GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

no action req'd

Date: December 8, 1976

Project Title: Gas Turbine Bearing Program -- Tasks II and III

Project No: E-25-668

Project Director: Dr. Ward O. Winer

Sponsor: General Electric Co.;Gas Turbine Mfg.Dept.;Schenectady, NY 12345

Agreement Period: From 11/3/76 Until 4/1/77

Type Agreement: Purchase Order No. 087-ETBM-72359, dated 11/3/76

Amount: $22,000 (Fixed Price)

Reports Required: Task II Report; Task III Report

Sponsor Contact Person (s):

Technical Matters	Contractual Matters (thru OCA)
Mr. J. D. McHugh	C. J. Kowalski
Bearing and Sealing System Design	Purchasing
Building No. 53-334	Gas Turbine Manufacturing Dept.
General Electric Company	General Electric Company
One River Road	P. O. Box 952
Schenectady, NY 12345	Schenectady, NY 12345

Defense Priority Rating: None

Assigned to: Mechanical Engineering (School/Laboratory)

COPIES TO:

Project Director	Library, Technical Reports Section
Division Chief (EES)	Office of Computing Services
School/Laboratory Director	Director, Physical Plant
Dean/Director—EES	EES Information Office
Accounting Office	Project File (OCA)
Procurement Office	Project Code (GTRI)
Security Coordinator (OCA)	Other
Reports Coordinator (OCA)	

CA-3 (3/76)

no action
OCA

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT TERMINATION

Date: 12/4/78

Project Title: Gas Turbine Bearing Program -- Tasks II and III

Project No: E-25-668

Project Director: Dr. Ward O. Winer

Sponsor: General Electric Co.; Gas Turbine Mfg. Dept.; Schenectady, NY 12345

Effective Termination Date: 4/1/77 (Fixed Price)

Clearance of Accounting Charges: ---

Grant/Contract Closeout Actions Remaining:

X Final Invoice ~~and Closing Documents~~

_ Final Fiscal Report

_ Final Report of Inventions

_ Govt. Property Inventory & Related Certificate

_ Classified Material Certificate

_ Other ____________

Assigned to: Mechanical Engineering (School/Laboratory)

COPIES TO:

- Project Director
- Division Chief (EES)
- School/Laboratory Director
- Dean/Director—EES
- Accounting Office
- Procurement Office
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- Other ____________

CA—4 (3/76)

KAMAN HIGH TEMPERATURE CABLE EVALUATION

Final Report

GENERAL ELECTRIC CORPORATION

P.O. #087-ETBM-72359

by

Ward O. Winer
Professor
and
Principal Investigator

David M. Sanborn
Associate Professor

Scott Bair
Research Engineer

William Dean
Research Assistant

Georgia Institute of Technology
School of Mechanical Engineering
Atlanta, Georgia

March, 1977

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KAMAN HIGH TEMPERATURE CABLE EVALUATION

SUBMITTED TO

J. D. McHugh
General Electric Corporation
Bearing & Sealing System Design
Schenectady, New York 12345

SUBMITTED BY

Ward O. Winer
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Georgia Institute of Technology
School of Mechanical Engineering
Atlanta, Georgia

March, 1977

Ward O. Winer, Professor
School of Mechanical Engineering

SUMMARY

A high temperature cable was evaluated by using a Kaman Science Corporation Multi-vit displacement system. The system is described in the appendix. The range of displacement measurement of the system is .1 inch (0.01 to 0.11 inch). The steady and unsteady (up to 55 Hz) measurements were taken at cable temperatures of 76, 350, 700, 1000, 1400F. A thermal cycling test to indicate the repeatability of any measurement and a mechanical ruggedness test consisting of 90° bends were also made. An immersion test in triaryl phosphate ester to simulate a break in the sheath was performed.

The static calibration changed with cable temperature, but once calibrated at a given cable temperature both static and dynamic responses were within five percent full scale output (FSO). No hystersis was observed in the thermal cycling test and the mechanical ruggedness test resulted in no observable changes in performance. The immersion test indicated that calibration was changed because of the capacitance change in the cable but the instrument could be recalibrated.

INTRODUCTION

A high temperature cable supplied by General Electric for a Kaman Science Corporation Multi-Vit displacement measuring system (Model KD-2300-25) was evaluated (Figure 1). The Kaman probe is a non-contacting variable impedance displacement transducer. The purpose of the program was to establish the effect of cable temperature, thermal cycling, cable bending, and cable immersion in a phospate ester on the static and dynamic response of the transducer system.

DESCRIPTION OF APPARATUS AND PROCEDURE

The displacement measurements were made with the probe head adjacent to an eccentric cam made of cold rolled steel (Figure 2). The static measurements were made with no shaft rotation and the dynamic measurements with the shaft rotating up to 55 Hz. The probe head and cam were at room temperature while approximately six feet of cable were coiled in a resistance oven and maintained at the test temperature (Figure 3). The total cable length was ten feet.

The probe head mount was coupled with a micrometer to use as a basis for the displacement measurement (Figure 4). The displacement range for the static measurement was 0.1 inch (from 0.01 to 0.11 inch). Readings were taken at intervals of 0.01 inch. In the dynamic measurement the probe head was fixed and the cam lobe varied the displacement $\pm$ 0.02 inch about a mean of 0.05 inch.

A static calibration was performed with the cable temperature of 76^{o}, 350^{o}, 700^{o} and 1400^{o}F. Dynamic calibration was performed at 76^{o} and 1000 F with shaft speeds of 15, 35, 40 and 55 Hz.

The cable was also thermally cycled from room temperature to 1000 F one hundred times and the static calibration was repeated at room temperature.

The mechanical ruggedness test consisted of introducing six 90^{o} bends with 1/4 inch radius in the cable. Static calibration was made at 76 F before the bends were made and static measurements made at both 76 and 1000 F after the bends were introduced.

The effect of immersion in a phosphate ester of a cable with a ruptured sheath was evaluated by immersing a second piece of cable 46" long with an open end in the lubricant at 180 F for four weeks. Resistance and capacitance of the cable were measured at the start and after two and four weeks of immersion. The effect of the changes in cable resistance and capacitance due to immersion were evaluated by introducing similar resistance and capacitance elements across the unimmersed cable-probe assembly.

DISCUSSION OF RESULTS

Effect of Cable Temperature on Static Reading:

The static displacement curves for various temperatures are shown in Figure 5. For temperatures of up to 700 F, and calibration at 76 F, the readings are within $\pm$ 5% FSO (Full Scale Output). But at higher temperatures the error increases to around 32% FSO at 1400 F without recalibration. The sensitivity at midrange (.05 inch) as a function of operating temperature and initial calibration at 76 F is shown in Table 1. As can be seen the slope is a function of temperature past 700 F and at 1400 F the slope is 23% greater than at ambient.

which shows the transducer output reading for a fixed probe head displacement of 0.060 inch.

If the system is calibrated at a given cable temperature, the readings are within ± 0.5% FSO for that cable temperature. Measurements were made with the system calibrated for cable temperatures of 76, 350, 700, 1400 F. If plotted, these data would be indistinguishable from the 76 F curve in Figure 5.

Effect of Cable Temperature on Dynamic Reading:

The sensitivity of the probe reading to temperature for dynamic displacement is shown in Table 2. The system was calibrated with a cable temperature of 76 F, and the displacement variation was measured in the static mode while manually rotating the shaft. The actual displacement variation was .0146 inch and the probe readings were .0146 inch at 76 F and .0159 inch at 1000 F. The dynamic readings were then taken for various shaft rotational speeds and cable temperatures of 76 F and 1000 F. Harmonic motion of the particular test apparatus effected the readings but the results indicate that the dynamic response is at best as good as the static response.

Effect of Thermal Cycling:

The effect of thermal cycling was evaluated by cycling the cable between 80 F and approximately 1000 F one hundred times. The typical cycle period was five minutes. A thermocouple was attached to the fixed coil of cable and the oven, set at 1300 F, was moved around the cable coils. When the cable thermocouple stabilized above 1000 F the oven was removed until the cable thermocouple stabilized at 80 F. The system was calibrated with the cable at 76 F and static readings were taken at

76 F after the 100 thermal cycles. The results are shown in Figure 7. The readings after thermal cycling are within 1.1% FSO of initial calibration.

Effect of Mechanical Bending:

The system was calibrated at 76 F and then six 90^{o} bends were introduced. The bends were made by bending the cable around a rod of 0.3 inches diameter. The bends have inside diameters of approximately 1/4 inch. One of the bends began to show signs of crimping. After the bends were made static readings were taken at 76 F and 1000 F (Figure 8). These readings were within 0.7% FSO at 76 F and 10.6% FSO at 1000 F. These readings were as expected based on the previous static measurements. That is, these bends had no adverse effects on the measurements made.

Effect of Open Cable Sheath in Phosphate Ester Environment:

A 46 inch section of cable open at one end was soaked in a phosphate ester bath (triaylphosphate ester, Stauffer Chemical Company Fyrquel 150 R&O), at 180 F for four weeks.

The resistance and capacitance of the cable were measured initially and after two weeks and four weeks. The results are shown in Table 3. The capacitances were measured at 1 KHz. To simulate the capacitance change observed a capacitance was added to the bridge circuit. The system retained the zero calibration but the gain changed when the capacitance was added. The gain adjustment could be changed to compensate for the capacitance change to obtain correct calibration. The resistance change of the insulation, because of its magnitude compared to the dry cable-probe resistance, will not change the performance of the instrument.

Therefore the intrusion of phosphate ester into the cable insulation will change the gain of the instrument but this gain change can be compensated for by normal gain adjustments.

CONCLUSIONS

1. When the system is calibrated and used at the same cable temperature, the static response is within 0.5 % FSO of actual displacement.

2. When the system is calibrated with a cable temperature of 76 F and used with different cable temperatures the error increased with cable temperature for both static and dynamic measurement. For cable temperatures up to 700 F the maximum error was five percent FSO. The error increased to 32% FSO at a cable temperature of 1400 F.

3. When the system is calibrated at a cable temperature of 76 F the change in sensitivity is minimal (less than 1%) below 700 F but increases to 23% at 1400 F.

4. Thermal cycling within the range studied did not adversely influence the system performance.

5. Mechanical bending of the cable within the range studied did not substantially influence the system performance.

6. Phosphate ester penetration of the insulation through a sheath break caused the system gain to change within a range that could be compensated for by the gain adjustment provided.

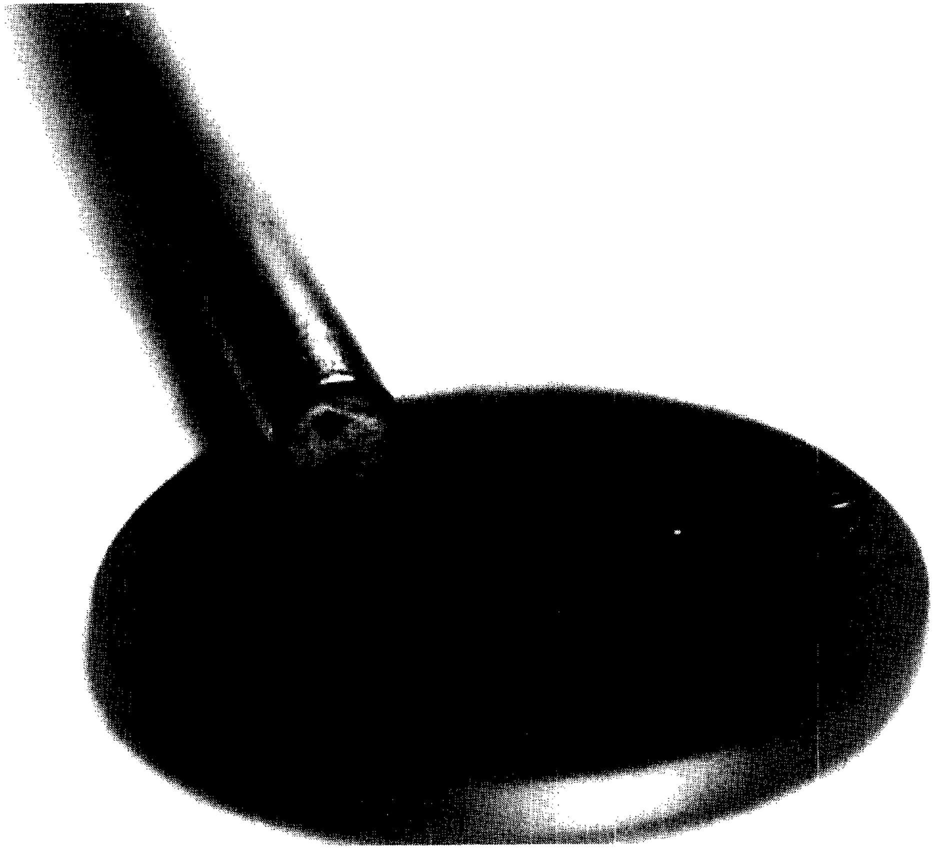


Figure 1. Cable Cross Section.

