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SECOND QUARTERLY TECHNICAL PROGRESS REPORT

ALKALI METAL RESISTANT ELECTRICAL DEVICES

USAF CONTRACT AF33(615)-3528
BUDGET NO. (BPSN) 6(638128 62405214)

JANUARY 15, 1967
WAED 66.62E

Westinghouse Electric Corporation
Aerospace Electrical Division
Lima, Ohio

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(September 26, 1966 - December 25, 1966)

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January 15, 1967

WAED 66.62E

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NOTICE

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FOREWORD

This second quarterly report is submitted by the Aerospace Electrical Division, Westinghouse Electric Corporation, Lima, Ohio, on Air Force Contract AF33(615)-3528, Budget No. (BPSN) 6(638128 62405214) Alkali Metal Resistant Electrical Devices. The contract is administered by the Air Force Aero Propulsion Laboratory, Research and Technology Division, Wright-Patterson Air Force Base, Dayton, Ohio. Mr. Lester Schott is Project Engineer for APIE on this contract.

The work described in this report was done by personnel in the Materials Development and Research and Development Groups of Westinghouse Aerospace Electrical Division, Lima, Ohio. The engineers and their areas of responsibility, in which they contributed are as follows: A. J. Krause - Test Engineering and Mechanical Design, R. E. McVay - Metallurgical Studies, and R. E. Stapleton - Ceramic Technology.

ABSTRACT

This report covers the second quarter from 26 September to 25 December 1966 on Air Force Contract AF33(615)-3528, Alkali Metal Resistant Electrical Devices.

All but one material was procured for potassium vapor exposure specimens. Specimens were prepared and given pre-exposure tests. Capsules for potassium vapor exposure tests were fabricated. Hiperco 27 alloy for use in transformers was evaluated. Rowland ring core box sides were fabricated and ceramic ends were ordered. A continuous measurement container for conductor evaluation was designed and material ordered.

Short term potassium vapor exposure tests were run on selected ceramic and ceramic/metal interface specimens, and test results evaluated. Alumina-titanium-Hiperco 27 alloy test specimens were not appreciably affected by the 600°C potassium vapor. Attempts were made to fabricate ceramic/metal electrical feed throughs using rhodium and alumina powders and cold and hot pressing techniques. Three configurations for brazing columbium-1% zirconium to sapphire windows were evaluated. Leak tight seals were not obtained.

Transformer E and I laminations were obtained. Conductors were ordered and a shipment of squared round wire was received. Transformer ceramic insulation was ordered.

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SECTION I

INTRODUCTION

This report covers the second quarter from 26 September to 25 December 1966 on Air Force Contract AF33(615)-3528, Alkali Metal Resistant Electrical Devices.

This program involves the study and evaluation of electrical device material for 600°C, 5000-hour, potassium vapor operation. Conductors, insulators, and magnetic materials capable of being used in potassium vapor exposed electrical circuits will be exposed to 600°C potassium vapor for times up to 5000 hours. Positive identification of degradation over this time period will be established with the goal of providing materials compatible with environmental test conditions. Processes and techniques necessary to insure mechanical and electrical compatibility and integrity of metal to metal and ceramic to metal interfaces will be investigated. The goal is to provide processing techniques for potassium vapor resistant electrical device fabrication. Transformers rated at 5 KVA will be fabricated and results of electrical tests in ionized and non-ionized 600°C potassium vapor will be evaluated.

SECTION II

SUMMARY OF WORK PERFORMED AND MAJOR RESULTS

This section provides a summary of the work performed and the major results obtained on the program in three general areas.

A. MATERIALS FOR 600°C POTASSIUM VAPOR EXPOSURE

1. Potassium Vapor Exposure Specimens

All materials for potassium vapor exposure tests were obtained except for aluminum oxychloride. Specimens were prepared from these materials. Pre-exposure magnetic, mechanical and physical tests were conducted.

2. Potassium Vapor Exposure Test Containers

Stainless steel test capsules were assembled and degassed. Columbium-1% zirconium test capsules were assembled and annealed. Transport containers were fabricated and tested. Rowland ring core box sides were fabricated and annealed, and ceramic parts ordered. Design drawings were made for the conductor continuous measurement test container.

B. PROCESSES AND TECHNIQUES FOR POTASSIUM VAPOR RESISTANT ELECTRICAL DEVICES

1. Specimen Fabrication

Fourteen specimens consisting of ceramic modulus of rupture bars and ceramic/metal interface coupons were prepared for potassium vapor exposure. Zirconium and titanium were sputtered on sapphire. Aluminum was reactively sputtered with oxygen and nitrogen.

2. Short Term Potassium Vapor Exposure Tests

Potassium vapor exposure test capsules were prepared, loaded with potassium and specimens, evacuated and sealed and subjected to a 600°C, 200-hour test.

3. Evaluation of Potassium Vapor Exposure Specimens

Hiperco 27 alloy substrates with plasma sprayed titanium hydride and alumina appeared to be more potassium resistant when vacuum heat-treated at 1800°F as compared to 2400°F.

Alumina-yttria eutectic appeared to be unaffected by the test as was unheat-treated strontium zirconate. Heat treated strontium zirconate disintegrated in 600°C potassium vapor.

4. Ceramic/Metal Composites

Successful alumina to alumina/rhodium composites were made. Pure rhodium powder would not adhear to either alumina or alumina/rhodium -50%/50% cermet.

C. DESIGN AND FABRICATION OF THE 5 KVA TRANSFORMERS

1. Magnetic Materials

Transformer E and I laminations were obtained.

2. Conductors

Nickel clad silver conductor material was received as squared wire from the previous program. New conductor material was ordered.

3. Insulation

Transformer insulation was ordered and a partial order of plasma spray powder was received.

4. Electrical Feedthroughs

The order for twenty beryllia feedthrough terminals was modified to require ten beryllia and ten alumina terminals.

5. Sapphire Window Seals

Three geometries were used in attempts to make sapphire windows seals. Brazing windows into tubular configurations gave better results than brazing into sheet. Leaks were found in all braze attempts.

SECTION III

EXPERIMENTAL WORK

This section describes the experimental work conducted on the program in three general areas.

A. EVALUATION OF ELECTRICAL DEVICE MATERIALS IN 600°C POTASSIUM VAPOR

Various magnetic materials, electrical conductors, and insulation materials will be exposed to 600°C potassium vapor for various times through 5000 hours and evaluated to determine degradation. The potassium used for these tests will contain not more than 25 ppm of O_2. Materials will be tested in quadruplicate and will be evaluated:

1) Prior to potassium vapor exposure.

2) After 1000 hours in 600°C potassium vapor.

3) After 2000 hours in 600°C potassium vapor.

4) After 3000 hours in 600°C potassium vapor.

5) After 5000 hours in 600°C potassium vapor.

Electrical conductors are being subjected to tensile testing, conductivity measurement, and visual and metallographic examinations. Magnetic materials are being subjected to magnetic testing, tensile testing, and visual and metallographic examinations. Ceramic bar materials are being subjected to modulus of rupture tests, weight change determinations, and microscopic examinations. Sapphire mat materials will be subjected to microscopic examinations and any weight changes determined.

Progress in the area of evaluating electrical device materials in potassium vapor is described below.

1. Potassium Vapor Exposure Test Specimens

a. Test Material Procurement and Preparation

All materials for potassium vapor exposure tests were obtained with the exception of aluminum oxychloride which was ordered from Alpha Inorganics, Beverly, Mass. Their first attempt at material formulations was unsuccessful.

Annealed rhodium wire 0.030-inch diameter in 99.95% Rh minimum purity was obtained from Sigmund Cohn Corp. and specimens cut to size. Annealed iridium wire 0.030-inch diameter in 99.8% minimum purity was obtained from Englehard Industries Inc. and specimens cut to size. Silver clad with approximately a 20% Inconel (cross-sectional area) was obtained in No. 10 round wire size from Sylvania Parts Division. This material was cut to potassium vapor exposure specimen size and ends plated with 0.005-inch thick nickel to protect the silver core. Silver clad with approximately 20% nickel was obtained as 0.080-inch by 0.127-inch rectangular wire from Sylvania Parts Division. Eight pounds of this material, purchased as No. 6 and No. 8 round wire on a previous program (Contract No. AF33(615) 1360) was redrawn to the rectangular form on this program. This material was also cut to specimen size and ends nickel plated. Figure 1 shows both types of clad silver wire.

Modulus of rupture (MOR) bars were obtained in Alite A-610 (99% Al_2O_3 - 1% MgO) from U. S. Storeware, AD999 (99.9% Al_2O_3 - 0.1% MgO) from Coors Porcelain Company, and BeO (99.8% BeO) from Brush Beryllium Company.

Alumina-yttria eutectic and strontium zirconate modulus of rupture bars were made at AED from hot pressed powders (see section below). Hot pressed discs were made to supply additional modulus of rupture bars.

Single crystal sapphire whiskers (99.99% Al_2O_3) in the form of 0.010-inch thick felted mat were received from Thermokinetic Fibers.

Specimens of Hiperco 27 alloy and Cubex alloy were prepared by annealing previously cut pieces. The annealing treatment for both Cubex alloy and Hiperco 27 alloy material was two hours at 900°C, (furnace temperature), in hydrogen, (entrance dewpoint -40°C) and a quick cool. The laminations were dusted with magnesium oxide to prevent sticking during the anneal.

b. Materials Processing by Hot Pressing Techniques

Several pressings of strontium zirconate ($SrZrO_3$) were made. The starting material in all cases was chemically pure $SrZrO_3$ from Titanium Alloy Manufacturing Division, National Lead Company. The first pressing was made by placing loose powder directly in a 1.375-inch diameter graphite hot press die and compacting the powder at

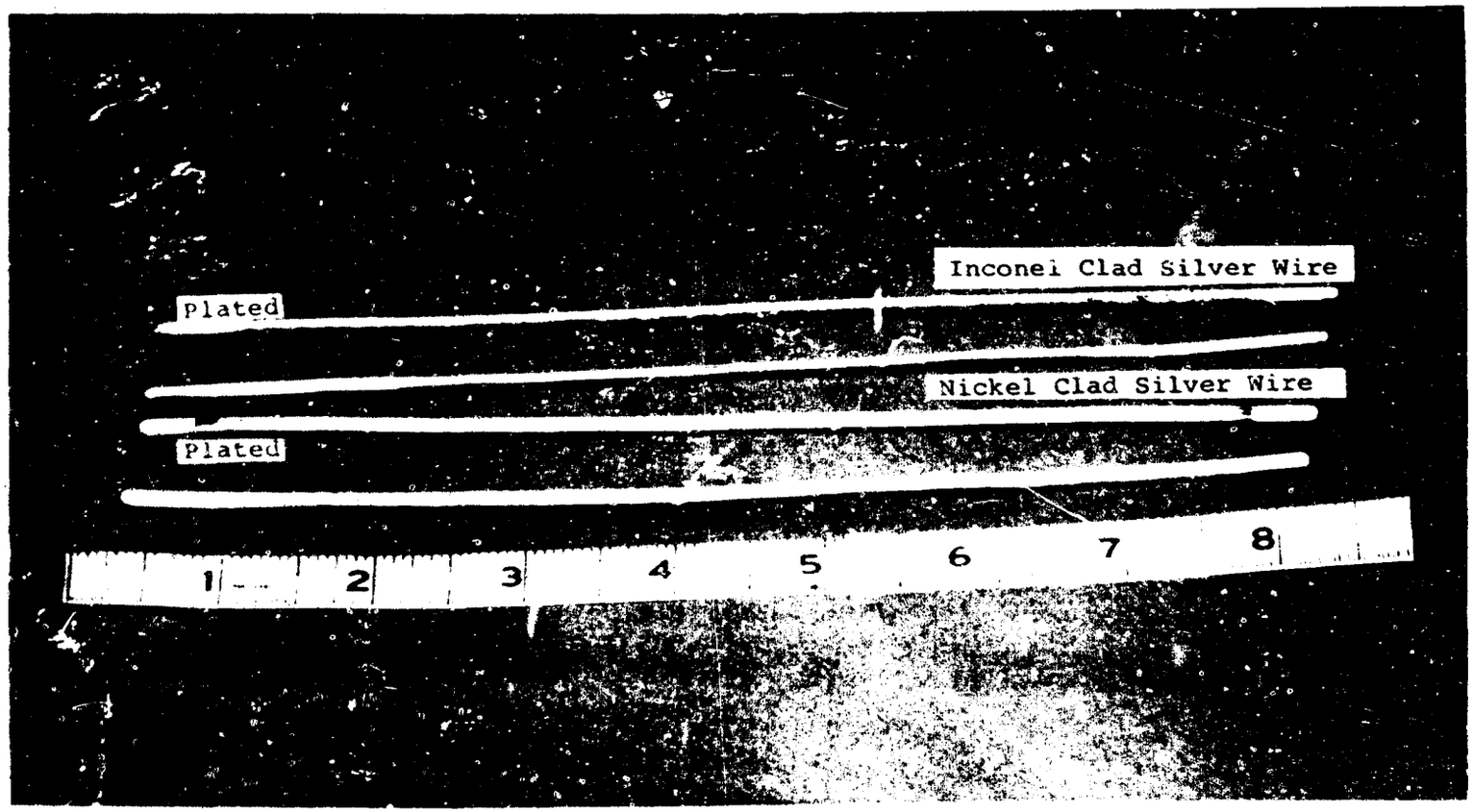


FIGURE 1. Clad Silver Wire Specimens Before And After Plating

5000 psi and 2800°F for 20 minutes. The resultant slug was dark in color and was subsequently heat treated in air for one hour at 2400°F to re-oxidize it. The heat treated slug was sliced on a water cooled precision diamond wheel. Examination of these slices revealed cracks and that only partial re-oxidation had been achieved.

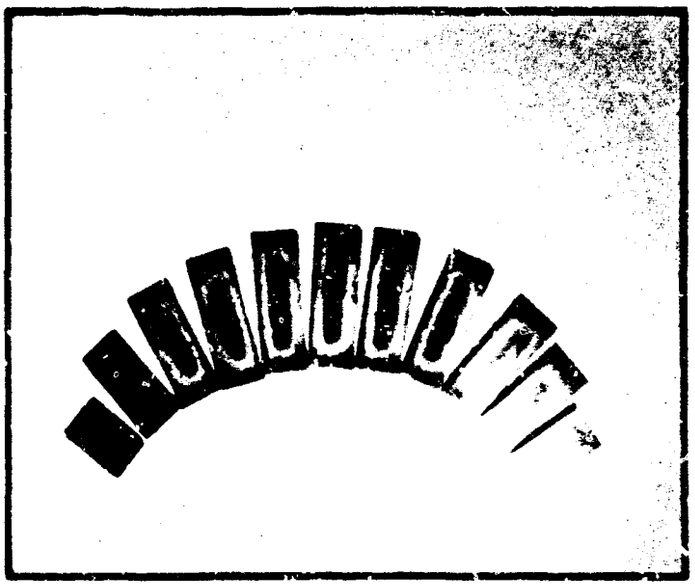
Cursory microstructure examination showed small grain size (1 to 10 microns size) and inhomogeneous (low-density) areas. The second slug was initially compressed cold in a steel die at 10,000 psi then hot pressed at 2900°F and 5000 psi for 40 minutes in the graphite die. The strontium zirconate slug reacted with and bonded to the graphite die punch faces. During cooling the higher expansion rate strontium-zirconate fractured. The third slug was initially cold pressed at 15,000 psi. GRAFOIL discs were placed between the cold compact and the punches to prevent bonding. Hot pressing was accomplished at 2800°F and 5000 psi for one hour. This slug was crack free.

Figure 2 shows a photograph of sectional slabs that were diamond sliced normal to the disc surfaces. A dark central core area is evident. These slabs were cut into MOR bars (0.010 inch by 0.010 inch by 1.000 inch) and several were exposed to potassium vapor.

Two hot pressed alumina-yttria eutectic disks (0.3-inch to 0.4-inches thick) were prepared using a ball milled (99.7% Al_2O_3 liner and balls) and calcined (1300°C, 1 hour) mixture of Al_2O_3 (82 mole percent) and Y_2O_3 (18 mole percent). Similar hot pressing techniques were used as those described for the $SrZrO_3$ material. The powder was cold pressed and then hot pressed at about 2550°F for 40 minutes. Figure 3 shows a photograph of the hot pressing assembly, designed to "float" the die body to achieve a more uniform compact density distribution. One alumina-yttria disk was diamond sliced into modulus of rupture bars and several exposed to potassium vapor. (Refer to Section III-B.)

c. Pre-Exposure Examinations and Tests

Magnetic tests were run on the Hiperco 27 alloy material in the form of Rowland rings. This material is also being used in the program for potassium vapor exposure specimens and transformer laminations. The Hiperco 27 alloy magnetic properties were determined in the "as received"



Disc was sectioned normal to its plane surface after heat treatment. Note dark center section.

