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DEVELOPMENT OF ELECTRICAL SWITCHGEAR FOR SPACE NUCLEAR ELECTRICAL SYSTEMS

QUARTERLY PROGRESS REPORT NO.1

For Period: December 4, 1964 Thru March 4, 1965

EDITED BY R. N. EDWARDS

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC
CINCINNATI, OHIO 45215

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Contract NAS 3-6467

Technical Management

NASA - Lewis Research Center
E. A. Koutnik

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO 45215

FOREWORD

The work described in this report is being performed by the General Electric Company under the sponsorship of the National Aeronautics and Space Administration, Contract NAS 3-6467. Its purpose, as outlined in the contract, is to design and develop ground prototype AC Circuit Breakers and DC Engine Contactors, suitable for and tested under space environment conditions. The AC Breakers will be rated 1000 volts, 600 amps, 2000 cycles, while the DC Contactors will carry a rating of 10,000 volts, 10 amperes.

R. N. Edwards, Consulting Engineer, Power and Propulsion Systems, is Program Manager for the General Electric Company, E. F. Travis of the Advanced Technology Laboratory is Project Engineer. Additional Contributors to the program and this report include D. S. Engleby, W. W Shoemaker and A. H. Powell of SPPS; R. B. Fleming, L. J. Goldberg and G. W. Kessler of ATL.

E. A. Koutnik of the National Aeronautics and Space Administration is the Technical Manager for this Contract.

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I. SUMMARY

During the first quarterly period of this program, major effort was devoted to three areas requiring basic decisions. These were:

1) Material for the Vacuum Interrupter enclosure and contacts.

2) Interrupter and actuator design concepts.

3) Facilities for making heat run and endurance tests.

While the work was conducted concurrently in all areas, it became apparent that proper selection of the materials required an early solution to the outgassing and contact resistance problems which developed. Definite progress was made, and tests initiated to obtain the needed information.

Theoretical studies indicated that, in the required 1000°F ambient, all possible materials would outgas to such an extent that continued scavenging would be required. The best four candidate materials were selected for further detail processing and checking. Those which were ordered for testing included:

1) Rodar, - a Nickel, Cobalt, Iron Alloy.

2) Thoria dispersed Nickel.

3) Commercially pure Titanium.

4) Arc cast Molybdenum.

Detailed checking of the contact resistance of the switch used for the Phase I interruption tests indicated high resistance and implied a resulting high temperature problem in the prototype switch.

A theoretical review of the contact problem, based on using Molybdenum for the contacts, provided information which pointed to high resistance (0.5 - 1 milliohm), high losses (400 watts) and high temperature rise (250 to 300°C) when the circuit breaker is carrying 600A.

Design effort was concentrated on the actuators, after the decision was made to produce a single pole design for both AC and DC applications. Preliminary work on the vacuum interrupter unit was influenced by the contact heating problem, so that detailed studies were initiated to determine the heat transfer requirements.

The major facility which must be applied for this program is the oven which will be mounted in the vacuum test chamber for the heat runs, high potential test and 1000 hour endurance check. Design of a suitable oven, using quartz lamps as the heat source, was developed and detailing started.

The next quarterly period will provide a decision on the proper interrupter unit enclosing material, and firm design layouts for both the AC circuit breaker and the DC contactors. With this information in hand, the overall schedule can be firmed up, parts ordering started and test planning initiated.

II VACUUM SWITCH TECHNOLOGY

A. Materials Outgassing and Permeation

1. Theoretical Considerations

The only sources of gas within the jacket after sealing off are outgassing and permeation. Actually, the process of "outgassing" involves permeation, as it is assumed that after a thorough bake-out the sorbed surface layers of gas have been removed, leaving only gas molecules buried beneath the surface which must permeate through the wall to the surface before they can enter the vacuum space.

Despite the connection between the two phenomena, they will be considered separately in estimating the gas influx into the vacuum space. The data available on permeation and outgassing (particularly outgassing after a bake-out) are very scarce and show a great deal of scatter. This is because outgassing and permeation are strong functions of the metallurgical state of the metal, the surface roughness and cleanliness; in addition, outgassing depends upon the degree of bake-out, and permeation depends upon surface chemical reactions. All of these conditions are difficult to specify. For these reasons, permeation and outgassing data should be considered approximate at best, and may well be in error by factors of 10 or more.

a. Outgassing - The outgassing of a surface will be defined as the gas load in a vacuum due to influx of molecules originally sorbed on the surface and buried beneath the surface. Outgassing is therefore considered independent of the metal thickness and of the pressure of gas on the outside.

There are probably not adequate data for outgassing of metal after bake-out. It is estimated, however, that a figure of 10^{-10} to 10^{-11} torr liters sec^{-1} cm^{-2} would be desirable. Choosing the larger of these and applying a temperature correction of 3[1], the outgassing rate will be about 3×10^{-10} torr liters sec^{-1} cm^{-2}, at a temperature of 540°C.

Based upon an outgassing area of about 800 cm^2, this would lead to a total outgassing load initially of 2×10^{-7} torr liters per sec. The gas would probably consist mostly of hydrogen.

b. Permeation - Permeation will be defined as the influx of molecules which permeate from the atmosphere surrounding the chamber, through the chamber walls, and flow into the vacuum space. Permeation is therefore a function of the wall thickness, and of the pressure and composition of gas outside the chamber walls. Hydrogen is the main gas to be considered, particularly for steel walls[2].

Chrome steel has a lower permeation rate than low carbon steel by a factor of about 15 at 540°C and molybdenum is lower than chrome steel by a factor of about 10. To estimate the permeation rate we shall make the following assumptions:

(1) Molybdenum walls

(2) Hydrogen is the only permeation gas of importance

(3) The partial pressure of hydrogen in the surrounding atmosphere is 0.5×10^{-6} atm (this corresponds to the partial pressure of H_2 in normal air)

(4) Permeation rate varies as the square root of pressure differential[2]

The bellows, being the thinnest member, contributes by far the largest permeation influx. Assume the bellows thickness to be 0.15 mm (0.006 in.) and the area to be 200 cm^2. The data given by Norton [3] for molybdenum at 540^{o}C, show a hydrogen permeation rate of about 10^{-6} cc (STP) mm. sec^{-1} $atm^{-1/2}$ cm^{-2}. (In comparison, the permeation rate at room temperature is less than about 10^{-12}.)

Using these numbers, the total hydrogen influx at 540^{o}C, with normal atmospheric air surrounding the bellows, would be about <u>8 x 10^{-7} torr liters/sec</u>.

This contribution to the gas load could be eliminated by conducting the high temperature testing in a vacuum.

2. Test Results

A series of vacuum bake-out tests were conducted at several ambient temperatures using the materials test vacuum capsule. Each successive test was conducted at a higher bake-out temperature and was continued until evidence of vacuum recovery was observed. A total of 8 successive tests were conducted. The purpose of the test was to determine the temperature at which the gas influx was equal to the pumping speed at an acceptable pressure.

The pressure curves in Figures 1 and 2 show the pressure decreasing in one to two hours after reaching a peak. It was assumed that this was a good indication that the system was leak tight, compared to outgassing rate.

The pressure curve of Figure 3 shows that the pressure is a function of temperature and increases and decreases with temperature. From this it was concluded that the major source of the gas was from the inside walls of the chamber. The stainless steel top and bottom of the chamber are 1/2" thick and the alumina side walls are 3/8". It was therefore assumed that permeation through the chamber walls was negligible for the duration of the individual tests and that outgassing of the 114 square inches of stainless steel walls was the major problem.

From the curves in Figure 4 it can be concluded that if the temperature had been held constant at 720^{o}F the pressure in the chamber would have been constant at approximately 1.5 x 10^{-8} Torr. Under these conditions the outgassing of the walls or gas influx (Q_1 per unit time) is equal to the gas pumped (Q_2 per unit time)

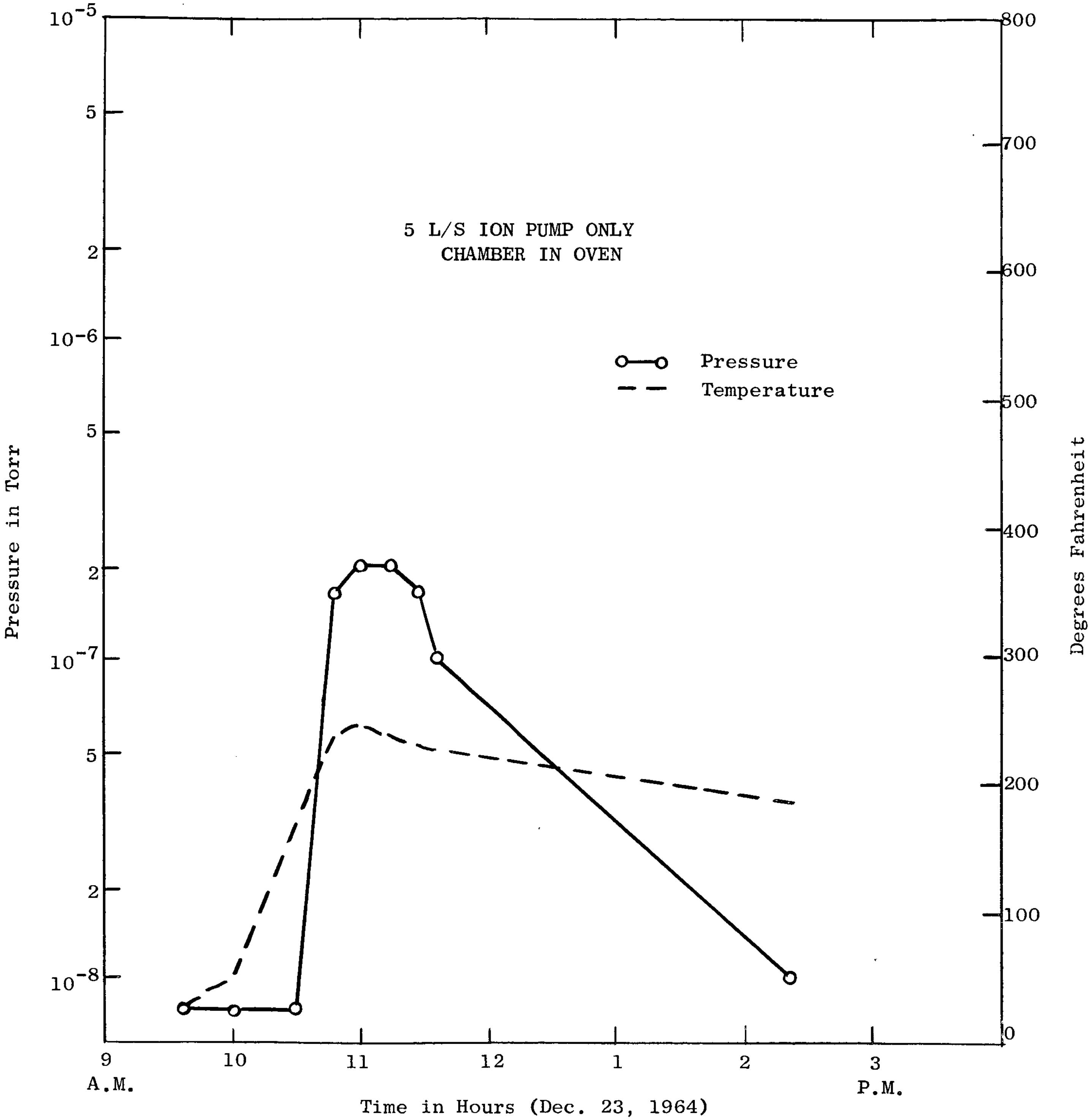

Figure 1. Materials Test Chamber - Temperature and Pressure vs. Time - 250°F Maximum.

