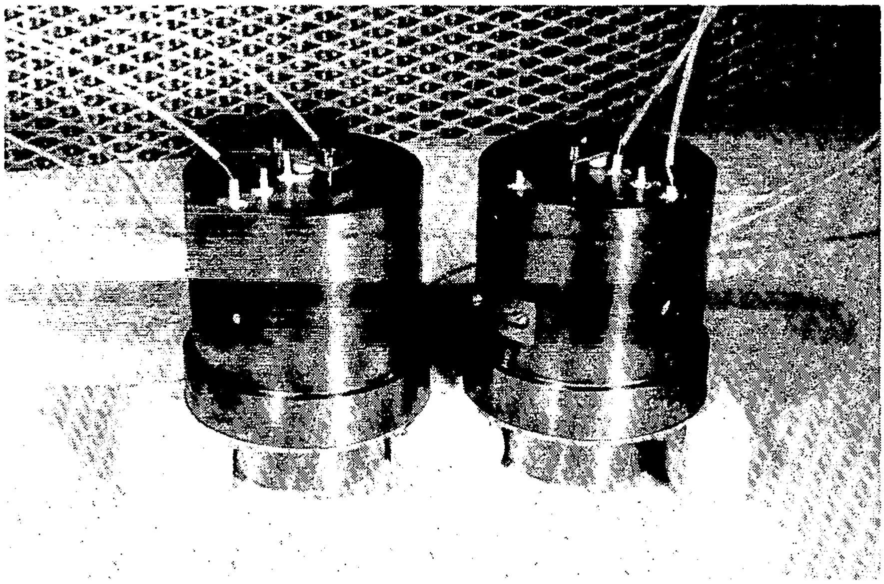


FIGURE II-54. Assembled Solenoids Less Thermocouples

holes and on screws and studs went together easily before cleaning. The cleaning procedures used removed all traces of lubricant, and extreme caution was required when assembling threaded parts to prevent galling and seizing.

Figure II-55 shows one of the 1300° F model windings after completion of the Anadur insulation bake-out cycle and the addition of chopped boron nitride fiber cement strips across the windings.

## 3. Thermal Vacuum Chamber Installation

The transformer installation cutaway drawing, figure II-34, also shows how the two solenoids were fitted into the vacuum chamber. All three components were installed at the same time, using the same brazing techniques for power leads and thermocouple seals that had been used for the stator installation.

## 4. Solenoid Test Connection

Figure II-56 is a schematic showing the test connections for applying dc power to the solenoid windings. Only one dc power supply was required, as one solenoid (S/N 3) was energized continuously except for periodic electrical meas-

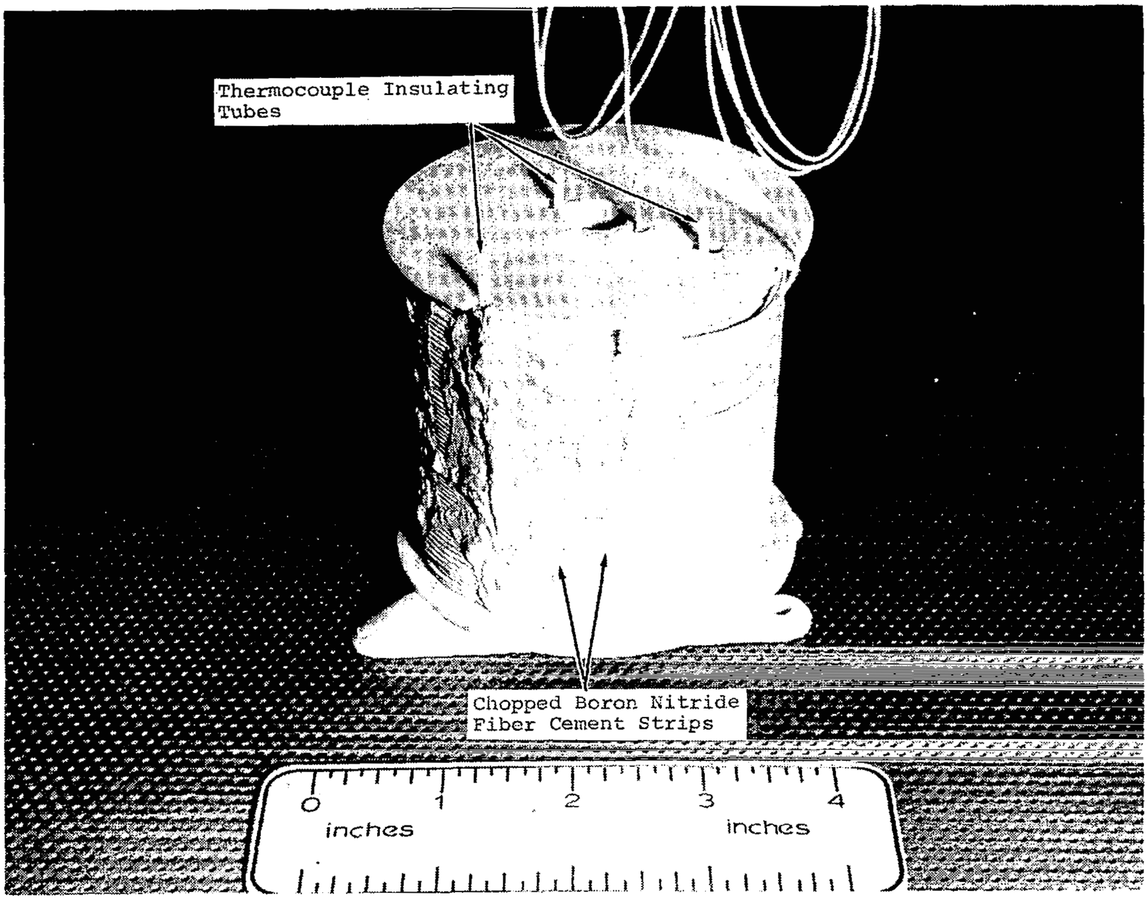



FIGURE II-55. Solenoid Winding Ready for Assembly Into Housing - 1300° F Model

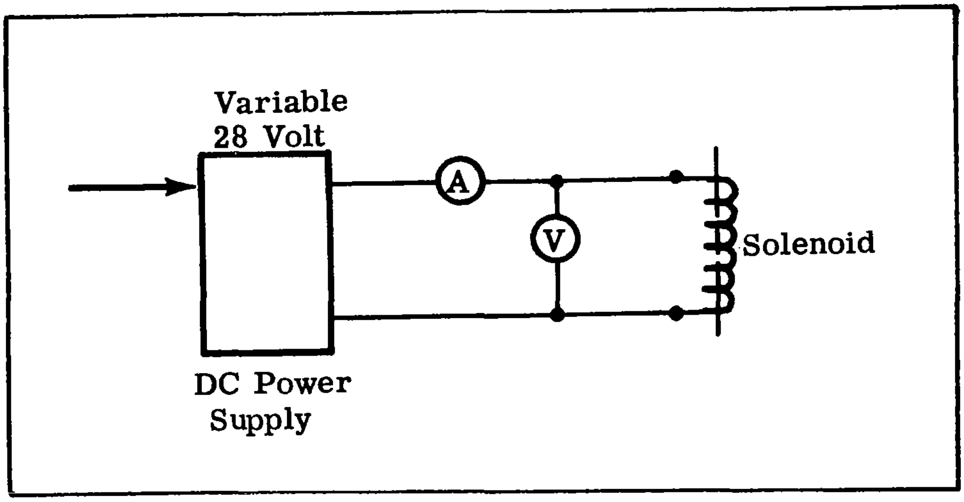



FIGURE II-56. Solenoid Circuitry

urements, and the other (S/N 4) was only actuated periodically to verify operation. The purpose of energizing one solenoid continuously was to determine if a continuous dc electrical stress had any long term effect on the stability of the magnetic material properties. The other solenoid was used as a control reference. The same power supply satisfied both requirements. The use of a variable dc power supply made it possible to adjust the energized solenoid current so as to match hot-spot temperatures with the transformer.

5. Solenoid Test Procedure - 1100° F Hot-Spot Models

Bench test electrical data were obtained for each solenoid before installation in the test chamber. The test chamber starting procedure was covered in the transformer discussion, section II.C.5.

After base line electrical data had been obtained for the solenoids and transformer, and a chamber bake-out program had been completed, power was applied to the energized solenoid, the transformer and the chamber heater element. Solenoid input voltage was adjusted downward several times to hold the solenoid and transformer hot-spot temperatures near the same value. Heater element power was increased in stages to bring the hot-spot temperature up to approximately 1100° F. When temperatures had reached a stable condition, electrical measurements were taken and formal endurance testing was started.

Readings were taken daily for thermocouples, energized solenoid voltage and current, heater element power, etc. Residual gas analysis spectrograms were covered in the transformer section. Once each week electrical performance data and solenoid pickup and dropout voltages and currents were measured and recorded for both solenoids.

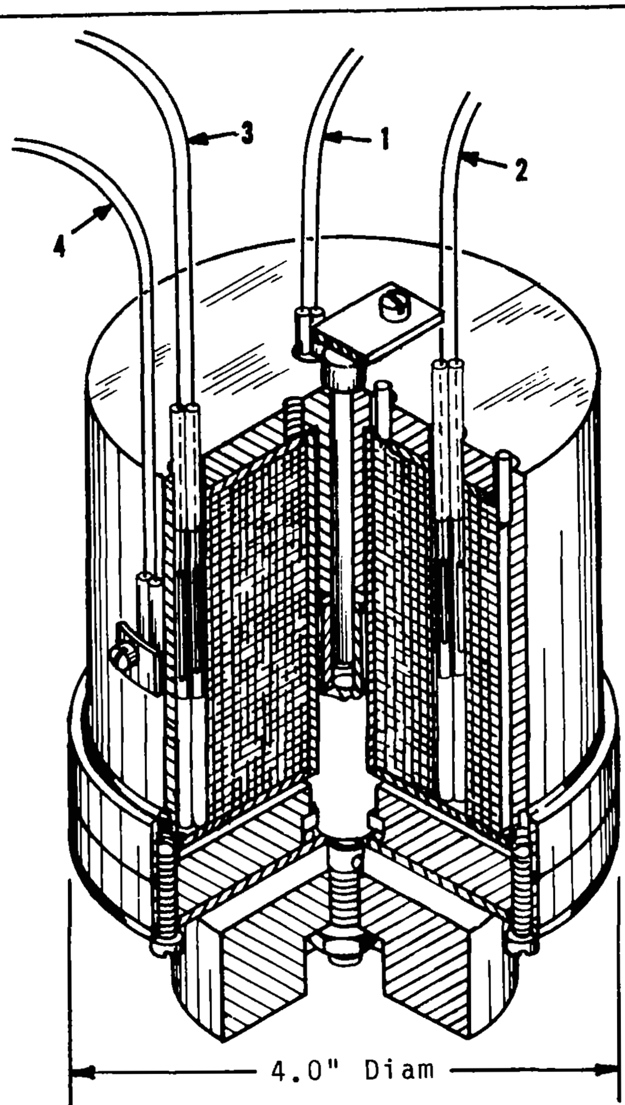
## 6. Solenoid Data and Discussion - 1100° F Hot-Spot Models

The energized solenoid current was stabilized at 0.40 amps with 15.2 volts dc applied to maintain a midwinding temperature of 1100° F. Current density was 500 amperes per square inch considering total conductor cross-section, and 625 amperes per square inch considering silver core only. The $I^2R$ loss was 6.1 watts.

Figure II-57 is a sketch showing the location of thermocouples in the solenoids with a tabulation identifying each location. Each solenoid had eight thermocouples, installed in alumina insulator tubes in pairs as shown. One housing outside diameter thermocouple on the unenergized solenoid was damaged beyond repair during installation in the chamber.

Table II-16 is a tabulation of representative solenoid temperatures taken after 1700 hours of endurance testing had been completed. The hottest spot in the energized solenoid was at the midwinding point. There is some spread in temperature reading between each pair of thermocouples. This spread was consistent throughout the 5000 hours and occurred in part because some of the thermocouples shifted slightly from their original position during chamber installation. Initially, the thermocouple tips were located in a horizontal plane which divided the winding into upper and lower halves. Some variation in readings also occurred because of small differences in conductance paths from the measured point through the alumina insulating tubes to the thermocouples. The unenergized solenoid was subjected to radiated heat only, resulting in an essentially constant temperature at all points. One winding outside diameter thermocouple consistently read 13° F higher than its mate. The reason may well be differences in actual thermal contacts. The same temperature difference was noted at the unenergized solenoid winding inside diameter.

Figure II-58 is a dimensionless plot of conductor resistance versus endurance test time for both solenoids. Resistance varied with temperature, but was constant at a given temperature throughout the test.




| No. | Quantity Installed | Description |
|---|---|---|
| 1 | 2 | Winding ID |
| 2 | 2 | Mid-winding |
| 3 | 2 | Winding OD-Housing |
| 4 | 2 | Housing OD<br>One lost on S/N 2 during assy |

FIGURE II-57. Solenoid Assembly Showing Thermocouple Locations and Junction Positions

TABLE II-16. Representative Solenoid Temperature Distribution at 1100° F Hot-Spot Temperature After 1700 Hours of Endurance Test

| Thermocouple Location | Temperature (°F) | |
|---|---|---|
| | S/N 1 (energized) | S/N 2 |
| Winding ID | 1085 | 1063 |
| Winding ID | 1073 | 1050 |
| Midwinding | 1105 | 1050 |
| Midwinding | 1100 | 1050 |
| Winding OD | 1055 | 1050 |
| Winding OD | 1068 | 1050 |
| Housing OD | 1073 | 1050 |
| Housing OD | 1068 | -- |

Table II-17 is a tabulation of insulation system performance for the energized and unenergized solenoids in terms of endurance test time. Readings were taken with a 500-volt dc potential between each winding and ground. Data have been adjusted from actual test temperatures to a reference midwinding temperature of 1100° F.

Minimum pick-up and holding voltage and current readings were taken weekly for each solenoid. Table II-18 compares ambient temperature bench test values obtained before chamber installation with values obtained at two stable test temperatures (1100° F hot-spot) and with ambient temperature post-test bench-test values. Pick-up and holding currents were essentially constant, regardless of temperature. These data indicate that high temperature aging in vacuum has not affected the solenoid magnetic properties or conductor resistance.

7. Post-Test Investigation - 1100° F Hot-Spot Solenoid Models

Removal of the two solenoids from the test chamber was covered along with the transformer removal in the transformer post-test investigation write-up. Figure II-42 shows the transformer and two solenoids on their support fixture after removal from the test chamber.

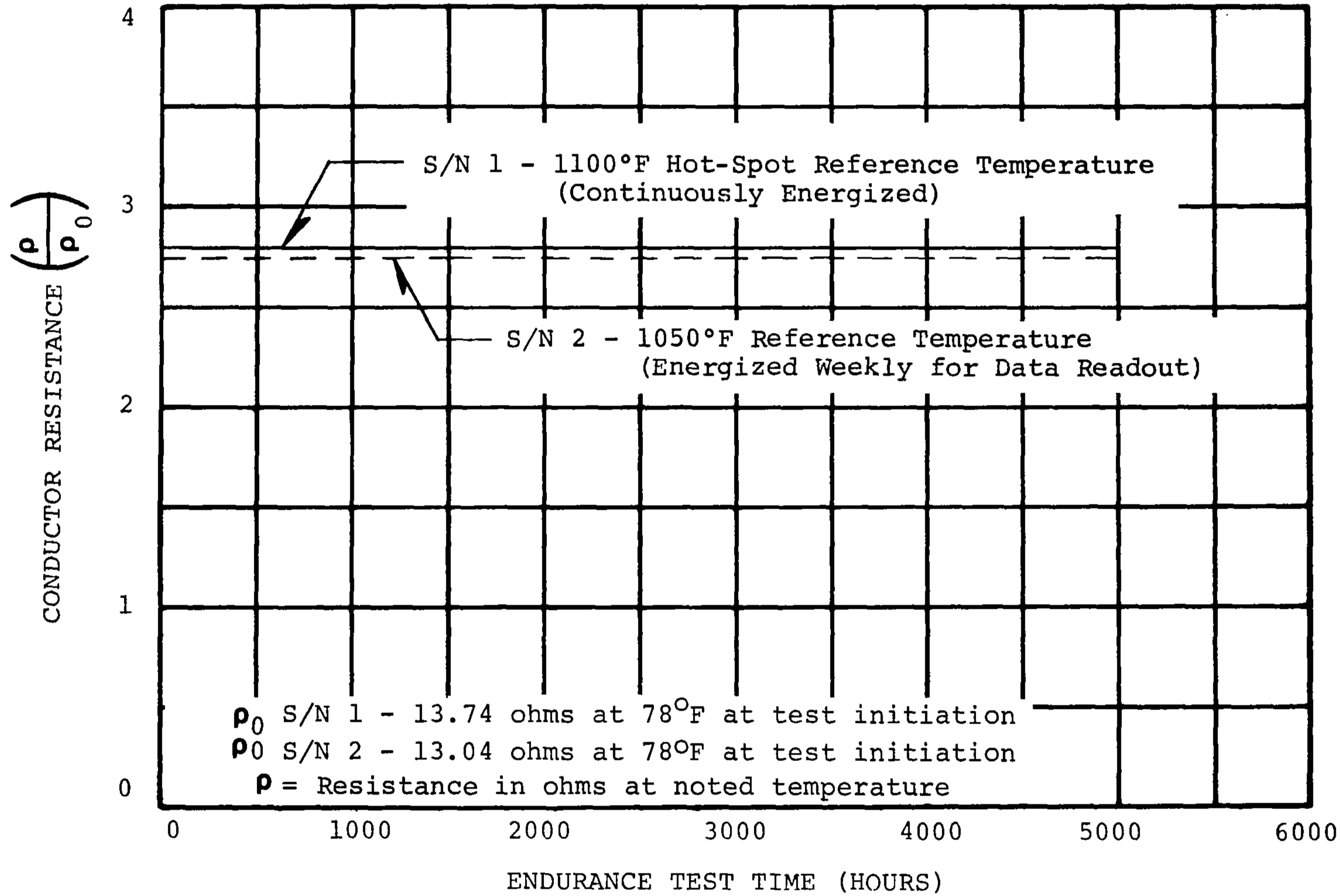



FIGURE II-58. Solenoid Conductor Resistance Versus Endurance Test Time - 1100° F Models (At Noted Reference Temperatures)

TABLE II-17. Solenoid Insulation Performance in Vacuum with Midwinding (hot-spot) Temperature at 1100° F

| Endurance Test Time (hours) | 0 | 2500 | 5000 |
|---|---|---|---|
| Insulation Resistance (ohms) With 500-V d-c Applied: | | | |
| S/N 1 (energized) (1100°F Ref. Temp.) Winding to Ground | $7x10^6$ | $6.9x10^6$ | $6.85x10^6$ |
| S/N 2 (not energized) (1050°F Ref. Temp.) Winding to Ground | $8.5x10^6$ | $8x10^6$ | $8.4x10^6$ |

Note: Conductor is 0.032-inch diameter nickel-clad silver wire with Anadur "E" glass insulation; 99% alumina winding spool and 99.5% alumina winding end plates.

TABLE II-18. Minimum Pick-Up and Holding Electrical Measurements for Solenoid Weight and Plunger - 1100° F Hot-Spot Model

| | Pre-Test -72°F Bench Test | | Chamber Test* | | Post-Test-72°F Bench Test | | Chamber Test** | |
|---|---|---|---|---|---|---|---|---|
| | S/N 1 | S/N 2 | S/N 1 | S/N 2 | S/N 1 | S/N 2 | S/N 1 | S/N 2 |
| Minimum Pick-up Voltage, d-c | 4.9 | 3.9 (a) | 15.0 | 12.0 (a) | 4.9 | 4.2 | 15.0 | 12.1 |
| Minimum Pick-up Current, AMPS | 0.41 | 0.34 | 0.39 | 0.34 | 0.39 | 0.35 | 0.38 | 0.38 |
| Minimum Holding Voltage, d-c | 0.9 | 0.85 | 1.9 | 2.1 | 0.7 | 0.85 | 2.0 | 2.1 |
| Minimum Holding Current, AMPS | 0.065 | 0.056 | 0.05 | 0.06 | 0.07 | 0.065 | 0.06 | 0.06 |

(a) The increase in voltage required to maintain a constant current is caused by the increase in wire resistance as conductor temperature increases.

* After 2000-hour Endurance Test ** After 5000-hour Endurance Test

Solenoid S/N 1 (energized) was disassembled for physical inspection and investigation of materials condition. Figure II-59 is a photograph showing the solenoid with the end bell removed and the winding still in the housing. The stop plate, end bell, and plunger were removed without any difficulty. There was no evidence of sticking between the plunger and the ceramic ($Al_2O_3$) bushing and bearing rod. The stain which appeared on the inside of the end bell and on the winding end plate was purple, and was assumed to be cobalt extracted from the Fe-27Co alloy pending further investigation (covered later). W-839 potting compound was used to take up clearance between the winding assembly and the end bell, and one piece which was chipped loose from the winding end plate appears in the photograph.

The plunger showed some polishing and minor traces of scuffing from movement in the ceramic bushing. The bushing inside diameter showed an irregular ring stain indicating that the bushing high spots were supporting the plunger all the way around the circumference. The two-hole $Al_2O_3$ tube (ceramic lead insulation) in the left of the photograph shows stains of silver or silver compounds, which were caused by silver from the transformer secondary winding when it failed.

Except for the potting compound discoloration on the end plate, the winding assembly looked the same as it did at original assembly. The Anadur insulation was intact on the windings and the W-839 potting compound strips which were used to anchor the outermost winding layer were undisturbed.

A sample of discolored W-839 potting compound and a new, unaged sample were submitted to spectrographic and chemical analysis. The significant changes in composition between the two samples were as follows:

| Material | Original Zircon Potting Compound W-839 (%) | Post-Endurance Test Zircon Potting Compound W-839 (%) |
|---|---|---|
| Iron | 0.05 | 0.35 |
| Cobalt | 0.01 | 0.15 |
| Phosphorus | 3.51 | 3.25 |

The phosphate in the potting compound appeared to have reacted with the Iron-27 Cobalt alloy forged material, extracting iron and cobalt.

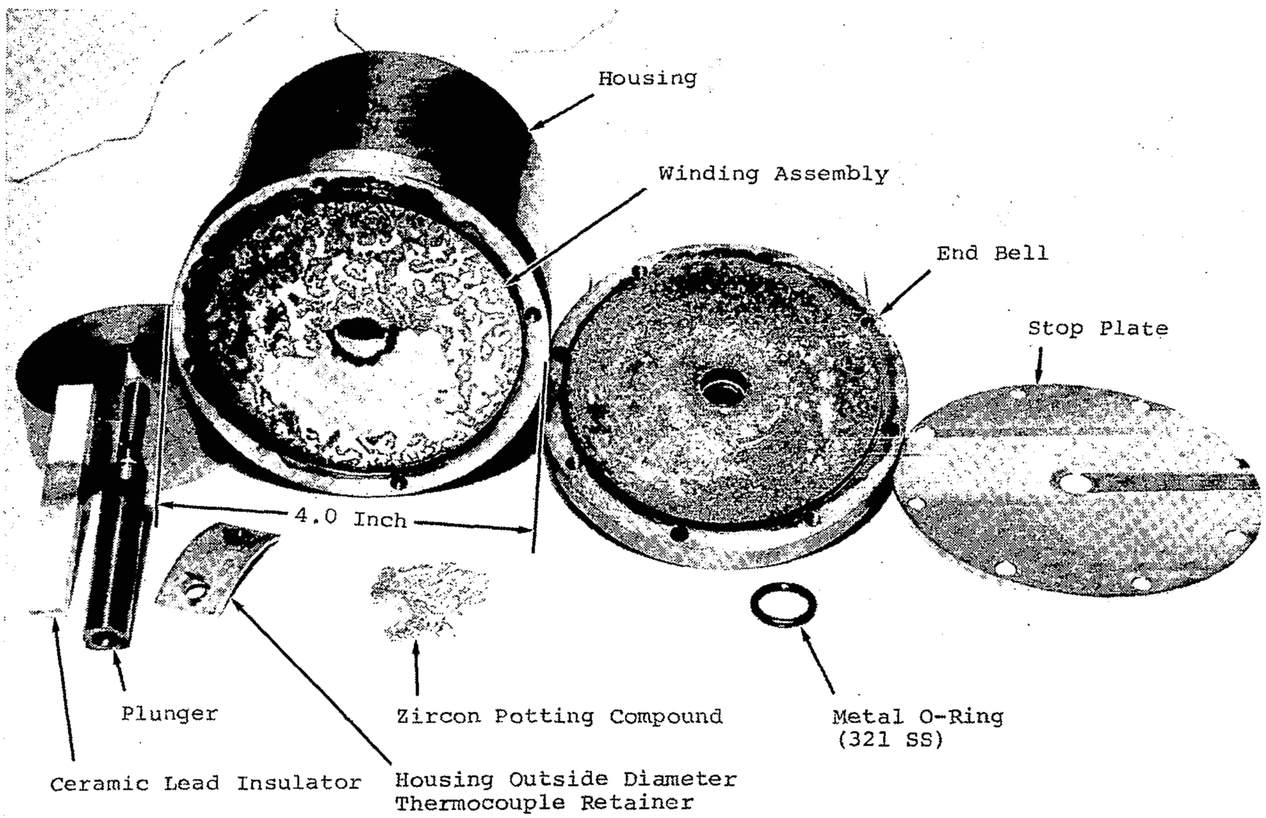



**FIGURE II-59. Solenoid S/N 1 Partially Disassembled After Completion of 5000-Hour Test**

The stain on the alumina insulator tube which carried the solenoid leads through the top heat shields was subjected to spectrographic analysis. As mentioned previously, the stain was made up of silver and/or silver compounds.

As part of the post-endurance test investigation the S/N 2 solenoid (unenergized) was put through a single-axis vibration scan and five-minute dwell at resonant frequencies. Figure II-60 is a photograph of the solenoid and vibration test fixture mounted on the shaker. Arrows and numbers identify the accelerometers used for the test. The No. 1 accelerometer was mounted on the test fixture bed plate and was used to monitor input g's to the assembly. No. 2 was a lightweight accelerometer mounted at the parting line between the end bell and the housing. The No. 3 accelerometer is not visible in the photograph (indicated by dashed line), but it also was a lightweight accelerometer mounted on top of the housing at the lead end. The vibration axis was in the vertical direction.

A vibration scan was made over the range of 5 to 2000 cps, to locate solenoid resonant frequencies. The input was held at 5g's and response of the two lightweight accelerometers was monitored for resonant frequencies. The weight was removed for this test as it represented a connected load which would not normally be a dead weight in the vibration plane.

Resonant frequencies were found at 1546, 1600, 1800, and 1900 cps; and the solenoid was vibrated for five minutes at each of the four frequencies. Unfortunately, a calibration factor for the lightweight accelerometers was misapplied by a factor of 10, and the resonant tests were run with a response of 100g's rather than the 10g response that was intended. The solenoid was not able to withstand this degree of vibration. The 99.6g response occurred at the end bell-housing interface accelerometer (No. 2), indicating that there may have been some relative motion between the housing and end bell.

The solenoid was checked electrically after the vibration test. Conductor resistance was the same as before the test, but insulation resistance to ground had broken down. The most likely point for grounding was where the outside lead passed through the housing. Figure II-61 shows the solenoid disassembled after the vibration test. Approximately two tablespoons of powdered Anadur were extracted from the housing along with the winding. The broken $Al_2O_3$ winding end plate which can be seen in the right hand side of the photo was cracked during removal of the winding from the

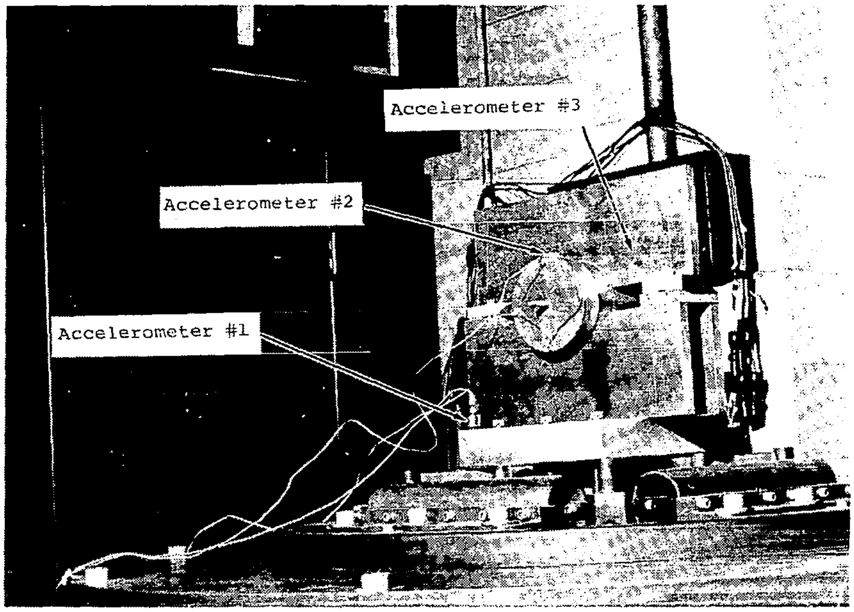



FIGURE II-60. Solenoid Assembly and Test Fixture Installed on Shaker for Vibration Test - 1100° F Model

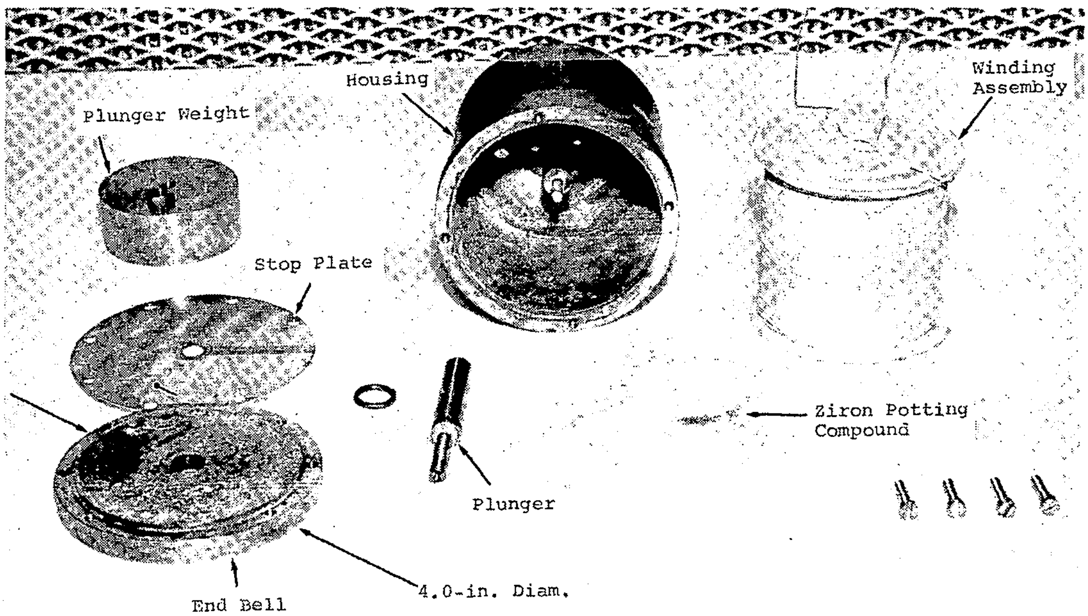



FIGURE II-61. Solenoid S/N 2 Disassembled After 5000 Hours Endurance Test and Vibration Test - 1100° F Model housing. The fractures had sharp edges and points which fitted together to show hairline marks, so there was no apparent abrasion which would have occurred if the fractures had happened during the test. The inner side of the end bell shows the same purple stain on the W-839 potting compound that was discussed previously for solenoid S/N 1. The bottom edge of the winding, which was next to the end bell, had shifted to the left as a result of vibration. The accelerometer at this end of the winding had the 99.6g response.

8. <u>Solenoid Test Procedure - 1300° F Hot-Spot Models</u>

Bench test electrical data was obtained for each solenoid before installation in the test chamber. The test chamber starting procedure was covered in the transformer discussion, section II.C.8.

After base line electrical data had been obtained for the solenoids and transformer, and the chamber bake-out had been completed, power was applied to the chamber heater element to bring the temperature up in stages. Electrical performance data were taken at each stage when temperatures throughout the models were essentially stable. When a 1300° F temperature was reached, heater element power was reduced and power was applied to the transformer and energized solenoid. Solenoid power was set at 24 volts dc and 0.55 ampere.

Data were taken daily for thermocouples, solenoid voltage and current, heater element power, etc. Residual gas analysis spectrograms were discussed in the transformer section. Once each week electrical performance data, including solenoid pick-up and drop-out voltages and currents, were measured and recorded for both solenoids.

9. <u>Solenoid Data and Discussion - 1300° F Hot-Spot Models</u>

The energized solenoid current was stabilized at 0.55 ampere with 24.0 volts dc applied, to maintain a midwinding temperature of approximately 1300° F. Current density was 688 amperes per square inch (total conductor cross-section) and 955 amperes per square inch (silver core only). The $I^2R$ loss was 13.1 watts.

Thermocouples were installed in the same locations as in the 1100° F models (see figure II-57). All thermocouples were successfully brazed at the time the models were installed in the test chamber.

Table II-19 is a tabulation of representative solenoid temperatures, taken after 3220 hours of endurance testing had been completed. As with the 1100° F model, the hottest temperature occurred at the midwinding location. The increase in radiation emissivity with increasing temperature (4th power function of absolute temperature) can be seen by comparing the $\Delta T$ from midwinding to housing outside diameter for the two test temperatures. The 1100° F model $\Delta T$ was 32° F (av), compared with 92.5° F for the 1300° F model. This is almost the same ratio of $\Delta T$ change as was noted between the 1100° and 1300° F stator models. The unenergized solenoid temperature was nearly constant at all locations.

Figure II-62 is a dimensionless plot of conductor resistance versus endurance test time for both solenoids. Resistance varied with temperature but has remained constant at a given temperature throughout the test, except as noted in the following paragraph.

Table II-20 is a tabulation of insulation system performance for the energized and unenergized solenoids in terms of endurance test time. Solenoid S/N 3 experienced a grounded winding after 984 hours of test. Insulation resistance to ground dropped to approximately 50 ohms, although the winding continued to function as far as picking up the weight and holding it was concerned. No change

TABLE II-19. Representative Solenoid Temperature Distribution at 1300° F Hot-Spot Temperature After 3220 Hours of Endurance Test

| Thermocouple Location | Temperature (°F) | |
|---|---|---|
| | S/N 3 (energized) | S/N 4 |
| Winding ID | 1235 | 1188 |
| Winding ID | 1239 | 1188 |
| Midwinding | 1295 | 1190 |
| Midwinding | 1297 | 1190 |
| Winding OD | 1201 | 1193 |
| Winding OD | 1201 | 1192 |
| Housing OD | 1205 | 1193 |
| Housing OD | 1202 | 1194 |

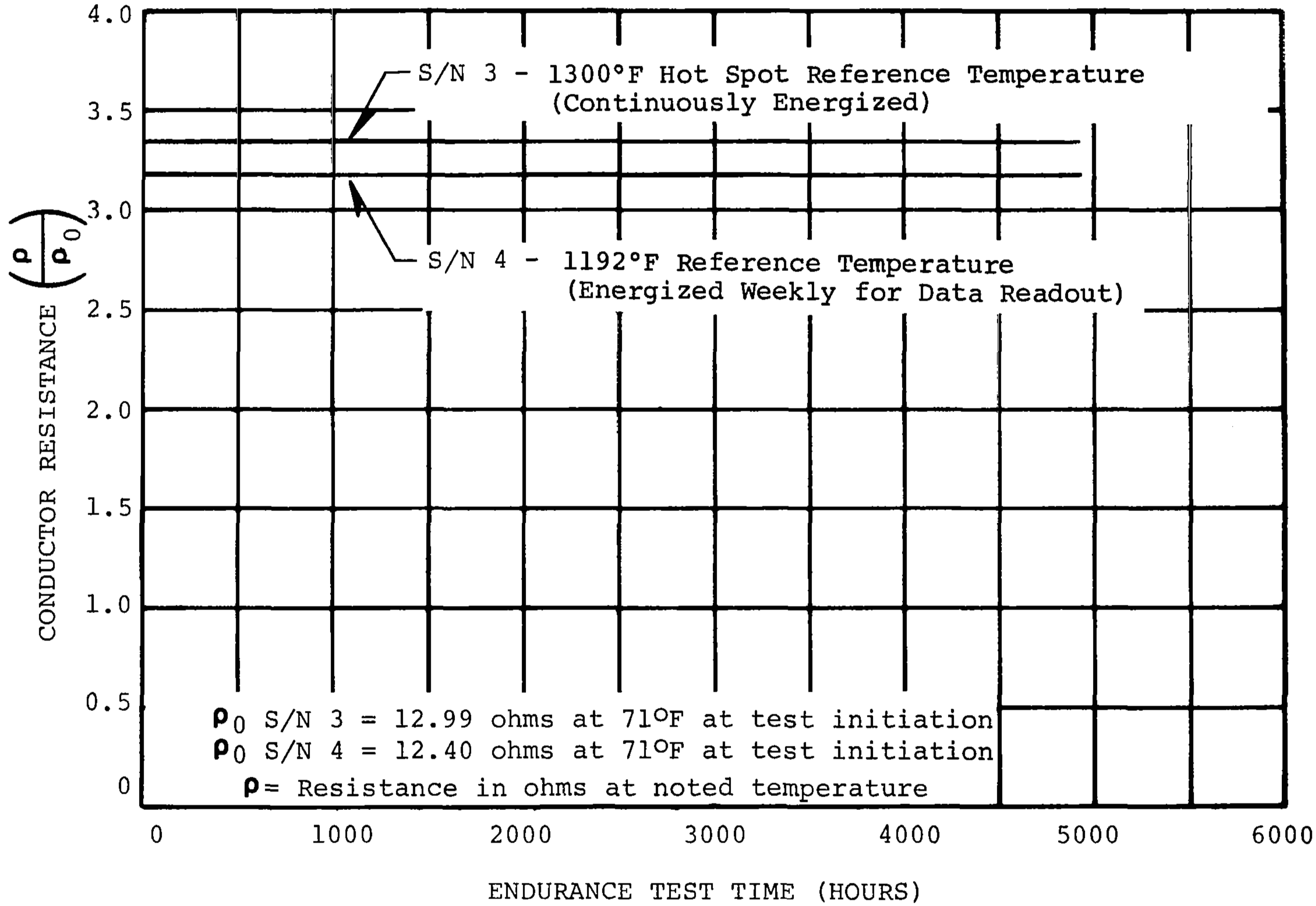



FIGURE II-62. Solenoid Conductor Resistance Versus Endurance Test Time - 1300° F Models (At Noted Reference Temperatures)

TABLE II-20. Solenoid Insulation Performance in Vacuum With a Midwinding (Hot-Spot) Temperature at 1300° F

| Endurance Test Time (hours) | 0 | 2500 | 4900 |
|---|---|---|---|
| Insulation Resistance (ohms) with 500 V d-c Applied: | | | |
| S/N 3 (energized) | | | |
| Winding to Ground (Referenced to 1300°F) | $7.0x10^6$ | 50.7 [a] | 49.8 [b] |
| S/N 4 (not energized) | | | |
| Winding to Ground (referenced to 1200°F) | $10.5x10^6$ | $5.8x10^6$ | $5.4x10^6$ |

(a) Solenoid winding experienced a low insulation resistance after 984 hours of endurance testing. Winding was still functioning properly and in same manner as initially.

