NASA Contractor Report 4266

High Temperature Capacitive Strain Gage

S. P. Wnuk, Jr., S. P. Wnuk III,
and V. P. Wnuk

CONTRACT NAS1-18668
JANUARY 1990

NASA Contractor Report 4266

High Temperature Capacitive Strain Gage

S. P. Wnuk, Jr., S. P. Wnuk III,
and V. P. Wnuk
Strain Gage Development Laboratory
HITEC Products, Inc.
Ayer, Massachusetts

Prepared for
Langley Research Center
under Contract NAS1-18668

NASA
National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Division
1990

CONTENTS

LIST OF FIGURES

ABSTRACT

Capacitive strain gages designed for measurements in wind tunnels to 2000°F were built and evaluated. Two design approaches were followed; one based on fixed capacitor plates with a movable ground plane inserted between the plates to effect differential capacitive output with strain, the second based on movable capacitor plates suspended between sapphire bearings, housed in a rugged body, and arranged to operate as a differential capacitor.

A sapphire bearing gage (1/4" Diameter x 1" in size) was built with a range of 50,000 and a resolution of 200 microstrain. Apparent strain on Rene' 41 was less than ±1000 microstrain from room to 2000°F.

Three gage models were built from The Ground Plane Differential concept. The first was 1/4" square by 1/32" high and useable to 700°F. The second was 1/2" square by 1/16" high and useable to 1440°F. The third, also 1/2" square by 1/16" high was expected to operate in the 1600 to 2000°F range, but was not tested because time and funding ended.

1.0 SUMMARY

The objective of this program was to develop a capacitive strain sensor capable of measuring static strain in wind tunnel environments at temperatures to 1093°C (2000°F). The sensors were intended for use with existing capacitive mode card instrumentation.

The scope of the effort was limited to developing a low profile, rugged sensor, and improving its performance in a high temperature environment. A large part of the development effort was associated with fabrication techniques as well as with techniques to improve performance.

Two design approaches were pursued in this project. The first involved the ground plane differential (GPD) concept, consisting of fixed parallel capacitor plates with a ground plane inserted between the plates to effect a differential capacitor sensitive to strain. The second approach utilized sapphire bearings to support a differential capacitor within a rugged housing. Development effort for sapphire bearings to support differential capacitor plates within rugged housing.

Development effort for sapphire bearing gages included housing design, plate spacing optimization, and construction techniques. Developmental effort for the GPD gage involved gage body material selection, capacitor plate construction and attachment to gage body, electrical isolation of capacitor plates from each other, electrical isolation of the ground plane from capacitor plates, and precision machining of gage components.

The technical discussion in this report highlights gage design, and methods used to improve high temperature operation. Significant attention is given to manufacturing processes including sputtering, diffusion welding, Electronic Discharge Machining (EDM), and Chemical Vapor Deposition (CVD). Some instrumentation modifications were made to improve performance, although instrumentation development was not part of this project.

First model GPD gages (5 mil gap) were limited to 400°C (750°F) operation. The second GPD design (20 mil gap) extended operation to 760°C (1400°F). The third design (20 mil gap) was not tested because time ran out, but planned inmprovements should permit operation in the 900°C to 1100°C (1650°F to 2000°F) range.

Sapphire bearing gages were capable of making static strain measurements to 1093°C (2000°F) within the following specifications:

Specifications

Temperature Range: 20 to 1093°C.
Apparent Strain: Chord slope essentially zero between 20 - 1093°C
Band width 1000 μ"or better
Resolution: 0.4% of full scale
Drift: 120 μ" in 20 minutes at 1093°C (2000°F)

These results represent an improvement over those results reported in Phase I over the temperature range of 20 TO 1093°C.

It must be noted that there is a large potential for further performance improvement through future modifications of capacitive instrumentation.

2.0 INTRODUCTION

2.1 PURPOSE

The objective of this program was to develop a capacitive strain gage capable of measuring static strain in wind tunnel environments at temperatures to 1093°C (2000°F). Desired properties of the gage included small size, rugged construction, low profile, and negligible actuating force.

2.2 CURRENT STATE OF THE ART

Traditional wire gages are capable of measuring dynamic strain to 1315°C (2400°F) and static strain to 760°C (1400°F) with severe limitations. Existing capacitive gages are capable of measuring static strain at temperatures to 815°C (1500°F) and experimentally to 1093°C (2000°F). The standard Boeing gage manufactured by Hitec Products under license from The Boeing company, and the platinum version of the same gage respectively represent the current state of the art in capacitive strain gage technology. The fragility and high profile of these devices are major limitations in wind tunnel testing.

In Phase I a differential capacitance gage employing ceramic bearings in place of flexures was developed which operated to 1093°C (2000°F). The gage was substantially more rugged, and about two-thirds the height of a standard Boeing gage. Near the end of Phase I, a new concept for a very low profile, and even more rugged design was conceived. The intent of Phase II of this program was to further develop the sensor concepts of Phase I and to extend the current state of the art in terms of ruggedness and profile to allow use of capacitive gages in high temperature wind tunnel test environments.

2.3 APPROACH

The approach for GPD gage development was based on the conceptual design developed under Phase I of the program and reproduced as figure 1. The overall approach was guided by four objectives consisting of:

1. Construction of a large scale prototype to validate design equations.

2. Construction of a miniature gage to validate gage operation at small scale.

3. Construction of a miniature high temperature gage to evaluate gage performance at high temperature.

4. Refine designs based on results of high temperature testing.

Development of the sapphire bearing gage was based on design modification of prototype Model SB-1 sapphire bearing gages constructed under Phase I of the program. This gage is reproduced schematically in figure 2, and pictorially in figure 3. The overall approach was to improve rigidity and ruggedness of the gage by redesigning structural elements of the gage, and to simplify manufacturing.

2.4 DESCRIPTION OF PROGRAM EFFORT

Program efforts were directed toward design of the GPD gage, improvement of sapphire bearing structural design, development of manufacturing processes for both gages, and evaluative testing of both gages. Processes investigated for construction of the GPD gage included a means for applying conductive films, lead wire attachment techniques, precision arrangment of gage components, methods to electrically isolate capacitor plates, means for electrically insulating the ground plane from other gage components, and means for structurally bonding gage components securely for use at high temperatures. Development was conducted in incremental steps consisting of:

- prototype design and concept confirmation
- body material selection
- conductive film application
- ceramic to metal bonding techniques
- electrical isolation of capacitor plates
- lead attachment
- ground plane construction
- electrical isolation of ground plane
- design modification based on high temperature testing
- instrument modification

Evaluative testing was conducted at each developmental step prior to proceeding to the next step. Milestone tasks guiding investigation and development included construction and evaluation of large, miniature, and high temperature prototype gages. The first prototype was a large scale gage (1 inch gage length) intended to validate design formulas. Prototype performance was close to anticipated, and gage miniaturization was set as the next milestone objective. Miniature (1/4 inch gage length) prototypes were successfully constructed about halfway through the program. The prototypes performed as anticipated, but highlighted a need to maintain extremely precise construction tolerances. High temperature prototypes were fabricated and evaluated. These first gages exhibited short life at temperatures above 870°C (1600°F) and excessive electrical leakage at temperatures above 815°C (1500°F). The prototypes could be made functional at higher temperatures through modification of capacitive mode card instrumentation, but this work was beyond the project scope.

The approach for improving sapphire bearing gage consisted of first improving the structural frame of the gage and later replacing the frame with a tubular body. New processes necessary for sapphire bearing gage construction included a means of mounting bearings in the tube frame, and improved methods of capacitor plate attachment. Prototype gages designated model SB-3, were tested at temperatures from room through 1093°C (2000°F).

3.0 TECHNICAL DISCUSSION

3.1 GPD GAGE DESIGN

The Ground Plane Differential (GPD) gage is based on the concept of a differential capacitor sensitive to strain by means of a movable ground plane. The concept is shown sectionally in figure 1. and electrically in figure 4., and entails two out-of-phase capacitor plates coupling to a signal plate through an opening in a movable ground plane sandwiched between the excitation and signal plates.

Design of the sensor is based on capacitive coupling between the signal and excitation plates as given by the following relation:

$$C = .225e_r((N-1)A/t)$$

where:

- C = capacitance in picofarads
- A = coupling area in square inches
- N = number of plates
- t = thickness of dielectric in inches
- e_r= dielectric constant relative to air

The relation can be simplified by assuming operation in air, a two plane configuration (i.e. excitation plate plane, and signal plate plane), large capacitance plate area relative to ground plane opening area, and negligible plate separation between excitation plates. With these assumptions the relation reduces to:

$$C = .225A/t$$

Where A is the area of the ground plane opening in square inches. Using this relation, an initial gage total capacitance of .5 Pf was selected based on known input characteristics of capacitive mode card instrumentation. A series of design curves for allowable ground plane opening dimensions for various plate separations was then generated as shown in figure 5. Other design considerations of the gage included a desired gage length of 6.35 mm (1/4 inch), a desired range of +/- 20,000 micro-strain (5,000 µ" per 1/4 inch), highest resolution obtainable, and lowest feasible profile.

3.2 MATERIAL SELECTION

Gage body material selection was based on criteria of superior electrical resistivity, mechanical strength, Temperature Coefficient of Expansion (TCE) and compatability with platinum. Desired material properties include high resistivity at elevated temperature (>20 megohm-cm at 1093°C), high strength (>138 x 10^6 N/m^2 or 20,000 PSI at 870°C), TCE compatability with platinum (capacitor plate material). Electrical properties of low dielectric constant, high dielectric strength, and negligible loss angle tangent at high temperature were also desired. A schedule of properties of candidate materials is provided in figure 6.

Candidate materials were obtained and rigorously evaluated for use in constructing a high temperature gage. Alpha-quartz material was rejected due to structural instability with temperature. This material apparently went through a crystal transition to beta-quartz at about 574°C (1065°F) and often fractured at this temperature. Amorphous quartz, an initially promising material, was later rejected during diffusion welding experiments. This material exhibited a temperature or chemical incompatibility with platinum (or some combination thereof) causing poor diffusion weld bonds at temperatures above 1038°C (1900°F), and was also found to exhibit unacceptably low volume resistivity at high temperature. High purity Boron Nitride (grade HP) was rejected due to inadequate physical strength and hardness properties. Another grade of Boron Nitride (grade M) exhibited better physical properties, but was rejected during diffusion welding tests due to problems suspectedly associated with the materials' high silica content. A thin (17 mil) wafer of single crystal aluminum oxide (sapphire) with optically flat surfaces was obtained from Union Carbide Corporation. This material exhibited excellent physical strength, hardness, and thermal/chemical compatibility with platinum and was ultimately selected for use in constructing high temperature gage prototypes. Additional sapphire obtained from Adolf Meller Co. exhibited similarly acceptable properties. Ultra-high purity (99.995%) polycrystalline aluminum oxide available through Ceramco remains a promising material, but was not exhaustively evaluated during this project because of high tooling/machining costs and the previous acceptance of sapphire as an acceptable gage material.

Other materials considered, but not accepted for evaluation include beryllia (properties highly dependent on purity, and hazardous to machine), silicon carbide (volume resistivity too low), and silicon nitride (questionable volume resistivity at high temperature, difficult and expensive to obtain and machine).

3.3 CONDUCTIVE FILMS

Several conductive films were considered for use as gage capacitor plates. Thick film coatings were considered, but not selected for evaluation due to reports of poor high temperature properties. Platinum ink was evaluated and found unsuitable because of poor adhesion to gage body materials. Sputtered platinum films were selected for conductive film development because successful applications of platinum films to aluminum oxide demonstrated excellent adhesion at high temperatures.

A DC diode sputter system was designed after an MIT model and constructed for in-house use. Sputtered platinum films applied to rough alumina and silica surfaces were found to be tenacious, conductive, and capable of withstanding thermal shocks to 1315°C (2400°F)

Developmental problems associated with sputter coatings consumed a large amount of project hours. The first, and potentially most serious problem was an inability to obtain tenacious sputter coatings of platinum on optically flat ceramic surfaces. Initial platinum coatings applied to polished surfaces were quite delicate and could be easily removed with a razor blade. This problem was ultimately resolved by techniques acquired through consultation with industrial sources, a literature review, and extensive in-house experimentation. Tenacious platinum coatings were obtained by eliminating sources of contamination, development of surface preparation techniques, pre-sputtering an interfacial layer of chromium between the ceramic and sputtered platinum, and application of a heat treat cycle to the parts.

Another problem with sputtered platinum coatings was an apparent "de-sputtering" of the platinum under certain conditions above 1038°C (1900°F). This phenomenon is not consistently repeatable, and its' underlying causes are not completely understood. An effort was made to reduce or eliminate this effect by over-coating the sputtered platinum with aluminum oxide. Several techniques for accomplishing this were tried. The first technique involved sputtering aluminum directly onto the platinum and then oxidizing the coating with heat. A variation of this technique was an attempt to sputter aluminum in a partial pressure of oxygen and argon. The second technique involved indirect sputtering from an aluminum oxide target placed passively within an argon plasma. Both techniques produced unacceptably thin coatings of aluminum oxide. RF sputtering of aluminum oxide at a specified thickness of 0.5 microns was performed by an outside organization. This coating failed to produce a tenacious coating. Aluminum oxide applied by Chemical Vapor Deposition (CVD) were only partially successful because chlorine involved in the process chemically attacked the platinum.

