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LOFT TECHNICAL REPORT LTR 141-54

MARCH 1977

DEVELOPMENT OF AN EDDY CURRENT DISPLACEMENT TRANSDUCER FOR THE LOFT DRAG DISK

M. E. Yancey, R. W. Shuftliff

EG&G Idaho, Inc.

ENERGY SAFETY ENVIRONMENT

IDAHO NATIONAL ENGINEERING LABORATORY

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LOFT PROGRAM

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ABSTRACT

An eddy current displacement transducer has been developed as part of a program to improve the design and performance of the LOFT drag-disk turbine transducer.

Tests indicate that the eddy current displacement transducer will operate satisfactorily in the LOFT environment. The transducer has a total displacement range of 0.140 inch.

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SUMMARY

An eddy current transducer was developed for monitoring the displacement of the LOFT drag disk operating under LOFT environmental conditions.

In the development of the displacement transducer a computer program developed by Oak Ridge National Laboratory was used to evaluate the proposed transducer's sensitivity to displacement as a function of frequency, temperature and the diaphragm thickness. The results of this study indicated that a useful transducer could be obtained using a 100 KHz signal frequency and a 0.040 inch diaphragm thickness. The results of the computer program were verified by actual laboratory test.

A prototype transducer was fabricated and evaluated under LOFT temperature and pressure conditions. The transducer had an outside diameter 0.625 inch, with an overall length of 1.3 inches. Associated with the transducer are two targets, one a fixed reference target and the other a movable sense target. The transducer has a useful range of approximately 0.140 inch.

A 100 KHz phase sensitive electronic system was used with the transducer in the evaluation program. The following tests were conducted with the system results indicated:

1. Temperature tests over the range from 302^{o}F to 649^{o}F yield an output change equivalent to 0.004 inch maximum.
2. A 24 hour drift test on the electronics resulted in a maximum change in the output equivalent to 0.0015 inch.
3. Autoclave pressure and temperature tests yielded an output change corresponding to less than 0.004 inch.
4. Thermal Shock Test yielded a maximum change in output corresponding to less than 0.001 inch.

In summary, the system error resulting from changes in temperature, pressure, and drift corresponded to a maximum change in displacement of 0.0045 inch over a range from 0.030 inch to 0.110 inch. This change in the output corresponds to an error of ± 5.65% for a total range of ± 0.040 inch. The materials used in the fabrication were selected for their ability to withstand the LOFT environmental conditions as defined in S.D.D. 1.4.1.[1] The LOFT radiation environment was considered in the design and selection of the materials used in the fabrication. Radiation tests will be performed on the ceramic material prior to qualification for LOFT use. The test results indicate that the transducer should operate satisfactorily in the LOFT environment.

1.0 INTRODUCTION

The drag disk eddy current transducer was designed for use in monitoring the drag disk displacement. An eddy current displacement measuring system is comprised of a transducer and associated electronics. The transducer consists of two matched coils which form two arms of an impedance bridge. The coil impedance is a function of the displacement between the coil and a target, as well as the conductivity and permeability of the metal sensed by the coil. When measuring displacement, the variation in coil impedance which results from changes in conductivity and permeability produce undesirable results. By using two matched coils in an impedance bridge, the changes in environment which are common to both coils will be nulled out. The associated electronics consists of a 100kHz impedance bridge and a phase sensitive demodulator for optimizing the systems sensitivity to displacement.

2.0 TRANSDUCERS DEVELOPMENT

In developing the drag disk displacement transducer, an initial computer study was made using computer programs developed by Oak Ridge National Laboratory(2) to determine the effects of frequency, material conductivity which is a function of temperature and the diaphram thickness on the transducer performance. A prototype of the transducer was then fabricated and evaluated.

2.1 Requirements

The following design requirements were specified for the drag disk eddy current displacement transducer.(3)

Temperature - The transducer should be operable over a temperature from room temperature to 650°F. The transducer should be designed to minimize temperature effects over a range of 300 to 650°F, since 98% of all data will be taken in this range during a LOFT LOCE.

Pressure - LOFT maximum operating pressure: 2500 psig
Maximum cold hydrostatic: 3150 psig

Radiation - Total neutron flux = 7.2×10^{18} nvt
Total gamma flux = 2×10^{10} R

Water Chemistry - The LOFT primary coolant system chemistry specifications are shown in Appendix A.

Response Time - 10 milliseconds

Displacement Range - ±0.040 inch

Accumulative Accuracy - ±5% of range (±0.002 inch)

2.2 Transducer Modeling

The transducer's performance was modeled using the computer program (3 CONDT), which calculates the normalized coil impedance as a function of diaphragm thickness and conductivity and coil operating frequency. Figure 1 shows a sketch of the configuration and identifies the parameters considered in the computer program. The following fixed parameters were used:

l_1 = 0.002 inch

l_2 = 0.120 inch

r_2 = 0.050 inch

r_2 = 0.190 inch

$\mu_1 = \mu_2 = \mu_3 = 1$

$\sigma_2 = 0$

The resistivity of both the target and diaphragm were varied to simulate a temperature variation for 75° to 800°F. Computer data was obtained for a resistivity variation of 72 to 122 $\mu\Omega$ cm, and a displacement between the diaphragm and target ranging from 0.010 inch to 0.110 inch. The following diaphragm thickness and frequencies were considered.

C_1 = 0.040 inch and 0.060 inch

f = 50 kHz and 100 kHz

The results of the computer program have been plotted in Figures 2 and 3. These plots show the real and imaginary components of the coil impedance. The solid lines are a plot of $\omega\mu\sigma\ \bar{r}^2$, where:

ω = angular frequency

μ = permeability

σ = conductivity

$\bar{r}^2$ = square of the mean radius of the coil

The dashed lines represent changes in the displacement between the diaphragm and target, i.e. transducer liftoff. Areas corresponding to changes in both stainless steel and Inconel 625 have been marked on the impedance plot.

It can be seen by comparing the plots of Figures 2 and 3 that a 0.040 inch diaphragm provides greater sensitivity to transducer lift-off than the 0.060 inch diaphram.