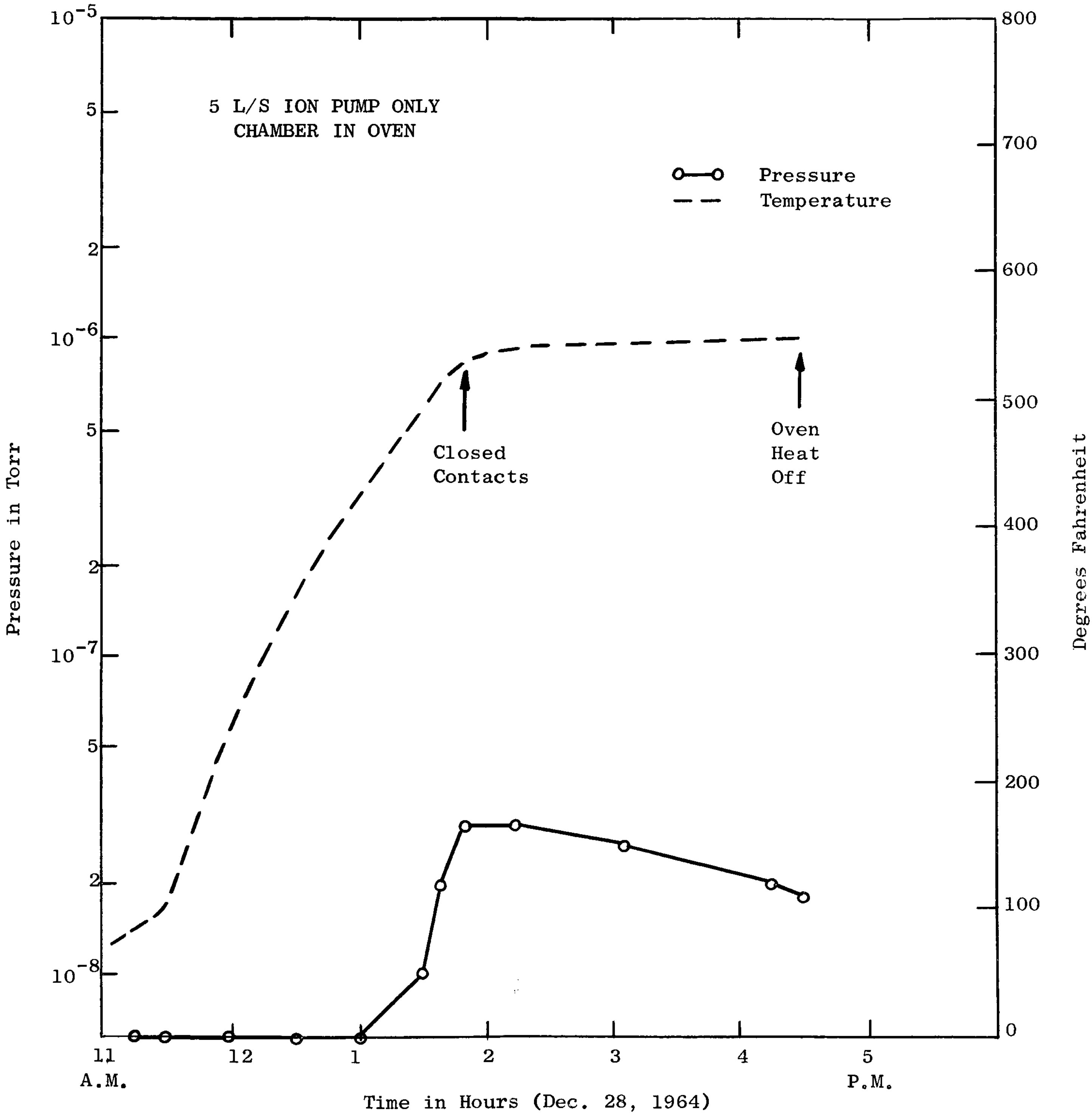

Figure 2. Materials Test Chamber - Temperature and Pressure vs. Time - 550°F Maximum.

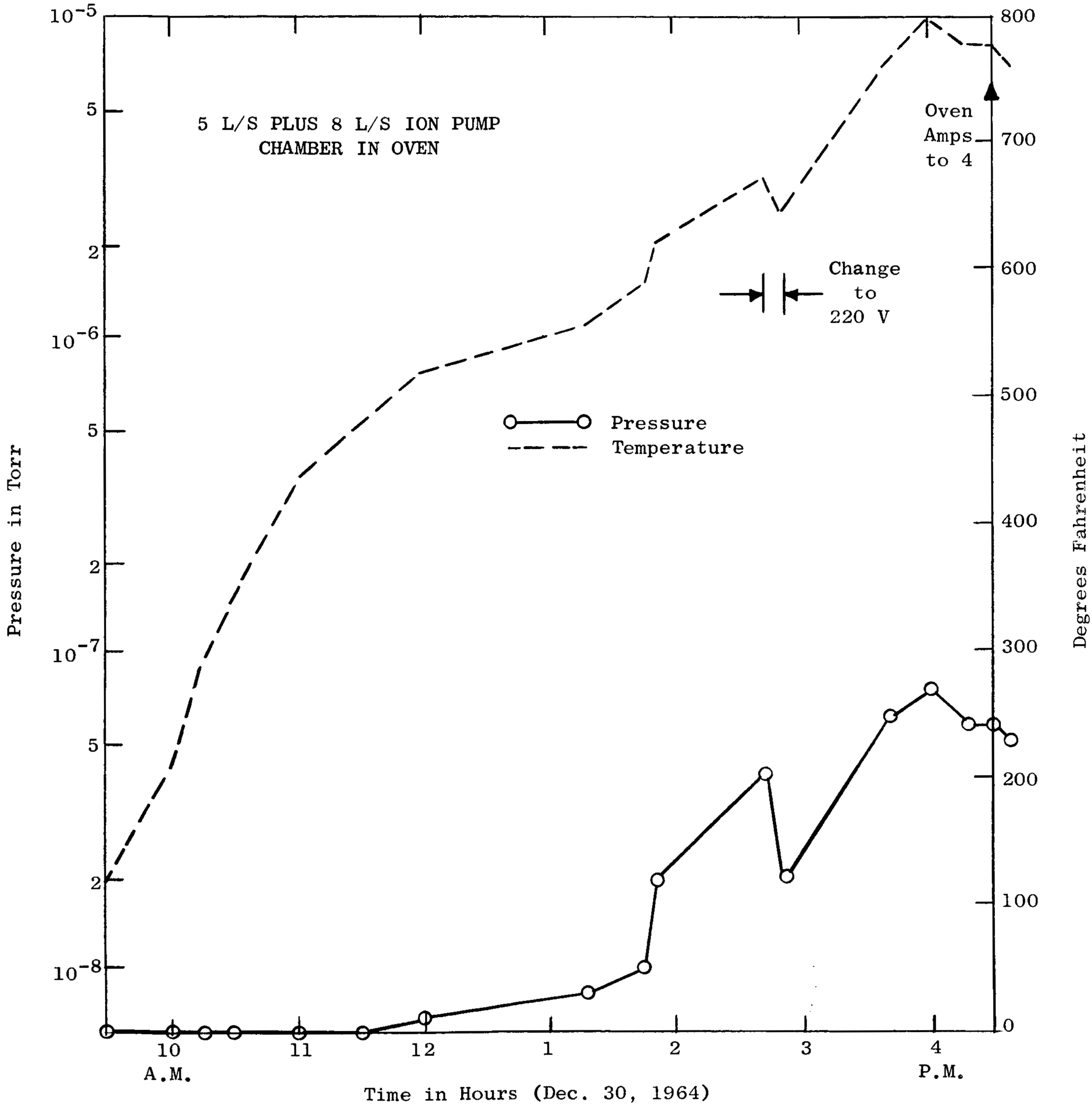

Figure 3. Materials Test Chamber - Temperature and Pressure vs. Time - 800°F Maximum.

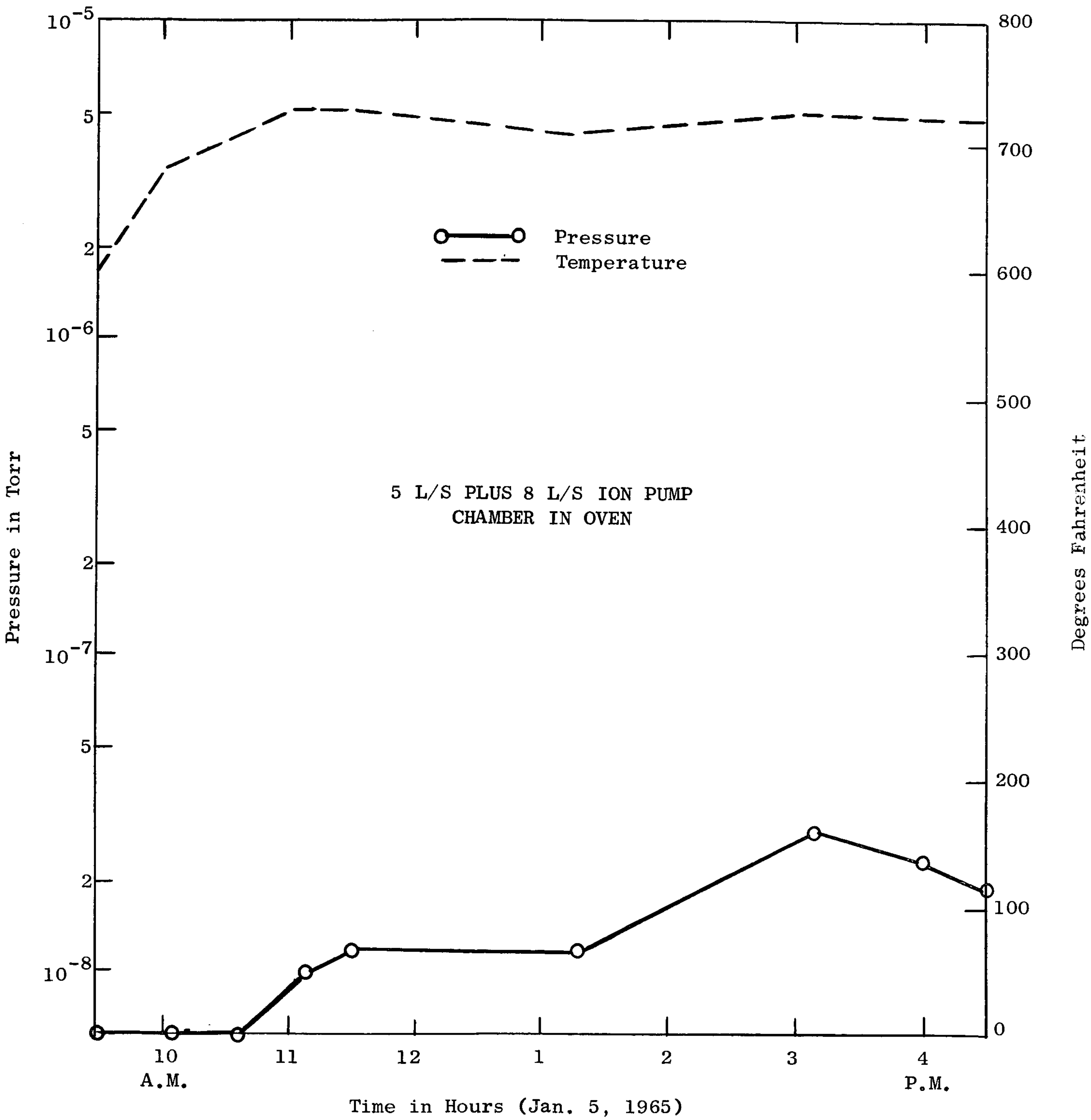

Figure 4. Materials Test Chamber - Temperature and Pressure vs. Time - 720°F Continuous.

With no pumping the gas influx is

$$Q_1 = V \frac{dp}{dt}$$

V = Volume in liters
P = Pressure Torr
t = Time seconds

The pumping speed Q_2 is

$$Q_2 = SP$$

P = Pressure in Torr
S = Speed L/S

with $Q_1 = Q_2$

$$V \frac{dp}{dt} = SP$$

also $\frac{\Delta P}{\Delta t} = \frac{SP}{V}$

The estimated pumping speed of the system is 8 liters per second at 1.5×10^{-8} Torr and the volume of the vacuum capsule is 0.5 liters.

Therefore $\frac{\Delta P}{\Delta t} = \frac{8 \times 1.5 \times 10^{-8}}{0.5}$

and $\frac{\Delta P}{\Delta t} = 24 \times 10^{-8}$ Torr per second

Thus the rate of pressure increase is 9×10^{-4} Torr per hour at 720°F and at a pressure of 1.5×10^{-8} Torr the outgassing would raise the pressure to the range of 10^{-4} Torr in one hour.

These results indicate that there should be a continuing effort in the study, investigation and/or testing of:

- Fabrication materials for the vacuum capsule
- Continuous gettering materials and processes
- Methods of continuously pumping

3. <u>Materials Selection</u>

a. The selection of materials for the oven, the capsules simulating the switchgear, and the miscellaneous hot supporting structure was governed by (1) the amount of dissolved gases in the materials, (2) the high temperature strength of the material and its fabricability, (3) the vapor pressures of the alloying elements at the anticipated temperatures, and (4) availability.