(b) After 4900 hours the winding became a short circuit to ground. Winding leads to ground resistance became essentially zero.

Wire is 0.032-inch diameter Inconel 600-clad silver with Anadur "S" glass insulation; 99% alumina winding spool and 99.5% alumina winding end plates.

was noted in pickup and holding voltage and current or in the conductor resistance. The suspected cause of the grounding was a thin deposit of silver on one of the ceramic lead insulators coming through the solenoid housing. The source of the silver would be the transformer primary winding, which has shown up as an open circuit since it failed, indicating that part of the winding was destroyed. The Anadur insulation surface would not be impervious to silver atoms if silver was migrating from the transformer area and condensing, so that a thin condensed silver layer could form a relatively low resistance bridge from the conductor to the end bell.

The magnitude of the resistance varied up and down by a few ohms from week to week, but held close to a value of approximately 50 ohms. Just after the 4900-hour test point the leads became shunted across the winding. Apparently the other ceramic lead insulator had accumulated enough migrating silver to also become grounded to the housing. This resulted in an electrical path from lead-to-housing-to-lead, with essentially zero resistance. This failure was charged to external causes.

Solenoid S/N 4 showed some degradation in insulation performance but not enough to indicate that silver condensation was responsible.

Minimum pick-up and holding voltage and current readings were taken weekly for each solenoid. Table II-21 compares ambient temperature bench test values obtained before chamber installation with values obtained at a stable test temperature. Normally, pick-up currents are constant while the voltage required to produce the current varies as the conductor resistance varies with temperature. The test data indicate that friction between the Fe-27Co alloy plunger and alumina bearings may be influencing plunger movement.

TABLE II-21. Minimum Pick-Up and Holding Voltage and Current Measurements for Solenoid Weight and Plunger - 1300° F Hot-Spot Model

| | 760 Torr Pre Test Bench Test | | $3.2x10^{-9}$ Torr Chamber Test* | |
|---|---|---|---|---|
| | S/N 3 (72°F) | S/N 4 (72°F) | S/N 3 (1257°F) | S/N 4 (1182°F) |
| Minimum Pick-up Voltage, d-c | 5.0 | 4.8 (a) | 15.0 | 19.0 (a) |
| Minimum Pick-up Current, AMPS | 0.4 | 0.39 | 0.35 | 0.47 |
| Minimum Holding Voltage, d-c | 0.6 | 0.8 | 1.9 | 2.0 |
| Minimum Holding Current, AMPS | 0.05 | 0.07 | 0.05 | 0.05 |

(a) The increase in voltage required to maintain a constant current is caused by the increase in wire resistance as conductor temperature increases.

* At 4900 hours endurance test point - Temperature as Noted.

After completion of the 5000-hour test the test chamber and models were placed on a standby basis, pending a decision to conduct additional endurance testing.

10. Conclusions for 1100° F Solenoids and Comparison of 1100° and 1300° F Solenoid Model Performance

a) The materials used in both sets of models were compatible electrically and mechanically.

b) Maintaining an essentially continuous electrical stress on the energized solenoids at temperature for 5000 hours did not cause any change in magnetic operating characteristics at either test temperature.

c) The alumina guide rods and bushings provided satisfactory bearing surfaces for the Fe-27 Co alloy plungers in this vertical load application, and also prevented cold welding between the plungers and housings.

d) An analysis of insulation system performance between the energized 1100° and 1300° F models cannot be made because the apparent migration of silver from the failed transformer in the 1300° F tests caused the solenoid leads to become shorted to the housing.

e) The zircon potting compound (source of phosphorus) used in the 1100° F solenoid models reacted with the forged Fe-27 Co alloy end bells to extract cobalt and iron, but did not affect magnetic performance. This phosphorus activity is similar to that shown in the stator laminations.

# APPENDIX A

## SPECIFICATIONS

I. PROCUREMENT INFORMATION

II. MANUFACTURING PROCEDURES

III. DESIGN SPECIFICATIONS

## INTRODUCTION

A development and evaluation program on high temperature magnetic and electrical materials for space electric power systems was performed under NASA Contract NAS3-6465. A part of this program incorporated various combinations of materials, previously evaluated on Contract NAS3-4162, into two stators (with and without a bore seal), two transformers and four solenoids, all of which were evaluated under space-simulated conditions at two different elevated temperatures.

The materials used in the construction of the test components varied from readily available commercial compounds and alloys, and custom made materials, to a special flexible sheet insulation developed by Westinghouse Aerospace Electrical Division to meet dielectric strength requirements greater than 200 volts per mil at 1400°F.

This appendix is a compilation of procurement, processing and design information documents for use in conjunction with the engineering drawings of the test components also generated under NAS3-6465, (Reference Appendix B introduction). Together, these two packages made possible the successful fabrication and tests of these test vehicles.

It is emphasized that these documents are for information only, since the state-of-the-art is constantly changing. Developments of new and improved materials are being announced regularly. Other materials evaluated on NAS3-4162, because of their specialized nature and low sales activity, have been withdrawn from the market.

Finally, these documents will define only those areas necessary for the proper performance of each individual material or component. Procurement or purchasing specifications are used only to establish product quality and product reproducibility. The process information documents, however, provide the detail information necessary for the fabrication and assembly of each component.

# I. PROCUREMENT INFORMATION

## Introduction

This first section of Appendix A contains procurement information which defines the various qualities required in raw and finished materials, whether the materials are obtained from vendors or an internal source. The method of preparation or manufacture is not controlled, but the product must meet specified requirements to be acceptable for further processing or final use.

PI-1

Procurement Information for Fe-27Co (*Hiperco 27) Alloy Strip

1. This specification covers vacuum melted, cold rolled, iron cobalt alloy strip (0.010 inch thick and less) in coils or cut lengths.

2. PROCESS: The alloy shall be vacuum melted.

3. CONDITION: The material shall be in the cold rolled condition.

4. CHEMICAL COMPOSITION: The material shall conform to the following requirements as to chemical composition:

| | | | Permissible Variation on Check Analysis | |
|---|---|---|---|---|
| | Heat Analysis | | Under Min | Over Max |
| Cobalt | 26.00-28.50 | Percent | 0.25 | 0.25 |
| Chromium | .30- .70 | " | .02 | .03 |
| Nickel, Max | .70 | " | - | .03 |
| Manganese, Max | .50 | " | - | .03 |
| Silicon, Max | .50 | " | - | .02 |
| Sulfur, Max | .025 | " | - | .005 |
| Phosphorus, Max | .015 | " | - | .005 |
| Carbon, Max | .020 | " | - | .005 |
| Iron | Remainder | | - | - |

5. CHECK ANALYSIS:

(5.1) Check analyses may be made by the purchaser from finished material representing each vacuum melted heat.

(5.2) Sampling methods shall be in accordance with ASTM E-59 and referee analysis in accordance with ASTM E-30.

(5.3) The composition thus determined shall conform to the requirements specified in Section 4 subject to the permissible variations for check analysis specified.

---

* Registered Trademark of Westinghouse Electric Corporation.

6. **DENSITY:** The density shall be 7.95 grams per cubic centimeter at 25°C (77°F).

7. **LAMINATION FACTOR:**

(7.1) The lamination factor shall not be less than 96 percent.

(7.2) Lamination factor shall be determined in accordance with ASTM A-344.

8. **MAGNETIC PROPERTIES:**

(8.1) (Core Loss) After annealing as specified in Section 10, the material shall have a core loss conforming to the following:

| Thickness, In | AC Core Loss at 19 Kg and 400 Cycles, Watts per Lb, Max |
|---|---|
| 0.004 | 40 |
| .008 | 45 |
| .010 | 55 |

(8.2) (DC Induction) After annealing as specified in Section 10, the DC induction ($B_m$) shall conform to the following for the magnetizing forces listed:

| Magnetizing Force (H) Oersteds | Induction ($B_m$), Kilogausses | |
|---|---|---|
| | Min | Max |
| 50 | 18.7 | - |
| 100 | 20.3 | - |
| 150 | 21.2 | - |
| 200 | 21.7 | - |
| 250 | 22.6 | 23.7 |

(8.3) The core loss shall be determined in accordance with ASTM A-343.

(8.4) For magnetizing forces of 50 and 100 oersteds the induction shall be determined in accordance with ASTM A-341 using the DC test with 25 centimeter Epstein Double Lap Joints. For magnetizing forces of 150, 200 and 250 oersteds the induction shall be determined by means of a Fahy permeameter using the same specimens used for Epstein tests.

9. MECHANICAL PROPERTIES:

(9.1) After annealing as specified in Section 10, the material shall conform to the following requirements as to mechanical properties:

| | |
|---|---|
| Tensile Strength, Psi, Min | 75,000 |
| Yield Strength, Psi, Min | 40,000 |
| Elongation in 2", Per cent, Min | 12 |

Tensile properties determined per ASTM E-8 using the 0.2 percent offset method when determining yield strength.

10. QUALIFICATION ANNEAL: The factors of the annealing cycle to demonstrate conformance to Sections 8 and 9 shall conform to the following:

| Factor | Requirement |
|---|---|
| Atmosphere | Dry hydrogen with dew point -40 C (-40 F) or lower. |
| Holding Time | 2 to 4 hours at temperature between 800 C and 900 C (1472 F and 1652 F) to develop requirements in Sections 8 and 9. Soak temp selected within this range shall be held within ± 25 C (± 45 F) of nominal. |

11. PERMISSIBLE VARIATIONS: The thickness, width, and camber tolerances shall conform to the following:

| Dimension | Width, Inches | Permissible Variation | Crown Allowance |
|---|---|---|---|
| Thickness, Inches | | | |
| 0.004 | All | ±0.0003" | - |
| .008 | All | ± .0005" | - |
| .010 | All | ± .0007" | - |
| .047 | 15 and less | ± .0025" | .002" |
| Width | 1/2 to 9 Incl | ± .005" | |
| | Over 9 to 15 " | ± .010" | |
| Camber | 1-1/2 and less | 1/2" max in any 8 ft. | |
| | Over 1-1/2 to 24 Excl | 1/4" max in any 8 ft. | |

12. **QUALITY:** Material shall be smooth, and free from carburization, buckles, wrinkles, burrs, roll and tool marks, and other imperfections that will be deleterious to fabrication or to performance of parts.

13. **REJECTIONS:** Material not conforming to this specification or to authorized modifications will be subject to rejection.

Procurement Information For Fe-27Co (*Hiperco 27) Alloy Forgings

1. This specification covers vacuum melted and annealed iron-cobalt alloy Forgings.

2. PROCESS: The alloy shall be vacuum melted.

3. ANNEALING: The forgings shall be annealed in hydrogen or dissociated ammonia using the following heating and cooling cycle: Parts shall be heated uniformly to 925 C ± 14° (1697°F ± 25), held for 1 to 2 hours and cooled in a chamber to below 200°C (392°F) then air cooled to room temperature.

4. QUALITY: The parts shall be uniform in quality and condition, sound and free from scale, foreign materials, and internal or external imperfections detrimental to the fabrication or performance of the parts.

5. CHEMICAL COMPOSITION: The material shall conform to the following requirements as to chemical composition:

| | Heat Analysis | Permissible Variation on Check Analysis | |
|---|---|---|---|
| | | Under Min | Over Max |
| Cobalt | 26.00 - 28.50 Per Cent | 0.25 | 0.25 |
| Chromium | .30 - .70 " | .02 | .03 |
| Nickel, Max | .70 " | - | .03 |
| Manganese, Max | .50 " | - | .03 |
| Silicon, Max | .50 " | - | .02 |
| Sulfur, Max | .025 " | - | .005 |
| Phosphorus, Max | .015 " | - | .005 |
| Carbon, Max | .020 " | - | .005 |
| Iron | Remainder | - | - |

6. CHECK ANALYSIS:

(6.1) Check analysis may be made by the purchaser from finished material representing each vacuum melted ingot.

(6.2) Sampling methods shall be in accordance with ASTM E-59 and referee analysis in accordance with ASTM E-30.

(6.3) The chemical composition thus determined shall conform to the requirements specified in Section 5.

* Registered Trademark of Westinghouse Electric Corporation.

7. MECHANICAL PROPERTIES:

(7.1) The material shall conform to the following requirements as to mechanical properties:

| | |
|---|---|
| Tensile Strength, Psi, Min | 75,000 |
| Yield Strength, Psi, Min | 40,000 |
| Elongation in 2", Per cent, Min | 12 |

(7.2) The tensile properties shall be determined in accordance with ASTM E-8 using the 0.2 per cent offset method when determining yield strength.

8. MAGNETIC PROPERTIES:

(8.1) The DC induction at a magnetizing force of 250 oersteds shall not be less than 22.0 kilogausses.

(8.2) The induction shall be determined in accordance with ASTM A-341 using the Rowland Ring method.

9. REJECTIONS: Material not conforming to this specification or to authorized modifications will be subject to rejection.

PROCUREMENT INFORMATION

FOR

SPRING MATERIAL FOR ROLLPINS

"REFER TO AMS5506"

PROCUREMENT INFORMATION

FOR

NICKEL-MOLYBDENUM ALLOY SHEET AND PLATE
(Hastelloy 'B')

"REFER TO ASTM B 333-62"

PI-5

Purchasing Information For Clad Silver Conductor

NICKEL CLAD FINE SILVER

1. This document covers round and rectangular clad silver conductors designated as follows:

| Item No. | Description |
|---|---|
| 1 | Nickel clad fine silver 0.091"x0.144" wire per EDSK 326531 |
| 2 | Nickel clad fine silver 0.032" round per EDSK 326533 |
| 3 | Nickel clad fine silver 0.144" round per EDSK 326535 |

Drawings attached

NOTE: Unless otherwise specified, the following requirements apply to all items:

2. No change shall be made in the quality of successive shipments of material furnished under this document without first obtaining the approval of the purchaser.

MANUFACTURE

3. The wire shall be manufactured by the tube-bar method using the appropriate swaging machines, draw benches and flattening rolls (for rectangular conductors).

RAW MATERIALS

4. The silver core material used shall be lithium deoxidized fine silver.

5. The nickel clad shall be commercial Grade 'A' nickel tubing.

CLAD AREA

6. The clad area shall not be less than 18 percent or more than 22 percent as measured by accepted metallographic techniques. The eccentricity of the clad with respect to the silver core shall not exceed a 2:1 ratio of maximum clad thickness to minimum thickness.

TEMPER, APPEARANCE, AND SURFACE CONDITION

7. The conductors shall be in the soft, bright-annealed temper.

8. The conductors shall be free of laps, slivers, seams, cracks, and scratches and other imperfections.

9. All joints between lengths shall be suitably marked for removal.

PROPERTIES AND TESTS

10. Electrical resistivity shall not exceed $2.35 \times 10^{-6}$ ohm - cm when measured at 68°F by the 4 probe kelvin bridge technique.

11. No minimum or maximum values are assigned to the tensile strength, however, annealed elongation at room temperature shall not be less than 20 percent over a 12 inch long section.

SPOOLING AND PACKAGING

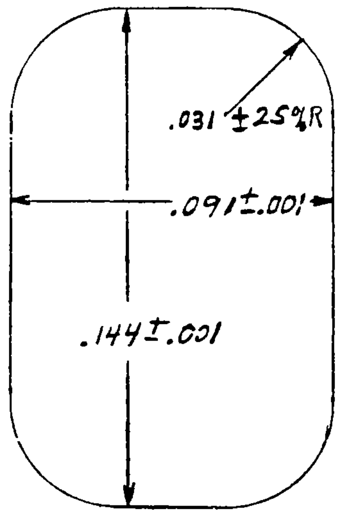
12. Unless otherwise specified, the wires shall be wound on plastic, metal, or metal bound reels in even turns and layers.

13. The wire shall be wound under sufficient tension as will give an even, compact winding.

14. The wire shall be protected by a wrapping of heavy paper or cardboard followed by enclosure in cardboard boxes.

15. All spools and reels shall be marked with the name of the manufacturer, purchase order number, type of wire, size, gross, tare and net weight. The cardboard boxes shall be similarly marked.

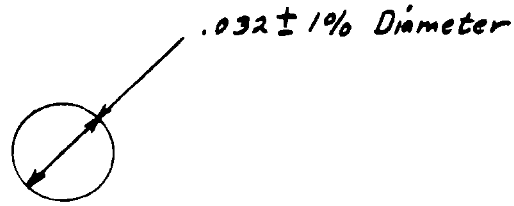
Conductor
20 Area Percent Nickel-Clad Silver




Dimensions in inches
Scale 20:1

EDSK 326531

Conductor
20 Area Percent Nickel-Clad Silver

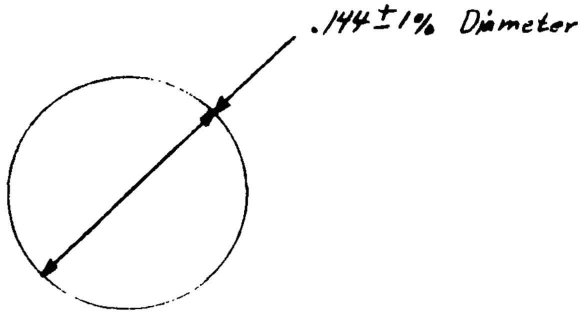



Dimensions in inches
Scale 20:1

EDSK 326533

PI-5

Conductor
20 Area Percent Nickel-Clad Silver




Dimensions in inches
Scale 10:1

EDSK 326535

PI-6

Same as PI-5 except in the following sections

INCONEL 600-CLAD SILVER CONDUCTOR

1.

| Item No. | Description |
|---|---|
| 1 | Inconel 600-clad fine silver 0.091"x0.144" wire per EDSK 326532 A |
| 2 | Inconel 600-clad fine silver 0.032" round per EDSK 326534 A |
| 3 | Inconel 600-clad fine silver 0.144" round per EDSK 326536 A |

MANUFACTURE

4. The silver core material shall be lithium deoxodized fine silver.

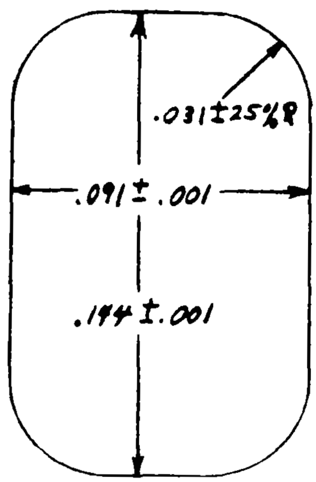
5. The Inconel 600-clad shall be Inconel 600 tubing per AMS 5580D.

CLAD AREA

6. The clad area shall not be less than 26 percent or more than 28 percent as measured by accepted metallographic techniques. The eccentricity of the clad with respect to the silver core shall not exceed a 2:1 ratio of maximum clad thickness to minimum thickness.

PI-6

Conductor
28 Area Percent Inconel 600-Clad Silver



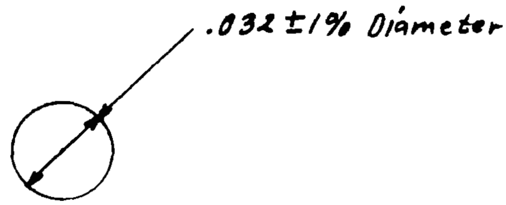

Dimensions in inches
Scale 20:1

EDSK 326532A

PI-6

Conductor

28 Area Percent Inconel 600-Clad Silver



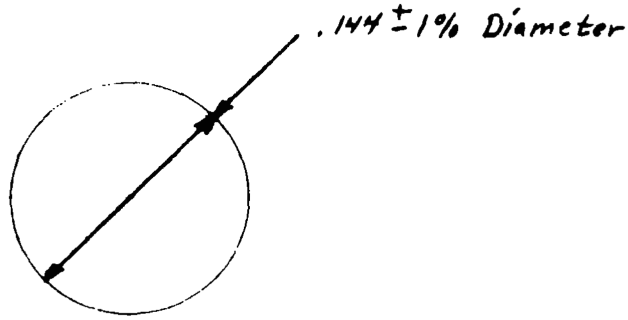

Dimensions in inches

Scale 20:1

EDSK 326534A

PI-6

Conductor
28 Area Percent Inconel 600-Clad Silver




Dimensions in inches
Scale 10:1

EDSK 326536A

PROCUREMENT INFORMATION

FOR

SINTERED TUNGSTEN ALLOY WEIGHT

"REFER TO AMS7725"

# PROCUREMENT INFORMATION

# FOR

# BRAZING ALLOY "LITHOBRAZ 'BT'" FILLER METAL (SILVER BASE)

"REFER TO ASTM B-260-62T"

PROCUREMENT INFORMATION

FOR

BRAZING ALLOY FILLER METAL (NICKEL BASE)

" REFER TO AMS4778"

PROCUREMENT INFORMATION

FOR

METAL 'O'-RING

"REFER TO AMS7325"

Procurement Information For Aluminum Oxide Ceramic Parts - 99$^+$ percent $Al_2O_3$ grade

1. This document covers high density aluminum oxide parts for application as electrical insulation in elevated temperature electrical aparatus.

NOTE: Unless otherwise specified, the following requirements apply to all items.

2. No change shall be made in the quality of successive shipments of material furnished under this document without first obtaining the approval of the purchaser.

MANUFACTURE

3. The parts shall be made according to the supplied drawing by the techniques of ceramic fabrication using the appropriate presses and furnaces.

COMPOSITION

4. The finished parts shall meet the following composition limits as specified on the drawing as follows:

| | Composition I (weight percent) | Composition II (weight percent) |
|---|---|---|
| $SiO_2$ | 0.30 max | 0.50 max |
| $Cr_2O_3$ | 0.20 max | --------- |
| MgO | 0.20 max | 0.20 max |
| $Fe_2O_3$ | 0.02 max | --------- |
| CaO | ---------- | 1.00 max |
| $Al_2O_3$ | 99.50 min grade | 99.00 min grade |

DENSITY

5. The finished parts shall have uniform density within the limits specified below.

| Composition I | Composition II |
|---|---|
| 3.80 - 3.89 g/cc | 3.78 - 3.90 g/cc |

CONDITION AND APPEARANCE

6. All parts shall be clean, white and free of surface discoloration, finger prints, or surface contamination.

7. All parts shall be free of chips, nicks, scratches, cracks and other deleterious imperfections as determined by visual techniques and the techniques of dye penetrant inspection.

8. Each part shall conform to the drawing supplied with regard to dimensions, and surface finish.

PROPERTIES AND TESTS

9. A certified chemical analysis of representative samples from each material lot and shipment shall be supplied.

10. Density, as determined by fluid displacement, shall be supplied on at least two (2) representative samples from each geometrical configuration from each shipment.

PACKAGING

11. Unless otherwise specified, the parts shall be packaged in clean plastic air-tight packages and protected from contamination and breakage due to handling.

12. Each shipping carton shall be marked with the name of the manufacturer, Purchase Order Number and weight.

# PURCHASING INFORMATION FOR ANADUR "E" GLASS CONDUCTOR INSULATION

1. SCOPE

1.1 This specification covers the requirements for Anaconda Anadur "E" Glass Fiber Insulation.

2. CONSTRUCTION

2.1 The finished insulation system shall consist of any of several conductors with a single glass-resin layer covered by a single (SGSK) or double (DGSK) layer of glass yarn, treated between layers and bonded with several coats of slurry and/or clear resin.

3. INSULATION

3.1 The specified conductor shall be wrapped firmly, closely, evenly and continuously with a covering of glass yarn. The glass fiber shall be continuous-filament glass yarn of good quality, conforming to the latest NEMA Standard GF-1 for continuous-filament glass yarn.

3.2 When more than one layer of glass yarn is applied, adjacent layers shall be wound in opposite directions.

3.3 The glass fiber servings shall be applied over a slurry enamel base coat composed of an organic resin and a finely pulverized glass filler.

3.4 The glass components used in the slurry shall have the required electrical characteristics and shall have suitable melting points to form the necessary vitreous bond.

3.5 The glass fiber serving for Type SGSK insulation shall be treated with the resin slurry (described in Paragraphs 3.3 and 3.4) over all, and finished with one coat of clear resin.

3.6 The Type DGSK insulation shall have the slurry applied both between servings and over all, and shall be finished with one coat of clear resin.

3.7 The completed insulation shall meet the test requirements outlined in Section 4.0.

4. TEST REQUIREMENTS

4.1 Adherence and Flexibility - A sample of finished wire and unfired insulation shall be elongated 20% in 10 inches. There shall be no cracks or ruptures visible in the film coating when examined with normal vision and without removal of the glass fiber coating.

4.2 Dielectric - Four electrodes (3 inches long) shall be prepared by applying a 1/4 inch wide thin metal foil to the center of a 1/2 inch wide pressure-sensitive tape. These electrodes shall be applied at right angles to the finished wire at intervals of approximately 2 inches and shall be wrapped smoothly and firmly around the wire a minimum of one and a half turns, with the foil in contact with the insulation.

A source of 60-cycle voltage of substantially sinusoidal wave form shall be applied between the electrode and the conductor. The source shall have a rating of at least 500 volt-amperes. The voltage shall start at zero and shall be raised at a uniform rate of approximately 100 volts per second until breakdown occurs. The voltage shall be measured in RMS volts. The insulation, in three of the four positions, shall withstand a stress of not less than 90 volts per mil plus 250 volts.

4.3 Dielectric Retest - In case of failure under the conditions specified in Paragraph 4.2, the wire shall be conditioned in an unbent and unstretched form for 48 hours at 100°C, followed by 4 hours at 50% relative humidity at room temperature. Two additional sets (8 total) of electrodes shall be applied. Both sets shall pass the requirements for dielectric strength (Paragraph 4.2) for acceptance of the insulation.

5. PACKAGING

5.1 Unless otherwise specified, each spool or reel shall contain one continuous length of insulated wire, and the wire shall be wound evenly and compactly.

5.2 Each spool or reel shall be packaged so as to protect the wire and insulation from contamination and physical damage caused by handling.

5.3 Each shipping carton shall be marked with the name of the manufacturer, Purchase order number, and weight.

PI-13

## PURCHASING INFORMATION FOR ANADUR "S" GLASS CONDUCTOR INSULATION

1. SCOPE

1.1 This specification covers the requirements for Anaconda Anadur "S" Glass Fiber Insulation.

2. CONSTRUCTION

2.1 The finished insulation system shall consist of any of several conductors with a single glass-resin layer covered by a single (SGSK) or double (DGSK) layer of glass yarn, treated between layers and bonded with several coats of slurry and/or clear resin.

3. INSULATION

3.1 The specified conductor shall be wrapped firmly, closely, evenly and continuously with a covering of glass yarn. The glass fiber shall be continuous-filament "S" glass yarn of good quality, conforming to the latest NEMA Standard GF-1 for continuous-filament glass yarn.

3.2 When more than one layer of glass yarn is applied, adjacent layers shall be wound in opposite directions.

3.3 The glass fiber servings shall be applied over a slurry enamel base coat composed of an organic resin and a finely pulverized glass filler.

3.4 The glass components used in the slurry shall have the required electrical characteristics and shall have suitable melting points to form the necessary vitreous bond.

3.5 The glass fiber serving for Type SGSK insulation shall be treated with the resin slurry (described in Paragraphs 3.3 and 3.4) over all, and finished with one coat of clear resin.

3.6 The Type DGSK insulation shall have the slurry applied both between servings and over all, and shall be finished with one coat of clear resin.

3.7 The completed insulation shall meet the test requirements outlined in Section 4.0.

4. TEST REQUIREMENTS

4.1 Adherence and Flexibility - A sample of finished wire and unfired insulation shall be elongated 20% in 10 inches. There shall be no cracks or ruptures visible in the film coating when examined with normal vision and without removal of the glass fiber coating.

4.2 Dielectric - Four electrodes (3 inches long) shall be prepared by applying a 1/4 inch wide thin metal foil to the center of a 1/2 inch wide pressure-sensitive tape. These electrodes shall be applied at right angles to the finished wire at intervals of approximately 2 inches and shall be wrapped smoothly and firmly around the wire a minimum of one and a half turns, with the foil in contact with the insulation.

A source of 60-cycle voltage of substantially sinusoidal wave form shall be applied between the electrode and the conductor. The source shall have a rating of at least 500 volt-amperes. The voltage shall start at zero and shall be raised at a uniform rate of approximately 100 volts per second until breakdown occurs. The voltage shall be measured in RMS volts. The insulation, in three of the four positions, shall withstand a stress of not less than 90 volts per mil plus 250 volts.

4.3 Dielectric Retest - In case of failure under the conditions specified in Paragraph 4.2, the wire shall be conditioned in an unbent and unstretched form for 48 hours at 100°C, followed by 4 hours at 50% relative humidity at room temperature. Two additional sets (8 total) of electrodes shall be applied. Both sets shall pass the requirement for dielectric strength (Paragraph 4.2) for acceptance of the insulation.

5. PACKAGING

5.1 Unless otherwise specified, each spool or reel shall contain one continuous length of insulated wire, and the wire shall be wound evenly and compactly.

5.2 Each spool or reel shall be packaged so as to protect the wire and insulation from contamination and physical damage caused by handling.

PI-14

# PROCUREMENT INFORMATION FOR BORON NITRIDE FIBER

1. This document covers the procurement of boron nitride fibers.

2. No change shall be made in the quality of successive shipments of material furnished under this specification without first obtaining the approval of the purchaser.

## APPROVED SUPPLIERS

3. There is only one approved supplier for this material; The Carborundum Company, New Products Branch, P.O. Box 337, Niagara Falls, New York, 14302.

## MANUFACTURE

4. This material shall consist of $99^{+}\%$ boron nitride in the form of long staple fiber, 10 to 15 inches long and 5 to 7 microns in diameter.

## PACKAGING

5. Unless otherwise specified, the material shall be packed in sealed plastic bags which in turn are protected against puncture by a cardboard shipping container. The fiber mass should not be compressed tightly for shipment and storage.

PI-15

Procurement Information for High Purity Aluminum Oxide (99.9% $Al_2O_3$) Powder

1. This document covers high purity Aluminum Oxide powder for insulation between the stacked laminations of magnetic devices to be operated at temperatures to 1600°F. This powder is intended for application by the techniques of plasma-arc spraying.

2. No change shall be made in the quality of successive shipments of material furnished under this specification without first obtaining the approval of the purchaser.

APPROVED SUPPLIERS

3. There is only one (1) approved supplier for this material; namely, Union Carbide Electronics Corporation Linde Division, 4120 Kennedy Avenue, East Chicago, Ind.

MANUFACTURE

4. This material shall be manufactured under the trade name "Linde A" by any process which results in a product fitting the product description for "Linde A".

COMPOSITION AND PHYSICAL PROPERTIES

5.

| | | |
|---|---|---|
| $Al_2O_3$ | | 99.90 percent min. |
| Other | | .05 percent max. per element not to exceed a total level of 0.10 percent combined. |
| Crystallographic Structure | - | Cubic |
| Hardness (Moh Scale) | - | 8 |
| Average Particle Size | | 0.30 micron |
| Maximum Particle Size | - | 0.40 micron |

PACKAGING

6. Unless otherwise specified, this material shall be packaged in glass, metal, or plastic lined paper containers so as to protect the powder from contamination and moisture.

7. Each shipping container shall be marked with the name of the manufacturer, purchase order number, and weight.

PI-16

Procurement Information for W-839 Potting Compound Formulation

1. This document specifies the formulation used in preparing zircon potting compound (W-839) as follows:

   A. Zirconium Silicate, Pulverized (M#20305 BA)
   B. Compound, Bonderizing and Phosphatizing (M#8344-11)

2. The following shall apply to Zirconium Silicate, Pulverized.

   FURNISHED BY - Orefraction Minerals, Inc.
   Andrews, South Carolina

   ORDER FROM SUPPLIER AS - Electrical Zircon, 200 mesh.

   CHARACTERISTICS - Ground zirconium silicate practically free from titanium. Loss on ignition is less than 0.2%. Material is 99.8% pure and shows the following sieve analysis; 2-3% on 200 mesh, 5-8% on 325 mesh, 2-5% on 400 mesh.

3. The following shall apply to Compounds,Bonderizing and Phosphatizing.

   CAUTION: AVOID CONTACT WITH THE SKIN.

   FURNISHED BY - Monsanto Chemical Co.
   Lindbergh and Olive St. Rd.
   St. Louis 4, Missouri

   ORDER FROM SUPPLIER AS - Alkophos C

   CHARACTERISTICS - Liquid containing 33.1% $P_2O_5$ and 8.6% $Al_2O_3$. Density is 1.48. Ignition loss is 59.3%. pH of 1% solution is 2.2.

PI-17

## PROCUREMENT INFORMATION FOR PYROCERAM BRAND CEMENT

1. This document covers the procurement of Pyroceram Brand glass solder cement.

2. No change shall be made in the quality of successive shipments of material furnished under this specification without first obtaining the approval of the purchaser.

### APPROVED SUPPLIERS

3. There is only one (1) approved supplier for this material; Corning Glass Works, Corning, New York.

### MANUFACTURE

4. This material shall consist of a glass frit and mixing vehicle, and shall be manufactured under the trade name Pyroceram Brand Cement Type #45 by any process which results in a product fitting the product description.

### PACKAGING

5. Unless otherwise specified, the material shall be packaged in tightly closed glass containers so as to protect the material from contamination and deterioration.

6. Each shipping container shall be marked with the name of the manufacturer, purchase order number and weight.

# PROCUREMENT INFORMATION FOR BURNIL BRAND CM-2 PAPER

1. This document covers the procurement of Burnil Brand CM-2 paper.

2. No change shall be made in the quality of successive shipments of material furnished under this specification without first obtaining the approval of the purchaser.

## APPROVED SUPPLIERS

3. There is only one approved supplier for this material; 3M Company, New Products Division, St. Paul 19, Minnesota.

## MANUFACTURE

4. This material shall consist of Burnil Brand platelets of synthetic mica with no organic additives contained in the finished product. Small amounts of ceramic fibers shall be added to enhance the mechanical properties of the sheet. The material shall be prepared on standard paper-making equipment.

## PACKAGING

5. Unless otherwise specified, the material shall be packaged in flat, durable cartons, sealed to prevent moisture contamination.

6. Each shipping container shall be marked with the name of the manufacturer, purchase order number, material thickness, and quantity.

# II. MANUFACTURING PROCEDURES

## Introduction

This section contains processing specifications, which control processes such as manufacturing, cleaning, application of one material to another, etc., using materials which have previously met the procurement specification requirements.

## Special Cleaning, Degreasing and Ultrasonic Degreasing of Metal Parts with Trichloroethylene

SAFETY REQUIREMENTS: See Safe Practice Data Sheets SPDS D-3 and SPDS T-4

Avoid contact with cleaning solution and any parts producing ultrasonic vibrations during cleaning.

1. GENERAL: The ultrasonic cleaning equipment used shall be capable of producing ultrasonic vibrations in the range of 18-21 kc. The 500 watt Westinghouse cleaner or an equivalent is satisfactory to use.

2. SOLVENT: Use trichloroethylene 51550BZ. *

3. VAPOR DEGREASING: Place the parts on a rack or suitable metal basket. If the part or parts are of such configuration that soils from one surface will not fall off or fall to another surface, the parts shall be repositioned for another cleaning cycle. When cleaning laminations, suspend or rack the parts so as not to screen any surface from the cleaning vapors.

   Vapor is produced from boiling solvents within machine and is continually condensed by means of water jackets and returned to heating compartment to be used again.

4. CLEANING: After degreasing, subject work is to be cleaned to the following: Rack or place the parts in a basket as in 3 above, and clean in the ultrasonic tank for 4 to 5 minutes using trichloroethylene 51550BZ, solvent rinse twice in clean solvent.

5. DRYING:

   5.1 Simple shapes: Air dry.

   5.2 Other Complex Shapes: Oven dry for 2 hours at 240 ± 20°F.

6. HANDLING: After cleaning, all parts shall be handled with clean, lint free gloves.

7. STORAGE: Store in clean dry plastic bags between cleaning cycles. Bags need not be sealed.

* Equivalent to Mil-T-7003

6.29.65

## Cleaning of Electrical Apparatus, Components, Wound Apparatus and Tooling With Ultrasonic Cleaner

SAFETY REQUIREMENTS: See Safe Practice Data Sheets SPDS S-6 and A-14

Avoid contact with cleaning solution and any parts producing ultrasonic vibrations during cleaning.

1. GENERAL: The cleaning equipment used shall be capable of producing ultrasonic waves in the range of 18-21 kc. The 500 watt Westinghouse cleaner or an equivalent is satisfactory to use.

2. SOLVENT: Use a distilled water solution containing 0.5 to 1.0 ounce of detergent (PDS 53512HK)* per gallon. The solution shall be neutral (pH 7 ± .5) at all times during operation. The pH may be checked by indicator papers or a pH meter.

3. SOLVENT TEMPERATURE: The solvent temperature shall be adjusted to 150° ± 10°F.

4. CLEANING: Place the parts in the cleaning tank preferably on a rack or in a metal basket. Clean for 4 to 5 minutes. If the part is of such configuration that soils from one surface will not fall off or fall to another surface, the part shall be repositioned for another cleaning cycle. When cleaning laminations, suspend or rack the parts so as not to screen any surface from the cleaning fluid.

5. RINSING: Immediately after cleaning, the parts shall be rinsed with hot (150°F) distilled water, followed by a rinse in ethanol PDS 1701** and a second and third rinse in hot distilled water and ethanol.

6. DRYING:

   6.1 Simple Shapes: Air dry.

   6.2 Other Complex Shapes: Oven dry for 2 hours at 240° ± 20°F.

7. HANDLING: After cleaning, all parts shall be handled with clean, lint free gloves.

8. STORAGE: When parts are to be assembled more than one hour after cleaning or are to be moved from one location to another or are finished and ready for test, all parts are to be SEALED in clean dry plastic bags in dry nitrogen with new desiccant.

6.29.65

* ALCONOX, Alconox, Inc., N.Y., N.Y.
** Equivalent to MIL-A-6091

MP-3

Manufacturing Procedure for plasma-arc spraying of High Purity Alumina for Interlaminar Insulation

1. Follow the procedures specified herein:

2. CLEANING

2.1. All laminations for spraying shall be free of oxides, dirt, grease, oils and moisture. Clean the parts according to MP-1 and 2 (EDSK 327655 and EDSK 327656) immediately before plasma-arc spraying. Store in clean plastic bags.

NOTE: Handle all cleaned parts with clean lint free gloves.

3. SPRAYING

3.1. Use a Plasmadyne Corporation Model SG-1 Plasma spray unit.

3.2. Use Aluminum oxide powder (PI-16, EDSK 342857) Linde A, 99.90% $Al_2O_3$, 0.03 micron particle size.

3.3. Use a spray gun work distance of 7" $\pm$ 1.0 inches.

3.4 Use a circular spray pattern of 1/2 inch in diameter.

3.5 Use a plasma-arc current of 500 to 650 amperes at 30 to 40 volts d.c.

3.6 Use an arc gas (Argon) flow of 1.50 on the control panel flow meter and a powder gas (Argon) flow of 1.1

3.7 Spray one side of each lamination to obtain an average coating thickness of 0.1 mil as determined by stacking factor measurements.