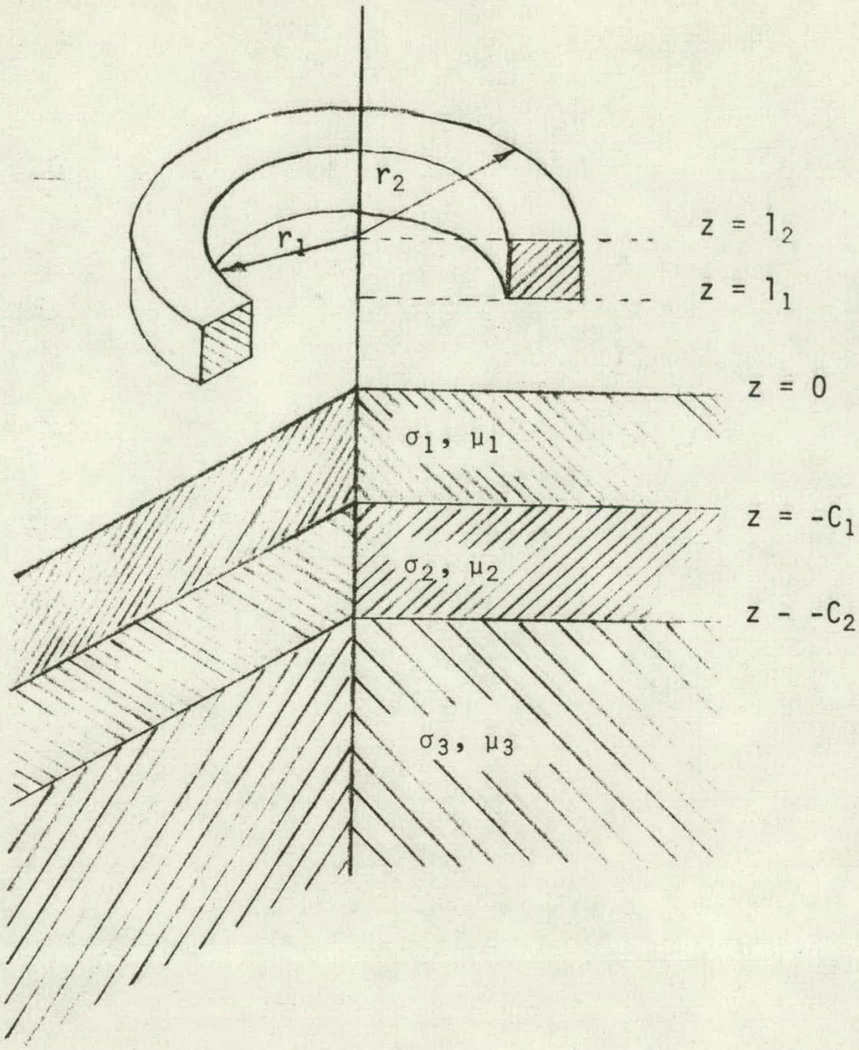


FIGURE 1: Coil, Diaphragm and Target Configuration Used in the Computer Program

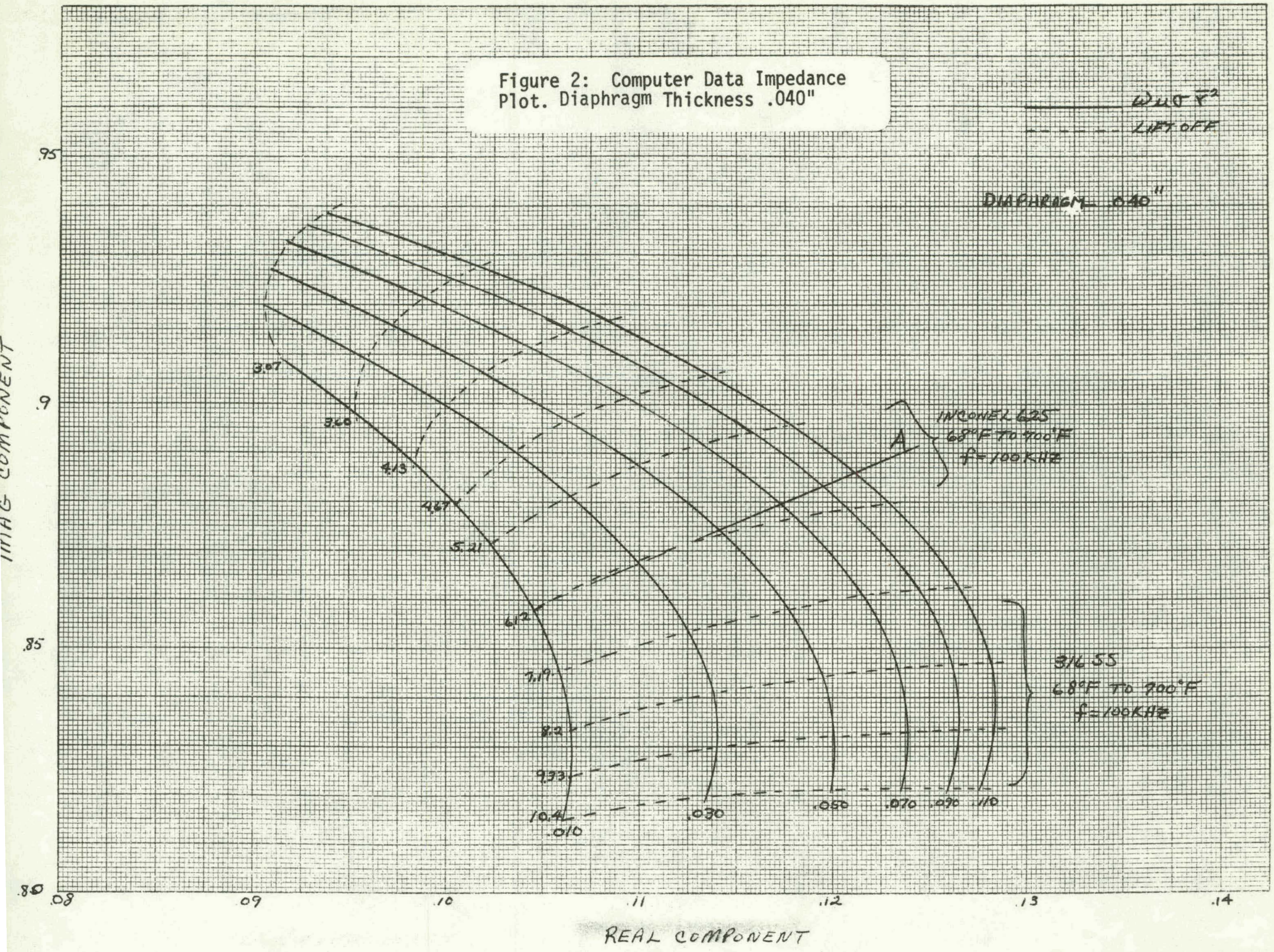


Figure 2: Computer Data Impedance Plot. Diaphragm Thickness .040"