FIGURE 2. Strontium-Zirconate Disc - Sectioned

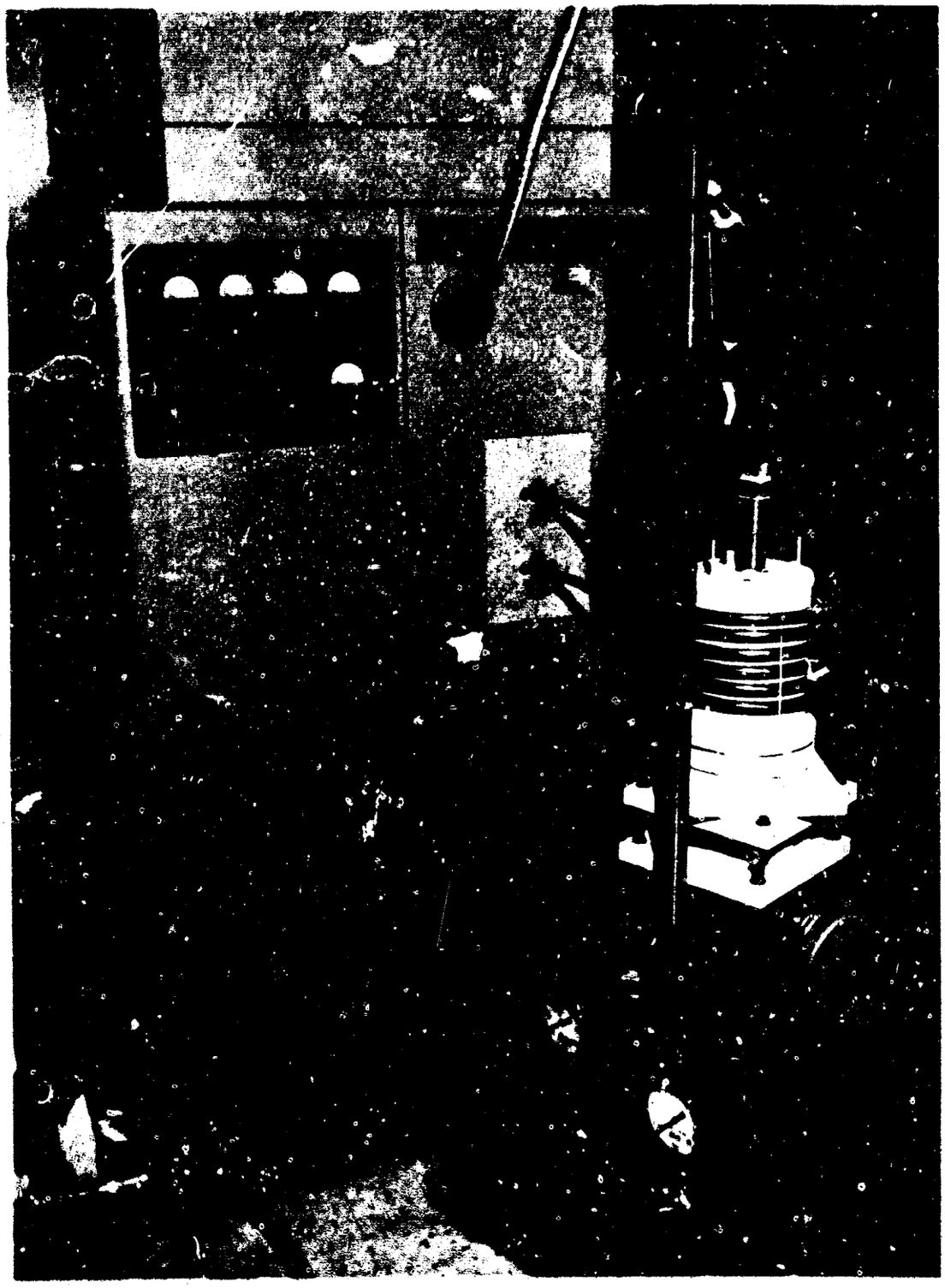


FIGURE 3. "Floating Die" Hot Press Assembly And R.F. Generator

(cold rolled) condition and the annealed condition. The a-c core loss in the annealed material is lower at high induction levels with square wave excitation than sine wave excitation at 400 Hz (cps) as shown in Figures 4 to 7. In the "as-received" condition, sine wave excitation does not always cause higher losses, especially at medium flux densities at 400 Hz (cps), as shown in Figures 8 to 11.

The remaining core loss curves, apparent power curves, the d-c hysteresis loops, the a-c hysteresis loops, and the d-c magnetization curves are shown in Figures 12 to 20. The Constant Current Flux Reset (CCFR) data is shown in Table I.

In all tests, the temperature rise of the cores was checked to prevent a significant change in the results.

The 25,000 Hz (cps) specific core loss and apparent power curves were made at low flux densities due to power limitations of the Communications Measurements Laboratory (CML) power supply. The rise time of the CML square wave excitation was 12 microseconds.

The following magnetic test equipment was used:

1) Ballantine Peak Voltmeter (two units)

2) Mosely Autograf DC Voltmeter, Model 22

3) K & S DC Regulated Power Supply

4) Hewlett Packard Oscilloscope, Model 130 B

5) Hewlett Packard Electronic Counter, Model 521 CR

6) Ballantine DC, AC Precision Calibrator, Model 421

7) Communications Measurements Laboratory (CML) Sine or Square Wave Power Supply with CML Sine or Square Wave Oscillator

8) Hewlett Packard RMS Voltmeter, Model 3400 A

9) Hewlett Packard 400 H Average Reading Voltmeter

10) NJE DC Power Supply

11) John Fluke, Model 102, VAW Meter

12) Tektronix Oscilloscope, Type 516

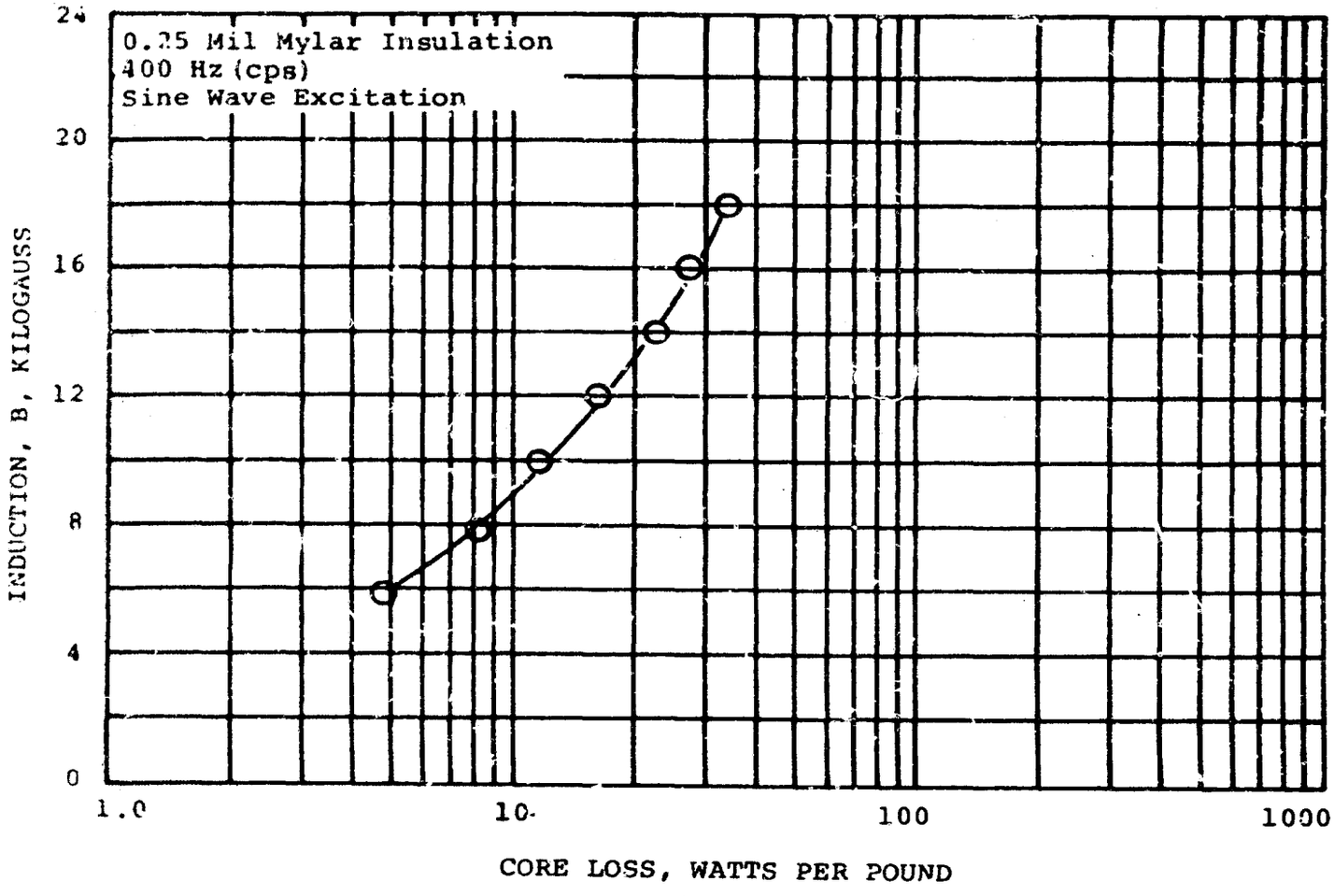


FIGURE 4. Core Loss, P_c, Annealed 0.008-Inch Thick Hiperco 27 Alloy Rowland Rings With Sine Wave Excitation

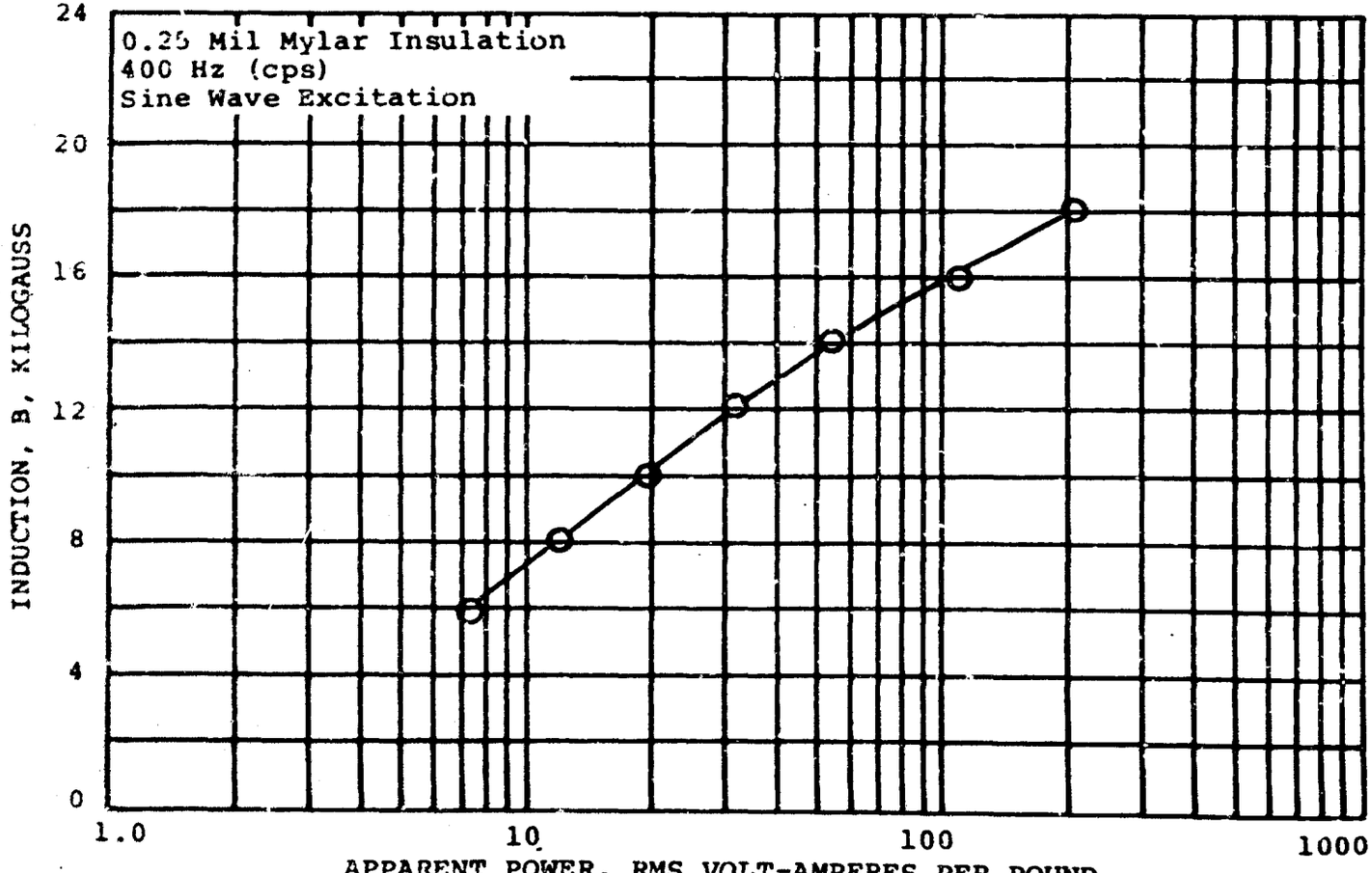


FIGURE 5. Apparent Power, P_a, Annealed 0.008-Inch Thick Hiperco 27 Alloy Rowland Rings With Sine Wave Excitation

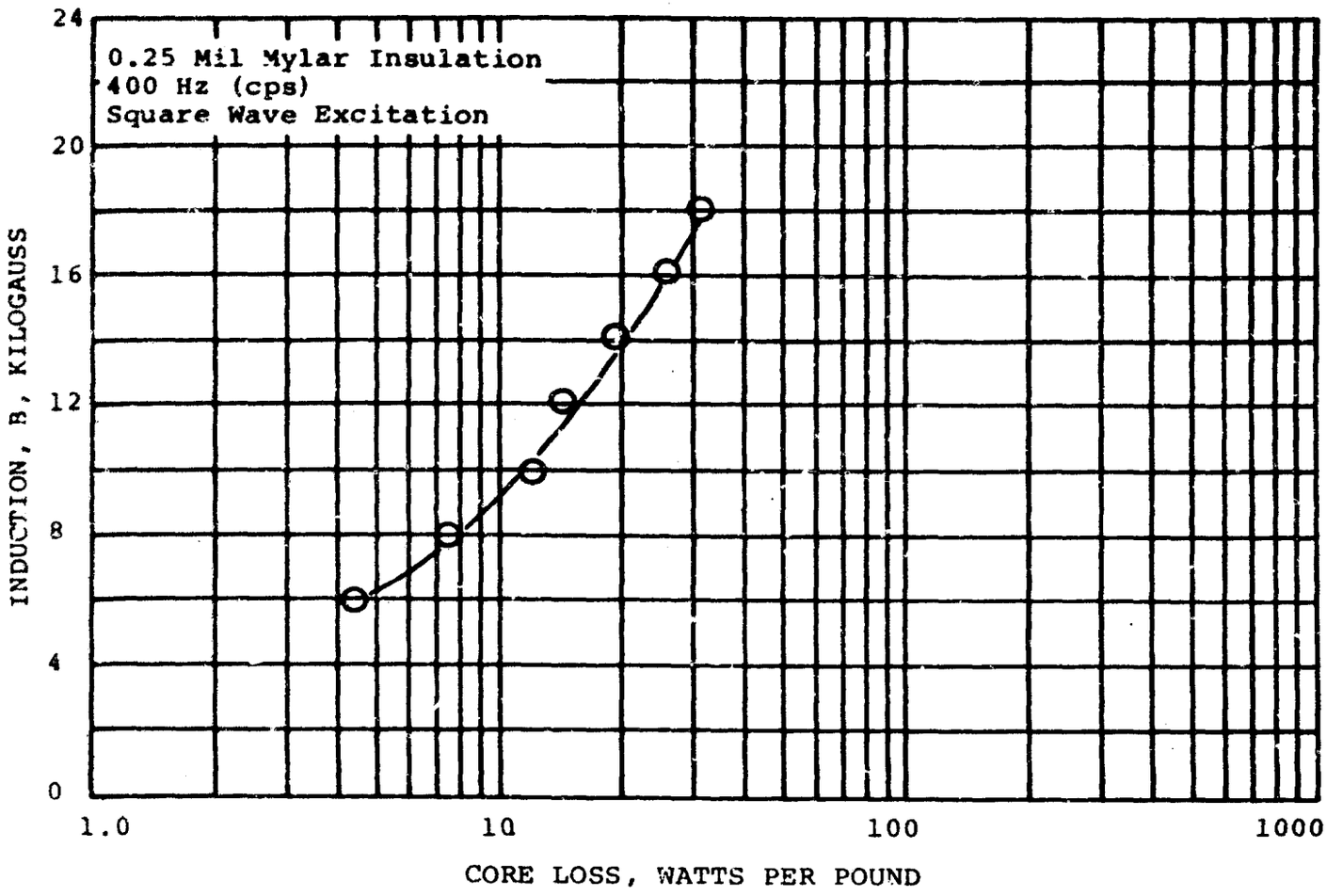


FIGURE 6. Core Loss, P_c sq., Annealed 0.008-Inch Thick Hiperco 27 Alloy Rowland Rings With Square Wave Excitation

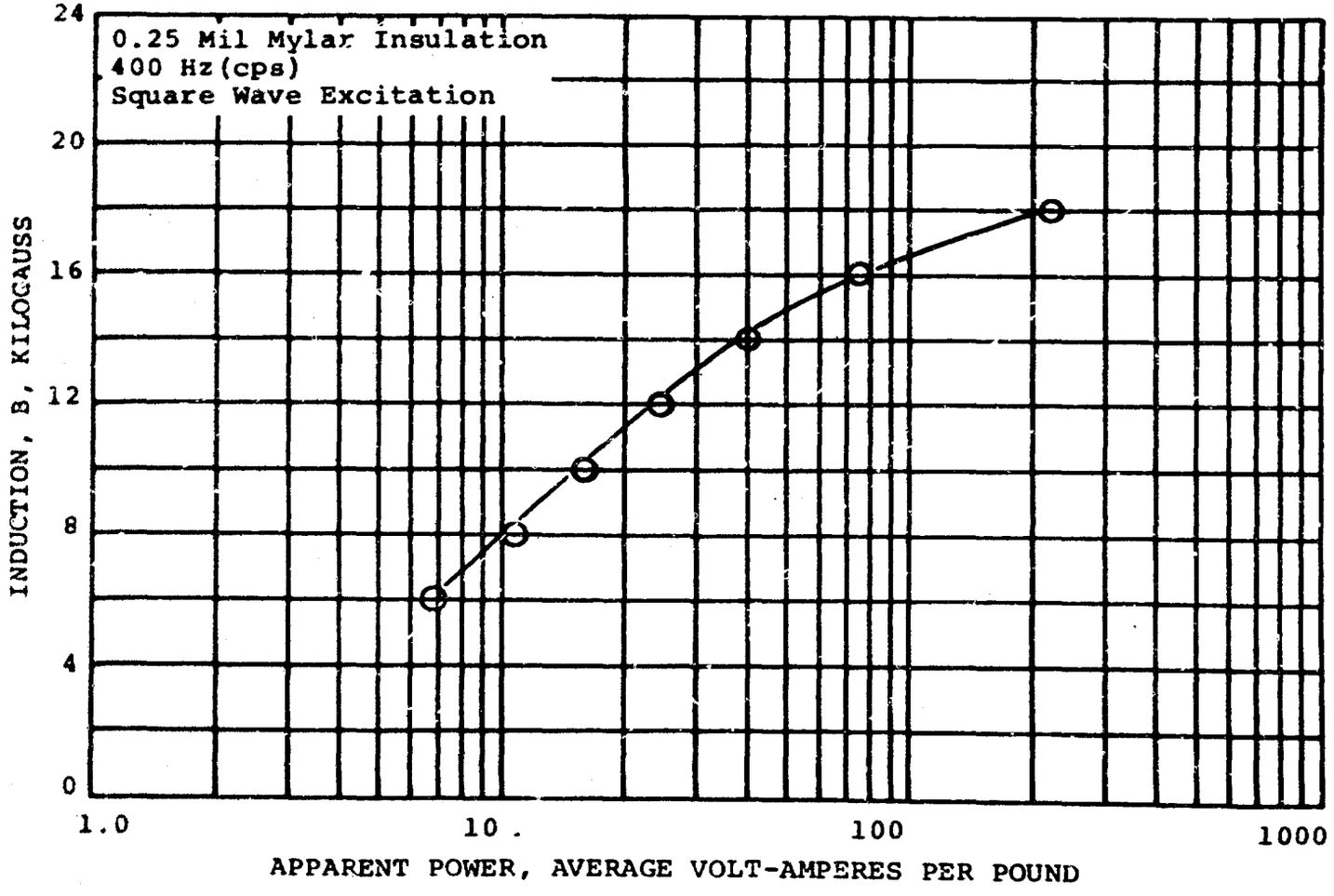


FIGURE 7. Apparent Power, $P_{a\ sq.}$, Annealed 0.008-Inch Thick Hiperco 27 Alloy Rowland Rings With Square Wave Excitation