4. STORAGE

4.1. Protect the sprayed laminations from contamination by storage in a plastic bag.

# MANUFACTURING PROCEDURE

# FOR

# NICKEL ALLOY BRAZING

"REFER TO AMS2675"

MP-5

Manufacturing Procedures for Fluxless Conductor and Sheathed Thermocouple to Feedthrough Brazing.

1. Follow the Procedures Specified herein.

| Procedure Designation | Brazing Alloy | Application |
|---|---|---|
| 1.1 Conductor to feedthrough | ASTM B260-63T B Ag-8a (Lithobraz 'BT') Strip 0.002"T and 0.020" wire | Nickel Clad or Inconel-600 Clad Silver Conductors to OFHC Copper feedthroughs |
| 1.2 Sheathed Thermocouple | ASTM B260-63T B Ag-8a (Lithobraz 'BT') 0.020" wire | Inconel-600 Sheathed Thermocouples to Kovar tubular feedthroughs |

OPERATIONS

2. Cleaning
    2.1 All materials to be brazed shall be free of dirt, grease, oils, oxides and moisture. Clean the parts according to MP 1 and 2 (EDSK 327655 and 327656) immediately (less than 2 hours) prior to brazing. Store the parts in a plastic bag until ready for use.

    NOTE: Handle all parts with clean lint free gloves.

3. Assembly and Brazing
    3.1 Conductor to feedthrough
        3.1.1 Assembly
        Using clean lint-free gloves, assemble the plated end of the conductor longitudinally along the feedthrough using a shim of 0.002" thick braze alloy between the conductor and feedthrough. Fix the conductor in place with banding wire at two locations.

        3.1.2 Brazing
        Cover the assembly with a suitable transparent enclosure having provisions for entry by the torch operator and purge the area thoroughly with argon gas. Adjust an oxyacetyene torch to give a reducing flame as indicated by a yellow orange feather on the inner core. Heat the parts, by holding the flame on the heavier member, to a temperature high enough to cause the brazing alloy to flow freely and wet the metals being joined. Add additional alloy as necessary by hand to form a uniform fillet. Localized overheating

can be avoided by keeping the torch in motion. Remove the wires holding the conductor in place unless the wires have become brazed to the feedthroughs, in which case the wires may be left in place so long as they do not contact adjacent feedthroughs. Post braze cleaning will not be necessary.

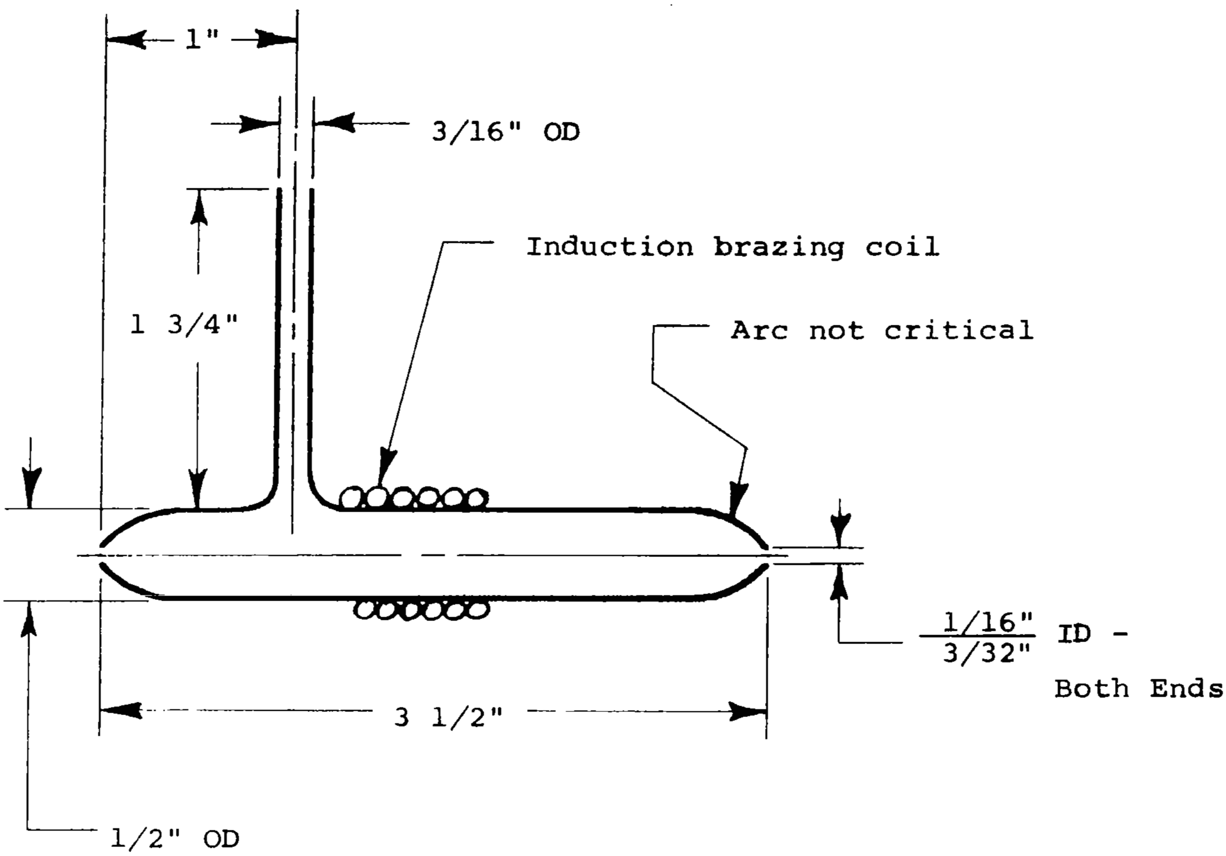
3.2 Sheathed Thermocouple to Feedthrough

3.2.1 Assembly

Using clean lint-free gloves carefully insert the end of each thermocouple into the Kovar feedthrough tubes and gently push the T/C's through the tubes one at a time until the end of each T/C appears at the opposite end of the tube. Pull each T/C through the tube the desired amount. Locate a four turn segment of brazing wire pre-form (wound over a 0.040" mandrel) over the junction between Inconel and the Kovar. Locate a suitable glass enclosure over the joint area and locate a six turn 5/8" I.D. induction heating coil over the glass envelop so that the Kovar-Inconel Junction is centered in the induction coil.

The induction coil should be connected to a Lepel model RW AG 7.5 (Serial 6529) RF induction heating unit. The glass enclosure should have a gas port tube (see attached drawing) located outside the area enclosed by the induction coil. Flow a gas mixture of 85% argon, 15% hydrogen (Maximum allowable gaseous impurities 25ppm) at the rate of 55CFH through the glass enclosure for 60 seconds prior to and during induction brazing. Actuate the induction brazing unit and heat the assembly to a temperature high enough to cause the brazing alloy to flow freely and uniformly wet the metals being joined. Localized overheating of the sheathed thermocouple is to be avoided by judicious location of the joint area in the induction coil. Cool the assembly under the argon- hydrogen cover gas.

NOTE: Post Brazing Cleaning operations will not be necessary.




GLASS THERMOCOUPLE BRAZING AMPULE

Material: Vycor, Pyrex or Equivalent

EDSK 342861

MP-6

Manufacturing Procedure for Annealing Hastelloy Alloy "B" (ASTM B333-58T)

1. Follow the Procedure specified herein.

OPERATIONS

2. Cleaning

2.1 Surfaces of parts to be annealed shall be free of dirt, grease, oils, and other surface contaminants. Parts may be cleaned by grit blasting or by the procedures of MP-1 or MP-2 (EDSK 327655 or 327656).

3. Annealing

3.1 Heating shall be performed in a furnace with a suitable atmosphere free from sulfur compounds. A dry hydrogen atmosphere with a dew point not higher than -40°F is required. The parts shall be heated to a temperature of 2100°F - 2175°F and held for a time not less than 1 hour or more than 1.5 hours at temperature.

3.2 Cooling of the parts shall take place in the hydrogen atmosphere at the fastest practical rate. Forced fan cooling may be used. The parts shall not be removed from the protective atmosphere above 200°F. Store the annealed parts in a plastic bag.

4. Hardness

4.1 Hardness after annealing shall not exceed Rockwell "B" 95.

MP-7

# MANUFACTURING PROCEDURE

# FOR

# LOW STRESS NICKEL PLATING

"REFER TO AMS2424A"

# MANUFACTURING PROCEDURE FOR ANADUR "E" AND "S" GLASS WIRE INSULATION SYSTEM BAKE-OUT

1. Follow the procedures specified in the sequence listed.

2. CLEANING

2.1 Specific cleaning of the Anadur insulation occurs during the final operation of the bake-out cycle.

2.2 Use clean, lint-free gloves and clean bench procedures in handling Anadur-insulated conductors prior to and after the Anadur bake-out cycle.

3. BAKE-OUT CYCLE PROCEDURE

3.1 After forming the Anadur covered conductors on suitable high temperature supporting insulation, place the coil, stator, transformer, solenoid, etc., in an air oven and carry out a bake-out cycle according to the following temperature and time schedule.

| Temperature - °F | Time - Hours |
|---|---|
| 350 | 2 |
| 550 - 600 | 16 |
| 750 - 800 | 4 |
| 1225 ± 25 | 0.5 |

The firing steps may be carried out in one furnace, with the coil left undisturbed between stages. Time at 1225 ± 25°F should be marked as soon as the furnace reaches 1200°F. The final stage of firing at 1225°F may be performed in an inert gas or vacuum if oxidation-sensitive components are present in the assembly.

3.2 Remove power from the furnace and allow the coil to cool slowly to near-room-temperature in the furnace.

4. STORAGE

4.1 Protect the baked-out coil from contamination by storing it in a clean plastic bag.

## Manufacturing Procedure for Zircon (W-839) Potting Compound

1. Follow the procedures specified herein:

2. CLEANING

2.1. All parts to be potted shall be free of dirt, grease, mold release, etc. Reference MP-1 and MP-2 for cleaning procedures.

3. MIXING

3.1. Mix potting compound components in the following range of ratios, depending on the consistency desired.

| | | |
|---|---|---|
| (Reference PI-18, EDSK 342868) | M# 20305BA (Powder) | 78-71 grams |
| | M# 8349-11 | 22-29 grams |

Use plastic, plastic coated paper or stainless steel containers and mixing tools. Water will clean tools.

4. POT LIFE

4.1. The useful pot life after mixing is approximately 30 minutes when exposed to air continually. Pot life may be prolonged for several days if the container is sealed while not in actual use.

5. APPLICATION

5.1. The mixture may be applied by pouring or by using any suitable applicator.

6. CURING

6.1. After application, cure the potting compound in air according to the following time-temperature schedule:

| Temperature - °F | Time - Hours |
|---|---|
| Room Temperature | (16 hours approximately) |
| 120-130 | 1 |
| 145-155 | 1 |
| 185-195 | 2 |
| 215-225 | 2 |
| 340-360 | 2 |
| 440-460 | 2 |

Cool slowly to below 125°F before opening the oven.

7. REPAIR

7.1. Excessive cracks in the cured surfaces may be repaired by using the same mixture, except the repair area shall be pre-wet with distilled water prior to filling cracks. The cure shall be the same as specified above.

# MANUFACTURING PROCEDURE FOR THE APPLICATION AND CURE OF PYROCERAM BRAND CEMENT

1. <u>Follow the Procedures Specified Herein</u>

2. CLEANING

2.1 All ceramic parts to be cemented shall be free of dirt, grease, oils and moisture. Clean the parts according to MP-1 and MP-2 (EDSK 327655 and EDSK 327656) before applying the Pyroceram cement. Store in clean plastic bags.

<u>NOTE:</u> Handle all cleaned parts with clean, lint-free gloves.

3. PREPARATION

3.1 Suspension preparation. A 250 ml glass beaker or small glass custard cup and a small stainless steel spatula are convenient for mixing the suspension. A nitrocellulose lacquer such as clear metal lacquer No. 1130, produced by E. I. DuPont de Nemours and Company, Wilmington, Delaware., is a suitable vehicle for holding the Pyroceram cement in place during the glazing operation. Mix only enough material to complete the job at hand. A glass-to-vehicle weight ratio of 12:1 results in a suspension viscosity suitable for brush application.

3.2 The container holding the ground glass must be tightly closed except when removing material for use. Leaving the glass open to the air for prolonged periods may result in a change in its suspension characteristics.

3.3 The vehicle must also be kept tightly stoppered, as evaporation of the solvent will affect suspension characteristics. The vehicle may be thinned with amyl acetate (CP) if required for ease of application.

4. APPLICATION

4.1 Use a small paint brush to apply the suspension to each pair of ceramic surfaces that are to be cemented. If more than one joint is involved, form and cure the joints one at a time.

4.2 Assemble the parts to form the joints using fixtures as required to hold the parts in place.

5. CURE CYCLE

5.1 General - The sequence of events during a curing operation leading to a strong joint are as follows. The solder glass melts, maintaining a sufficiently low viscosity long enough to allow the excess glass to flow out of the interface and form a fillet. During this stage there is wetting of the substrate by the solder glass and mutual interaction to form a good bond. Devitrification of the solder glass to a mixture of crystals and a harder glass then takes place, to result in a final state with higher softening point than the original solder glass.

5.2 Cure the cemented joint according to the following time-temperature schedule.

| Temperature - $^{\circ}$F | Time - Hours |
|---|---|
| 350 | 2 |
| 550 - 600 | 2-16 |
| 750 - 800 | 2 |
| 1225 - 1275 | 0.5 |
| 1400 $\pm$ 25 | 0.25 at temperature |

The heating at 1250$^{\circ}$F and 1400$^{\circ}$F may be performed in inert gas if required for protection of oxidation-sensitive components.

5.3 Heating rates - The rate of heating between temperature steps should be 6$^{\circ}$-10$^{\circ}$F/minute.

5.4 Cooling rates - Rate of cooling after completion of the cure cycle should be 6-15$^{\circ}$F/minute.

MP-11

Procedure For Pre-Test Vacuum Bake-Out of
High-Temperature, High-Vacuum Test Models

1. Follow the procedures specified herein.

EQUIPMENT REQUIREMENTS

2. This procedure requires the use of a vacuum chamber having an integral heating element and control and a vacuum pumping system capable of attaining chamber pressures of $1 \times 10^{-6}$ torr or lower at 1100°F when the chamber is clean, dry and empty. Liquid nitrogen cold traps shall be used as required to prevent backstreaming from the pump.

3. Thermocouples with an accuracy of ± 5°F are required for sensing the temperature of the test model during bake-out.

TEST MODEL INSTALLATION AND BAKE-OUT

4. Attach at least two thermocouples to the test model in such a manner that the model temperature will be sensed directly.

5. Install the test model in the vacuum chamber, using clean room handling procedures.

6. Start the vacuum pumping system and reduce the chamber pressure to the lowest value that can be attained.

7. When chamber pressure has become stabilized, set the heating element power controller at 200°F. Monitor and periodically record test model temperature and chamber temperature and pressure. If necessary, allow time for the chamber pressure to stabilize at a new value. Increase the heating element controller setting in increments of 200-250°F, allowing time after each step change for the pressure to approach a stable value. As the test model reaches the 900-1000°F temperature, materials outgassing rates may dictate smaller temperature increments to keep the chamber pressure within limits imposed by the vacuum system.

8. When the test model temperature has stabilized at required test temperature, maintain temperature and continue pumping the system until the chamber pressure reaches an apparent minimum value. Maintain this condition for at least 12 hours.

9. Remove power from the chamber heater element and let the test model come down to room temperature. Keep the vacuum pumping system on.

10. Shut down the vacuum pumping system and bring the vacuum chamber pressure up to 2 psig, using dry argon gas to backfill the chamber.

TEST MODEL STORAGE

11. If possible, leave the test model in the vacuum chamber until ready for the next operation. If the model must be removed from the chamber, store it under dry argon gas in a bag made from plastic or other material which can be hermetically sealed.

## SECTION III

## DESIGN SPECIFICATIONS

Contents

# III. DESIGN SPECIFICATIONS

## Introduction

Section III contains design specifications, which are used for the same purpose as procurement specifications. However, the design specification defines the qualities required for an assembly or system, rather than for individual materials or parts.

DESIGN REQUIREMENTS FOR A THERMAL-VACUUM TEST CHAMBER

1. SCOPE

1.1 This specification defines the general requirements for a combination furnace and vacuum chamber suitable for high-temperature, high-vacuum endurance testing of selected test specimens.

2. GENERAL REQUIREMENTS

2.1 The thermal-vacuum test chamber must be capable of continuous operation for periods to 10,000 hours at 2200°F (or 1800°F, see Para. 3.1) and must be capable of sustained operation at a pressure below 5 x $(10)^{-9}$ torr when at temperature and clean, dry and empty.

2.2 Any requirements in this specification which result in increased equipment costs as opposed to alternate means of attaining the desired test conditions should be pointed out by the vendor.

3. FURNACE REQUIREMENTS

3.1 Heater Element - The heater element and associated equipment shall be rated for two operating temperature levels, 400-2200°F and 400-1800°F, for purposes of cost comparisons.

3.1.1 Test Chamber - The high temperature test chamber shall have a useable test space of 8 inches diameter minimum and 10 inches height minimum.

3.2 Furnace Construction - The furnace shall have a tantalum heater element, and tantalum heat shields around the heater element and at the top and bottom of the test chamber.

3.3 Test Specimen Mounting - Provisions shall be included for mounting the test specimen rigidly to the base plate or to the furnace cover if it is a well type. Object is to be able to complete all electrical and instrumentation connections to the test specimen before installation in the vacuum chamber. Maximum test specimen weight will be approximately 25 pounds.

3.4 Heater Element Power Leads - The heater element shall be supplied with power by means of two water-cooled copper feedthroughs which are electrically isolated from other components.

3.5 Test Specimen Power and Instrumentation Leads - Furnace construction shall be such that 8 power leads, 1 ground lead and 12 chromel-alumel thermocouple sets (24 wires) can be brought from the test chamber to the outside of the furnace. (see Para. 4.8 for vacuum chamber feedthrough requirements.)

3.6 Heater Element Power Supply - The thermal-vacuum test assembly shall include the necessary conversion and control equipment to adopt a 440 volt, 60 cps single or three phase power supply to the requirements of the heater element. A furnace temperature monitoring and recording device shall be included as part of the instrumentation.

3.7 Furnace Temperature Control - Temperature control shall be quoted on the basis of automatic control and manual control for cost comparison purposes. For automatic control, the controlled operating temperature range shall be from 400°F to 2200°F (or 1800°F) and the required test temperature shall be maintained within ± 20°F. The temperature control capabilities using manual control shall be outlined.

4. VACUUM CHAMBER REQUIREMENTS

4.1 Vacuum Operation - The vacuum chamber, including the furnace, shall be capable of maintaining a vacuum at a pressure below $5 \times 10^{-9}$ torr when the chamber is at rated maximum temperature and clean, dry and empty.

4.2 Vacuum Pumping System and Controls - The pumps described in the following subparagraphs shall include operating controls and safety precautions as required.

4.2.1 The roughing system shall be cryogenically pumped and shall be capable of pumping the chamber to 10 microns within ten minutes. The roughing pump(s) shall be attached to the chamber through a bakeable valve, and shall be cart mounted with associated equipment.

4.2.2 The system shall include an ion pump suitable for extended operation at low pressures and with a capacity of at least 500 l/sec.

4.2.3 A titanium sublimation pump shall be included and considered in two configurations:

(a) Standard, short intermittent duty cycle operation at $10^{-8}$ to $10^{-9}$ torr, and
(b) 100-200 day duration capability at $10^{-8}$ to $10^{-9}$ torr.

The object of having a long duration sublimation pump capability is to provide a long-term boost assist for the ion pump in the event continued severe outgassing prevents the ion pump from reaching the required vacuum level.

4.2.4 The vacuum chamber shall include a cold finger for $LN_2$, to speed up removal of water vapor from the chamber during initial operation.

4.3 Vacuum Monitoring Gages.

4.3.1 The vacuum chamber shall include a thermocouple roughing gage and associated equipment for monitoring vacuum at relatively high pressure levels.

4.3.2 The vacuum chamber shall include a nude ionization gage and associated equipment for monitoring vacuum at low pressure levels. The gage control should be designed to facilitate pressure recording.

4.4 Furnace Cold Wall - The vacuum chamber shall serve as a cold wall for the furnace, and shall include a cooling water jacket.

4.5 Bakeout Provisions - The vacuum chamber shall include bakeout heaters and temperature indicators, located as required, to permit bakeout of the thermal-vacuum assembly at a temperature of 250°C.

4.6 Residual Gas Analyzer Connection - The vacuum chamber shall include a flanged feedthrough suitable for mating with the flange on a CVC 12-614 residual gas analyzer. The chamber assembly must also provide sufficient clearance for installing the residual gas analyzer.

4.7 Cryogenic Sample Valve and Flange - The vacuum chamber shall include a feedthrough having a bakeable valve and flange suitable for attaching a cryogenic sampling system by means of a gold flange gasket. Valve size shall be at least one inch.

4.8 Additional Chamber Penetrations - In addition to the vacuum chamber feedthroughs required for the integral thermal-vacuum assembly components and cryogenic sample hookup, test specimen feedthroughs will be required as follows: (These are the same as identified in Paragraph 3.5)

(a) Eight (8) test specimen power leads - 50 a. capacity.
(b) One (1) test specimen ground lead.
(c) Twelve (12) thermocouples (24 wires). (Chromel-Alumel).

4.9 Sight Port - The vacuum chamber shall include a sight port for viewing the test specimen in the high-temperature chamber.

DESIGN REQUIREMENTS FOR A HIGH TEMPERATURE THERMOCOUPLE

1. SCOPE

1.1 This specification defines the requirements for two sizes of corrosion resistant, metal sheathed metallic oxide insulated dual wire thermocouples, suitable for continuous service to a maximum temperature of 1600°F in a vacuum of $10^{-15}$ torr.

2. APPLICABLE DOCUMENTS

The following standards and documents shall be used to the extent to which they are applicable.

2.1 MILITARY SPECIFICATIONS

MIL-R-5031. Rods and Wire, Welding, Corrosion and Heat Resistant Alloys.

MIL-C-19874. Cleaning Requirements for Nuclear Primary Coolant Equipment Including Piping Systems.

2.2 OTHER SPECIFICATIONS

American Society For Testing Materials (ASTM)

E-142 Methods for Controlling Quality of Radiographic Testing.

B-163-58T Seamless Nickel and Nickel Alloy Condenser and Heat Exchanger Tubes.

Instrument Society of America (ISA)

RP-1 Section 1.3 Thermocouples and Thermocouple Extension Wires - Terminology, Limits of Error, and Wire Sizes.

2.3 STANDARDS

Federal Test Standard 151.
National Bureau of Standards
NBS Circular 561. Reference Tables for Thermocouples.
NBS Circular 590. Methods of Testing Thermocouples and Thermocouple Materials

Military
Mil-Std-271. Nondestructive Testing Requirements for Metals.

3. REQUIREMENTS

3.1 Physical Dimensions - The physical dimensions of the two thermocouple sizes are defined by EDSK 326795 and EDSK 326796, which form a part of this specification. Both leads shall be enclosed within a single circular sheath.

3.2 Conductors - The conductor material will be Platinel II, and representative wire size in the finished product shall be similar to the dimensions listed in Paragraph 4.3 of this specification, to insure adequate insulation.

3.3 Sheath - The sheath material shall be Inconel -600 Alloy.

3.3.1 Eddy Current Inspection - The sheath tubing shall not contain internal defects greater than 3/32 inch in an axial direction or greater than .0015 inch in a radial direction. This fact shall be certified by eddy current inspection techniques with equipment capable of resolving defects which are 1/16 inch in the axial direction and .001 inch in the radial direction.

3.4 Insulation - The insulation material surrounding the conductors shall be alumina having a minimum $Al_2O_3$ content of 99.6%. Maximum boron plus cadmium content shall not exceed 30 PPM. The minimum insulation thickness between wires and each wire and the sheath shall be as indicated in Paragraph 4.3 of this specification.

3.5 Welding Rod - Consumable filler rod material used for making closure welds shall be compatible with the Inconel -600 sheath material.

4. THERMOCOUPLE ASSEMBLY

4.1 Method - The sheath, insulation and conductors forming the constant diameter thermocouple (EDSK 326796) shall be processed into a homogeneous assembly by means of a single pass swaging operation or other approved vendor process. Assembly of the reduced tip diameter thermocouple (EDSK 326795) shall be by the same method except that the reduced tip diameter shall be formed by a multiple swaging operation or other approved vendor process.

4.1.1 Sealing - Both ends of the thermocouples shall be permanently sealed.

4.1.2 Compaction - The insulation shall be compacted to a minimum of 90% of theoretical density as a result of Paragraph 4.1.

4.1.3 Homogeneity - A check for homogeneity made by applying a 1500°F sharp gradient along the sheath shall not produce a voltage greater than .01 millivolts.

4.1.4 Cleanliness

4.1.4.1 Conductors and Sheath - The conductors and sheath are to be thoroughly cleaned immediately before assembly. However, the use of compounds which contain nuclear poisons or may become sources of corrosion is prohibited before, during, and after assembly.

4.1.4.2 Insulation - The insulation shall be baked at a minimum temperature of 1800°F to remove all contaminants and moisture immediately before assembly.

4.1.4.3 General Fabrication Area - The requirements of Mil-C-19874 as applicable shall be met during fabrication.

4.2 Anneal - The sheath of the finished material shall be fully annealed and shall not be sensitized. Annealing temperature shall be a maximum of 1900°F for 15 minutes, after which the material must be cooled below 800°F within 2 minutes.

4.2.1 Atmosphere - Annealing shall be done in a controlled atmosphere furnace and shall produce a finished product having a bright clean sheath.

4.3 Mechanical and Electrical Characteristics - The mechanical and electrical characteristics of the finished product shall approximate the design values listed in the following table for each sheath O.D. size.

| | | |
|---|---|---|
| Sheath O.D. | | |
| Nominal | .026" | .037" |
| Tolerances | ±.001" | ±.001" |
| Minimum Wall Thickness | .004" | .006" |
| Minimum Insulation Thickness Between Wires and Each Wire to Sheath | .002" | .004" |
| Minimum Wire Diameter (Dual Wire Construction) | .0035" | .005" |
| Minimum Insulation Resistance - 50 Feet Continuous Length @72°F | 250 megohms | 1000 megohms |
| Applied DC Voltage - Direct and Reverse Polarity | 50 VDC | 500 VDC |

4.3.1 To assure that insulation resistance is maintained in the final product, a waterproof cement or silicon varnish shall be used to seal the open ends of the material.

4.4 Thermocouple Junction - The thermocouples shall have isolated junctions and a spherical end closure, the thickness of which shall be no more than the sheath diameter and no less than one-half the sheath diameter. The distance of the thermal junction from the welded end closure shall be a maximum of one-half the sheath diameter and a minimum of one-quarter of the sheath diameter.

4.4.1 Closure Diameter - The outside diameter of the welded sheath closure at the isolated junction end shall be smooth and within the outside diameter tolerances shown in Paragraph 4.3.

4.4.2 Non-junction End - The non-junction end of the thermocouple shall have bare wire terminations a minimum of one-quarter inch long, and a sealed closure which is smooth and within the outside diameter tolerances shown in Paragraph 4.3. The thermocouple and bare wire terminals must be able to pass through a .039 inch minimum I.D. tube bore.

5. PERFORMANCE TESTS

5.1 Electrical Continuity - The thermocouple wire shall demonstrate electrical continuity after the measuring junction has been thermal cycled five times between ambient temperature and 750° ± 50°F in a non-corrosive atmosphere. The thermocouple wire shall have a minimum of 12 inches at the end containing the thermal junction immersed in the test chamber. Measurements shall be taken at the maximum and ambient temperatures during the last cycle.

5.1.1 The measurement shall be made with equipment capable of determining values with an accuracy of ± 2%. Resistance values obtained both at ambient and elevated temperatures shall be recorded and identified for each thermocouple, and shall be within 10% of the calculated resistance for the type and gauge of wire used.

5.2 Thermal Junction Integrity - A length of thermocouple extending a minimum of 4 inches from the junction welded closure shall be radiographed in two views 90° apart and perpendicular to the thermocouple axis. The radiography shall be performed in accordance with Mil-Std-271 at a sensitivity level of 2.1 T using a 0.002 inch thick penetrometer, and shall not show indications of the following:

a. Cracks, notches, crevices, voids, inclusions or local reduction in dimensions in the thermocouple wires or sheath.

b. Any notches, crevices, voids, inclusions or local reduction in dimensions in the welded end closure.

The thermocouple wires shall show positive evidence of a junction.

Copies of the radiographs shall be shipped with the thermocouples. The x-rays shall be correlated with the thermocouples to easily distinguish each particular thermocouple on the film.

5.3 Sheath Integrity - A sheath integrity test shall be performed to determine structural integrity of the outside sheath by ascertaining its ability to be penetrated by helium gas under high pressure. There shall be no evidence of leaks through the sheath when the full length of the material in its final condition is subjected to the following test. The maximum permissible leak rate listed below is the combined leak rate when simultaneously testing a minimum of 25 pieces 50 feet long. Tests shall be performed with material in a straight condition.

5.3.1 Material with both ends sealed closed, suitably protected from scratches, shall be carefully installed in a pressure pipe and subjected to ambient temperature helium at 2000 ± 200 PSIG for 15 minutes.

The material shall be removed from the pressure chamber, blown off with dry nitrogen to remove residual helium, and installed within 15 minutes into a vacuum chamber.

The vacuum chamber is then to be pumped down to 8 microns Hg and monitored with a mass spectrometer leak detector. Monitoring shall be continued uninterrupted for a minimum of 10 minutes after the chamber pressure has dropped to 8 microns Hg or less. If a measurement of $6 \times 10^{-9}$ or greater standard cc/second of helium is obtained, it will be taken as evidence of excessive leakage. All material shall then be individually evaluated to find the defective piece or pieces. The reduced lot shall then be re-subjected to the entire test procedure.

Certification of the test data shall include the following:

a. Standard calibration scale deflection
b. Background scale deflection
c. Test scale deflection
d. Calculated leak

## 5.4 Surface Condition

5.4.1 Surface Finish - The surface finish of the sheath material in its final condition shall not have a roughness greater than 32 micro-inches.

5.4.2 Surface Defects (Visual) - There shall be no cracks or defects such as gouges, dents, die or tool marks greater than .002 inch in depth on the surface of the finished material, as evidenced by examination at 5X.

5.4.3 Surface Defects (Liquid Penetrant)- There shall be no cracks, holes, seams or other defects on the surface of the material as evidenced by a fluorescent dye penetrant test. The dye penetrant test shall be performed in accordance with Mil-Std 271. Type IV fluorescent penetrant shall be used.

5.5 Calibration - Thermal emf for each thermocouple shall be measured at temperatures of 500°F, 1000°F, and 1250°F. The calibration temperature shall be reported with reference to a cold junction temperature of 32°F. Limits of error shall be ± 2°F to 500°F and ± 3/8% from 500°F to 1250°F.

5.6 Certification and Test Reports - Material certifications and test and inspection reports covering each item listed below shall be submitted to the purchaser.

Spec Para.

| | |
|---|---|
| 3.2 | Premium grade wire |
| 3.3 | Tubing to ASTM spec |
| 3.3.1 | Eddy current |
| 3.4 | Insulation purity |
| 3.5 | Welding rod to Mil or ASTM spec |
| 4.3 | Insulation resistance |
| 4.3 | Dimensional |
| 5.1 | Thermal cycle |
| 5.2 | X-ray |
| 5.3 | Helium leak test |
| 5.4.1 | Surface finish |
| 5.4.2 | Surface defects (Visual) |
| 5.4.3 | Surface defects (Liquid Penetrant) |
| 5.5 | Calibration - 3 points |

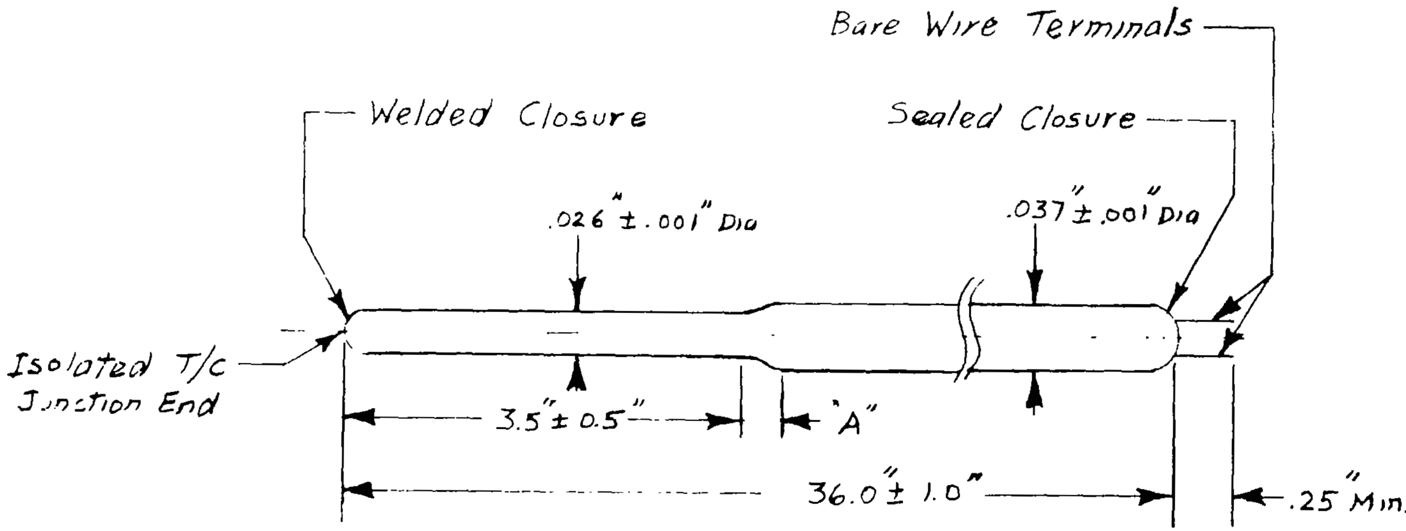
6. *PREPARATION FOR DELIVERY*

6.1 Identification - Thermocouples shall be individually identified by two corrosion resistant steel tags attached with paper or plastic coated corrosion resistant wire. The tags shall bear the manufacturer's name and material identification number on one face and the buyer's purchase order on the other face. The identification system shall be such that raw materials (sheath, insulation and conductors) and test records can be identified with any particular item.

6.1.1 Polarity Identification - The leads which protrude at the opposite end from the junction on each thermocouple will have positive and/or negative polarity identified.

6.2 Packing - The thermocouples shall be shipped in straight lengths, individually wrapped and sealed in a moisture proof material. Provisions shall be made to protect the exposed leads. Shipping containers shall be rugged enough to insure that the thermocouples are protected from damage during handling and shipping. Shipping containers should also be suitable for use as storage containers after receipt by the buyer.

6.3 Marking - Each shipping container will be plainly marked with the manufacturer's address, manufacturer's job number, purchaser's address, purchase order number and thermocouple part number.



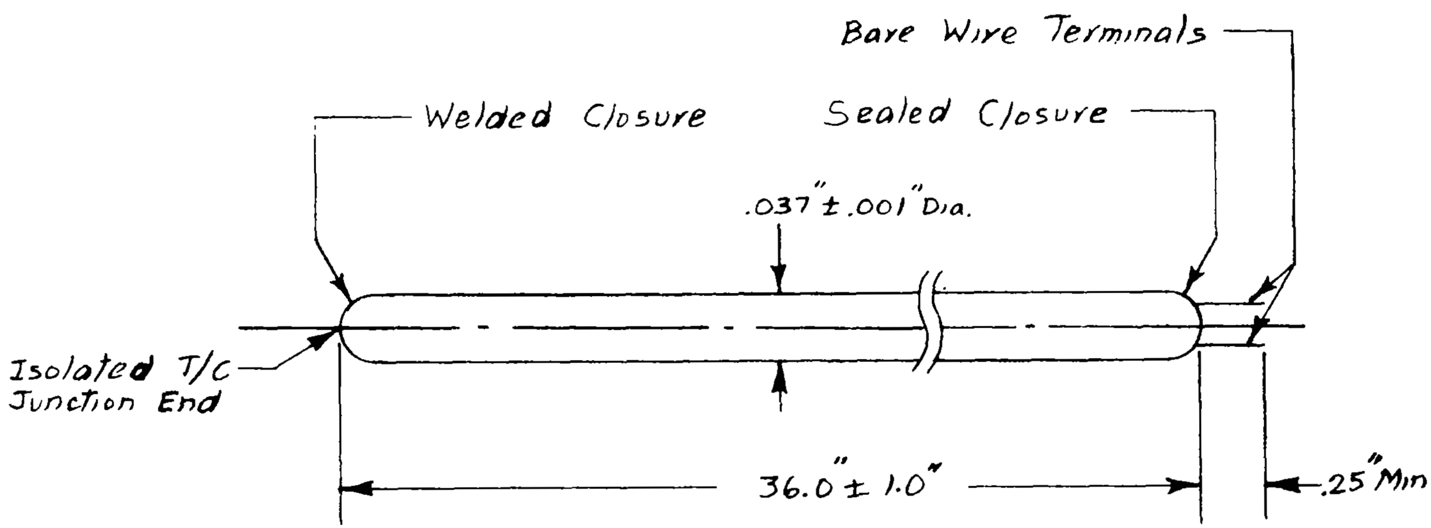

Note: Thermocouples are to be kept straight at all times.

"A" – Dimension as required for forming operation – 1.0 inch maximum. OD surface must be continuous thru transition.

DUAL DIAMETER SHEATHED THERMOCOUPLE

Reference (W) D-Spec # 709747

EDSK 326795




Note: Thermocouples are to be kept straight at all times.