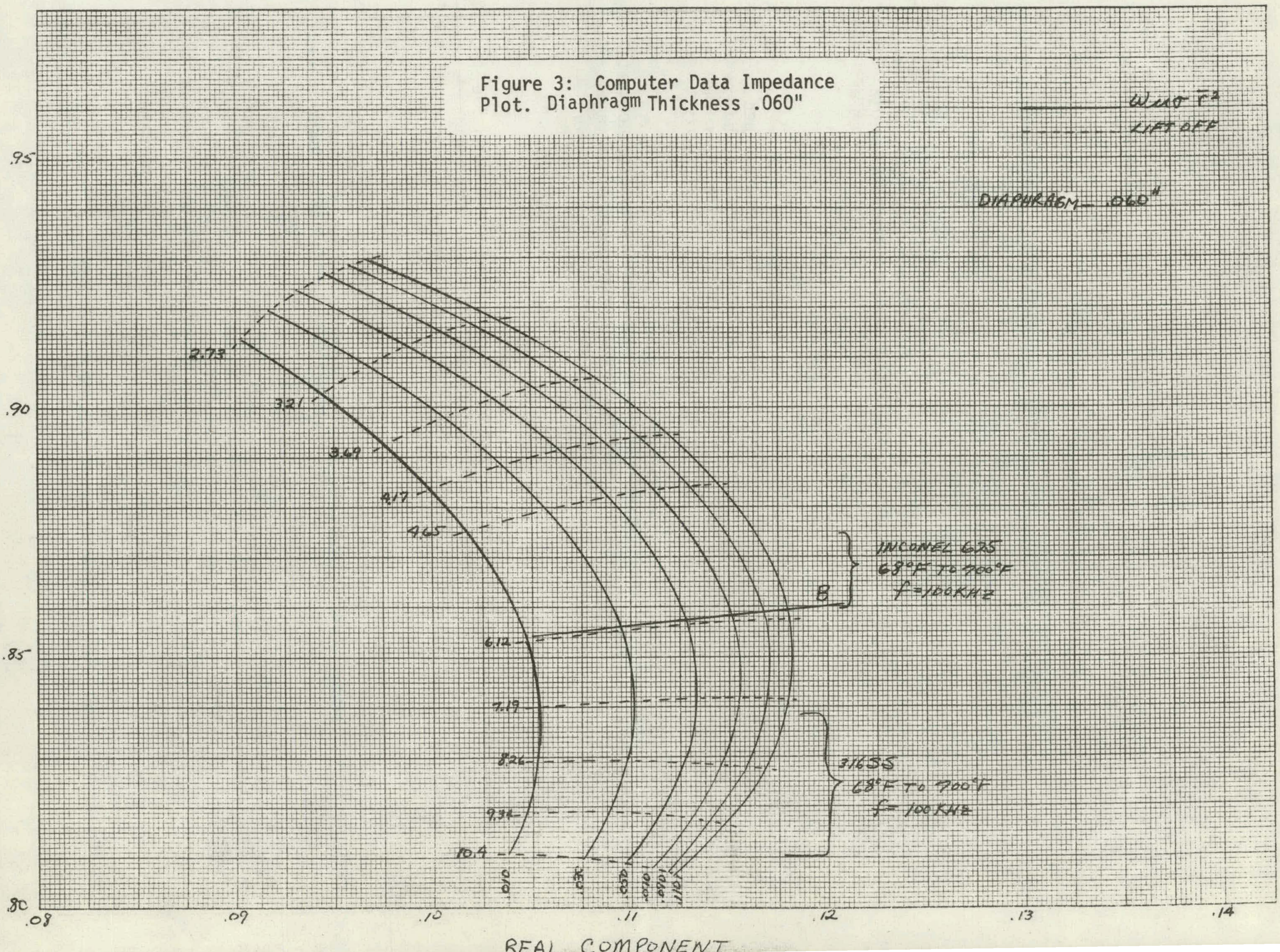


Figure 3: Computer Data Impedance Plot. Diaphragm Thickness .060"

2.3 Transducer Design

A series of scoping tests were conducted based on the data available from the computer program. Two coils were prepared with the following approximate dimensions:

r_1 = 0.050 inch

r_2 = 0.190 inch

l_1 = 0.002 inch

l_2 = 0.150 inch

The coils each had a 144 turns of 0.010 inch diameter Secon Alloy 406 wire. The wire with ceramic insulation had a diameter of 0.012 inch. The coil inductance was approximately 70 μ henries. A set of 0.040 inch and 0.060 inch Inconel 625 diaphragms and 0.125 inch targets were prepared with a diameter of 0.600 inch.

Using a set of existing 100 kHz eddy current electronics with the above coils, diaphragms and targets, two sets of data were obtained for each of the diaphragms. The first set of data was obtained by varying the displacement between diaphragm and target while recording the RMS amplitude and phase of the bridge voltage.

This data was then plotted on polar coordinate paper and a phase angle setting, which optimizes the system's sensitivity to displacement, was determined for the phase sensitive demodulator. A plot of this data is shown in Figure 4. The optimum phase setting for the 0.040 inch diaphragm configuration as shown by line A of Figure 4 was determined to be 80 degrees while a phase setting of 95 degrees (line B) was optimum for the 0.060 inch configuration.

The second set of data was obtained by adjusting the phase sensitive demodulator to the optimum phase setting and then recording the dc output from the electronics while varying the displacement. Figure 5 shows a plot of this data for both the 0.040 inch and 0.060 inch diaphragm configuration.

In order to determine the degree of correlation between the scoping test and the computer data, an axis representing the optimum phase angle necessary to obtain displacement data was determined. These axis are identified in Figure 2 and 3 as A and B respectively. The impedance changes which occurred along these axis were determined. These impedance changes were scaled such that the maximum impedance change corresponded with voltage output measured as the target was moved from 0.010 inch to 0.110 inch. These scaled values are shown on the plots of Figure 5. From Figure 5 it can be seen that there is good agreement between the actual data and the computer data. Another point of agreement is noted in the phase angle which occurs between axis A and B of Figure 2 and 3. This angle if approximately the same as the difference in the phase angle between A and B shown in Figure 4.

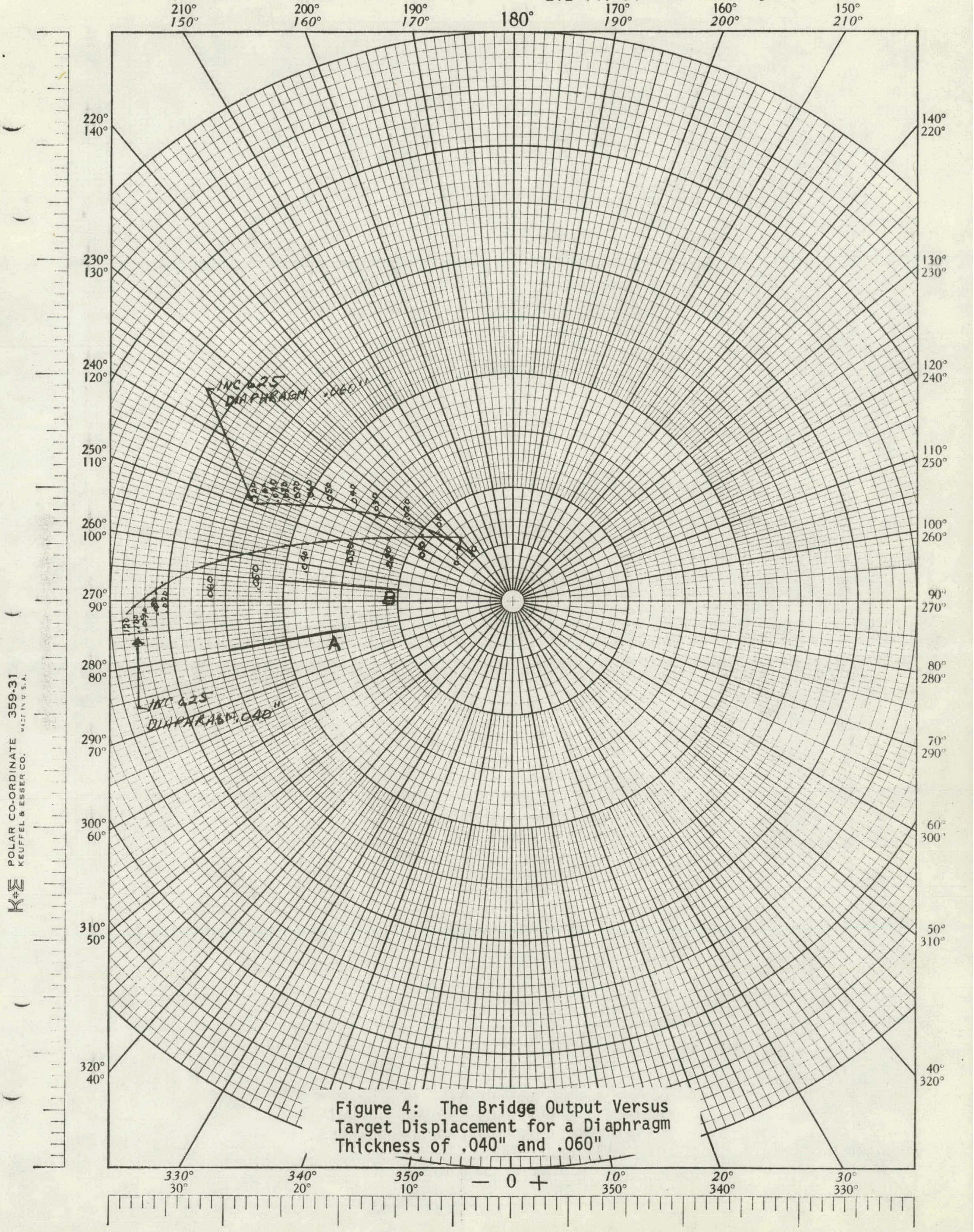


Figure 4: The Bridge Output Versus Target Displacement for a Diaphragm Thickness of .040" and .060"