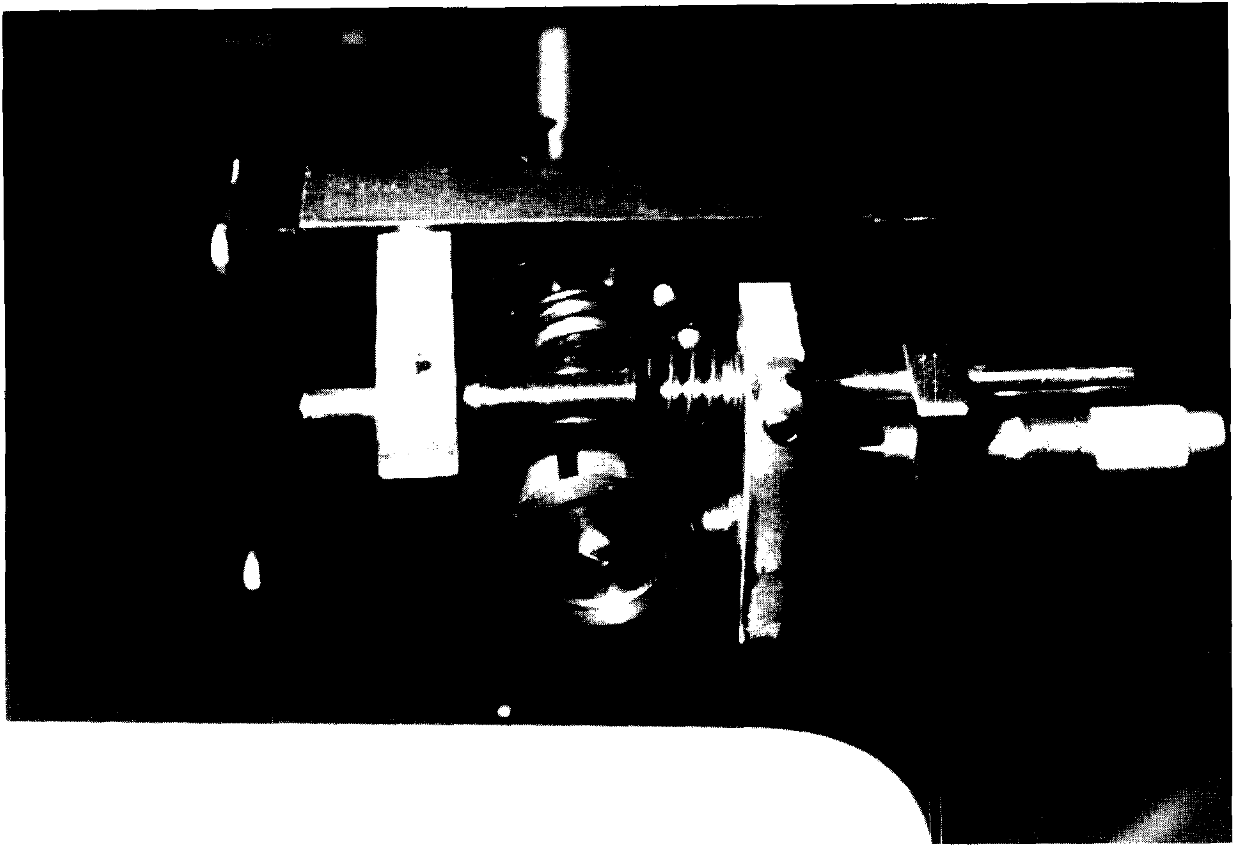


Figure 2. Test Head.

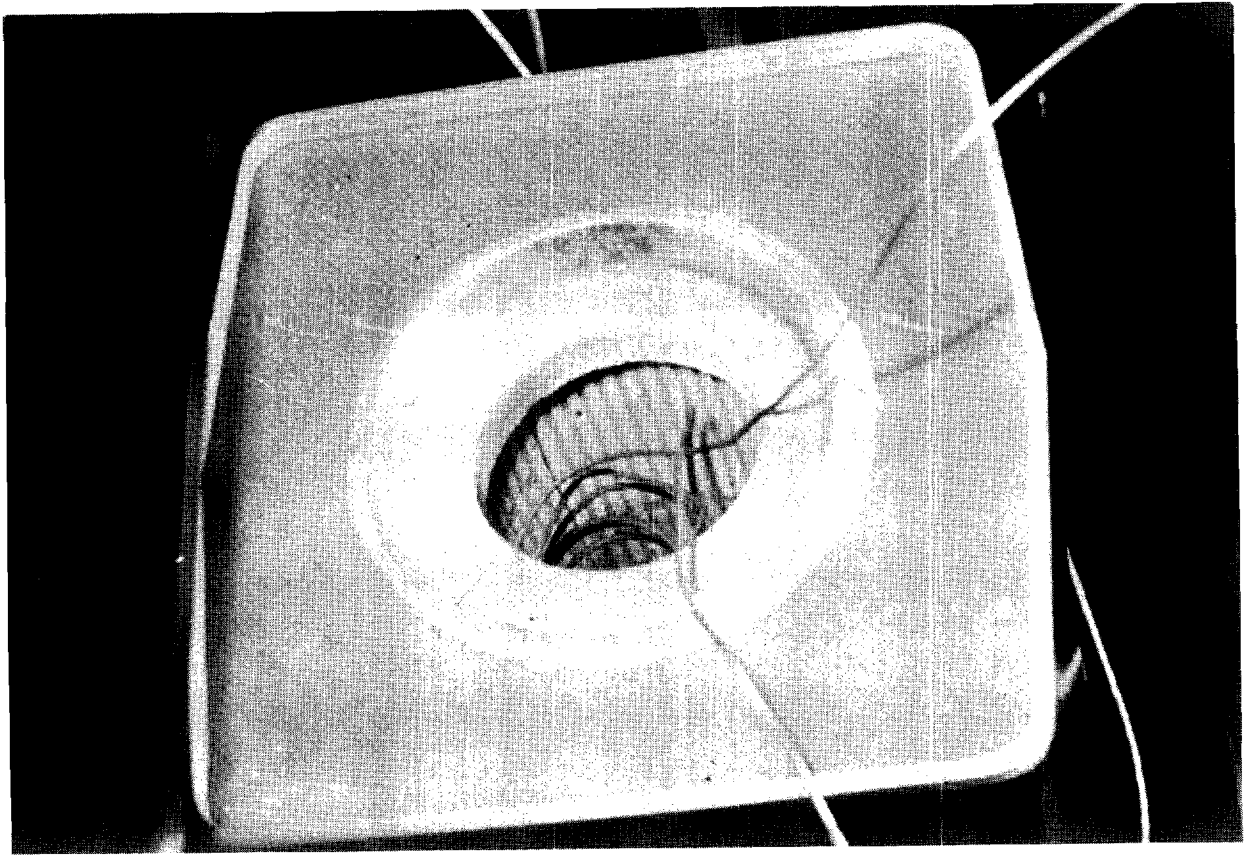


Figure 3. Oven with Cable Coil.

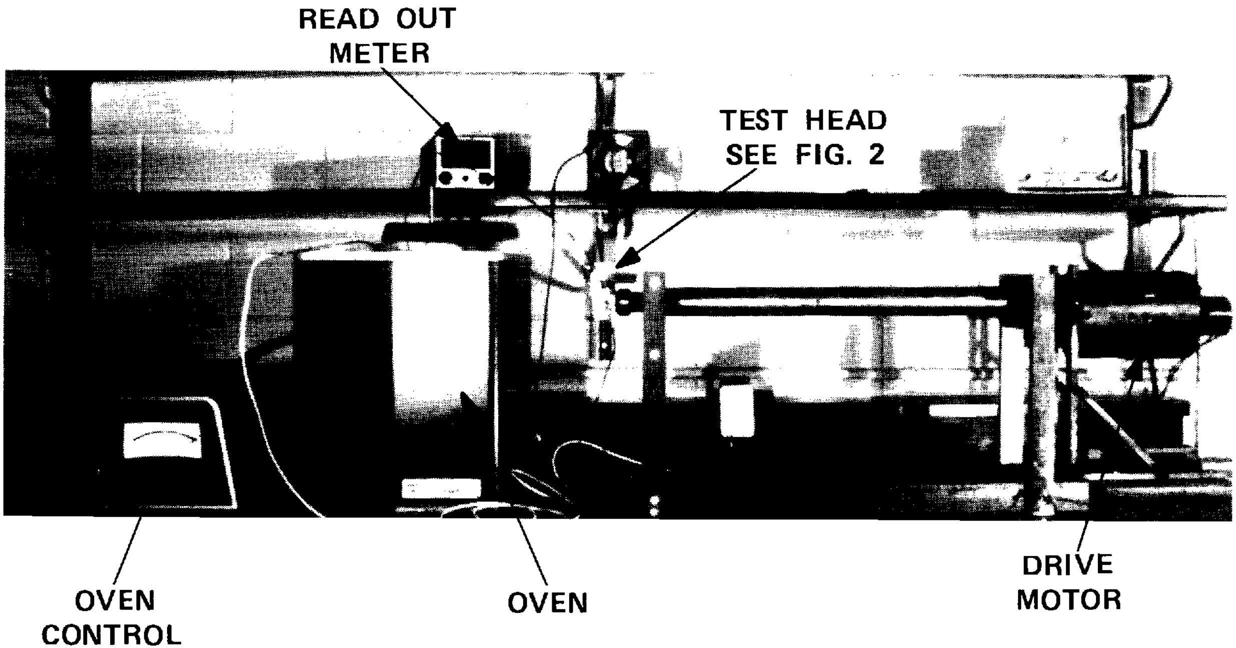


Figure 4. Displacement System Measuring Evaluated.

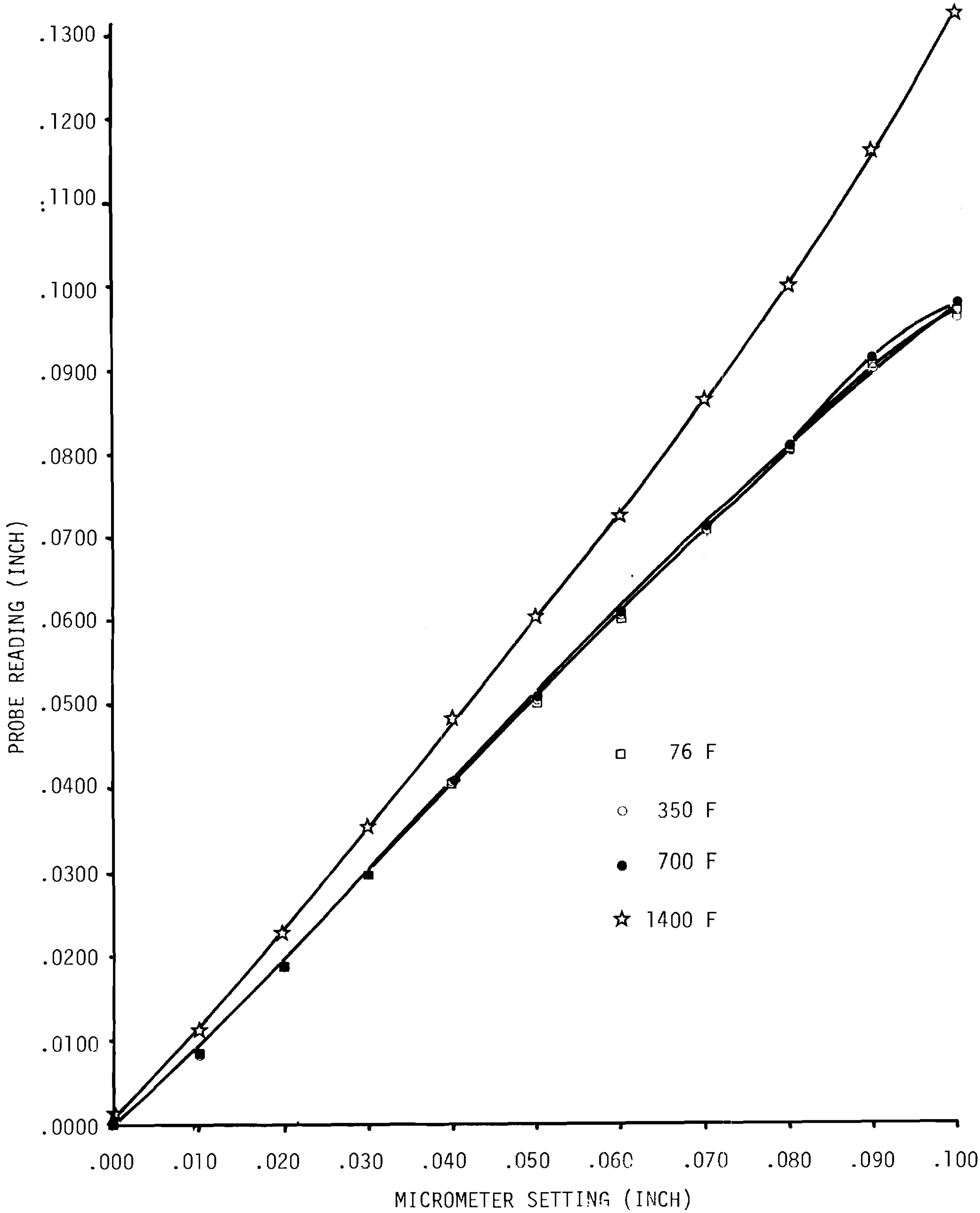


Figure 5. Static Calibration Test.