Another attempt to eliminate desputtering of platinum at high temperature involved elimination of the interfacial layer of chromium. Pre-sputtering a small amount of chromium has been essential for acceptable bond strength of platinum coatings, but may be a contributing factor in the high temperature failure of the coatings. The suspected mode of failure for this case is the alloying of chrome into platinum. Efforts to eliminate the use of chrome pre-coats included increasing surface roughness, pre-sputtering Tantalum (Ta), and pre-sputtering Titanium (Ti) elements. Increasing surface roughness was an attempt to improve physical (Van der Waals) bonding by increasing total surface area. This was accomplished by micro grit blasting substrate surfaces. Platinum applied directly to roughened surfaces displayed better adhesion than similar coatings applied to polished surfaces, but bond strength was still insufficient. Pre-sputtering Ta to increase platinum coating adhesion was attempted based on recommendations outlined in publication NASA CR-135282, "Development of a High Temperature Capacitive Pressure Transducer" by R. L. Egger. This method improved adhesion through a graded interface between sapphire and platinum. It was accomplished by reactively sputtering Ta in a partial pressure of oxygen with argon, followed by direct sputtering of Ta in argon, then overcoating with platinum sputtered in argon. Coatings produced by this method were excellent at low temperature, but failed by delamination during or after exposure to about 870°C (1600°F). Pre-sputtering Ti was an attempt to increase adhesion through chemical bonding, and was a hopeful alternative because chemical bonding is the adhesive mechanism that makes chrome pre-sputtering effective. This method failed due to limitations of our in-house sputter equipment. In short, we were unable to obtain a uniform coating of Ti material on the surface.

Final sputter parameters selected for gage construction consisted of mild surface roughening, followed by an extremely thin sputtered chrome pre-coat and a sputtered platinum overcoat. This procedure produced coatings of sufficient tenacity to allow diffusion welding (see section 3.5) and were sufficiently substantial to withstand 1093°C. Some coatings survived temperature far longer than others, suggesting better coatings could be achieved through a more precisely controlled sputtering process. Potential improvements of sputter coatings can be expected through use of a multi-head sputter system (precludes breaking vacuum between steps) with precision process controls. Application of aluminum oxide through chlorine free CVD processes may also improve sputter coatings.

3.4 PLATE ISOLATION

Electrical isolation of capacitor plates from each other and from metallic gage components was required for proper operation of the gage. Techniques attempted for plate isolation included sputter masking and Electrical Discharge Machining (EDM) etching of sputtered films.

Sputter masking was achieved through use of finely cut tape bars and metal bars of chromel. Tape bars failed to hold shape under action of the sputter plasma, thereby resulting in uneven mask patterns. Prototype gages constructed with tape sputter masks exhibited unacceptably non-linear output. Chromel ribbon produced fine, but inconsistent, mask lines because intimate contact could not be maintained between the mask and sputter coating. Application of a dilute adhesive to the ribbon mask was unsuccessful. No prototype gages were constructed with the sputter mask method because complete electrical isolation of plates could not be achieved.

Plate isolation was eventually achieved by selectively removing the sputtered films with a fine electrically charged wire. This technique evolved from attempts to EDM the opening of the ground plane component of the gage. The process consisted of applying a 12 volt AC potential to a probe tipped with a 3-mil tungsten wire, grounding the sputtered film, and contacting the probe to the sputtered film. The result was a fine, 3 to 5-mil etch line in the sputter film. Resistivity between plates isolated with this method was greater than 20 megohms at room temperature.

3.5 CERAMIC TO METAL & CERAMIC TO CERAMIC BONDING

Ceramic to metal bonds were developed to fasten capacitor plates and mounting shims to the gage body. Since the gage capacitor plates consisted of sputtered platinum films, attention was directed toward diffusion welding platinum and platinum metal alloys to the sputter coating. High quality welds were initially made to sputtered platinum films by placing the sputtered surface in high pressure contact with platinum-rhodium wire (137.9 x 10[6] N/m[2] or 20,000 PSI) and heating the joint to 871°C (1600°F) for 20 minutes. Subsequently, diffusion welds of pure platinum to sputtered platinum were accomplished with a contact pressure of 34.5 N/m[2] (5,000 PSI) by heating the joint to 1038°C (1900°F) and allowing the assembly to furnace cool.

Further improvement of diffusion welding techniques were made through construction of a specialized diffusion welder. The fixture was constructed by modifying a pneumatically actuated Hughes spot weld head to apply precise pressure using dead weights. The weld head was thermally insulated from custom fitted silicon carbide heater elements. The elements were constructed by diamond cutting from solid SiC rods. Power was supplied by a 2.1KVA Variac and temperature monitoring was accomplished with a chromel/alumel thermocouple. This fixture represented a substantial improvement over previous diffusion welding fixtures requiring an oven and delicate loading mechanism. High quality welds could be accomplished quickly, and numerous 5 mil gap prototype gage bodies were constructed with the fixture. Typical weld parameters for a 5 mil gap prototype were 27.6 N/m[2] (4,000 PSI) applied to the weld joint at 843°C (1550°F) for 12 minutes.

Brazing was tried as a method to attach Hastalloy-X mounting feet onto the gage. The procedure involved sputtering platinum onto a ceramic surface, electroplating the platinum with a 1 mil thickness of nickel, then brazing the nickel to Hastalloy-X with a Nicrobraz® filler via torch or vacuum oven. Electroplating was accomplished with Midas brand plating solution, a pure nickel anode, and application of 1.5-2.0 volts D.C.. The electroplating procedure is extremely critical. Too fast a process produces stresses in the plated nickel which causes the sputtered coating to lift from the ceramic. The plating rate was found to be dependent on the resistivity of the sputter coating and temperature of the solution. Torch brazing to the nickel was unsuccessful because flux needed to control oxides attacked the thin nickel coating. Vacuum brazing produced good bonds between the braze material and ceramic, but only fair to poor overall bonds between the Hastalloy-X and ceramic. The primary cause of failure was differences between the thermal expansion coefficients of the ceramic, braze filler, and Hastalloy-X. This thermal expansion mismatch manifested itself in the form of warped Hastalloy-X shims and cracked ceramic. Attachment of gage mounting shims was successfully accomplished using platinum foil shims diffusion welding to the gage body.

Ceramic to ceramic bonds were developed to fasten upper and lower gage body halves together. Techniques considered included use of glass frits, ceramic cements, silica and metallic interfacial layers.

Glass frits were avoided due to known low resistivity properties of these materials at high temperatures. Ceramic cements were likewise avoided because past experience with these compounds indicated that bond strength would be insufficient. Preliminary testing of silica as a bonding agent yielded poor results, and development was subsequently abandoned in favor of metallic bond material.

Ceramic to ceramic bonds were ultimately achieved by sputtering a platinum coating onto ceramic, using EDM methods to electrically isolate the attachment area, then diffusion welding the attachment area to a platinum shim. Gage body halves were joined with this method by sputtering an attachment area, sandwiching a platinum shim of desired thickness between the two gage halves, and diffusion welding the entire ceramic to metal to ceramic joint. This method had advantages of maintaining extremely tight tolerances, providing a means of lead attachment to capacitor plates, and made use of existing processes.

3.6 GROUND PLANE CONSTRUCTION

Dimensional tolerances of the ground plane component were found to be critical early in the program. Because the gage design is a capacitive half-bridge, linear operation requires that the amount of area decoupled from one excitation plate (due to ground plane movement) be coupled with an equal area of the other plate. Simply put, as strain causes movement of the ground plane window to shade an area of one excitation plate, an equal area of the other excitation plate must be exposed. Failure to maintain this balance causes non-linear gage output. This required precise angular and dimensional tolerances of the ground plane window.

Ground planes constructed early in the program consisted of 2-mil thick copper foil with a photo etched opening. Later prototypes required ground planes made of high performance materials such as Hastelloy-X. In-house attempts to construct Hastelloy-X ground planes through electrochemical, electrical discharge and traditional machining methods were unsuccessful. Acceptable ground planes were ultimately obtained by having them precision machined at NASA Langley facilities.

3.7 CVD DEPOSITED INSULATION

The original design concept called for capacitor plates to be recessed within the gage body. Problems with lead attachment, sputter film deposition, and machining were encountered with the recess cavity concept. These problems were resolved by eliminating the recess cavity and positioning capacitor plates flush on the gage body surface. The only drawback of this configuration was potential direct contact between ground plane and capacitor plate surfaces, and a corresponding requirement to electrically isolate the surfaces from each other. This requirement was satisfied by applying a layer of aluminum oxide over the ground plane by a Chemical Vapor Deposition (CVD) process.

3.8 SAPPHIRE BEARING GAGE DESIGN AND CONSTRUCTION

Three of the changes responsible for increasing the upper temperature limit to 1093°C (2000°F) are:

a) Using 99.995% pure alumina or sapphire signal insulator.
b) Changing capacitor plate material from Hastelloy-X to platinum, thus reducing thermionic emission.
c) Increasing the gap between excitation and signal plates.

Since a) and b) above are relatively fixed parameters it was necessary to determine the effect of reducing the gap between the plates on the upper temperature limit of the gage. Three sets of platinum capacitor plates with air gap as the only variable were tested.

GAP [MILS]	MAX. TEMPERATURE [°C, (°F)]
9 mil	905°C (1500°F)
14 mil	993°C (1800°F)
20 mil	1093°C (2000°F)

The above shows that to achieve 1093°C operation, a 20 mil gap is required. Therefore, mineaturization would reduce the upper temperature limit of the gage, (all other parameters being equal).

The first redesign employed a bearing housing and capacitor plate assembly similar to that shown in fig. 3, except that the attachment ribbons were replaced by a two point attachment system. Difficulties in fabricating the frame resulted in a redesign employing a tubular body. The tubular body greatly simplified gage construction and improved component allignment as well. The tubular body was fabricated from solid Hastelloy-X stock on a lathe. A simple cut out was made to exit gage leads. The sapphire bearings were attached using a cement to bond them to the housing. The bond withstood repeated cycling to 1093°C without failure. The cross section of the gage is shown in fig. 11C. The gage employs two point attachment instead of the usual four point attachment ribbons. Two point attachment eliminates problems of thermal expansion mismatch between attachment ribbons and specimen. Standard Boeing terminals and lead wires (Nextel insulated) were used with this gage.

3.9 INSTRUMENT MODIFICATION AND CALIBRATION

Evaluative testing of prototype gages revealed a large growth in the resistive component of the gage signal with temperature. The growth became significant at about 815°C (1500°F), and often caused instrument overload at or above this temperature. Consultation with Boeing engineers resulted in two instrument modification techniques that significantly improved instrument performance at high temperature.

The first modification was a new calibration procedure to optimize instrument excitation frequency to reduce phase angle distortion in the instrument charge amplifier. This procedure reduced the effect of the resistive component of the gage signal on the instrument multiplier output.

The second modification was a redesign of the bandpass filter network to effect acceptable roll-off properties and a reduction in the amount of front-end instrument gain. This change helped reduce signal clipping in the instrument charge amplifier, and reduced instrument sensitivity to gages with high conductivity at elevated temperature.

4.0 FINAL DESIGN AND ASSEMBLY

4.1 5-MIL GAP GPD

The final GPD gage design is shown in figure 7. The gage body is constructed from optically flat sapphire with sputtered platinum capacitor plates. Gage body spacers and mounting shim are platinum. The ground plane is aluminum oxide coated Hastelloy-X.

Construction of the gage is accomplished as follows:

A. Optically flat sapphire is bonded to an X-Y table and the sapphire is cut with a diamond wheel using water as a coolant.

B. Cut sapphire is lightly grit blasted, rinsed in distilled water, bathed in Methyl Ethyl Ketone (MEK) for 10 minutes, bathed in Hydrochloric acid solution (20% HCl) for 10 minutes, and rinsed in distilled water. Parts are then baked at 815°C for 10 minutes.

C. Parts are examined under a microscope for surface contamination. Clean parts are sputtered with chrome to a surface resistivity of 15-20 megohms, and then sputtered with platinum to a surface resistivity of less than 100 ohm-inch. They are then baked at 815°C for 10 minutes and examined for bond quality. Bottom gage halves are sputtered with chrome and platinum on both sides. Top gage halves are sputtered on only one side.

D. Excess platinum is removed from the sides of parts by masking the face with tape and grit blasing edges with an S.S. White machine. Capacitor plates are formed by grounding the platinum sputter coating and etching plate separation lines with an electrically charged wire. Etching is accomplished under a microscope with the aid of a precision graduated recticle.

E. Body shims are formed by rolling 10-mil pure platinum wire to a thickness of 5-mils. The shims are then cut to length and put into position on the lower gage body half. The top body half is added to the assembly and is then placed into a diffusion welding jig and welded. Typical diffusion weld parameters are 27.6 N/m[2] (4,000 PSI) applied over the weld area at 843°C (1550°F) for 12 minutes.

F. Ground planes were precision machined at NASA Langley facilities. Ground planes are then batch CVD overcoated with aluminum oxide. A mounting shim is added to the ground plane by removing a section of the overcoat with a diamond file and spot welding the shim to the ground plane.

G. Final assembly consists of inserting the ground plane into the gage body and calibrating the unit in the room temperature calibration stand.

4.2 20-MIL GAP GPD

Design of the 20-mil gap gage was undertaken to reduce electrical leakage associated with the 5-mil gap gage. Attention was directed at determining the cause of gage electrical leakage at high temperature. Accordingly, three possible causes were identified: ionic conduction, surface conduction, and thermionic emission. Several tests were devised to detect these phenomena. Tests for ionic conduction within ceramic gage components were conducted by bringing the gage to temperature, applying a DC voltage, then measuring long term current response to a reverse in polarity. Tests conducted on cables, cable termination insulators, and prototype gages suggested negligible ionic conduction in all cases.