SINGLE DIAMETER SHEATHED THERMOCOUPLE

Reference (W) D-Spec # 709747

EDSK 326796

# APPENDIX B

## DRAWINGS AND MATERIALS LISTS

SECTION I. STATOR

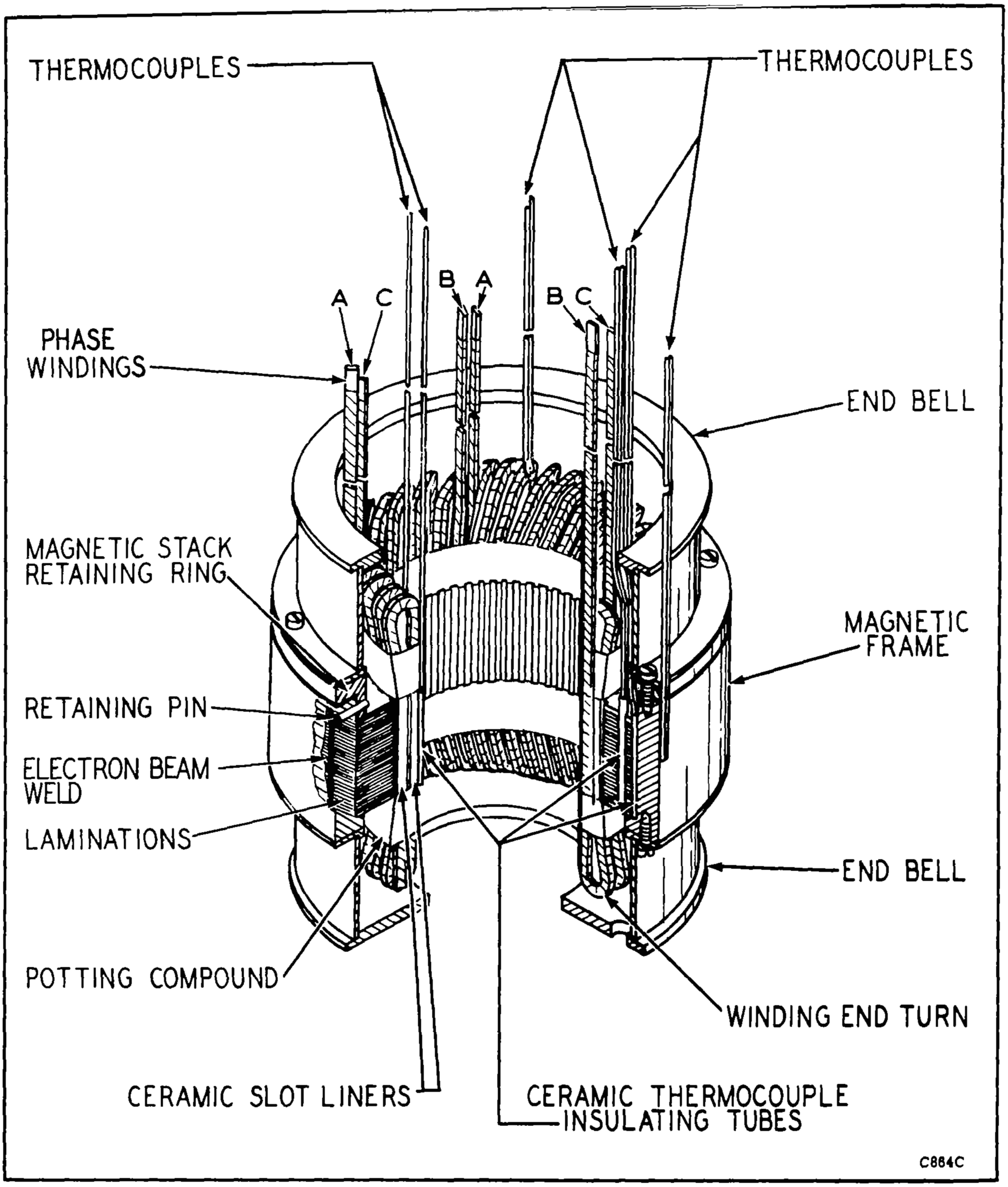
SECTION II. TRANSFORMER

SECTION III. SOLENOID

# INTRODUCTION

This appendix contains cutaway model construction drawings, materials lists for the three model designs, and model drawing lists and drawings.

I. STATOR




Cutaway View of Stator Without a Bore Seal

## Stator - Magnetic Insulation and Conductor Materials Summary 1100°F Hot-Spot Model

| Part | Material | Source NAS3-4162 |
|---|---|---|
| Frame | Fe-27Co Forging (Hiperco 27) | NASA-CR-54091 p. 59, 323 |
| Frame Ring | Fe-27Co Forging (Hiperco 27) | |
| Laminations | Fe-27Co 0.008 mil (Hiperco 27) | |
| Interlaminar Insulation | Plasma-arc sprayed $Al_2O_3$ (Linde A) | NASA-CR-54092 p. 98, 593 |
| Slot Liners | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Spacers | $Al_2O_3$-99.5% | NASA-CR-54092 p. 92, 453 |
| Wedges | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Thermocouple Insulators | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Conductor Insulation | Anadur (Ni-clad silver wire)-1100°F Owens Corning E - Glass fiber double serving overcoated with a proprietary oxide-loaded silicone wire enamel. | NASA-CR-54092 p. 86, 287 |
| Potting Compound | Zircon-type (Aluminum Orthophosphate and Zirconium Silicate)(W-839) | NASA-CR-54092 p. 97, 579 |
| Conductors (Rectangular) (0.091x0.144 inch) | Nickel clad silver - 1100°F (20% Nickel "A" cross-sectional area) | NASA-CR-54092 p. 81, 249 |
| End Bells, Hardware<br>Lamination Plates<br>Spring Pin<br>Thermocouples | Hastelloy Alloy B<br>Hastelloy Alloy B<br>C Res. AMS 5506<br>Inconel 600 Sheath - Platinel II Wire System | |

## Stator - Magnetic Insulation and Conductor Materials Summary 1300°F Hot-Spot Model

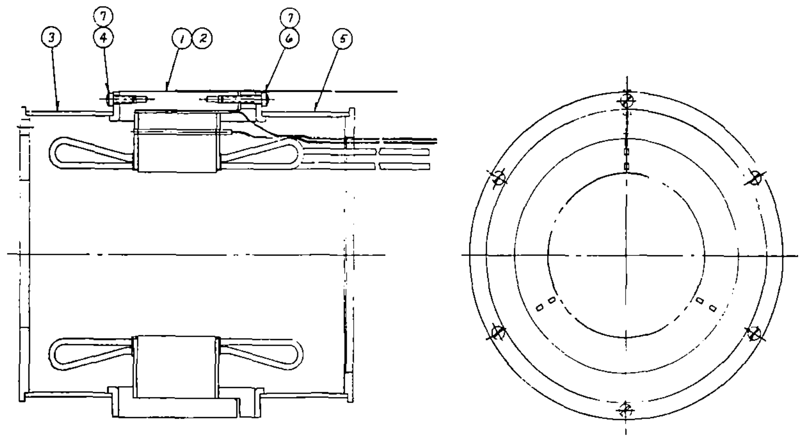
| Part | Material | Source NAS3-4162 |
|---|---|---|
| Frame | Fe-27Co Forging (Hiperco 27) | NASA-CR-54091 p. 59, 323 |
| Frame Ring | Fe-27Co Forging (Hiperco 27) | |
| Laminations | Fe-27Co 0.008 mil (Hiperco 27) | |
| Interlaminar Insulation | Plasma-arc sprayed $Al_2O_3$ (Linde A) | NASA-CR-54092 p. 98, 593 |
| Slot Liners | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Spacers | $Al_2O_3$-99.5% | NASA-CR-54092 p. 92, 453 |
| Wedges | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Thermocouple Insulators | $Al_2O_3$-99% | NASA-CR-54092 p. 92, 462 |
| Conductor Insulation | Anadur (Inconel-clad silver wire) 1300°F Owens Corning S - Glass fiber double serving overcoated with a proprietary oxide-loaded silicone wire enamel. | |
| Potting Compound | Boron Nitride (BN) Fiber Cement | |
| Conductors (Rectangular) (0.091x0.144 inch) | Inconel-clad silver - 1300°F (28% Inconel-600 cross-sectional area) | NASA-CR-54092 p. 81, 249 |
| End Bells, Hardware<br>Lamination Plates<br>Spring Pin<br>Thermocouples | Hastelloy Alloy B<br>Hastelloy Alloy B<br>C Res. AMS 5506<br>Inconel 600 Sheath - Platinel II Wire System | |

## APPENDIX B - SECTION I, STATOR DRAWING LIST AND DRAWINGS

| Drawing No. | Title | Material |
|---|---|---|
| EDSK 326681 | Stator Assembly | - |
| EDSK 326618 | Stack, Stator, Wound | - |
| EDSK 326602 | Stack, Stator, Wound (Practice)[1] | - |
| EDSK 326550 | Details | See Drawing |
| EDSK 326603 | Details | See Drawing |
| EDSK 326620 | Details | See Drawing |
| EDSK 326622 | Details | See Drawing |
| EDSK 326549 | Punching Stator | Hiperco 27 Alloy (27Co-Fe) |
| EDSK 326619 | Forging | Hiperco 27 Alloy (27Co-Fe) |
| EDSK 326793 | Forging, Cut Up | Hiperco 27 Alloy (27Co-Fe) |
| EDSK 326686 | Insulator, Tube | 99% $Al_2O_3$ |
| EDSK 326680 | Insulator, Tube | 99% $Al_2O_3$ |
| EDSK 326626 | Details, Slot | 99% $Al_2O_3$ |
| EDSK 326625 | Insulation, Liner | 99% $Al_2O_3$ |
| EDSK 326794 | Insulation, Tube | 99% $Al_2O_3$ |
| EDSK 326795 | Thermocouple | Inconel Cladding, Platinel II wire system, $Al_2O_3$ Insulation |
| EDSK 326796 | Thermocouple | (same as above) |
| EDSK 327502 | Screw | Hastelloy Alloy B |
| EDSK 326531 | Conductor | Nickel-Clad Silver (20% Clad area)[2] |
| EDSK 326532A | Conductor | Inconel 600-Clad Silver (28% Clad area)[2] |
| P15C8278-12 | Pin, Spring | CRES-AMS 5506 |

[1] - Used in a program to define conductor winding methods.

[2] - All conductors insulated with Anaconda's Anadur a refractory-oxide-filled glass insulation. "Nickel-clad silver wire is insulated with Anadur "E" glass and Inconel 600-clad silver wire is insulated with Anadur "S" glass."

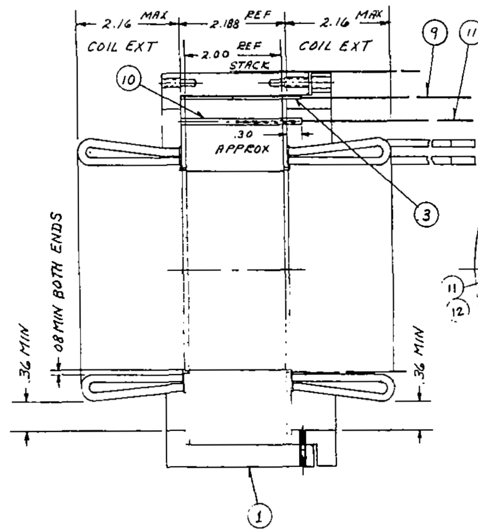


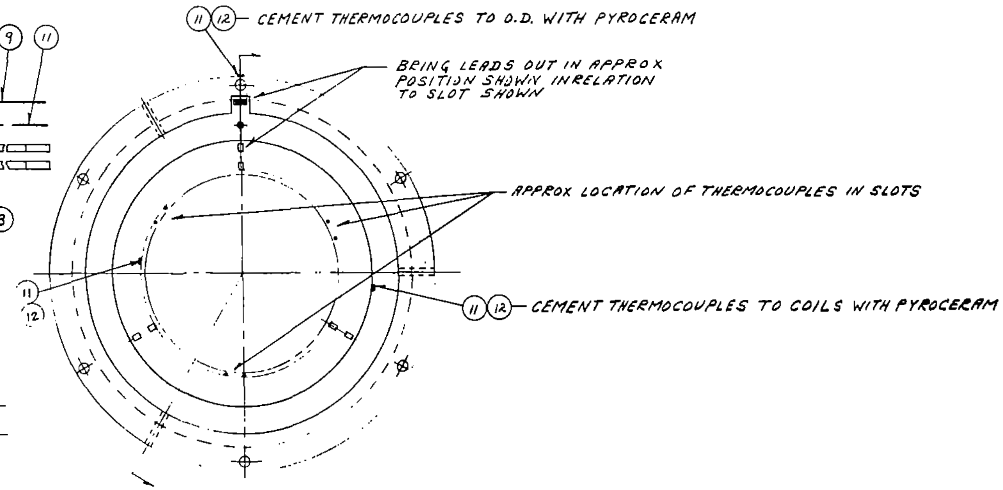

EDSK 326681

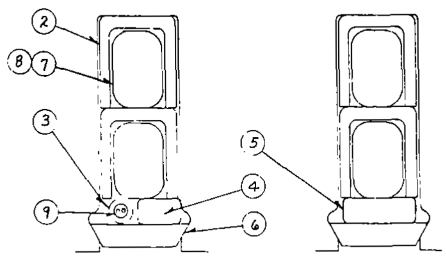
| QTY REQD PN-2 | QTY REQD PN-1 | SYM | NOMENCLATURE OR DESCRIPTION | PART NO OR IDENT NO. | SPECIFICATION | MATERIAL OR NOTE | INTERNAL INFORMATION | ITEM NO. |
|---|---|---|---|---|---|---|---|---|
| AR | AR | B | WIRE, SST | .032 DIA 7860-2 | | | | 7 |
| 6 | 6 | | SCREW | EDSK 327502-4 | | | | 6 |
| 1 | 1 | | END BELL | EDSK 326622 ASSY NO. 2 | | | | 5 |
| 6 | 6 | | SCREW | EDSK 327502-3 | | | | 4 |
| 1 | 1 | | END BELL | EDSK 326622 ASSY NO. 1 | | | | 3 |
| 1 | - | | STACK, STATOR | EDSK 326618 PN-2 | | | | 2 |
| - | 1 | | STACK, STATOR | EDSK 326618 PN-1 | | | | 1 |

LIST OF MATERIAL OR PARTS LIST

STATOR ASSEMBLY



~NOTES~

1- ALL THERMOCOUPLE TIPS TO BE ASSEMBLED APPROX IN CENTER OF STACK WHEN USED IN STACK

2- USE POTTING COMPOUND ITEM 13 AS REQUIRED TO FILL VOIDS IN SLOTS, CHANNELS AND AROUND WEDGES AND SPACERS. EXTEND POTTING OUT APPROXIMATELY HALF WAY TO THE COIL END TURNS.

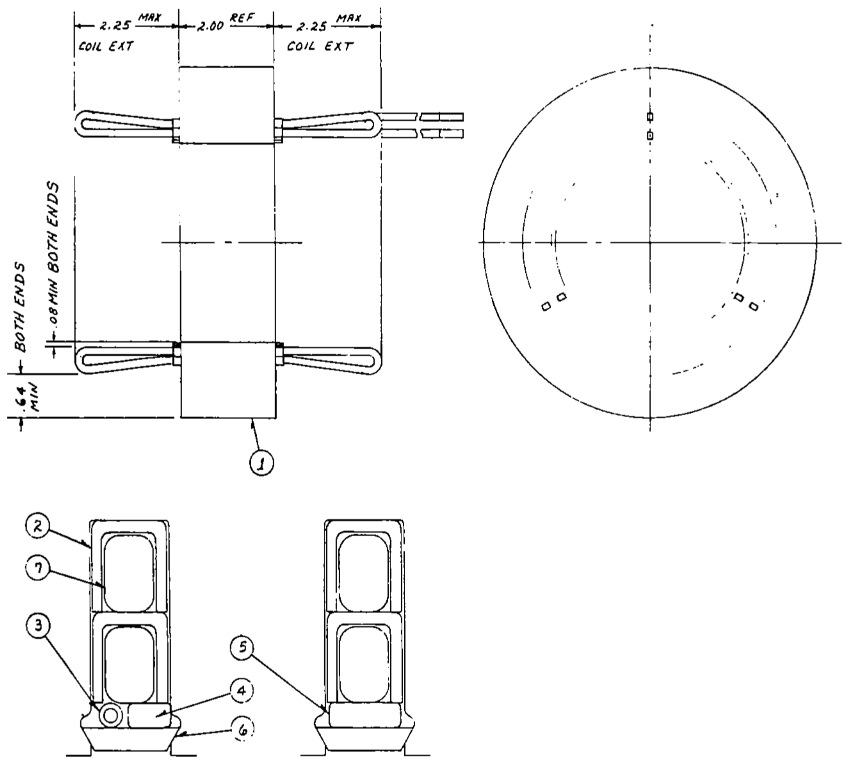
3- AFTER STATOR ASSEMBLY USE THE FOLLOWING SCHEDULE FOR POTTING COMPOUND BAKE-OUT AND SETTING OF CONDUCTOR ANADUR INSULATION: OVERNIGHT AT 125-150°F, 2 HOURS AT 450-500°F, 2 HOURS AT 800-900°F, ½ HOUR AT 1200-1250°F.

| QTY REQD PN-2 | QTY REQD PN-1 | SYM | NOMENCLATURE OR DESCRIPTION | PART NO. OR IDENT NO. | SPECIFICATION | MATERIAL OR NOTE | INTERNAL INFORMATION | ITEM NO. |
|---|---|---|---|---|---|---|---|---|
| AR | AR | B | POTTING COMPOUND | W-839 (WESTINGHOUSE) | | | | 13 |
| AR | AR | B | PYROCERAM | | | | | 12 |
| 8 | 8 | | THERMOCOUPLE | EDSK 326796 | | | | 11 |
| 1 | 1 | | INSULATOR | EDSK 326794 | | | | 10 |
| 8 | 8 | | THERMOCOUPLE | EDSK 326795 | | | | 9 |
| 3 | - | | COIL, STATOR | EDSK 326603 ITEM NO. 3 | | | | 8 |
| - | 3 | | COIL, STATOR | EDSK 326603 ITEM NO. 2 | | | | 7 |
| 36 | 36 | | WEDGE | EDSK 326626 ITEM NO. 3 | | | | 6 |
| 30 | 30 | | SPACER | EDSK 326626 ITEM NO. 2 | | | | 5 |
| 6 | 6 | | SPACER | EDSK 326626 ITEM NO. 1 | | | | 4 |
| 8 | 8 | | INSULATOR | EDSK 326680 | | | | 3 |
| 72 | 72 | | INSULATION, LINER | EDSK 326625 | | | | 2 |
| 1 | 1 | | STACK, STATOR | EDSK 326620 ASSY NO. 1 | | | | 1 |

LIST OF MATERIAL OR PARTS LIST

EDSK 326618

STACK, STATOR WOUND




NOTE 1 ~ USE POTTING COMPOUND ITEM 8 AS REQUIRED TO FILL VOIDS IN SLOTS, CHANNELS AND AROUND WEDGES AND SPACERS. EXTEND POTTING OUT APPROX. HALF WAY TO THE COIL TURNS.

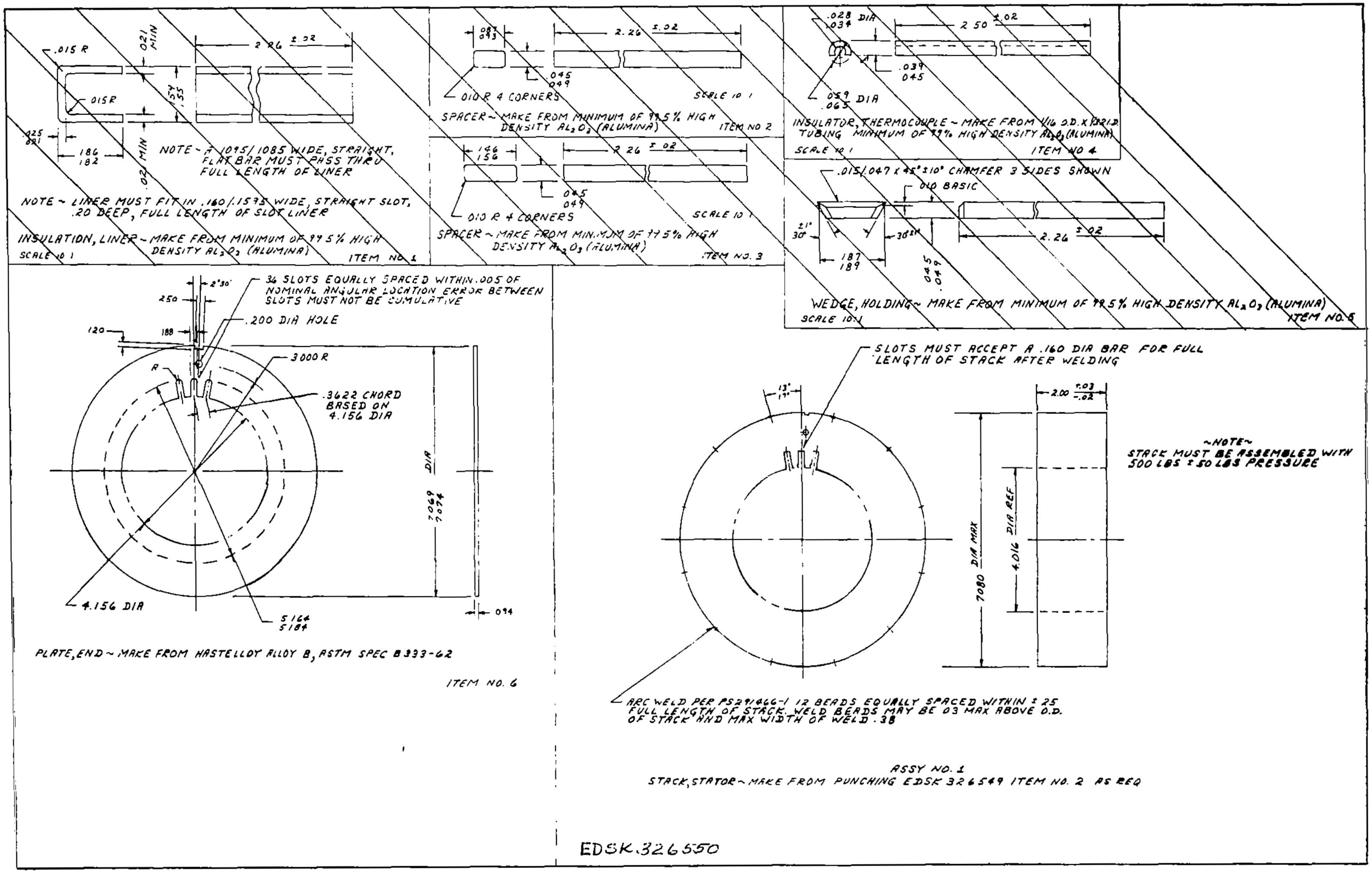
NOTE 2 ~ AFTER STATOR ASSEMBLY USE THE FOLLOWING SCHEDULE FOR POTTING COMPOUND BAKE-OUT: OVERNIGHT AT 125-150°F FOLLOWED BY 2 HOURS AT 450-500°F.

| QTY REQD | SYM | NOMENCLATURE OR DESCRIPTION | PART NO. OR IDENT NO. | SPECIFICATION | MATERIAL OR NOTE | INTERNAL INFORMATION | ITEM NO. |
|---|---|---|---|---|---|---|---|
| AR | 8 | POTTING COMPOUND | W-839 (WESTINGHOUSE) | | | | 8 |
| 3 | | COIL, STATOR | EDSK 326603 ITEM NO. 1 | | | | 7 |
| 36 | | WEDGE | EDSK 326626 ITEM NO. 3 | | | | 6 |
| 30 | | SPACER | EDSK 326626 ITEM NO. 2 | | | | 5 |
| 6 | | SPACER | EDSK 326626 ITEM NO. 1 | | | | 4 |
| 6 | | INSULATOR | EDSK 326680 | | | | 3 |
| 72 | | INSULATION, LINER | EDSK 326625 | | | | 2 |
| 1 | | STACK, STATOR | EDSK 326550 ASSY NO. 1 | | | | 1 |

LIST OF MATERIAL OR PARTS LIST

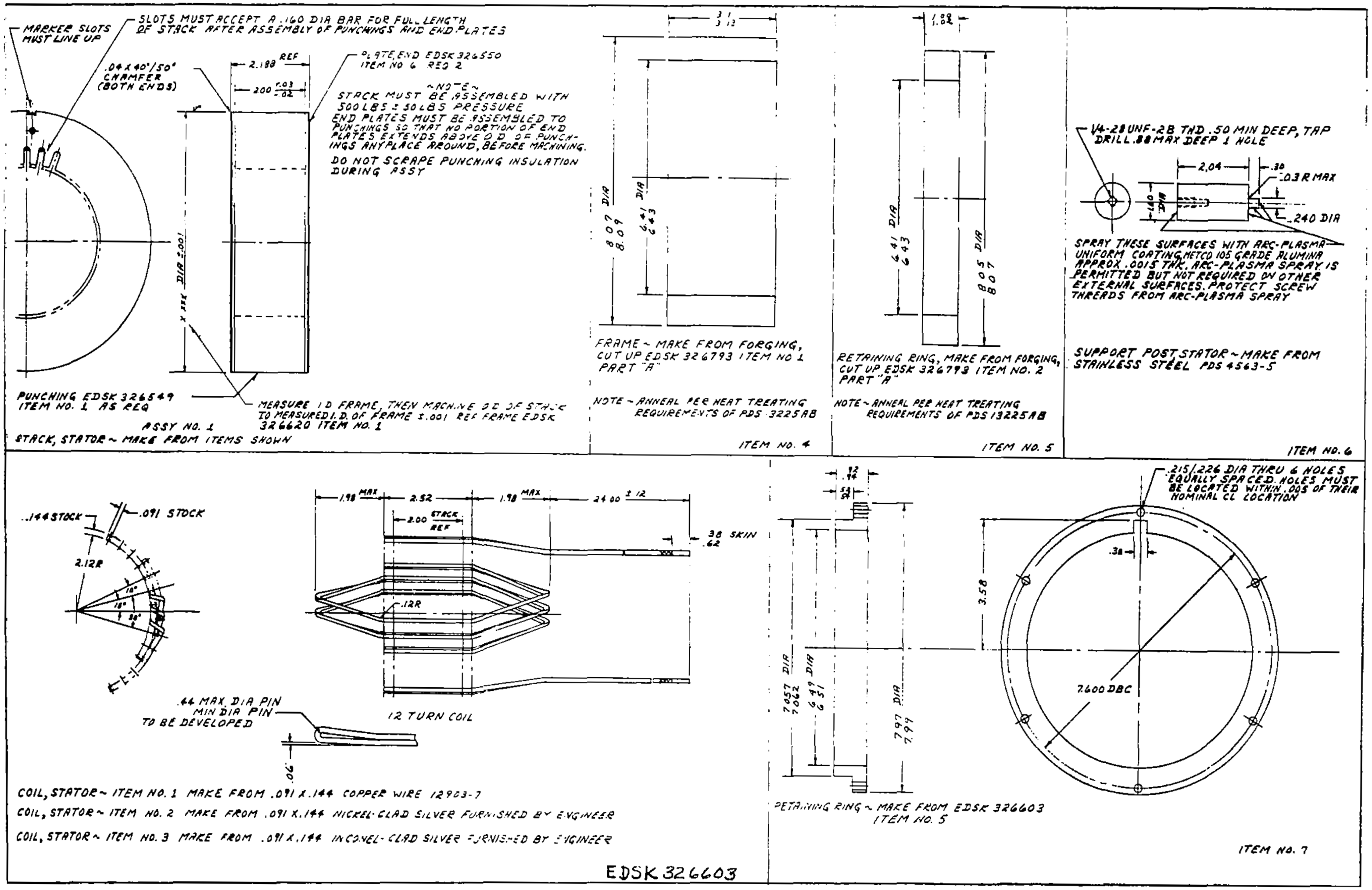
EDSK326602

STACK, STATOR WOUND

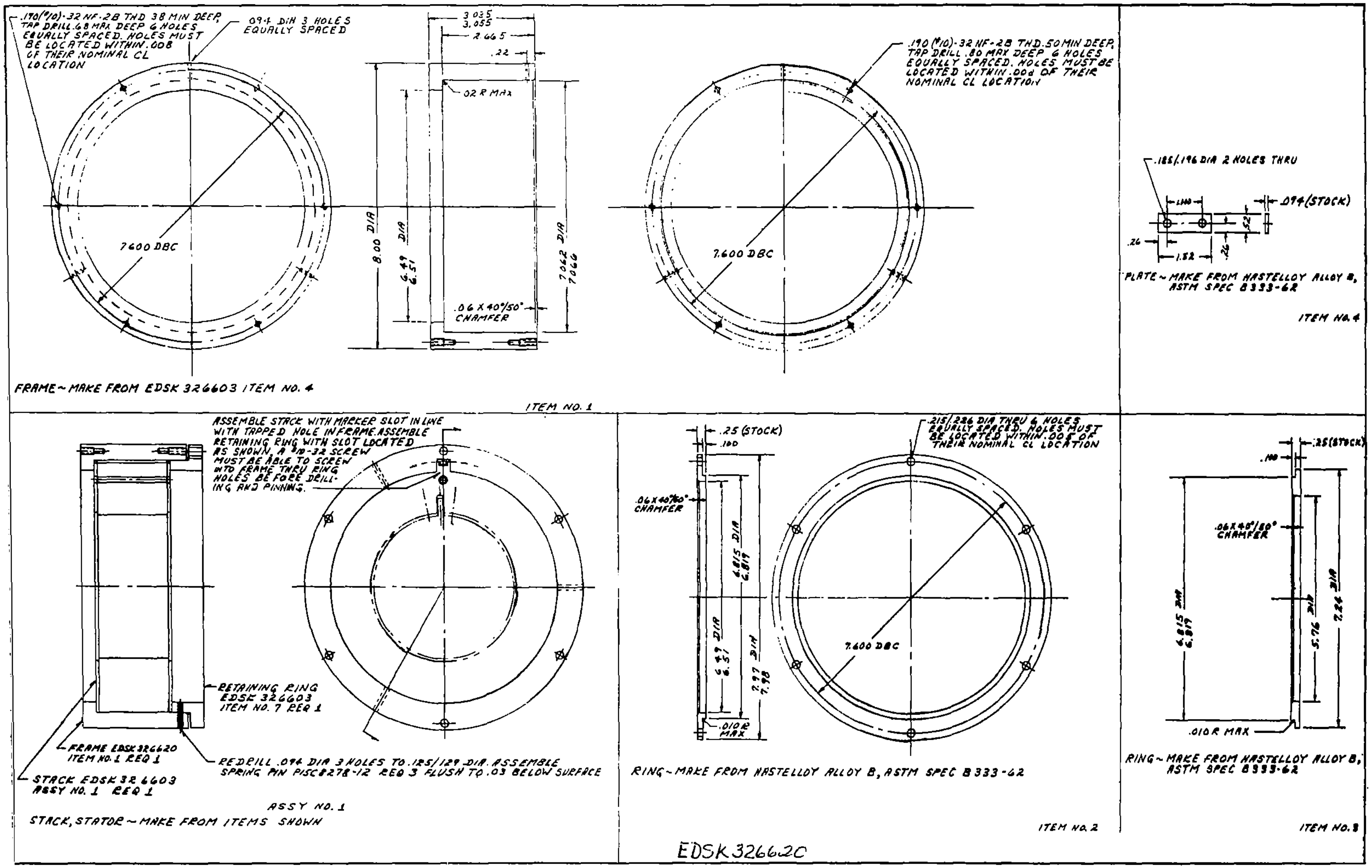


.015 R
.021 MIN
2.26 ±.02
.015 R
.54 .55
.025 .031
.186 .182
.02 MIN
NOTE ~ A .1095/.1085 WIDE, STRAIGHT, FLAT BAR MUST PASS THRU FULL LENGTH OF LINER
NOTE ~ LINER MUST FIT IN .160/.1595 WIDE, STRAIGHT SLOT, .20 DEEP, FULL LENGTH OF SLOT LINER
INSULATION, LINER ~ MAKE FROM MINIMUM OF 99.5% HIGH DENSITY $AL_2O_3$ (ALUMINA)
SCALE 10:1
ITEM NO. 1
.087 .093
2.26 ±.02
.045 .049
.010 R 4 CORNERS
SCALE 10:1
SPACER ~ MAKE FROM MINIMUM OF 99.5% HIGH DENSITY $AL_2O_3$ (ALUMINA)
ITEM NO. 2
.146 .156
2.26 ±.02
.045 .049
.010 R 4 CORNERS
SCALE 10:1
SPACER ~ MAKE FROM MINIMUM OF 99.5% HIGH DENSITY $AL_2O_3$ (ALUMINA)
ITEM NO. 3
.028 DIA .034
2.50 ±.02
.039 .045
.059 DIA .065
INSULATOR, THERMOCOUPLE ~ MAKE FROM 1/16 O.D. X 1/32 I.D. TUBING MINIMUM OF 99% HIGH DENSITY $AL_2O_3$ (ALUMINA)
SCALE 10:1
ITEM NO. 4
.015/.047 X 45° ±10° CHAMFER 3 SIDES SHOWN
.010 BASIC
30° 21'
30° 21'
.187 .189
2.26 ±.02
.045 .049
WEDGE, HOLDING ~ MAKE FROM MINIMUM OF 99.5% HIGH DENSITY $AL_2O_3$ (ALUMINA)
SCALE 10:1
ITEM NO. 5
36 SLOTS EQUALLY SPACED WITHIN .005 OF NOMINAL ANGULAR LOCATION ERROR BETWEEN SLOTS MUST NOT BE CUMULATIVE
2°30'
.250
.200 DIA HOLE
.120
.188
R
3.000 R
.3622 CHORD BASED ON 4.156 DIA
7.069 7.074 DIA
4.156 DIA
5.164 5.184
.094
PLATE, END ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO. 6
SLOTS MUST ACCEPT A .160 DIA BAR FOR FULL LENGTH OF STACK AFTER WELDING
13° 17°
2.00 +.03 -.02
~NOTE~
STACK MUST BE ASSEMBLED WITH 500 LBS ± 50 LBS PRESSURE
7.080 DIA MAX
4.016 DIA REF
ARC WELD PER PS29/466-1 12 BEADS EQUALLY SPACED WITHIN ±.25 FULL LENGTH OF STACK. WELD BEADS MAY BE .03 MAX ABOVE O.D. OF STACK AND MAX WIDTH OF WELD .38
ASSY NO. 1
STACK, STATOR ~ MAKE FROM PUNCHING EDSK 326549 ITEM NO. 2 AS REQ
EDSK 326550

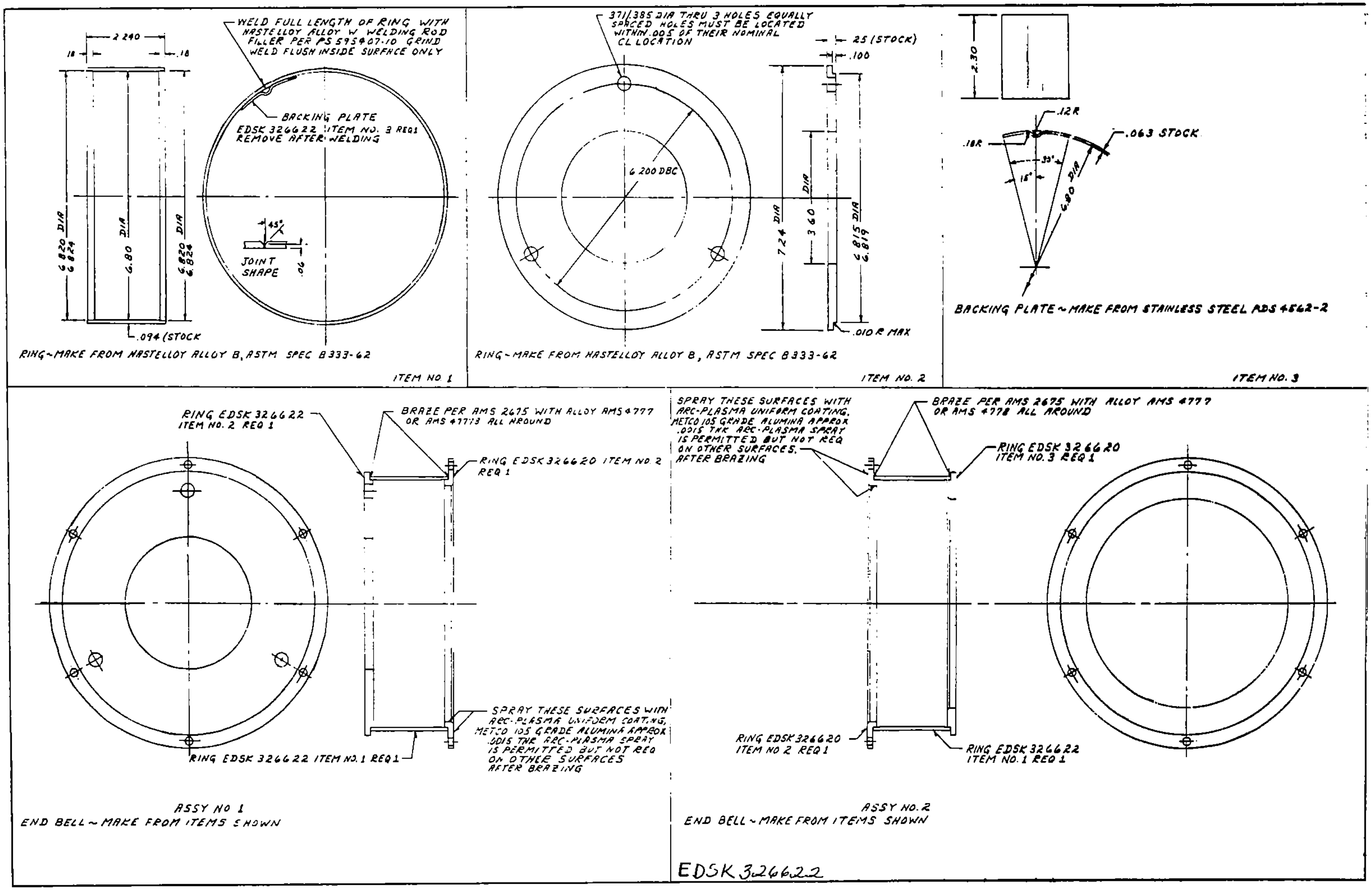

DETAILS


MARKER SLOTS MUST LINE UP
SLOTS MUST ACCEPT A .160 DIA BAR FOR FULL LENGTH OF STACK AFTER ASSEMBLY OF PUNCHINGS AND END PLATES
.04 X 40°/50° CHAMFER (BOTH ENDS)
2.188 REF
200 +.03 -.02
PLATE, END EDSK 326550 ITEM NO 6 REQ 2
~NOTE~
STACK MUST BE ASSEMBLED WITH 500 LBS ± 50 LBS PRESSURE
END PLATES MUST BE ASSEMBLED TO PUNCHINGS SO THAT NO PORTION OF END PLATES EXTENDS ABOVE O.D. OF PUNCHINGS ANYPLACE AROUND, BEFORE MACHINING.
DO NOT SCRAPE PUNCHING INSULATION DURING ASSY
X XXX DIA ±.001
PUNCHING EDSK 326549 ITEM NO. 1 AS REQ
MEASURE I.D FRAME, THEN MACHINE O.D. OF STACK TO MEASURED I.D. OF FRAME ±.001 REF FRAME EDSK 326620 ITEM NO. 1
ASSY NO. 1
STACK, STATOR ~ MAKE FROM ITEMS SHOWN
3.1 / 3.12
8.07 / 8.09 DIA
6.41 / 6.43 DIA
FRAME ~ MAKE FROM FORGING, CUT UP EDSK 326793 ITEM NO 1 PART "A"
NOTE ~ ANNEAL PER HEAT TREATING REQUIREMENTS OF PDS 3225AB
ITEM NO. 4
1.88 / 1.82
6.41 / 6.43 DIA
8.05 / 8.07 DIA
RETAINING RING, MAKE FROM FORGING, CUT UP EDSK 326793 ITEM NO. 2 PART "A"
NOTE ~ ANNEAL PER HEAT TREATING REQUIREMENTS OF PDS 13225AB
ITEM NO. 5
1/4-28 UNF-2B THD .50 MIN DEEP, TAP DRILL .88 MAX DEEP 1 HOLE
2.04
.30
.03 R MAX
.60 DIA
.240 DIA
SPRAY THESE SURFACES WITH ARC-PLASMA - UNIFORM COATING, METCO 105 GRADE ALUMINA APPROX .0015 THK. ARC-PLASMA SPRAY IS PERMITTED BUT NOT REQUIRED ON OTHER EXTERNAL SURFACES. PROTECT SCREW THREADS FROM ARC-PLASMA SPRAY
SUPPORT POST, STATOR ~ MAKE FROM STAINLESS STEEL PDS 4563-5
ITEM NO. 6
.144 STOCK
.091 STOCK
2.12R
1.98 MAX
2.52
1.98 MAX
24.00 ± 12
2.00 STACK REF
.38 SKIN
.62
.12R
.44 MAX DIA PIN
MIN DIA PIN TO BE DEVELOPED
12 TURN COIL
.06
COIL, STATOR ~ ITEM NO. 1 MAKE FROM .091 X .144 COPPER WIRE 12903-7
COIL, STATOR ~ ITEM NO. 2 MAKE FROM .091 X .144 NICKEL-CLAD SILVER FURNISHED BY ENGINEER
COIL, STATOR ~ ITEM NO. 3 MAKE FROM .091 X .144 INCONEL-CLAD SILVER FURNISHED BY ENGINEER
EDSK 326603
7.057 / 7.062 DIA
6.49 / 6.51 DIA
7.97 / 7.99 DIA
RETAINING RING ~ MAKE FROM EDSK 326603 ITEM NO. 5
.215/.226 DIA THRU 6 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .005 OF THEIR NOMINAL CL LOCATION
.38
3.58
7.600 DBC
ITEM NO. 7