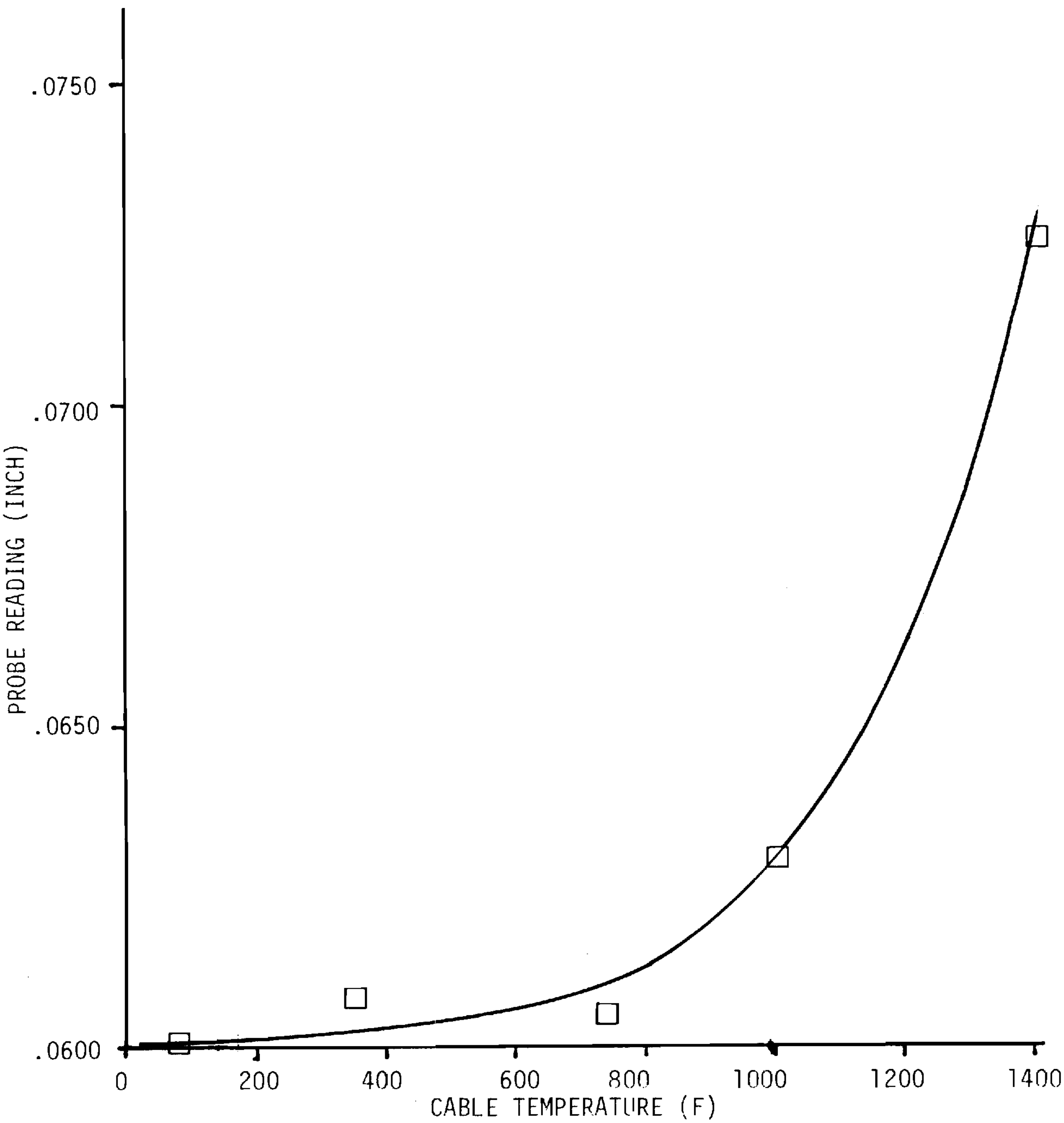
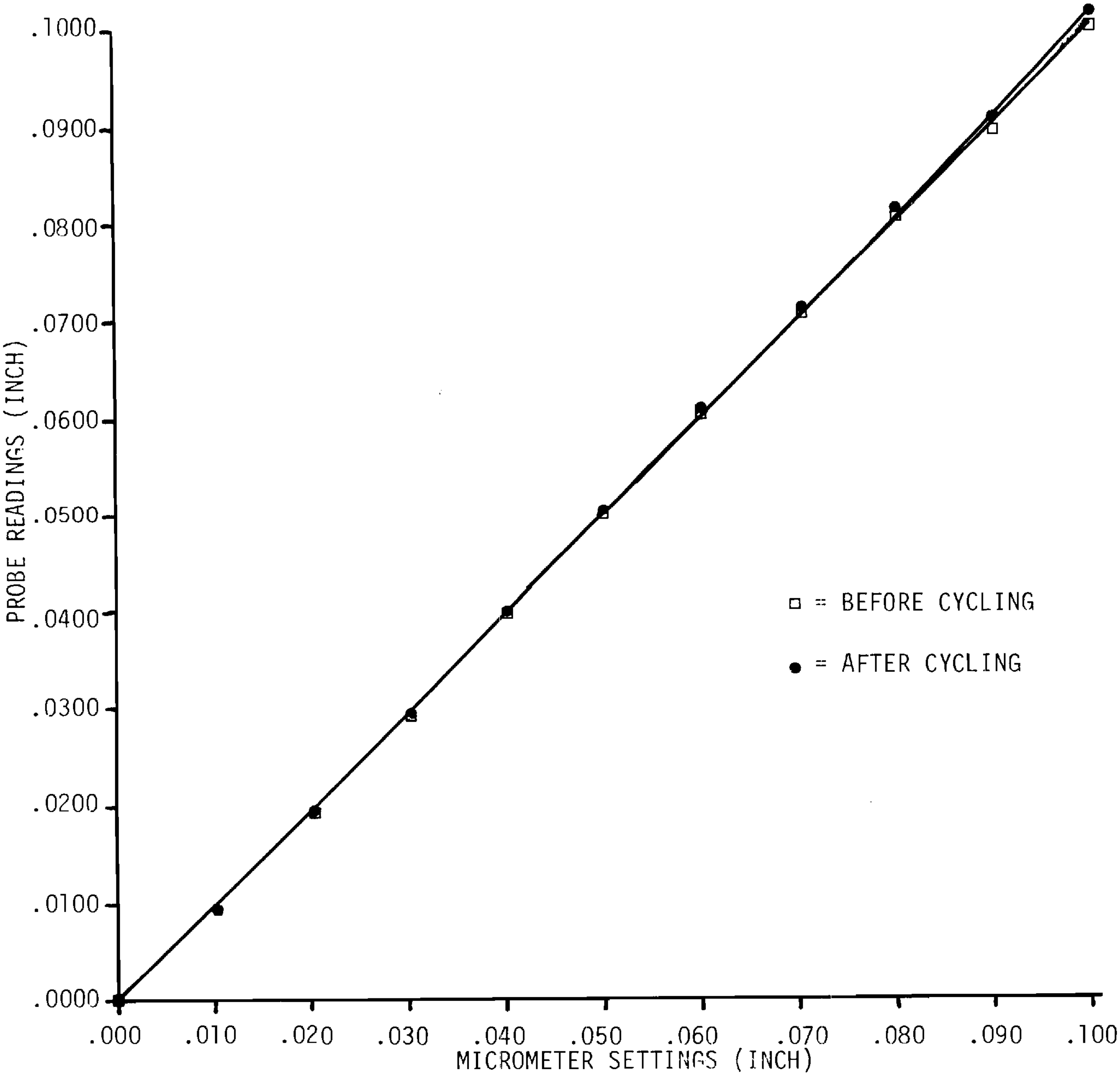


Figure 6. Probe Reading (Constant Probe Position, .060 Inch from Metal) vs Cable Temperature.



MICROMETER	BEFORE CYCLING	AFTER CYCLING
.000	.0000	.0000
.010	.0092	.0092
.020	.0190	.0191
.030	.0293	.0294
.040	.0398	.0399
.050	.0500	.0502
.060	.0603	.0607
.070	.0705	.0709
.080	.0803	.0812
.090	.0896	.0906
.100	.1000	.1011

Figure 7. Thermal Cycling Test.

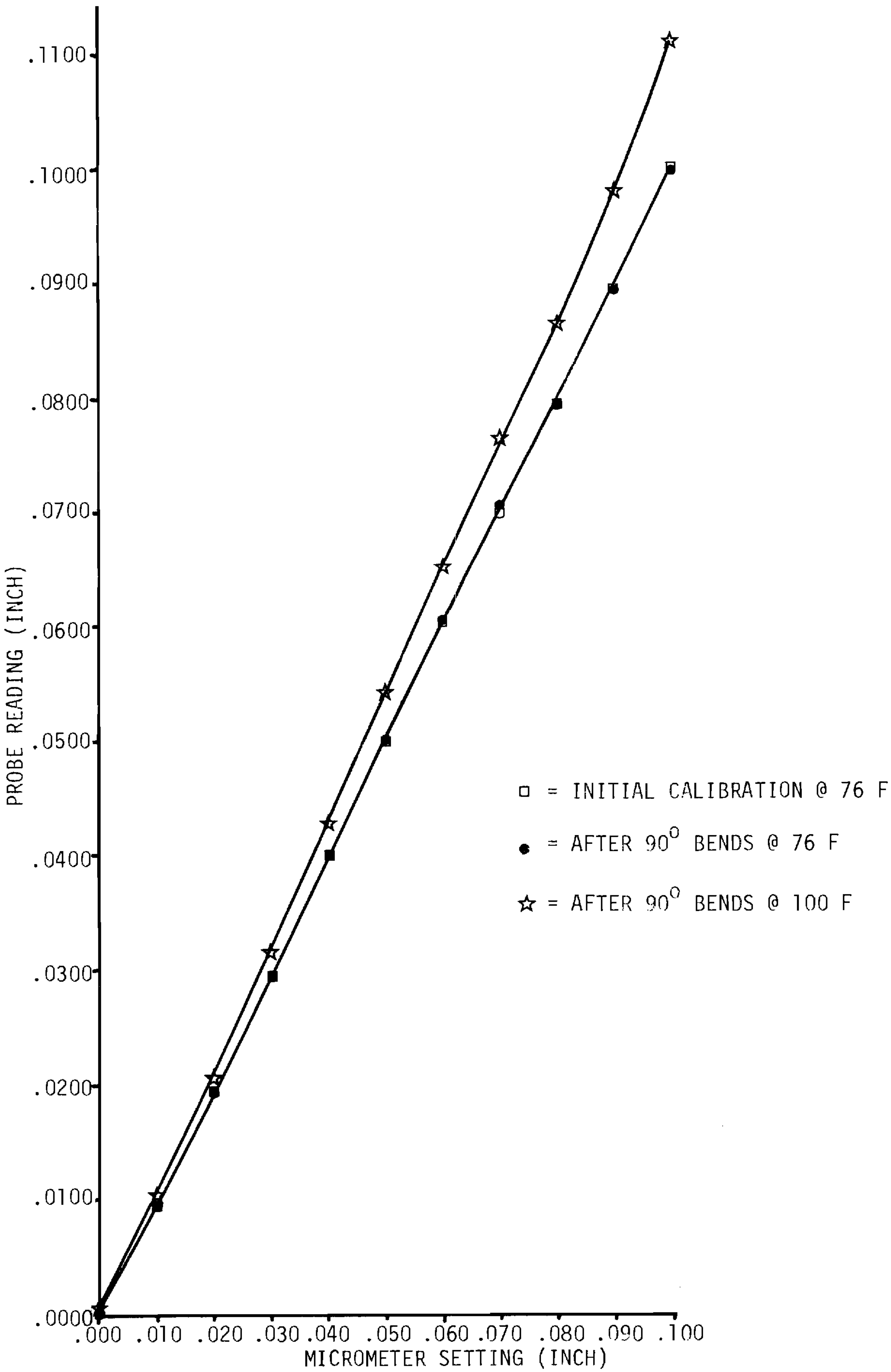


Figure 8. Mechanical Ruggedness Test.