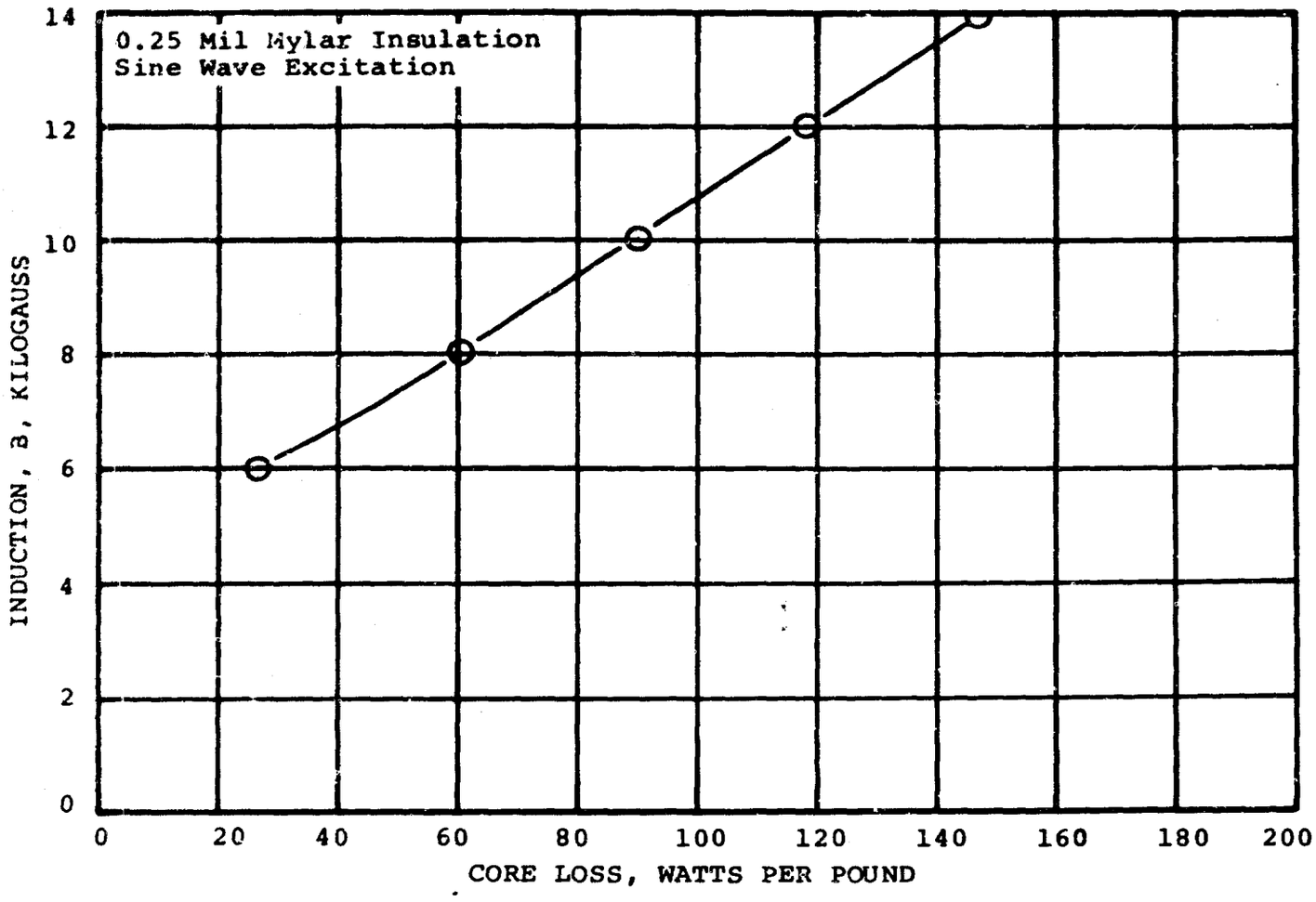


FIGURE 8. Core Loss, P_C, As-Received 0.008-Inch Thick Hiperco 27 Alloy Rowland Rings With Sine Wave Excitation

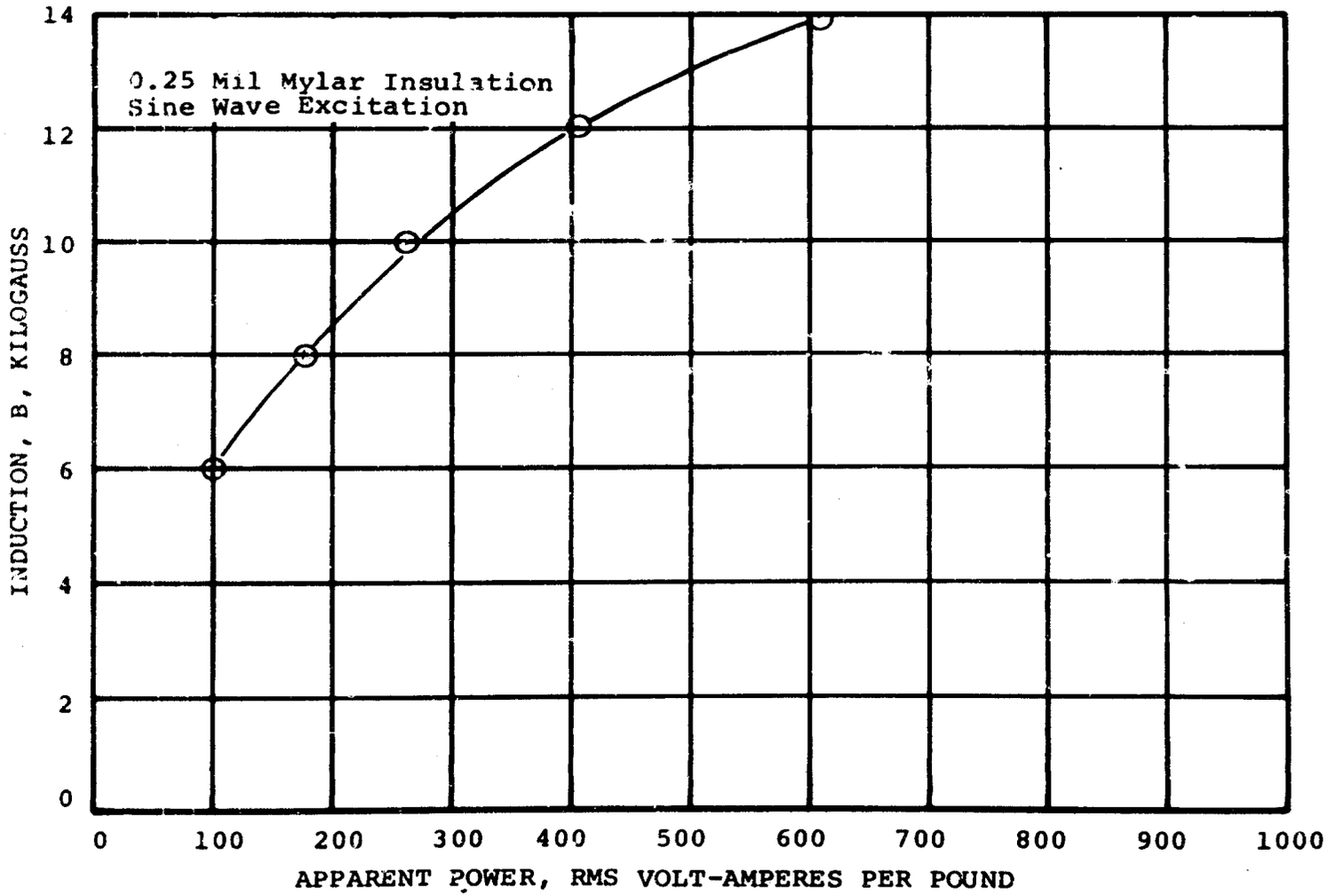


FIGURE 9. Apparent Power, P_a, As-Received 0.008-Inch Thick Hiperco 27 Alloy Rowland Rings With Sine Wave Excitation

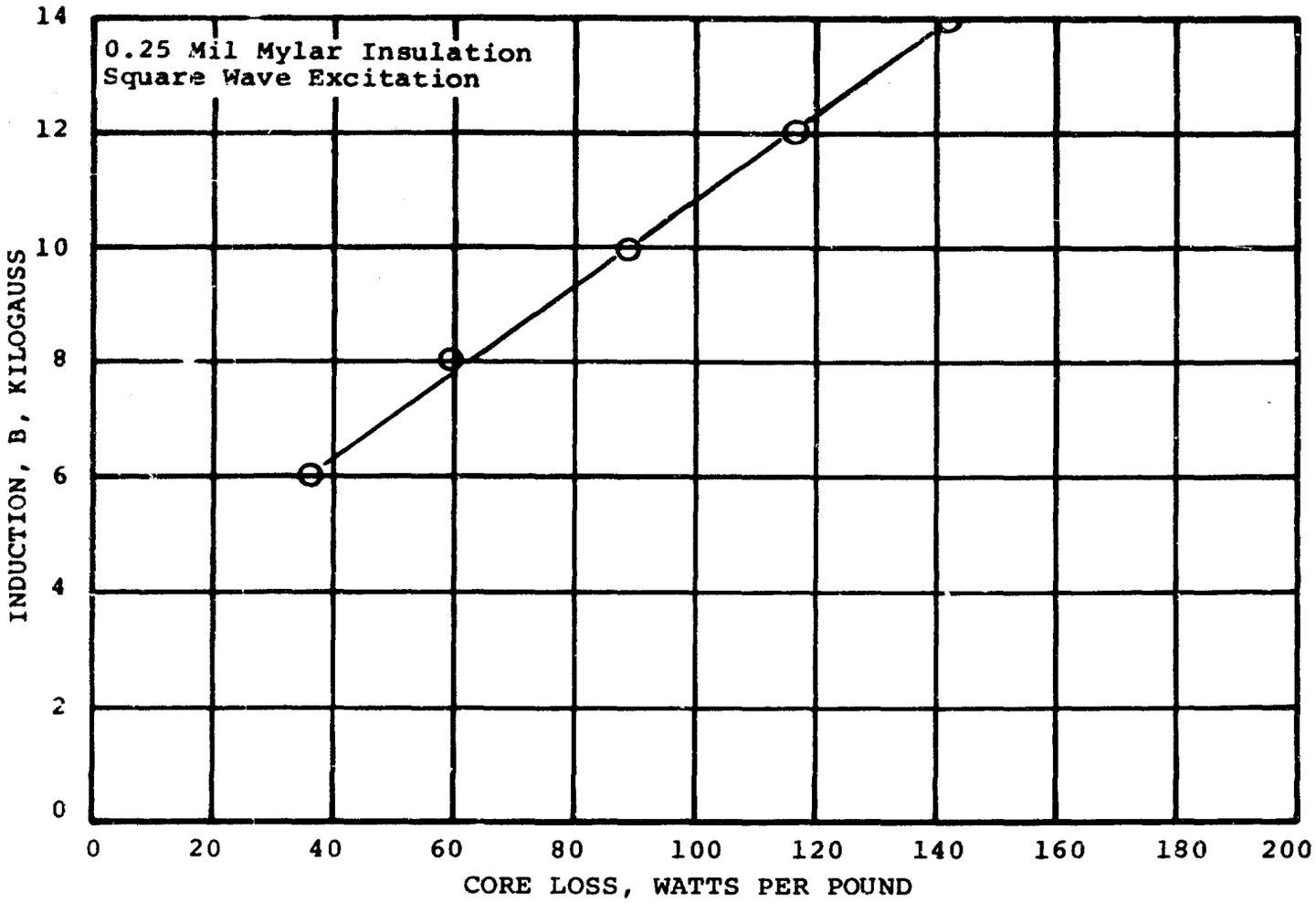


FIGURE 10. Core Loss, $P_{c\ sq.}$, As-Received 0.008-Inch Thick Hiperco 27 Alloy Rowland Rings With Square Wave Excitation

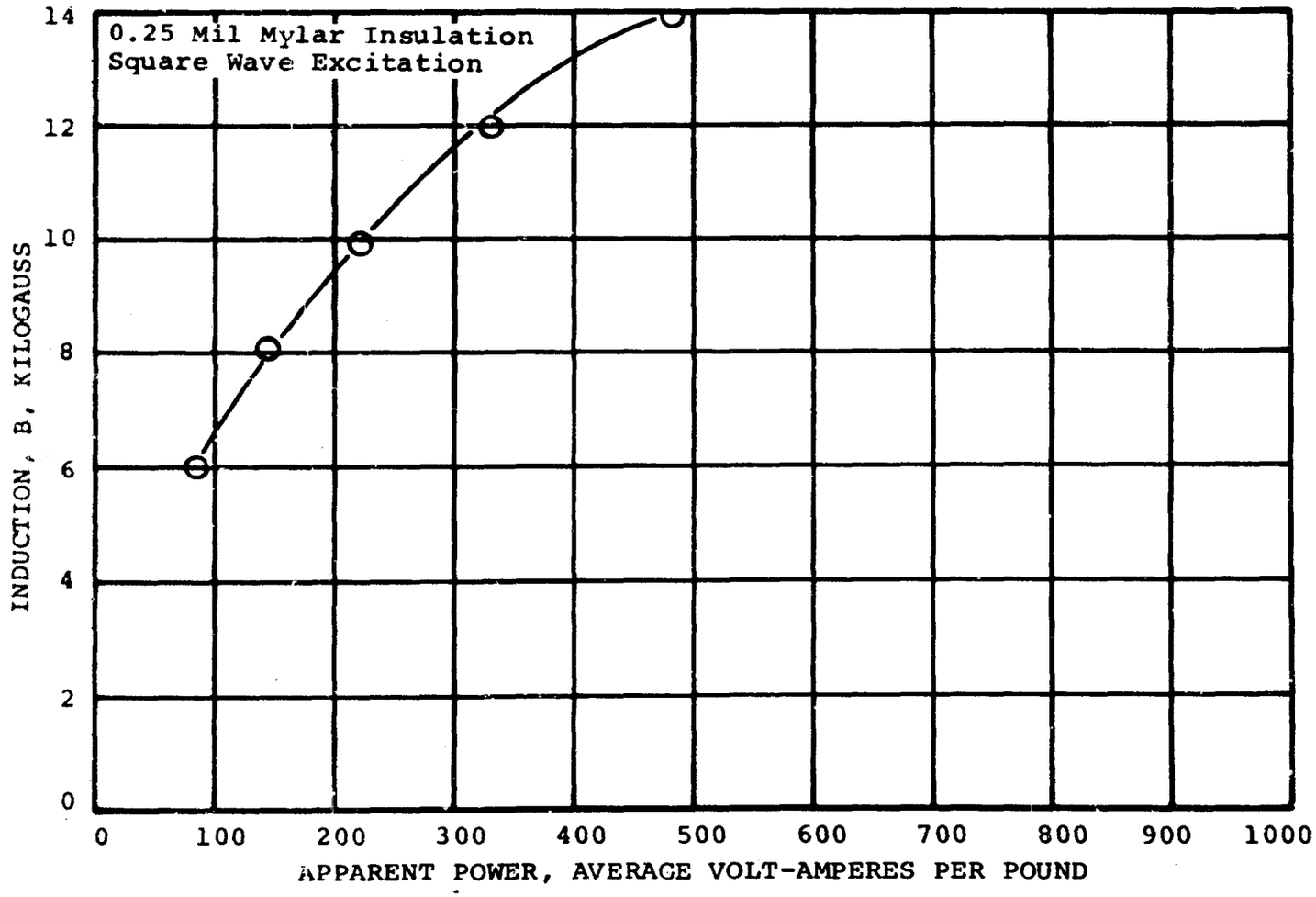
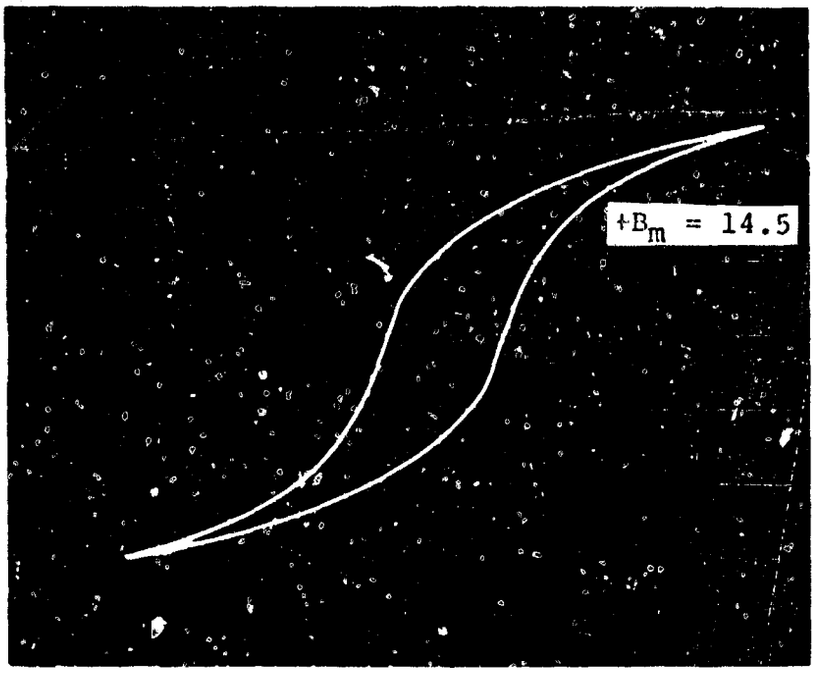


FIGURE 11. Apparent Power, $P_{a\ sq.}$, As-Received 0.008-Inch Thick Hiperco 27 Alloy Rowland Rings With Square Wave Excitation

Sine Wave
Excitation

B = 5 Kg/div.
H = 25 Oe/div.