DETAILS

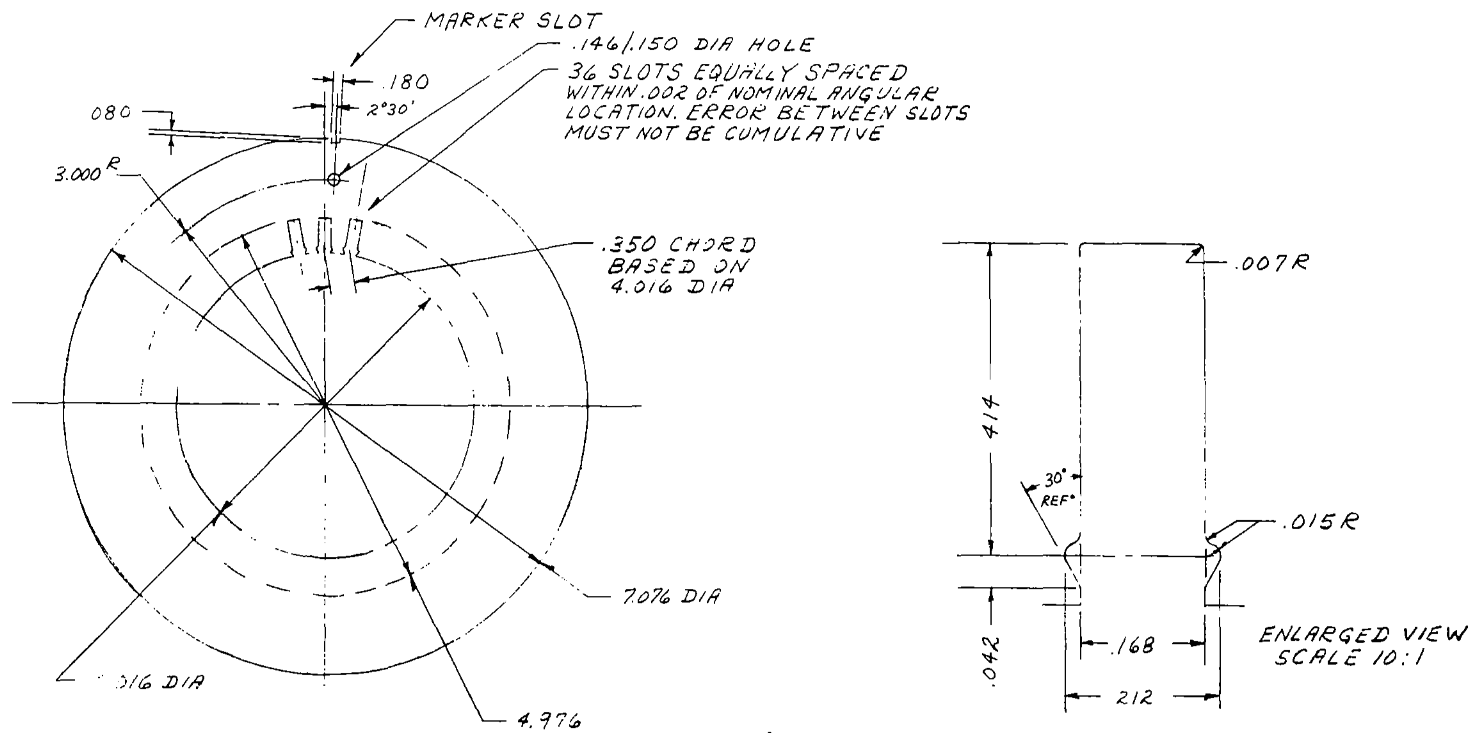

.190(#10)-32 NF-2B THD 38 MIN DEEP TAP DRILL .68 MAX DEEP 6 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .008 OF THEIR NOMINAL CL LOCATION
.094 DIA 3 HOLES EQUALLY SPACED
7.600 DBC
8.00 DIA
6.49 6.51 DIA
7.062 7.066 DIA
.02 R MAX
.06 X 40°/50° CHAMFER
.22
FRAME ~ MAKE FROM EDSK 326603 ITEM NO. 4
ITEM NO. 1
.190 (#10)-32 NF-2B THD .50 MIN DEEP, TAP DRILL .80 MAX DEEP 6 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .008 OF THEIR NOMINAL CL LOCATION
7.600 DBC
.185/.196 DIA 2 HOLES THRU
.094 (STOCK)
.26
1.52
.52
PLATE ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO. 4
ASSEMBLE STACK WITH MARKER SLOT IN LINE WITH TAPPED HOLE IN FRAME. ASSEMBLE RETAINING RING WITH SLOT LOCATED AS SHOWN. A #10-32 SCREW MUST BE ABLE TO SCREW INTO FRAME THRU RING HOLES BEFORE DRILLING AND PINNING.
RETAINING RING EDSK 326603 ITEM NO. 7 REQ 1
FRAME EDSK 326620 ITEM NO. 1 REQ 1
STACK EDSK 326603 ASSY NO. 1 REQ 1
REDRILL .094 DIA 3 HOLES TO .125/.129 DIA. ASSEMBLE SPRING PIN PISC#278-12 REQ 3 FLUSH TO .03 BELOW SURFACE
ASSY NO. 1
STACK, STATOR ~ MAKE FROM ITEMS SHOWN
.25 (STOCK)
.100
.06 X 40°/50° CHAMFER
6.815 6.819 DIA
6.49 6.51 DIA
7.97 7.98 DIA
.010 R MAX
.215/.226 DIA THRU 6 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .008 OF THEIR NOMINAL CL LOCATION
7.600 DBC
RING ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO. 2
.25 (STOCK)
.100
.06 X 40°/50° CHAMFER
6.815 6.819 DIA
5.76 DIA
7.24 DIA
.010 R MAX
RING ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO. 3
EDSK 326620

DETAILS



WELD FULL LENGTH OF RING WITH HASTELLOY ALLOY W WELDING ROD FILLER PER PS 595407-10 GRIND WELD FLUSH INSIDE SURFACE ONLY
2.240
.18
.18
BACKING PLATE
EDSK 326622 ITEM NO. 3 REQ 1 REMOVE AFTER WELDING
45°
JOINT SHAPE
.06
6.820 DIA
6.824
6.80 DIA
.094 (STOCK
RING~MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO. 1
.371/.385 DIA THRU 3 HOLES EQUALLY SPACED HOLES MUST BE LOCATED WITHIN .005 OF THEIR NOMINAL CL LOCATION
.25 (STOCK)
.100
6.200 DBC
7.24 DIA
3.60 DIA
6.815 DIA
6.819
.010 R MAX
RING~MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO. 2
2.30
.12R
.18R
.063 STOCK
33°
15°
6.80 DIA
BACKING PLATE~MAKE FROM STAINLESS STEEL AMS 4562-2
ITEM NO. 3
RING EDSK 326622 ITEM NO. 2 REQ 1
BRAZE PER AMS 2675 WITH ALLOY AMS 4777 OR AMS 4777 ALL AROUND
RING EDSK 326620 ITEM NO 2 REQ 1
SPRAY THESE SURFACES WITH ARC-PLASMA UNIFORM COATING, METCO 105 GRADE ALUMINA APPROX .0015 THK ARC-PLASMA SPRAY IS PERMITTED BUT NOT REQ ON OTHER SURFACES AFTER BRAZING
RING EDSK 326622 ITEM NO. 1 REQ 1
ASSY NO 1
END BELL~MAKE FROM ITEMS SHOWN
SPRAY THESE SURFACES WITH ARC-PLASMA UNIFORM COATING, METCO 105 GRADE ALUMINA APPROX .0015 THK ARC-PLASMA SPRAY IS PERMITTED BUT NOT REQ ON OTHER SURFACES. AFTER BRAZING
BRAZE PER AMS 2675 WITH ALLOY AMS 4777 OR AMS 4778 ALL AROUND
RING EDSK 326620 ITEM NO. 3 REQ 1
RING EDSK 326620 ITEM NO 2 REQ 1
RING EDSK 326622 ITEM NO. 1 REQ 1
ASSY NO. 2
END BELL~MAKE FROM ITEMS SHOWN
EDSK 326622


DETAILS



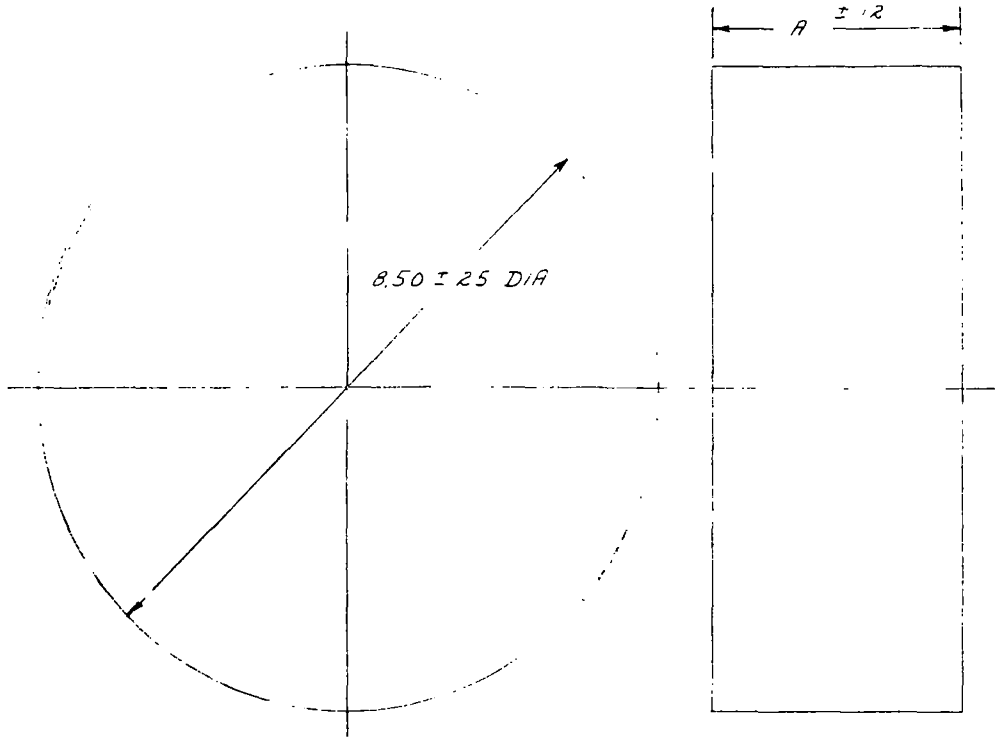

EDSK326549 ITEM 1 ONLY, ANNEAL PER PDS 80002 AK BY MAGNETICS INC, BUTLER, PA CODE 90797
AFTER ANNEHLING INSULATE PER INSTRUCTIONS OF ENGINEER

EDSK 326549

| QTY REQD | SYM | NOMENCLATURE OR DESCRIPTION | PART NO. OR IDENT NO. | SPECIFICATION | MATERIAL OR NOTE | INTERNAL INFORMATION | ITEM NO. |
|---|---|---|---|---|---|---|---|
| 1 | | PUNCHING | | | STEEL SHEET | .014 THK 10501 DC | 2 |
| 1 | | PUNCHING | HIPERCO 27 | | SHEET | .008 THK 13202 AC | 1 |

LIST OF MATERIAL OR PARTS LIST

PUNCHING, STATOR, STEEL



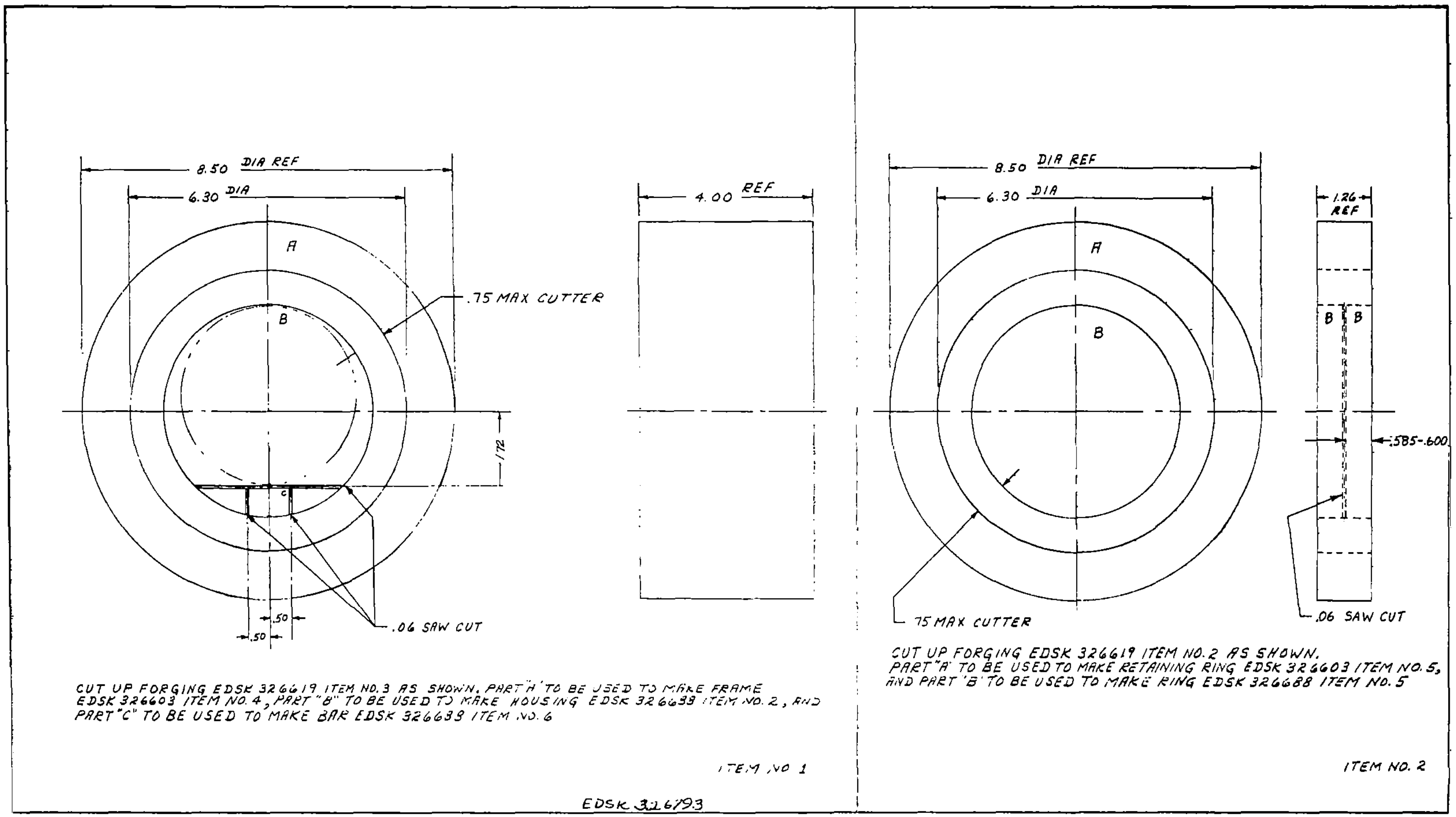

| EDSK 326619 | DIM "A" |
| --- | --- |
| ITEM NO. 1 | 3.40 |
| ITEM NO. 2 | 1.26 |
| ITEM NO. 3 | 4.00 |

~NOTE~

MATERIAL SHALL BE MADE TO MEET WESTINGHOUSE PDS 13225AB WITH THE FOLLOWING ADDITIONAL REQUIREMENTS 1: THAT CERTIFICATION OF ACCEPTABLY PASSING ULTRASONIC INSPECTION BE PROVIDED. 2: THAT THE MATERIAL BE SHIPPED WITHOUT BEING ANNEALED, HOWEVER IN THE ANNEALED CONDITION SAID FORGING SHALL BE CERTIFIED TO MEET THE MECHANICAL AND MAGNETIC PROPERTIES OF PDS 13225AB

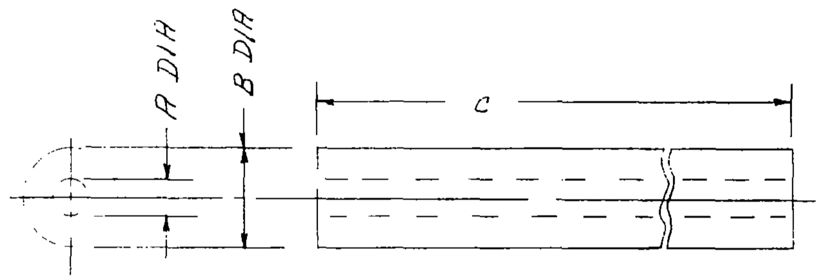
EDSK 326619

FORGING




FORGING, CUT UP

| PART NO. | DIA A | DIA B | LENGTH C |
|---|---|---|---|
| -1 | .062 | .125 | .70 |
| -2 | .062 | .188 | 2.50 |
| -3 | .044 | .094 | 2.50 |



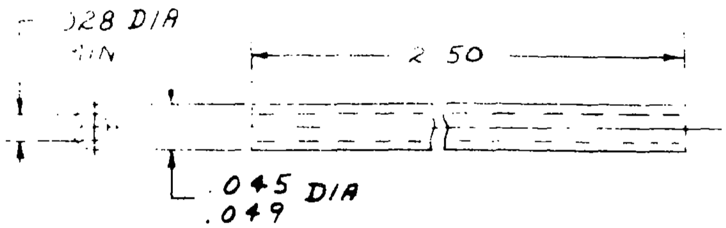

NOTE ~ STRAIGHTNESS TOLERANCE 1/16 INCH PER FOOT OF LENGTH

INSULATOR ~ MAKE FROM MINIMUM 99% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

EDSK 326686



INSULATOR, TUBE

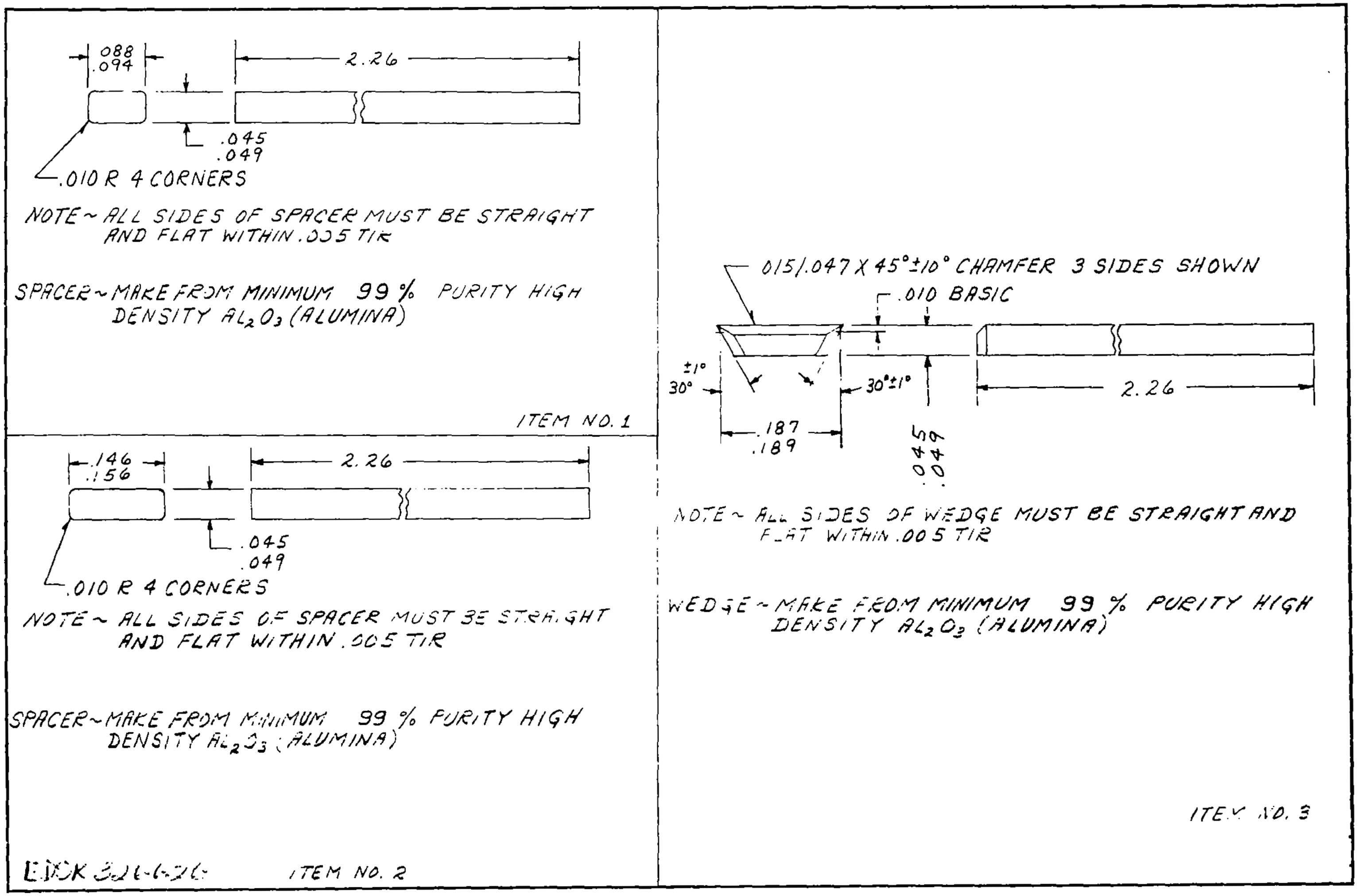



NOTE ~ STRAIGHTNESS TOLERANCE 1/16 INCH PER FOOT OF LENGTH

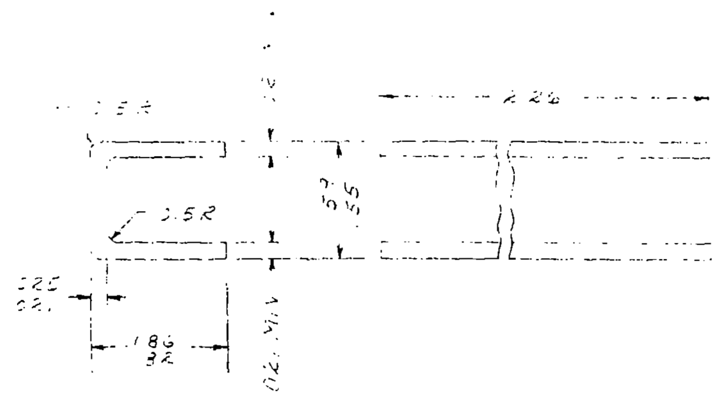
INSULATOR ~ MAKE FROM MINIMUM 99% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

EDSK 326680

INSULATOR, TUBE




DETAILS, SLCT



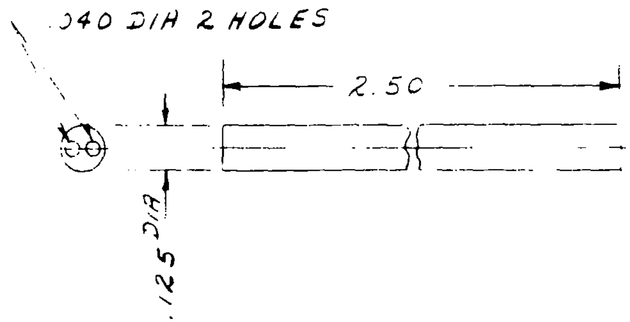

NOTE - LINER MUST FIT IN .160/.157 WIDE, STRAIGHT SLOT, .25 DEEP, FULL LENGTH OF LINER

NOTE - A .10[illegible]/.1085 WIDE, STRAIGHT FLAT BAR MUST PASS THRU FULL LENGTH OF LINER

INSULATION LINER - MAKE FROM MINIMUM 99% PURITY HIGH DENSITY $Al_2O_3$ (ALUMINA)

EDCK 3266-25

INSULATION LINER

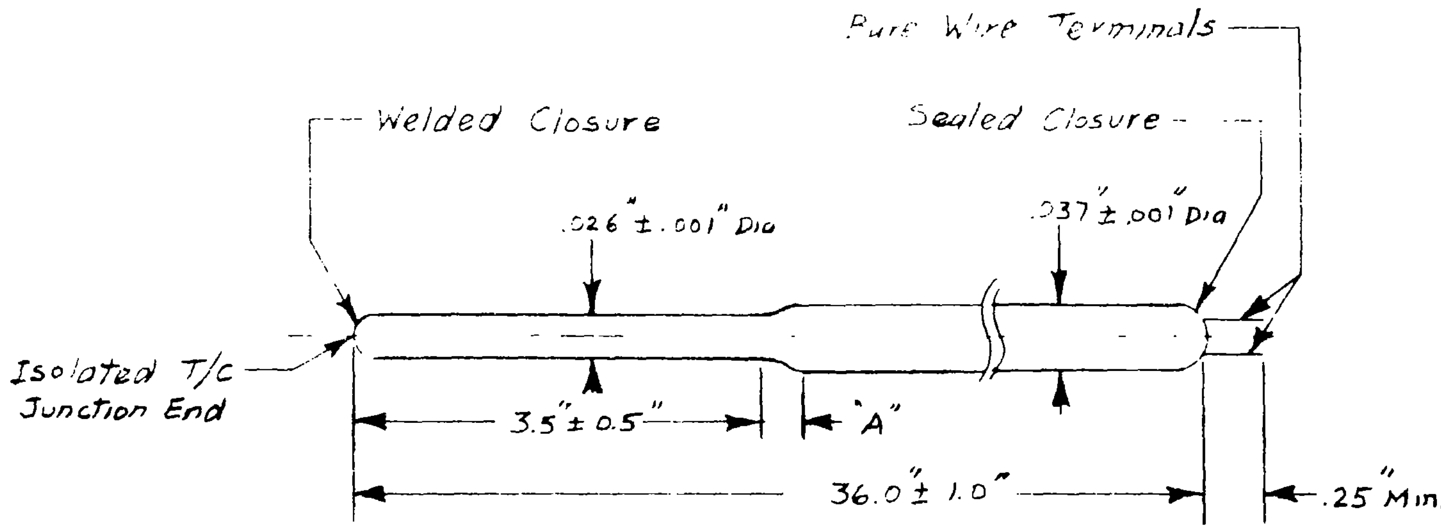



NOTE ~ STRAIGHTNESS TOLERANCE 1/16 INCH PER FOOT OF LENGTH

INSULATOR ~ MAKE FROM MINIMUM 99% PURITY HIGH DENSITY $Al_2O_3$ (ALUMINA)

EDSK 32[illegible]4

INSULATOR, TUBE



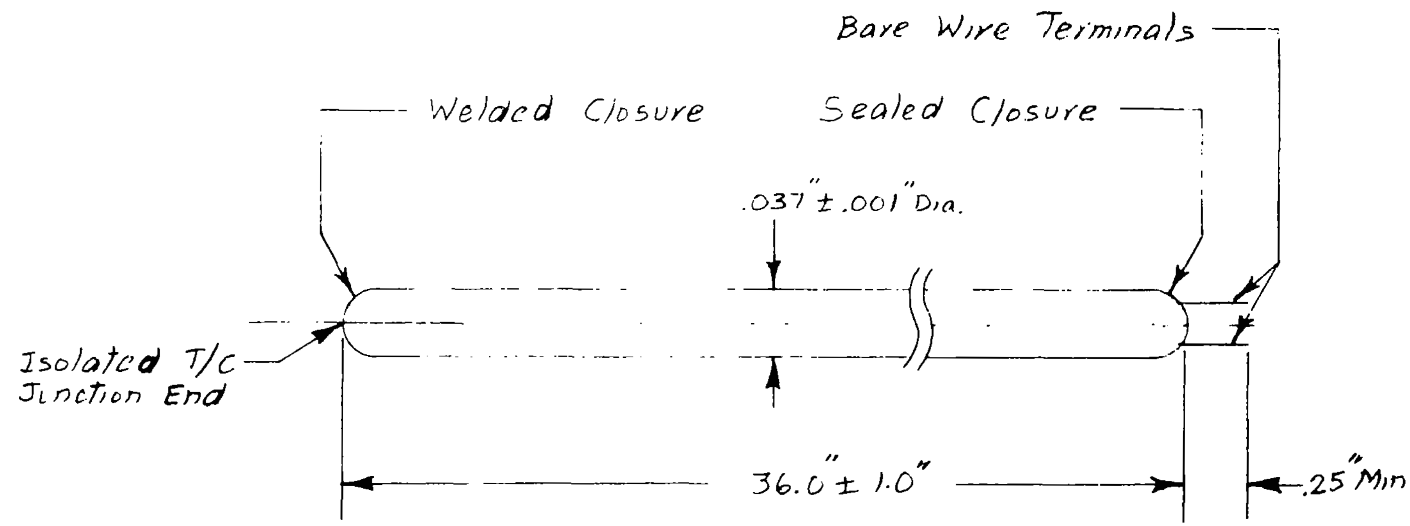

Note: Thermocouples are to be kept straight at all times.

"A" – Dimension as required for forming operation – 1.0 inch maximum. OD surface must be continuous thru transition.

DUAL DIAMETER SHEATHED THERMOCOUPLE

Reference (W) D-Spec # 709747

EDSK 326795

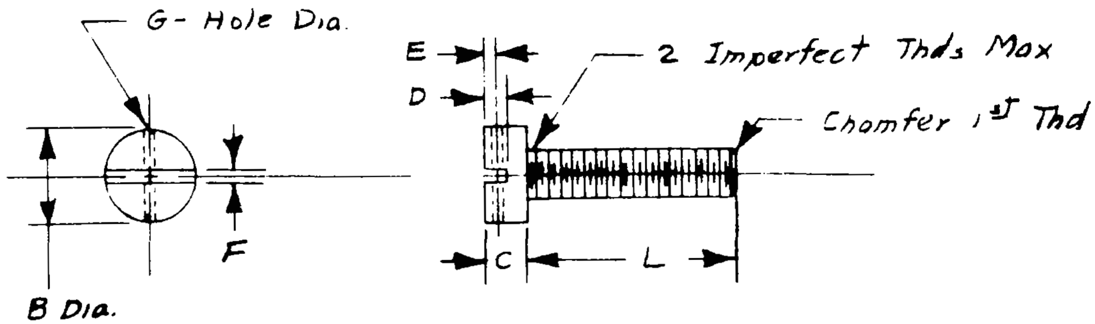



Note: Thermocouples are to be kept straight at all times.

SINGLE DIAMETEK SHEATHED THERMOCOUPLE

Reference (W) D-Spec # 709747

EDSK 326796




Material – Hastelloy Alloy B Rod

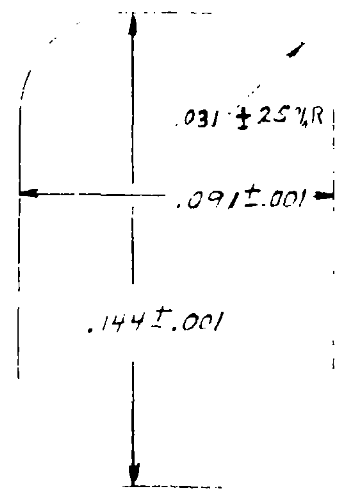
| Dash No. | Thread | B Dia ±.003 | C ±.003 | D ±.005 | E ±.005 | F ±.003 | G Dia ±.002 | L ±.005 | Stock |
|---|---|---|---|---|---|---|---|---|---|
| 1 | #8 (.164)-32 NC-2A | .270 | .156 | .078 | .050 | .062 | .040 | .500 | 3/8 Dia |
| 2 | " " " " | .270 | .156 | .078 | .050 | .062 | .040 | .750 | 3/8 Dia |
| 3 | #10 (.190)-32 NF-2A | 313 | 156 | .078 | .050 | .062 | .040 | .500 | 7/16 Dia |
| 4 | " " " " | .313 | .156 | .078 | .050 | .062 | .040 | 1.00 | 7/16 Dia |
| 5 | 1/4-28 UNF-2A | 414 | .207 | .103 | .078 | .062 | .040 | .500 | 1/2 Dia |

SCREW - FLAT FILLISTER HEAD

EDSK 327502

Conductor

20% Nickel-Clad Silver

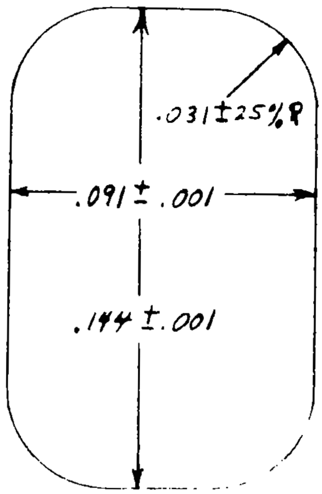



Dimensions in inches

Scale 20:1

EDSK 326531

Conductor
28 % Inconel-Clad Silver




Dimensions in inches
Scale 20:1

| REVISIONS | | | |
|---|---|---|---|
| SYM | DESCRIPTION | DATE | APPROVED |
| AB | REDRAWN. ADDED "ENGRG REF" TO GOVT PART NO. COL. REMOVED "K.T." COL AND ADDED "APPROVAL" COL. DRAWING WAS "SOURCE" CONTROL DWG. | 9/15/61 | [illegible] |
| AC | PART NUMBER -32, -60 & -23 ADDED. | [illegible] | [illegible] |
| AD | PART NO. -6 ADDED | 2-2-65 | C TILLER |
| AE | PART NO -24 ADDED. | 2-26-65 | C TILLER |

| .250 DIA | | | | |
|---|---|---|---|---|
| PART NO. | A | CATALOG NO. | GOVT PART NO. ENGRG REF | APPVL |
| P15C8278-1 | 7/8 | 79-048-250-0875 | MS171652 | Q |
| -2 | 3/4 | 79-048-250-075 | MS171650 | Q |
| -3 | 2 | 79-048-250-2000 | MS171662 | Q |
| -4 | 3 1/4 | 79-048-250-3250 | MS171667 | Q |
| -5 | 1 3/8 | 79-048-250-1375 | MS171657 | Q |
| -6 | 1 1/2 | 79-048-250-1500 | MS171658 | Q |

| .062 DIA | | | | |
|---|---|---|---|---|
| PART NO | A | CATALOG NO. | GOVT PART NO. ENGRG REF | APPVL |
| P15C8278-18 | 3/8 | 79-012-062-0375 | MS171434 | Q |
| -19 | 5/16 | 79-012-062-0312 | MS 171433 | Q |
| -20 | 1/4 | 79-012-062-0250 | MS171432 | Q |
| -21 | 3/16 | 79-012-062-0188 | MS171431 | Q |
| -22 | 7/16 | 52-012-062-0437 | | A |
| -23 | 1/2 | 79-012-062-0500 | MS171436 | Q |
| -24 | 1/8 | 52-012-062-0125 | | A |

| .125 DIA | | | | |
|---|---|---|---|---|
| PART NO. | A | CATALOG NO. | GOVT PART NO. ENGRG REF | APPVL |
| P15C8278-9 | 3/8 | 79-028-125-0375 | MS171524 | Q |
| -10 | 7/16 | 52-028-125-0437 | | A |
| -11 | 7/16 | 79-028-125-0437 | MS171525 | Q |
| -12 | 3/4 | 79-028-125-0750 | MS171530 | Q |
| -13 | 1 | 79-028-125-1000 | MS171534 | Q |
| -14 | 1 3/8 | 79-028-125-1375 | MS171537 | Q |
| -15 | 1/4 | 79-028-125-0250 | MS171522 | Q |
| -16 | 1 3/4 | 79-028-125-1750 | MS171540 | Q |
| -17 | 5/8 | 52-028-125-0625 | | A |
| -60 | 9/16 | 79-028-125-0562 | MS171527 | Q |

| .188 DIA | | | | |
|---|---|---|---|---|
| PART NO | A | CATALOG NO | GOVT PART NO ENGRG REF | APPVL |
| P15C8278-26 | 11/16 | 79-040-187-0687 | MS 171589 | Q |
| -27 | 13/16 | 79-040-187-0813 | MS171591 | Q |
| -28 | 3/8 | 79-040-187-0375 | MS171584 | Q |
| -29 | 1 1/8 | 79-040-187-1125 | MS171595 | Q |
| -30 | 1 | 79-040-187-1000 | MS171594 | Q |
| -31 | 1 3/8 | 79-040-187-1375 | MS171597 | Q |
| -32 | 7/16 | 79-040-187-0438 | MS171585 | |

| .156 DIA | | | | |
|---|---|---|---|---|
| PART NO. | A | CATALOG NO. | GOVT PART NO. ENGRG REF | APPVL |
| P15C8278-35 | 1/2 | 79-032-156-0500 | MS171556 | Q |
| -36 | 7/16 | 52-032-156-0437 | | A |
| -37 | 1 1/2 | 79-032-156-1500 | MS171568 | Q |

| .312 DIA | | | | |
|---|---|---|---|---|
| PART NO. | A | CATALOG NO. | GOVT PART NO. ENGRG REF | APPVL |
| P15C8278-40 | 1 | 52-062-312-1000 | | A |

| .094 DIA | | | | |
|---|---|---|---|---|
| PART NO. | A | CATALOG NO. | GOVT PART NO. ENGRG REF | APPVL |
| P15C8278-45 | 1/2 | 79-022-094-0500 | MS171496 | Q |
| -46 | 3/8 | 79-022-094-0375 | MS171494 | Q |
| -47 | 5/16 | 79-022-094-03125 | MS171495 | Q |
| -48 | 1/4 | 79-022-094-0250 | MS171492 | Q |

| .219 DIA | | | | |
|---|---|---|---|---|
| PART NO. | A | CATALOG NO. | GOVT PART NO. ENGRG REF | APPVL |
| P15C8278-51 | 1/2 | 79-048-219-0500 | MS171616 | Q |

## REQUIREMENTS

1. PIN, SPRING
2. DIMENSIONS - NOMINAL DIA AND LENGTH PER TABLE.
3. MATERIAL - FOR MS NUMBERS - CRES, AMS 5506 OR AISI 420.
   - FOR NON-"MS" NO. - HIGH CARBON STEEL, AMS 5120 OR AMS 5121.
4. FINISH - FOR CRES, PASSIVATE
   FOR HIGH CARBON STEEL, CAD. PLATE PER QQ-P-416, TYPE I, CLASS 3.
5. PARTS MUST BE IDENTIFIED WITH MFR'S PART NO. PER MIL-STD-130.