Leakage tests were conducted by applying a constant DC voltage to gages and measuring current with varying temperature. Typical results of prototype gages are shown in figure 8. The tests revealed measurable conduction between positive and negative excitation plates, measurable conduction between the signal plate and both excitation plates, and comparatively small conduction between signal plate and ground. The small conduction between signal plate and ground is thought to indicate negligible ionic conduction through the sapphire gage halves. The conduction between +/- excitation plates is thought to result from surface conduction that should be reducible by increasing the separation distance between plates. The conduction between signal plate and excitation plates is thought to result from thermionic emission. Classical theory predicts thermionic saturation current to be a function of temperature and electron affinity of a radiating material by the following relation:

$$I_s = C_1 T^2 \exp(-wC_2/T)$$

where:

- I_s = saturation current per unit area
- C_1 = constant particular to radiating metal
- T = absolute temp in °K
- C_2 = universal constant
- w = electron affinity of radiating metal

The saturation current function is dominated almost entirely by the exponential factor. Tests for thermionic current leakage were conducted on a standard Boeing gage by applying a DC potential between the signal ring and both excitation rings, then measuring current flow as temperature was reduced from 2000°F to room temperature. Test results (figure 9.) indicated leakage current varied exponentially with temperature, thereby suggesting thermionic emission as a cause of gage leakage current. This test was particularly relevant because two of the modifications required to make a boeing gage function at 2000°F also reduce thermionic emission. The first modification, changing signal and excitation rings from hastelloy-X to platinum, raises electron affinity of the radiating surface from about 3 to 5 electron volts. The second modification, increasing the gap between signal and excitation rings, also reduces thermionic current emission as shown by the equation relating thermionic current to applied voltage and electrode spacing:

$$I_d = C_3 A E^{1.5} / d^2$$

where:

I_d = current at temperature saturation
C_3 = constant
A = area
E = applied voltage
d = spacing between electrodes

Noticing that thermionic leakage current drops as a square of plate spacing, and that capacitance drops proportionally with plate spacing, we decided to reduce gage leakage current by designing a larger gap gage.

Design of the 20 mil gap gage was based on the premise that thermionic emission current drops as a square of plate spacing, whereas gage capacitance drops only proportionally with gage spacing. A gap of 20 mils was selected because this was the minimum spacing required on 2000°F Boeing gages. Given plate spacing, remaining design of the gage was straightforward. The only special consideration was that the spacing between excitation plates and lead connections were to be increased to reduce surface conduction. The resulting design is shown schematically in figure 10.

Construction of the 20 mil gage was similar to the 5 mil gage with two exceptions: Ceramic spacers over-sputtered with platinum replaced solid platinum spacers for establishing gage gap, and new diffusion welding load transfer saddles were required. Parts were cut with a diamond saw, cleaned, neutralized, rinsed with distilled water, heat treated, and sputtered. Subsequently, excess platinum was removed where necessary by diamond file. Isolation of excitation plates and lead connections was accomplished through EDM process using a 10 mil diameter tungsten wire. Diffusion welding was accomplished by constructing large aluminum oxide saddles, adding reflective heat shields, and increasing weld fixture power. Because of time and equipment constraints, ground plane assemblies were not constructed.

4.3 SAPPHIRE BEARING GAGE

Design of the final version Model SB-3, sapphire bearing gage is shown in figure 11. The original concept (shown in figure 2.) was modified to include a rigid outer body tube frame. The tube frame served as the major structural element of the gage, with the signal ring centered between two end caps secured by spot welding. Bearings were cemented into the bearing housing in the end caps, and further secured by a retaining wire spot welded at the bearing periphery. Excitation and signal ring components were constructed from platinum foil applied over ultra-high purity alumina insulators. Leads were brought out of the gage through an opening in the center of the tube frame. Features of the redesigned gage include simple construction (relative to a standard Boeing gage), zero actuation force, high immunity to electrical noise (tube frame serves as grounded shield) and a high degree of ruggedness. A photo of Model SB-3 prototype before testing is shown in figure 12.

5.0 PERFORMANCE EVALUATION

5.1 5-MIL GPD

Room temperature calibration was conducted by mounting prototype gages in the room temperature calibration stand, and measuring gage output vs displacement. Typical output of a prototype gage with NASA machined ground plane is shown in figure 13. Over a 1 inch gage length, the gage displayed a linear range of 20,000 (+/- 10,000) micro-strain. Maximum sensitivity at full gain of the 2004 card was about 1.5 micro-strain per milli-volt output, with maximum resolution of 10 micro-stain. Gages typically exhibited some hysteresis error that reduced maximum practical resolution to about 30 micro-strain (typically). At this gain setting, range of the system is approximately 8,000 micro-strain. Further increases in sensitivity could be achieved (at the expense of reduced range) through instrument modification to boost gain. It should be noted that above results were obtained through pure uni-axial loading applied statically. Gage performance under torsional, bending or dynamic loading was not evaluated.

Elevated temperature testing was conducted by mounting gages on a Rene 41' test bar and inserting the bar into a pre-heated oven. In general, tests were conducted without a protective ground shield over the gage, and temperature was monitored by a thermocouple mounted directly to the test bar. Initial test results were erratic above 315°C (600°F). Plots of total gage capacitance against temperature are shown in figure 14. The erratic output was caused by signal clipping at the output of the instrument charge amplifier. Further investigation revealed that the impedance of the gage dropped several orders of magnitude as a repeatable and predictable function of temperature. The reduced impedance of the gage with temperature was causing the instrument charge amplifier to overload, producing unuseable output. Attempts at resolving this problem were unsuccessful and a redesign of the gage to include a larger gap was undertaken.

5.2 20 MIL GPD

Testing of 20 mil gages was limited to evaluating the characteristics of gage bodies at elevated temperature. A quartz gage initially constructed to gain familiarity with construction methods (prior to working with higher value materials) predictably caused instrument overload below 538°C (1000°F) due to the low volume resistivity of quartz at elevated temperatures. An aluminum oxide gage body was built from high purity (99.8%)

alumina and evaluated on a test bar. Gage total capacitance vs temperature was plotted as shown in figure 14. Useable output of the gage body was increased to 760°C (1400°F), a substantial increase over the 5 mil gap gage but still below our target. In an effort to better understand gage characteristics, current leakage with varying potential applied between the signal and excitation plates was measured at 1093°C. Results showed leakage much lower than the 5-mil gap gage, but still at least an order of magnitude higher than allowable to prevent instrument overload. Subsequent disassembly of the gage body revealed that about 30 percent of the gage plates had apparently sublimed. There is speculation that desputtering platinum plates may somehow be related to unexpectedly high leakage of the gage body at high temperature. Diffusion welding platinum foil plates onto the sputter coating may reduce gage leakage and sputter coat sublimation. This was done successfully on 2000°F Boeing gages on another project. A 20 mil sapphire body was constructed, but time constraints precluded testing prior to this report.

5.3 SAPPHIRE BEARING GAGE MODEL SB-3

At room temperature the sapphire bearing gage prototype performed nearly identical to a high temperature Boeing gage. Total gage capacitance was .35 picofarads and minimum output (instrument at minimum gain) was 7.5 milli-volts per 1000 μ" displacement. Corresponding maximum output was 820 milli-volts per 1000 micro-strain. Room temperature calibration yielded results identical to the 2000°F version of the Boeing gage.

Further testing was conducted by mounting the gage on a Rene' 41 test bar. Dead weight loading revealed a zero load hysteresis not found in standard Boeing gages. This hysteresis of 60 to 140 μ" occurs when load goes from tension to compression and visa versa. The hysteresis would be negligible when the full scale span of the gage is used, but significant at high sensitivity.

Apparent strain vs temperature was run by inserting the bar into a 1149°C (2100°F) pre-heated oven. Gage temperature was measured with a thermocouple mounted directly to the test bar. No protective hood was provided for the gage, as none was required. Total capacitance of the gage was measured to a bar temperature of 1093°C (2000°F), although actual gage temperature was probably over 1093°C. Apparent strain output of the gage was also measured to beyond 1093°C.

These results (fig. 15) show a substantial improvement over the results reported in Phase I. The apparent strain is within ±1000 μ" from room temperature to 1093°C (2000°F). In Phase I testing, the apparent strain was about 5000 μ" at maximum temperature. The improvement is due, we believe, to the rigidity of the tube frame design. The total capacitance of the gages is also constant up to nearly maximum temperature. This indicates that full scale gage output does not change as reported in Phase I, but remains constant up to about 1050°C.

Except for the hysteresis described above, the sapphire bearing gage is most promising for high temperature structural testing. The gage might also serve as a basic sensor for measuring other physical parameters such as displacement, pressure, or load, at temperatures up to 1093°C (2000°F).

In light of the above data, the low profile flexure design, Model C, described in Phase I final report, has considerable merit. The Model C flexure not only provides a lower profile, but a much more rugged and vibration resistant gage with high lateral rigidity as compared to a standard Boeing type flexure.

6.0 CONCLUSIONS

Measurement of strain at 2000°F. and higher is definitely feasible through capacitive techniques.

1) The sapphire bearing gage developed under this program is a substantially more rugged device then the standard Boeing gage. The final design tested has a solid body which protects, and electrically shields the gage plates. This gage is a strong candidate for applications where large strains are to be measured at temperatures to 2000°F. However, over small strain ranges, the inherent hysteresis in this gage reduces accuracy. For small strain ranges, the standard Boeing type gage or a Boeing gage with Model C flexures holds promise of higher accuracy. The sapphire bearing sensor itself should be useful in transducers to measure loads, pressures, or displacements to 1093°C (2000°F).

2) The GPD gage has high potential as a rugged, low profile gage useable at high temperature, but requires further development to achieve this end. Additional development must be pursued to increase gage impedance characteristics at high temperature, and improve gage life.

3) Further improvement in upper temperature limit will require some improvements in instrumentation. Instrumentation must be made more tolerant to impedence changes in the gages.

Some of the processes developed under this project while not specifically achieving a 1093°C GPD gage, provided substantial benefits and improvements in the high temperature strain measurement state of the art. Some of these are:

1. Improved "2000°F" Boeing gage:

   a) The use of sputtered platinum followed by diffusion bonding platinum foil for capacitive plates substantially improved the gage by eliminating the need for ceramic cements to hold the capacitive plates to the insulators. The ceramic cements were a source of contamination causing leakage in the high purity insulators.

   b) The use of CVD applied Alumina over platinum capacitor plates increases gage life at elevated temperatures.

   c) Diffusion bonding of leads to platinum foil plates is far superior to spot welding and is now being used on 2000°F Boeing gages.

2. Sputtered strain gages, temperature sensors, and displacement sensors:

CVD insulation coating of metal parts followed by application of sputtered strain or temperature sensors has potential for elevated temperature dynamic applications. Similarly constructed capacitive displacement sensors also have good high temperature potential.

7.0 RECOMMENDATIONS

1. The most beneficial intermediate gage development for 1093 °C structural test strain measurement would be to develop the Model C low profile flexures for the Boeing Gage. This would produce a substantially more rugged flexure system (especially from the standpoint of lateral stability), a gage with 30 percent reduction in vertical profile, eliminate the vulnerable flexure sticking up above the gage and yet provide zero hysteresis, and good performance to 1093°C. This development would provide a rugged gage for high temperature structural tests for many years to come, with very modest development expense.

2. The GPD gage: Although the ultimate in low profile capacitive sensors, this gage should be developed in stages. Full development of a 20 mil gap gage is, we believe, close to completion and development is continuing. The next step is to diffusion bond platinum foil plates to sputtered platinum, and CVD overcoating the plates with alumina. Increasing the spacing between excitation plates to that of the Boeing gage will also reduce surface conduction and increase temperature range. Once a large scale version is developed for 2000°F operations then progressive miniaturization can proceed.

GPD GAGE: Development of sputter coatings capable of withstanding 1093°C for long periods of time should be undertaken by improving sputtering techniques. Use of a multi-head sputter system with precision process controls is recommended. Achieving this objective will increase gage life at temperature, and may reduce electrical leakage responsible for overloading instrumentation. Sputtered films are ideal for fabricating gage plates because the sputter process can lead to mass production of less expensive gages.

3. SAPPHIRE BEARING GAGE: This sensor makes an excellent displacement sensor and it is in this area future development should be directed. Necessary bearing clearances prohibit total elimination of residual hysteresis, but the sensor is useful for measuring large strains.

4. INSTRUMENT: Instrument modification to reduce overload at lower gage impedance must be pursued. Reduction of instrument front-end gain proportional to temperature could feasibly permit operation of the 5 mil gap gage at 1093°C. Incorporation of a variable attenuation (or amplification) stage driven by temperature into the instrument front-end is recommended.

5. SYSTEM: A specialized high temperature strain measurement system should be developed by incorporating a feedback loop into existing gages and instrumentation. This system could cancel out changes in gage impedance by comparing a strain signal with a feedback signal and rejecting common mode signal components.

BIBLIOGRAPHY

"Chemical Vapor Deposition", Proceedings of the Fourth International Conference, The Electrochemical Society, Electrothermics and Metallurgy Division, Princeton, New Jersey, 1973.

Coors Porcelain Co., Golden Colorado, "Materials Comparison Chart".

Dean, P., "Instrumentation Development for the National Aerospace Plane, Option #4", A final report on Contract #F33657-86-C-2125, October 1987, Lockheed Aerospace Co., Valencia, CA.

Egger, R.L., "Development of a High Temperature Capacitive Pressure Transducer", NASA CR-135282, October 1977.

Foster, R.L., and Wnuk, S.P., Jr., "High Temperature Capacitive Displacement Sensors" ISA 1985 Paper # 85-0123.

Gillette, O. Larry, "Research and Development of a High Temperature Strain Gage for Operation to 2000°F, AFFDL-TR-71-103, October 1971, Wright-Patterson Air Force Base, Ohio.

Grant, H.P., Przybyszewski, J.S., Anderson, W.L. and Chaing, R.G., "Thin Film Strain Gage Development Program", Final Report, Contract NAS 3-21262, CR-174707, NASA Lewis Research Center, Cleveland, OH, December 1983.

Hannah, R.L. and Carroll, D., "NASP Instrumentation Option #4", Proceedings of the Western Regional Strain Gage Committee, January, 1988, SEM, Bethel, CT.

Harting, Darrell R., "Evaluation of a Capacitive Strain Measuring system for use to 1500°F." ISA ASI 75251(289-297) 1975.

Hulse, C.O., Bailey, R.S., Grant, H.P. and Przybyszewski, J.S., "High Temperature Static Strain Gage Development Contract", Contract No. NAS3-23722, CR-180811, NASA Lewis Research Center, Cleveland, OH, August 1987.

Hulse, C.O., Bailey, R.S. and Lemkey, F.D., "High Temperature Static Strain Gage Alloy Development Program", Contract No. NAS3-23169, CR-174833, NASA Lewis Research Center, Cleveland, OH, 1985.