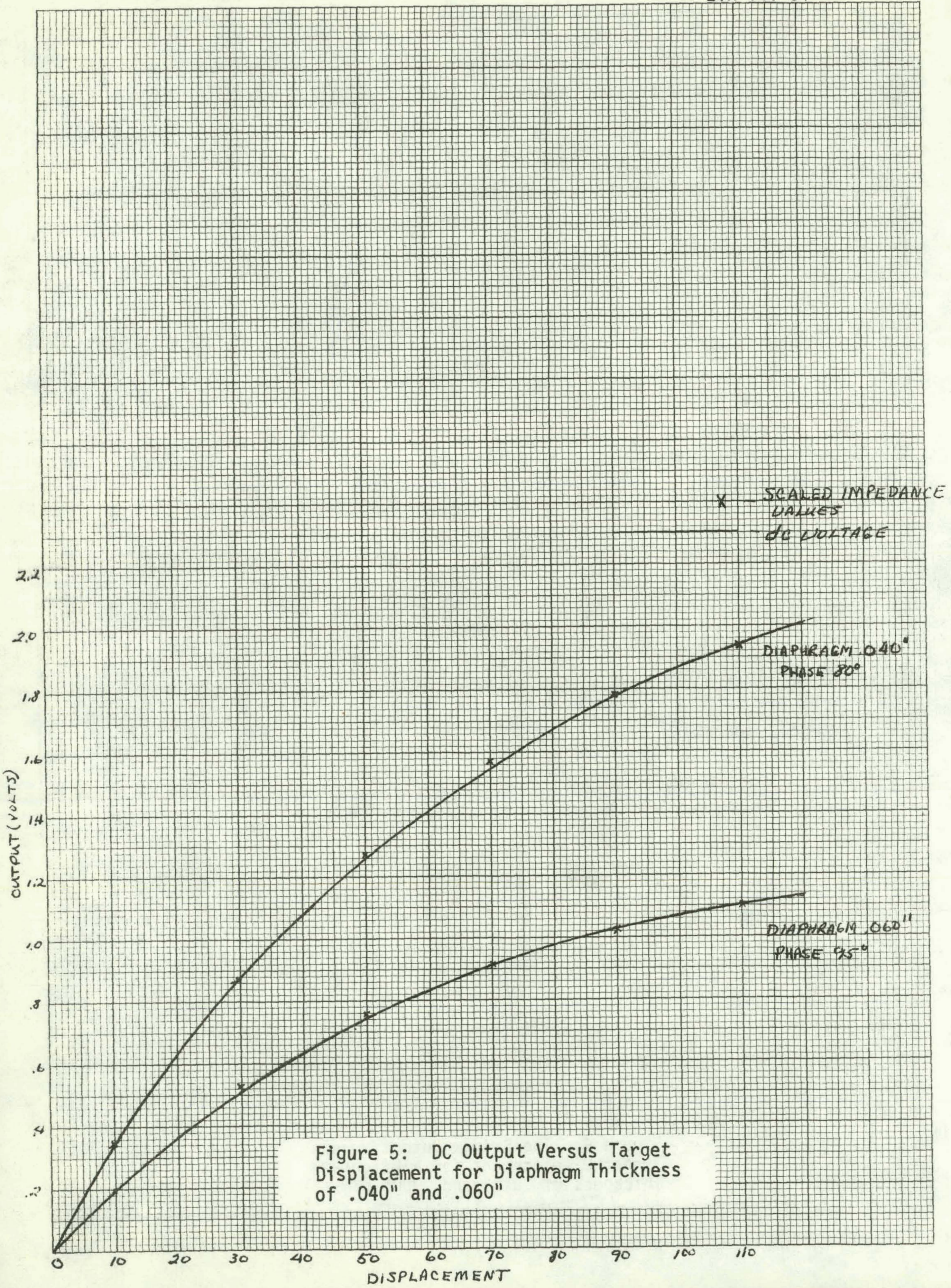


Figure 5: DC Output Versus Target Displacement for Diaphragm Thickness of .040" and .060"

In order to facilitate the fabrication of a transducer and reduce the deflection of the diaphragm under pressure, a diaphragm with a center post was considered. A 0.040 inch thick diaphragm with a 0.060 inch center post was prepared. The diameter of the center post was increased by flame spraying a 0.020 inch layer of ceramic on the center post. The flame sprayed surface provided an insulated form for the coil. The insulated center post also reduces the eddy current losses by reducing the amount of metal in close contact with the coil windings. An evaluation of this configuration indicated that sensitivities equal to or better than that of the diaphragm with no center post could be obtained. Based on these above tests, a transducer was fabricated per the drawing shown in Figure 6 to operate at 100 kHz.

The maximum deflection of a 0.5 inch diameter Inconel 625 diaphragm with a thickness of 0.040 inch was determined assuming the diaphragm's edges were fixed with a uniform load of 2250 psi over the entire surface. A maximum deflection of 0.00077 inch was calculated. It is expected that this deflection would be reduced somewhat by the addition of a center post.

In selecting the items to be used in the fabrication of the transducer, the high temperature and radiation environment were of prime importance. Therefore, only inorganic materials were used. Inconel Alloy 625 was selected for the prototype transducer design because of its high strength, high temperature properties, good oxidation resistance, nonmagnetic properties and excellent weldability. Figure 7A, B, C and D shows the transducer at various stages of assembly. In Figure 7A the following items are identified:

A - 0.001 inch Phlogopite Mica

B - Flame Spray Metco # 105

C - Secon Alloy 406 0.010 inch Diameter Wire/Type E Insulation

D - A fixture used in winding coils

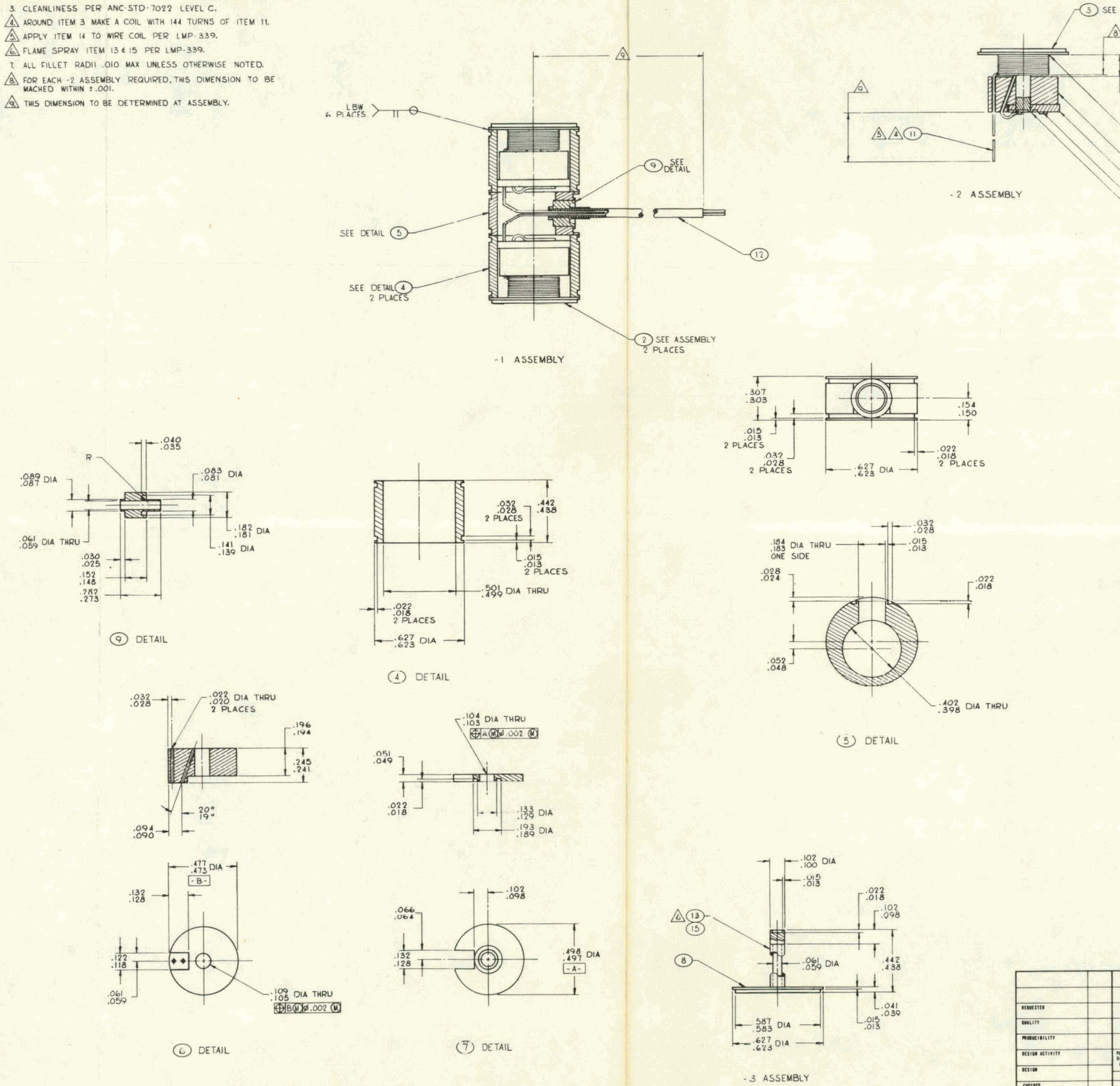
The phlogopite mica can be used at temperatures up to 1550^{o}F. The Type E high temperature ceramic insulation is a high purity Al_2O_3 rated for continuous operation at 1600^{o}F. The Metco #105 is an Aluminum Oxide powder rated for temperatures up to 3000^{o}F.