## QUALIFICATION TESTS

NOT APPLICABLE

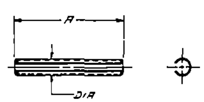
## LIMA ROUTINE ACCEPTANCE GUIDE

1. DIMENSIONS PER REQUIREMENT NO. 2.
2. PART IDENTIFICATION.

209

-NOTE-

ORDERING INFORMATION FOR Ⓦ INTERNAL COLUMN ORDER Ⓦ PART NO.
FOR GOVT COLUMN ORDER GOVT PART NO. IF AVAILABLE OTHERWISE SPECIFY Ⓦ PART NO. AND NOTE "VENDOR ITEM. SEE SPECIFICATION CONTROL DRAWING."



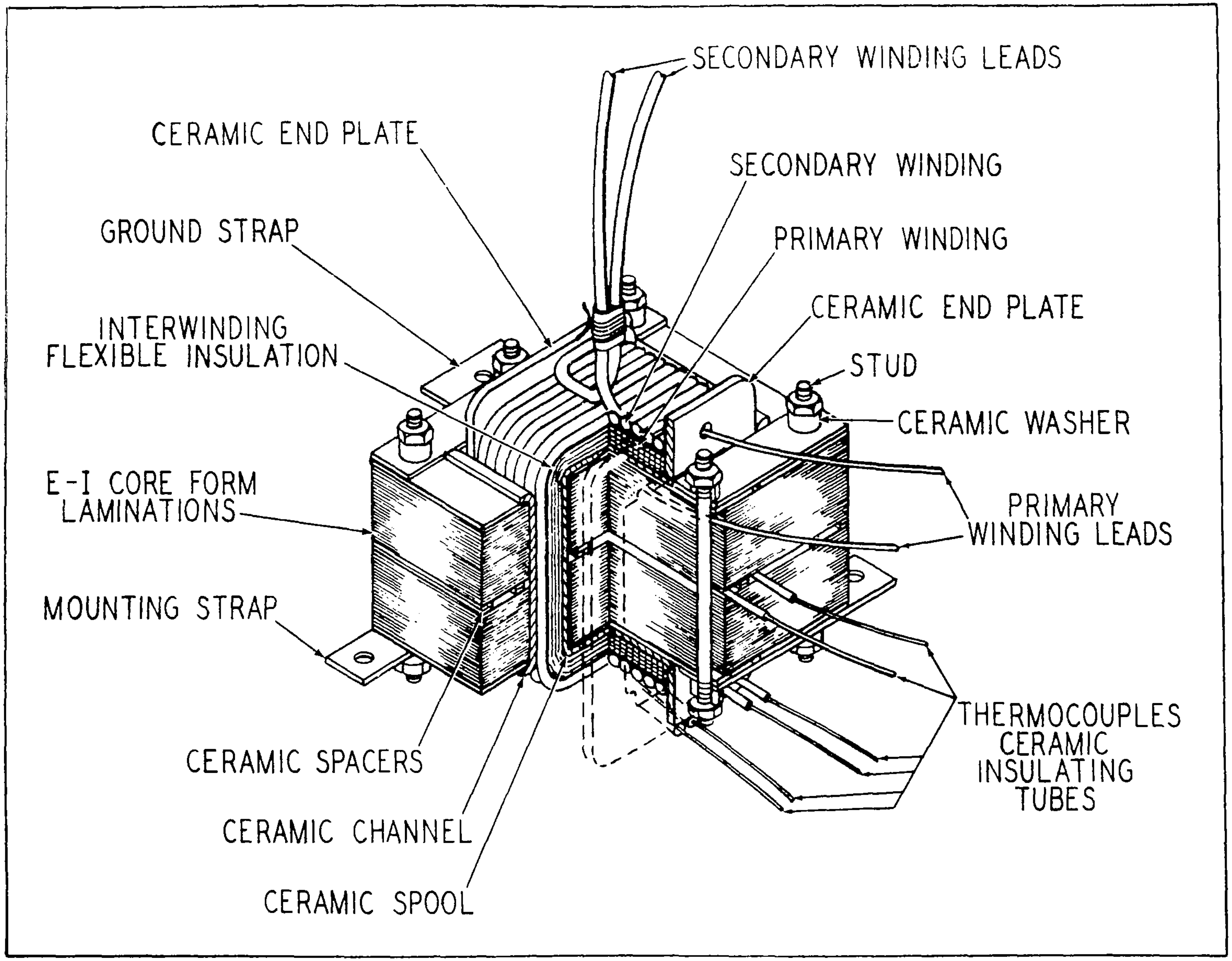

EXPLANATION OF APPROVAL LETTERS
E = EXPERIMENTAL-NOT AN APPROVED SOURCE TO BE USED FOR SPEC'D SAMPLES ONLY. CERTIFICATION NOT REQUIRED
A = INTERIM APPROVAL-QUALIFICATION INCOMPLETE-APPROVED SOURCE
Q = QUALIFICATION APPROVAL-APPROVED SOURCE.

SPECIFICATION CONTROL DRAWING FOR ITEMS WITH ONLY CATALOG NUMBERS.

P15C8278

PIN, SPRING (STANDARD APPARATUS)

# II. TRANSFORMER




Cutaway View of Transformer

## Transformer - Magnetic, Insulation and Conductor Materials Summary - 1100°F Hot-Spot Model

| Part | Material | Source-NAS3-4162 |
|---|---|---|
| Laminations | Fe-27Co 0.008-mil thick (Hiperco 27) | NASA-CR-5401 p. 59, 323 |
| Interlaminar Insulation | Plasma-arc sprayed $Al_2O_3$ (Linde A) | NASA-CR-54092 p. 98, 593 |
| Coil Spool | $Al_2O_3$ - 99.5% | NASA-CR-54092 p. 92, 453 |
| Coil End Plates | $Al_2O_3$ - 99.5% | |
| Coil Channels | $Al_2O_3$ - 99.5% | |
| Thermocouple Insulators | $Al_2O_3$ - 99% | NASA-CR-54092 p. 92, 462 |
| Stud Spacer | $Al_2O_3$ - 99% | |
| Lamination Spacer | $Al_2O_3$ - 99% | |
| Flexible Insulation | Burnil CM-2 (Li $Mg_2$ Li $So_4$ $O_{10}$ $F_2$ and Alum. Silicate) | NASA-CR-54092 p. 89, 346 |
| Conductor Insulation | Same as Stator - 1100°F (Anadur E Glass) | NASA-CR-54092 p. 86, 287 |
| Potting Compound | Zircon Type (Aluminum Orthophosphate-Zirconium Silicate) (W-839) | NASA-CR-54092 p. 97, 579 |
| Conductors-Sizes #20 and #7 AWG | Nickel-clad silver - 1100°F | NASA-CR-54092 p. 81, 249 |
| Lamination Support Plates | Hastelloy Alloy B | |
| Hardware | Hastelloy Alloy B | |
| Thermocouples | Inconel 600 Sheath - Platinel II Wire System | |

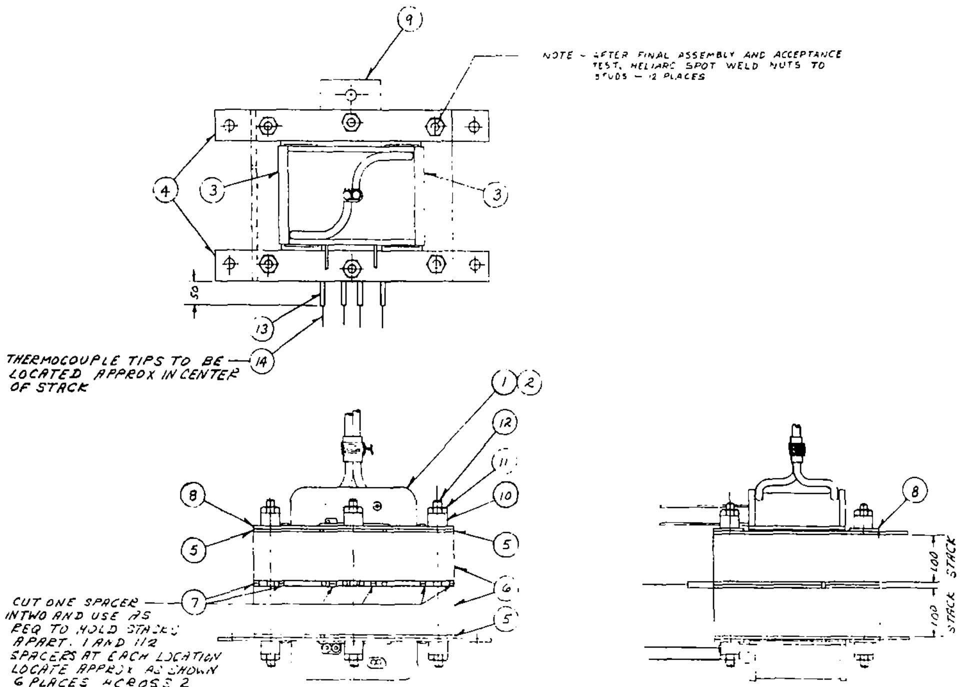
## Transformer - Magnetic, Insulation and Conductor Materials Summary - 1300°F Hot-Spot Model

| Part | Material | Source-NAS3-4162 |
|---|---|---|
| Laminations | Fe-27Co 0.008-mil-thick (Hiperco 27) | NASA-CR-54091 p. 59, 323 |
| Interlaminar Insulation | Plasma-arc sprayed $Al_2O_3$ (Linde A) | NASA-CR-54092 p. 98, 593 |
| Coil Spool | $Al_2O_3$ - 99.5% | NASA-CR-54092 p. 92, 453 |
| Coil End Plates | $Al_2O_3$ - 99.5% | |
| Coil Channels | $Al_2O_3$ - 99.5% | |
| Thermocouple Insulators | $Al_2O_3$ - 99% | NASA-CR-54092 p. 92, 462 |
| Stud Spacer | $Al_2O_3$ - 99% | |
| Lamination Spacer | $Al_2O_3$ - 99% | |
| Flexible Insulation | BN Fiber Mat | |
| Conductor Insulation | Same as Stator - 1300°F (Anadur S Glass) | NASA-CR-54092 p. 86, 287 |
| Potting Compound | BN Fiber Cement | |
| Conductors - Sizes #20 and #7 AWG | Inconel 600-clad silver - 1300°F | NASA-CR-54092 p. 81, 249 |
| Lamination Support Plates | Hastelloy Alloy B | |
| Hardware | Hastelloy Alloy B | |
| Thermocouples | Inconel 600 Sheath - Platinel II Wire System | |

## APPENDIX B - SECTION II, TRANSFORMER LIST AND DRAWINGS

| Drawing No. | Title | Material |
|---|---|---|
| EDSK 326761 | Transformer Assembly | - |
| EDSK 326760 | Winding, Transformer | - |
| EDSK 326762 | Details | See Drawing |
| EDSK 326756 | Punching, Transformer | Hiperco 27 Alloy (27Co-Fe) |
| EDSK 326626 | Details, Slot | 99% $Al_2O_3$ |
| EDSK 326686 | Insulation, Tube | 99% $Al_2O_3$ |
| EDSK 326757 | Channel | 99.5% $Al_2O_3$ |
| EDSK 326758 | Spool | 99.5% $Al_2O_3$ |
| EDSK 326759 | End Plates | 99.5% $Al_2O_3$ |
| EDSK 326786 | Spacer | 99% $Al_2O_3$ |
| EDSK 326796 | Thermocouple | Inconel Cladding, Platinel II wire system, $Al_2O_3$ Insulation |
| EDSK 327503 | Nut | Hastelloy Alloy B |
| EDSK 326533 | Conductor | Nickel-Clad Silver (20% Clad area)[1] |
| EDSK 326534A | Conductor | Inconel 600-Clad Silver (28% Clad area)[1] |
| EDSK 326535 | Conductor | Nickel-Clad Silver (20% Clad area)[1] |
| EDSK 326536A | Conductor | Inconel 600-Clad Silver (28% Clad area)[1] |

1 - All conductors insulated with Anaconda's Anadur a refractory-oxide-filled glass insulation. "Nickel-clad silver wire is coated with Anadur "E" glass and Inconel 600-Clad silver wire is insulated with Anadur "S" glass".




NOTE - USE DUCO CEMENT TO HOLD SPACERS (ITEM NO 7 AND INSULATORS ITEM NO 13) IN PLACE AT CENTER OF STACK DURING ASSY. AFTER CEMENT SETS, POT AS REQ BETWEEN SPACERS AND INSULATORS

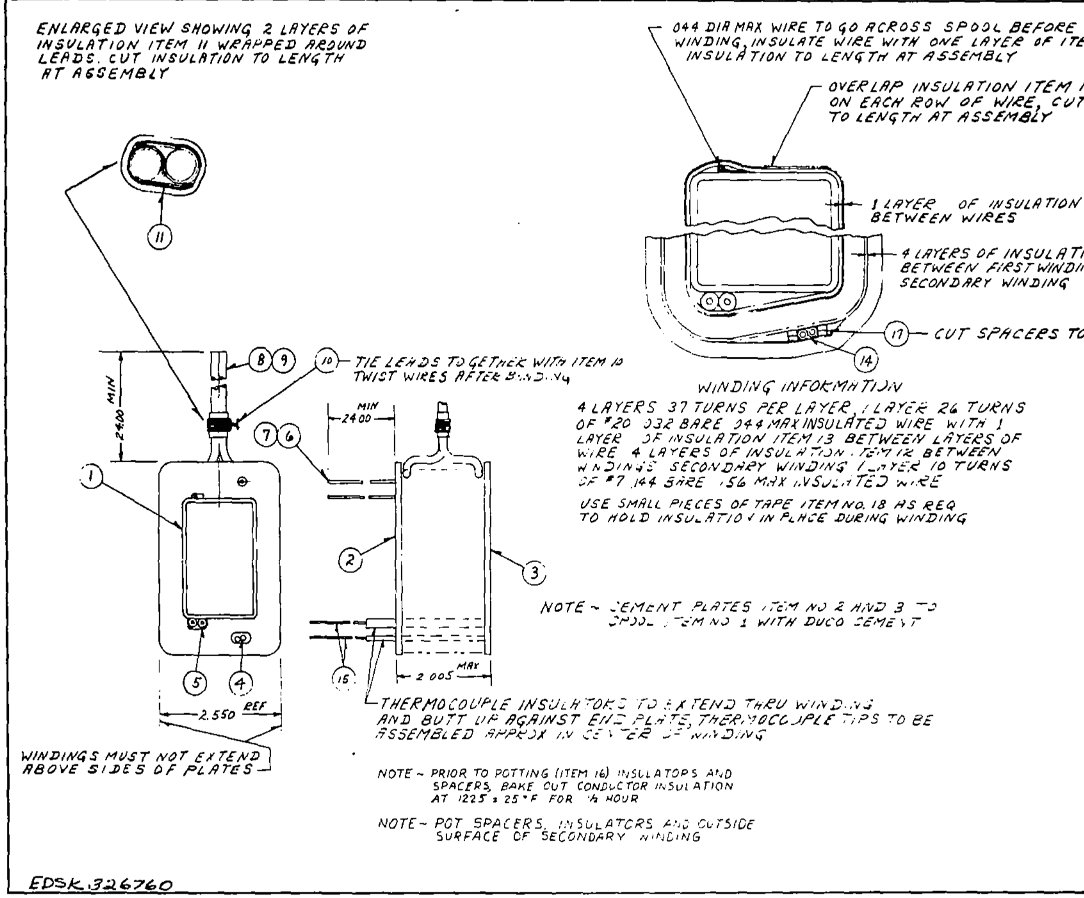
NOTE - DO NOT SCRAPE PUNCHING INSULATION DURING ASSY

| QTY REQD PN-2 | QTY REQD PN 1 | SYM | NOMENCLATURE OR DESCRIPTION | PART NO OR IDENT NO | SPECIFICATION | MATERIAL OR NOTE | INTERNAL INFORMATION | ITEM NO. |
|---|---|---|---|---|---|---|---|---|
| AR | AR | B | POTTING COMPOUND WESTINGHOUSE W-839 | | | | | 15 |
| 4 | 4 | | THERMOCOUPLE | EDSK 326796 | | | | 14 |
| 4 | 4 | | INSULATOR | EDSK 326686-3 | | | | 13 |
| 6 | 6 | | STUD | EDSK 326762 ITEM NO. 7 | | | | 12 |
| 12 | 12 | | NUT | EDSK 327503-1 | | | | 11 |
| 12 | 12 | | SPACER | EDSK 326786 | | | | 10 |
| 2 | 2 | | STRAP, GROUND | EDSK 326762 ITEM NO. 4 | | | | 9 |
| 2 | 2 | | PLATE | EDSK 326762 ITEM NO. 2 | | | | 8 |
| 18 | 18 | | SPACER | EDSK 326626 ITEM NO. 1 | | | | 7 |
| AR | AR | | PUNCHING | EDSK 326756 | | | | 6 |
| 4 | 4 | | PLATE, SUPPORT | EDSK 326762 ITEM NO 3 | | | | 5 |
| 2 | 2 | | PLATE, MOUNTING | EDSK 326762 ITEM NO. 1 | | | | 4 |
| 2 | 2 | | CHANNEL | EDSK 326757 | | | | 3 |
| 1 | - | | WINDING | EDSK 326760 PN-2 | | | | 2 |
| - | 1 | | WINDING | EDSK 326760 PN-1 | | | | 1 |

LIST OF MATERIAL OR PARTS LIST

EDSK 326761

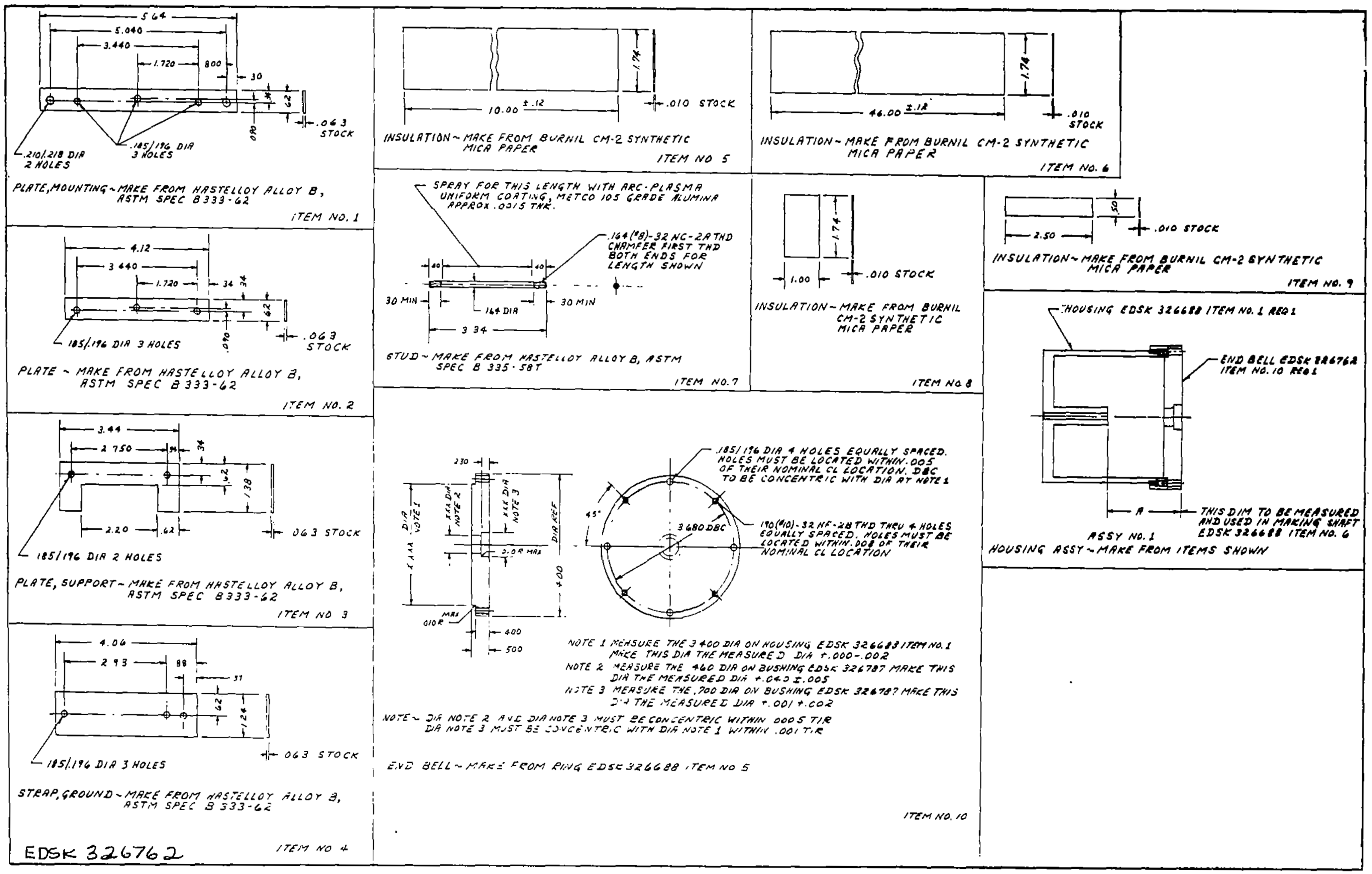
TRANSFORMER



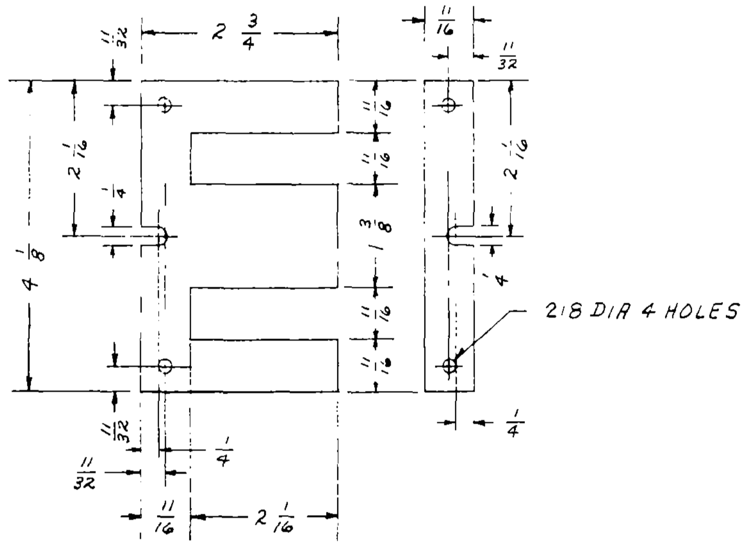

| QTY REQD PN-2 | QTY REQD PN-1 | STM | NOMENCLATURE OR DESCRIPTION | PART NO. OR IDENT NO. | SPECIFICATION | MATERIAL OR NOTE | INTERNAL INFORMATION | ITEM NO. |
|---|---|---|---|---|---|---|---|---|
| AR | AR | B | TAPE, ADHESIVE | .0025 X .500 9948-3 | | | | 18 |
| 4 | 4 | | SPACER | EDSK 326626 ITEM NO. 1 | | | | 17 |
| AR | AR | | POTTING COMPOUND WESTINGHOUSE H839 | | | | | 16 |
| 4 | 4 | | THERMOCOUPLE | EDSK 326796 | | | | 15 |
| 2 | 2 | | INSULATION | EDSK 326762 ITEM NO. 8 | | | | 14 |
| 4 | 4 | | INSULATION | EDSK 326762 ITEM NO. 5 | | | | 13 |
| 1 | 1 | | INSULATION | EDSK 326762 ITEM NO. 6 | | | | 12 |
| 1 | 1 | | INSULATION | EDSK 326762 ITEM NO. 9 | | | | 11 |
| AR | AR | B | WIRE, SST | .032 DIA 7860-2 | | | | 10 |
| AR | - | B | WIRE #7 (.144 DIA) INCONEL-CLAD SILVER FURNISHED BY ENGINEER | | | | | 9 |
| - | AR | B | WIRE #7 (.144 DIA) NICKEL-CLAD SILVER FURNISHED BY ENGINEER | | | | | 8 |
| AR | - | B | WIRE #20 (.032 DIA) INCONEL-CLAD SILVER FURNISHED BY ENGINEER | | | | | 7 |
| - | AR | B | WIRE #20 (.032 DIA) NICKEL-CLAD SILVER FURNISHED BY ENGINEER | | | | | 6 |
| 2 | 2 | | INSULATOR | EDSK 326686 PN-2 | | | | 5 |
| 2 | 2 | | INSULATOR | EDSK 326686 PN-3 | | | | 4 |
| 1 | 1 | | END PLATE | EDSK 326759 ITEM NO. 1 | | | | 3 |
| 1 | 1 | | END PLATE | EDSK 326759 ITEM NO. 2 | | | | 2 |
| 1 | 1 | | SPOOL | EDSK 326758 | | | | 1 |

LIST OF MATERIAL OR PARTS LIST

WINDING, TRANSFORMER


PLATE, MOUNTING ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO. 1
.210/.218 DIA 2 HOLES
.185/.196 DIA 3 HOLES
.063 STOCK
PLATE ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO. 2
185/.196 DIA 3 HOLES
PLATE, SUPPORT ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO 3
185/196 DIA 2 HOLES
STRAP, GROUND ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO 4
185/.196 DIA 3 HOLES
EDSK 326762
INSULATION ~ MAKE FROM BURNIL CM-2 SYNTHETIC MICA PAPER
ITEM NO 5
.010 STOCK
INSULATION ~ MAKE FROM BURNIL CM-2 SYNTHETIC MICA PAPER
ITEM NO. 6
SPRAY FOR THIS LENGTH WITH ARC-PLASMA UNIFORM COATING, METCO 105 GRADE ALUMINA APPROX .0015 THK.
.164(#8)-32 NC-2A THD CHAMFER FIRST THD BOTH ENDS FOR LENGTH SHOWN
30 MIN
.164 DIA
STUD ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B 335-58T
ITEM NO. 7
INSULATION ~ MAKE FROM BURNIL CM-2 SYNTHETIC MICA PAPER
ITEM NO. 8
INSULATION ~ MAKE FROM BURNIL CM-2 SYNTHETIC MICA PAPER
ITEM NO. 9
HOUSING EDSK 326688 ITEM NO. 1 REQ 1
END BELL EDSK 326762 ITEM NO. 10 REQ 1
THIS DIM TO BE MEASURED AND USED IN MAKING SHAFT EDSK 326688 ITEM NO. 6
ASSY NO. 1
HOUSING ASSY ~ MAKE FROM ITEMS SHOWN
.185/.196 DIA 4 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .005 OF THEIR NOMINAL CL LOCATION. DBC TO BE CONCENTRIC WITH DIA AT NOTE 1
.190(#10)-32 NF-2B THD THRU 4 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .008 OF THEIR NOMINAL CL LOCATION
3.680 DBC
NOTE 1 MEASURE THE 3.400 DIA ON HOUSING EDSK 326688 ITEM NO. 1 MAKE THIS DIA THE MEASURED DIA +.000-.002
NOTE 2 MEASURE THE .460 DIA ON BUSHING EDSK 326787 MAKE THIS DIA THE MEASURED DIA +.040 ±.005
NOTE 3 MEASURE THE .700 DIA ON BUSHING EDSK 326787 MAKE THIS DIA THE MEASURED DIA +.001 +.002
NOTE ~ DIA NOTE 2 AND DIA NOTE 3 MUST BE CONCENTRIC WITHIN .0005 TIR
DIA NOTE 3 MUST BE CONCENTRIC WITH DIA NOTE 1 WITHIN .001 TIR
END BELL ~ MAKE FROM RING EDSK 326688 ITEM NO 5
ITEM NO. 10

DETAILS

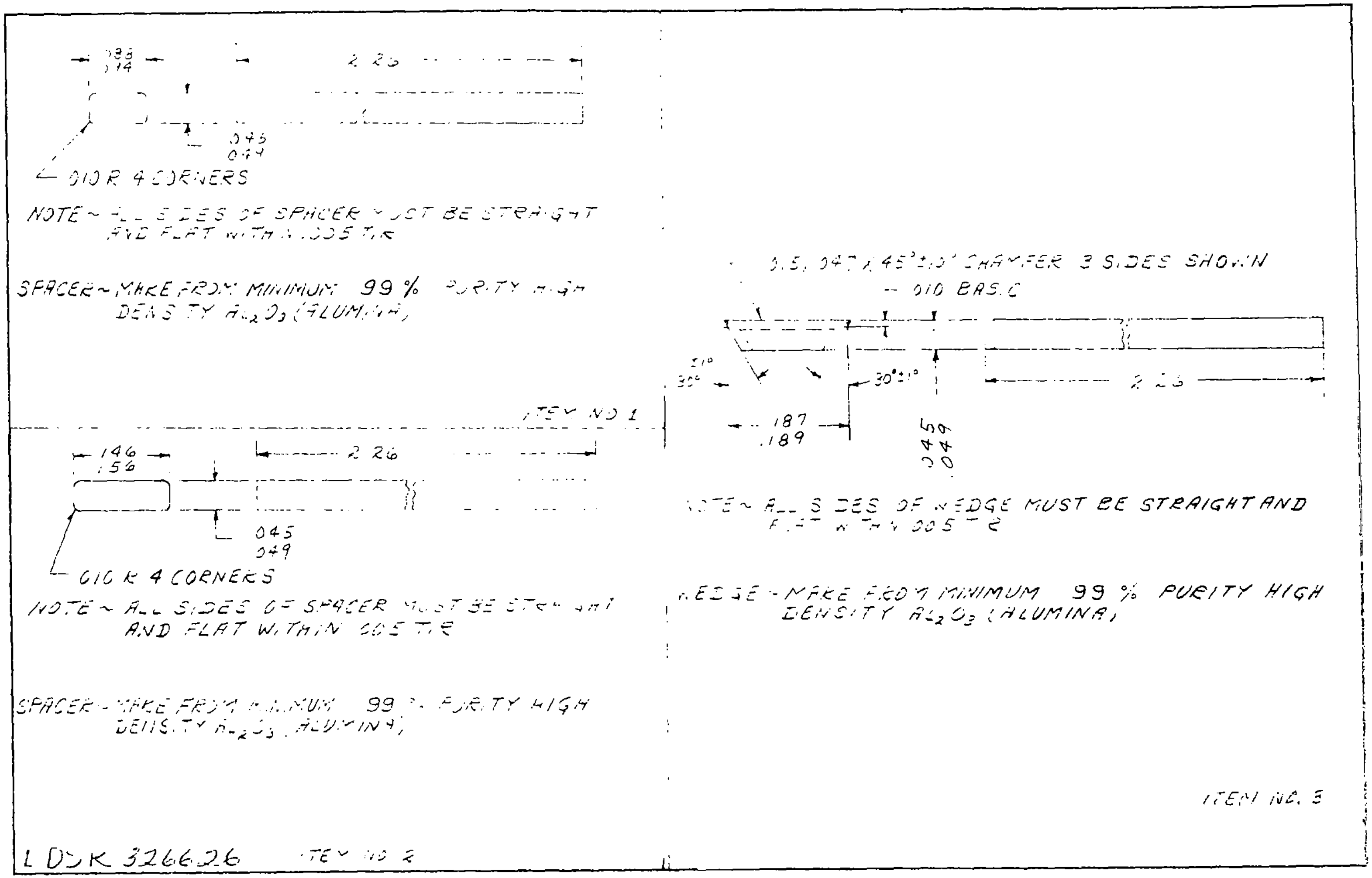



ANNEAL PER PDS 80002AK BY MAGNETICS INC, BUTLER, PA CODE 90797
AFTER ANNEALING INSULATE PER INSTRUCTIONS OF ENGINEER

PUNCHING ~ MAKE FROM HIPERCO 27 .008 THK 13202AC
DIMENSIONS PER LAMINATION TYPE 138-EI

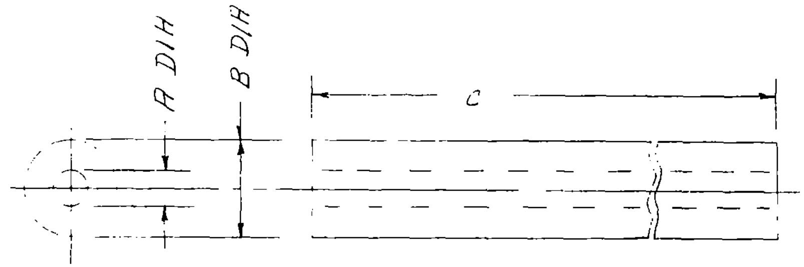
EDSK326756

PUNCHING, TRANSFORMER




DETAILS, SLOT

| PART NO. | DIA A | DIA B | LENGTH C |
|---|---|---|---|
| -1 | .062 | .125 | .70 |
| -2 | .062 | .188 | 2.50 |
| -3 | .044 | .094 | 2.50 |

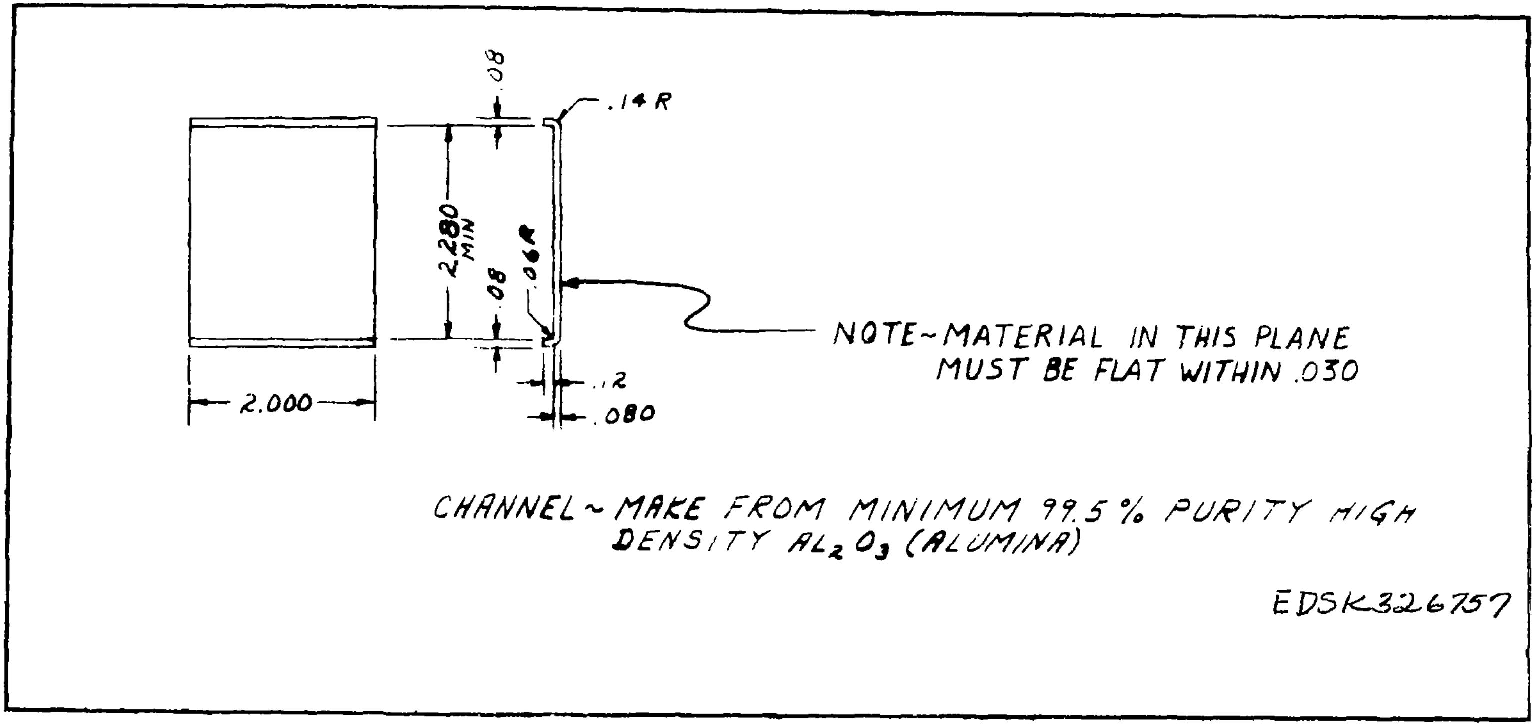



NOTE ~ STRAIGHTNESS TOLERANCE 1/16 INCH PER FOOT OF LENGTH

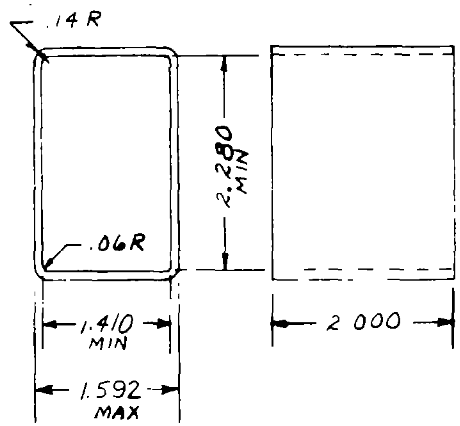
INSULATOR ~ MADE FROM MINIMUM 99% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

EDSK 326686

INSULATOR, TUBE


.08
.14 R
2.280 MIN
.08
.06 R
NOTE~MATERIAL IN THIS PLANE MUST BE FLAT WITHIN .030
.12
.080
2.000
CHANNEL~MAKE FROM MINIMUM 99.5 % PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)
EDSK326757