A material having the minimum dissolved gas content will be obtained by limiting the selection of material to that which has been vacuum melted and processed in the most acceptable manner. Pickling and cleaning of the selected material will be carefully controlled to restrict any additional gas absorption to the absolute minimum. Materials containing appreciable amounts of chromium, manganese and aluminum, which have marginal to unacceptable vapor pressures at the desired test temperatures, were necessarily eliminated from the list of candidates.

The candidate materials have been reduced to the following four selections:

(1) Vacuum melted RODAR, per General Electric specification B7Y36, which has the following nominal composition: 26% Ni, 17% Co, 0.05% max Mn, 0.001% max Pb, 0.001% max Sn, 0.06% max C, bal Fe. A typical analysis would be: oxygen, 5 ppm; nitrogen, 200-250 ppm; hydrogen, 0.2 ppm, approximately.

(2) TD nickel (thoria dispersed high purity nickel), per General Electric specification B50T97. Typical gas analysis would be: 15 ppm nitrogen, 5 ppm hydrogen (the oxygen analysis complicated by the large amount contained in the stable thoria dispersion).

(3) Commercially pure titanium, per General Electric specification B50T1. Typical gas analysis would be: 700 ppm nitrogen, 125 ppm hydrogen. A high oxygen content is indicated; however, this oxygen is expected to be in the form of a stable titanium oxide and would not normally be available in gaseous form.

(4) Molybdenum, arc cast, per AMS 7801. Specified gas analyses would be: 30 ppm oxygen, 10 ppm nitrogen.

b. A Materials Support Program has been defined which will identify the gas content of the as-received candidate capsule materials. By a series of vacuum heat treatments and subsequent gas analyses, a processing technique will be defined which will produce a low level of dissolved gases in the materials.

For this program, small vacuum fusion specimens will be taken from each of the materials upon their receipt. Duplicate specimens will be heated to appropriate outgassing temperatures in a vacuum system such as is shown in Figure 5.

Outgassing cycles will be used with times of 6 and 50 hours so that the outgassing characteristics may be extrapolated. A vacuum of 10^{-8} mm of mercury will be maintained during the outgassing tests.

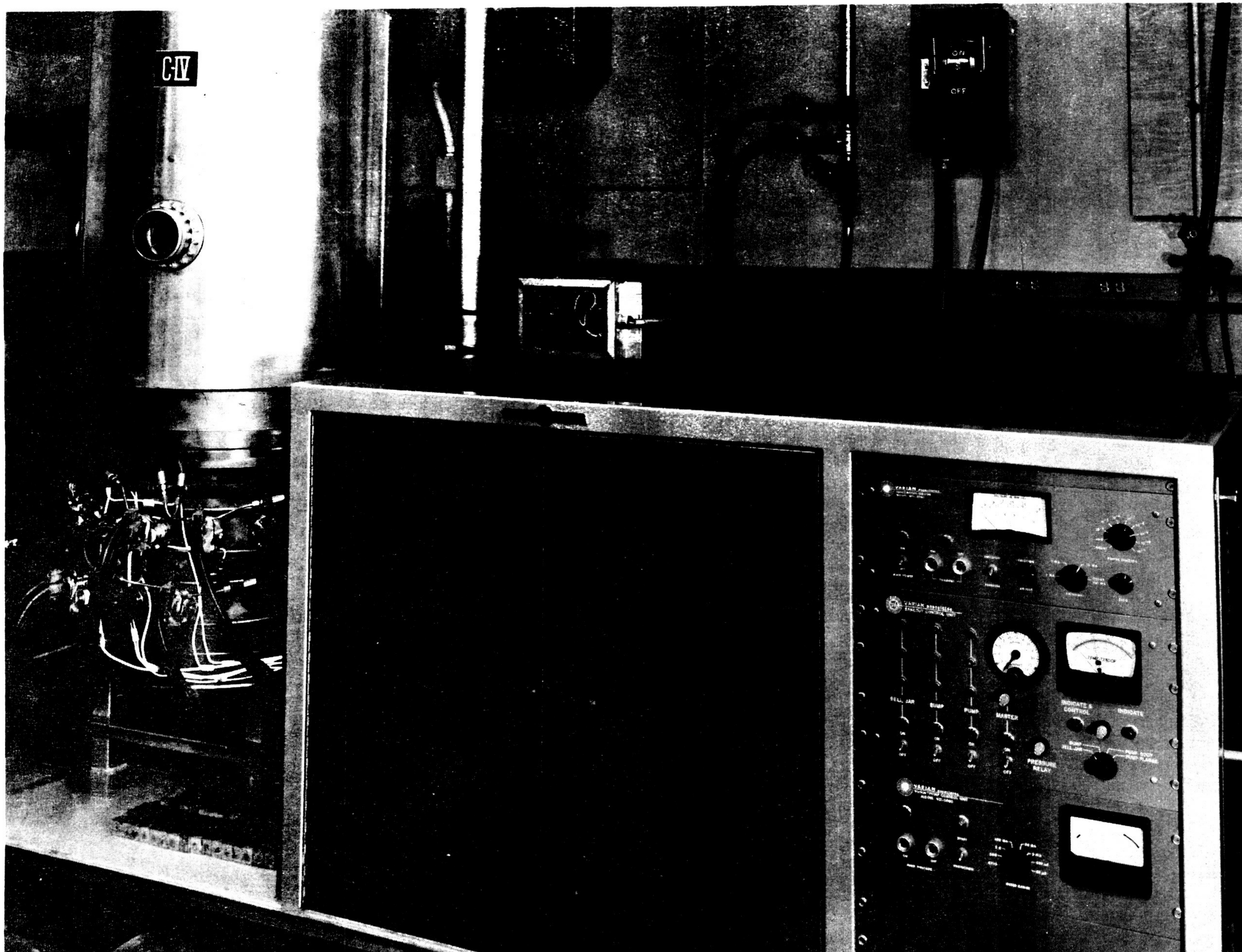

Figure 5. High-Vacuum System (10^{-10} Torr Range) In Which Samples Will Be Heated For Outgassing Analysis.

B. Contact Resistance Phenomena

1. Theoretical Considerations

The study of contact between material surfaces has been of concern for many decades[4,5,6,7,8] in connection with a wide variety of problems. We are concerned here with the problem of electrical contact resistance, but similar effects are involved in thermal transfer between surfaces and in friction and wear in sliding surfaces. Surfaces make contact only over a small fraction of the apparent area (even when they are flat within the best degrees obtainable) at the asperities, or high spots of the contour. At moderate pressures contact may, therefore, take place over only a fraction of 1% of the total area. This leads to high shearing stresses in sliding surfaces (at the asperities) with resultant wear. In thermal and electrical conduction it leads to the constriction resistance phenomena.

All of the current flowing through an intermetallic joint must pass through the actual regions of contact at the asperities. It will be seen that these areas are very small, and that the resultant current densities will be very high. It is apparent that the effective resistance of the constriction may then be substantial (equivalent to a substantial length of the electrode which carries current to the contact point). The contacts which may be made between hard materials such as molybdenum fall in this category of "long constrictions" and the electrical resistance of the electrode itself may be largely neglected.

Holm gives expressions in his classic work[4] for the equipotential surfaces surrounding the actual area of contact between asperities. In his most general form (for elliptical contact area) this is:

$$\frac{x^2}{\alpha^2 + \mu^2} + \frac{y^2}{\beta^2 + \mu^2} + \frac{z^2}{\mu^2} = 1$$

α, β ellipic semi-axes
μ ellipic parameter

It may be shown that the reduction in constriction resistance which will result from irregularities in the contact area is relatively small. For example a 50:1 ratio of the major to minor axes (essentially line contact) will produce a reduction of only about 50%. Little generality is lost, then, by assuming circular contact areas, with a considerable simplification of the subsequent analysis. The equation for these surfaces (still ellipsoids of revolution) is:

$$\frac{x^2 + y^2}{\mu^2 + a^2} + \frac{z^2}{\mu^2} = 1$$

a contact radius - cm.
x, y, z Cartesian coordinates

In the actual contact of relatively smooth hard surfaces, it may be expected that a flexibly mounted contact will settle into position on three points. In general, one of these points will probably lie much closer to the center of pressure, as sketched in Figure 6 , and most of the contact deformation will occur at this point. Most of the current will also flow through this area and the contact will behave very much as a single point contact. The equipotential lines in this illustration are defined by values of μ which have been drawn from the basic constriction resistance equation:

$$r_\mu = \frac{\rho}{2 \pi a} \tan^{-1} \sqrt{\frac{\mu}{a}}$$

r_μ partial constriction resistance Ω
ρ resistivity Ω cm

The space between equipotential lines encompasses 1/6 of the total constriction resistance (assuming constant ρ , that is to say - low current). It may be seen that the constriction voltage drop occurs over a very small distance in the immediate vicinity of the actual contact.

The critical parameters in the constriction resistance equation above are seen to be the electrical resistivity, ρ , and the diameter of the contact

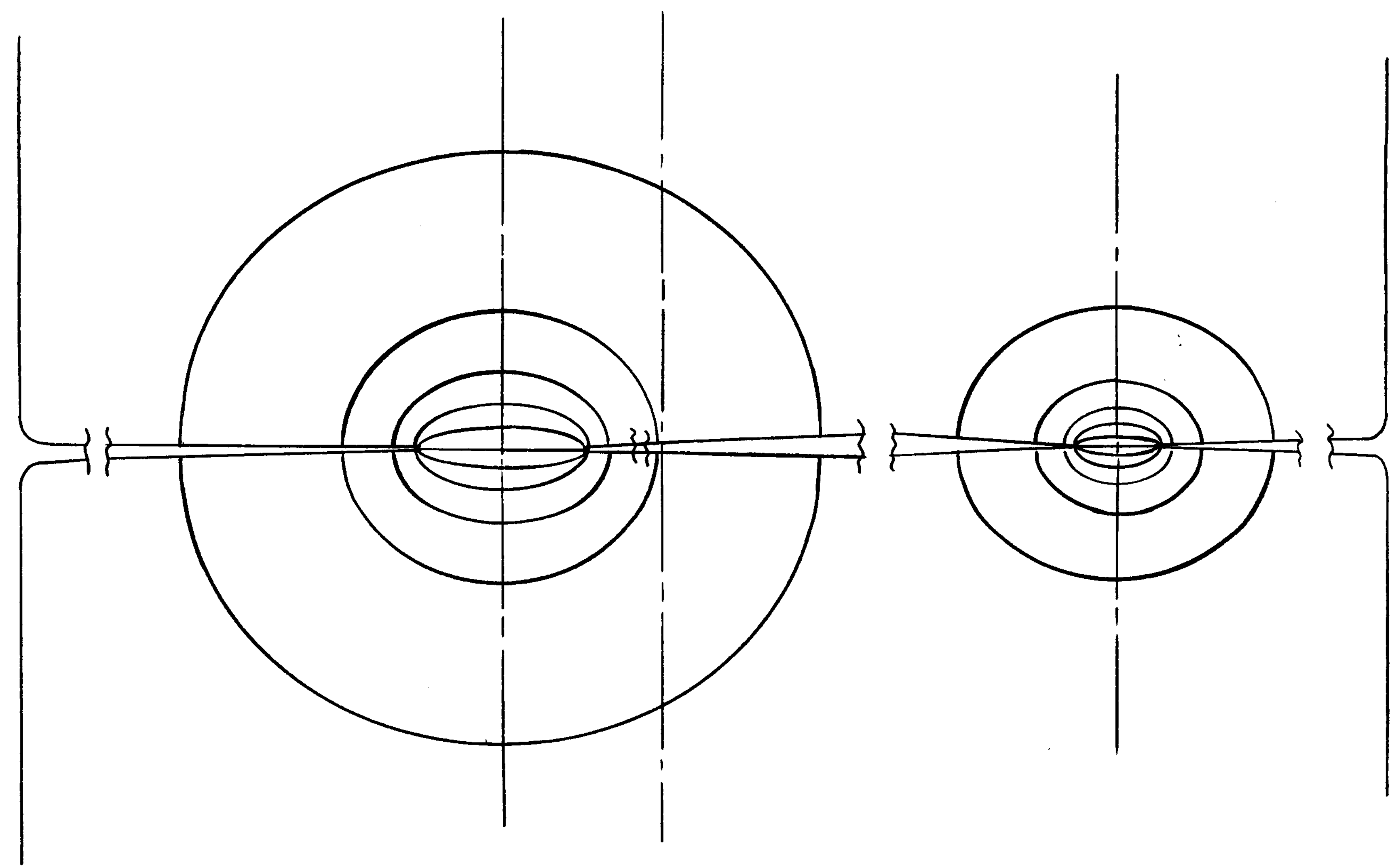

Figure 6. Equipotential Isotherms at Constrictions

point, a. The resistivity, as a function of temperature, is available from many sources [9,10]. The contact diameter involves an appraisal of the actual mechanism whereby the asperities are brought into sufficiently intimate contact to conduct. In general, current concepts (cf. 5,6) agree with Holm's early conclusion[4] that plastic deformation will occur at these points and that the effective stress for this effect may be chosen as three times the compressive yield stress. This figure appears to closely approximate the hardness, measured with a conical point (as indeed it should, since similar deformations are involved). Battelle reports values of compressive yield stress[11] which have been used to calculate the "hardness" curve shown in Figure 7 with the resistivity curve.