Instruction Manual, "Capacitive Strain Measuring System" HITEC Products, Inc., Ayer, MA 01432.

Jordan, E.C., "Reference Data for Engineers: Radio, Electronics, Computer, and Communications", 7th Ed., H.W. Sams and Company, 1985.

MA, L., Wu, T.T. and Ahzo, L., "Development of Temperature Compensated Resistance Strain Gages for use to 800°C" Proceedings of the International Conference on Experimental Mechanics, Oct. 1985, Beijing, Peoples Republic of China, Science Press Beijing.

"Metals handbook", American Society for Metals, November, 1984.

Mueller, R.N., Howard, J.L., Sikorra, C.F. and Swegle, A.R., "Calibration and Evaluation Tests of Strain Gages for Use on Structures Exposed to Cryogenic and Re-entry Temperatures", Air Force Flight Dynamics Laboratory Contract AF 33615-82-C-3202.

Powell, C.F., Campbell, I.E. and Gonser, B.W., "Vapor Plating", John Wiley and Sons, 1955.

Pulker, H.K., "Coatings on Glass", Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 1984.

Reich, H.J., "Theory and Applications of Electron Tubes", McGraw Hill, New York, 1944.

Ryshkewitch, E. and Richerson, D.W., "Oxide Ceramics", Academic Press, Orlando, Florida, 1985.

Sax, N.I. and Lewis, R.J., Sr., "Hazardous Chemical Desk Reference", Van Nostrand Rienhold Company, New York, 1987.

Sze, S.M., "Semiconductor Devices, Physics and Technology", John Wiley and Sons, New York, 1985.

Technical Data, "High Temperature Capacitive Strain Gage" HITEC Products, Inc., Ayer, MA 01432,

Technical Data, "Strain Measuring Module" HITEC Products Inc., Ayer, MA 01432.

Vossen, J.L., and Kern, W., "Thin Film Processes", Academic Press, Orlando, Florida, 1978.

Weise, R.A. and Foster, J.H., "High Temperature Strain Gage System for Application to Turbine Engine Components", AFWAL-TR-80-2126, Jan. 1981, Wright-Patterson Air Force Base, Ohio.

Weise, R.A., Foster, J.H. and Hadesty, G.B., "High Temperature Strain Gage System for Application to Turbine Engine Components", Phase I, Contract No. F33615-76-C-2075, AFPRO, Wright-Patterson AFB, OH, 1977.

Wnuk, S.P., Jr. and Foster, R.L., "Research in Progress on High Temperature Strain Gages and Displacement Sensors" Conference on High Temperature Measurements for Experimental Mechanics, Knoxville, TN, March 28, 1985.

Wnuk, S.P., Jr., "Current Developments in High Temperature Strain Gages" Proceedings of the Western Regional Strain Gage Committee, Portland, Oregon, June 1988, SEM Bethel, CT.

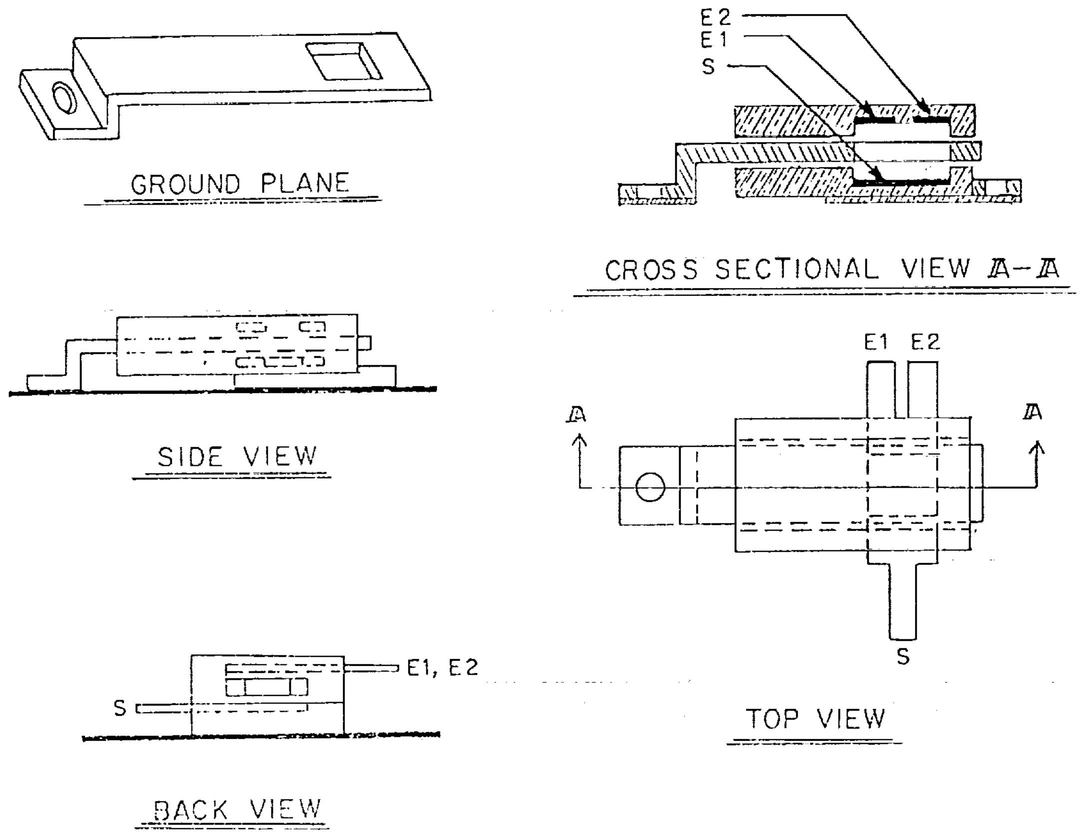
Wnuk, S.P., Jr., "High Temperature Strain Gage Alloys" Proceedings of the International Conference on Experimental Mechanics, Oct. 1985, Beijing, Peoples Republic of China, Science Press, Beijing.

Wnuk, S.P., Jr., "Capacitive Strain Gages for Measurements to 2000°F", presented at The Fifth Annual Hostile Environments and High Temperature Measurements Conference, March, 1988, SEM, Bethel CT.

Wnuk, S.P., Jr., "High Temperature Strain Gages for Short Term Static Testing", Proceedings T.C.S.G., May 1974, SEM, Bethel, CT.

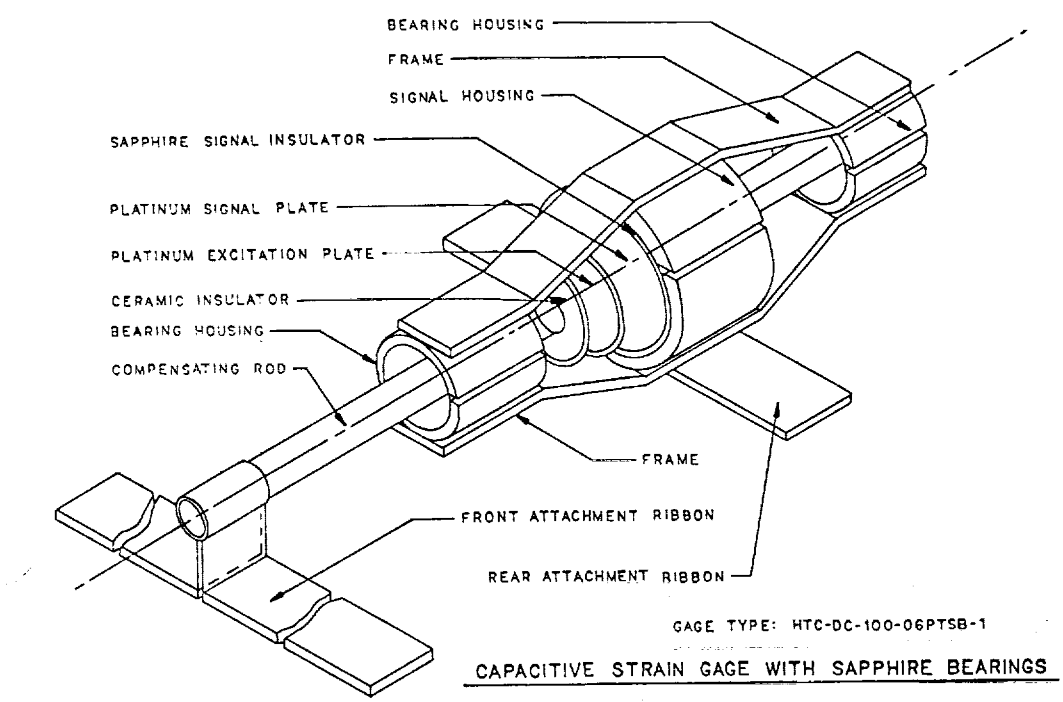
Wnuk, S.P., Jr., Low, M.E. and MacLean, J.G., "Development of Strain and Temperature Measurement Techniques for Use in Combined Thermal Acoustic Environment", Oct. 74, AD B000924-L NTIS, 5285 Port Royal Road, Springfield, VA 22160.

Wnuk, S.P. and Wnuk, V.P., "High Temperature Capacitive Strain Gage" NASA Langley Research Center, Contract NAS1-18411, August 1987, Phase I Final Report.



GPD CAPACITIVE STRAIN GAGE

FIGURE 1



CAPACITIVE STRAIN GAGE WITH SAPPHIRE BEARINGS

FIGURE 2

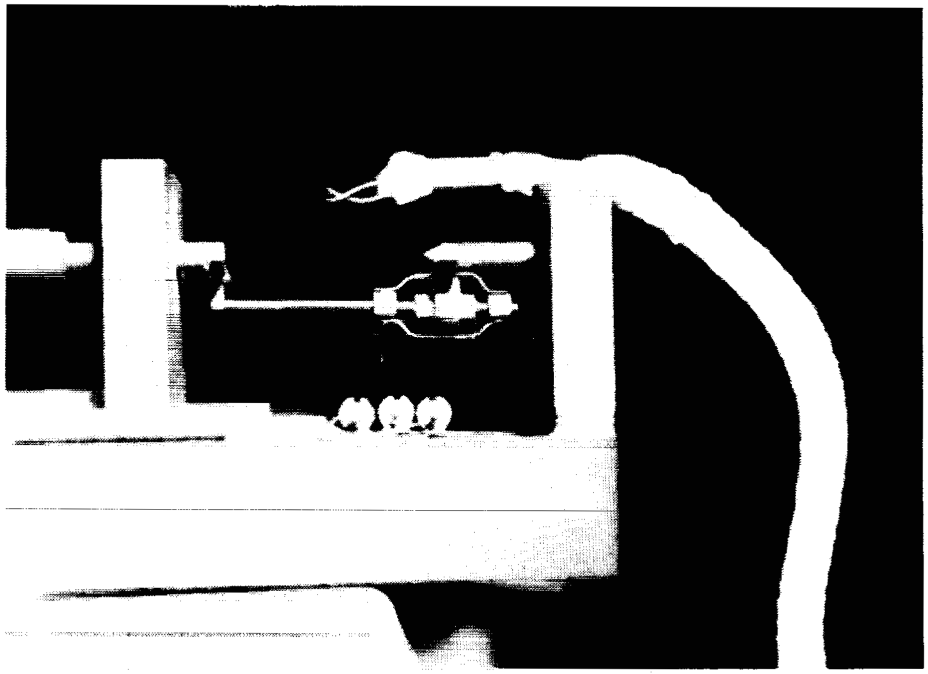
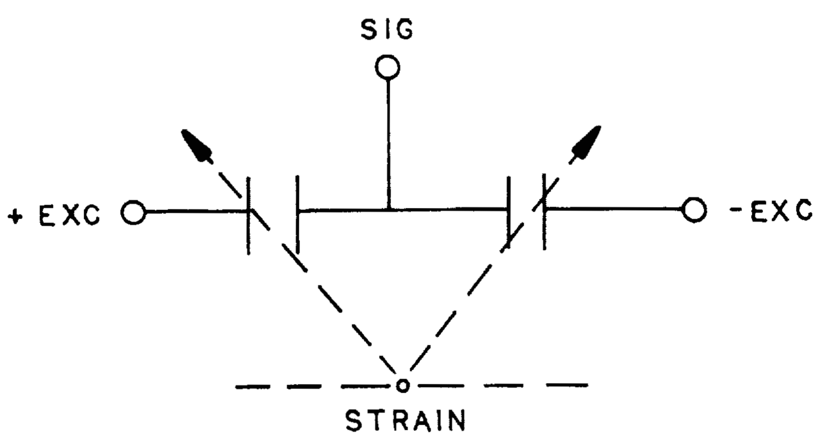