In Figure 7B the letter A denotes joints which were laser welded in the assembly process.

The letter B identifies ceramic bonding cement used to encapsulate the coil windings. The ceramic bonding cement used was Dylon Grade C7, which has a Al_2O_3 base and useful at temperatures to 3000^{o}F. This ceramic cement produces a strong, 100% ceramic bond with high mechanical strength and dielectric properties at elevated temperatures. Figure 7C shows the transducer assembly nearing completion where A denotes areas of additional ceramic bonding cement and B denotes laser welded joints. In future transducer fabrications, the laser

NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES.
2. SURFACE ROUGHNESS 63√ UNLESS OTHERWISE NOTED.
3. CLEANLINESS PER ANC-STD-7022 LEVEL C.
4. △ AROUND ITEM 3 MAKE A COIL WITH 144 TURNS OF ITEM 11.
5. △ APPLY ITEM 14 TO WIRE COIL PER LMP-339.
6. △ FLAME SPRAY ITEM 13 & 15 PER LMP-339.
7. ALL FILLET RADII .010 MAX UNLESS OTHERWISE NOTED.
8. △ FOR EACH -2 ASSEMBLY REQUIRED, THIS DIMENSION TO BE MACHED WITHIN ±.001.
9. △ THIS DIMENSION TO BE DETERMINED AT ASSEMBLY.



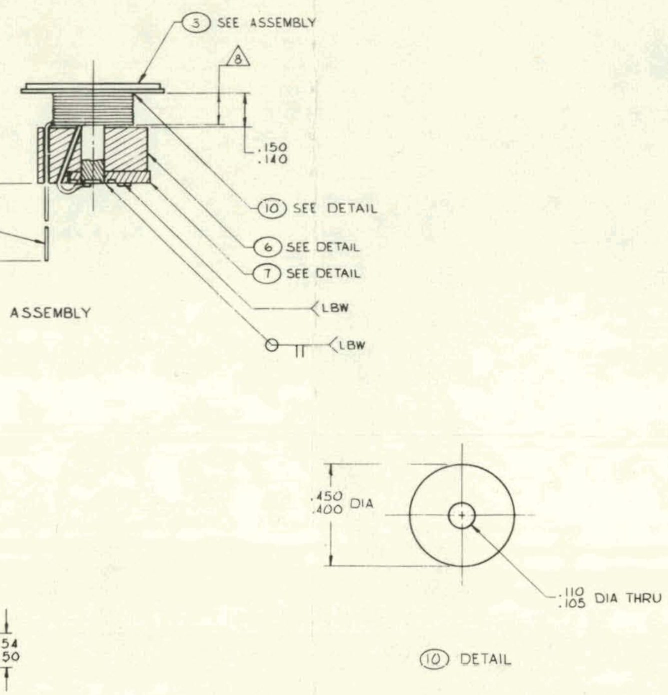


Fig. 6

-3	-2	-1	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL/SPECIFICATION	QL	ITEM NO
AR			43C	NICKEL-CHROME ALLOY	METCO INC. LONG ISLAND, NY	II	15
	AR		C7	CERAMIC CEMENT	DYLON INDUSTRIES, INC. CLEVELAND, OH	II	14
AR			105	ALUMINA POWDER	METCO INC. LONG ISLAND, NY	II	13
		1	-12	CABLE	MAKE FROM .062 OD 2-CONDUCTOR TWISTER 316 SST CABLE WITH TYPE MgO INSULATION SENSOR DYNAMICS EDISON, IL	II	12
	1		-11	WIRE COIL	MAKE FROM SECON ALLOY 406 WIRE WITH TYPE E INSULATION, .010 OD SECON METALS CORP. WHITE PLAINS, NY	II	11
	1		-10	MICA DISC	MAKE FROM PHLOGOPITE MICA DISC .0009-.0011 THK ASHEVILLE-SCHOONMAKER MICA CO. NEW PORT NEWS, VA	II	10
		1	-9	CABLE ADAPTER	625 INCONEL	II	9
1			-8	DIAPHRAM		II	8
		2	-7	COIL FORM SUPPORT		II	7
		2	-6	CERAMIC SPACER	MAKE FROM AREMCOLOX MACHINABLE CERAMIC #502-1100 AREMCO PRODUCTS, INC. OSSINING, NY	II	6
		1	-5	TUBE	625 INCONEL	II	5
		2	-4	TUBE		II	4
\	1		-3	DIAPHRAM WITH CENTER POST		II	3
	\	2	-2	COIL FORM ASSEMBLY		II	2
		\	-1	ASSEMBLY		II	1

QTY REQ'D — PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONING AND SYMBOLOGY ARE AMERICAN NATIONAL STANDARD
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010
FRACTIONS ± 1/8
ANGULAR ± 2°
DO NOT SCALE DRAWING

EG&G Idaho, Inc.