The diameter of the contact spot, or spots, may be readily calculated[12] using the relationship:

$$\pi a^2 H = P/n$$

Yielding:

$$a = \sqrt{\frac{P}{\pi n H}}$$

H "hardness" plastic yield stress KG/cm^2

P contact load KG

n number of equally loaded contact points

This value of a may then be substituted in the solution of the equation for the constriction resistance to define the contact resistance. It will be noted that the diameter of the individual contact point decreases as the load is shared by a number of points. It will be seen that the addition of parallel paths, each of higher constriction resistance, still leads to lowered contact resistance.

The solution of the equation for r_μ yields the overall constriction resistance for a "long constriction" when $\mu \rightarrow \infty$. The constriction resistance, for the path in both electrodes, is then given by:

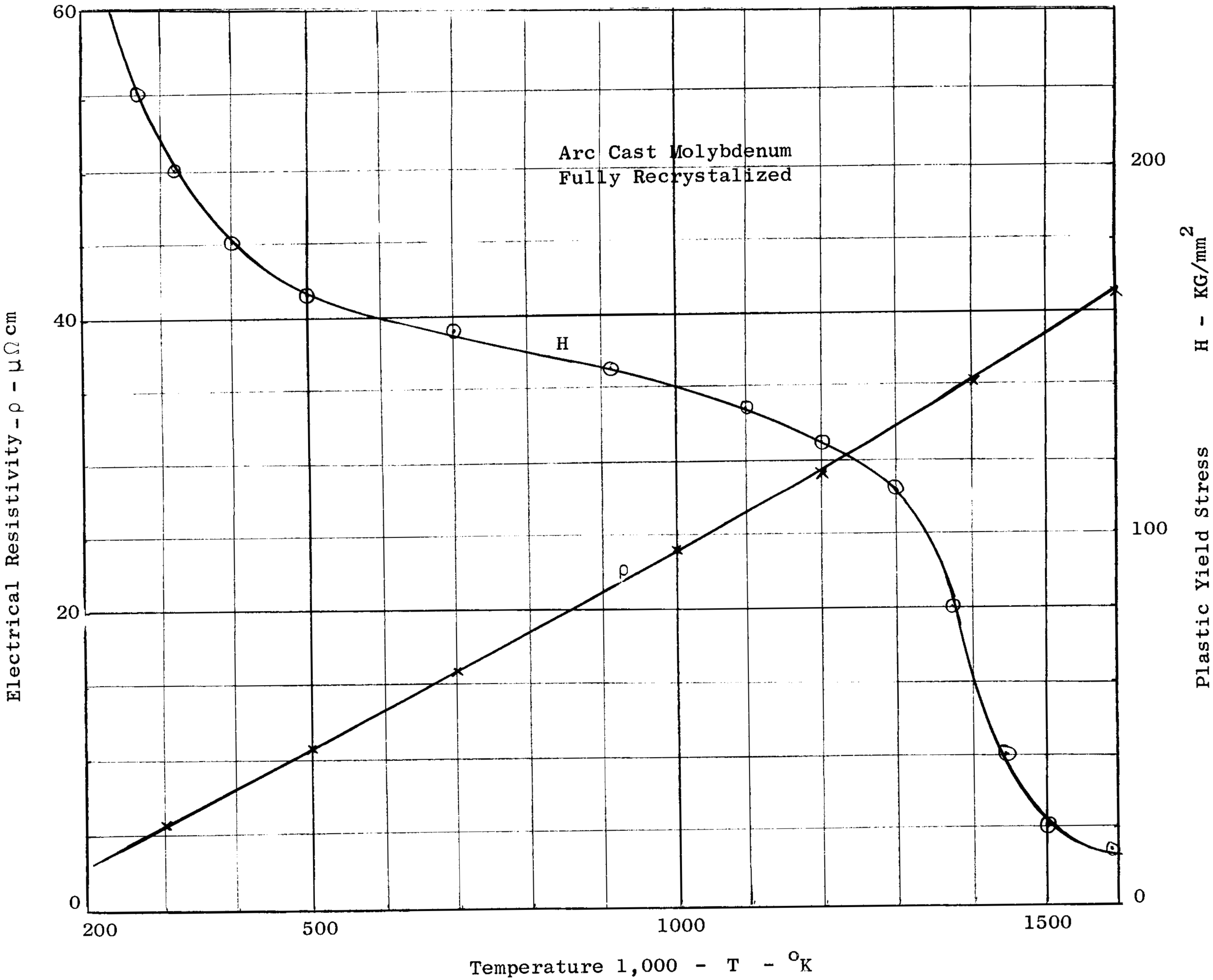

Fig. 7 Temperature Dependance of H, ρ For Molybdenum

$$\lim_{\mu \to \infty} 2\, r_{\mu} = R_c = \frac{\rho}{2\,a}$$ R_c = constriction resistance Ω

Substitution of the value for a from the deformation equation, and reduction by parallel paths yields:

$$R = R_c/n = \frac{\rho}{2}\sqrt{\frac{\pi H}{n P}}$$ R = contact resistance Ω

The equations for a and R have been used, as seen in Figure 8 , to calculate the contact resistance and equivalent diameter for a vacuum switch with molybdenum contacts (assuming no surface contamination) over a range of operating temperatures. It should be carefully noted that these calculations assume uniform temperature of the contact material over the constriction region, and therefore, correspond to low current operation. The increase in contact resistance over the range from room temperature (where the initial tests for this program were run) to the target ambient of 1,000°F will be about 2.8:1, while an electrode temperature increase of about 750°F would increase the ratio to 4:1.

It may be seen in Figure 7 that molybdenum shows an initial softening (leading to machinability) a few hundred degrees above room temperature. Of more serious possible consequences to the operation of a high temperature vacuum switch is the softening which occurs between 1,350 and 1,450°K (about 2,100°F). This softening effect will limit the temperature rise of the constriction contact surfaces, but may lead to a potential welding hazard. In general then, the temperature rise in this switch must not bring the actual contact surfaces into this temperature regime, if welding is to be avoided.

The current densities encountered in the constriction region will be of the order of 100,000 amperes/cm^2 and the power dissipated in this region will be

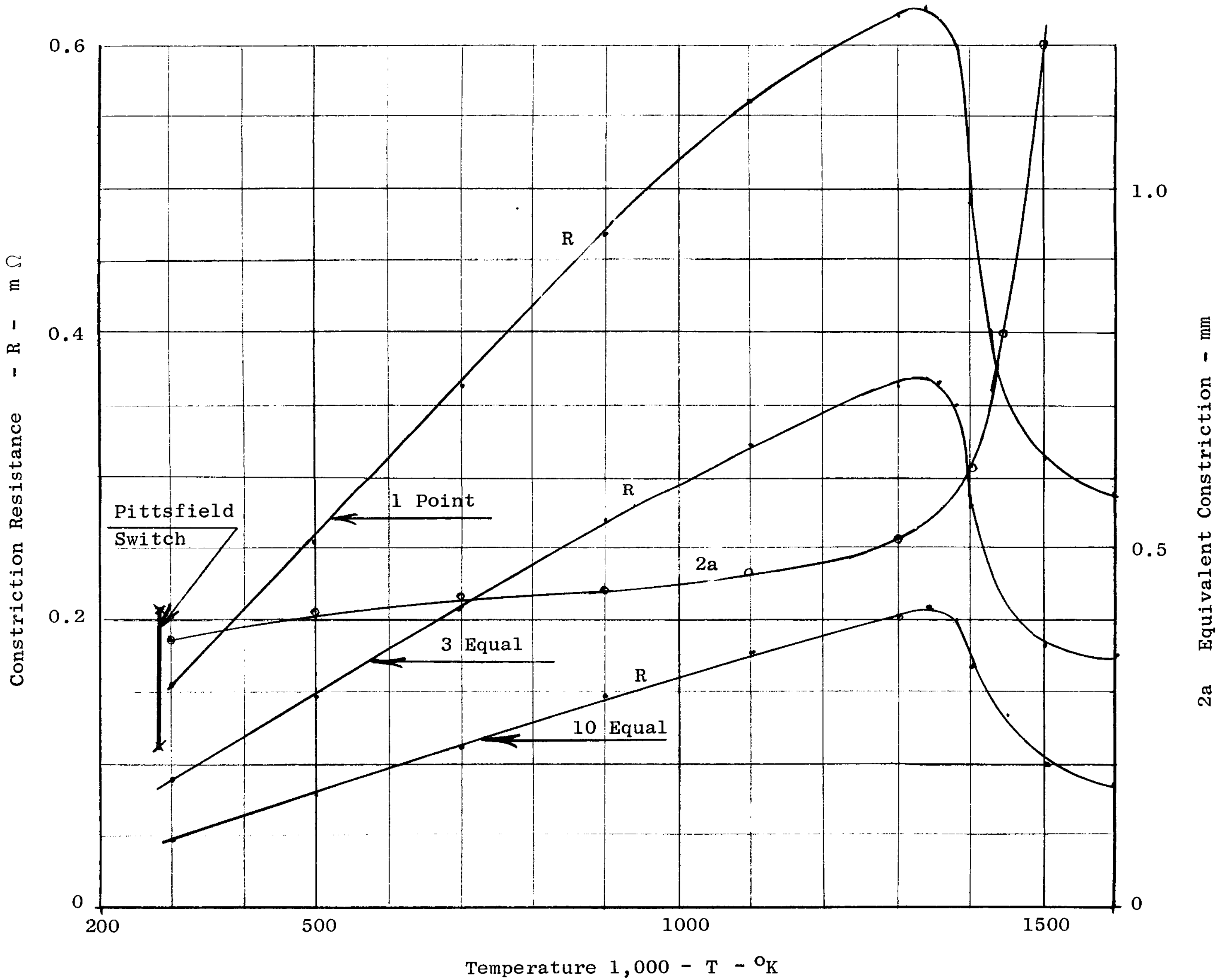

Fig. 8 Molybdenum Contact Constriction Properties

several MW/cm^3 so it will be necessary to seriously consider the heating effects in the contacts when high current operation is required. Additional studies will, therefore, be carried out to provide detailed temperature profiles in the electrodes and constriction region under steady state operation and under transient conditions, such as the specified close-open test cycle. These theoretical studies will furnish information that will aid in evaluating, in detail, switch design parameters.

2. Experimental Measurements

An attempt was made to measure the contact resistance of molybdenum and tungsten contacts in air, realizing that an oxide film would be present that would tend to give higher values than when measured in a vacuum. The resistances measured for molybdenum contacts, however, varied over such a wide range that the results were valueless. At 51 lbs contact force and a d-c current of 15 amperes the voltage drop ranged from 1.3 to 28 millivolts, a resistance range of 0.086 to 1.86 milliohms. The tungsten contacts were more consistent and averaged 1.5 milliohms.

Since the materials test vacuum capsule was still pumped down to a pressure less than 1 x 10^{-8} Torr at room temperature, the resistance of the molybdenum contacts were measured at several contact forces. The data recorded is included in Appendix A. Figure 9 is a curve showing the decrease in apparent resistance from 12 milliohms at 35 pound contact force to 2.8 milliohms at 47 pounds.

These resistance values included the resistance of both of the stainless steel electrodes, 0.3 milliohms and the contact resistance between both of the contact tips and the electrodes 0.08 milliohms.

Since the resistance values were measured at 15 amperes d-c and are considerably higher than expected the effect of high current on the resistance was investigated. To obtain the high current, the measurements were made using 60 cps power. Figure 10 shows the variation in the voltage drop across the vacuum capsule for a-c currents up to 300 amperes. The data recorded is included in Appendix A. The resistance decreases from 6.6 milliohms at 30 amperes to 1.7 milliohms at 300 amperes, as measured in the external circuit.