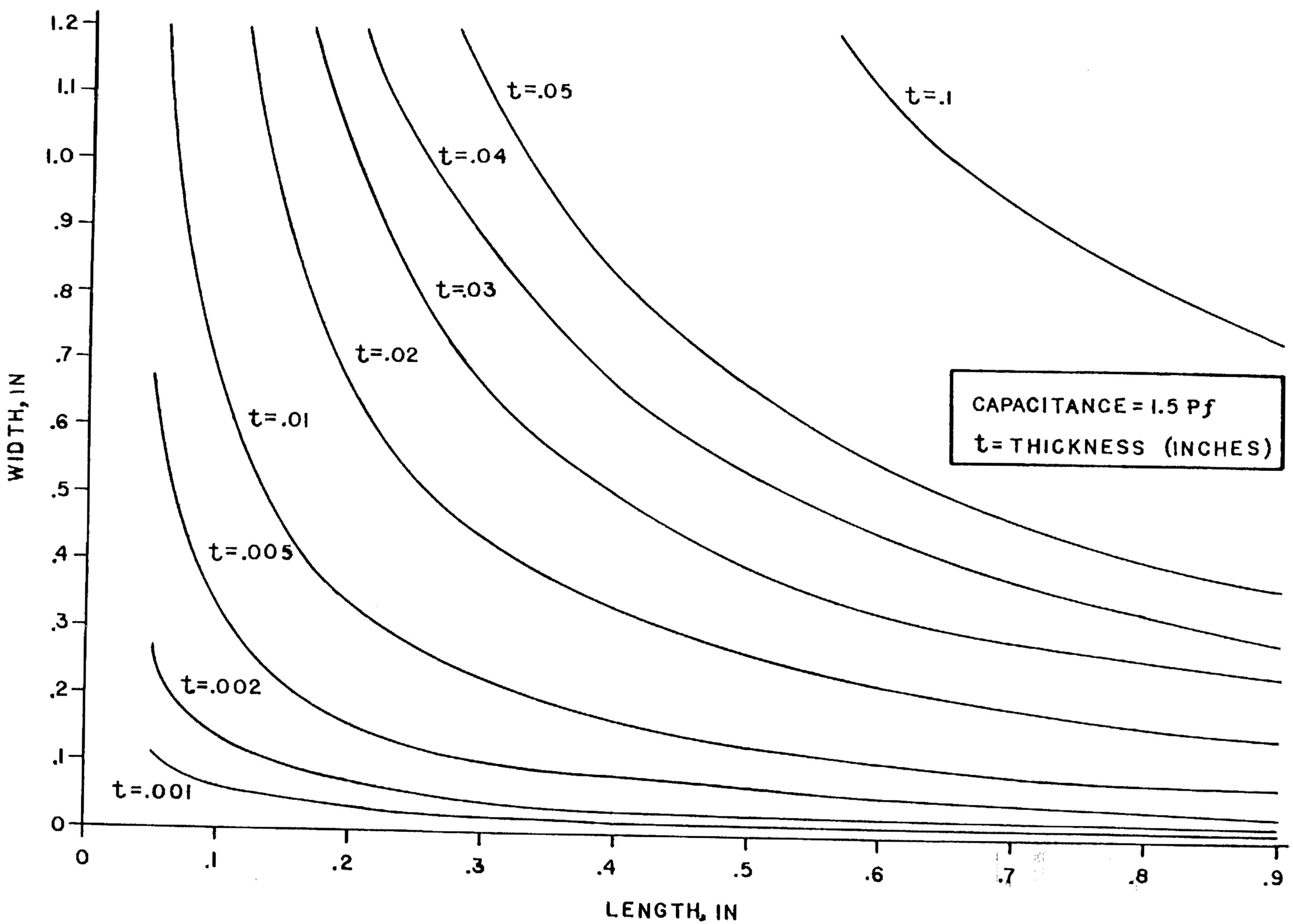
FIGURE 3



GPD GAGE

— ELECTRICAL EQUIVALENT CIRCUIT —

FIGURE 4



GROUND PLANE OPENING DESIGN CURVES

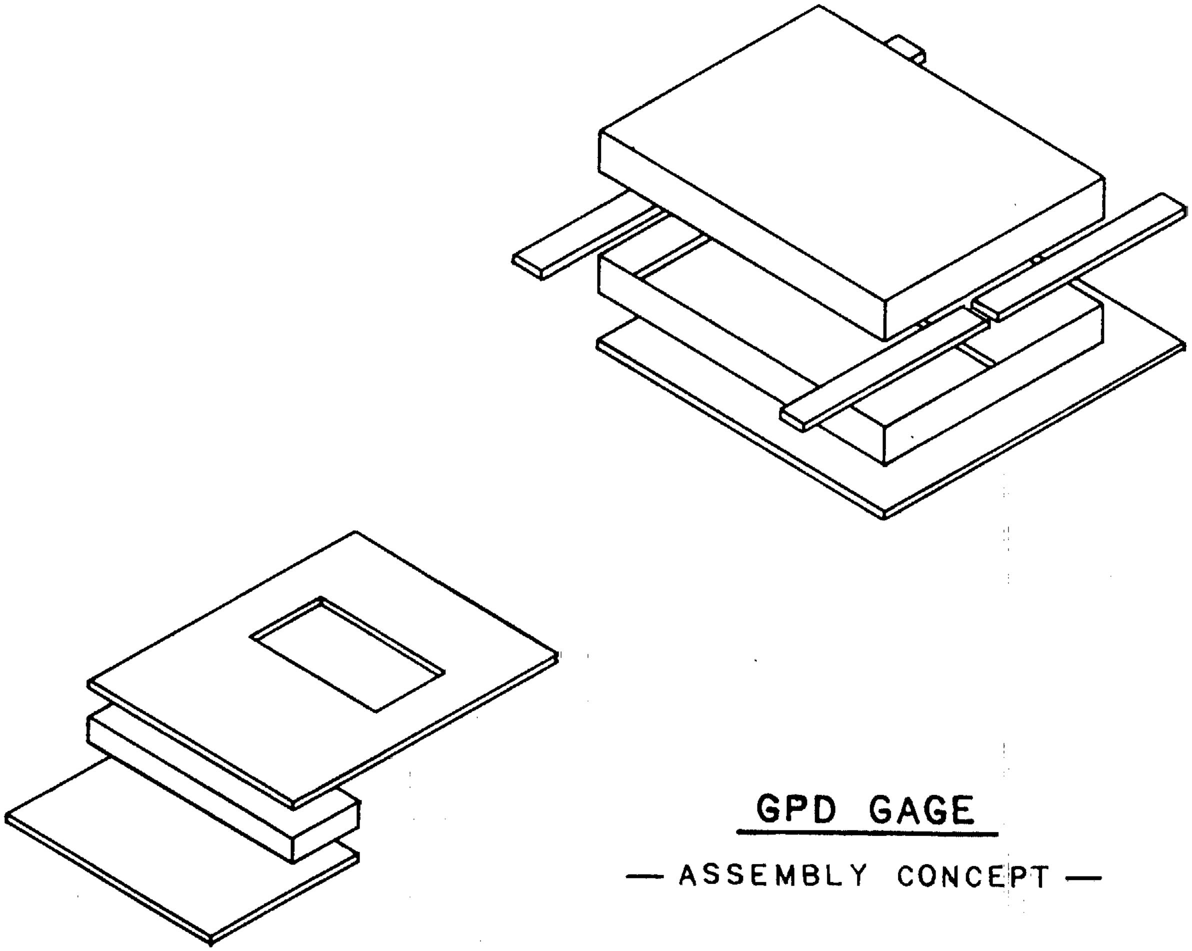
FIGURE 5

MATERIAL	RESISTIVITY (OHM/CM)	TENSILE STRENGTH ($N/m^2 X10^{-6}$)	HARDNESS (MOH'S)	THERMAL EXPANSION COEF. (TCE) (PPM-°C @ 25-800°C)	EASE OF MACHINABILITY	COMMENT
ALUMINA	10^6@ 1100°C	233@ 1000°C	9	8.0	DIFFICULT	Good Mechanical and Electrical Properties
BERYLLIA	$8X10^{12}$@ 2100°C	68@ 1000°C	9	7.5	VERY DIFFICULT	Poisenous Potentially Lethal
SILICA	$5X10^3$@ 1300°C	120@ 1000°C	7	0.6	MODERATE/ EASY	Poor Resistivity At High Temp.
SAPPHIRE	10^{11}X@ 500°C	352@ 1000°C	9	5.0*	DIFFICULT	Good Mechanical and Electrical Properties
SILICON CARBIDE	$7X10^3$@ 1000°C	(307@ 25°C)	9	4.5	DIFFICULT	Poor Resistivity all Temp's
SILICON NITRIDE	10^{10}@ 480	-	9	3.0*	DIFFICULT	TCE Incompatable with Platinum
BORON NITRIDE	$2.3X10^{10}$@ 480°C	43@ 1000°C	2	7.5*	EASY	Low Physical Strength Properties
PLATINUM	.69@ 20°C	(140@ 25°C)	-	8.9	EASY	Capacitor Plate Material