Square Wave
Excitation

B = 5 Kg/div.
H = 25 Oe/div.

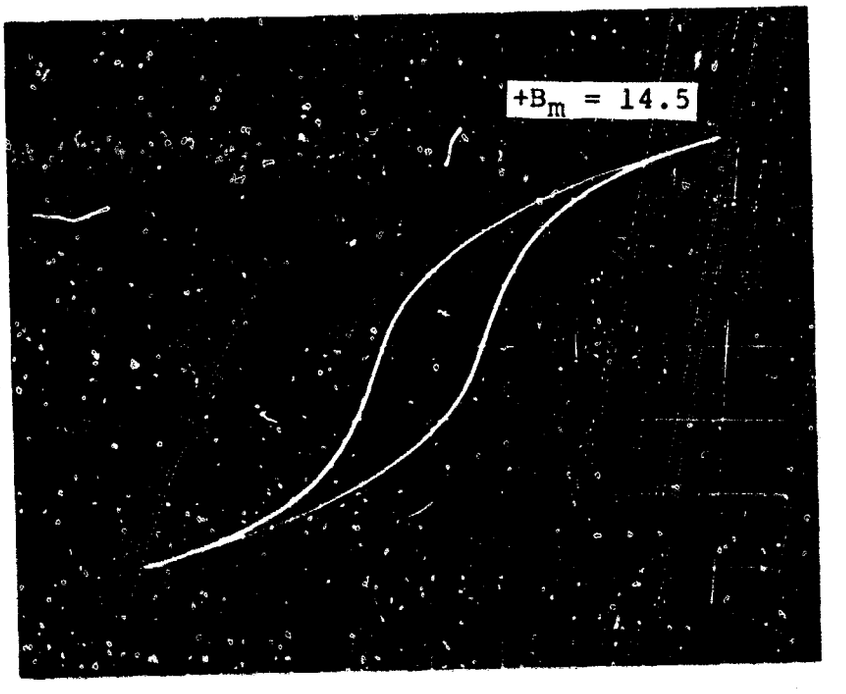


FIGURE 12. AC Hysteresis Loops, 0.008-Inch Thick As-Received Hiperco 27 Alloy Rowland Rings, 0.25 Mil Mylar Insulation, 400 Hz

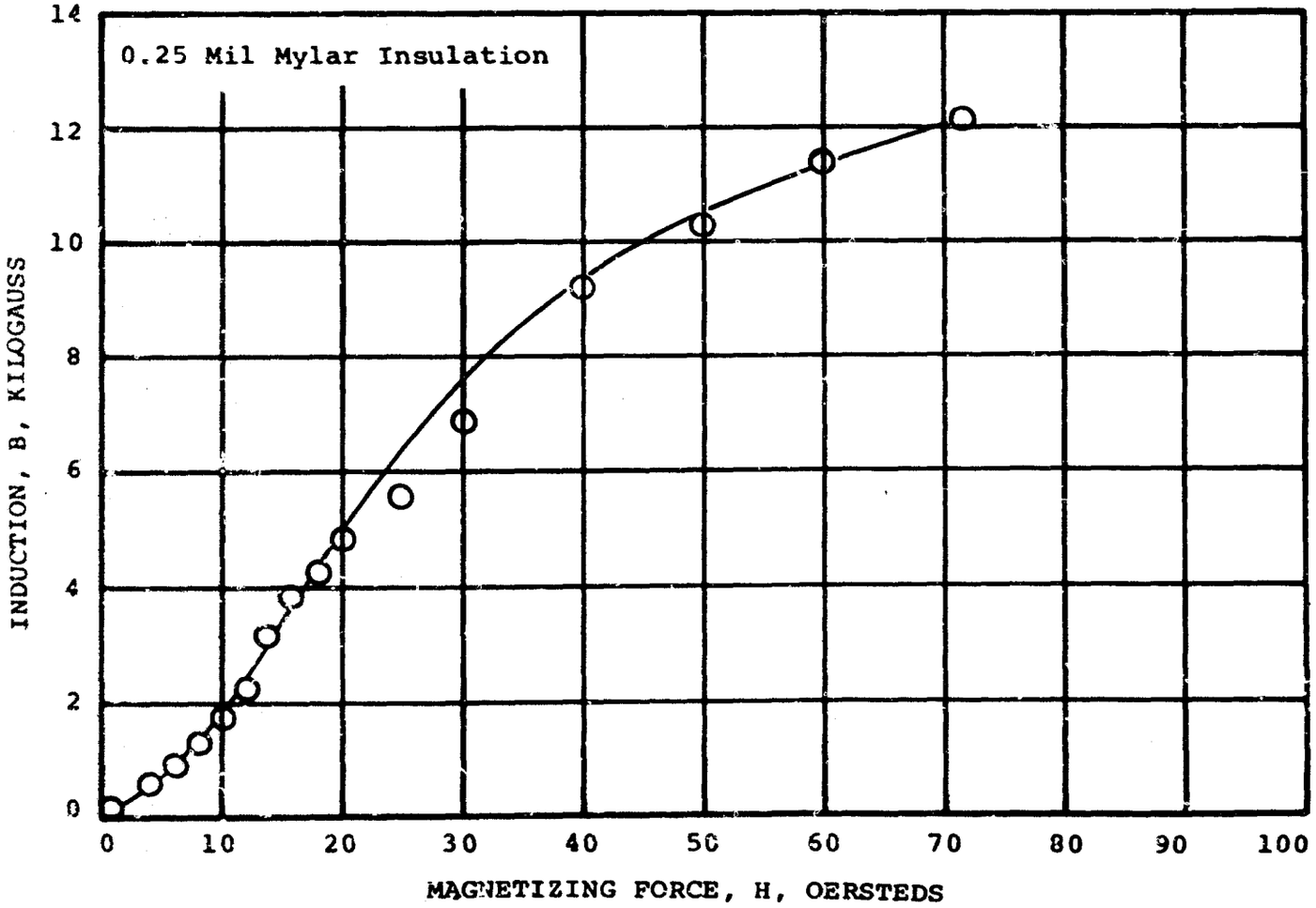


FIGURE 13. DC Magnetization Curve, As-Received 0.008-Inch Thick Hiperco 27 Alloy Rowland Rings

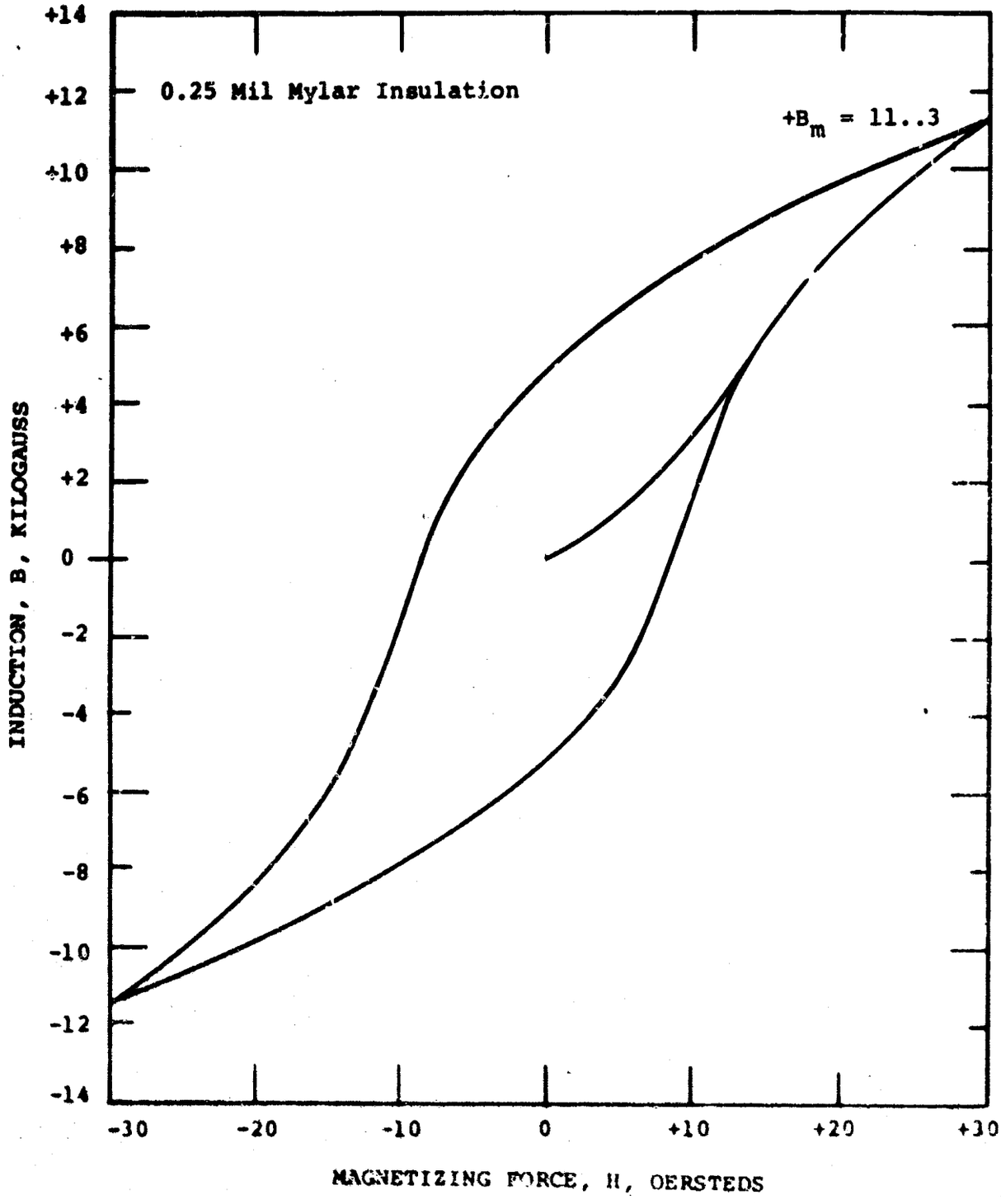


FIGURE 14. DC Hysteresis Loop 0.008-Inch Thick As-Received Hiperco 27 Alloy Rowland Rings

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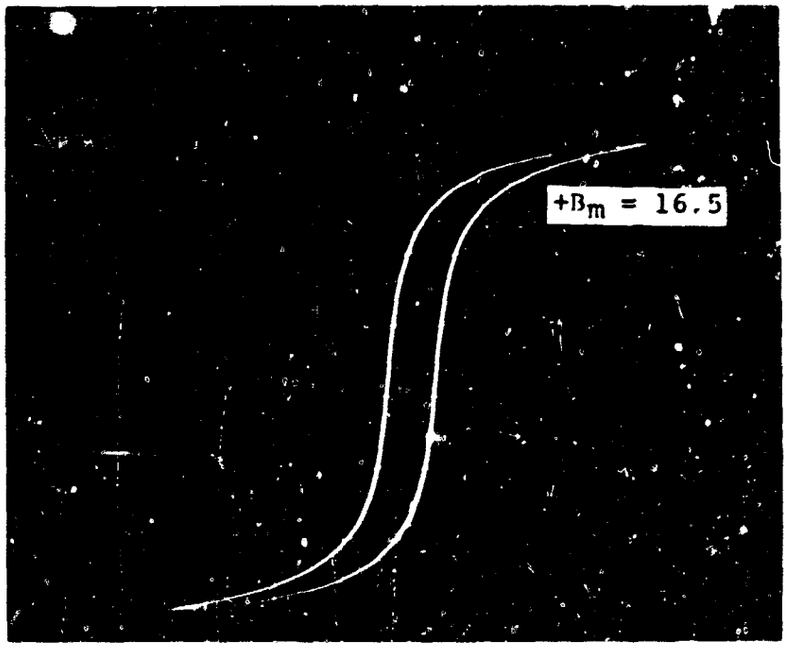
Square Wave
Excitation
B = 5 Kg/div.
H = 5 Oe/div.



Sine Wave
Excitation
B = 5 Kg/div.
H = 5 Oe/div.

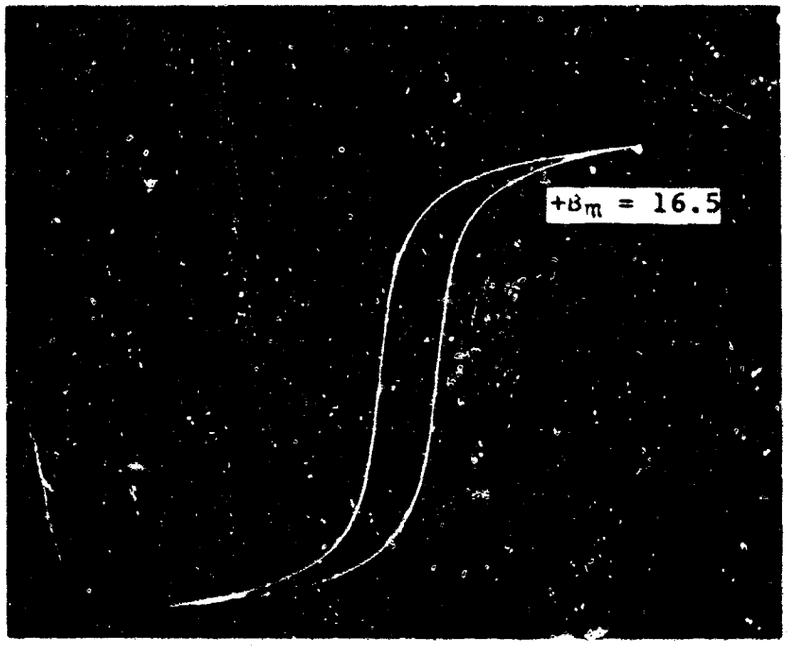


FIGURE 15. AC Hysteresis Loops, Annealed 0.006-Inch Thick Hiperco 27 Alloy Rowland Rings, 0.25 Mil Mylar Insulation, 400 Hz (cps)

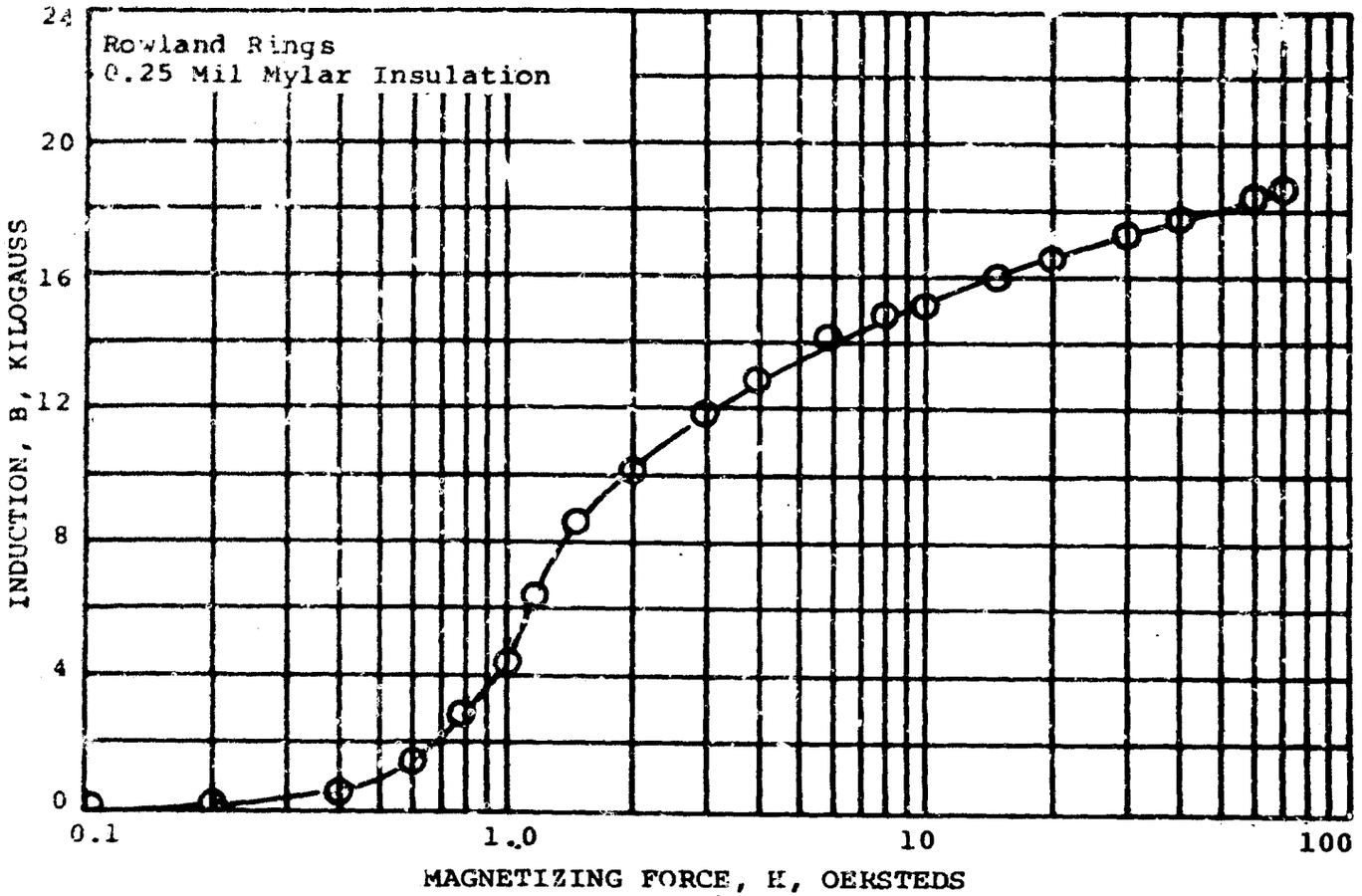


FIGURE 18. DC Magnetization Curve, Annealed 0.008-Inch Thick Hiperco 27 Alloy Rowland Rings