TITLE: LOFT DRAG DISK EDDY CURRENT DISPLACEMENT TRANSDUCER

DWG SIZE: E — INDEX CODE NUMBER: AREA 036, DWG TYPE 0806, CL 46, ORIG 220

SCALE 4/1 — DWG CAT. ED

DRAWN: D JUDY — DATE 12/17/76

Figure 7A: Unassembled Transducer

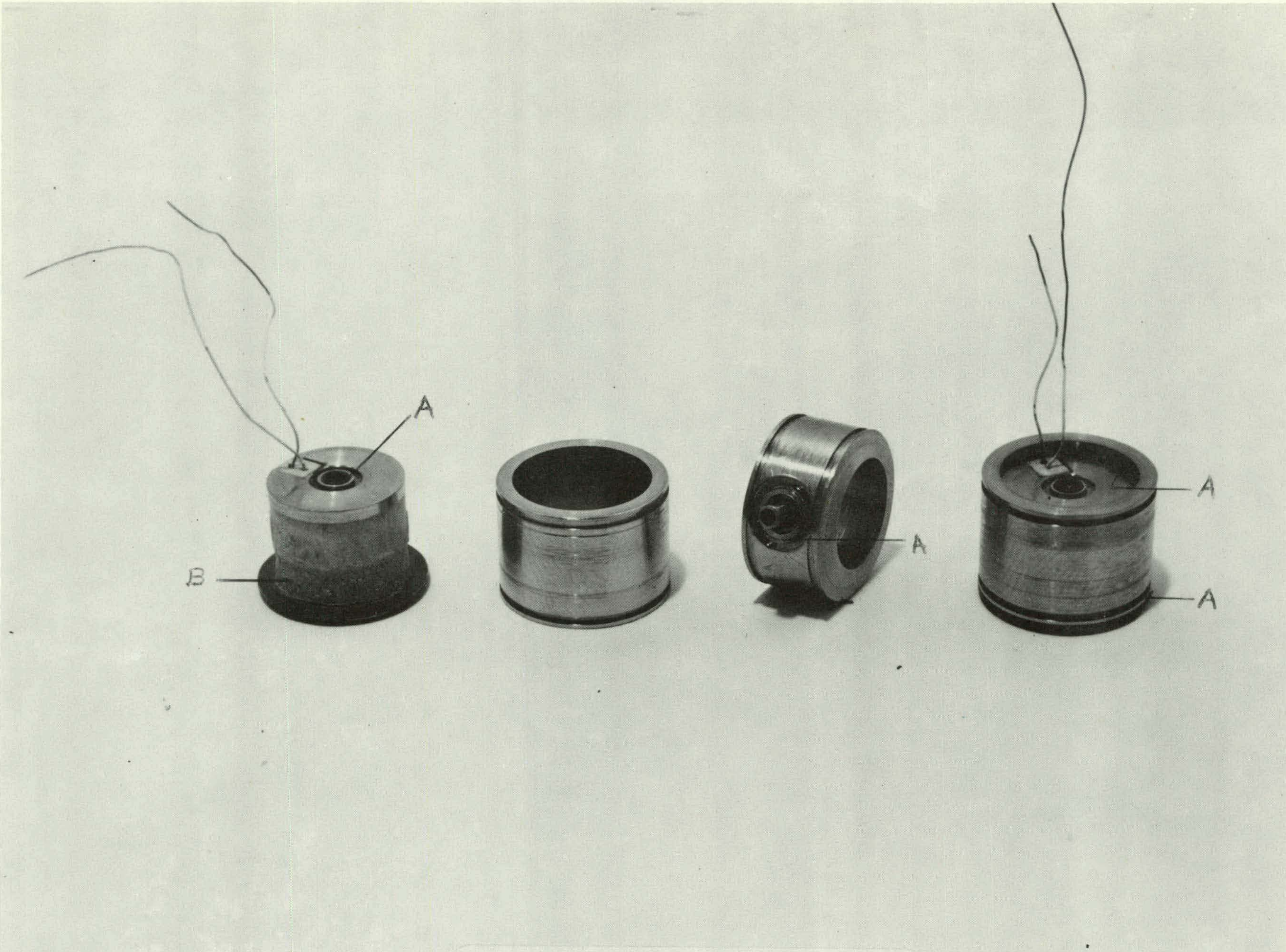


Figure 7B: Partially Assembled Transducer

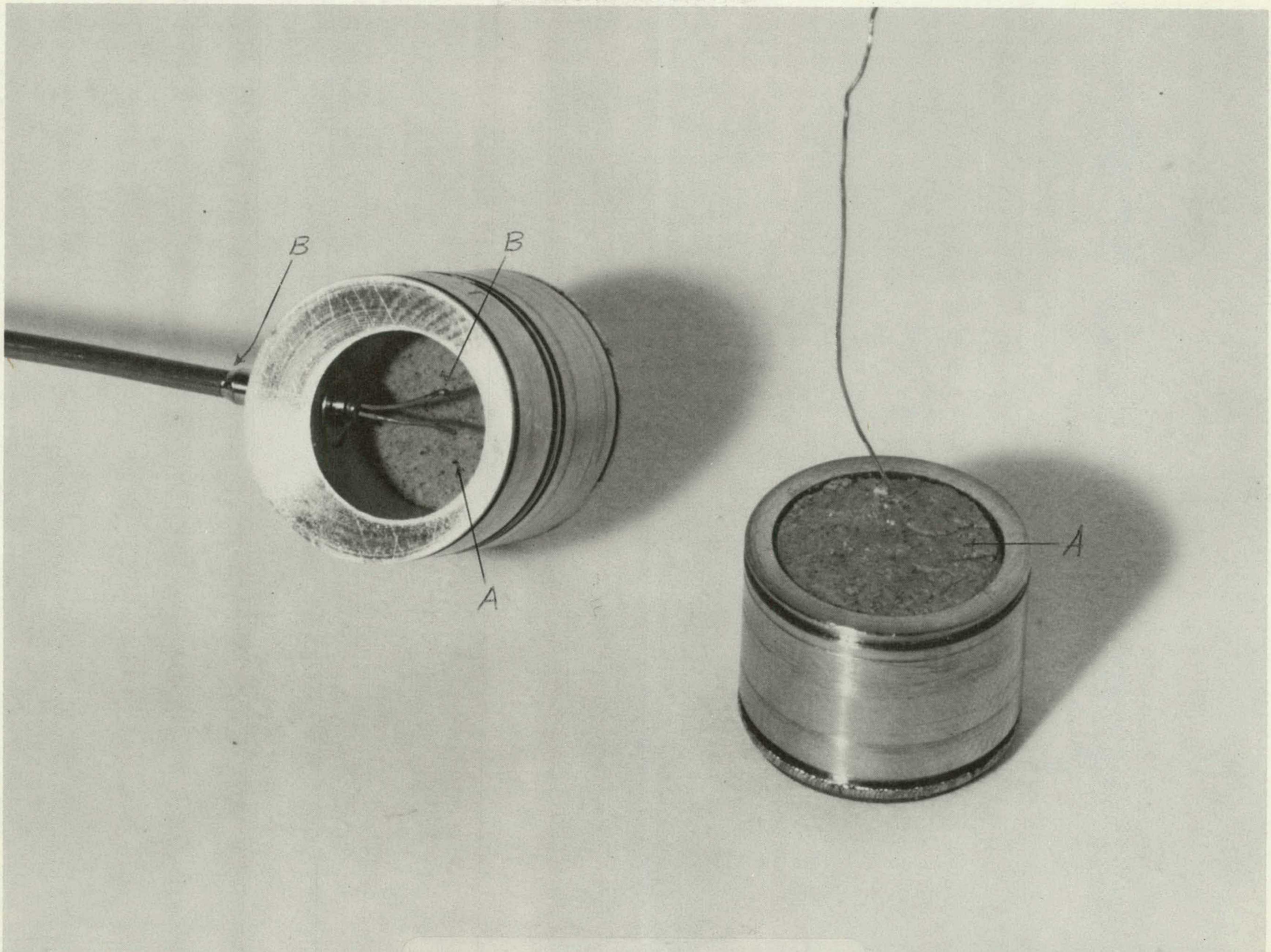


Figure 7C: Partially Assembled Transducer

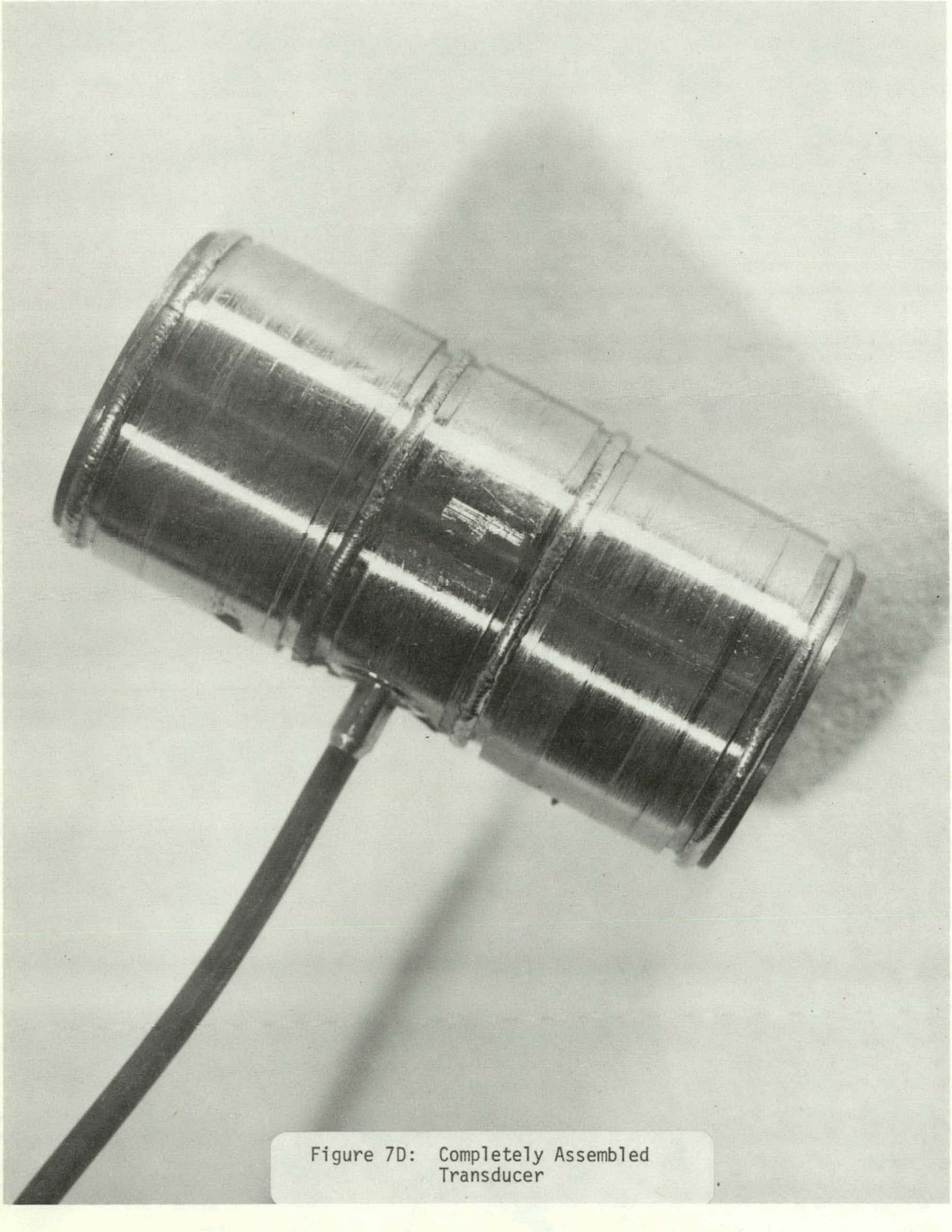


Figure 7D: Completely Assembled Transducer weld made to join the sheathed cable to the cable adapter will be made at the end of sheathed cable instead as shown in Figure 7C. The completed transducer is shown in Figure 7D. The transducer was heated to 650°F for several hours before the final seal welds were made to eliminate internal outgassing. A helium leak test was performed on the transducer to ensure that it was completely sealed.

The sheathed cable used in this transducer design had an outer diameter of 0.062 inch and two 0.010 inch diameter conductors. The sheath and conductor materials were 316 L stainless steel. In order to reduce pickup noise the two conductors were twisted.

3.0 ELECTRONICS

The electronics designed for use with this transducer consists of two units, i.e. a 100 kHz frequency source and a set of signal conditioning electronics. The frequency source consisted of two separate power supplies and two 100 kHz oscillators designed to provide a back-up 100 kHz signal to the electronics should a failure occur in the oscillator system being used. The frequency source was designed to drive up to ten sets of eddy current electronics with four additional buffered oscillator