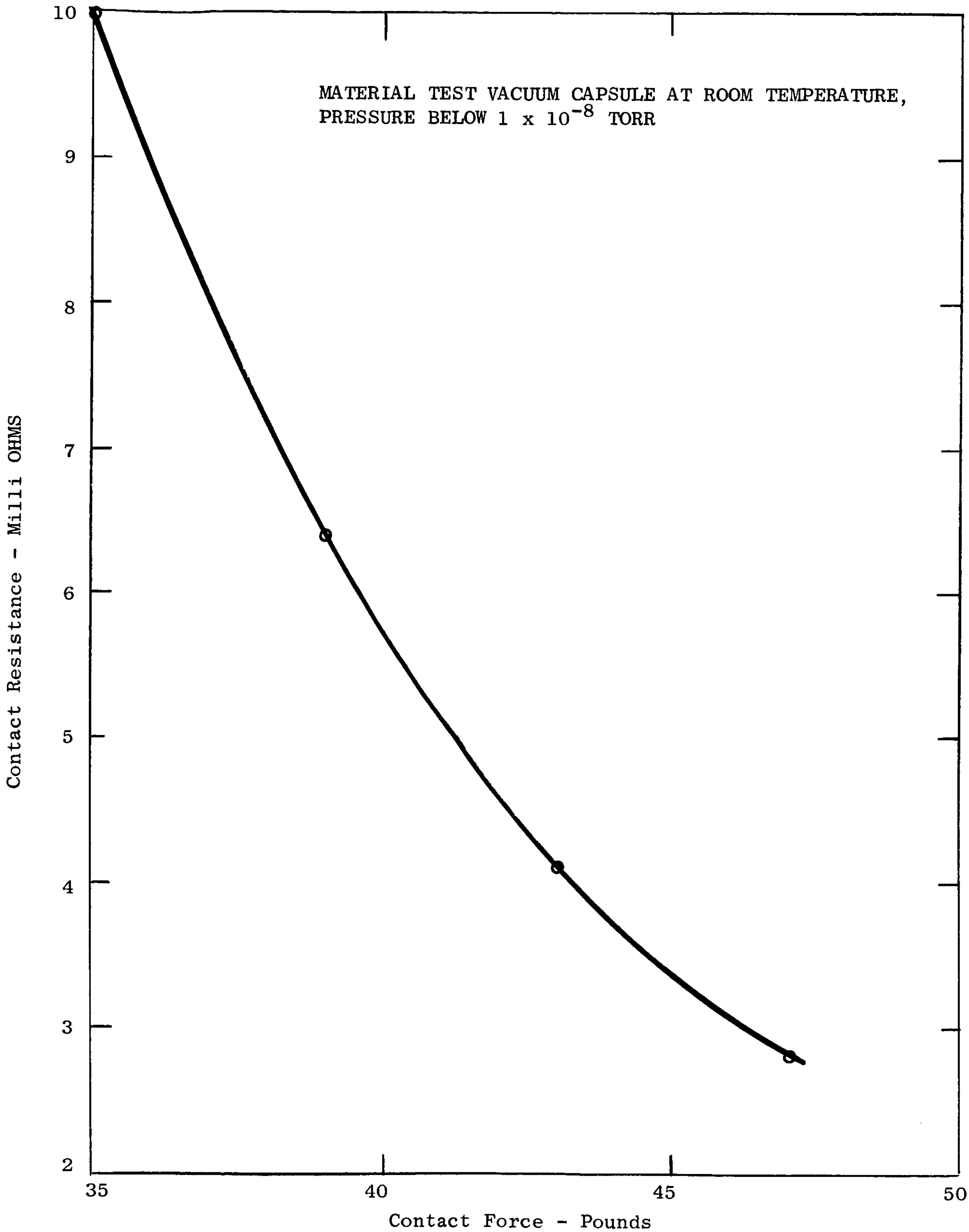

Figure 9. Contact Resistance vs. Pressure, of Molybdenum Contacts After Interruption Tests, with 15 Amp. D.C.

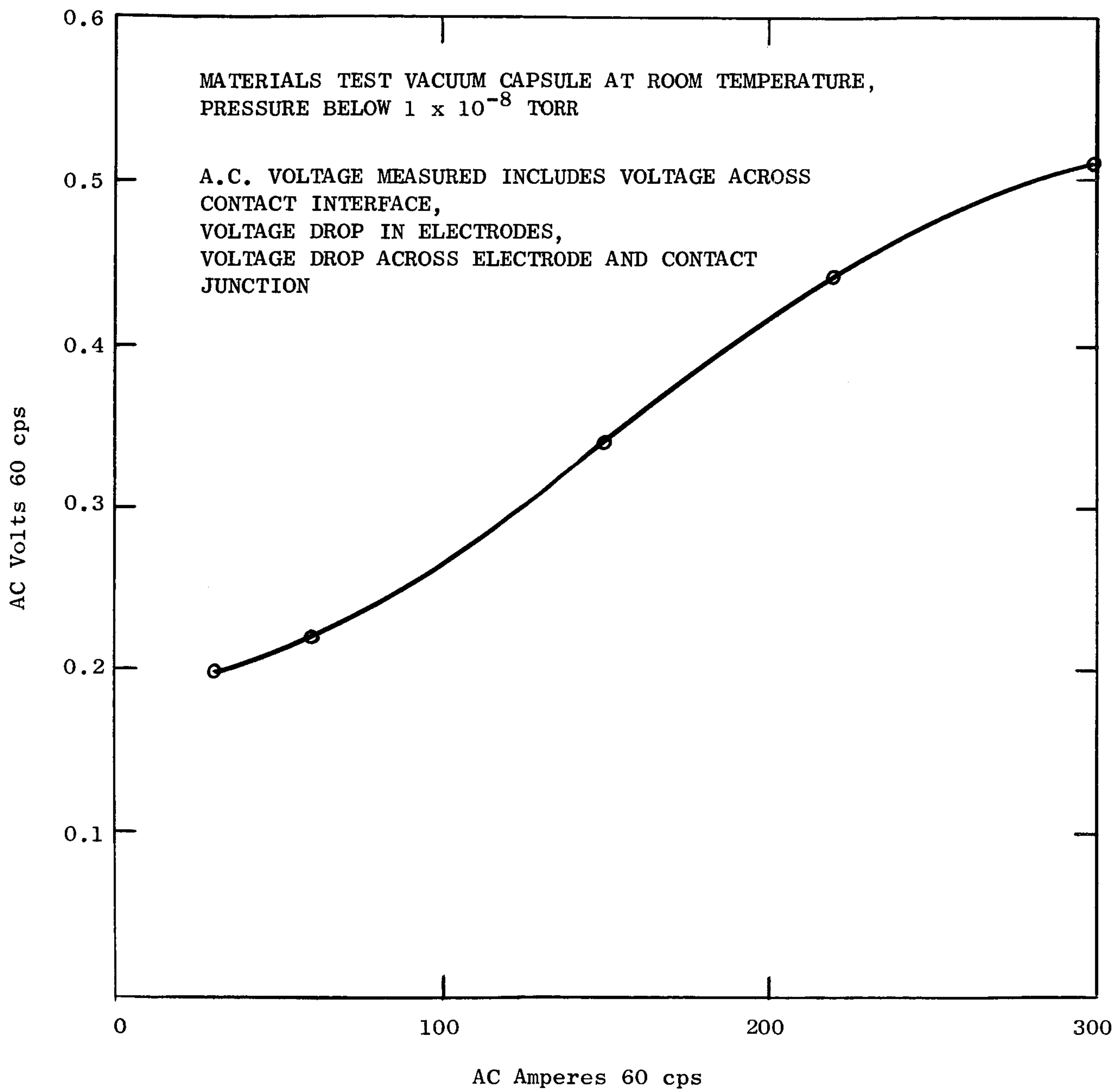

Figure 10. Voltage Drop vs. Pressure, of Molybdenum Contacts After Interruption Tests, with 300 Amps A.C.

As a further check on the method of resistance measurement the contact resistance of two development samples of vacuum switch manufactured by the Distribution Protective Equipment Department in Pittsfield were measured. These switches had molybdenum contacts 3/8" in diameter. The counter balance spring was adjusted so that the contacts just closed at a force of 1 pound. The data recorded is included in Appendix A. The resistance value measured at 24 pounds contact force on switch #1 is slightly less than the value, 0.3 milliohms, measured during the development test of the switch. For switch #2 the contact resistance at 24 pounds contact force was considerably less, being 0.18 milliohms. If these resistance values are scaled down in proportion to a $\sqrt{24/P}$ ratio for 50 # contact force, nominal, the resultant 0.207 and 0.125 milliohms compare closely to the calculated values.

C. Single Break Mechanical Design

To minimize contact bounce a new vacuum switch design was presented at the meeting held at ATL on February 9, 1965. Figure 11 is a sketch of this design.

The expected large bounce of the previous designs was a serious concern to some members of this project. In large industrial breakers, cams, linkages, etc., are utilized to minimize bounce. But in our environment these are not feasible. Therefore, another method was required. The one utilized and shown in the sketch is the principle of a small mass backed up by a stiff spring. The mass of the moving contact--bridging contact--is much less than that of the previous proposed designs.

In this design the electrical insulation for the moving contact is inside of the vacuum enclosure. The amount of creepage path required is considerably reduced by this method, and no ceramic to metal seal is needed. The ceramic material is utilized in the compression mode. The bushings shown in the sketch are commercial vacuum seal types.

As a result of the double break the gap was decreased to 1/8" and the force increased to 100#, 50# per contact. An additional request of the group at the meeting was to incorporate a double bellows. This would provide a small buffer region which would be filled with an inert gas such as argon or krypton to provide a barrier to hydrogen permeation through the thin metal bellows. This effectively provides a thick bellows with only double the operating force of a single thin bellows.

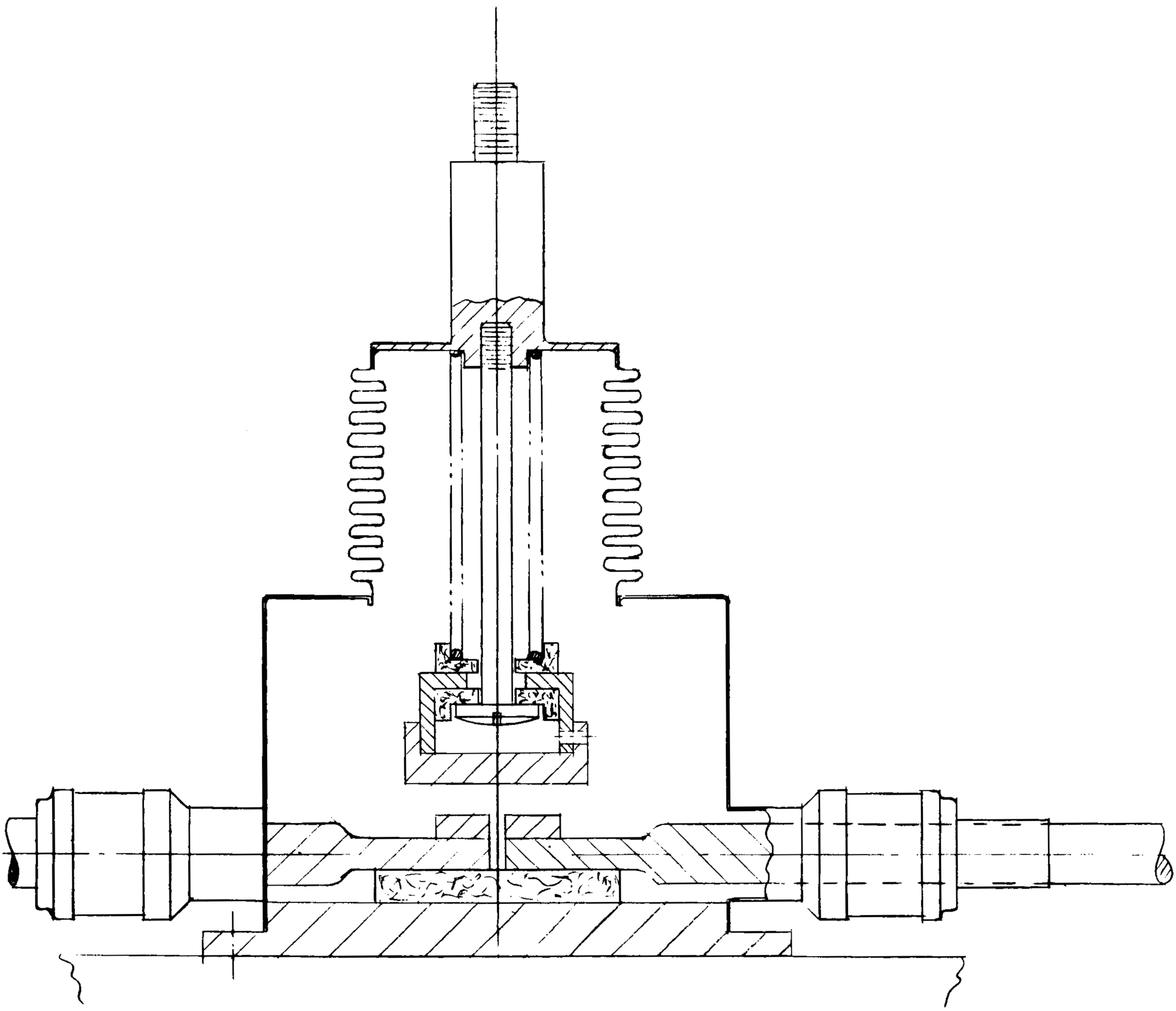

Figure 11. Double Break, Low Contact Bounce, Design Concept of Vacuum Switch (Interrupter).