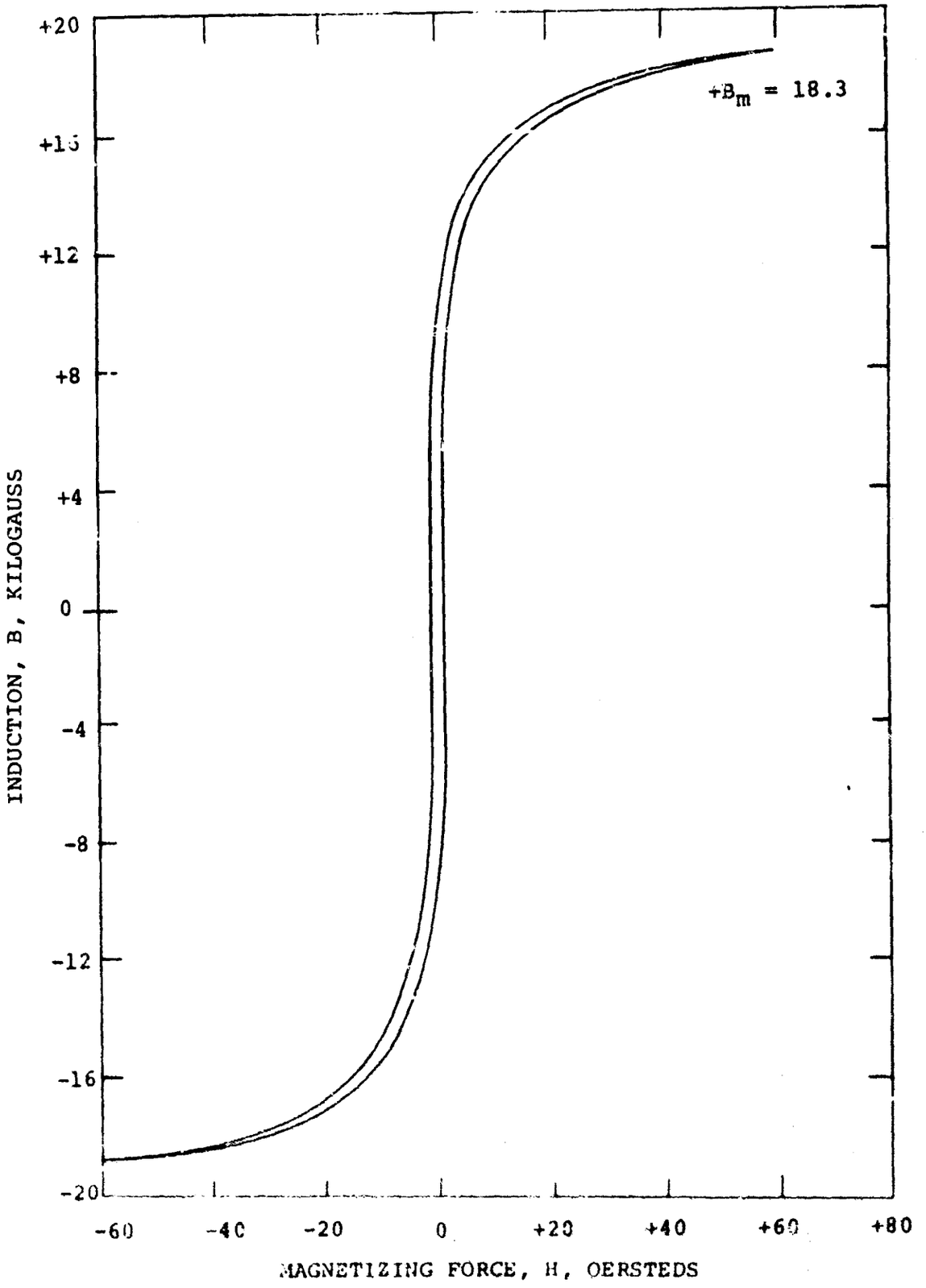


FIGURE 19. DC Hysteresis Loop, 0.008-Inch Thick Annealed Hiperco 27 Rowland Rings

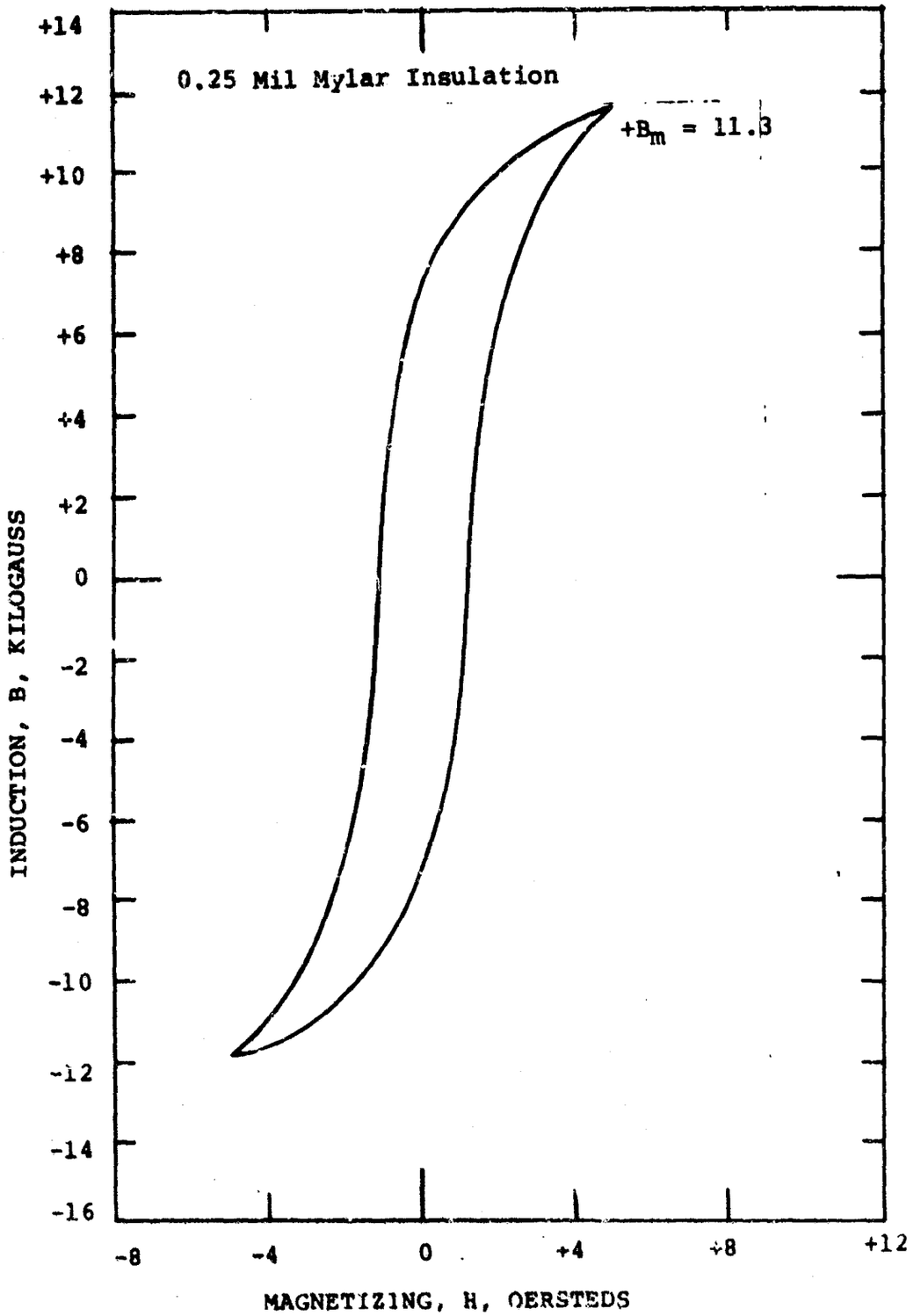


FIGURE 20. DC Hysteresis Loop 0.008-Inch Thick Annealed Hiperco 27 Alloy Rowland Rings

TABLE I. CCFR PROPERTIES OF ANNEALED 0.008-INCH THICK HIPERCO 27 ALLOY ROWLAND RINGS, SINE CURRENT 400 Hz (cps)

T	B_r	AT	DAT
Squareness Ratio B_r/B_m	Gausses	H_1 (Oersteds)	$\Delta H(H_2-H_1)$ (Oersteds)
0.781	11,672	0.653	1.182

SAT	G	H_m	
B_m (Gausses)	Gain x 10^{-3}	Oersteds SAT&T	AT&DAT
14,440	4.21	10	20

Where:

B_r = Residual induction.

B_m = SAT = Maximum flux density.

AT = DC reset magnetizing force, H_1, required to produce a cycle change in induction equal to 1/3 of a value of two times SAT.

DAT = The incremental change in magnetizing force ($H_2 - H_1$) where H_2 is equal to the d-c reset magnetizing force required to produce a cyclic change in induction equal to 2/3 of a value two times SAT.

H_m = Peak magnetizing force.

NOTE: Discussion of testing and description of terms is given in Appendix.

The remaining magnetic tests were made to ASTM Designation: A346-64 (Adopted 1958; Revised 1964) and ASTM Designation: A341-64 (Adopted 1949; Revised 1964).

Pre-exposure mechanical tests were conducted on magnetic material (Cubex and Hiperco 27 alloy), conductors (Inconel and Nickel clad silver, rhodium, and inidium), and modulus of rupture bars (Beryllia, Alite A-610, strontium zirconate, and atumina-yttria eutectic). Data from these tests will be used, along with other examinations, to establish a pre-exposure base for potassium vapor exposure testing.

2. Potassium Vapor Exposure Test Containers

a. Test Capsules

Cleaned, welded, and leak checked stainless steel capsules were assembled with the addition of a clean 0.030-inch thick perforated disc to each capsule. These discs have 50% open area with 0.075-inch diameter holes spaced on 0.100-inch staggered centers. Discs have a diameter larger than the capsule inside diameter resulting in a tight fit so that they remain in position. They are located in the capsule by a groove around the capsule above the liquid potassium reservoir. Table II gives the tube material chemical analyses. After assembly, stainless steel capsules were degassed according to the following:

1) Capsules were placed in a Marshal vacuum furnace, and furnace evacuated to 10^{-6} torr.

2) Capsules were degassed at 1100°F for 8 hours.

3) Capsules were cooled in a vacuum of 10^{-6} torr then the furnace back-filled with high purity dry argon.

4) The furnace was opened and the capsules transferred to argon filled transport containers.

5) Transport containers were closed and a 40 psig pressure of argon applied to the containers to seal "O" rings.

Capsules are presently sealed in transport containers with the 40 psig argon pressure. Prior to loading, capsules will be re-evacuated.

TABLE II. STAINLESS STEEL TUBE CHEMICAL ANALYSIS

Chemical Composition (suppliers analysis)	
Element	Percent Content
C	0.051
Mn	1.60
P	0.016
S	0.011
Si	0.63
Cr	17.84
Ni	11.99
Cu	0.13
Cb/Ta	0.87
Mo	0.35

NOTE: Stainless steel tubing meets specifications MIL-T-8808A and AMS 5571B. Heat No. 28979. 1/2 inch OD x 0.028 inch thick wall

Columbium-1% zirconium capsule material was received as 0.500-inch outside diameter tubing with 0.020-inch thick wall. Table III gives the composition of the Wah Chang starting material and the oxygen content of the as-redrawn tube.

Tubes were processed according to the following:

1) Tubing was cut to length.

2) Tubes were cleaned in petroleum ether.

3) Tubes were rinsed in chemically pure acetone.

4) Tubes were oven dried at 200°F for 30 minutes.

5) Tube ends were pinched closed giving approximately 3/16-inch flat length.

6) Pinched ends were recleaned with chemically pure acetone and air dried at 200°F for 30 minutes.

7) Tubes were placed in the inert atmosphere glove box vestibule and the vestibule evacuated.

8) Tubes were transferred to the inert atmosphere glove box.

9) Tube pinched ends were TIG welded in a continuously monitored argon atmosphere. Combined oxygen and moisture content of the argon atmosphere was maintained below 0.3 ppm as shown by oxygen and moisture monitors.

10) All capsules were helium leak tested and found to be leak free.

11) Perforated discs of columbium-1% zirconium with the same perforations as the stainless steel discs were prepared. These discs have a diameter of 29/64 inches.

12) Capsules were then grooved, the perforated disc installed, and a second groove placed above the disc thus securing it in place.

13) Completed capsules were then vacuum annealed by heating them to 2200°F in a vacuum of 10^{-8} torr and maintaining this temperature for one hour.

TABLE III. COLUMBIUM-1% ZIRCONIUM TUBE CHEMICAL ANALYSIS

Heat Analysis (Suppliers Analysis)		
Composition in Percent		
	Top	Bottom
Zr	0.80	0.82
Cb	Balance	Balance
Impurity Content, ppm		
Al	<20	<20
B	<1	<1
C	50	40
Cd	<5	<5
Co	<10	<10
Cr	<20	<20
Cu	<40	<40
Fe	<50	<50
H	3.9	4.6
Hf	<80	<80
Mg	<20	<20
Mn	<20	<20
Mo	35	35
N	35	35
Ni	<20	<20
O	<50	<50
Pb	<20	<20
Si	<50	<50
Sn	<10	<10
Ta	<500	<500
Ti	<40	<40
V	<20	<20
W	70	80
Product chemistry of 0.625 inch OD by 0.065 inch ID tube, ppm		
C		<30
N		48
O		120
H		3.6
Product chemistry of 0.400 inch OD by 0.020 inch wall tube, ppm		
O		228

14) Capsules were furnace cooled to room temperature and removed from furnace. Care was exercised to prevent contamination.

b. Test Containers

Stainless steel containers which will contain the potassium vapor exposure capsules during test are completed and ready to be sealed with test capsules inside.

c. Transport Container

Stainless steel containers to transport clean potassium vapor exposure capsules to and from the potassium loading facility were completed. Containers are made of three inch schedule 40 type 316 stainless steel pipe with a 0.375-inch plate of the same material welded to form a bottom. The top is of type 316 stainless steel with an "O" ring for sealing and is held in place by 3 studs which are welded to the pipe.

Each container top has two valves. One valve is used for container evacuation and the other to introduce a protective gas atmosphere. Figure 21 shows examples of these containers.

d. Rowland Ring Core Boxes

Figure 22 shows two columbium-1% zirconium rings which will be used to fabricate a Rowland ring core box. These rings were rolled from 0.030-inch thick sheet, edges beveled forming a butt joint, and this joint electron beam welded.

The longitudinal seam on each ring was electron beam butt welded as follows: The rings were fixtured by fastening a stainless steel hose clamp around the center of each ring and tightening the clamp until the desired fitup was obtained. This was determined by holding the joint to be welded in front of a light and examining for gaps. The rings were then tacked with a 1/4-inch long tack weld at one end, removed from the chamber and examined the second time for a gap in the joint. If a gap was noticed the hose clamp was moved and tightened until the gap was closed. The rings were then tacked at the other end of the joint and examined the second time for fitup. After tacking, the hose clamp was removed and a small tack made in the center of each ring. The longitudinal weld was made in the free-state without the use of fixturing.