outputs. The buffered output may be used to provide a 100 kHz signal to other systems. Since one frequency source will be used in conjunction with several sets of electronics, a back-up 100 kHz signal was provided. A block diagragm of the eddy current signal conditioning system is shown in Figure 8. Signal conditioning system consists of a phase sensitive demodulator and a four arm bridge network. A constant current driver is used in conjunction with the bridge network to provide a constant current signal to the transducer. The constant current drive system is used where the transducer requires a cable with high lead resistance such as stainless steel. A bridge balance network is used to null the bridge output which is then amplified and filtered. This signal is then conditioned by a phase sensitive demodulator. As the displacement seen by the transducer increases or as the transducer temperature changes the amplitude and phase of the signal changes. A polar plot showing typical phase and amplitude changes is shown in Figure 4. The use of a phase sensitive demodulator makes it possible to minimize temperature effects by selecting the proper phase angle for system operation. Additional information on the phase shift network is contained in Appendix C.

The output amplifier of the signal conditioning electronics has a response time of 10 milliseconds and has the capability of driving a 0.1μf capacitive load and a 1K Ω resistive load.

4.0 SYSTEM EVALUATION

In evaluating the transducer's performance, a series of tests were outlined which included: A - High temperature effects; B - Drift; C - Thermal shock; D - Pressure effects.