Additional sketches were made of vacuum switches during the ensuing days. Also some contact resistance tests were made. The latter indicated that the double contact was likely to produce too much heat to be practical. Therefore, the single break approach was reactivated. However, it was almost mandatory that the low bounce principle be retained. To have both features the idea presented in the sketch of Figure 12 was proposed.

In Figure 12 , the connection to the movable contact is a group of parallel thin flat laminations. If these laminations are .005" thick, 1/2" wide, and average 2" long, and ten are used in a group with these groups equally spaced around the contacts; the resistance would be 366 $\mu\Omega$ in nickel at 800^{o}K. At 600 amps this would produce 131 watts. Possibly thicker lamina could be used, or more of them, or a higher conductivity material, i.e., tantalum.

The force required to roll one nickel lamina through the required 1/4" contact travel is approximately 1 oz. Therefore, 30 such laminations would require less than 2 lbs total force. This is small enough so that thicker or more laminations could be used. If molybdenum were used with no change in dimension or quantity the resistance would lower to 178 $\mu\Omega$ and the force increase to approximately 3 lbs. This is a net gain as the power loss would be only 64 watts with a 50% higher force. Of course, thinner laminations with a larger quantity put in to maintain the cross section would reduce force also, but at increased fabrication difficulties.

Of course, it is highly essential that the laminations do not touch, especially at temperature, since they will be very clean and in an ideal welding environment. During launch they may touch momentarily but at room temperature. When carrying current there will be forces tending to move them

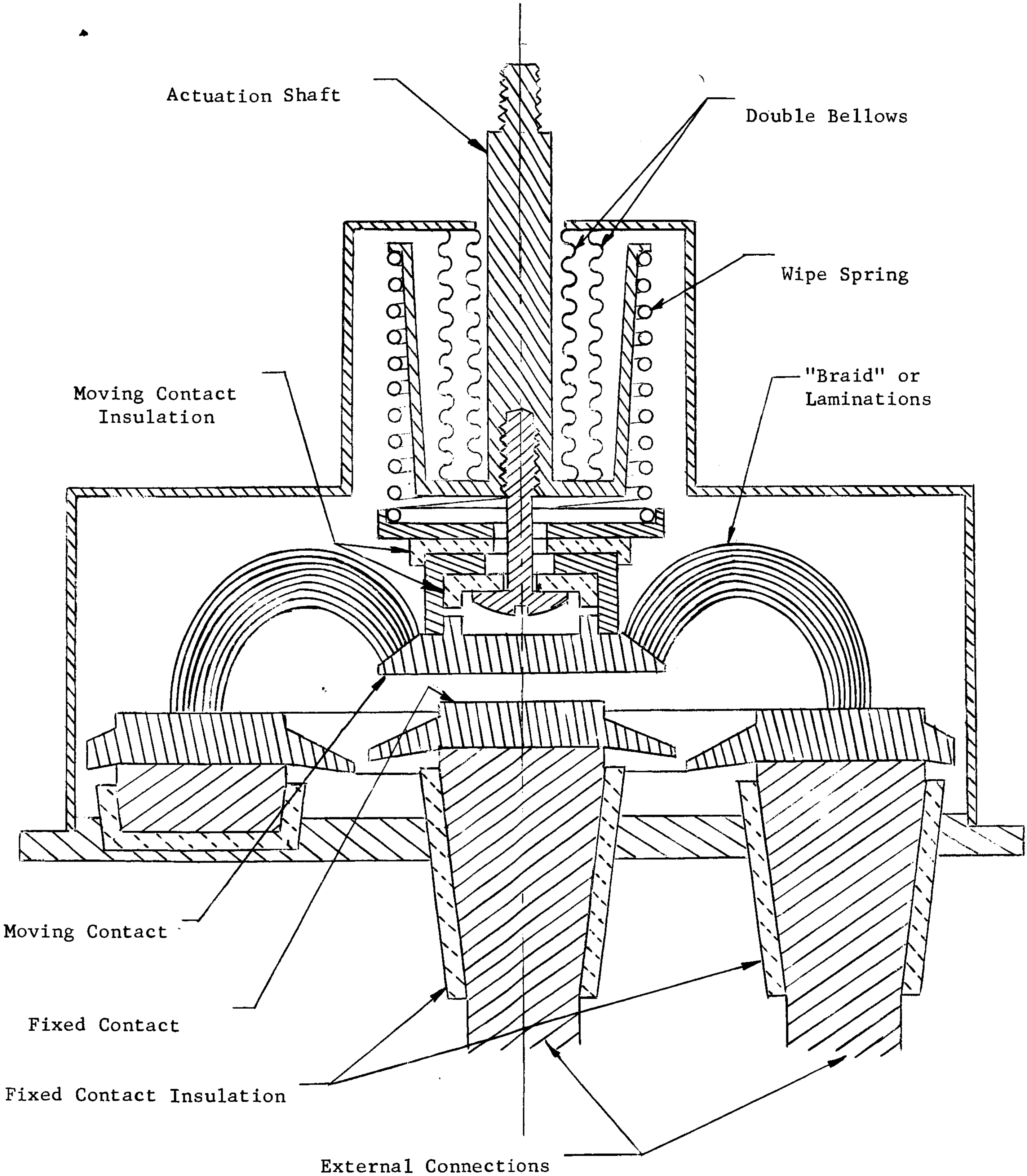

Figure 12. Design Concept of Single Break Vacuum Interrupter with Internal Connections to Movable Contact

outward which will not make them touch, when properly designed. Also, when carrying current there will be constrictive forces tending to collapse the assembly. How high these forces are, has not been analyzed yet.

The sketch shows contact skirts to shield the insulation. It also shows the two electrodes extending through the tapered insulation for heat sink thermal connections. The tapers would be made at an angle that naturally locks and also the insulation (probably high density alumina) would be wetted with metal in the joint region so that it would all braze together for a vacuum tight joint with excellent thermal contact. It is intended that the insulation around the two electrodes continue down into the heat sink plate with the metal thermal contact carrying the heat to this sink.

The design concept at present seems to be better in most every way than the previous designs. The following are desirable features of any design we may use for the vacuum interrupter:

1) A small diameter bellows, doubled.
2) A low mass moving contact assembly--low bounce.
3) Wipe spring should be outside the vacuum enclosure.
4) Electrical insulation should be near the moving contact inside the vacuum enclosure--small and light weight.
5) The pivot point of the moving contact should be as near as possible to the point of contact.

The design offered meets all of these except number three. The reason for desiring the spring outside is to keep all foreign materials outside the vacuum envelope to reduce the outgassing problems. It is difficult to get the force of the spring applied at the right place unless it is inside the vacuum. Also the large diameter spring is a better spring design and the small diameter bellows is a better bellows design.

A phone call to Mr. F.L. Perry of the Huntington Alloy Products Division of the International Nickel Company, Inc. revealed the opinion that Inconel "X" should not present outgassing problems even at 1000°F. He did not have bonafide vacuum data on Inconel "X".

Note that this design offers an all grounded envelope--no need for electrical insulators between the vacuum envelope and the actuator shaft and ground or frame.

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III ACTUATOR DESIGN

A. Single Pole vs. Multipole Design

Previous to the Project Review Meeting of February 9, 1965, all of the AC design concepts were shown as 3Ø, 3 pole models. The 50 lb force per contact resulted in a large solenoid having approximately 200 lb of force and a flexural pivot of a size that Bendix engineers were questioning could be manufactured. At this meeting it was decided that the AC breaker model would be a single pole device as well as the DC engine contactor. The following is a summary of the features this decision brought to light--both pro and con.

Advantages:

- Less design time--less drafting. The single pole design was required for the DC Engine Contactor.
- Many of the parts for the AC and DC designs would be the same. We planned to use the same actuator mechanism, same solenoid, same mounting, same flexural pivots, etc. The difference would be in the vacuum switches. The AC requires large contacts for high current, electrical insulation for 1000 volts; while the DC requires small contacts and heat sinks for low current carrying capacity but increased electrical insulation for the 10,000 volt rating.
- The moving mass is appreciably less in the single pole design having a small force solenoid with accompanying smaller armature and no spider to carry force to the three side mounted switches.

- It can be packaged in a tube for a simple, inexpensive yet strong, light weight mechanical design.
- The flexural pivots are smaller and can definitely be made in a 1" size which fits the standard production machines at Bendix; thus reducing cost. Single pivots can be used at each joint with 50# contact force. Only a single engineering charge will be made by Bendix to engineer the one pivot design.
- Can be tested in a smaller diameter facility; however, it must be longer. The longer facility would have been required for the DC model.
- Smaller actuator solenoid and smaller trip solenoid.
- The single pole design increases reliability in the event one pole fails.

Disadvantages:

- The design requires more total flexurals than the single unit 3-phase design.
- The total weight of actuator equipment will be greater.

B. Flexural Linkages

1. Bendix Flexural Pivots

Bendix Corporation can furnish a 1" dia. x 1.6" long double ended flexural pivot made of Inconel "X" for use in the single break, single pole 50 lb contact force design. This requires linkage arms of 6.25" length which makes the over-all design long while the single pole makes it slender. This long slender design, if mounted from one end--the interrupter end--makes a poor vibration and shock design. The center of gravity is located in or near the solenoid--12 inches or less up from the base. This is not unreasonable for a device with a 7" dia. base. The mounting surface could be the long dimension of the switch with the heat sink on the base end--a very practical method of mounting.

The polyphase breaker composed of three single pole breakers could be bolted or strapped together.

2. <u>Alternate Linkage Pivot Design</u>

Early discussions with Bendix on the former three pole design indicated that flexural pivots may be out of the question for the loads involved. This prompted thinking of other ways of accomplishing the latch linkage function. Figure 13 shows a sample mechanism demonstrating an idea utilizing extension springs. The figure(s) show the mechanism "latched", and "tripped", in Fig.14 .

Advantages:

- Small, short, light weight structure for given contact gap.
- Strong--will carry tremendous compression load.
- Inexpensive.
- Self protecting under dynamic tensile forces as encountered during breaker closing.

Disadvantages:

- Will gall where wires roll on each other at the inside of the spring opening.
- May fully "cold weld" which will freeze strut completely or partially "cold weld" which will cause maldistribution of bending load--either would cause eventual failure.