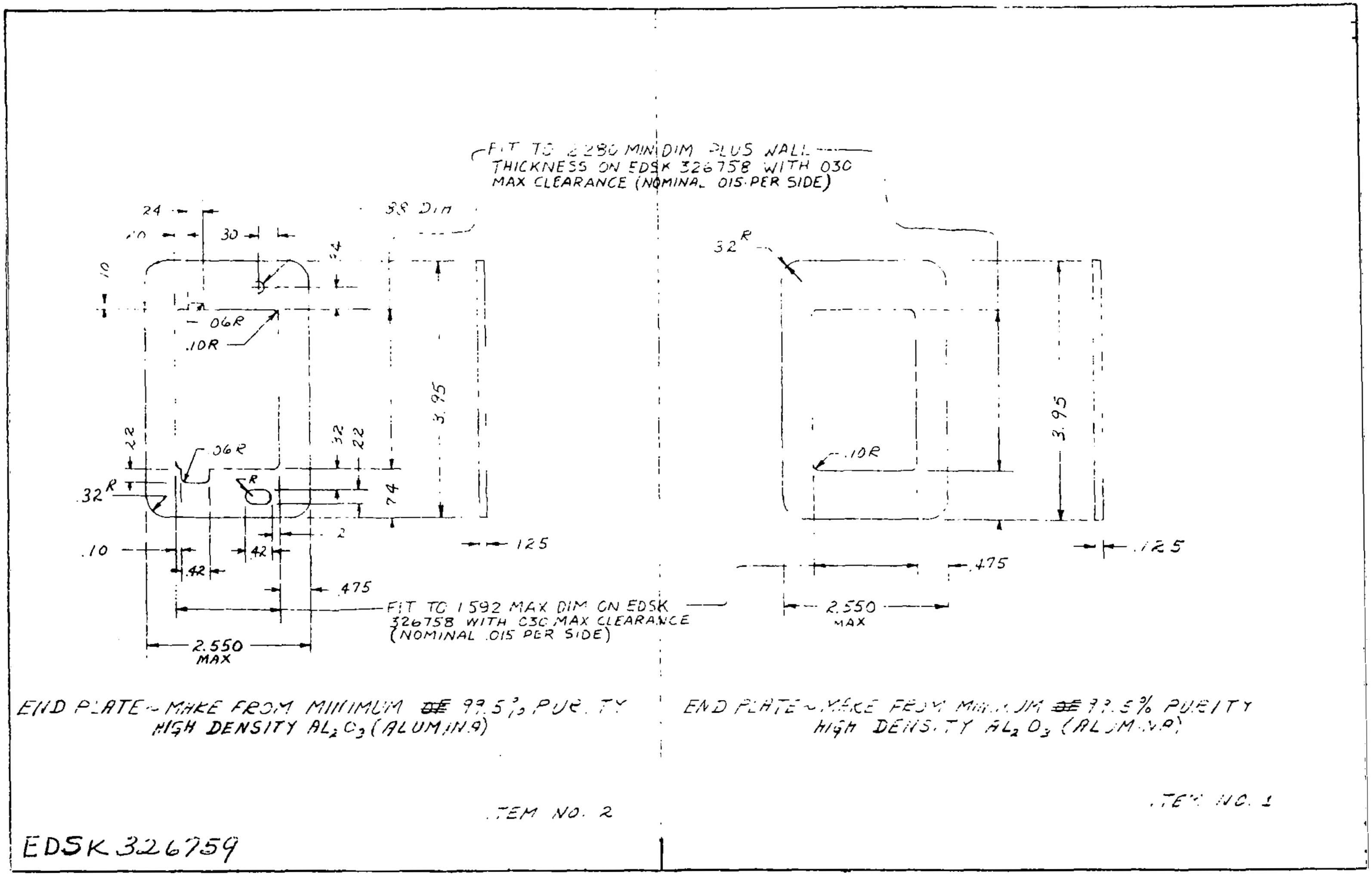
CHANNEL



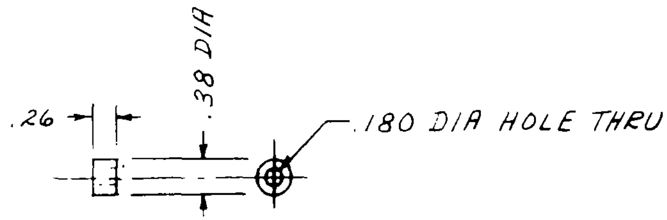

SPOOL ~ MAKE FROM MINIMUM 99.5% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

EDSK 326758

SPOOL


FIT TO 2.280 MIN DIM PLUS WALL THICKNESS ON EDSK 326758 WITH .030 MAX CLEARANCE (NOMINAL .015 PER SIDE)
.38 DIA
.24
.30
.14
.10
.06R
.10R
3.95
.22
.32
.74
.32R
.125
.10
.42
.2
.475
FIT TO 1.592 MAX DIM ON EDSK 326758 WITH .030 MAX CLEARANCE (NOMINAL .015 PER SIDE)
2.550 MAX
END PLATE ~ MAKE FROM MINIMUM 99.5% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)
ITEM NO. 2
ITEM NO. 1
EDSK 326759

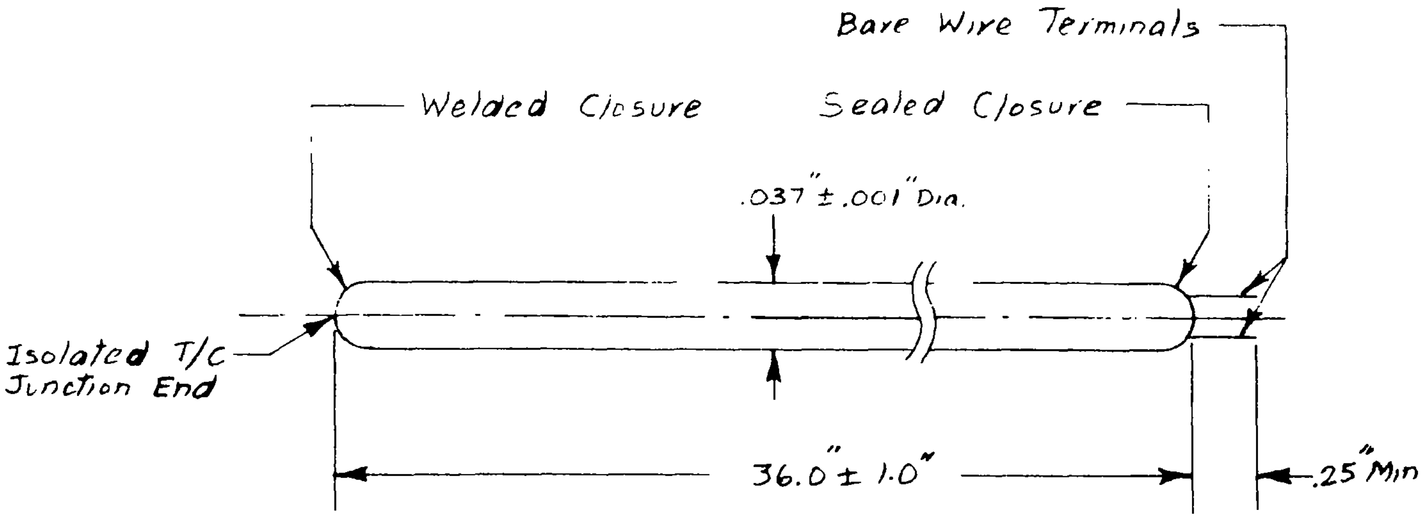
END PLATES




SPACER ~ MAKE FROM MINIMUM 99% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

EDSK326786

SPACER

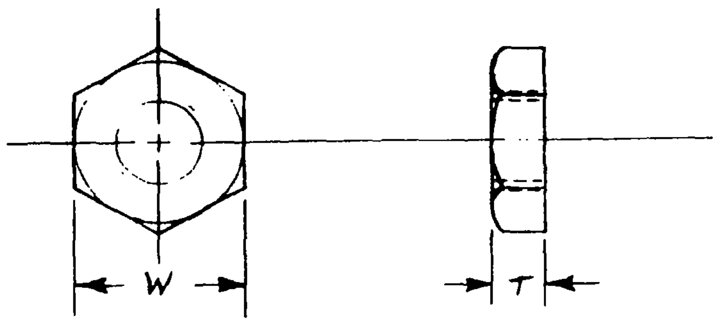



Note: Thermocouples are to be kept straight at all times.

SINGLE DIAMETER SHEATHED THERMOCOUPLE

Reference (W) D-Spec # 709747

EDSK 326796

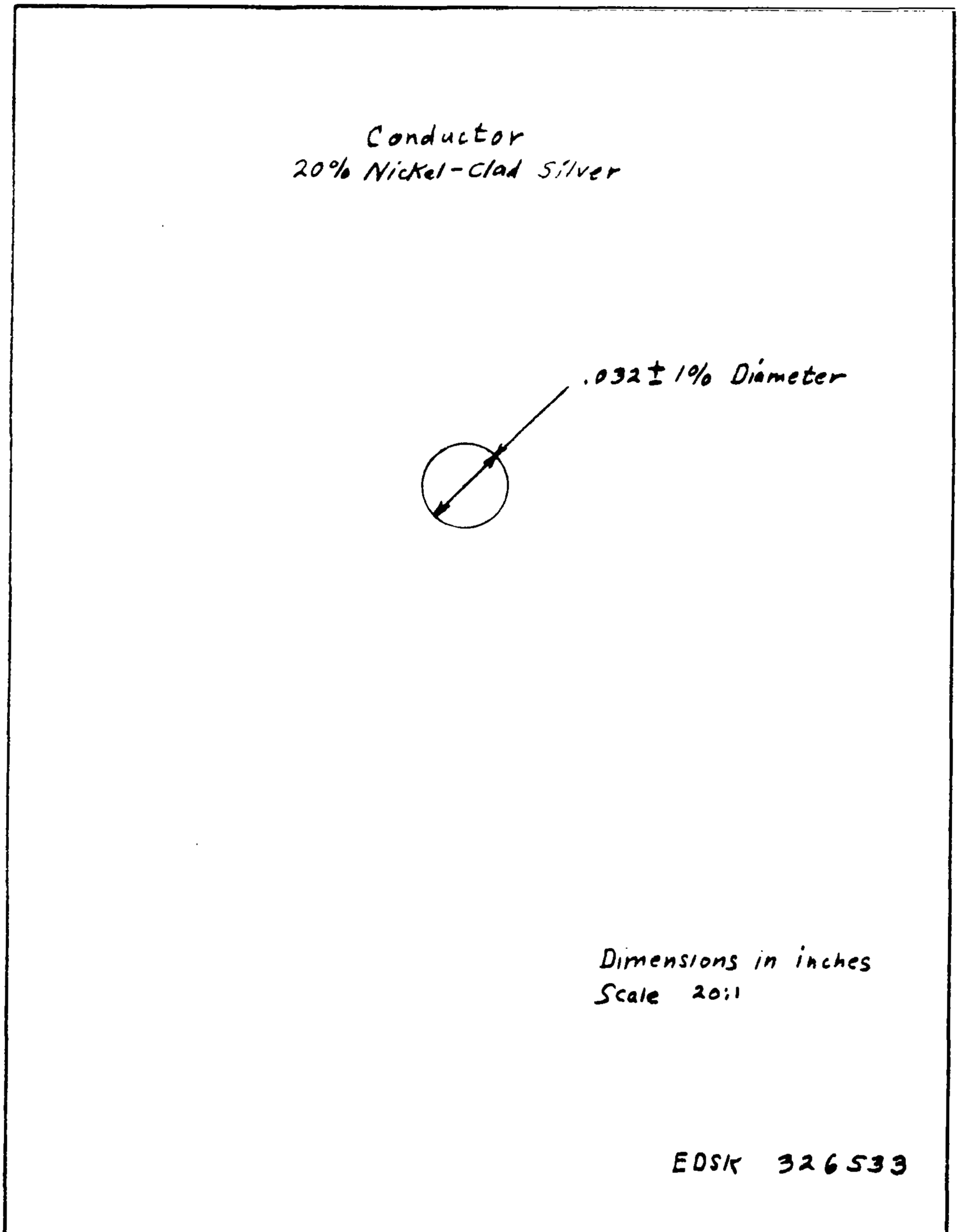



Material - Hastelloy Alloy B Rod

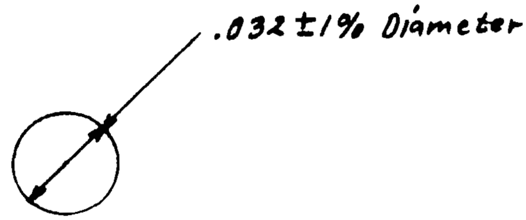
| Dash No. | Thread | W ±.005 | T ±.008 | Stock |
|---|---|---|---|---|
| 1 | #8 (.164)-32 NC-2B | .338 | .187 | 1/2 Dia |
| 2 | 1/4-28 UNF-2B | .428 | .219 | 5/8 Dia |

NUT - HEXAGONAL

EDSK 327503

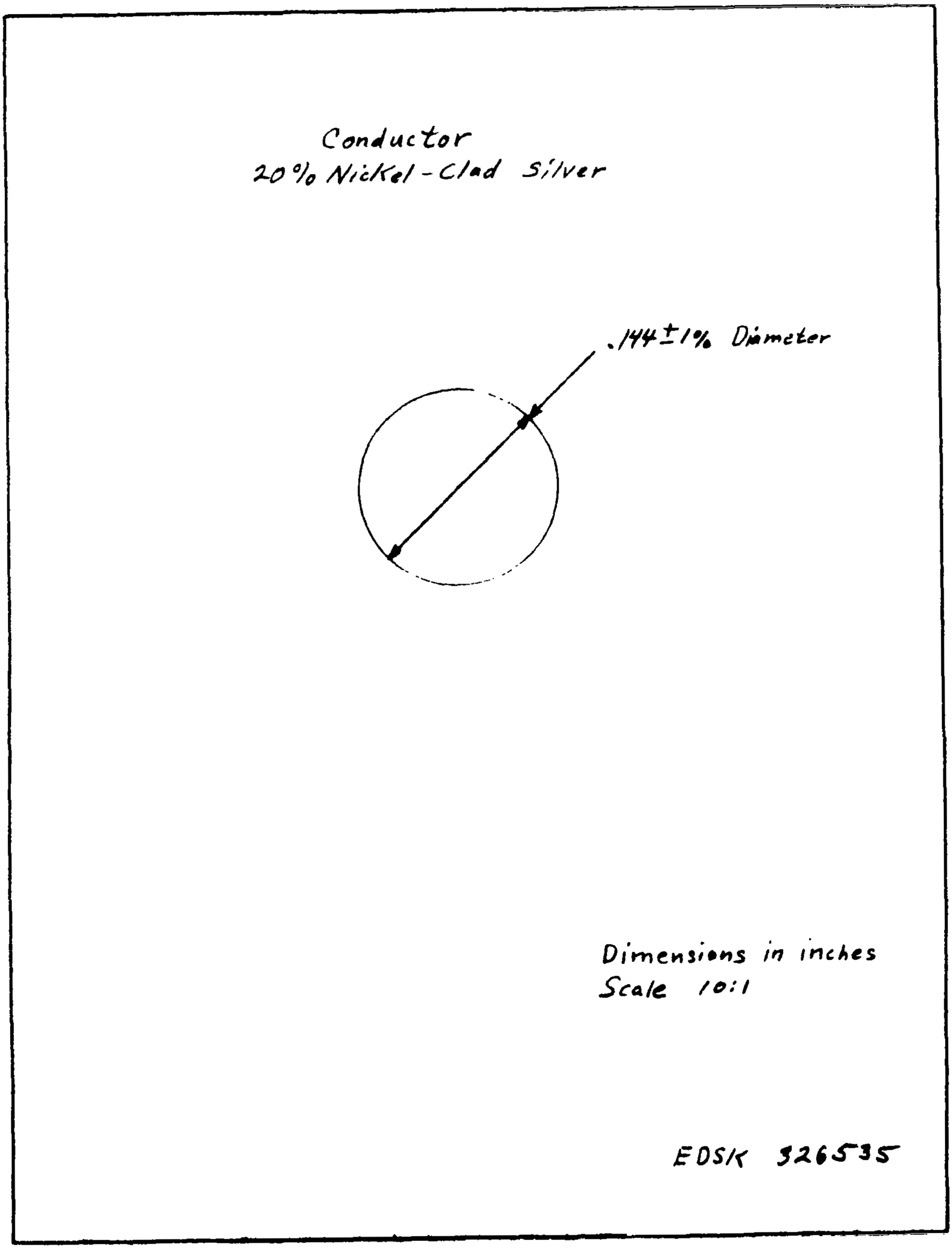

Conductor
20% Nickel-Clad Silver
.032 ± 1% Diameter
Dimensions in inches
Scale 20:1
EDSK 326533

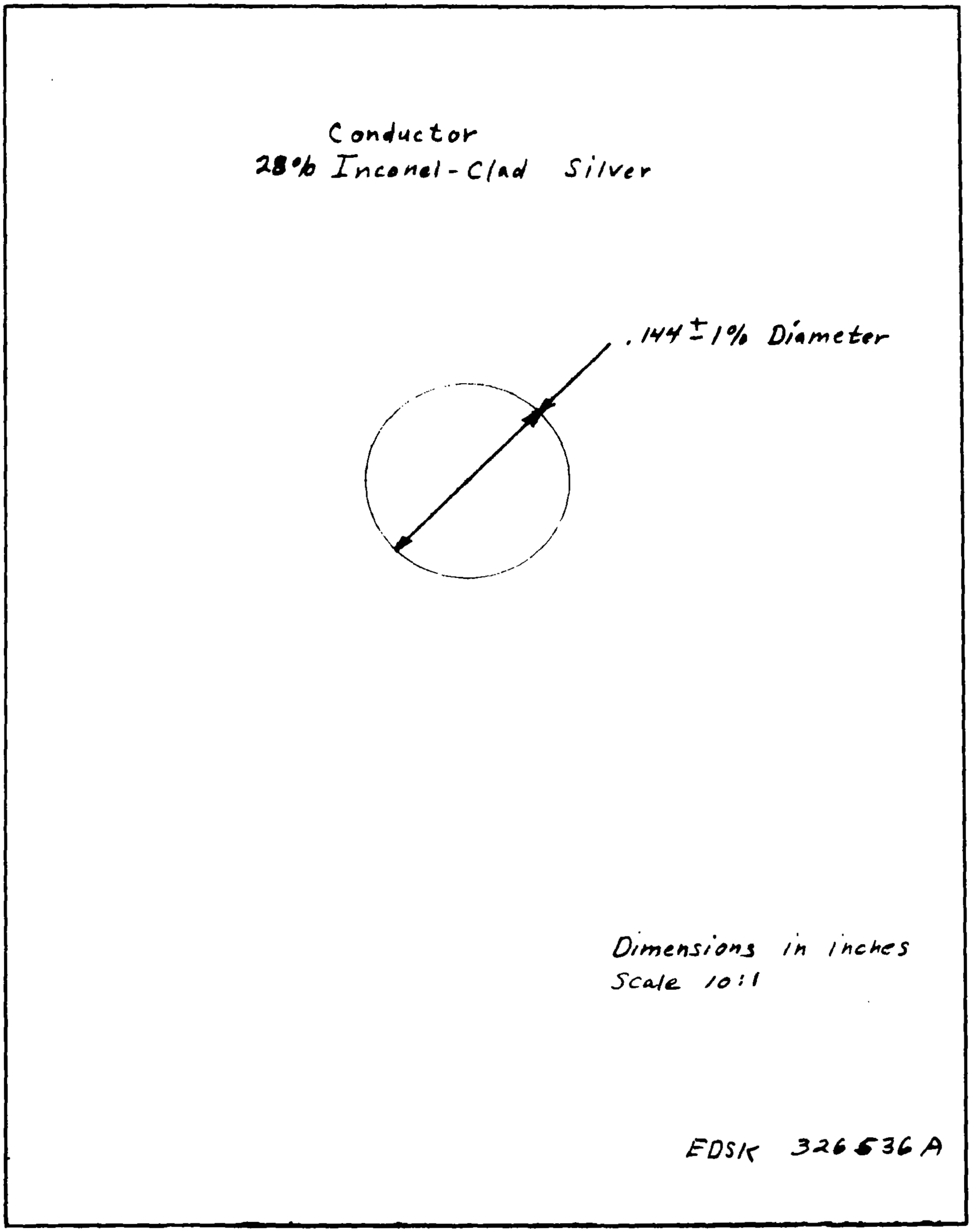
Conductor
28% Inconel-Clad Silver



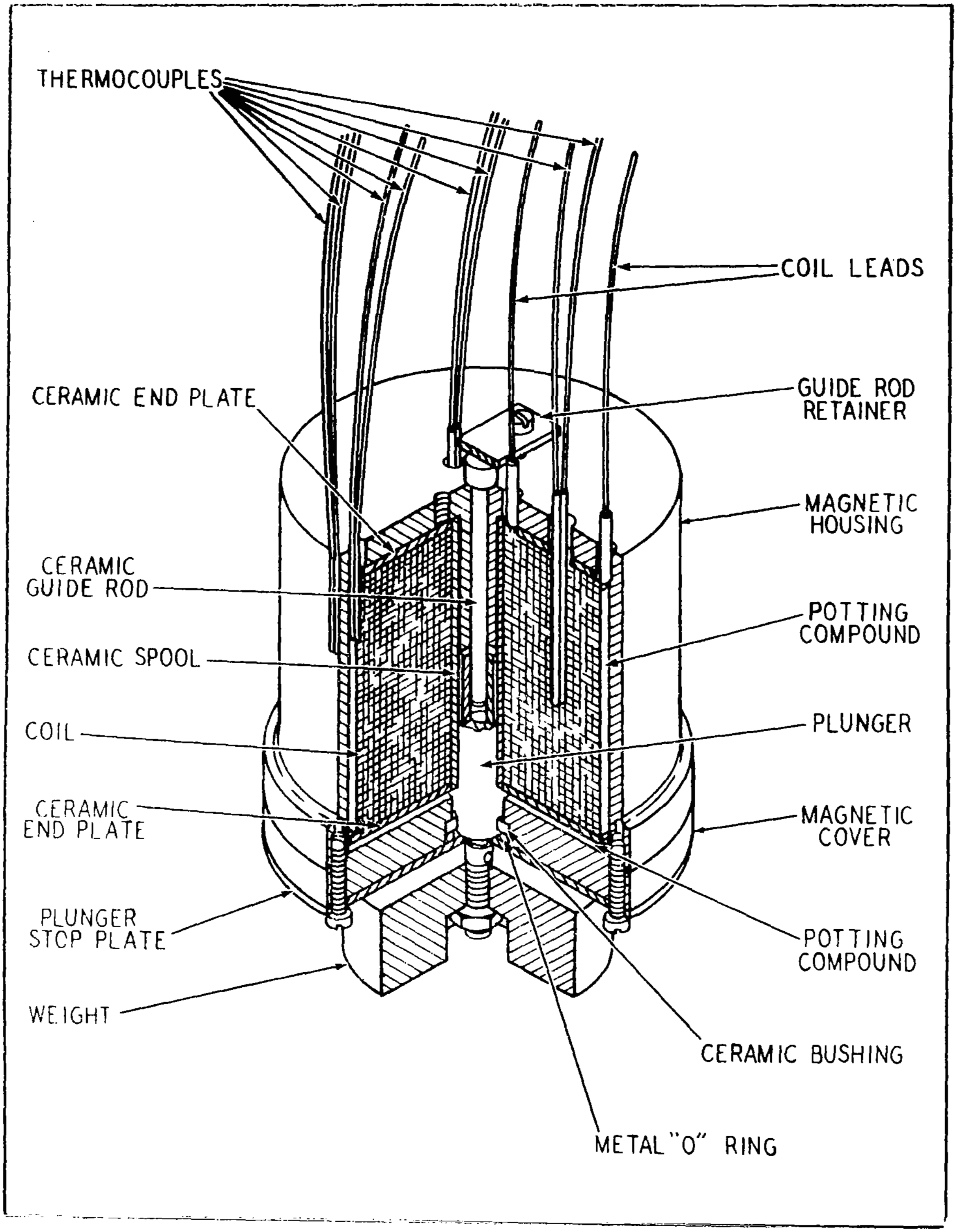

Dimensions in inches
Scale 20:1

EDSK 326534 A


Conductor
20% Nickel-Clad Silver
.144 ± 1% Diameter
Dimensions in inches
Scale 10:1
EDSK 326535


Conductor
28% Inconel-Clad Silver
.144 ± 1% Diameter
Dimensions in inches
Scale 10:1
EDSK 326536A

# III. SOLENOID




Cutaway View of Solenoid

## Solenoid - Magnetic, Insulation and Conductor Materials Summary - 1100°F Hot-Spot Model

| Part | Material | Source-NAS3-4162 |
|---|---|---|
| Housing | Fe-27Co - Forging (Hiperco 27) | NASA-CR-54091 p. 59, 323 |
| End Bell | Fe-27Co - Forging (Hiperco 27) | |
| Plunger | Fe-27Co - Forging (Hiperco 27) | |
| Plunger Bushing | $Al_2O_3$ - 99.5% | NASA-CR-54092 p. 92, 453 |
| Plunger Guide Rod | $Al_2O_3$ - 99.5% | |
| Coil End Plates | $Al_2O_3$ - 99.5% | |
| Coil Spool | $Al_2O_3$ - 99% | NASA-CR-54092 p. 92. 462 |
| Coil Lead Insulators | $Al_2O_3$ - 99% | |
| Thermocouple Insulators | $Al_2O_3$ - 99% | |
| Conductor Insulation | Same as Stator - 1100°F (Anadur E Glass) | NASA-CR-54092 p. 86, 287 |
| Potting Compound | Zircon-type (aluminum orthophosphate-zirconium silicate) (W-839) | NASA-CR-54092 p. 7, 579 |
| Conductors-Size #20 AWG Wire | Nickel-clad silver - 1100°F | NASA-CR-54092 p. 81, 249 |
| End Plates, Hardware<br>Weight<br>Thermocouples<br>Metal "O" Ring | Hastelloy Alloy B<br>Mallory 1000<br>Inconel 600 Sheath-Platinell II Wire System<br>321 SS | |

## Solenoid - Magnetic, Insulation and Conductor Materials Summary - 1300°F Hot-Spot Model

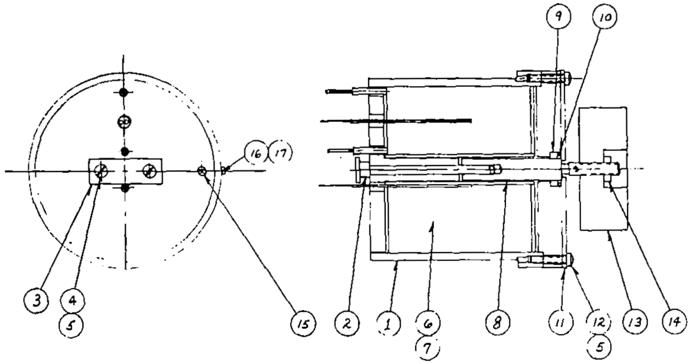
| Part | Material | Source-NASA3-4162 |
|---|---|---|
| Housing | Fe-27Co - Forging (Hiperco 27) | NASA-CR-54091 p. 59, 323 |
| End Bell | Fe-27Co - Forging (Hiperco 27) | |
| Plunger | Fe-27Co - Forging (Hiperco 27) | |
| Plunger Bushing | $Al_2O_3$ - 99.5% | NASA-CR-54092 p. 92, 453 |
| Plunger Guide Rod | $Al_2O_3$ - 99.5% | |
| Coil End Plates | $Al_2O_3$ - 99.5% | |
| Coil Spool | $Al_2O_3$ - 99% | NASA-CR-54092 p. 92, 462 |
| Coil Lead Insulators | $Al_2O_3$ - 99% | |
| Thermocouple Insulators | $Al_2O_3$ - 99% | |
| Conductor Insulation | Same as Stator-1300°F (Anadur S Glass) | NASA-CP-54092 p. 86, 287 |
| Potting Compound | BN Fiber Cement | |
| Conductors - Size #20 Wire | Inconel 600-clad silver - 1300°F | NASA-CR-54092 p. 81, 249 |
| End Plates, Hardware<br>Weight<br>Thermocouples<br>Metal "O" Ring | Hastelloy Alloy B<br>Mallory 1000<br>Inconel 600 Sheath-Platinell II Wire System<br>321 SS | |

## APPENDIX B - SECTION III, SOLENOID LIST AND DRAWINGS

| Drawing No. | Title | Material |
|---|---|---|
| EDSK 326788 | Solenoid Assembly | - |
| EDSK 326689 | Winding, Solenoid | - |
| EDSK 326762 | Details | See Drawing |
| EDSK 326688 | Details | See Drawing |
| EDSK 326620 | Details | See Drawing |
| EDSK 326619 | Forging | Hiperco 27 Alloy (27Co-Fe) |
| EDSK 326793 | Forging, Cut Up | Hiperco 27 Alloy (27Co-Fe) |
| EDSK 326787 | Bushing | 99.5% $Al_2O_3$ |
| EDSK 326687 | Solenoid Armature, Guide Rod | 99.5% $Al_2O_3$ |
| EDSK 326684 | End Plate | 99.5% $Al_2O_3$ |
| EDSK 326686 | Insulator, Tube | 99% $Al_2O_3$ |
| EDSK 326685 | Insulator, Tube | 99% $Al_2O_3$ |
| EDSK 326680 | Insulator, Tube | 99% $Al_2O_3$ |
| EDSK 326795 | Thermocouple | Inconel Cladding, Platinel II |
| EDSK 326796 | Thermocouple | Wire System, $Al_2O_3$ Insulation |
| EDSK 327502 | Screw | Hastelloy Alloy B |
| EDSK 327503 | Nut | Hastelloy Alloy B |
| EDSK 326533 | Conductor | Nickel Clad Silver (20% Clad area)[1] |
| EDSK 326534A | Conductor | Inconel 600-Clad Silver (28% Clad area)[1] |

[1] - All conductors insulated with Anaconda's Anadur a refractory-oxide-filled glass insulation. "Nickel-clad silver wire is insulated with Anadur "E" glass and Inconel 600-clad silver wire is insulated with Anadur "S" glass".

NOTE 1- WINDING POTTING PROCEDURE. APPLY FOUR STRIPS OF POTTING COMPOUND W-839 3/8-1/2 INCH WIDE AND LOCATED APPROX. 90° APART. COATING MUST BE THICK ENOUGH TO PROVIDE CONTACT BETWEEN WINDING AND HOUSING AFTER ASSEMBLY. AVOID AREA OCCUPIED BY THERMOCOUPLES ITEM 15.

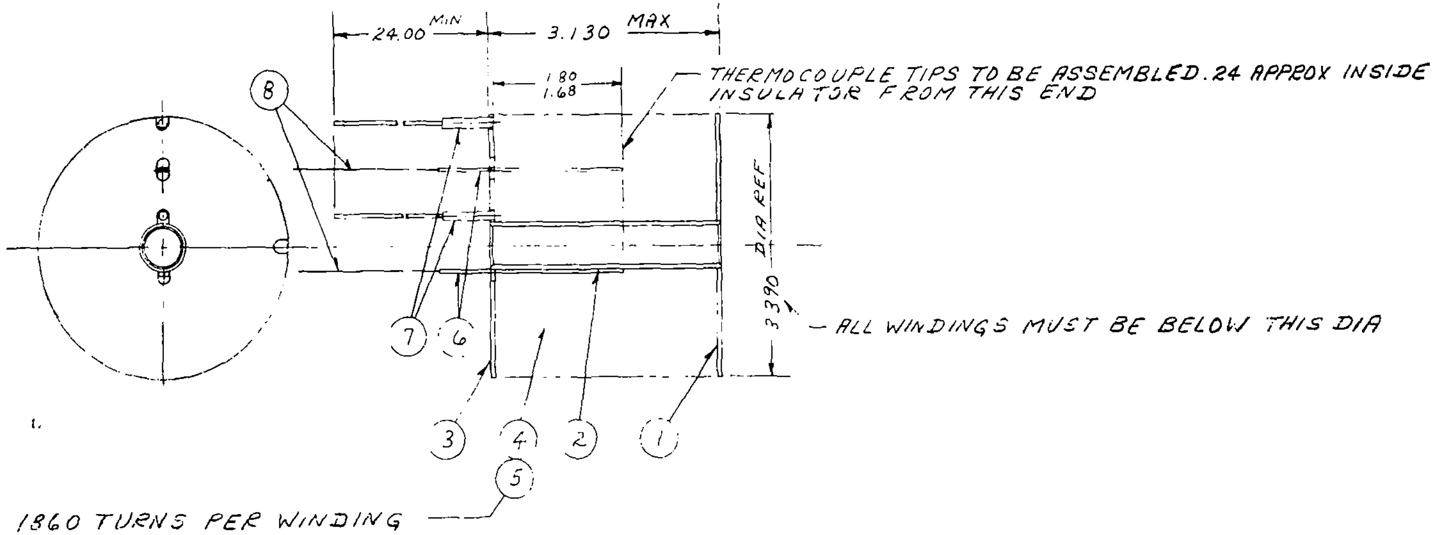



| QTY REQD PN-2 | QTY REQD PN-1 | SYM | NOMENCLATURE OR DESCRIPTION | PART NO. OR IDENT NO. | SPECIFICATION | MATERIAL OR NOTE | INTERNAL INFORMATION | ITEM NO. |
|---|---|---|---|---|---|---|---|---|
| AR | AR | B | POTTING COMPOUND | W-839 (WESTINGHOUSE)(SEE NOTE 1) | | | | 18 |
| AR | AR | B | PYROCERAM | | | | | 17 |
| 2 | 2 | | THERMOCOUPLE | EDSK 326796 | | | | 16 |
| 2 | 2 | | THERMOCOUPLE | EDSK 326795 | | | | 15 |
| 1 | 1 | | NUT | EDSK 327503-2 | | | | 14 |
| 1 | 1 | | WEIGHT | EDSK 326688 ITEM NO. 4 | | | | 13 |
| 4 | 4 | | SCREW | EDSK 327502-2 | | | | 12 |
| 1 | 1 | | PLATE | EDSK 326688 ITEM NO. 3 | | | | 11 |
| 1 | 1 | | STAINLESS STEEL O'RING CAT NO. U-8212-00688-NPN UNITED AIRCRAFT PRODUCTS, INC DAYTON, OHIO | | | | | 10 |
| 1 | 1 | | BUSHING | EDSK 326787 | | | | 9 |
| 1 | 1 | | SHAFT | EDSK 326688 ITEM NO. 7 | | | | 8 |
| 1 | - | | WINDING | EDSK 326689 PN-2 | | | | 7 |
| - | 1 | | WINDING | EDSK 326689 PN-1 | | | | 6 |
| AR | AR | B | WIRE, SST | .020 DIA 7860-2 | | | | 5 |
| 2 | 2 | | SCREW | EDSK 327502-1 | | | | 4 |
| 1 | 1 | | PLATE | EDSK 326620 ITEM NO. 4 | | | | 3 |
| 1 | 1 | | GUIDE ROD | EDSK 326687 | | | | 2 |
| 1 | 1 | | HOUSING ASSY | EDSK 326762 ASSY NO. 1 | | | | 1 |

LIST OF MATERIAL OR PARTS LIST

EDSK 326788

SOLENOID

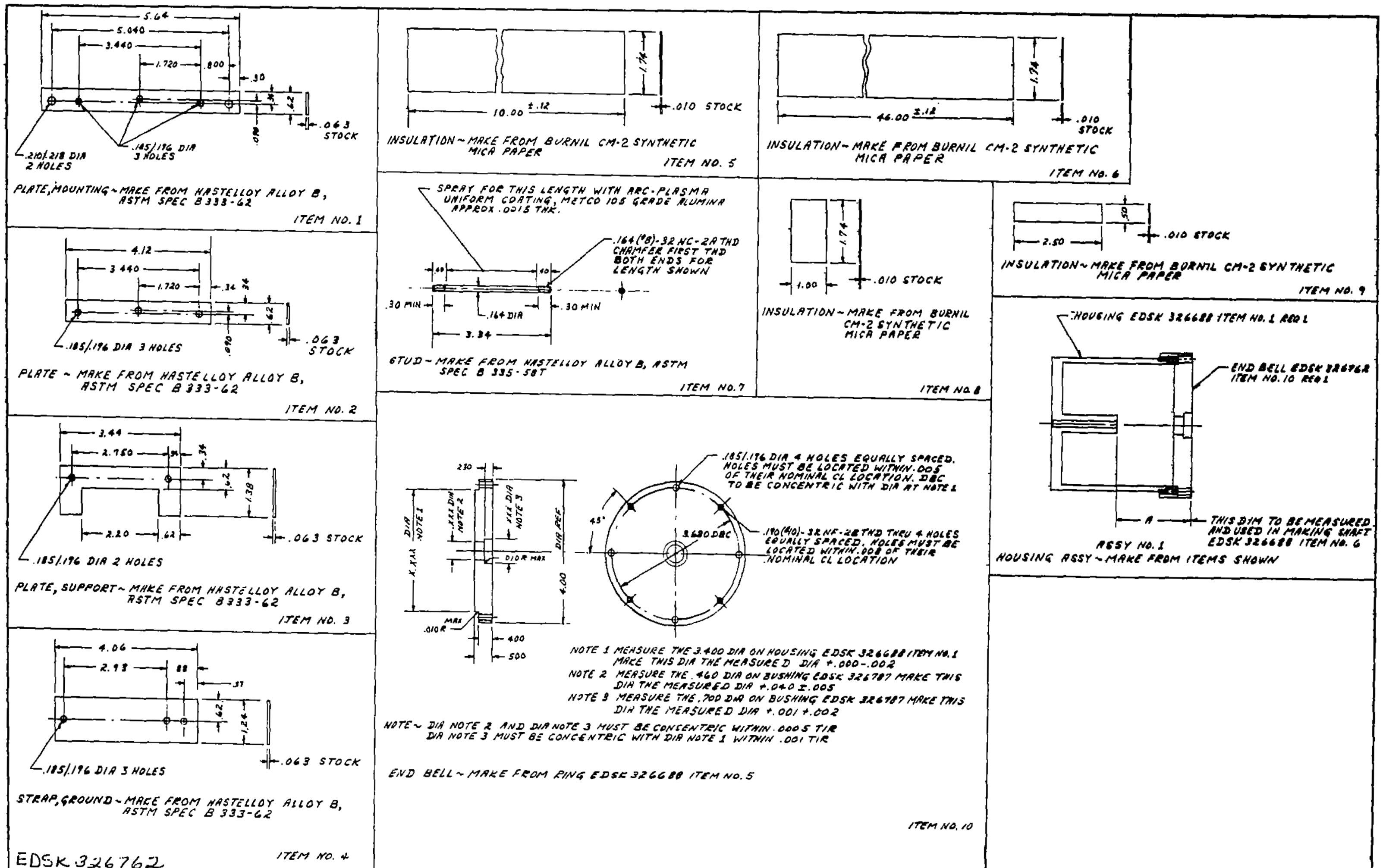



NOTE ~ CEMENT PLATES ITEM NO. 1 AND 3 TO TUBE ITEM NO. 2, CEMENT INSULATORS ITEM NO. 7 TO PLATE ITEM NO. 3 WITH DUCO CEMENT