Table 1. Sensitivity at .05 Inch with Calibration at 76 F

Temperature $^{\circ}$F	Slope Volt/in	% Change*
76 F	10.0	0
350 F	10.0	0
700 F	10.0	0
1000 F	11.35	14
1400 F	12.30	23

$$*\%\ \text{CHANGE} \equiv \left(\frac{\text{SLOPE AT T}}{\text{SLOPE AT 76 F}} - 1\right) \times 100\%$$

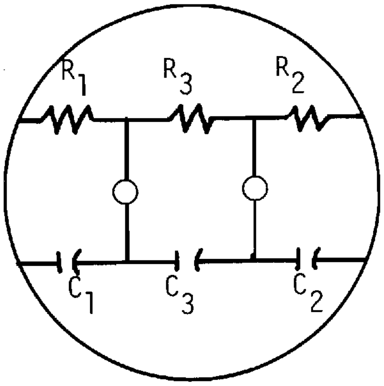
Table 2. Dynamic Test.

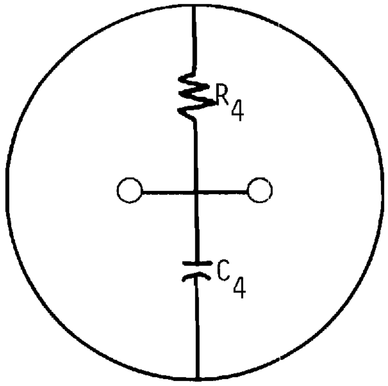
Calibration at 76 F

SHAFT SURFACE SPEED (FT/MIN)	SHAFT SPEED (HZ)	PROBE READING: DISPLACEMENT VARIATION 76 F (INCH)	1000F (INCH)
360	15	.0137	.0149
780	35	.0143	.0155
1300	40	.0141	.0150
1600	55	.0145	.0158
MANUAL ROTATION (STATIC MODE)		.0146	.0159

Table 3. Lubricant Immersion Test.

Cable = 46" Long





Initially

C_1 = 52.4 pf	$R_1 = 8.5 \times 10^{11}$ Ω
C_2 = 60.0 pf	$R_2 = 4 \times 10^{11}$ Ω
C_3 = 49.0 pf	$R_3 = 1.1 \times 10^{12}$ Ω
C_4 = 88.1 pf	$R_4 = 7 \times 10^{11}$ Ω

After Two Weeks

C_1 = 77.7 pf	$R_1 = 4.5 \times 10^{7}$ Ω
C_2 = 79.5 pf	$R_2 = 3.5 \times 10^{7}$ Ω
C_3 = 63.0 pf	$R_3 = 7 \times 10^{7}$ Ω
C_4 = 118.3 pf	$R_4 = 2.7 \times 10^{7}$ Ω

After Four Weeks

C_1 = 180.1 pf	$R_1 = 4.4 \times 10^{7}$ Ω
C_2 = 182.5 pf	$R_2 = 4.3 \times 10^{7}$ Ω
C_3 = 113.0 pf	$R_3 = 6.8 \times 10^{7}$ Ω
C_4 = 222.9 pf	$R_4 = 2.9 \times 10^{7}$ Ω

APPENDIX

DESCRIPTION OF DISPLACEMENT MEASURING SYSTEM EMPLOYED

The meter first used in the testing procedure was defective and had to be replaced. According to Homer Pransy who is the head of repair work on the displacement systems for Kaman Sciences in Colorado Springs, Colorado there was a 40% return rate on the voltmeters and power supply packs. The volt meter and power supply pack is not manufactured by Kaman Sciences but they use it with their displacement measuring systems.

GENERAL ELECTRIC

GAS TURBINE PRODUCTS DIVISION

GENERAL ELECTRIC COMPANY, ONE RIVER ROAD, SCHENECTADY, N. Y., U.S.A. 12345
Phone (518) 374-2211, Telex 145354

September 30, 1976

Prof. W. O. Winer
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Dear Ward:

I will be sending you shortly a Kaman Sciences proximity probe, cable and read-out meter for evaluation at Georgia Institute of Technology, as we discussed. An outline of the proposed test plan is included as Task 3 in a request for quotation which you will also be receiving from me shortly.

The instrumentation system, which will be returned to General Electric upon completion of the test plan, consists of:

1 - Power Supply P-3106 with AC and DC digital voltmeter

1 - Special KS-2300-2S Displacement Measuring System including (a) special sensor with end of twin wire Enviroline Cable potted in sensor, (b) 10 feet of twin-wire Enviroline Cable with two free sliding sleeves and 3/8" diameter 2 pin connector, and (c) 10 feet of 50 foot Teflon Cable with mating connections for Enviroline Cable and electronics.

I left with you on my last trip to Atlanta a copy of a Kaman Sciences catalog describing their system, as well as a copy of an instruction manual for the MULTI-VIT Model KD-2300-2S giving the details of calibration, pin connectors, etc. I am enclosing with this letter an instruction manual for the Kaman Model P-3106, power supply/AC-DC Digital Voltmeter. This voltmeter will be used for both static and dynamic probe system evaluation.

The system was obtained through:

Richard E. Dambman
District Sales Manager,
Kaman Sciences Corp.
49 Hildurcrest Drive
Simsbury, Conn. 06070
(203) 658-1126

GENERAL ELECTRIC

If you need further information on the measurement system in order to proceed, I suggest that you contact Mr. Dambman directly. You will find him to be very cooperative.

Sincerely,

J. D. McHugh, Manager
Bearings, Seals, Rotor Systems

JDM/pn

Copy: G. Graham
R. Dambman
G. Robson

INSTRUCTION MANUAL

Kaman Model P-3106

Power Supply/AC-DC Digital Voltmeter

The P-3106 is intended for use with Kaman KD-2300 series displacement measuring sysems, especially in applications involving the monitoring of moving "targets." The P-3106 is similar to the P-3100 Power Supply/Digital Voltmeter package, but it also contains an AC to DC converter which enables it to read the peak to peak value of the input voltage. Thus when used with a KD-2300 series displacement system, the user can read directly the peak to peak movement of a "target."

Located on the rear of the P-3106 is a switch labeled "AC-DC." The "DC" position is used during the calibration of the displacement system. (See the displacement system instruction manual for a further description of this procedure.) The "DC" position would also be used for measuring static displacements. However, once the target is set in motion, neither the digital voltmeter nor the eye is capable of following the movement. Then, the user can switch to the "AC" position and read the peak to peak movement displayed on the digital voltmeter.

Note that the P-3106 contains a true peak to peak converter and thus will display the true peak to peak value regardless of the shape of the input waveform. In many applications, this has a considerable advantage over an averaging type of AC converter which senses the area under the curve and multiplies by a constant to convert a sine wave to a peak to peak value.

The P-3106 AC converter is constructed to respond very quickly to the peak signal; and, in order to obtain good low frequency response, it has a long decay time. For this reason, when the input selector or the range selector is switched or any other transient occurs at the input, the high peak voltage generated will overrange the meter and it may take as long as one minute for the reading to decay to a lower, in-range value.

The zero for the AC converter may be set by removing the cover from the unit. (Be careful not to come in contact with the 115 Volt line voltage inside.) The zero adjustment potentiometer can be found on the right side of the unit, mounted on the small Printed Circuit Board. When setting this adjustment the input terminals should be shorted and must have a DC path to the "COM" terminal of the power supply. The adjustment can also be made when the unit is connected to a displacement system with the target not moving and near "zero" displacement (to minimize output noise).

The "zero" and "full scale" adjustments for the meter can be performed in the DC mode by removing the meter's filter screen and adjusting the exposed potentiometers located near the top of the meter. The "zero" potentiometer is toward the center and the "full scale" toward the right. These adjustments are preset at the factory before shipment and normally will not require adjustment by the customer.

SPECIFICATIONS

P-3106

Power Input:

Voltage: 105-125 VAC

Frequency: 50-60 Hz

Power: 30 Watts

Temperature Ratings

Operating Range: $30^{O}F$ to $120^{O}F$ ($0^{O}C$ to $50^{O}C$)
(air circulation required)

Storage Range: $-85^{O}F$ to $260^{O}F$ ($-65^{O}C$ to $125^{O}C$)

Power Supply Output Characteristics:

Voltage: Plus and minus 12 VDC ± 0.1VDC

Current: Plus and minus 450 mA max.
(Short circuit protected)

Regulation: Line and Load ± 0.2%

Ripple: 2.5 mVrms

Tempco: ± 0.01%/^{O}F

Digital Voltmeter DC Characteristics:

Range: ±1.999 (1V)
±19.99 (10V)

Accuracy: ±0.05% of reading ± 1 count (1V)
±0.10% of reading ± 1 count (10V)

Tempco: ±0.004%/^{O}F (1V)
±0.007%/^{O}F (10V)

Digital Voltmeter AC Characteristics:

Range: ±1.999 (1V)
±19.99 (10V)

Accuracy: ± (2% reading + 0.5% range)

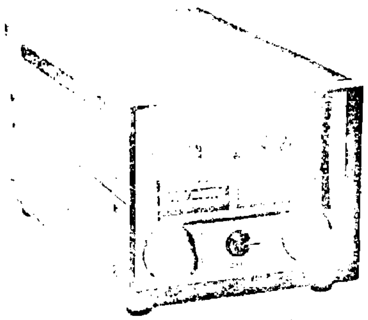
Frequency Response: ±1% from 30 Hz to 20 KHz
(with respect to 1.5Vpp @ 1KHz)
Note: Display jitter may limit reading capability below 30 Hz.

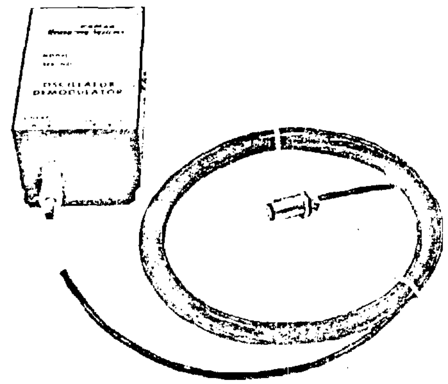
Zero Shift: ±0.5 counts/^{O}F

Sensitivity Shift: ±0.05%/^{O}F

Maximum Input Voltage: ± 12V peak (AC plus DC)

MULTI-VIT
DISPLACEMENT MEASURING SYSTEM





KAMAN Measuring Systems

KAMAN'S MULTI-VIT

(MULTIple purpose Variable Impedance Transducer) series of non-contacting displacement measuring systems provide a wide range of measuring capabilities at a very moderate price. Various targets and configurations can be gauged by a single unit due to the simple system calibration procedure. Most conducting materials present an acceptable target. Full scale ranges from a few mils to greater than two full inches are available.

The system operates on the eddy-current loss principle. A bridge circuit is activated by a one megahertz carrier. Two arms of the bridge are in the transducer. Magnetic flux lines emanating from the transducer at a one megahertz rate pass into the conductive surface being sensed and produce eddy-currents. As a conductive surface moves closer to the transducer, more eddy-currents are generated and the losses within the bridge circuit become greater. As the conductive surface moves away from the transducer, the losses become less. These impedance variations are converted to dc voltage proportional to the distance being sensed. Because of the high (1Mhz) frequency of the eddy-currents, they penetrate the conductive surface only a few mils. Displacement of conductive surfaces as thin as 0.50 mils have been successfully measured.

Kaman's patented dual coil impedance bridge circuit provides some unique features found in no other non-contacting displacement transducer system. The first coil is the active element which senses the target movement. The second coil, in the opposing arm of the impedance bridge, serves as a compensating coil to balance and cancel most of the effects of temperature change. This arrangement provides for an extremely stable system.

The range of an individual sensor depends on the size of the sensor. Systems are available with full scale ranges of 0.0 to 0.050 in. up to 0.0 to 2.500 in. Standard gage ranges are shown on the accompanying data sheets. Other ranges are available on special order.

Options include longer interconnecting cable lengths (up to 30 ft). A power supply package providing the required plus and minus 12 Vdc is available with and without a digital readout capability. The MULTI-VIT System is easily field calibrated and the output can be calibrated to read in engineering units (e.g. mils). Factory calibration for specific materials and shapes is offered as an option. As you can see, Kaman Measuring Systems can provide you with a complete displacement measuring system. If you have any questions concerning Kaman's capability to provide the ultimate in non-contact gauging capability, please write or call:

KAMAN SCIENCES CORPORATION
P. O. BOX 7463 • COLORADO SPRINGS, COLORADO 80933

1500 Garden of the Gods Rd.
Telephone: (303) 599-1500
Telex: 452412
A Kaman Company

MV-734

Printed in the U.S.A.