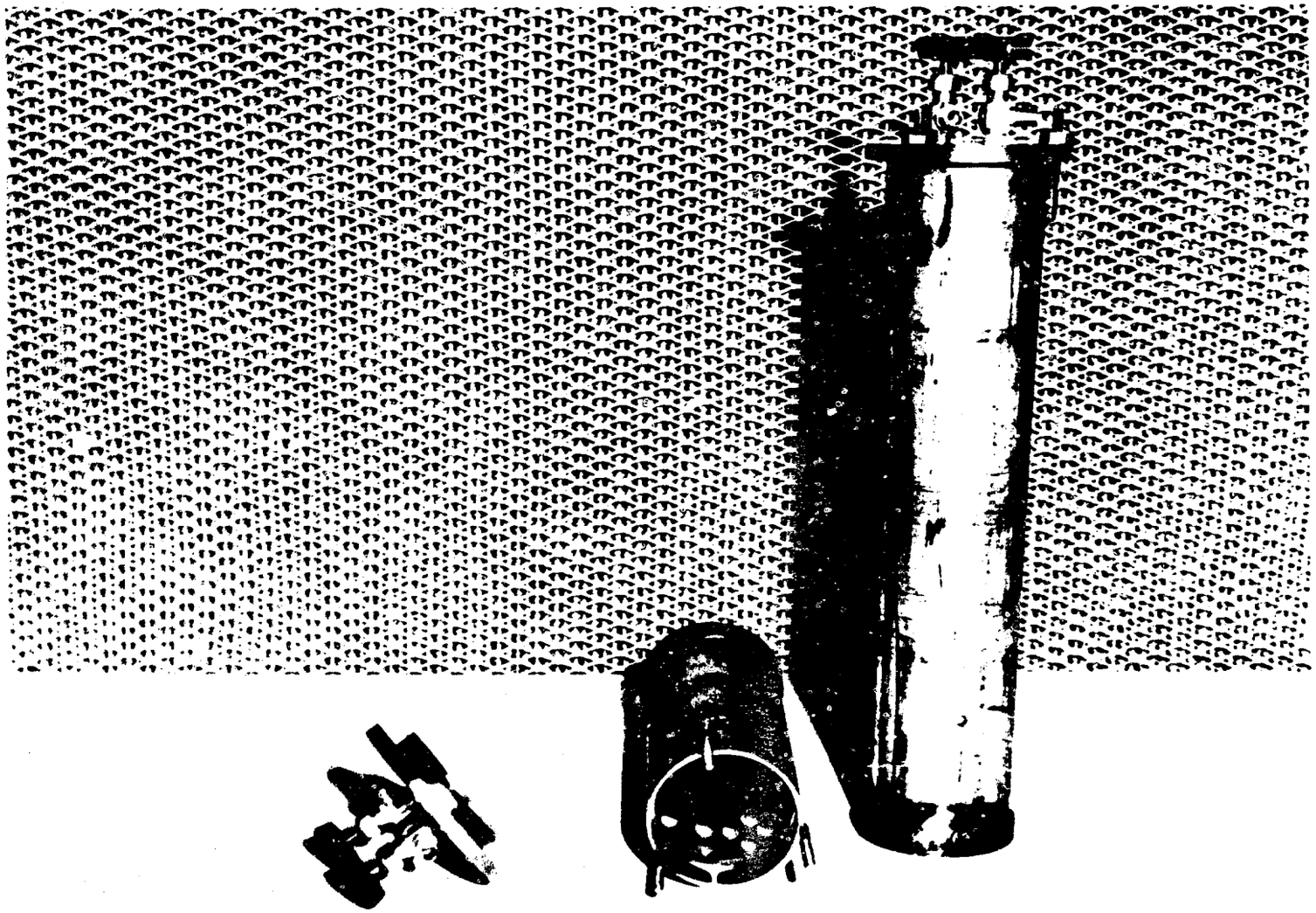


FIGURE 21. Assembled and Disassembled Transport Containers

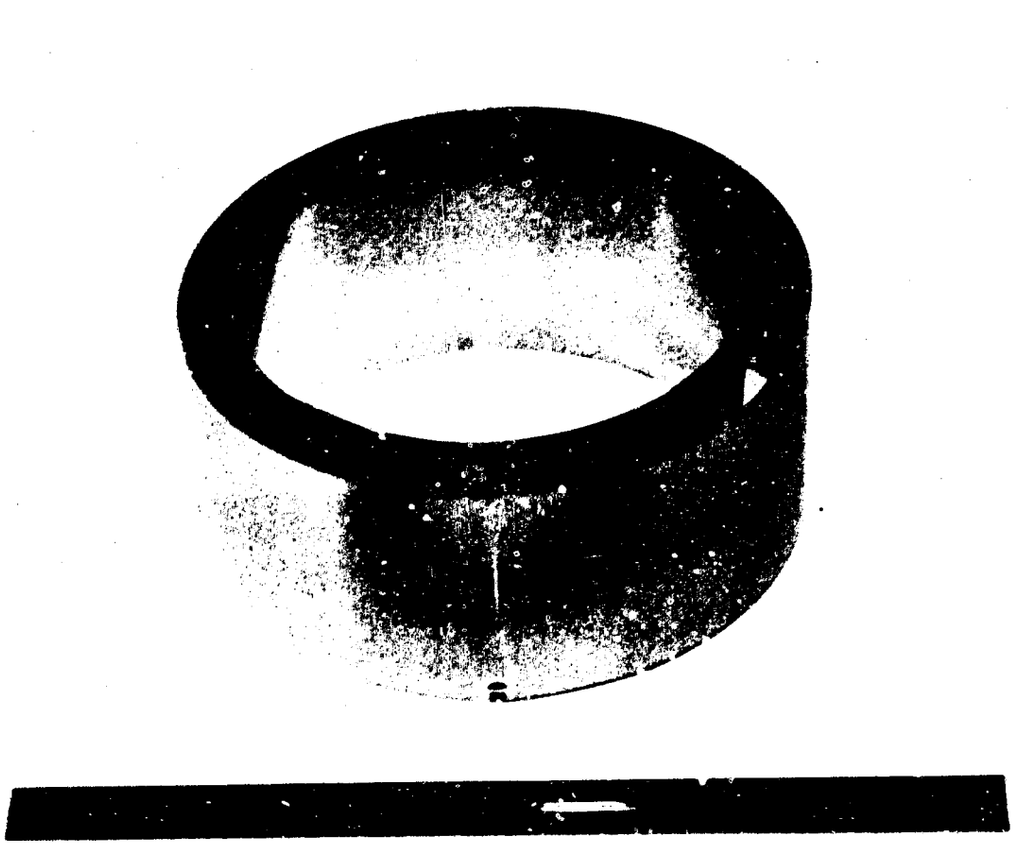


FIGURE 22. Rowland Ring Core Box Sides

After welding, these rings were vacuum annealed by heating them to 2200°F at a pressure of 10^{-8} torr and holding this temperature for one hour. These rings were handled with extreme care to avoid contamination. The design of a ceramic insulator to join the columbium-1% zirconium metal rings together by active metal brazing techniques showing in Figure 23. This non-metallic ring is necessary to break the one-turn circuit of a metallic core box.

e. Conductor Continuous Measurement Containers

The test container for continuously monitoring the performance of an electrical conductor in 600°C potassium vapor was designed. The container consists of a six-inch length of six inch diameter schedule 40 pipe in type 316 stainless steel, top and bottom plates of 0.125-inch thick type 316 stainless steel plate, a type 347 stainless steel potassium fill and evacuation tube 0.500 inch outside diameter, and two potassium vapor resistant electrical feedthroughs. All container materials except the electrical feedthroughs have been received. The test container is complete except for the container top. Figure 24 is an assembly drawing of this container.

B. PROCESSES AND TECHNIQUES FOR POTASSIUM VAPOR RESISTANT ELECTRICAL DEVICE FABRICATION

Several materials and combinations of materials, applied in various ways, are being investigated as potassium vapor resistant electrical insulation for conductor and interlaminar applications. High alumina materials, aluminum nitride, alumina-yttria eutectic, and strontium zirconate are being either sprayed, radio frequency (R.F.) sputtered, or slip coated and fired on conductor or metal substrates. The substrates include Inconel 600, nickel, rhodium, iridium, and Hiperco 27 alloy. Nickel aluminide, zirconium, and titanium are being evaluated as a binder between the metal and the various ceramic insulations.

Progress in the investigation of processes and techniques for fabrication of potassium resistant materials into electrical components is given in the following section.

1. Specimen Fabrication

a. Short Term Potassium Vapor Exposure Test Specimens

Fourteen specimens were prepared for short term (200 hours) 600°C potassium vapor exposure tests. Eight

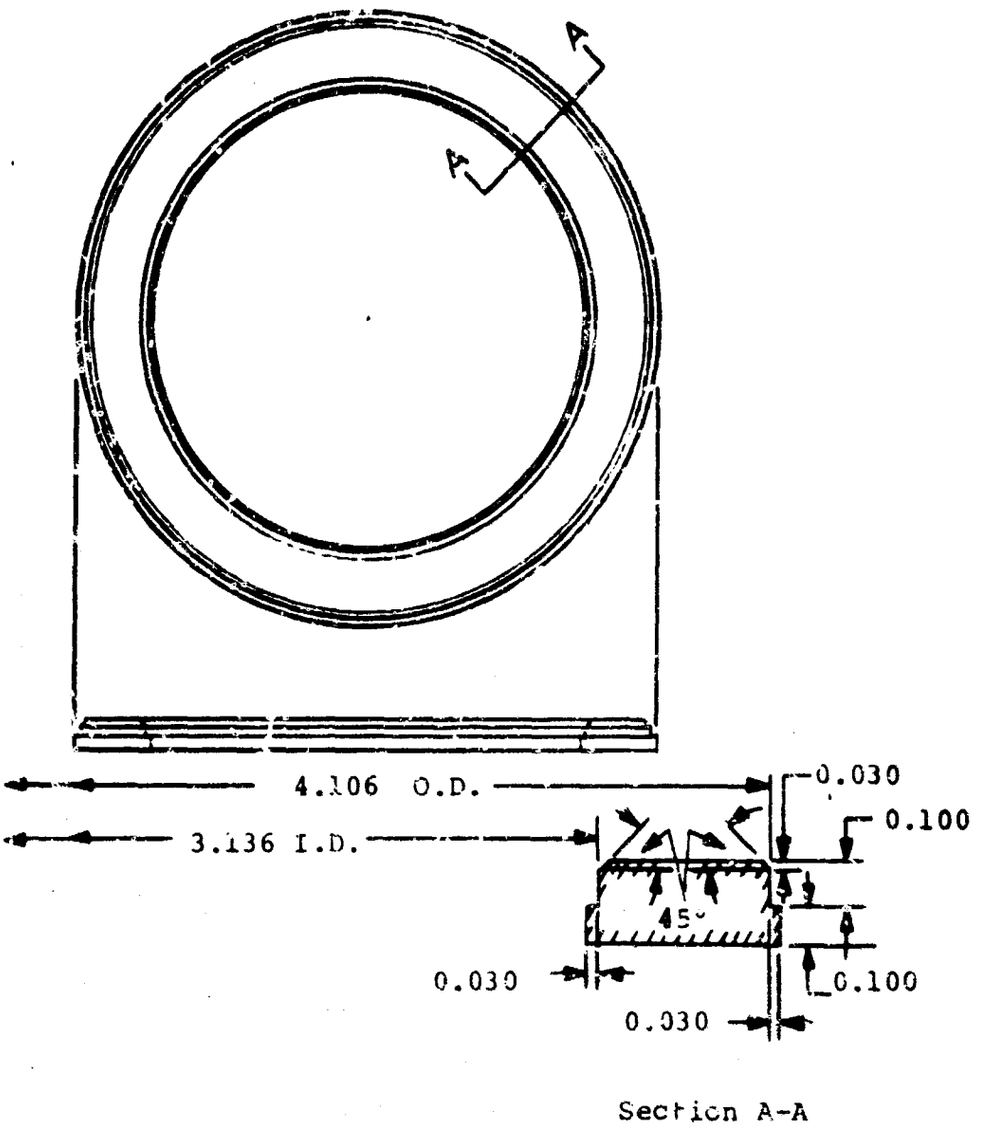


FIGURE 23. Rowland Ring Core Box Ceramic Washer - Alite A-610

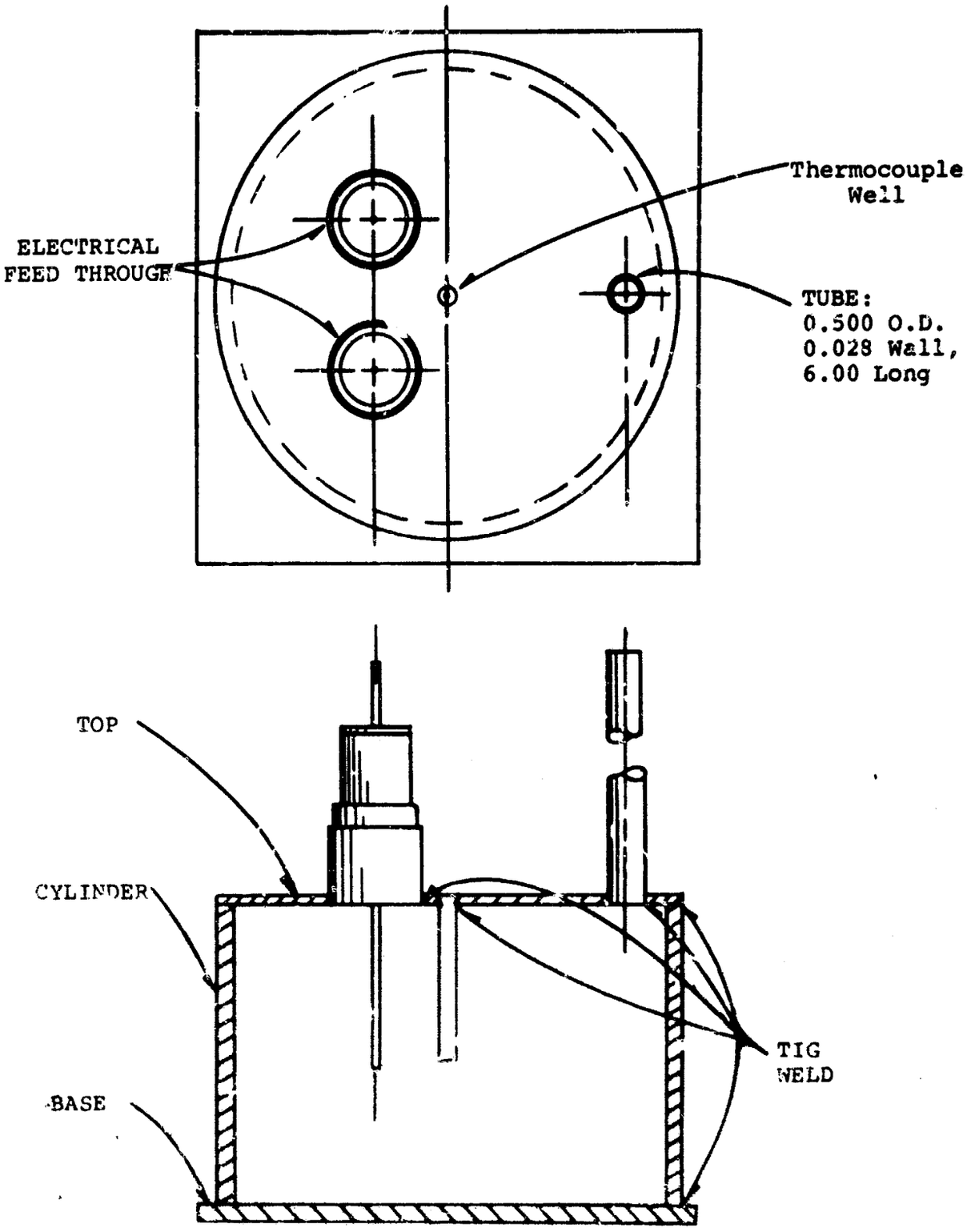


FIGURE 24. Electrical Conductor Continuous Measurement Container

modulus of rupture bars were made as described in section III-A and heat treated as follows:

Material	Quantity	Heat Treatment
Al_2O_3-Y_2O_3	2	None
Al_2O_3-Y_2O_3	2	2 hours at 2372°F in air
$SrZrO_3$	2	None
$SrZrO_3$	2	2 hours at 2400°F in air

Six ceramic/metal interface specimens were made by plasma spraying (in air) a titanium hydride base layer followed by a high purity alumina on Hiperco 27 alloy substrates. Coating thicknesses were measured (see Table VI). Specimens were then treated under one of the following set of conditions:

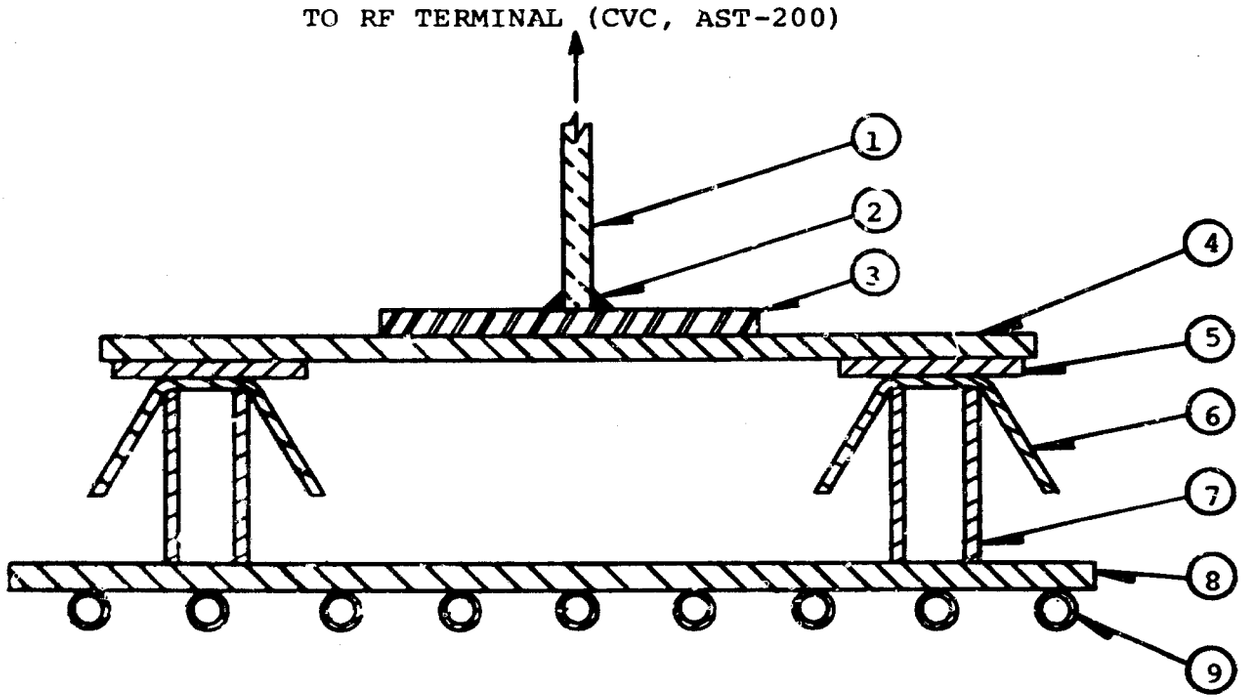
Temperature (°F)	Time at Temperature (min.)	Pressure Range (torr)
1800	30	10^{-7}
2400	30	low 10^{-5}

b. Radio Frequency Sputtering

Three ultra high purity, zone refined metal sputtering targets (titanium, zirconium, and aluminum) were received from Materials Research Corporation. Special fixturing and electrical connections were made for these materials to minimize contamination during deposition in the CVC AST-200 RF Sputtering System.

Metallic zirconium and titanium films ranging in thickness from 3900 Å to 4000 Å (interferometer measurement) were deposited around the edges of sapphire disks (masked with 3/4-inch diameter Al_2O_3 disks) to promote braze wetting (see section III C-5). Diode sputtering configuration was used. Films were deposited in a pure argon plasma at about 5 microns total pressure. The substrates were mounted on a water cooled copper plate. Total sputtering time was approximately 50 minutes (~80 Å/minute deposition rate).