*AXIS/ORIENTATION DEPENDENT

PROPERTIES OF GAGE BODY MATERIAL CANDIDATES

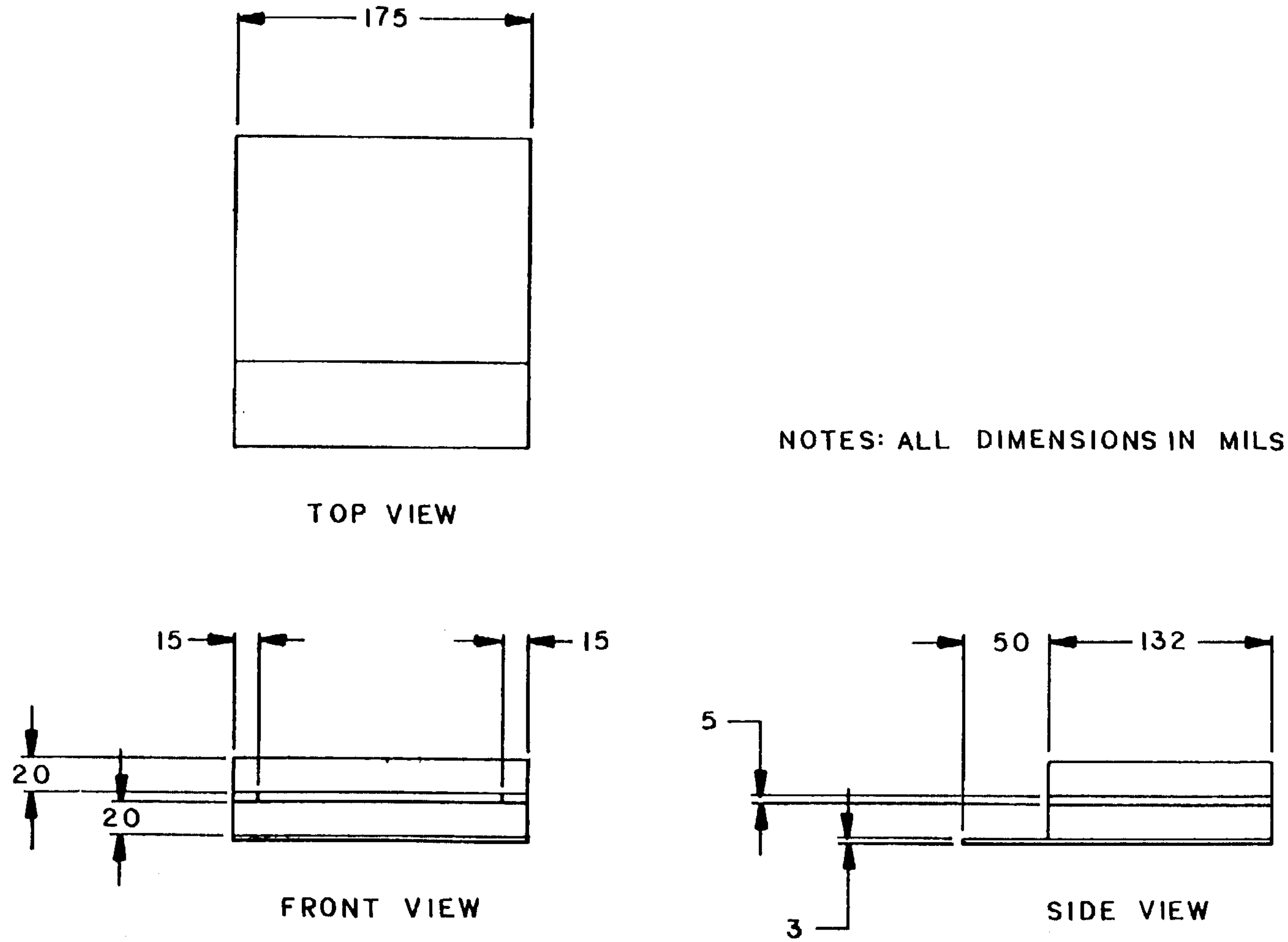
FIGURE 6



GPD GAGE

— ASSEMBLY CONCEPT —

FIGURE 7a



GPD GAGE BODY

5 MIL GAP DIMENSIONS

FIGURE 7b

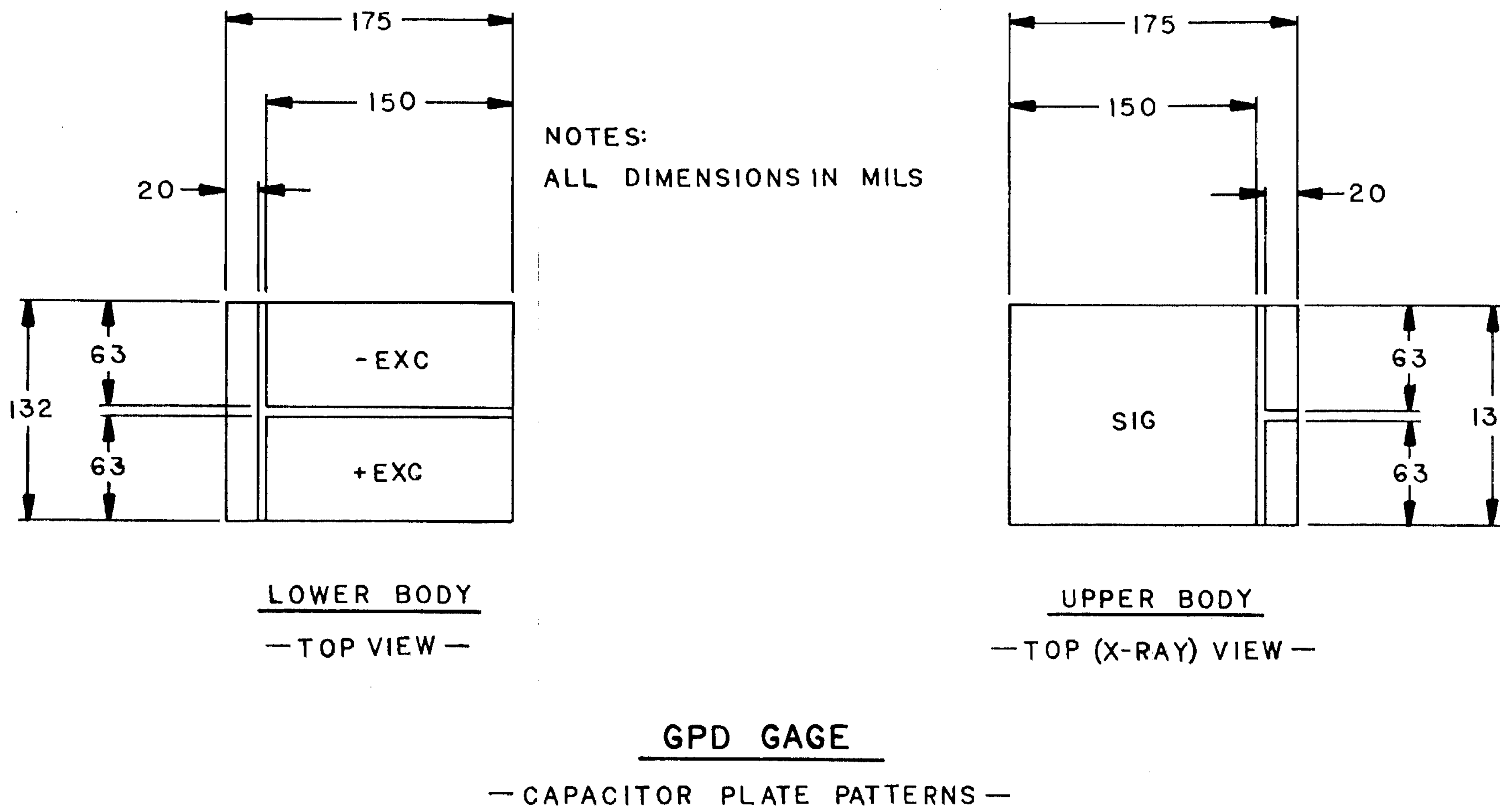
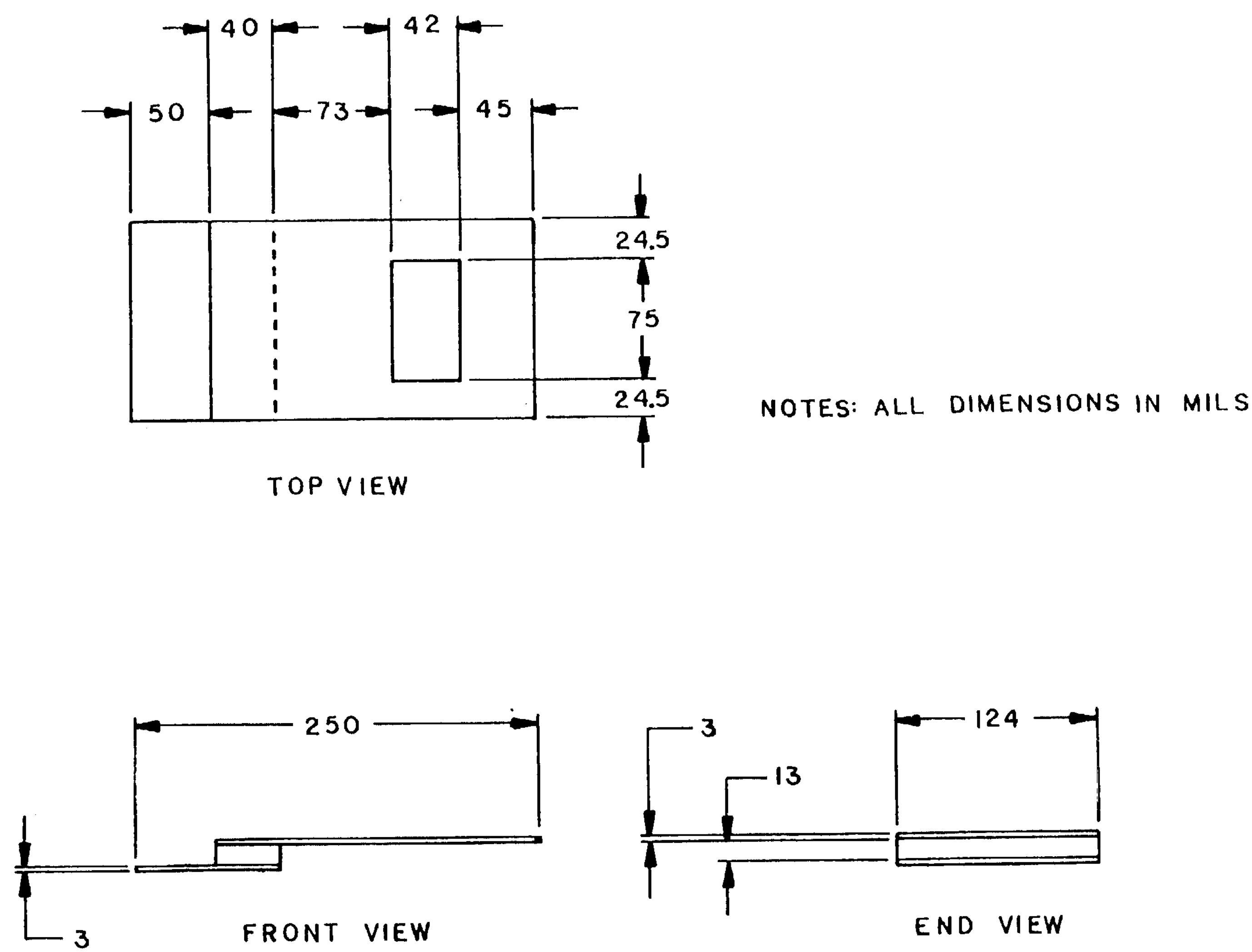

175
150
20
NOTES:
ALL DIMENSIONS IN MILS
63
132
63
-EXC
+EXC
175
150
20
SIG
63
132
63
LOWER BODY
— TOP VIEW —
UPPER BODY
— TOP (X-RAY) VIEW —
GPD GAGE
— CAPACITOR PLATE PATTERNS —