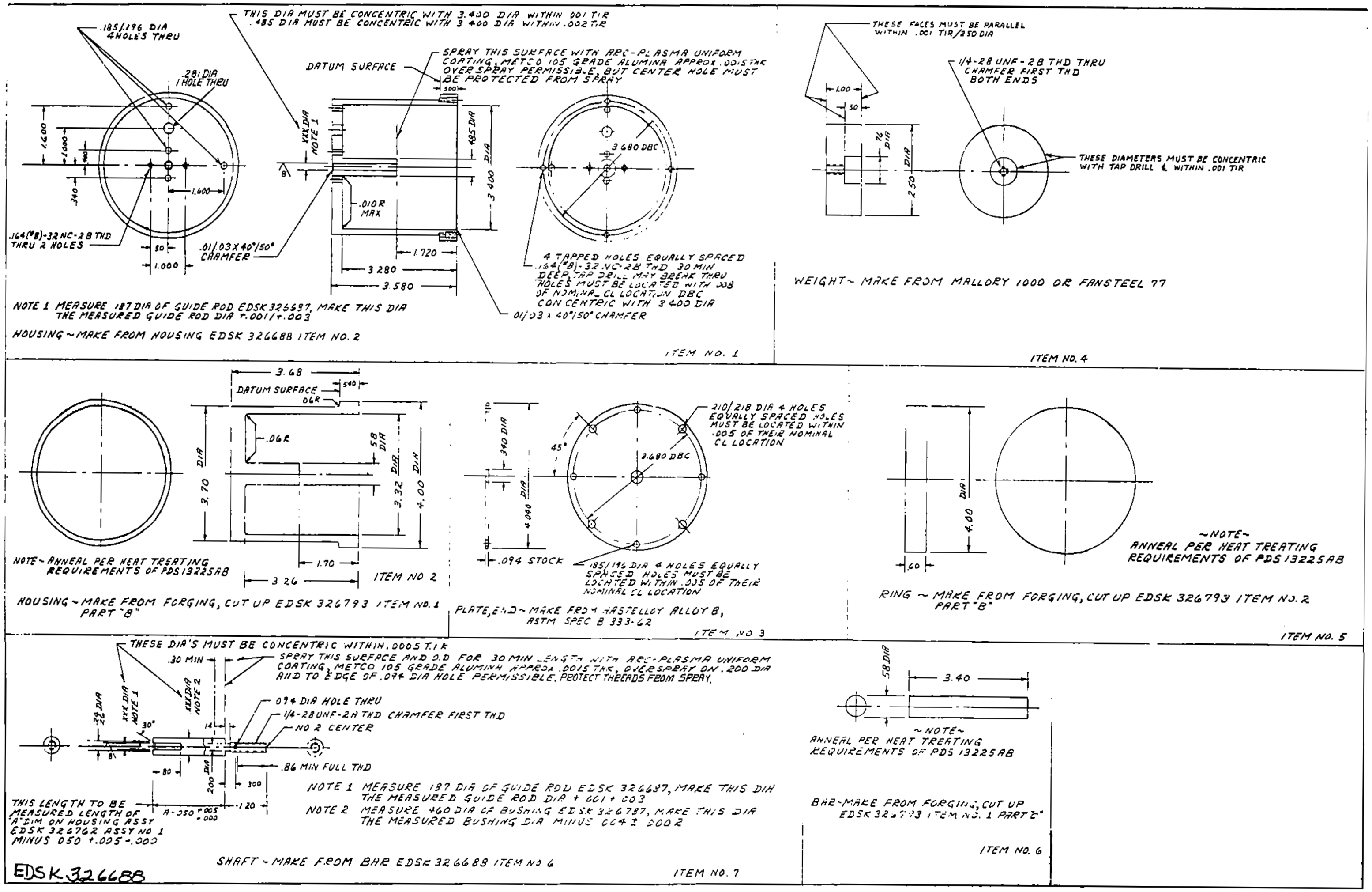
| QTY REQD PN-2 | QTY REQD PN-1 | SYM | NOMENCLATURE OR DESCRIPTION | PART NO. OR IDENT NO. | SPECIFICATION | MATERIAL OR NOTE | Ⓦ INTERNAL INFORMATION | ITEM NO. |
|---|---|---|---|---|---|---|---|---|
| 4 | 4 | | THERMOCOUPLE | EDSK 326795 | | | | 8 |
| 2 | 2 | | INSULATOR | EDSK 326686 PN-1 | | | | 7 |
| 4 | 4 | | INSULATOR | EDSK 326680 | | | | 6 |
| AR | - | B | WIRE #20 (.032 DIA) INCONEL-CLAD SILVER FURNISHED BY ENGINEER | | | | | 5 |
| - | AR | B | WIRE #20 (.032 DIA) NICKEL-CLAD SILVER FURNISHED BY ENGINEER | | | | | 4 |
| 1 | 1 | | END PLATE | EDSK 326684 ITEM NO. 2 | | | | 3 |
| 1 | 1 | | INSULATOR, TUBE | EDSK 326685 | | | | 2 |
| 1 | 1 | | END PLATE | EDSK 326684 ITEM NO. 1 | | | | 1 |

LIST OF MATERIAL OR PARTS LIST

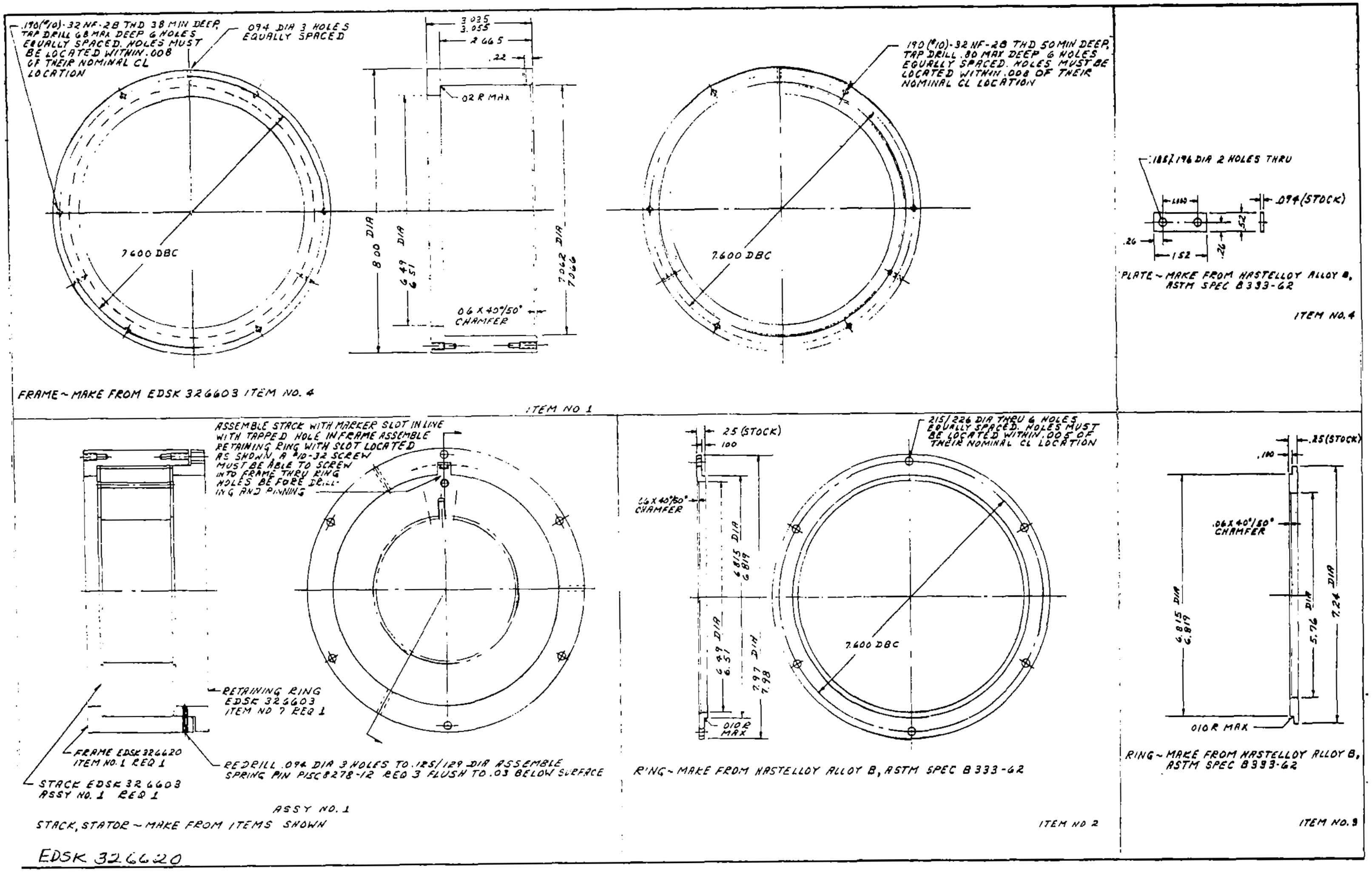
WINDING, SOLENOID


PLATE, MOUNTING ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B 333-62
ITEM NO. 1
.210/.218 DIA 2 HOLES
.185/.196 DIA 3 HOLES
.063 STOCK
PLATE ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B 333-62
ITEM NO. 2
.185/.196 DIA 3 HOLES
.063 STOCK
PLATE, SUPPORT ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B 333-62
ITEM NO. 3
.185/.196 DIA 2 HOLES
.063 STOCK
STRAP, GROUND ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B 333-62
ITEM NO. 4
.185/.196 DIA 3 HOLES
.063 STOCK
INSULATION ~ MAKE FROM BURNIL CM-2 SYNTHETIC MICA PAPER
ITEM NO. 5
.010 STOCK
INSULATION ~ MAKE FROM BURNIL CM-2 SYNTHETIC MICA PAPER
ITEM NO. 6
.010 STOCK
SPRAY FOR THIS LENGTH WITH ARC-PLASMA UNIFORM COATING, METCO 105 GRADE ALUMINA APPROX .0015 THK.
.164(#8)-32 NC-2A THD CHAMFER FIRST THD BOTH ENDS FOR LENGTH SHOWN
STUD ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B 335-58T
ITEM NO. 7
INSULATION ~ MAKE FROM BURNIL CM-2 SYNTHETIC MICA PAPER
ITEM NO. 8
.010 STOCK
INSULATION ~ MAKE FROM BURNIL CM-2 SYNTHETIC MICA PAPER
ITEM NO. 9
.010 STOCK
HOUSING EDSK 326688 ITEM NO. 1 REQ 1
END BELL EDSK 326762 ITEM NO. 10 REQ 1
THIS DIM TO BE MEASURED AND USED IN MAKING SHAFT EDSK 326688 ITEM NO. 6
ASSY NO. 1
HOUSING ASSY ~ MAKE FROM ITEMS SHOWN
.185/.196 DIA 4 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .005 OF THEIR NOMINAL CL LOCATION. DBC TO BE CONCENTRIC WITH DIA AT NOTE 1
.190(#10)-32 NF-2B THD THRU 4 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .005 OF THEIR NOMINAL CL LOCATION
NOTE 1 MEASURE THE 3.400 DIA ON HOUSING EDSK 326688 (ITEM NO. 1) MAKE THIS DIA THE MEASURED DIA +.000 -.002
NOTE 2 MEASURE THE .460 DIA ON BUSHING EDSK 326787 MAKE THIS DIA THE MEASURED DIA +.040 ±.005
NOTE 3 MEASURE THE .700 DIA ON BUSHING EDSK 326787 MAKE THIS DIA THE MEASURED DIA +.001 +.002
NOTE ~ DIA NOTE 2 AND DIA NOTE 3 MUST BE CONCENTRIC WITHIN .0005 TIR
DIA NOTE 3 MUST BE CONCENTRIC WITH DIA NOTE 1 WITHIN .001 TIR
END BELL ~ MAKE FROM RING EDSK 326688 ITEM NO. 5
ITEM NO. 10
EDSK 326762

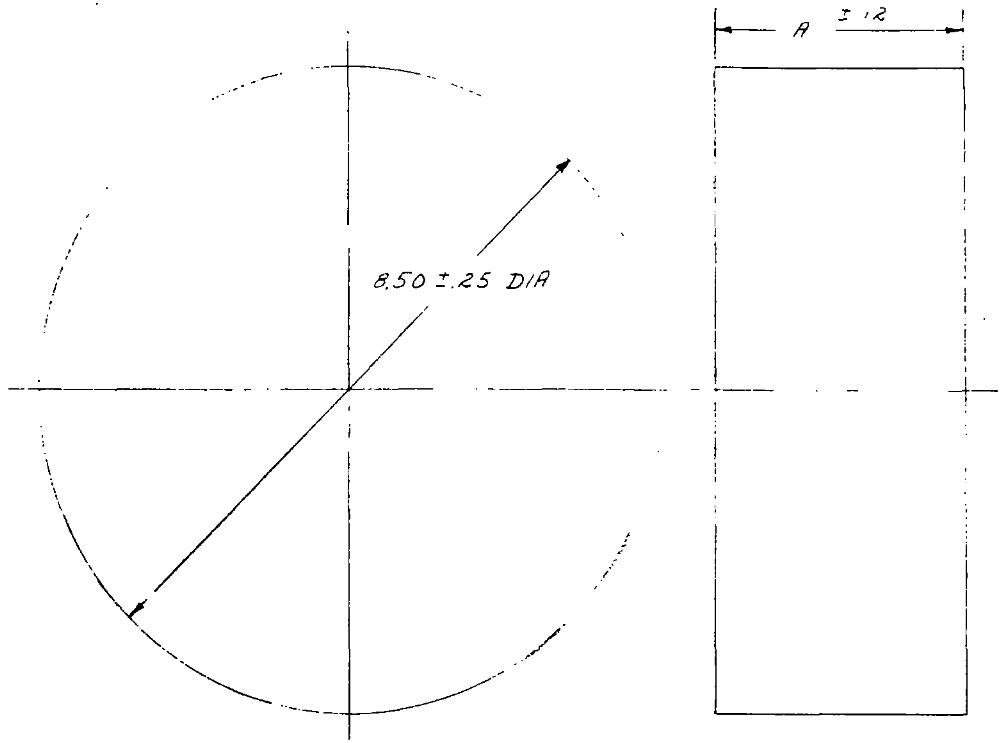
DETAILS


THIS DIA MUST BE CONCENTRIC WITH 3.400 DIA WITHIN .001 TIR
.485 DIA MUST BE CONCENTRIC WITH 3.400 DIA WITHIN .002 TIR
.185/.196 DIA 4 HOLES THRU
.281 DIA 1 HOLE THRU
DATUM SURFACE
SPRAY THIS SURFACE WITH ARC-PLASMA UNIFORM COATING, METCO 105 GRADE ALUMINA APPROX .0015 THK OVERSPRAY PERMISSIBLE, BUT CENTER HOLE MUST BE PROTECTED FROM SPRAY
.164(#8)-32 NC-2B THD THRU 2 HOLES
.01/.03 X 40°/50° CHAMFER
.010 R MAX
4 TAPPED HOLES EQUALLY SPACED .164(#8)-32 NC-2B THD .30 MIN DEEP, TAP DRILL MAY BREAK THRU. HOLES MUST BE LOCATED WITH .008 OF NOMINAL CL LOCATION. DBC CONCENTRIC WITH 3.400 DIA
.01/.03 X 40°/50° CHAMFER
NOTE 1 MEASURE .187 DIA OF GUIDE ROD EDSK 326687, MAKE THIS DIA THE MEASURED GUIDE ROD DIA +.001/+.003
HOUSING ~ MAKE FROM HOUSING EDSK 326688 ITEM NO. 2
ITEM NO. 1
THESE FACES MUST BE PARALLEL WITHIN .001 TIR/.250 DIA
1/4-28 UNF-2B THD THRU CHAMFER FIRST THD BOTH ENDS
THESE DIAMETERS MUST BE CONCENTRIC WITH TAP DRILL ℄ WITHIN .001 TIR
WEIGHT ~ MAKE FROM MALLORY 1000 OR FANSTEEL 77
ITEM NO. 4
DATUM SURFACE
NOTE ~ ANNEAL PER HEAT TREATING REQUIREMENTS OF PDS 13225AB
HOUSING ~ MAKE FROM FORGING, CUT UP EDSK 326793 ITEM NO. 1 PART "B"
ITEM NO 2
.210/.218 DIA 4 HOLES EQUALLY SPACED HOLES MUST BE LOCATED WITHIN .005 OF THEIR NOMINAL CL LOCATION
3.680 DBC
.094 STOCK
.185/.196 DIA 4 HOLES EQUALLY SPACED HOLES MUST BE LOCATED WITHIN .005 OF THEIR NOMINAL CL LOCATION
PLATE, END ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B 333-62
ITEM NO 3
~NOTE~ ANNEAL PER HEAT TREATING REQUIREMENTS OF PDS 13225AB
RING ~ MAKE FROM FORGING, CUT UP EDSK 326793 ITEM NO. 2 PART "B"
ITEM NO. 5
THESE DIA'S MUST BE CONCENTRIC WITHIN .0005 T.I.R.
SPRAY THIS SURFACE AND O.D FOR .30 MIN LENGTH WITH ARC-PLASMA UNIFORM COATING, METCO 105 GRADE ALUMINA APPROX .0015 THK, OVERSPRAY ON .200 DIA AND TO EDGE OF .094 DIA HOLE PERMISSIBLE. PROTECT THREADS FROM SPRAY.
.094 DIA HOLE THRU
1/4-28 UNF-2A THD CHAMFER FIRST THD
NO 2 CENTER
.86 MIN FULL THD
THIS LENGTH TO BE MEASURED LENGTH OF "A" DIM ON HOUSING ASSY EDSK 326762 ASSY NO 1 MINUS .050 +.005 -.000
NOTE 1 MEASURE .187 DIA OF GUIDE ROD EDSK 326687, MAKE THIS DIA THE MEASURED GUIDE ROD DIA +.001 +.003
NOTE 2 MEASURE .460 DIA OF BUSHING EDSK 326787, MAKE THIS DIA THE MEASURED BUSHING DIA MINUS .0042 .0002
SHAFT ~ MAKE FROM BAR EDSK 326688 ITEM NO 6
ITEM NO. 7
~NOTE~ ANNEAL PER HEAT TREATING REQUIREMENTS OF PDS 13225AB
BAR ~ MAKE FROM FORGING, CUT UP EDSK 326793 ITEM NO. 1 PART "B"
ITEM NO. 6
EDSK 326688

DETAILS


.190(#10)-32 NF-2B THD .38 MIN DEEP, TAP DRILL .68 MAX DEEP 6 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .008 OF THEIR NOMINAL CL LOCATION
.094 DIA 3 HOLES EQUALLY SPACED
3.035
3.055
2.665
.22
.02 R MAX
7.600 DBC
8.00 DIA
6.49
6.51 DIA
7.062
7.066 DIA
.06 X 40°/50° CHAMFER
FRAME ~ MAKE FROM EDSK 326603 ITEM NO. 4
ITEM NO 1
.190(#10)-32 NF-2B THD .50 MIN DEEP, TAP DRILL .80 MAX DEEP 6 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .008 OF THEIR NOMINAL CL LOCATION
7.600 DBC
.185/.196 DIA 2 HOLES THRU
.094 (STOCK)
.26
.152
.52
.26
PLATE ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO. 4
ASSEMBLE STACK WITH MARKER SLOT IN LINE WITH TAPPED HOLE IN FRAME ASSEMBLE RETAINING RING WITH SLOT LOCATED AS SHOWN. A #10-32 SCREW MUST BE ABLE TO SCREW INTO FRAME THRU RING HOLES BEFORE DRILLING AND PINNING
RETAINING RING EDSK 326603 ITEM NO 7 REQ 1
FRAME EDSK 326620 ITEM NO. 1 REQ 1
STACK EDSK 326603 ASSY NO. 1 REQ 1
REDRILL .094 DIA 3 HOLES TO .125/.129 DIA ASSEMBLE SPRING PIN PISC 8278-12 REQ 3 FLUSH TO .03 BELOW SURFACE
ASSY NO. 1
STACK, STATOR ~ MAKE FROM ITEMS SHOWN
.25 (STOCK)
.100
.06 X 40°/50° CHAMFER
6.815
6.819 DIA
6.49
6.51 DIA
7.97
7.98 DIA
.010 R MAX
.215/.226 DIA THRU 6 HOLES EQUALLY SPACED. HOLES MUST BE LOCATED WITHIN .005 OF THEIR NOMINAL CL LOCATION
7.600 DBC
RING ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO 2
.25 (STOCK)
.100
.06 X 40°/50° CHAMFER
6.815
6.819 DIA
5.76 DIA
7.24 DIA
.010 R MAX
RING ~ MAKE FROM HASTELLOY ALLOY B, ASTM SPEC B333-62
ITEM NO. 3
EDSK 326620

DETAILS



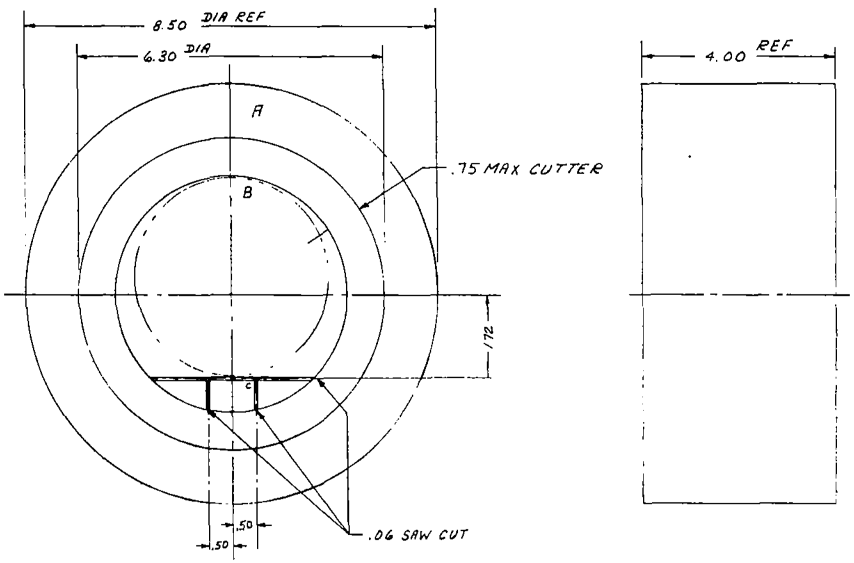

| EDSK 326619 | DIM "A" |
| --- | --- |
| ITEM NO. 1 | 3.40 |
| ITEM NO. 2 | 1.26 |
| ITEM NO. 3 | 4.00 |

~NOTE~

MATERIAL SHALL BE MADE TO MEET WESTINGHOUSE PDS 13225AB WITH THE FOLLOWING ADDITIONAL REQUIREMENTS 1: THAT CERTIFICATION OF ACCEPTABLY PASSING ULTRASONIC INSPECTION BE PROVIDED. 2: THAT THE MATERIAL BE SHIPPED WITHOUT BEING ANNEALED, HOWEVER IN THE ANNEALED CONDITION SAID FORGING SHALL BE CERTIFIED TO MEET THE MECHANICAL AND MAGNETIC PROPERTIES OF PDS 13225 AB

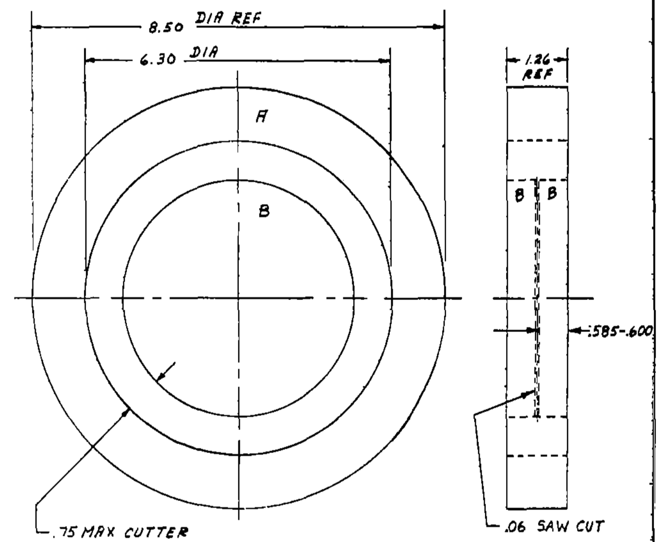
EDSK 326619

FORGING




CUT UP FORGING EDSK 326619 ITEM NO. 3 AS SHOWN. PART "A" TO BE USED TO MAKE FRAME EDSK 326603 ITEM NO. 4, PART "B" TO BE USED TO MAKE HOUSING EDSK 326688 ITEM NO. 2, AND PART "C" TO BE USED TO MAKE BAR EDSK 326688 ITEM NO. 6

ITEM NO 1

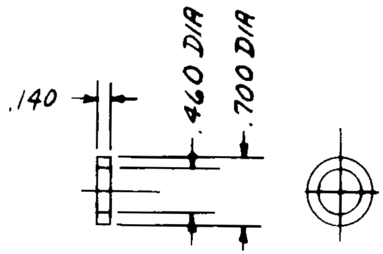



CUT UP FORGING EDSK 326619 ITEM NO. 2 AS SHOWN.
PART "A" TO BE USED TO MAKE RETAINING RING EDSK 326603 ITEM NO. 5,
AND PART "B" TO BE USED TO MAKE RING EDSK 326688 ITEM NO. 5

ITEM NO. 2

EDSK 326793

FORGING, CUT UP

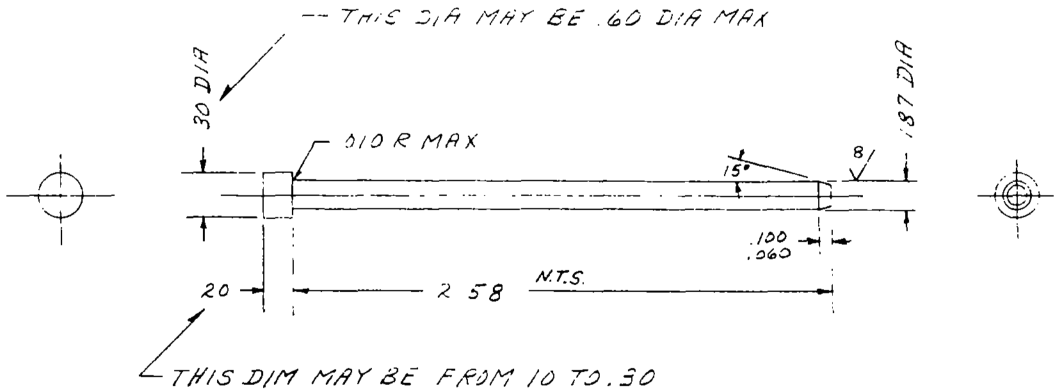



NOTE ~ .460 DIA MUST BE CONCENTRIC WITH .700 DIA WITHIN .0005 T.I.R.

BUSHING ~ MAKE FROM MINIMUM 99.5% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

EDSK 326787

BUSHING

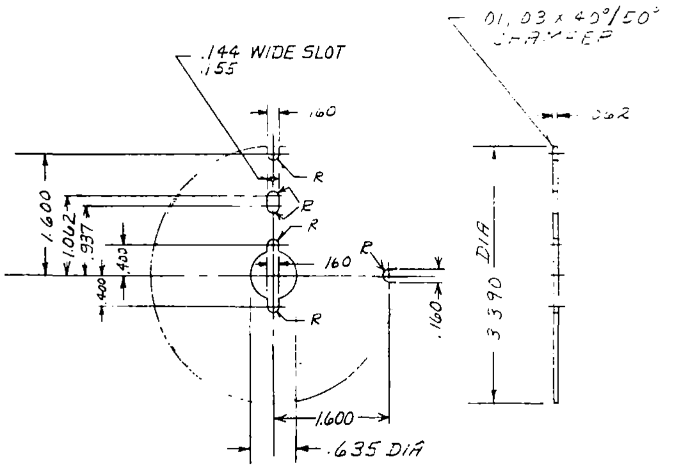



GUIDE ROD - MAKE FROM MINIMUM 99.5% PURITY HIGH DENSITY $Al_2O_3$ (ALUMINA)

EDSK 326687

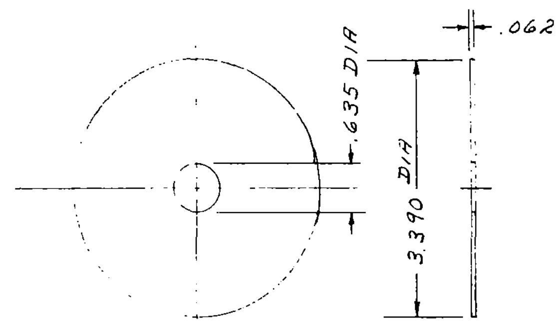
SOLENOID ARMATURE,

GUIDE ROD




END PLATE ~ MAKE FROM MINIMUM 99.5% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

ITEM NO. 2



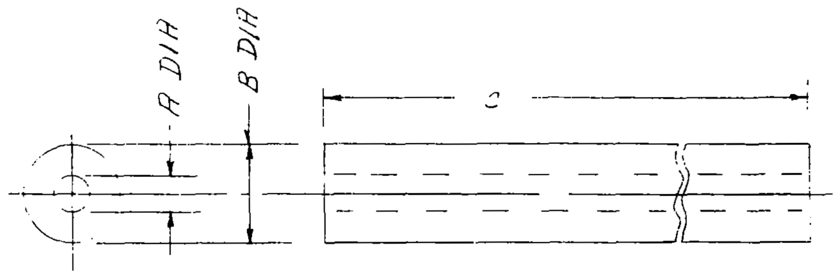

END PLATE ~ MAKE FROM MINIMUM 99.5% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

ITEM NO. 1

EDSK 326684

END PLATE

| PART NO. | DIA A | DIA B | LENGTH C |
|---|---|---|---|
| -1 | .062 | .125 | .70 |
| -2 | .062 | .188 | 2.50 |
| -3 | .044 | .094 | 2.50 |

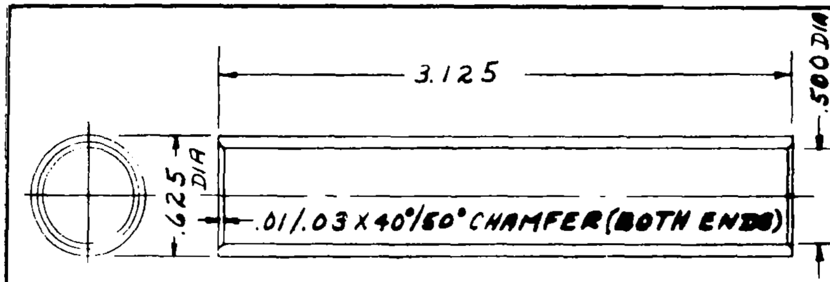



NOTE ~ STRAIGHTNESS TOLERANCE 1/16 INCH PER FOOT OF LENGTH

INSULATOR ~ MAKE FROM MINIMUM 99% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

EDSK 326686

INSULATOR, TUBE

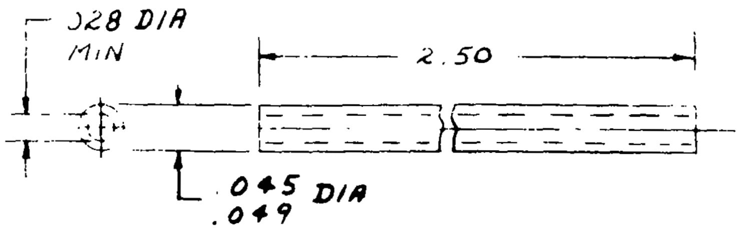



NOTE ~ TUBE I.D. MUST BE STRAIGHT WITHIN .005 TIR

INSULATOR ~ MAKE FROM MINIMUM 99% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

EDSK 326685

INSULATOR, TUBE

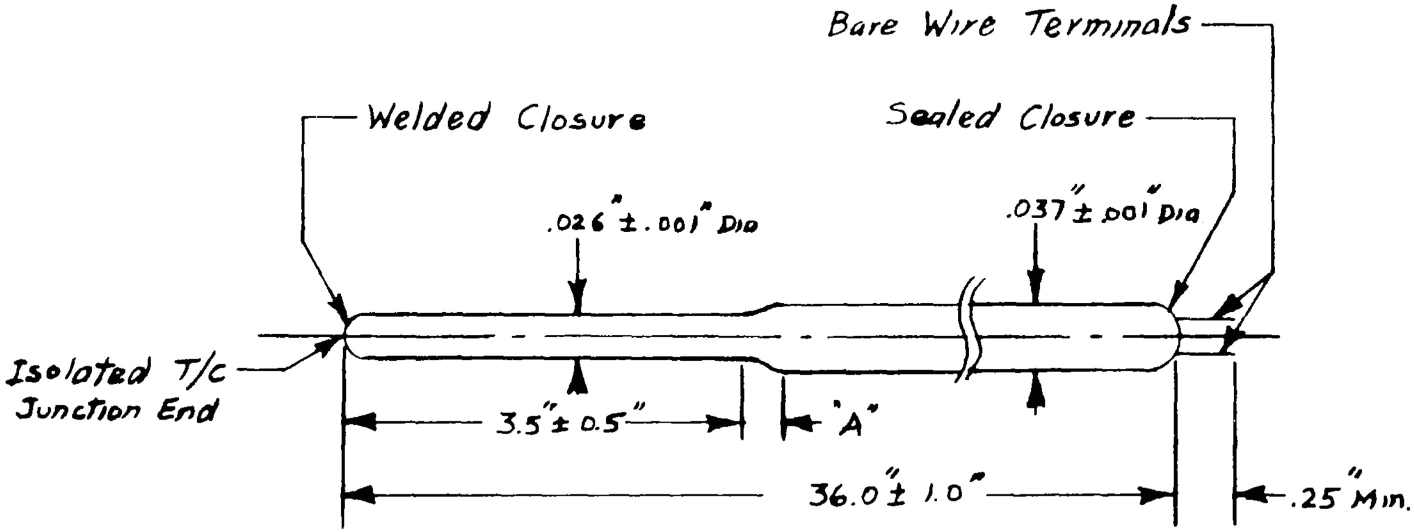



NOTE ~ STRAIGHTNESS TOLERANCE 1/16 INCH PER FOOT OF LENGTH

INSULATOR ~ MAKE FROM MINIMUM 99% PURITY HIGH DENSITY $AL_2O_3$ (ALUMINA)

EDSK 326680

INSULATOR, TUBE



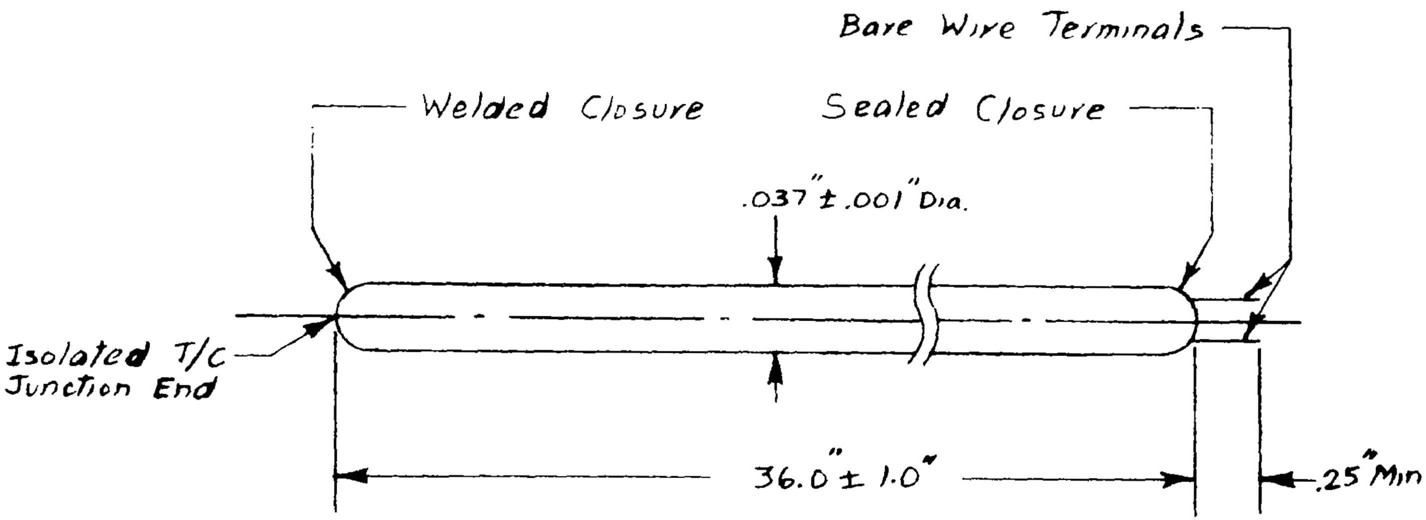

Note: Thermocouples are to be kept straight at all times.

"A" – Dimension as required for forming operation – 1.0 inch maximum. OD surface must be continuous thru transition.

DUAL DIAMETER SHEATHED THERMOCOUPLE

Reference Ⓦ D-Spec # 709747

EDSK 326795

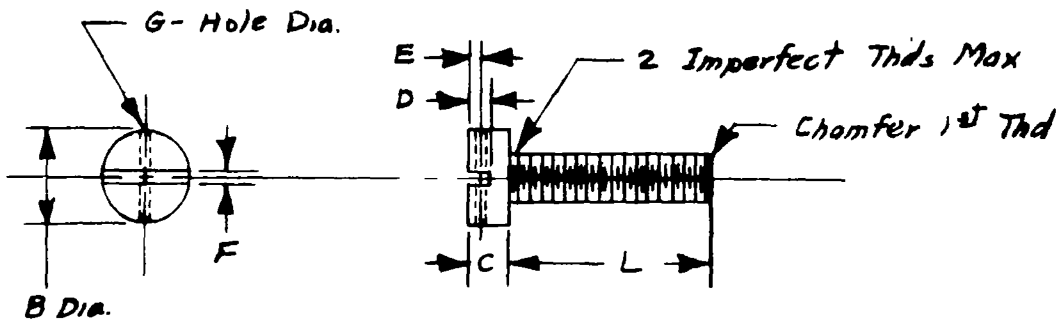



Note: Thermocouples are to be kept straight at all times.

SINGLE DIAMETER SHEATHED THERMOCOUPLE

Reference (W) D-Spec # 709747

EDSK 326796

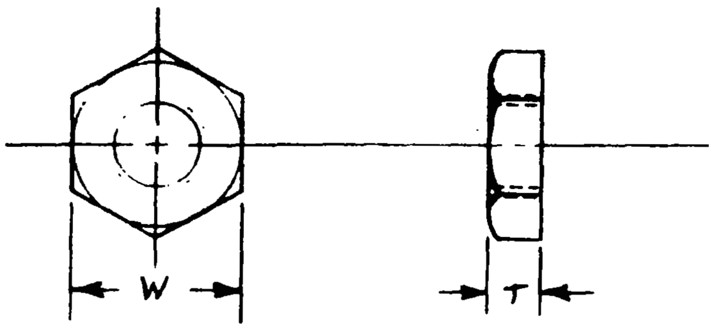



Material - Hastelloy Alloy B Rod

| Dash No | Thread | B Dia ±.003 | C ±.003 | D ±.005 | E ±.005 | F ±.003 | G Dia ±.002 | L ±.005 | Stock |
|---|---|---|---|---|---|---|---|---|---|
| 1 | #8 (.164)-32 NC-2A | 270 | .156 | .078 | .050 | 062 | .040 | .500 | 3/8 Dia |
| 2 | " " | 270 | .156 | .078 | .050 | .062 | .040 | .750 | 3/8 Dia |
| 3 | #10 (.190)-32 NF-2A | 313 | .156 | .078 | .050 | .062 | .040 | .500 | 7/16 Dia |
| 4 | " " | .313 | .156 | .078 | .050 | .062 | .040 | 1.00 | 7/16 Dia |
| 5 | 1/4-28 UNF-2A | 414 | .207 | .103 | .078 | .062 | .040 | .500 | 1/2 Dia |

## SCREW - FLAT FILLISTER HEAD

EDSK 327502



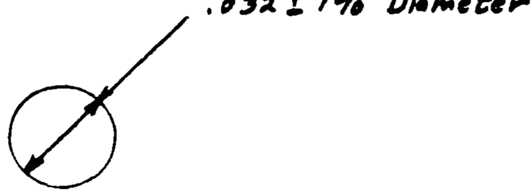

Material - Hastelloy Alloy B Rod

| Dash No. | Thread | W ±.005 | T ±.008 | Stock |
|---|---|---|---|---|
| 1 | #8 (.164)-32 NC-2B | .338 | .187 | 1/2 Dia |
| 2 | 1/4-28 UNF-2B | .428 | .219 | 5/8 Dia |

## NUT - HEXAGONAL

EDSK 327503

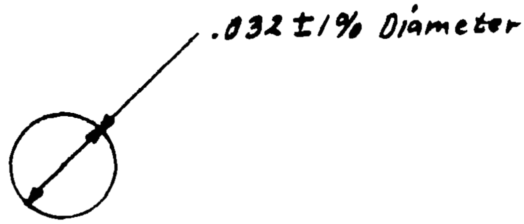
Conductor
20% Nickel-Clad Silver




Dimensions in inches
Scale 20:1

EDSK 326533

Conductor
28% Inconel-Clad Silver




Dimensions in inches
Scale 20:1

EDSK 326534A

## REFERENCE

1. Kueser, P. E.; Parkman, M. F.; and Toth, J. W.: Ceramic-Metal Bore Seal Development. NASA Contract NAS 3-6465, 1970.