Two runs were completed using the ultra high purity aluminum target (see Figure 25). The first run was made using a reactive atmosphere of 50% argon and 50%



(1) Aluminum rod conductor welded (2) to aluminum disk (3)
(4) Target - high purity aluminum
(5) Sapphire disks
(6) Inverted alumina crucibles (shields)
(7) Lucalox (alumina) tube (supports)
(8) (9) Water cooled base plate (substrate support)

FIGURE 25. Sectional View of RF Sputtering (diode) Assembly

oxygen (pre-mixed) at a total pressure of about 5 microns. An insulating film, approximately 2000 Å thick, was obtained (deposition rate about 35 Å/minute).

Another run was made in a pure nitrogen plasma to obtain an aluminum nitride film. Sputtering was continued for 2 hours. The film was deposited on a 5-mil thick tantalum sheet. A series of d-c breakdown voltage measurements were made on this film. Values ranging from 25 volts to 220 volts were obtained at different areas on the insulated sheet. The film thickness is estimated to range from 6000 Å to about 12,000 Å (0.0470 mils).

2. Short Term Potassium Vapor Exposure Tests

Ten capsules were prepared for short term 600°C potassium vapor exposure tests of specimens made by various processes and techniques. These stainless steel capsules were fabricated as the shorter capsules in Figure 4 of the first quarterly report. These capsules were prepared as described in the previous report and in sections II A-2 of this report. Capsules and potassium loading equipment were placed in the inert atmosphere glove box and the glove box evacuated to a pressure lower than 10^{-6} torr. Capsules and potassium loading equipment were heated to 400°F and held at this temperature in vacuum for 30 minutes to degas them. Purified argon was then introduced into the glove box and the capsules removed from the hot plate to cool.

Potassium transfer equipment, consisting of a heated hypodermic syringe and needle, was then set to maintain a temperature of approximately 200°F. One 5 gram potassium ampoule was opened and placed in a copper holding fixture on a hot plate. A temperature of approximately 225°F was maintained in the copper fixture. When proper temperatures were attained, approximately one gram of potassium was transferred from the ampoule to each of the ten capsules. (Two of the 5 gram ampoules were used.) Potassium was injected into the capsules so that no potassium contacted capsule walls above 3 inches from the top.

Specimens were then placed in proper test capsules. Potassium impurity analysis and oxygen analysis are given in Table IV.

Capsules loaded with potassium and a specimen were connected in pairs through separate valves to a manifold which was in turn connected to liquid nitrogen cooled adsorption and ion pumps. Connections to valved lines were made with stainless steel Swagelok fittings. Valves were

TABLE IV. POTASSIUM IMPURITY ANALYSIS

High Purity Potassium Lot No. ST7-857-1	
Element	Batch Analysis (ppm)
Fe	<5
B	<10
Co	<5
Mn	<1
Al	<2
Mg	<2
Sn	<5
Cu	2
Pb	<5
Cr	<5
Si	12
Ti	<5
Ni	<5
Mo	<3
V	<1
Be	<1
Ag	<1
Zr	<10
Sr	<1
Ba	<3
Ca	1
Na	4
K	Balance
An ampoule loaded at the same time as those received was analyzed for oxygen and was found to contain less than 10 ppm oxygen	

Hoke stainless steel welded bellows type.

A residual gas analyses (RGA) was used to determine the composition of the atmosphere in the capsules just prior to sealing. At a total pressure of 5×10^{-7} torr (measured at the RGA) only minute traces of gas were found. Hydrogen and water vapor were the predominent gases with the partial pressure of hydrogen equal to approximately 1×10^{-7} torr and that of water vapor equal to approximately 4×10^{-7} torr.

All capsules were sealed after the line pressure had reached 5×10^{-7} torr. Evacuated capsules were first flattened below the Swagelok fitting by a hydraulically actuated fixture with a flat ram. Next, a rounded ram was used to pinch the tube once in the upper and once in the lower portions of the flattened section. This fixture was left in place on the lower pinch as the tube line evacuation valve was closed, the capsule cut off at the upper pinch, and the capsule TIG welded closed. Figure 26 shows three of these capsules.

a. Leak Checking

Sealed capsules were helium leak checked. A test fixture consisting of a 2-inch tube test chamber and associated valves, helium source, vacuum pumping system, and helium leak checker was used. Each capsule was placed in the 2-inch tube test chamber through a 2-inch gate valve and the chamber evacuated. Helium was introduced and the capsule held at a pressure of 30 psig for 5 minutes. The helium source was then valved off and the test chamber evacuated. The helium leak checker was used to determine if any helium was leaking from the test capsule. All test capsules appeared to be leak free.

b. Testing

Test capsules were placed in a test container, container top welded on, container evacuated and leak checked, then container sealed with reduced pressure inside. The test container was then placed in an air atmosphere furnace and heated to 600°C. This temperature was maintained for 200 hours after which time the test container was cooled and removed from the furnace.

The test container was opened in an argon atmosphere dry box. Two of the capsules were observed to have potassium leaks in the region of the crimp seal. Both leaking capsules and their specimens were neutralized

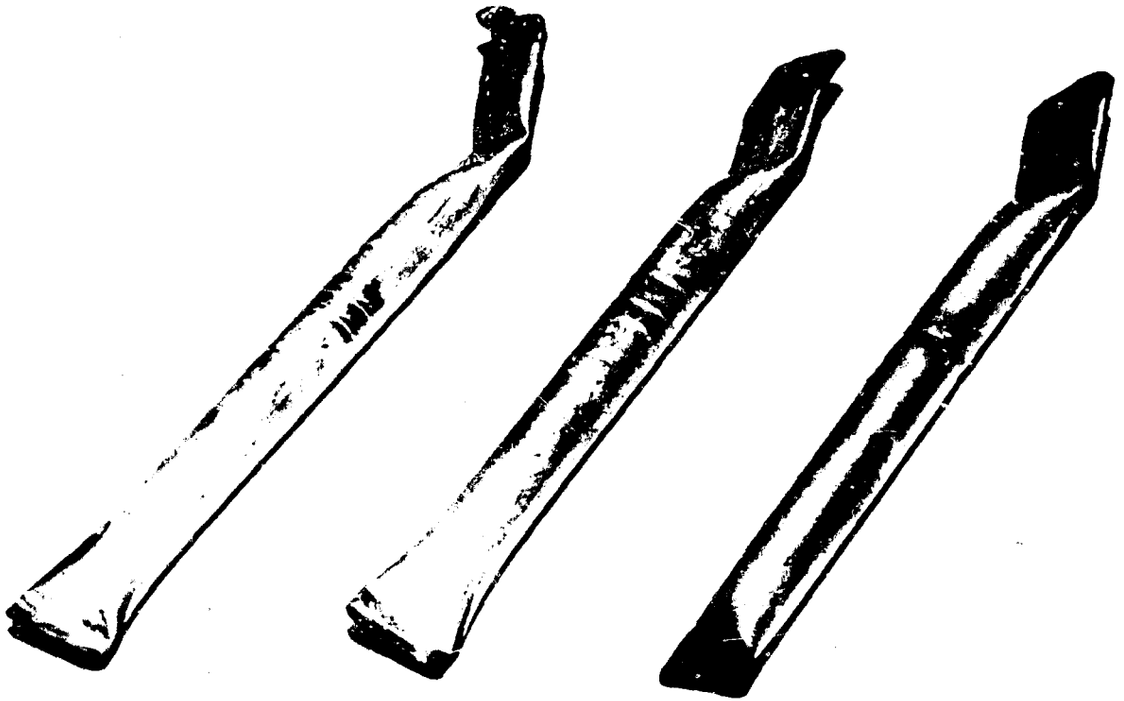


FIGURE 26. Short Term Potassium Vapor Exposure Test Capsules

in a 3% acetic acid solution. The non-leaking capsules were opened in the argon atmosphere glove box. The potassium was observed to the clean and silvery; specimens were observed to be held together and to the capsule walls by the solidified potassium. Capsules were heated to melt the potassium, the specimens removed, and specimens placed in numbered aluminum weighing dishes. Potassium adhearing to the specimens was then neutralized in a 3% acetic acid solution. Specimens were then ready for examination and testing.

3. Evaluation of Potassium Vapor Exposed Specimens

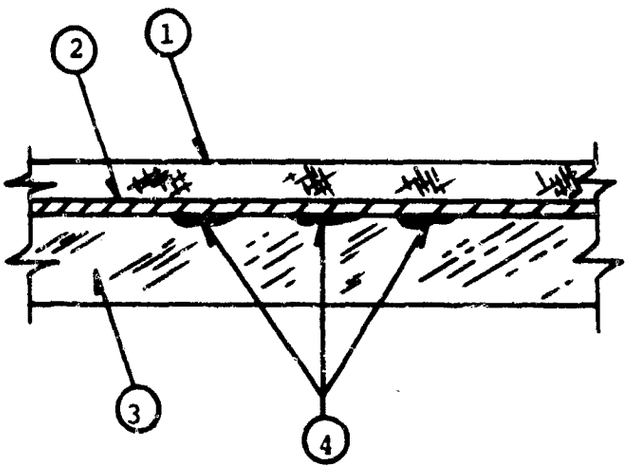
a. Plasma Sprayed Materials

Table V summarizes the evaluation of plasma sprayed materials on Hiperco 27 alloy. Visually, the insulating coatings appeared to be uneffected by potassium vapor exposure except for the samples that received the 2000°F vacuum treatment before exposure. Darker areas in these coatings were evident on several of these samples. Sample No. 2C was broken (Hiperco 27 alloy was quite brittle after exposure) to expose the cross section. Figure 27 shows a representation of the observed interface regions. Void areas were visible at the titanium/Hiperco 27 alloy interface. No voids were detected at the alumina/titanium interface. An effervescence was observed within the void areas when the specimen was broken in these areas and freshly exposed surfaces were immediately inspected at 30x magnification. Evidently trapped potassium remained in these voids after the samples were removed from the test capsules and cleaned.

The electrical data shown in Table V provides additional evidence that the Linde A coatings have about the same d-c breakdown voltages (per mil of coating thickness) and d-c resistivities as unexposed specimens (first quarterly report).

b. Hot Pressed Materials

Eight modulus of rupture bars were exposed to potassium vapor at 600°C for 200 hours. Two materials were exposed (hot pressed 82 mole % Al_2O_3 + 18 mole % Y_2O_3 and 100% $SrZrO_3$). The alumina-yttria specimens showed no visible corrosion effects; however, two strontium zirconate bars (specimens heat treated after hot pressing at 2400°F for 2 hours in air before exposure) showed severe corrosion (crumbled into several pieces). The same material not heat treated before exposure showed only surface



(1) Plasma sprayed Linde A - ∿3 mils thick
(2) Plasma sprayed TiH - ∿1 mil thick
(3) Hiperco 27 Substrate
(4) Void areas containing trapped potassium

} Vacuum annealed at 2400°F - 30 minutes before exposure

FIGURE 27. Cross Section of Plasma Sprayed Insulation on Hiperco 27 Alloy After 200 Hour Potassium Vapor Exposure at 600°C

TABLE V. EVALUATION OF CERAMIC/METAL INTERFACE SPECIMENS AFTER TERM POTASSIUM VAPOR EXPOSURE

Process History						Evaluation After K Vapor Exposure[2]			
	Coating Thickness[1]			Vacuum Heat Treatment		Appearance[4] After 200 hrs in K Vapor at 600°C	Electrical Tests		
Sample No.	Titanium Hydride (mils)	Linde A (mils)	Linde A (cm)	(°F)	(min)		DC Resistance at 100 V d-c (72°F) ohms	Calculated Resistivity (ohm-cm)	DC Breakdown Voltage[3] (volts)
2c	2.5	3.0	7.6×10^{-3}	2400	30	Gray with darker areas - adherence good	- - - - - - (not measured) -		- - - - -
2b	3.5	3.0	7.6×10^{-3}	1800	30	Grayish coating	1.1×10^{8}	1.8×10^{9}	700
2a	2.0	1.0	2.54×10^{-3}	2400	30	Speckled gray	4.0×10^{8}	2.0×10^{10}	200
1c	3.0	3.0	7.6×10^{-3}	2400	30	Gray with darker area at one edge	2.0×10^{8}	3.3×10^{9}	1000
1b	3.0	3.0	7.6×10^{-3}	1800	30	Grayish Coating	9.1×10^{8}	1.5×10^{10}	600
1a	2.0	1.0	2.5×10^{-3}	2400	30	Speckled gray	Breakdown[5] before test voltage (100 V d-c)	--	50

(1) Plasma sprayed in air ambient on Hiperco 27. Substrate thickness measured with micrometer (peak to peak measurement).
(2) Keithly Regulated Power Supply (0-1000 volts), Model 240 and Model 610B Electrometer, Mercury counter-electrode (0.39 cm diameter).
(3) Voltage increased at 15 second intervals in 100 volt increments until power supply relay tripped (10 ma current flow).
(4) All 3 mil coatings appeared somewhat whiter before exposure to K vapor; adherence of coating on sample 2c was very good based on scratch test with a dental pick.
(5) Insulating coating too thin for electrical measurement.

discoloration. One of these bars appeared to have been broken during the capsule unloading.

Table VI shows the results of modulus of rupture tests on the exposed bar materials. It is evident from these data that the strength of the alumina-yttria material was unaffected. In fact, the average MOR values indicate an increase in strength after the 200 hour exposure. Heat treating had no significant effects.

The strontium zirconate bars (Table VI) show no decrease in strength after K vapor exposure. However, the bars that received a post hot pressing heat treatment (2400°F, 2 hours in air) show a significant decrease in strength. As mentioned above, the heat treated bars exposed to potassium vapor disintegrated.

Further work is planned to prepare strontium zirconate MOR bars from calcined chemically pure powder or prefused and ground material. A distinct sulfide type odor was detected. It is possible that a sulfide compound is present in this material which oxidizes during the air heat treatment process and weakens the structure.

4. Ceramic/Metal Composites

Two alumina-rhodium end-to-end type composite disks were pressure sintered at approximately 2550°F for 35 minutes. One disk was prepared with no cermet interface layer between pure rhodium end pieces. The rhodium end disks showed no bond to the alumina after removal from the die. The second disk contained a cermet (50v/o Rh-50v/o Al_2O_3) transition layer between the pure alumina center disks and the rhodium end pieces. After hot pressing, the pure rhodium end pieces did not bond to the cermet. However, the cermet to alumina bond appeared to be quite good. Figure 28 shows the dimensions in cross section of the final configuration after a center hole was ultrasonically drilled. Figure 29 shows a photograph of the specimen. The electrical resistance of the cermet is less than one ohm indicating that the rhodium phase is continuous.

Comparing the results obtained for these two specimens demonstrates the significance of differences in thermal expansion coefficients. The total expansion of rhodium and alumina are as follows:

Rh (25° to 1500°C) 1.79%

Al_2O_3 (25° to 1500°C) 1.37%

TABLE VI. EFFECTS OF 200 HOUR POTASSIUM VAPOR EXPOSURE AT 600°C AND POST HOT PRESSING HEAT TREATMENT ON THE MODULUS OF RUPTURE OF CERAMIC INSULATORS

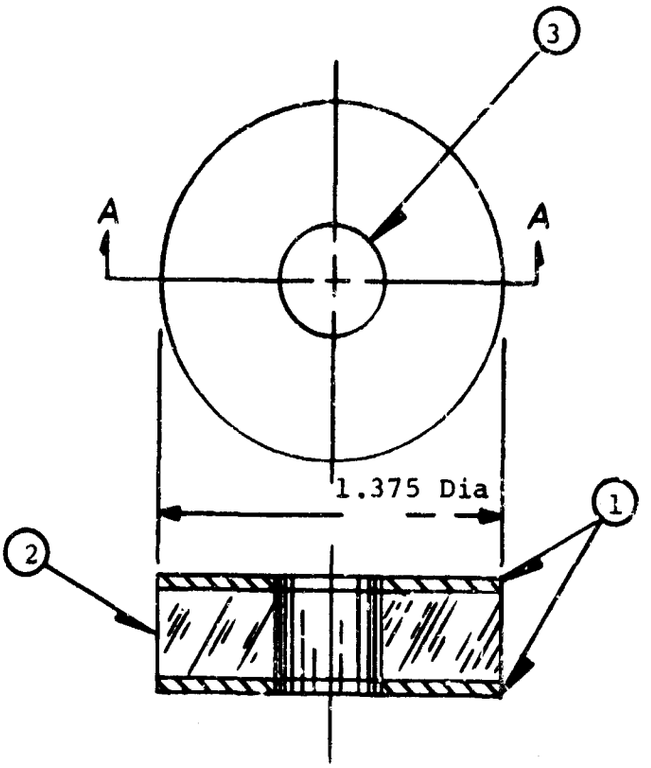
Specimen	Composition	Hot Pressing Data (grafite die)	Measured Cross Section (a x b)	Post Hot Pressing Heat Treatment (in air)	Modulus of Rupture Test Data(1)			
					Before K Vapor Exposure		After K Vapor Exposure	
					Total Force(lbs)	MOR(psi)	Total Force(lbs)	MOR(psi)
K 1935118-D2	18 Mole% Y_2O_3 82 Mole% Al_2O_3	5000 psi for 40 minutes at ~ 2550°F	95 x 98 mils	None	--	--	41	37,100(3)
K 1935118-D1	18 Mole% Y_2O_3 82 Mole% Al_2O_3	5000 psi for 40 minutes at ~ 2550°F	94 x 104 mils	None	--	--	60	48,700
K 1935118-H1	18 Mole% Y_2O_3 82 Mole% Al_2O_3	5000 psi for 40 minutes at ~ 2550°F	101 x 107 mils	2372°F 2 hrs	--	--	66	47,100
K 1935118-H2	18 Mole% Y_2O_3 82 Mole% Al_2O_3	5000 psi for 40 minutes at ~ 2550°F	102 x 102 mils	2372°F 2 hrs	--	--	64	49,700
K 1935118-D3	18 Mole% Y_2O_3 82 Mole% Al_2O_3	5000 psi for 40 minutes at ~ 2550°F	113 x 92 mils	None	50	43,200	--	--
K 1935118-H3	18 Mole% Y_2O_3 82 Mole% Al_2O_3	5000 psi for 40 minutes at ~ 2550°F	103 x 102 mils	2372°F 2 hrs	46	35,500	--	--
K 1935115-D2	100% $SrZrO_3$	5000 psi for 60 minutes at ~ 2700°F	100 x 100 mils	None	--	--	18	14,850(2)
K 1935115-H3	100% $SrZrO_3$	5000 psi for 60 minutes at ~ 2700°F	100 x 101 mils	2400°F 2 hrs	14.25	11,800	--	--
Average for Five samples K 1935115 series	100% $SrZrO_3$	5000 psi for 60 minutes at ~ 2700°F	Approx. 100 x 100 mils	None	18.7	15,400	--	--

(1) Rupture Force measured on an Instron Model PTC, Serial # 1340. Load applied at a rate of 0.1 inches/minute (2 inches/minute chart speed)

$$MOR\ (psi) = \frac{3(L-l)P}{2ab^2}$$; where

L = 0.8 inches
l = 0.250 inches
a = measured width (inches)
b = measured depth (inches)
P = Force (lbs)

(2) One additional specimen was tested in potassium vapor but broke during capsule unloading.
(3) Capsule leaked during exposure.