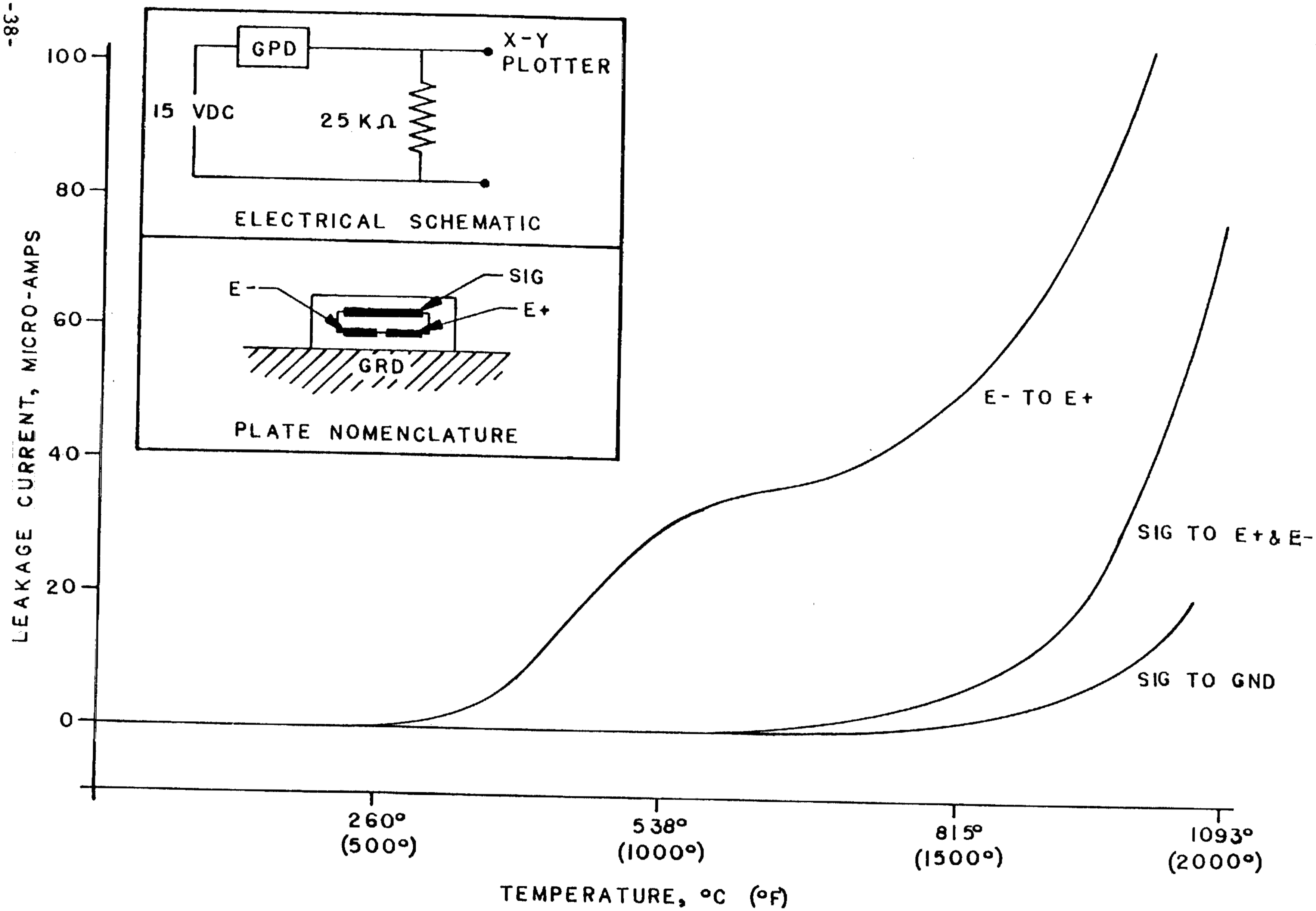
FIGURE 7c



GPD GAGE

— GROUND PLANE DIMENSIONS —

FIGURE 7d

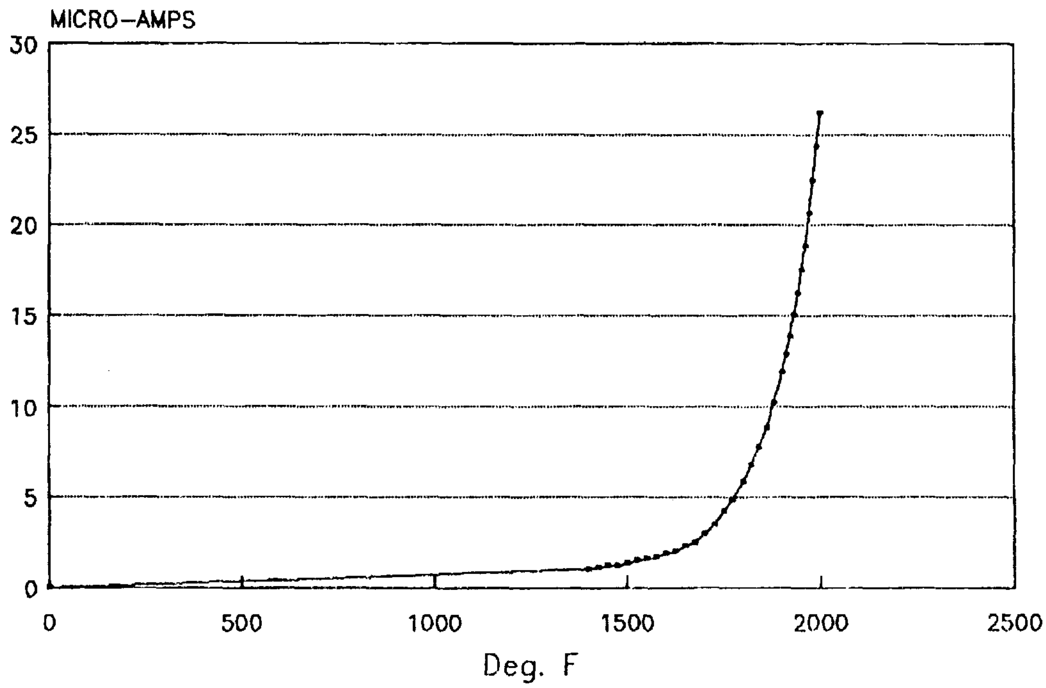


ELECTRICAL LEAKAGE CHARACTERISTICS OF 5 MIL GPD GAGE

FIGURE 8

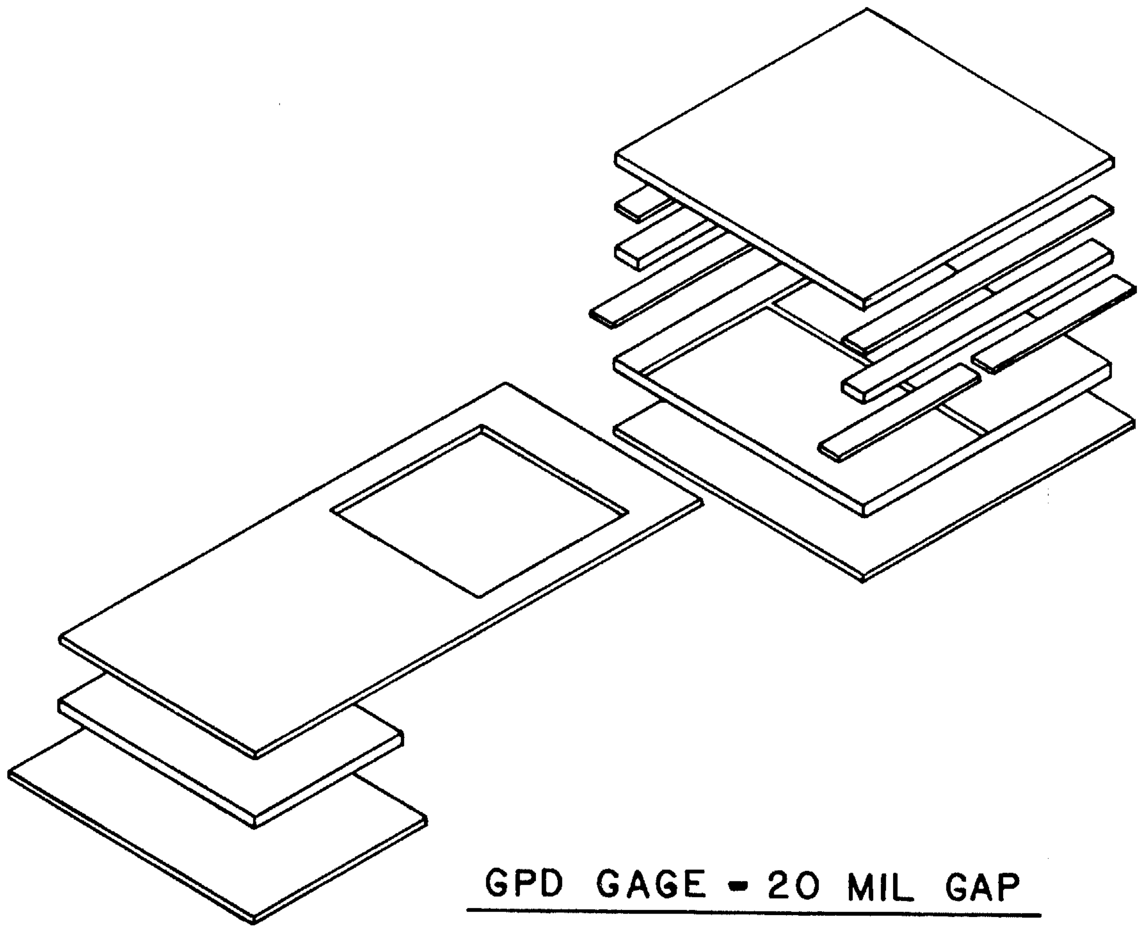
ELECTRICAL LEAKAGE OF STANDARD CAPACITIVE GAGE

CURRENT vs TEMPERATURE



15 VDC APPLIED BETWEEN EXC & SIG PLATES

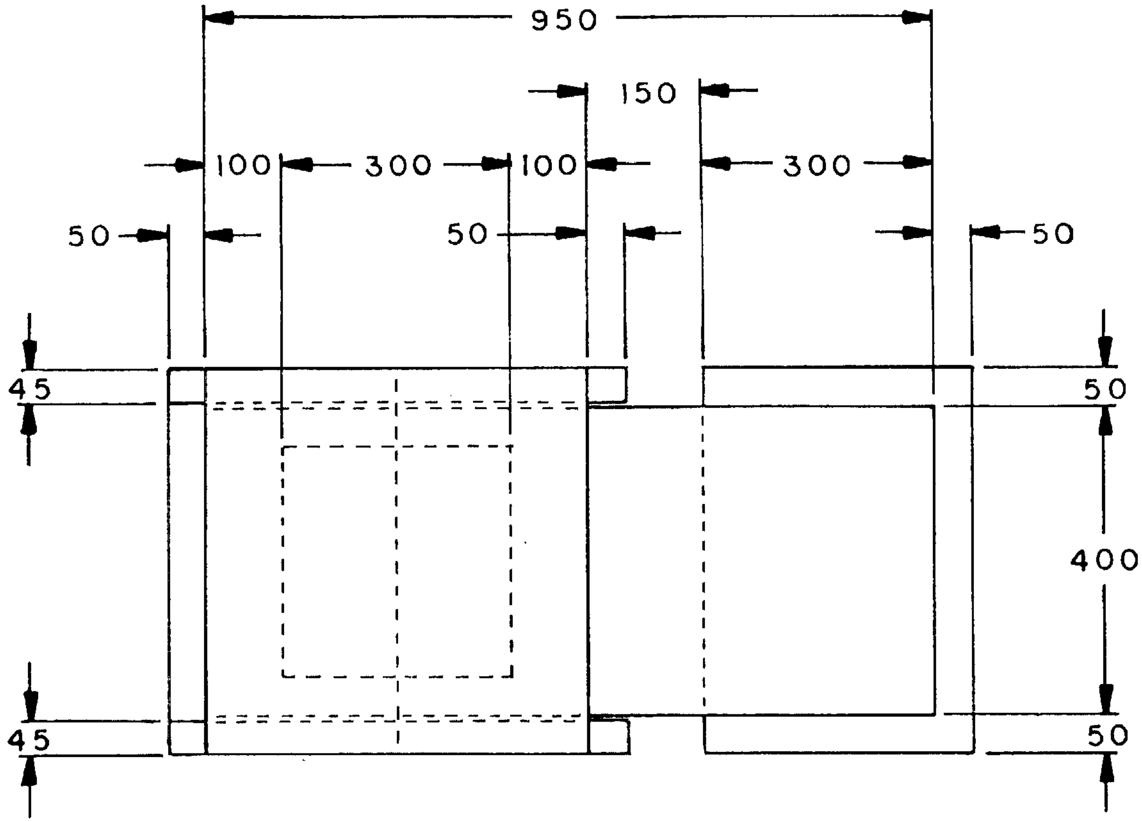
FIGURE 9



GPD GAGE - 20 MIL GAP

— ASSEMBLY CONCEPT —

FIGURE 10a

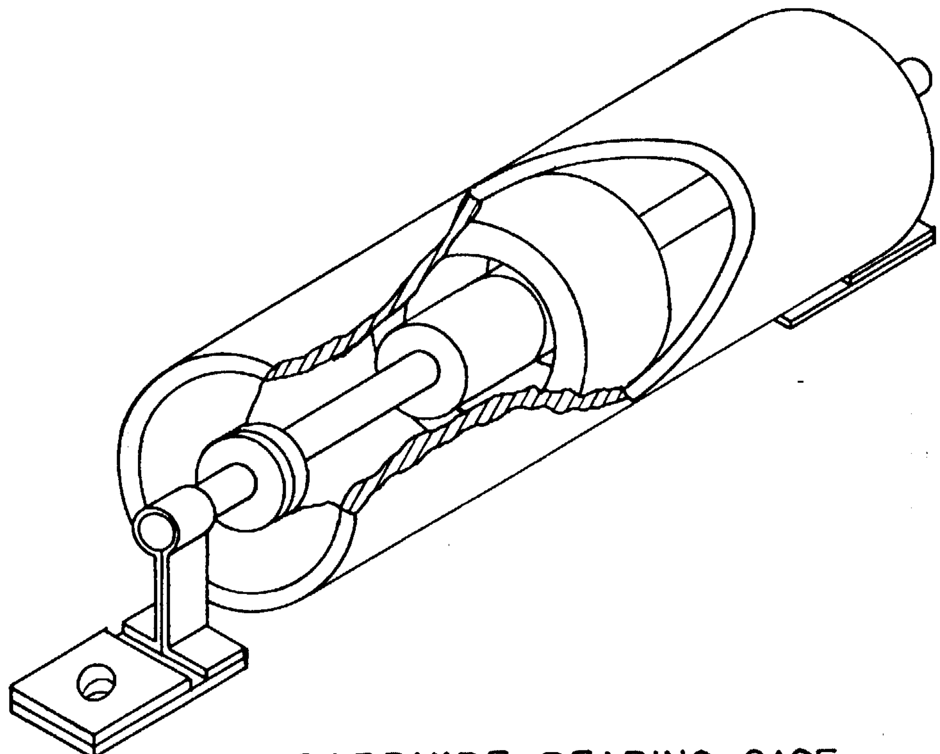


NOTES: ALL DIMENSIONS IN MILS

GPD GAGE - 20 MIL GAP

— DIMENSIONAL VIEW —

FIGURE 10b



SAPPHIRE BEARING GAGE

— ASSEMBLY CONCEPT —

FIGURE 11a

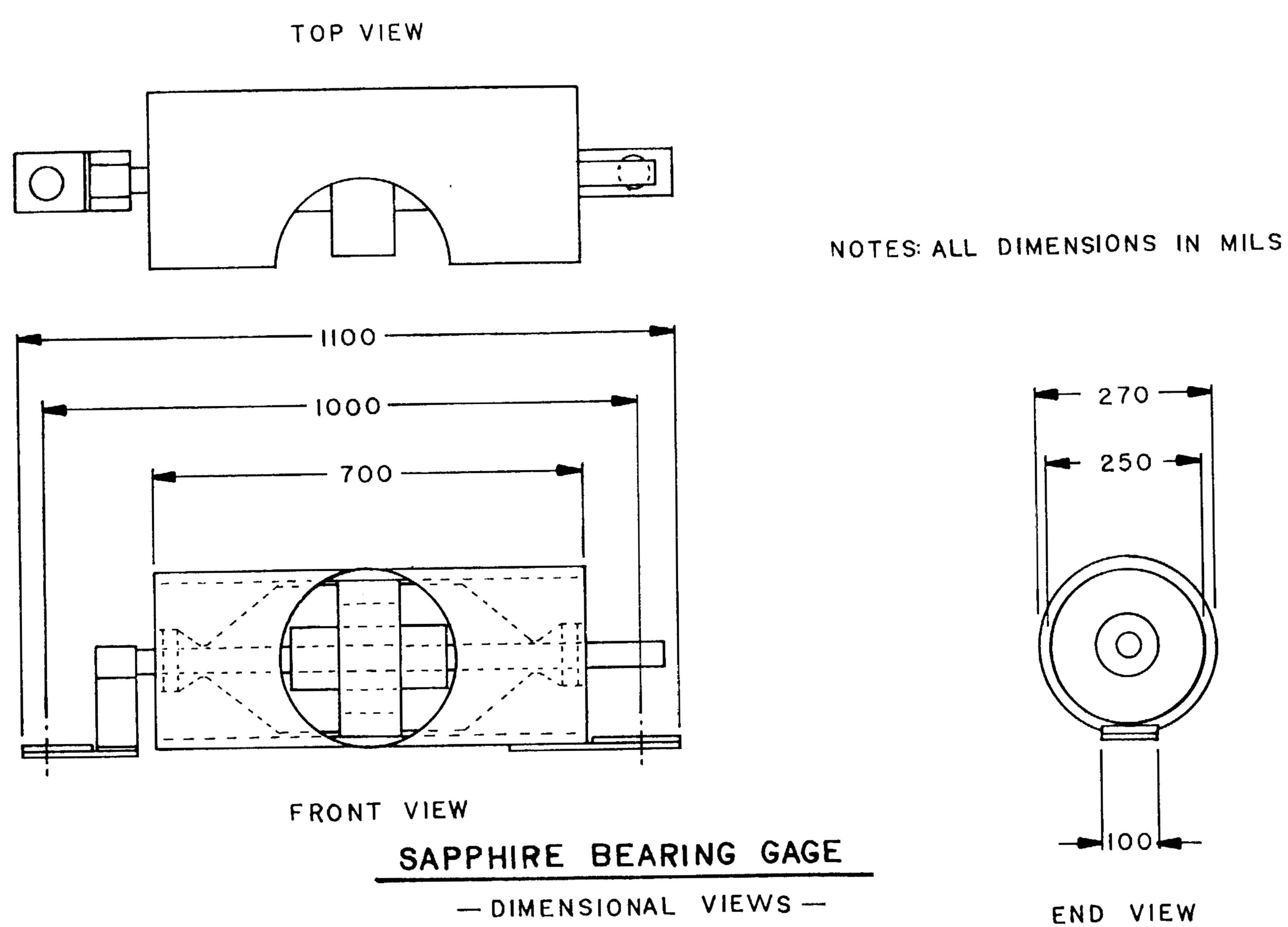
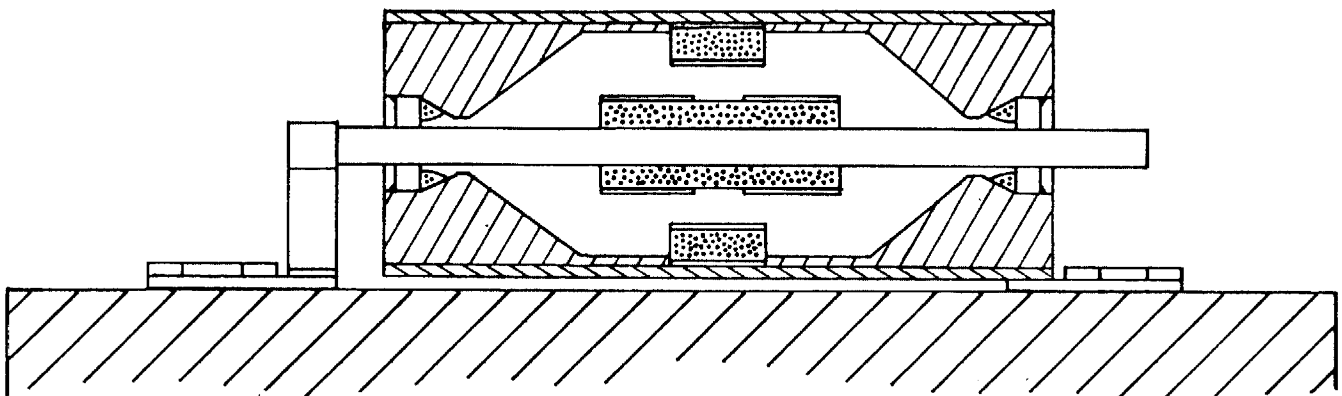

TOP VIEW
NOTES: ALL DIMENSIONS IN MILS
1100
1000
700
270
250
100
FRONT VIEW
END VIEW
SAPPHIRE BEARING GAGE
— DIMENSIONAL VIEWS —