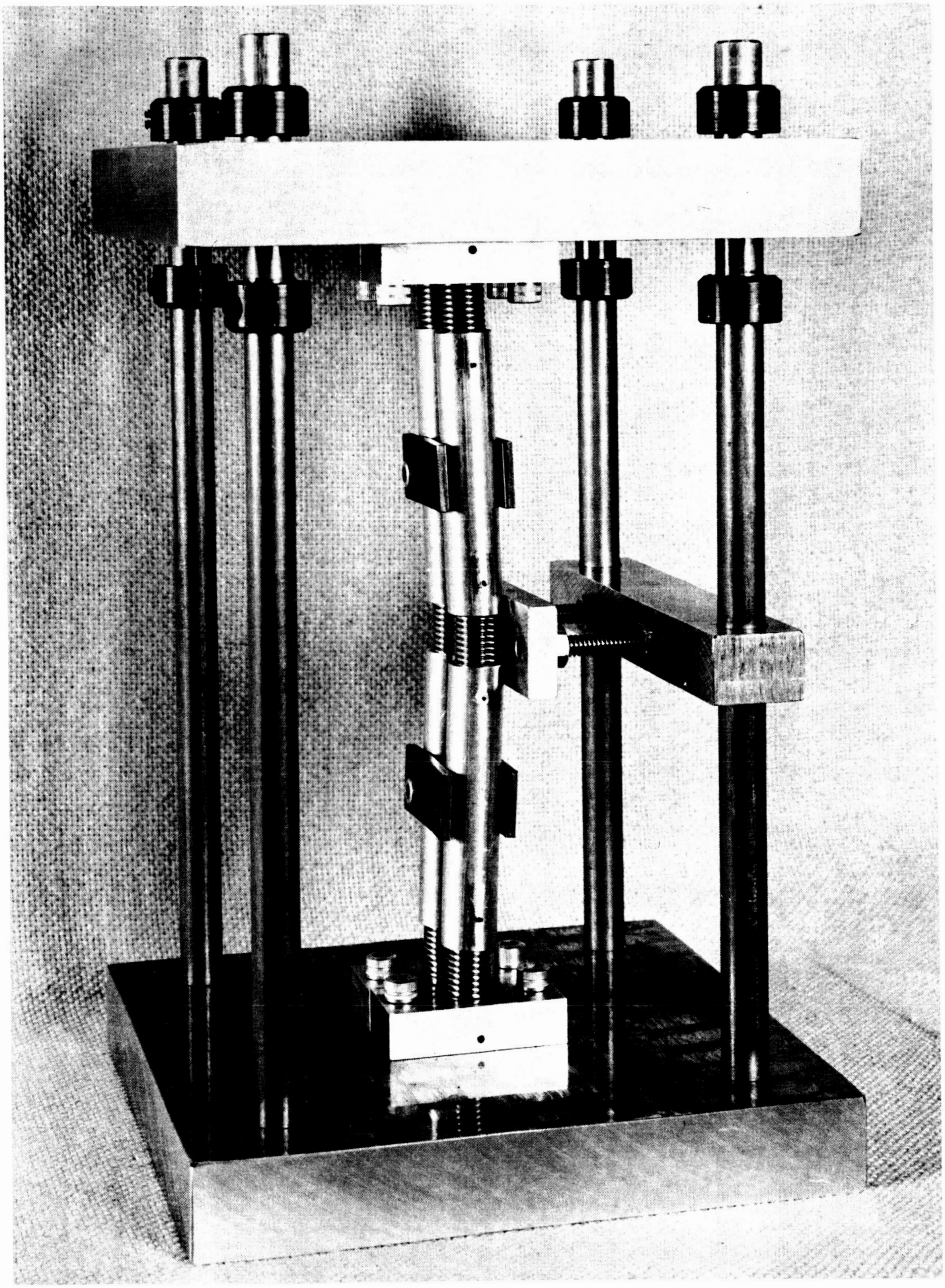

Figure 13. Extension Spring Type Strut Model for Switch Actuator (Latched Position).

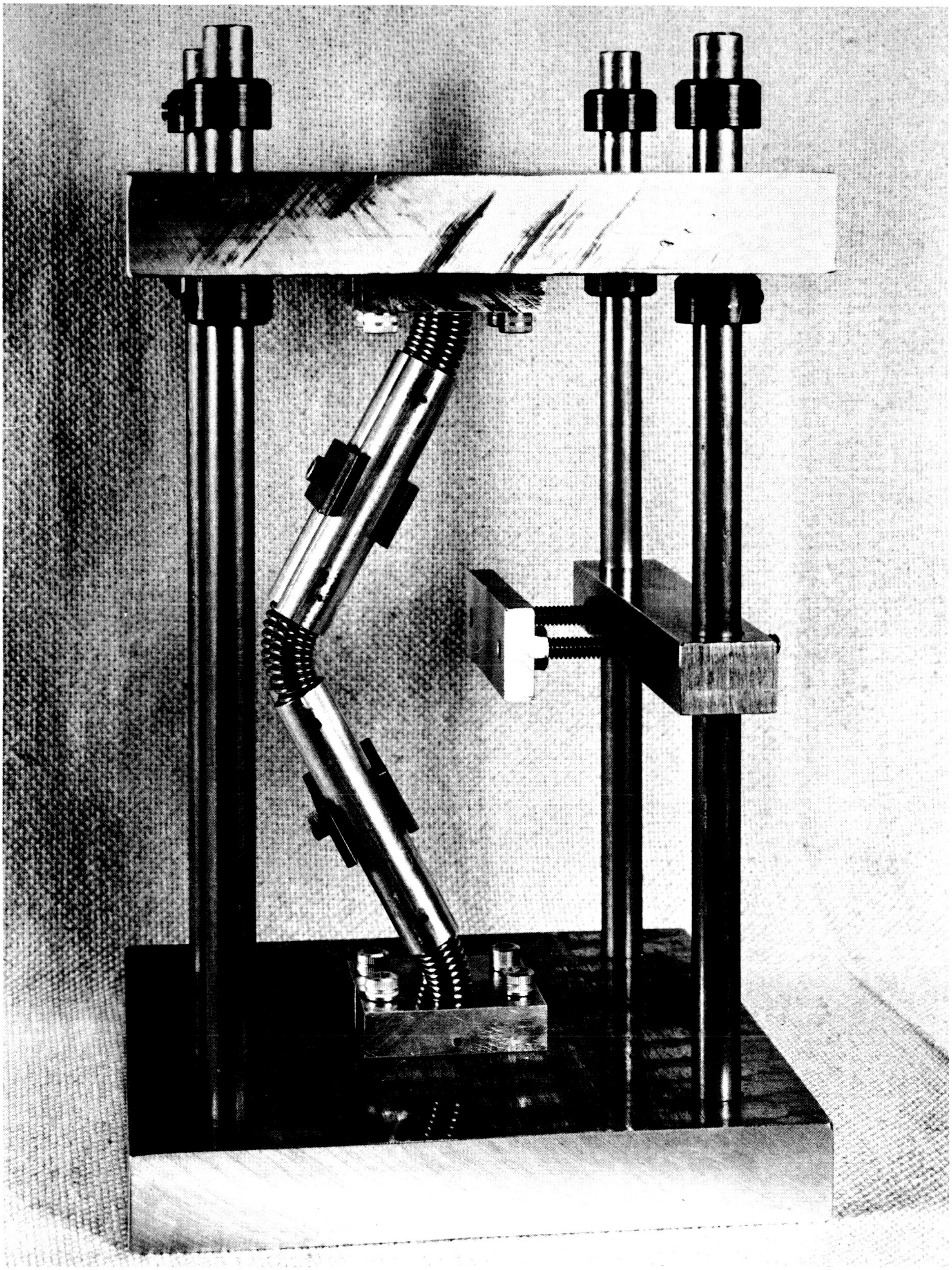

Figure 14. Extension Spring Type Strut Model for Switch Actuator (Unlatched Position).

The disadvantages are serious, not minor, and therefore this design has not been continued.

It may be possible to use materials for the springs that will not "cold weld" in the environment, but this is a separate development not deemed part of this project. The International Nickel Co. could not provide definite data on "cold welding" characteristics of Inconel "X" in a high temperature vacuum environment.

C. Solenoid Design

1. Actuating Solenoid

Early in the Phase II project a solenoid was designed to operate the three phase, three pole, single break AC breaker. After the meeting of Feburary 9, a new solenoid design was made to operate a single pole AC breaker. Figure 15 shows this solenoid. It is designed to provide a starting force of 32 lbs, a travel of 3/8", and an ending force of 70 lbs. This is done with a current density in the coil of 7650 amps/sq. in. If this current flows for one second the thermal rise will be approximately 17^{o}F if the coil is made of tungsten wire. The armature will weigh less than 1 lb.

2. Trip Solenoid

A trip solenoid was designed for the three phase, three pole, single break AC breaker. It is approximately 2 1/4" dia. x 2 3/4" long having 1/4" stroke. This solenoid is undergoing redesign for the single pole, single break model but is expected to be nearly the same size.

3. Flexible Diaphragms

In the second monthly report Figure 2 presented a diaphragm configuration and the test fixture. That configuration lasted about 1300

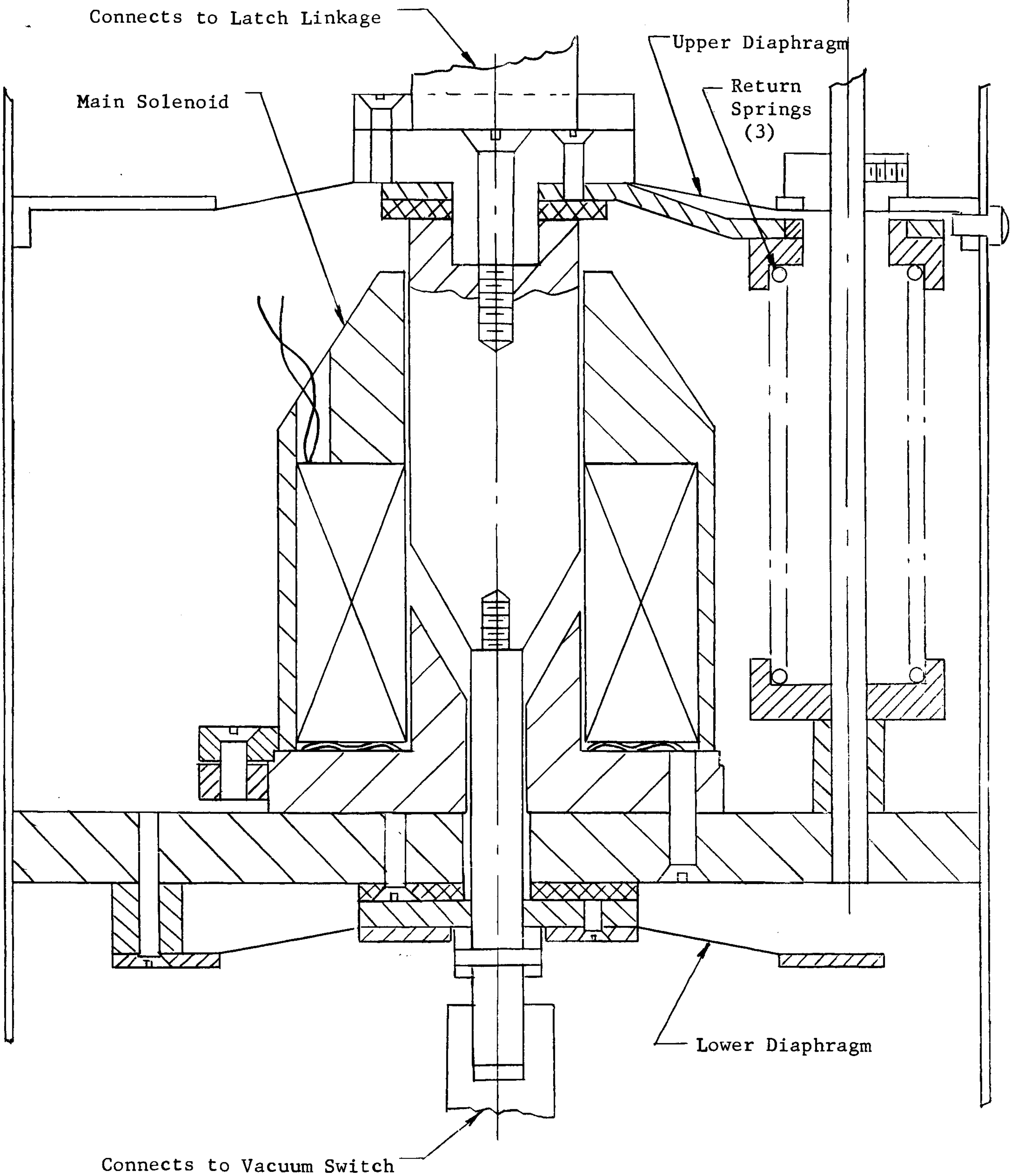

Figure 15. Main Solenoid & Diaphragms

cycles to failure. Modifications were tried with their resulting life being very disappointing.

A study of the action revealed that the right configuration should remove the tearing stress and result in nearly straight bending. Paper and cardboard models were made of the original and two subsequent designs. The latter of these was deemed worthy of constructing a metal model for testing.

Since this design was inherently more flexible both axially and radially, three thicknesses were made--.005, .010, and .015" in stainless steel shim stock. A quantity of plates were simply stacked up, clamped together, and machined as a group.

One .005" thick was tested at 3/8" travel for 6000 cycles before failure. A second diaphragm .010" thick was tested with the same travel for 12,000 cycles before cracking. It was intended that the diaphragms be made of Inconel "X" but stainless steel can be used at 1000°F and may actually be better material for the diaphragms. This will be investigated further.

With the long fatigue life the present design is a good diaphragm design. The necessary tooling is available for the main solenoid diaphragms. The same design scaled down in size will be used for the diaphragms for the trip solenoid.