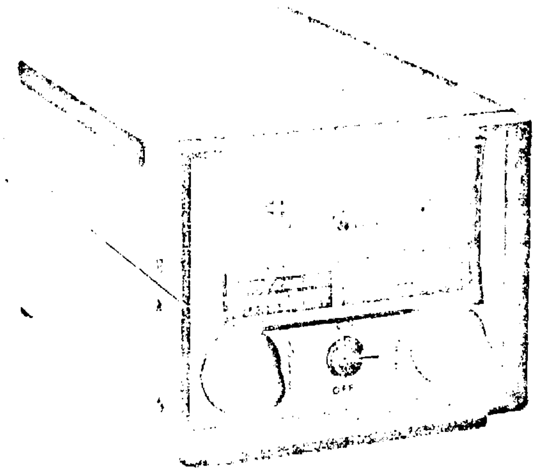
PRELIMINARY

P–3100

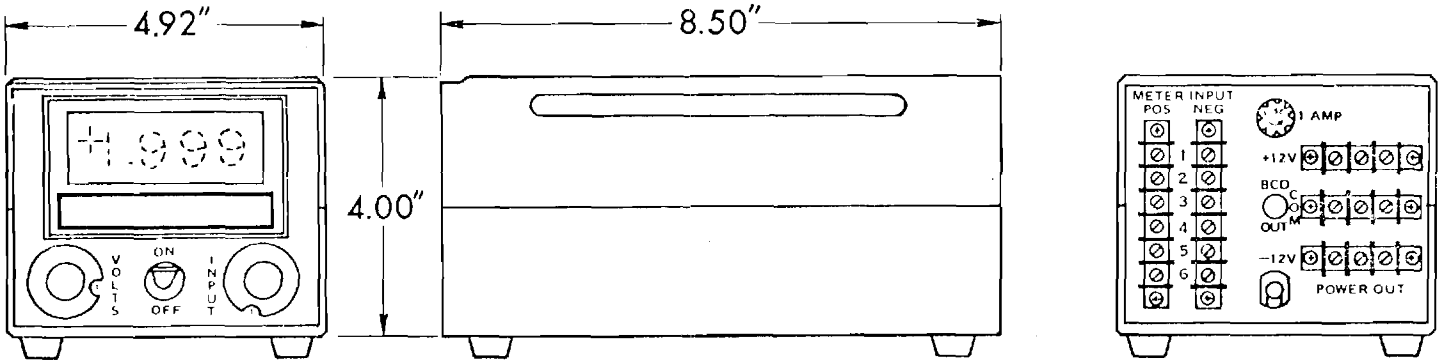
DUAL POWER SUPPLY – DIGITAL VOLTMETER

FEATURES

- REGULATED + and – 12 Vdc (±0.1 Vdc)
- 6 CHANNEL DVM ANALOG INPUT
- 3½ DIGIT DVM
- ALL SILICON DESIGN
- LOW COST
- MULTI-VIT COMPATIBLE



KAMAN'S new P–3100 Dual Power Supply—Digital Voltmeter provides regulated + and – 12 Vdc as well as a digital voltmeter to monitor 6 independent channels of analog input. Designed specifically to power up to 6 channels of KAMAN'S MULTI-VIT Displacement Measuring Systems, the P–3100 can also be used for other power supply and digital voltmeter functions. Selector switches are provided for changing voltmeter sensitivity and analog input channel. BCD voltage output from the digital voltmeter is available. The P–3100 uses IC regulators and is designed for integrated circuit applications.



KAMAN SCIENCES CORPORATION
P. O. BOX 7463 • COLORADO SPRINGS, COLORADO 80933

1500 Garden of the Gods Rd.
Telephone: (303) 599-1500
Telex: 452412
A Kaman Company

SPECIFICATIONS
P-3100

AC INPUT

Voltage: 105 - 130 Vac
50 - 60 Hz, Watts 30

TEMPERATURE RATINGS

OPERATING TEMPERATURE RANGE:
30°F to 150°F (0°C to 65°C)
(Air circulation required)

STORAGE TEMPERATURE RANGE:
– 85°F to 260°F (–65°C to 125°C)

OUTPUT CHARACTERISTICS

POSITIVE OUTPUT:
Voltage: +12.00 ± 0.1 Vdc
Maximum Current: 350 mA
Regulation – Line and Load: 0.2%
Ripple (rms): 0.02%
Temperature Coefficient: 0.006%/°F

NEGATIVE OUTPUT:
Voltage: – 12.00 ± 0.1 Vdc
Maximum Current: 450 mA
Regulation – Line and Load: 0.2%
Ripple (rms): 0.02%
Temperature Coefficient: 0.006%/°F

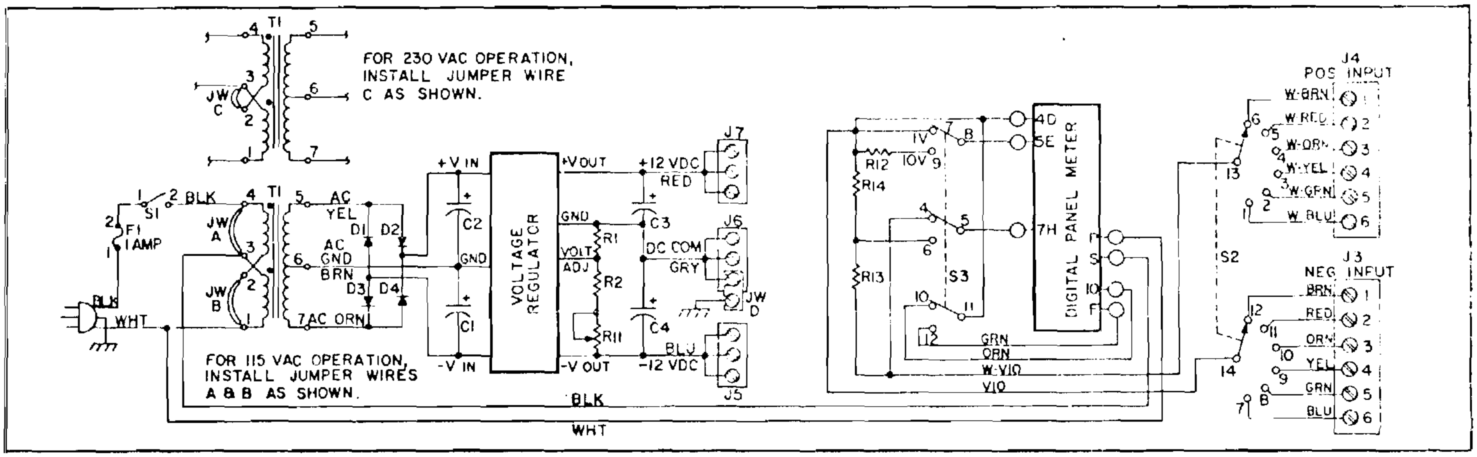
POSITIVE and NEGATIVE TRACKING:
Temperature Coefficient: 0.001/°F

DIGITAL VOLTMETER

ACCURACY:
0.05% of reading ± 1 count (1V)
0.10% of reading ± 1 count (10V)

RANGE:
± 1.999 (1V)
± 19.99 (10V)

TEMPERATURE COEFFICIENT:
0.004%/°F (1V)
0.007%/°F (10V)



ORDERING INFORMATION

SPECIFY MODEL NUMBER.
If 230 Vac is required, suffix A,
e.g. P-3100 A

DELIVERY OF STANDARD UNITS FROM STOCK.

KAMAN Measuring Systems
KAMAN SCIENCES CORPORATION

1P3172

Printed in the U.S.A.

INSTRUCTION MANUAL

MULTI-VIT

MODEL KD-2300-2S

The KAMAN Multi-Vit (Multi-purpose Variable Impedance Transducer) has been designed to provide exceptional accuracy for non-contacting measurement of conductive surface motion. The most significant feature of this new measuring system is its capability for highly linear calibration (typically within ± 0.5% F.S.) with almost any metal or alloy, whether flat or highly curved. Adjustment controls are provided such that the output voltage is readily calibrated to be directly proportional to displacement, as shown in Figure 1. Dynamic motion and vibration measurements are greatly facilitated by this linear transfer characteristic (constant sensitivity with position) and by the wide frequency response. The following procedures and recommendations are provided to help the user obtain optimum performance for his displacement measuring application.

GENERAL OPERATING PROCEDURE

The Model KD-2300-2S consists of a transducer with a 10 foot interconnecting cable, and oscillator-demodulator unit. The electronic circuitry has been optimized to provide maximum range and performance with the type 2S transducer with 10 foot cable, therefore:

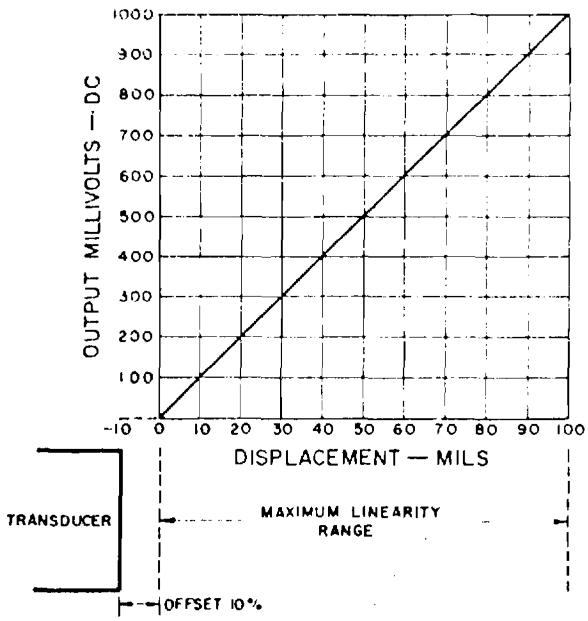


Figure 1

1. Transducer cable length should not be altered. (Special cable length systems may be ordered at additional cost).
2. Type 2S transducers are interchangeable with other 2S transducers of the same cable length (with calibration adjustment - see Calibration Procedure).

POWER CONNECTIONS

Input power requirements are: + and — 12 Vdc, (± 0.5 Vdc) at 70 mA. The Kaman Model P-3000 (for powering one to six units) or the Model P-3100 (including digital voltmeter with 6 channel selector switch) is recommended, although any 12 volt regulated dual supply is satisfactory. Connections to the Bendix PT06P-10-6S(SR) connector must be made in accordance with Figure 2.

PIN	FUNCTION
A	+ 12 Vdc (Positive supply input)
B	Ground (Supply input common)
C	- 12Vdc (Negative supply input)
D	+Output
E	- Output (common with ground)
F	No connection

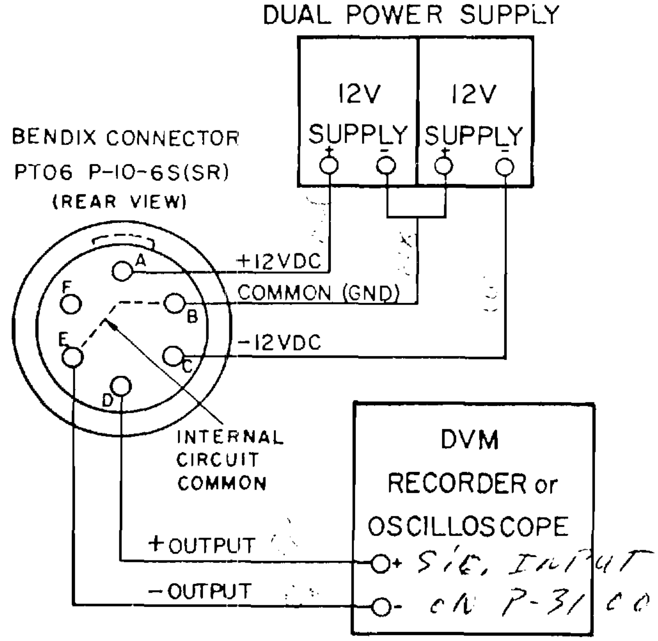


Figure 2

KAMAN Measuring Systems

Output connections to voltmeter, recorder or oscilloscope should be made as noted in Figure 2. Nominal output is 0 to + 1.000 Vdc or 0 to + 15mA (short circuit protected) from an output impedance of approximately 2 ohms. Increased Sensitivity and maximum output to 7 Vdc is available by means of internal modification. (see "Maximum Sensitivity").

CALIBRATION PROCEDURE

Calibration of the Model KD-2300-2S requires appropriate use of the following;

1. Target (sensed surface)
2. Micrometer fixture or non-conductive spacers (dimensional standard).
3. DC voltmeter (electrical standard).

Target:

The Multi-Vit transducer consists of a variable impedance bridge with an active and a reference coil. Variation in impedance results from the eddy currents induced in nearby conductive surfaces. Sensitivity is therefore dependent upon the material and shape of the target. When making calibration adjustments, it is recommended that a sample piece of the target to be measured (same material and shape) be used with a micrometer fixture or non-conductive gauging spacers.

Micrometer Fixture or Gauging Spacers:

The displacement dimensional standard used for calibrating the Multi-Vit must have equal or greater accuracy than will be required for subsequent measurements. A convenient dimensional standard consists of a micrometer head with a non-rotating spindle to which the sample target is attached. The transducer is then rigidly positioned at the appropriate distance from the sample target. (See illustration of a typical fixture, Figure 3).