FIGURE 11b



SAPPHIRE BEARING GAGE

— CUT AWAY VIEW —

FIGURE 11c

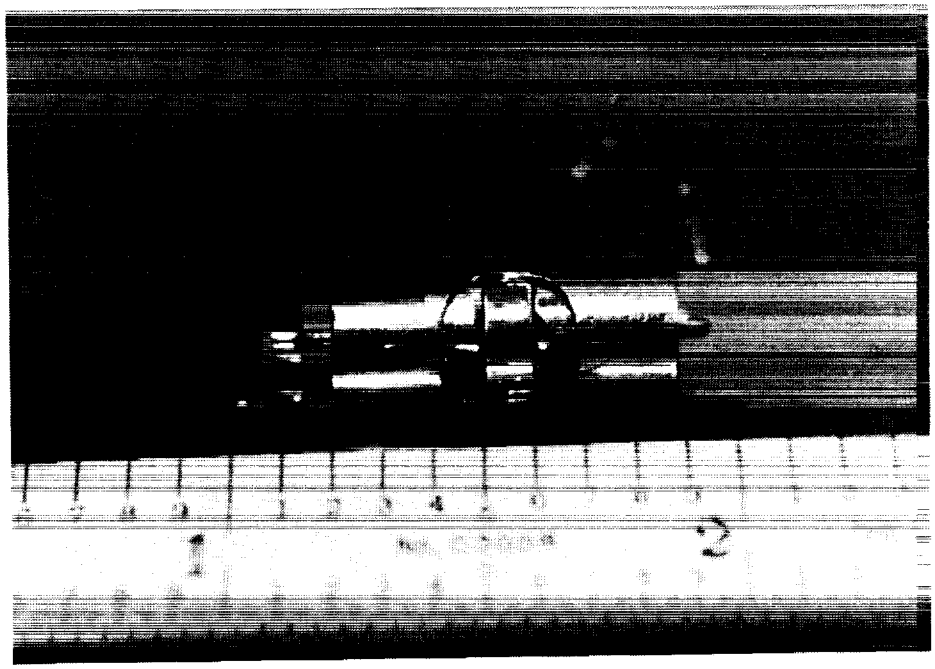
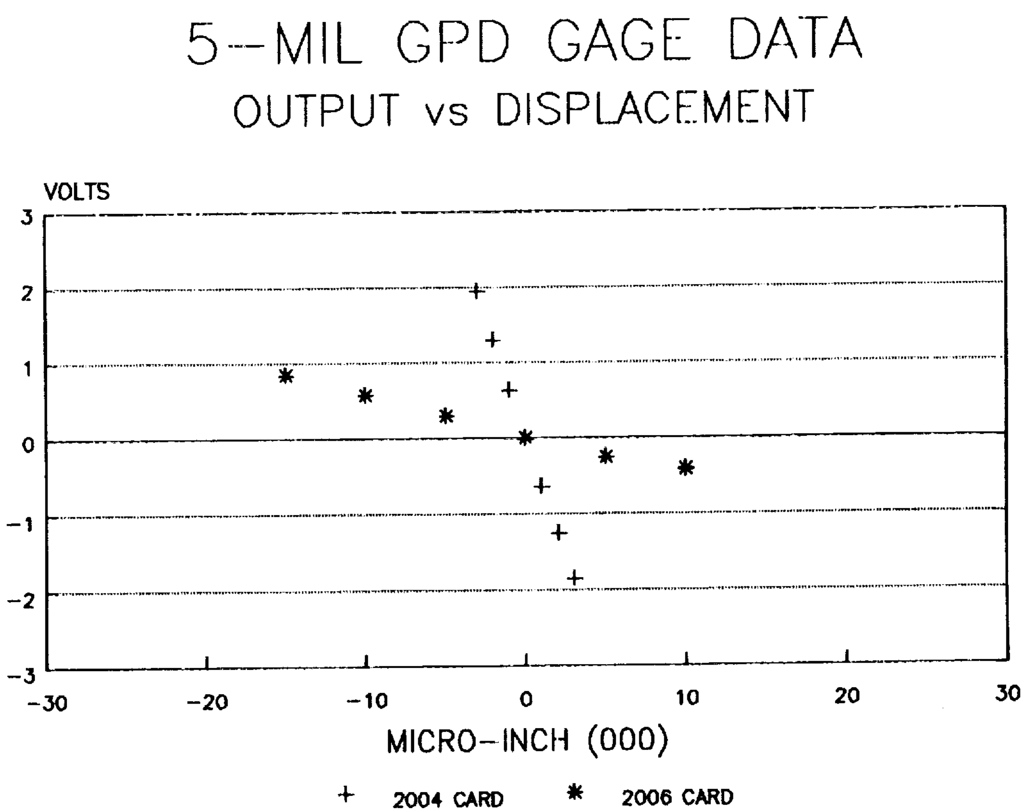


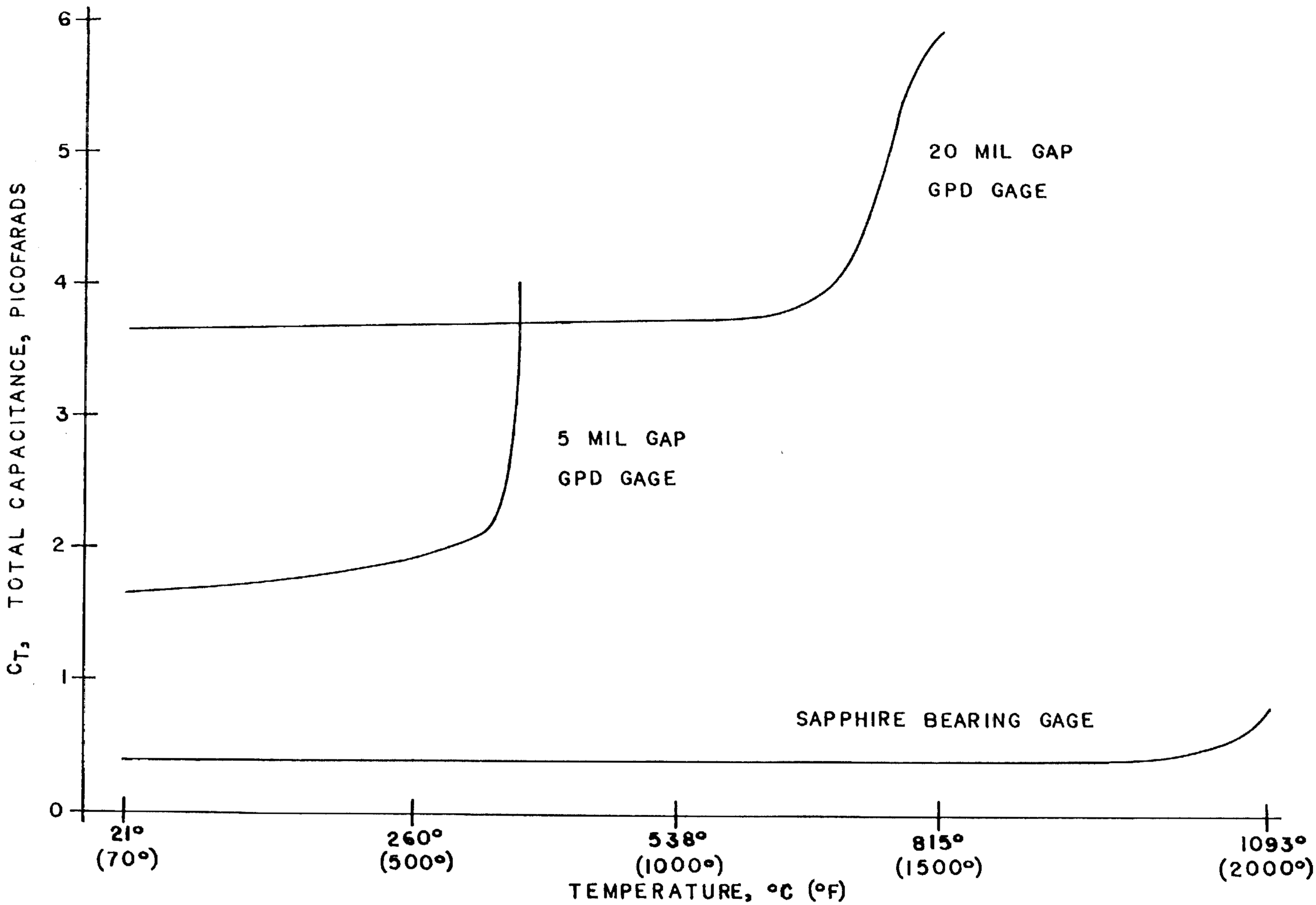
FIGURE 12



ROOM TEMP DATA ON STANDARD CAL STAND

FIGURE 13

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



TOTAL CAPACITANCE VS TEMPERATURE

FIGURE 14

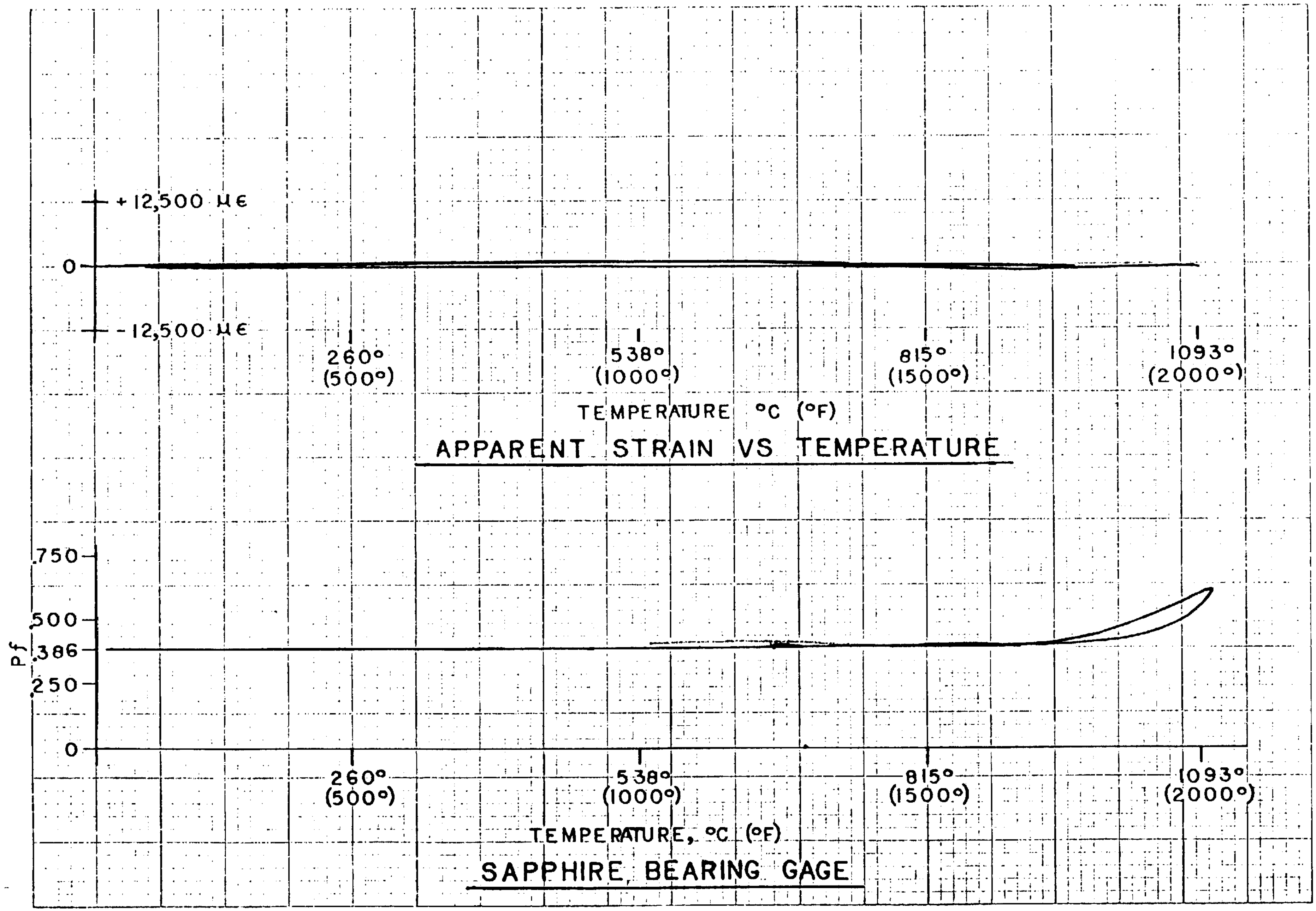

+12,500 με
0
-12,500 με
260° (500°)
538° (1000°)
815° (1500°)
1093° (2000°)
TEMPERATURE °C (°F)
APPARENT STRAIN VS TEMPERATURE
.750
.500
.386
.250
0
Pf
260° (500°)
538° (1000°)
815° (1500°)
1093° (2000°)
TEMPERATURE, °C (°F)
SAPPHIRE BEARING GAGE

FIGURE 15

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-4266		

4. Title and Subtitle	5. Report Date
High Temperature Capacitive Strain Gage	January 1990
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
S.P. Wnuk, Jr. S.P. Wnuk III V.P. Wnuk	
	10. Work Unit No. 324-02-00
9. Performing Organization Name and Address HITEC Products, Inc. P.O. Box 790 Ayer, MA 01432	11. Contract or Grant No. NAS1-18668
	13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address NASA Langley Research Center Hampton, VA 23665-5225	14. Sponsoring Agency Code

15. Supplementary Notes

Langley Technical Monitor: Thomas C. Moore
SBIR Phase II Final Report - 3/21/88 to 6/20/89

16. Abstract

Capacitive strain gages designed for measurements in wind tunnels to 2000°F were built and evaluated. Two design approaches were followed· one based on fixed capacitor plates with a movable ground plane inserted between the plates to effect differential capacitive output with strain, the second based on movable capacitor plates suspended between sapphire bearings, housed in a rugged body, and arranged to operate as a differential capacitor.

A sapphire bearing gage (1/4" Diameter x 1" in size) was built with a range of 50,000 and a resolution of 200 microstrain. Apparent strain on Rene' 41 was less than ±1000 microstrain from roon to 2000°F.

Three gage models were built from the Ground Plane Differential concept. The first was 1/4" square by 1/32" high and useable to 700°F. The second was 1/2" square by 1/16" high and useable to 1440°F. The third, also 1/2" square by 1/16" high was expected to operate in the 1600 to 2000°F range, but was not tested because time and funding ended.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
High Temperature Capacitive Strain Gages	Unclassified - Unlimited Subject Category 35

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	52	A04

NASA FORM 1626 OCT 86 NASA-Langley, 1990

For sale by the National Technical Information Service, Springfield, Virginia 22161-2171