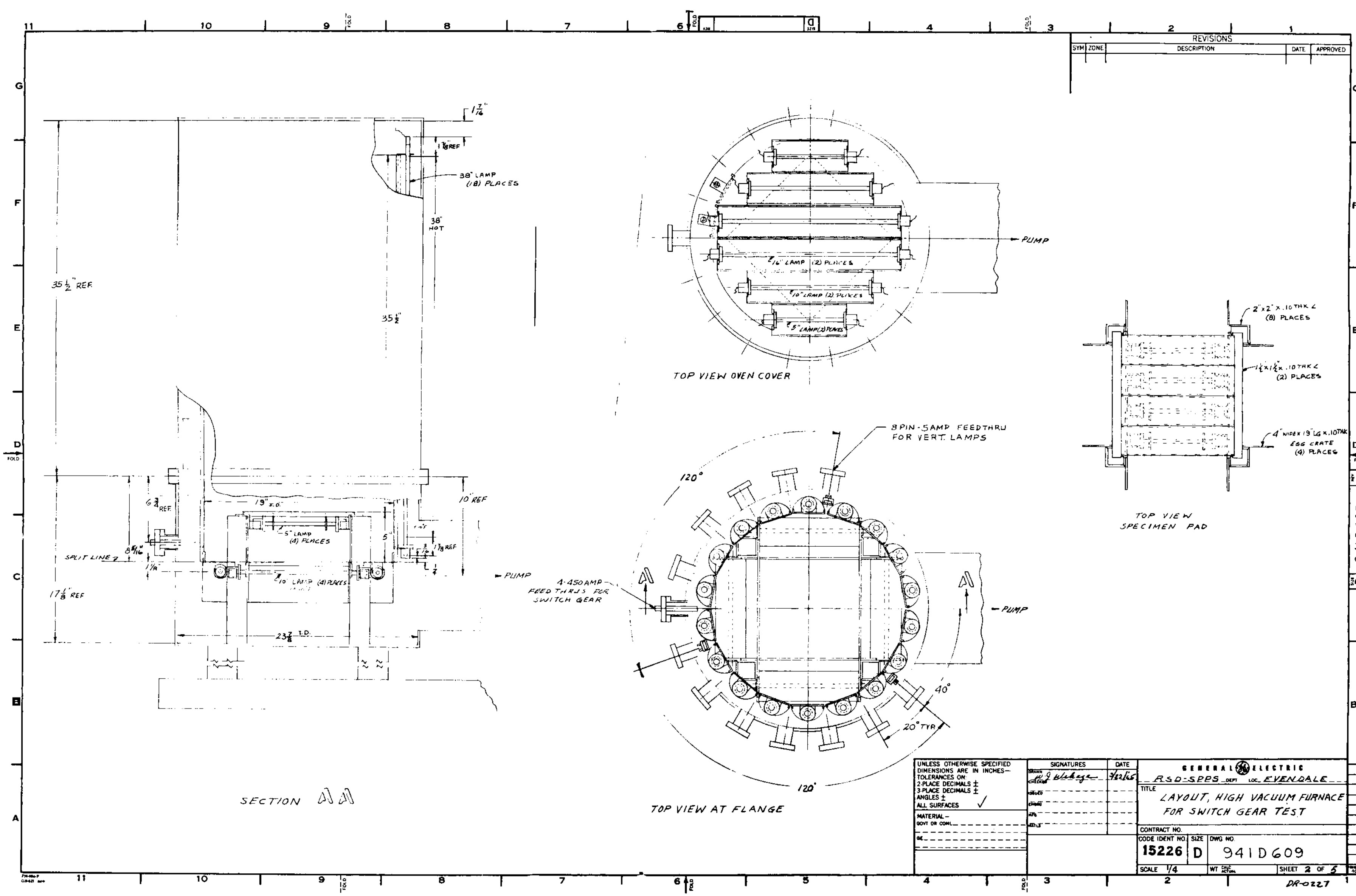

Figure 16. Radiant Heated Oven for Long Time Temperature Endurance Tests

IV. ENDURANCE TEST FACILITIES

A. Vacuum Chamber and Heated Oven

The furnace for the environment test portion of the switchgear program will be designed into an existing 24 inch diameter Varian vacuum tank, located in the SPPS Lab Area A of Bldg. 701. A layout of the furnace in the tank is shown on Figure 16 (Drawing 941D609). The internal dimensions of the furnace are 19 inches diameter by 35-1/2 inches high.

The furnace will be heated to 1000°F around the circumference and on the top and bottom with General Electric quartz lamps. The lamps will be capable of heating the furnace to a temperature in the neighborhood of 1300°F to hasten the outgassing of the furnace structure. The furnace will have "three zone" control. The furnace top, sides, and bottom will be independently controlled to insure proper temperature distribution within the furnace. The electrical circuits to the lamps will be arranged in such a way that individual lamp burnout can be detected.

The material used in the construction of the furnace will be an iron, nickel, cobalt alloy known as Kovar or Rodar. It is a vacuum melted, vacuum cast alloy that has the low outgassing qualities necessary for high vacuum service. The Rodar is available only in strip stock 4 inches wide by 0.1 inch thick. Therefore, the 4 inch width of the Rodar dictated a furnace design consisting of vertical slats with each slat containing a quartz lamp and reflector. The reflector is made from alternate layers of 0.003 inch Rodar that will be rolled from the 0.1

inch original material, and wire forms. Several reflector layers will be used behind each lamp to maintain the heat loss to the vacuum chamber at a level consistent with the chamber's heat removal capacity. A total of 18 lamps will be equally spaced around the circumference of the furnace to give good temperature distribution during the test.

The top and sides of the furnace are welded together to facilitate removal of the furnace for access to the switchgear under test. Access to the switchgear is accomplished by lifting up the bell of the vacuum chamber with the hoist provided with the chamber, then by lifting the top and sides of the furnace with the same hoist. The electrical connections to the top and side lamps will have to be disconnected, along with any thermocouple connections, prior to lifting the furnace to expose the switchgear. The bottom of the furnace is permanently fastened to the bottom of the vacuum chamber by 4 fabricated Rodar legs. The bottom of the chamber is lamped for proper temperature control and is constructed as a ring and disc to permit evacuation of the interior of the furnace. All electrical and cooling air connections to the switchgear will be ducted to the inside of the furnace through the vacuum feed-throughs of the tank, the ring, and disc bottom of the furnace.

APPENDIX A

Molybdenum Contact in Materials Test Vacuum Capsule. Capsule Pressure Less than 1×10^{-8} Torr at Room Temperature

Contact Force Pounds	DC Current Amperes	Voltage Drop Volts	Resistance Milliohms
35	15	0.185	
	15	0.18	
	15	0.18	
	15	0.18	12 avg.
39	15	0.084	
	15	0.094	
	15	0.098	
	15	0.098	
	15	0.096	
	15	0.096	6.4 avg.
43	15	0.062	
	15	0.065	
	15	0.064	
	15	0.060	
	15	0.062	
	15	0.066	
	15	0.062	4.2 avg.
47	15	0.046	
	15	0.044	
	15	0.040	
	15	0.042	
	15	0.043	
	15	0.041	
	15	0.041	2.8 avg.

Contacts opened and closed between successive measurements.

Current adjusted to 15 amperes for each measurement.

APPENDIX A (Cont'd)

Molybdenum Contact in Materials Test Vacuum Capsule. Capsule Pressure Less than 1 x 10^{-8} Torr at Room Temperature

Contact Force Pounds	60 cps Current Amperes	60 cps Voltage Drop Volts	Resistance Milliohms
47	30	0.2	6.7
	60	0.22	3.7
	150	0.34	2.3
	220	0.44	2.0
	300	0.51	1.7

60 cps a-c power was obtained from 2 current transformers with the high turn winding connected in parallel to an adjustable voltage source. The single turn windings of the transformers were connected in series.

APPENDIX A (Cont'd)

Pittsfield Vacuum Switches
Room Temperature
Molybdenum Contacts 3/8" Dia.

Switch #1

Contact Force Pounds	D-C Current Amperes	Voltage Drop Volts	Resistance Milliohms
13	15	0.0045	
	15	0.0042	
	15	0.0044	
	15	0.0045	
	15	0.0044	0.29 avg.
24	15	0.0037	
	15	0.0037	
	15	0.0035	
	15	0.0035	
	15	0.0035	0.24 avg.
Switch #2			
13	15	0.0045	
	15	0.0041	
	15	0.0042	
	15	0.0043	
	15	0.0042	0.28 avg.
24	15	0.0027	
	15	0.0027	
	15	0.0027	
	15	0.0027	
	15	0.0026	0.18 avg.

Contacts opened and closed between successive measurements.

Current adjusted to 15 amperes for each measurement.

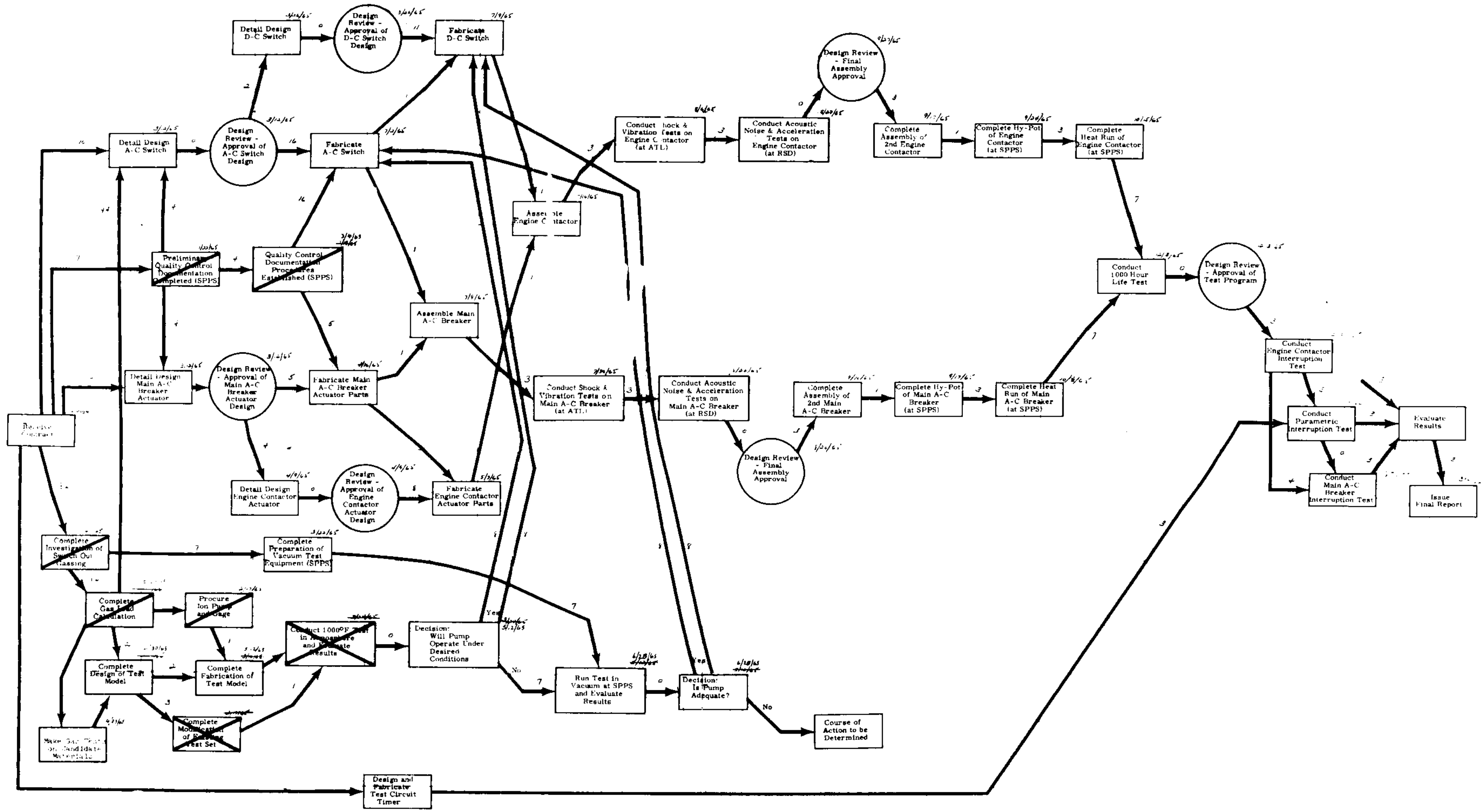

Figure 17. Pert Diagram.

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