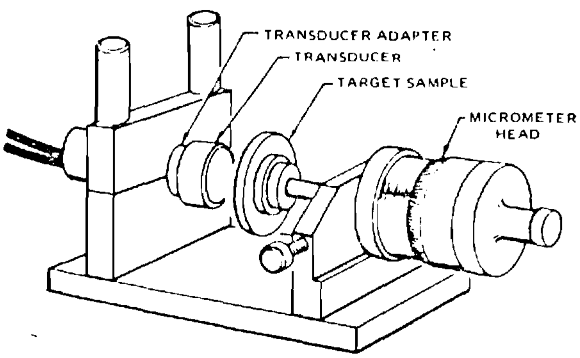


Figure 3

A simpler technique (with less accuracy) employs the use of plastic spacers between the sample target and transducer. Normally, a minimum of three calibrated spacers are required for Multi-Vit adjustment, namely;

1. 10 mil thick (to provide an offset gap between the face of the gage and the "zero" range point)*
2. 50 mil thick (added to the 10 mil offset for a total of 60 mils between the face of the gage and the 50 mil mid-range point).
3. 100 mil thick (added to the 10 mil offset for a total of 110 mils between the face of the gage and the 100 mil full range point).

A set of plastic spacers is supplied with the Multi-Vit for calibration to an accuracy of approximately ± 1 mil.

*NOTE: See "Calibration Steps" below for explanation of offset gap.

DC Voltmeter:

The electrical standard required for calibration and measurement with the Multi-Vit is a voltmeter with adequate range and resolution. A digital voltmeter with a range of at least 1.000 Vdc (1mV resolution) is recommended. The Multi-Vit unit as shipped from the factory has been internally adjusted to provide a nominal output of 1.000 Vdc equal to 100 mil displacement (10mV/mil sensitivity). Greater output up to a maximum of 7.000 Vdc (70mV/mil sensitivity) is possible by means of internal modification. **For this maximum output, a voltmeter with a range to 10.000 Vdc is recommended.

**NOTE: See "Maximum Sensitivity" instructions in this manual.

CALIBRATION STEPS

The 2S type transducer has been designed to provide a 0.010" offset plus an additional 0.1000" linear range (total of 0.110" range from gage face). This offset gap of 10 mils between the face of the gage and the start of the range (zero point) has been provided in order that "contact pressure" errors may be avoided and also to provide additional clearance to a moving target. With highly curved targets, better linearity may be obtained by eliminating the offset gap.

The various spacings of the sample target to the face of the transducer needed for calibration can be obtained by using plastic spacers (or other non-conductive spacers), or by using a micrometer spindle to move either the target or transducer.

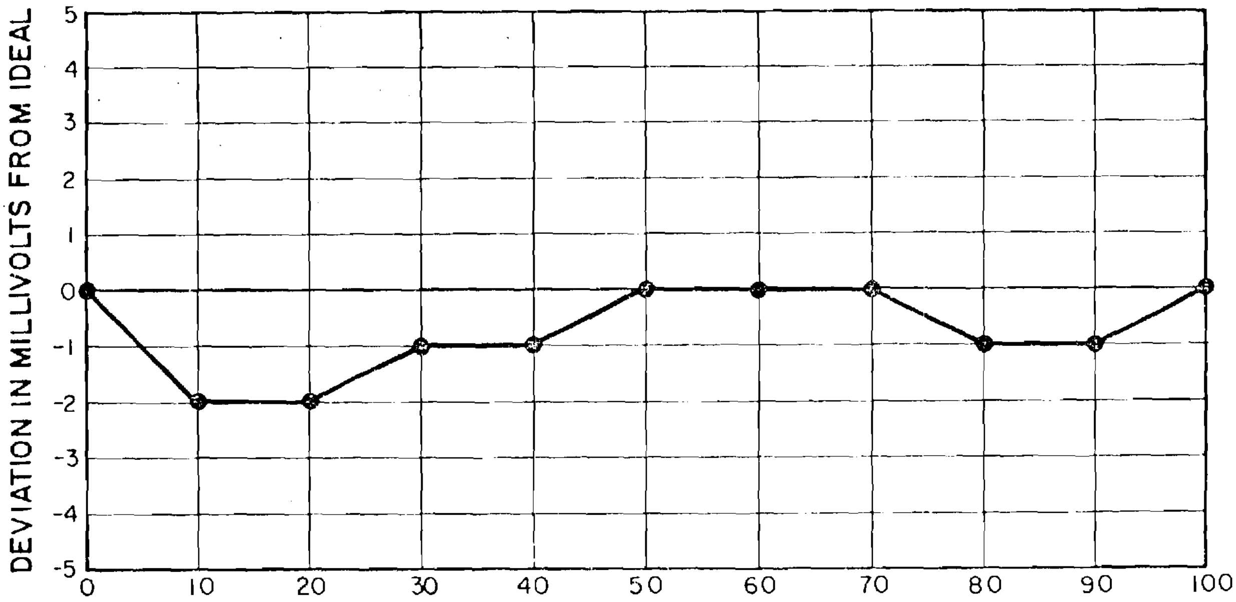
Step 1 With the target at "Zero" displacement (at the recommended 10% of full scale offset from the face of the transducer), adjust the zero control until the output reads zero volts. If zero volts output cannot be reached by adjusting the ZERO control, complete the adjustment using the COARSE LINEARITY control (until zero volts is within the range of the ZERO control).

TRANSDUCER TYPE—KD-2300-2S

CALIBRATION DATA

0	98	198	299	399	500	600	700	799	899	1000

MILLIVOLTS OUT



DISPLACEMENT—MILS

Figure 4

Step 2 Move the target away from the transducer to the displacement equal to half of the full range (plus offset). Adjust the GAIN control to obtain a half scale voltage reading at the output. If the half scale voltage cannot be obtained by adjusting the GAIN control, complete the adjustment using the COARSE LINEARITY control.

Step 3 Move the target to the full scale displacement point (plus offset) and adjust the COARSE LINEARITY control to full scale output reading. Use FINE LINEARITY control if better resolution is needed.

Step 4 Repeat steps 1 through 3 until best linearity is obtained.

NOTE: All clockwise rotation of adjustments cause the system output to go more positive. Each adjustment control has a total range of 15 turns but does not have positive stops at the ends of its adjustment range. The controls continue to turn at the ends of their ranges to eliminate the possibility of damage by forcing.

A typical calibration to a 3/8" diameter aluminum rod target is shown in Figure 4.

TRANSDUCER MOUNTING

The 2S type transducer is a "shielded coil" device. A threaded stainless steel housing and a ferrite cylinder surround the two coil bridge-arms within. The transducer therefore is shielded from metallic surroundings to the rear and to the sides of the threaded walls. The transducer thus can be easily mounted through a metal plate (15/32" diameter hole) by means of two instrument nuts provided, without changing calibration. A clearance counterbore is required, however, when mounting the transducer face flush with a metallic surface (see Figure 5) in order not to affect maximum range calibration. The transducer thread is a 15/32-32UNS-2A (the same thread that is used on electronic "Bat handle" switches). Additional instrument nuts are readily available at electronic supply houses.

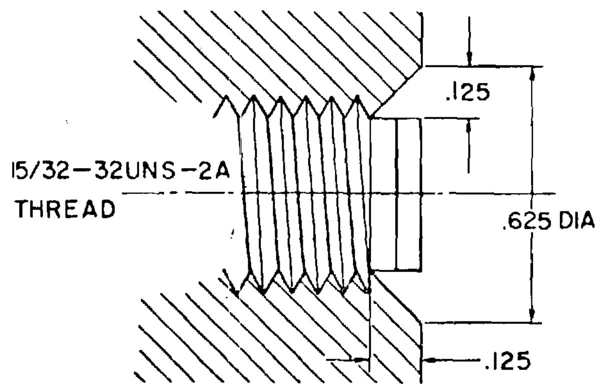


Figure 5

MAXIMUM SENSITIVITY

The Multi-Vit system as shipped from the factory has been roughly calibrated to provide a 1.000 Volt output at full range (10mV/mil sensitivity) with a flat aluminum target. At this sensitivity, output is readily adjusted to provide direct reading in engineering units for nearly all target shapes and conductive materials. If additional sensitivity is desired, (up to 70mV/mil and 7 volt maximum output), an internal jumper wire can be removed from the oscillator or demodulator in the following manner;

1. Remove cover by removing 8 cover screws.
2. Note jumper wire on printed circuit board (printed side) - remove by cutting wire free from board.

This will increase circuit gain by approximately 5 times. System frequency response will be reduced to approximately 10kHz (-3dB point).

MAXIMUM FREQUENCY RESPONSE

The Multi-Vit as shipped from the factory (with approximate sensitivity of 10mV/mil) will provide a wide frequency response and has been designed for optimum transient response. Characteristics are as follows:

Frequency Response — 0-20 kHz (-1dB point)
0-50 kHz (-3dB point)
Transient Response — 10 μsec rise time with no overshoot

Increasing the gain to maximum sensitivity (by internal jumper removal noted above) will reduce the frequency response to approximately 0 to 6 kHz (-1dB point), 0 to 10 kHz (-3dB point).

WARRANTY AND REPAIR

The Multi-Vit is warranted to be free from defects in material and workmanship for a period of one year from date of shipment. This warrantee is valid only if no modification (other than gain change) or repair is made to the oscillator-demodulator, cable or transducer. In the event of a malfunction, the unit should be returned prepaid with a description of the problem, to:

TRANSDUCER SERVICE DEPARTMENT
Kaman Sciences Corporation
1500 Garden of the Gods Road
Colorado Springs, Colorado 80907

In the event of transducer damage, replacement transducers (same range and cable length) may be ordered for operation with the oscillator-demodulator. Minor recalibration adjustments of the oscillator-demodulator controls will be required for operation with a replacement transducer.

GEORGIA INSTITUTE OF TECHNOLOGY
School of Mechanical Engineering
Atlanta, Georgia

FINAL REPORT

NO. 3 BEARING STUDY

G. E. SERVICE AGREEMENT
P. O. #087-ETBM-72359

by

Ward O. Winer
Professor
and
Principal Investigator

David M. Sanborn
Associate Professor

Scott Bair
Research Engineer

Sponsored by

General Electric Company
Large Gas Turbine Division
Schenectady, New York 12345

March, 1978

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NO. 3 BEARING STUDY

SUBMITTED TO

J. D. McHugh
Bearing & Sealing System Design
General Electric Company
Schenectady, New York 12345

SUBMITTED BY

Ward O. Winer
Professor
and
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David M. Sanborn
Associate Professor

Scott Bair
Research Engineer

Georgia Institute of Technology
School of Mechanical Engineering
Atlanta, Georgia

March, 1978

Ward O. Winer, Professor
School of Mechanical Engineering

GENERAL ELECTRIC NO. 3 BEARING OIL FLOW AND OIL LEAK TESTS

SUMMARY

Tests were conducted to determine the existence and severity of oil leaks at the housing joint and shaft seals of the No. 3 Bearing of a General Electric model MS 7000 large gas turbine, (See Figure 1). Leak tests were conducted at various sealing air pressures and with the housing joint shimmed open at various dimensions. Test conditions and results are presented in Table 1. In addition, one leak test was conducted in a hot (500F) environment. Temperatures measured during the hot leak test are shown in Table 2.

To reduce the oil pressure in the supply groove, which was a possible source of leakage at the housing joint, oil flowrate was measured as a function of supply pressure for the standard configuration and with oil nozzles enlarged from 0.250 to 0.375 inch diameter. Results are shown in Table 3 and Figure 2.

It was found that the Viton seal groove was a possible source of oil leakage into the housing joint and sealing the entrance to this passage at the drain cavity will reduce oil loss at the housing joint. Increasing the sealing air pressure did not reduce oil leaks through the seals but a reduction in drain cavity pressure was effective in reducing housing joint leaks. The final configuration does not produce an accumulation of liquid lubricant due to leaks in a hot environment (500F). It was found that the oil inlet pressure was reduced for a given flowrate by enlarging the liner oil feed holes.

FACILITY

The bearing test facility as used on previous No. 2 bearing studies for General Electric* was modified to accept the No. 3 bearing. The position of the bearing, a five tilting pad design, was reversed to conform to the rotational direction of the driving engine. To maintain a low ambient pressure in the test chamber and still have sufficient air supply pressure to feed the sealing air, the burner was backpressured with an orifice plate at the entrance to the test chamber.

Oil was supplied from the 600 gallon reservoir at 25 psig for the leak tests The lubricant in every test was a phosphate ester (tri aryl phosphate, Fyrquel 150 R&O) from Stauffer Chemical Company.

INSTRUMENTATION

Instrumentation consisted of 24 thermocouples, 9 pressure taps, 2 orifice plate flowmeters and an electrical engine tachometer. A listing of thermocouple locations is provided in Table 2 and G.E. Drawing 854E744. Pressure Tap locations are shown in Figure 1.

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*"Bearing and Seals Investigation of a No. 2 Bearing in Model MS 7000 Gas Turbine", General Electric Company, January 1973 (W. O. Winer, D. M. Sanborn and S. V. Shelton).

"Evaluation of Cooling Techniques for a No. 2, MS 7000 Gas Turbine Bearing", General Electric Company, February 1974 (W. O. Winer, D. M. Sanborn and S. V. Shelton).

"Bearings and Seals Investigation of No. 2 Bearing with Air Cooled Housing in Model MS 7000 Gas Turbine", The General Electric Company, Large Gas Turbine Division, July 1975, (W. O. Winer, D. M. Sanborn, S. V. Shelton, and S. Bair).