(1) 50 v/o Rh + 50 v/o Al_2O_3 - Approx. 0.015 Inch Thick
(2) 100 v/o Al_2O_3 (Linde C) - Approx. 0.280 Inch Thick
(3) 0.250 Inch Diameter Hole (ultrasonically cut)

FIGURE 28. Cross Section of Hot Pressed Rhodium/Alumina Composite

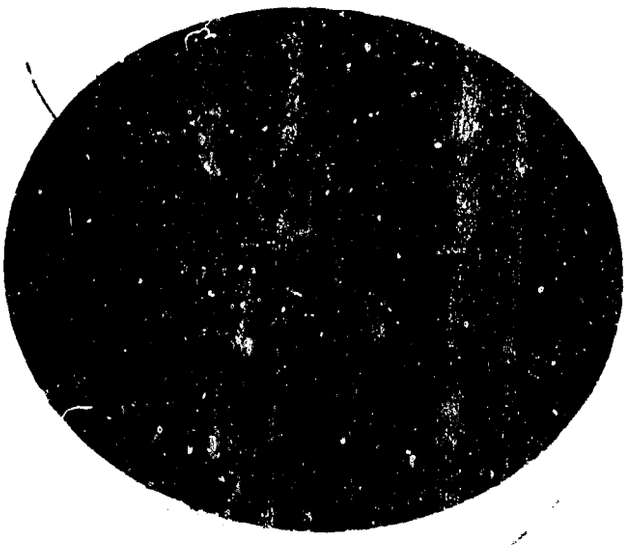


FIGURE 29. Hot Pressed Rhodium Cermet (50 v/o Rh + 50 v/o Al_2O_3) and Alumina End-to-End Seal

Rhodium expands about 31% more than alumina over the same temperature range. The stresses developed in the interface regions are apparently sufficient to rupture the rhodium/alumina bond as the composite is cooled to room temperature. To further minimize residual stresses and achieve a satisfactory metal to cermet bond additional graded cermet layers will be necessary.

C. FABRICATION AND TESTING OF FIVE KVA TRANSFORMERS

Two 5 KVA transformers will be built using Hiperco 27 alloy magnetic material, Linde A (99.9% Al_2O_3) interlaminar insulation, rectangular nickel clad silver conductors, and Alite A-610 (99% Al_2O_3-1% MgO) conductor insulation. These transformers will be evaluated in potassium vapor at 600°C; one of these in ionized potassium vapor. The life objective is 500 hours operation for the unionized vapor test.

Progress in design, fabrication, and evaluation of transformers is given below.

1. Magnetic Materials

Transformer E and I laminations of 0.008-inch thick Hiperco 27 alloy were procured. I's were sheared and E's were punched. Both E's and I's had burrs which are being removed by the following chemical procudure:

a) Etch in a solution of equal parts nitric acid, glacial acetic acid, and distilled water for one minute.

b) Rinse in distilled water.

c) Rinse in a 10% solution of sodium carbornate for five minutes.

d) Rinse in distilled water for five minutes.

e) Rinse in acetone for five minutes.

f) Air dry.

The deburring procedure left E's and I's in need of further cleaning. This cleaning was performed according to the following:

a) Dip in a solution containing equal parts of hydrochloric acid and distilled water.

b) Rinse in distilled water.

c) Rinse in chemically pure acetone.

d) Dry with forced hot air.

Figure 30 shows transformer E and I laminations prior to cleaning. Deburred magnetic material is now ready for hydrogen anneal.

2. Conductors

Nickel clad (20 percent) silver conductor wire in 0.081-inch by 0.129-inch rectangular form was ordered as new material and as squared No. 6 and 8 round wire from the previous program. The latter material was received as 0.080-inch by 0.127-inch rectangular wire.

3. Insulation

The ceramic insulation for transformer conductors was designed and material ordered. The coil form portion of conductor insulation was designed as a six piece unit. Four pieces will go around the four sides of the center of the E's and will be held together by two end pieces which fit through the windows. Figure 31 describes the coil form of Alite A-610.

Inter-turn insulation consists of Alite A-610 bars 0.020-inch thick which will separate straight portions of conductor turns. These insulation bars are on order. Plasma sprayed Alite A-610 will be used between conductors on the corners and as layer-to-layer insulation. This material was ordered and partial order of this material was received.

4. Electrical Feedthroughs

The original order for twenty beryllia electrical feedthroughs was changed to ten beryllia and ten alumina because of delivery problems with the beryllia. Both types of seals are of similar design with the differences being in the ceramic and the brazing materials.

5. Sapphire Window Seals

Three attempts were made to braze and hermetically seal a sapphire disk to columbium-1% zirconium parts for the test transformer container windows. Table VII gives the active metal braze alloy composition. A photograph of two of the most promising designs is shown in Figure 32. These seals were tested for helium leaks on a Veeco Model MS-9 Helium Mass Spectrometer and found to contain several small leaks

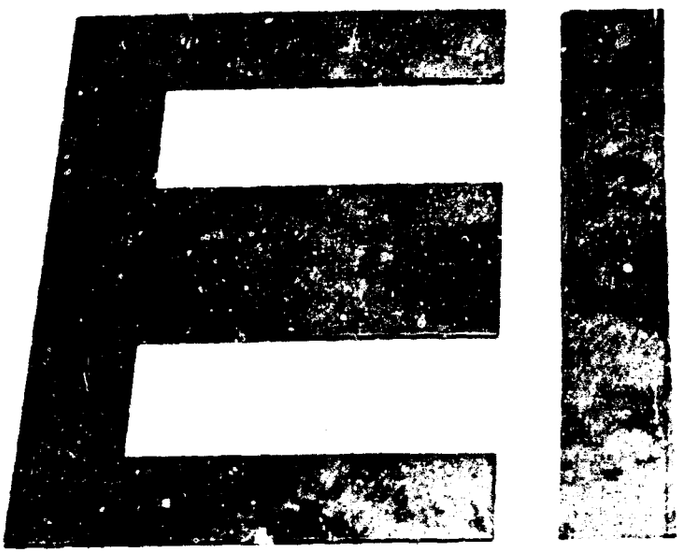


FIGURE 30. Transformer E and I Laminations

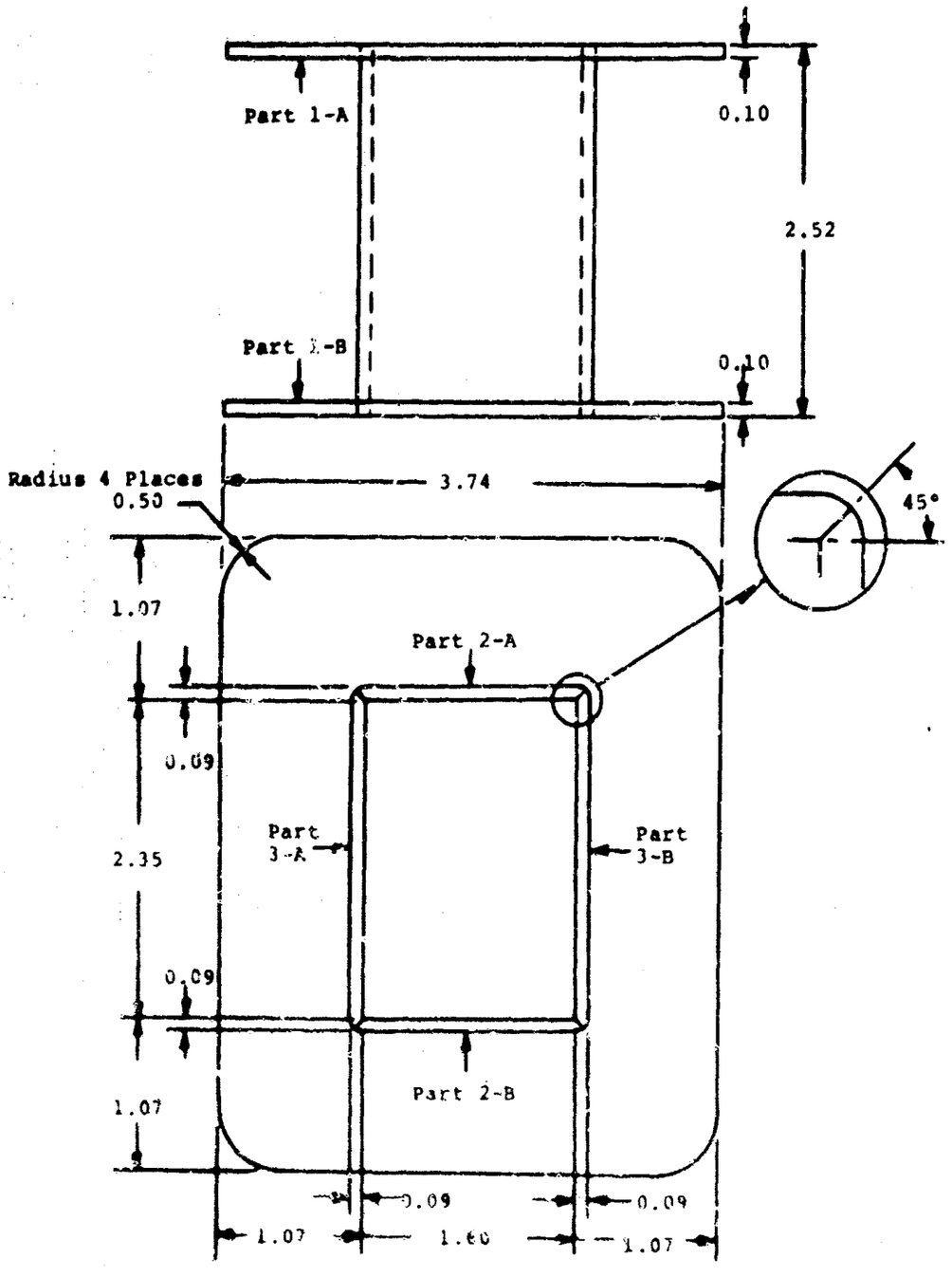


FIGURE 31. Transformer Coil Form

FIGURE 32. Sapphire Window Seals Vacuum Brazed with an Active Metal Braze Alloy and a Sputtered Zirconium Base Layer

TABLE VII. ACTIVE METAL BRAZE ALLOY COMPOSITION

Element	Weight Percent	Remarks
O	0.079	Gas analysis
N	0.048	Kjeldahl
H	0.0032	Gas analysis
Ti	48.8	X-ray flour
Cb	19.9	X-ray flour
Ni	32.5	Wet
Fe	est. 0.1	

before and after a second braze. The active metal braze material appears to wet and flow satisfactorily. The three seals were prepared as follows:

Seal No. 1 - A 1-inch diameter by 0.040-thick sapphire window was brazed around the periphery of a smaller diameter hole cut into the center of a 0.030-inch thick columbium-1% zirconium sheet. Prior to brazing, a 3000 Å thick coating of titanium was sputtered around the edge of the sapphire disk. The active metal braze powder was suspended in a dilute Nicrobraze Binder and applied in slurry form to the immediate braze area. The assembly was air dried and vacuum brazed at 1160°C (10^{-5} torr) with no soak period. After brazing several leak areas were detected. Additional braze alloy was applied and the seal was re-brazed at 1160°C with a 20 minute soak period. A circumferential crack was evident in the sapphire disk when the temperature was lowered.

Seal No. 2 and No. 3 - Seal designs were changed to a columbium-1% zirconium tube assembly to minimize tensile stresses and are shown in Figure 32. The same brazing techniques were used as described above except that a sputtered zirconium layer (~4000 Å thick) was applied to the sapphire disks. These seals showed leaks after the re-braze run but no cracks were evident in the sapphire.

In general, all braze fillets appeared to be less porous after the second braze run. The alloy was brittle. The titanium base layer was more adherent to the sapphire than the zirconium layer.

SECTION IV

PROGRAM FOR NEXT QUARTER

A. EVALUATION OF POTASSIUM EXPOSED MATERIALS

1. Long Term Tests

Test capsules will be loaded with potassium and specimens and long term testing begun. Pre-exposure test data will be evaluated.

2. Rowland Ring Tests

Rowland rings will be coated with plasma sprayed interlaminar insulation. Rowland ring core box will be assembled. Rowland rings will be given 600°C vacuum tests.

3. Conductor Continuous Measurement Tests

Conductor continuous measurement container will be completed. Nickel clad silver conductor will be installed and the container loaded with high purity potassium. The conductor will then be exposed to 600°C potassium vapor. Kelvin bridge conductivity data will be obtained.

B. PROCESSES AND TECHNIQUES FOR POTASSIUM VAPOR RESISTANT ELECTRICAL DEVICES

1. Plasma Sprayed Insulation

Additional materials (insulations and binders) will be plasma sprayed both in air and in a controlled inert atmosphere environment.

2. Sputtered Materials

Metal and insulating films will be prepared by both conventional and reactive sputtering techniques. These films will be evaluated and will be used in conjunction with plasma sprayed materials and in preparation for brazing.

3. Ceramic/Metal Composites

Electrical feedthroughs will be made using ceramic/metal composites and brazing of ceramics to metals. The alumina/rhodium - alumina composite core will be given a short term potassium vapor exposure test.

4. Hot Pressed Materials

Strontium zirconate specimens will be made from calcined chemically pure powder or pre-fused and ground materials. Modulus of rupture bars will be made of the forementioned and purchased bar material.

C. FABRICATION AND TESTING OF THE FIVE KVA TRANSFORMER

1. Magnetic Materials

E and I laminations will be deburred, annealed, and plasma sprayed with interlaminar insulation. Transformer assembly will be initiated.

2. Insulation

Transformer ceramic insulation consisting of coil forms, inter turn spacers, and plasma spray powder will be obtained.

3. Conductors

Squared conductor material will be used to assemble one transformer winding.

4. Transformer Test Containers

Containers to test transformers in potassium vapor will be designed.

5. Sapphire Window Seals

Sapphire window seals will be evaluated using different designs and procedures.

APPENDIX

DEFINITIONS USED IN CCFR TESTING*

Constant Current Flux Reset, CCFR

This test employs an excitation current consisting of half-wave sine current pulses of sufficient and constant magnitude to drive the core flux into positive saturation. A direct-current magnetizing force of adjustable magnitude is applied to the core so as to reset the magnetic flux away from positive saturation during the intervals between pulses of excitation current. The resultant cyclic flux change is measured by means of a sensitive flux voltmeter connected to a separate pickup winding on the core.

Flux Density Swing, Maximum; $2B_m$

The maximum flux density swing equal to the absolute total value of positive and negative peak induction or $2B_m$. ($2B_m$ = 2 SAT)

Gain, G

$G = \frac{\Delta B_2 - \Delta B_1}{\Delta H}$, a measure of loop steepness in terms of incremental permeability.

Induction, Delta (Delta Flux Density); ΔB

Delta induction is the change in induction (flux density) when a core is in a cyclically magnetized condition.

Induction, Fixed Delta: ΔB_1, ΔB_0, ΔB_2

1. ΔB_1 - delta induction equal to one third of $2B_m$, maximum flux density swing.

2. ΔB_0 - delta induction equal to one half of $2B_m$, maximum flux density swing.

3. ΔB_2 - delta induction equal to two thirds of $2B_m$, maximum flux density swing.

*Where applicable, AIEE, No. 432 (Jan. 1959) "Test Procedure for Toroidal Magnetic Amplifier Cores" has been used.

Induction, Residual (Residual Flux Density), B_r

Residual induction is the magnetic induction at which the magnetizing force is zero while the material is cyclically magnetized with a half-wave sinusoidal magnetizing force of a specified peak magnitude. (This definition differs from the standard definition which requires symmetrically cyclically magnetized conditions.)

Induction, Peak (Peak Flux Density), B_m

Peak induction is the magnetic induction corresponding to the peak applied magnetizing force. The peak induction will usually be slightly less than the true saturation (B_m = SAT)

Magnetizing Force, Dependent; H_1, H_0, H_2

1. H_1 - The d-c reset magnetizing force required to produce a cyclic change in induction ΔB_1 (H_1 = AT)
2. H_0 - The d-c reset magnetizing force required to produce a cyclic change in induction ΔB_0 (H_0 = AT + 1/2 DAT).
3. H_2 - The d-c reset magnetizing force required to produce a cyclic change of induction ΔB_2 (H_2 = AT + DAT).

Magnetizing Force, Incremental; ΔH

The incremental change in magnetizing force equal to $H_2 - H_1$. (ΔH = DAT)

Magnetizing Force, Peak; H_m

Peak magnetizing force is the maximum value of applied magnetomotive force per mean length of path of the core.

Squareness; $B_m - B_r$

The delta B induction change between the peak induction, B_m, and the residual induction, B_r.

Squareness Ratio: $\frac{B_r}{B_m}$

The ratio of residual induction, B_r, over peak induction, B_m

$$\left[\frac{B_r}{B_m} = 1 - \left(\frac{B_m - B_r}{B_m}\right) = T\right]$$