TEST PROCEDURE

Prior to an oil leak test the housing joint and shaft-seal interface were wiped dry with acetone. Sealing air pressure was adjusted by bleeding air from the supply line to reduce supply pressure. Three sealing air pressures were selected for each condition (including atmospheric pressure). When the oil inlet temperature reached 130F the temperature was maintained by cooling with a water fed heat exchanger. Total operating time was two hours. After the test the bearing was inspected for leaks.

Oil flow tests were conducted both at 3600 rpm shaft speed and at rest. Oil inlet pressure was selected with the flow regulating valve and oil flowrate measured with an oil over mercury manometer connected to an orifice plate in the oil supply pipe. Pressure tap tubing was purged of oil with shop air just before reading air pressures.

DISCUSSION

A. Oil Leak Tests

OL-1 through OL-3 were conducted on the bearing in the normal configuration. Leaks were seen at the housing joint and seals after each test. The housing joint also leaked air which appeared to carry oil out of the joint as the sealing air pressure was increased. Since the Viton seal (Figure 1) did not completely fill the sealing groove, it was thought that air and oil may have been carried from the drain cavity into the housing joint through the groove. High sealing air pressure tended to pressurize the drain cavity making this possible.

Tests OL-5 through OL-7 were conducted with the ends of the seal grooves plugged with silicone rubber at the entrance to the drain cavity. A reduction in leakage from both the housing joint and seals was noted.

Four shims of 0.010 inch thickness were installed in the joint (Figure 1) for tests OL-8 through OL-10 to simulate warpage of the housing that may occur in use. The next three tests incorporated 0.005 inch shims. Leakage increased as the joint was opened.

To this point all tests were made with a submerged drain. A high drain cavity pressure had been observed, which indicated that the submerged drain was backpressuring the drain. To more easily remove sealing air from the drain cavity a vent pipe was installed from the drain to the top of the oil reservoir for run OL-14 and all subsequent tests. Both the drain cavity pressure and the housing joint leakage were reduced. The pressure in the air space at the top of the drain pipe just upstream of the vent was measured in Run OL-17.

A hot (500F) environment was provided for test OL-19 to determine if thermal distortion of the housing might cause leakage. (Our heat exchanger was not capable of removing the additional heat transferred to the oil in this test and the inlet temperature rose to 160F). Immediately after the test, the chamber was opened to check for leaks. All surfaces were dry. Because of the possibility that leaking oil may have evaporated, another test was conducted. A steel plate was brought to a temperature of approximately 500F and a drop of Fyrquel

150 R&O placed on it. Blowing air over the oil drop caused it to disappear in less than one minute. Similar results were obtained with Shell Turbo 27. The high temperature evaporation of the test oil indicates not only that leakage cannot be detected in a hot test but that leakage levels in a hot environment are not sufficient in this configuration to produce an accumulation of liquid oil.

B. Oil Flowrate Tests

FR1 through FR14 were conducted with 0.250 inch diameter oil feed holes at various inlet pressures. No difference in flowrate was seen for tests at no shaft rotation and those at 3600 rpm. To reduce the oil feed groove pressure and thereby reduce the possibility of oil leaking into the housing joint from the feed groove, the oil feed holes were enlarged to 0.375 inch diameter. An additional pressure tap was installed in the pad region of the bearing liner (Figure 1). For a given flowrate, inlet pressure was substantially reduced. Pad region pressure was low, compared to inlet pressure, indicating that there is little restriction in the oil drain from the liner. Results of the flowrate tests are in Table 3 and Figure 2.

CONCLUSIONS

It was found that the viton seal groove was a possible source of oil leakage into the housing joint and sealing the entrance to this passage at the drain cavity will reduce oil loss at the housing joint. Increasing the sealing air pressure did not reduce oil leaks through the seals but a reduction in drain cavity pressure was effective in reducing housing joint leaks. The final configuration does not produce an accumulation of liquid lubricant due to leaks in a hot environment (500F). It was found that the oil inlet pressure was reduced for a given flowrate by enlarging the liner oil feed holes.

APPENDIX

In order to predict the supply pressure required to produce a needed lubricant flowrate, the individual components of the total system pressure drop were calculated. These were assumed to be:

A. The hydrostatic pressure at the supply pressure gauge.

B. Frictional losses in the two inch supply pipe which was about 14 feet long with two 90° elbows.

C. Frictional losses inthe 1-1/4 inch feed pipe which was about six feet long with two 90° elbows.

D. Frictional losses in the four inch x 1/4 inch feed channel surrounding the liner.

E. The orifice pressure drop arising at the five 1/4 inch diameter x 1 1/2 inch long feed holes.

F. Frictional losses in the feed holes.

The results are presented in Figure A-1 along with measured data. All frictional losses were calculated using friction factors for a smooth pipe. For each elbow an additional length of 25 pipe diameters was added. The discharge coefficient for the five long (L/D = 6) orifices was taken to be 0.77*. Pressure drops predicted in this way agree well with our measurements.

*Lichtarowicz, A., Duggins, R. K. and Markland, E., "Discharge Coefficients for Incompressible Non-Cavitating Flow through Long Orifices", Journal of Mechanical Engineering Science, 7, No. 2, 1965.

Table 1. Oil Leak Tests

3600 RPM, 25 PSIG OIL INLET

RUN	OIL INLET TEMP	OIL FLOW RATE	SEALING AIR TEMP	SEALING AIR FLOW	SEALING AIR PRESS	CHAMBER TEMP	P_2	P_3	P_4	P_5	P_6	OIL RESERVOIR	DRAIN PIPE	CHAMBER PRESS	LEAKAGE* HOUSING JOINT	LEAKAGE* SEAL	COMMENTS
	°F	GPM	°F	LBM/SEC	PSIG	°F	IN.HG	IN.HG	IN.HG	IN.HG	IN.HG	IN.HG	IN.HG	IN.HG			
OL-1	130	27.5	98	0	0	ROOM	0.05	0.05	0.05	0.30	0.05	-	-	0	L	H	AS RECEIVED
OL-2	127	25.0	101	0.65	3.8	ROOM	8.6	2.2	2.2	7.1	0.1	-	-	0	H	L	
OL-3	133	26.0	108	0.34	1.4	ROOM	3.3	1.5	1.5	2.5	0.05	-	-	0	L	H	
OL-5	125	27.0	100	0.45	2.6	ROOM	5.7	2.0	2.1	4.8	0.1	-	-	0	D	M	VITON GROOVE PLUGGED
OL-6	134	27.0	100	0.25	0.8	ROOM	1.8	1.1	1.1	1.6	0.1	-	-	0	D	M	
OL-7	137	26.0	100	0	0	ROOM	0	0	0	0	0	-	-	0	D	D	
OL-8	132	26.5	100	0	0	ROOM	0	0	0	0	0	-	-	0	L	D	0.010 INCH SHIM
OL-9	124	26.5	103	0.25	0.9	ROOM	1.9	1.2	1.2	1.7	0.05	-	-	0	M	H	
OL-10	114	24.5	100	0.67	4.0	ROOM	9.0	2.6	2.7	7.2	0.15	-	-	0	M	H	
OL-11	122	28.0	100	0	0	ROOM	0.05	0.05	0.05	0.05	0.05	-	-	0	D	D	0.005 INCH SHIM
OL-12	123	27.0	92	0.36	1.4	ROOM	3.3	1.5	1.5	2.5	0.05	-	-	0	L	L	
OL-13	114	28.0	100	0.59	3.0	ROOM	6.7	2.1	2.1	5.5	0.1	-	-	0	M	M	
OL-14	116	23.0	85	0.3	1.1	ROOM	2.4	0.5	0.5	1.9	0.05	-	-	0	D	M	DRAIN VENTED
OL-15	116	23.0	90	0.63	3.5	ROOM	7.4	1.3	1.3	6.8	1.1	-	-	0	L	M	
OL-16	126	25.0	95	0.65	3.0	ROOM	6.7	1.3	1.2	5.4	1.0	0.15	-	0	L	L	0.010 SHIM
OL-17	122	-	85	0.40	1.4	ROOM	3.2	0.7	0.7	2.4	-	0.10	0.7	0	L	L	
OL-19	160	36.0	ROOM	0.58	2.6	500	6.1	1.5	1.5	4.5	-	0.10	-	0.37	D	D	HOT ENVIRONMENT

*D - DRY   M - MEDIUM LEAK
L - LIGHT LEAK   H - HEAVY LEAK

TABLE 2. TEMPERATURES

RUN OL-19

RECORDER BANK POINT	G.E. PRINT NUMBER	LOCATION	TEMP ^{o}F
8-2	TT-B3 MDF-1	cap meta fwd drain area	270
4	TT-B3 MAF	352 seal area fwd metal	280-320
5	TT-B3 MDA-2	hsg bottom aft face drain metal	220
6	TT-B3 MS5	351 seal area fwd top outer metal	450
7	TT-B3 MAA	353 seal area aft top metal	280
9	TT-B3 MDA-1	aft drain top metal	260
10	TT-B3 MH-2	joint rhs aft metal	250
12	TT-B3 MH-3	joint lhs fwd metal	210
9-1	TT-B3 MS-4	352 seal area fwd top outer metal	380
2	LT-B3 DA-1	top aft drain cavity fluid	210
5	LT-B3 DF-1	top fwd drain cavity fluid	190
6	TT-B3 MS-3	top fwd drain area outer metal	320
7	LT-B3 AA	air supply 353 seal aft	230
11	LT-B3 AF	air supply 352 seal fwd	310
10-2	LT-B3 DA-2	aft drain cavity fluid	170
3	LT-B3 DF-2	fwd drain cavity fluid	180-220
4		front roller bearing	220
5	TT-B3 MS-1	353 seal area aft top outer metal	270
8	TT-B3 MS-2	top aft drain area outer metal	410
9		tank air	490
11		rear roller bearing	210
11-1		tank air vent	480
2		oil drain pipe	170
4		oil feed pipe	160

Table 3. Number 3 Bearing Oil Flow

COLD TEST

17 June 1977 — 5 x 0.250" FEED HOLES

RUN	RPM	FEED PIPE PRESS(PSIG)	OIL FLOWRATE (IN.HG.)	OIL FLOWRATE (GPM)	OIL INLET (°F) (11-4)	OIL DRAIN (°F) (11-2)	P_4 IN.HG.
FR-1	3600	46	5.7	39.5	116	123	DNR
FR-2	3600	45	5.7	39.5	129	137	0.15
FR-3	3600	28	3.0	28.5	128	140	0.15
FR-4	3600	15	1.4	20	131	143	0.15
FR-5	3600	5	0.8	16	132	151	0.15
FR-6	3600	50	Manometer Overranged				
FR-7	3600	51	6.1	41	132	140	0.05
FR-8	3600	39	5.1	37	133	142	0.05
FR-9	3600	21	2.6	26.5	132	145	0.05
FR-10	0	75	9.0	49.5	126	126	0.15
FR-11	0	56	6.9	43.5	126	126	0.15
FR-12	0	25	3.3	30	126	126	0.15
FR-13	0	11	1.4	20	126	126	0.15
FR-14	3600	77	9.4	50.5	128	135	0.20

26 January 1978 — 5 x 0.375" FEED HOLES

RUN	RPM	FEED PIPE PRESS(PSIG)	OIL FLOWRATE (IN.HG.)	OIL FLOWRATE (GPM)	OIL INLET (°F) (11-4)	OIL DRAIN (°F)(11-2)	LINER VOLUME PRESS IN.HG.
FR-21	3600	44	19.2	72	120	123	4.1
FR-22	3600	32	13.1	59.5	122	124	4.3
FR-23	3600	20	7.6	45.5	125	128	2.5
FR-24	3600	10	2.8	27.8	126	131	1.8
FR-25	3600	5	0.4	12	126	135	0.03

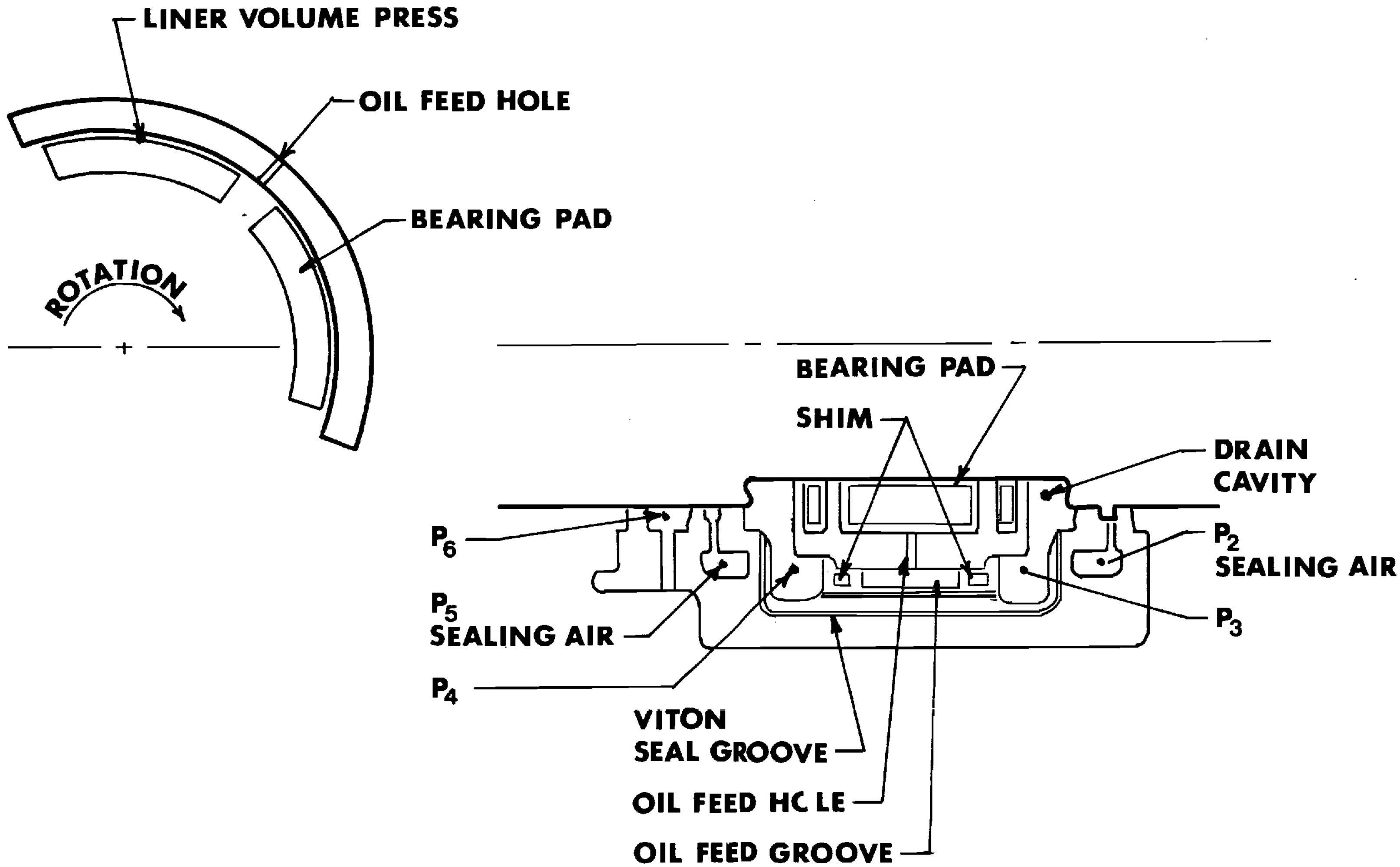

Figure 1a. MS 7000 No. 3 Bearing

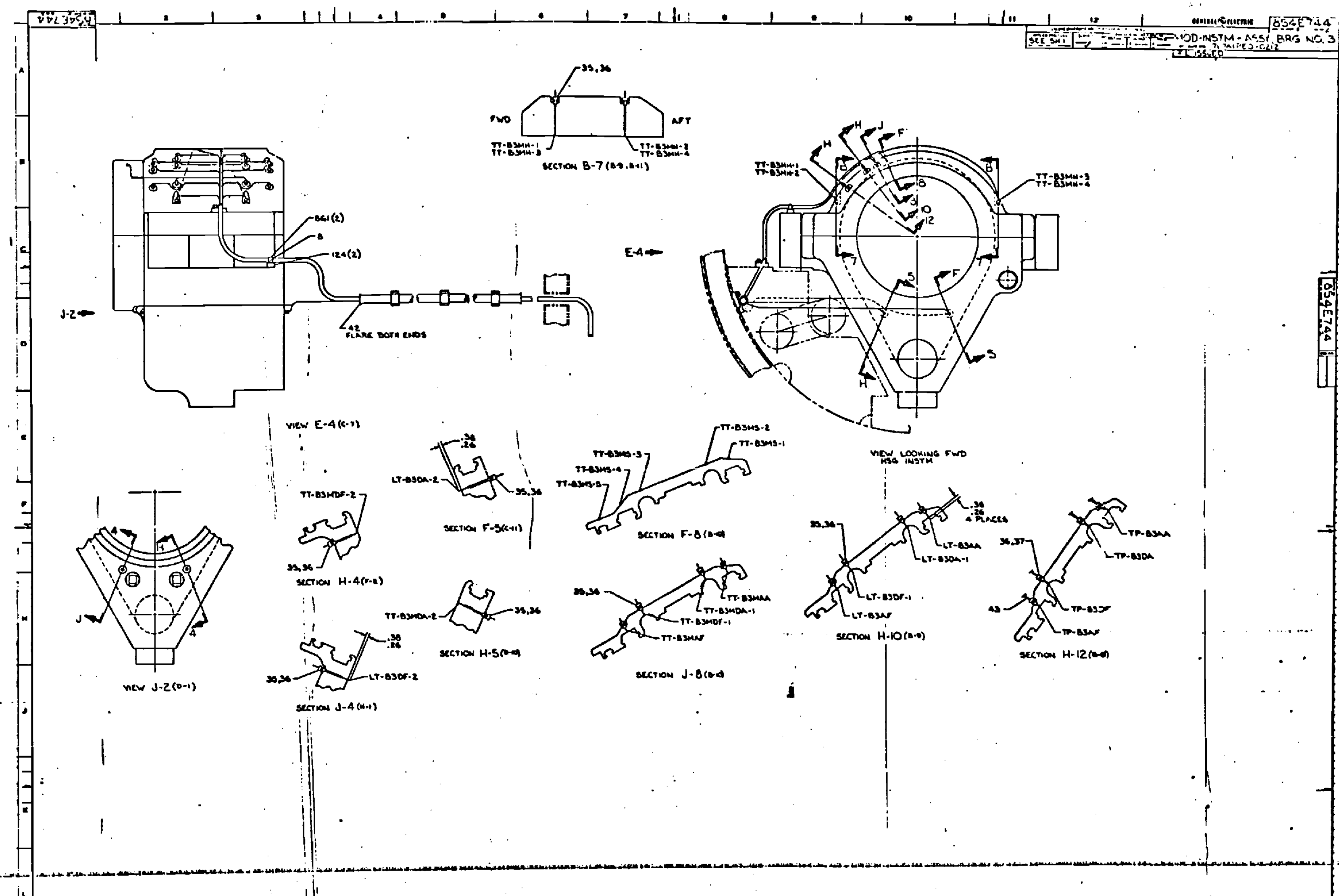

Figure 1b. Housing Instrumentation

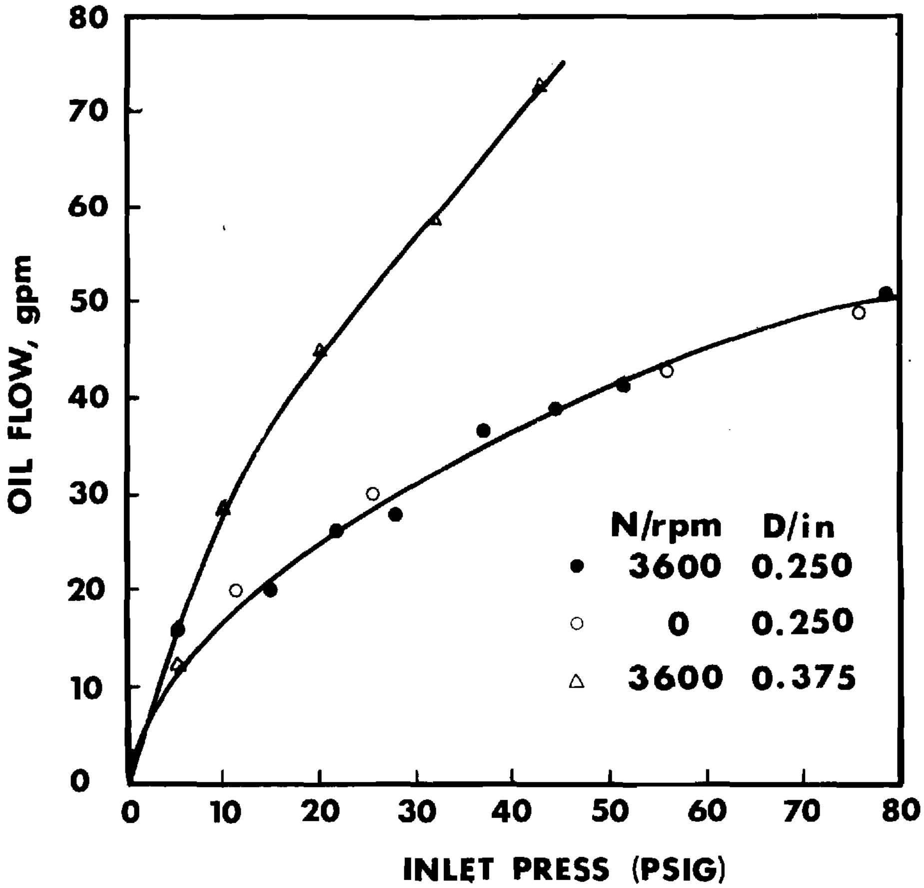

Figure 2. No. 3 Bearing Oil Flow

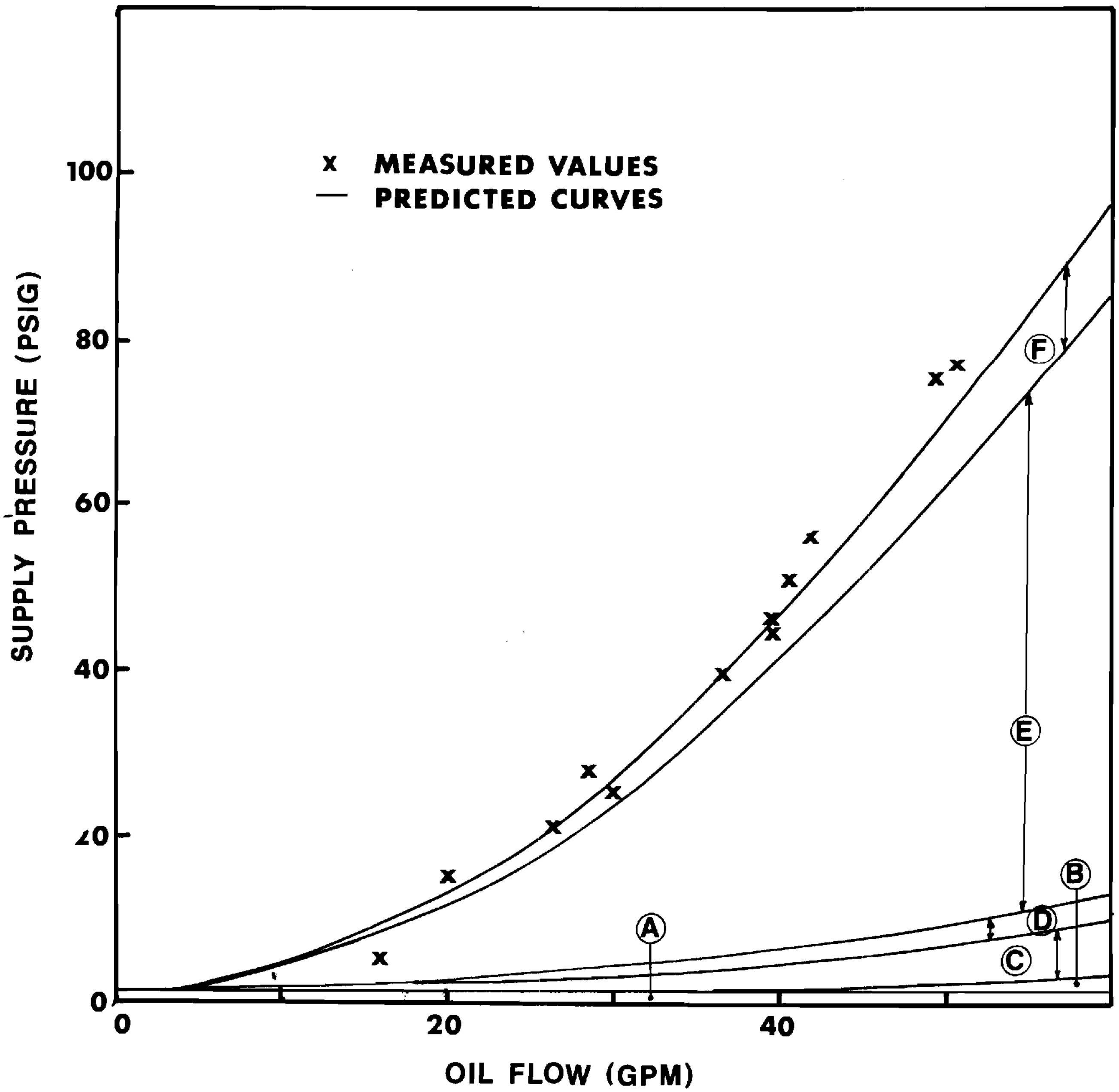

Figure A-1. Experimental and Predicted Oil Supply Pressure versus Oil Flowrate.