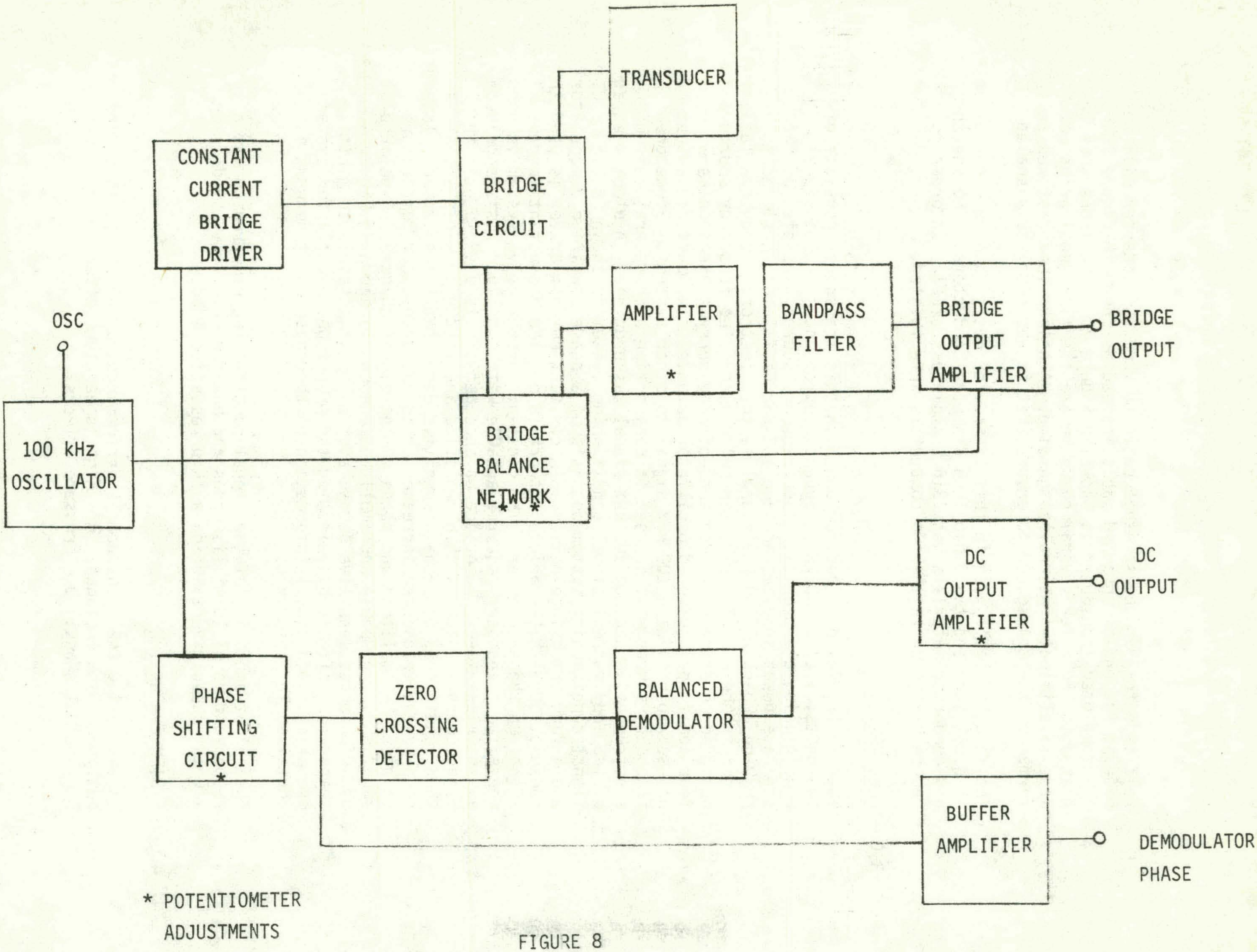


FIGURE 8

BLOCK DIAGRAGM OF EDDY CURRENT ELECTRONIC

A test plan covering these tests is included in Appendix D. Figures 9A and 9B show the test fixtures used in the evaluation.

A preliminary test was conducted to determine the optimum setting for the reference target. An evaluation of this data indicated that a setting of 0.050 inch provided the best temperature compensation. The data used in the evaluation is included in Appendix E. The bridge network was balanced with the sense target adjusted for zero displacement. Thus, during operation, the normal displacement range will not cause the bridge balance to go through null. Testing also indicated that the bridge network could be balanced with the sensing target at various locations without affecting the transducers sensitivity to displacement.

As the first step of the test plan it was necessary to determine the proper phase angle setting for the phase sensitive demodulator. This setting was determined by measuring the RMS amplitude of the bridge output and its phase with respect to the oscillator as the displacement was varied. These values were than plotted on polar coordinate paper as shown in Figure 10. From this plot an approximate phase angle was selected to provide good sensitivity to displacement. The dc output was also recorded as a function of displacement for various temperatures. Figure 11 shows a plot of the dc output versus displacement for 76^{o}F, 302^{o}F and 649^{o}F. The total error which occurred as the transducer's temperature varied from 302^{o}F to 649^{o}F corresponded to a maximum displacement of less than 0.004 inch.

A long term drift test was conducted with the electronics and the transducer at room temperature. The maximum drift for a 24 hour period was 0.022 volt. For an 88 hour period, the total drift was only 0.025 volt. The total drift corresponded to a maximum displacement of 0.0015 inch.

A series of tests were conducted in the autoclave to determine the effects of temperature and pressure on the transducer. These tests were conducted with the reference and sense targets set for 0.050 inch. In setting up for the autoclave tests a change in the optimum phase angle was noted. A phase angle setting of 35^{o} was used for these tests. Additional testing will be necessary to determine the cause of the change in the phase angle setting. In the first test the temperature was varied from 63^{o}F to 646^{o}F while the pressure increases to 2240 psi, resulting in a change of 0.138 volt in the output. This change corresponded to a displacement of 0.0037 inch. A second test was conducted in which the pressure varied from 1813 to 2500 psi with the temperature increasing from 61^{o}F to 650^{o}F. This test resulted in a 0.134 volt change in the output. The data from these two tests were repeatable within 0.003 volt for a pressure variation of 1803 to 2400 psi and temperature change from 63^{o}F to 646^{o}F.

As a result of a pressure change from 0 to 2250^{o}F with the temperature remaining at 63^{o}F, the output changed 0.034 volt which corresponds to a change in displacement of approximately 0.0009 inch.

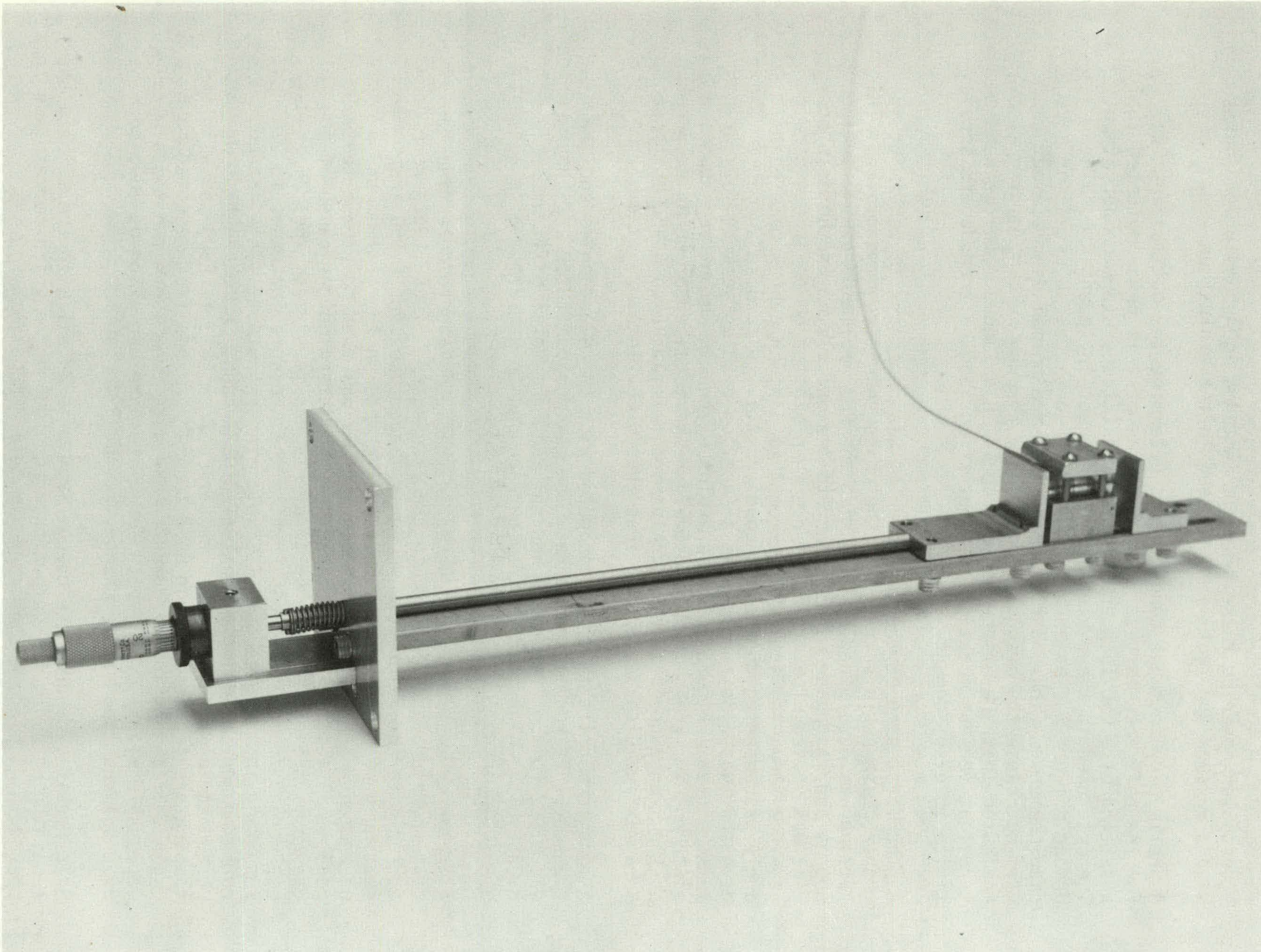


Figure 9A: High Temperature Test Fixture

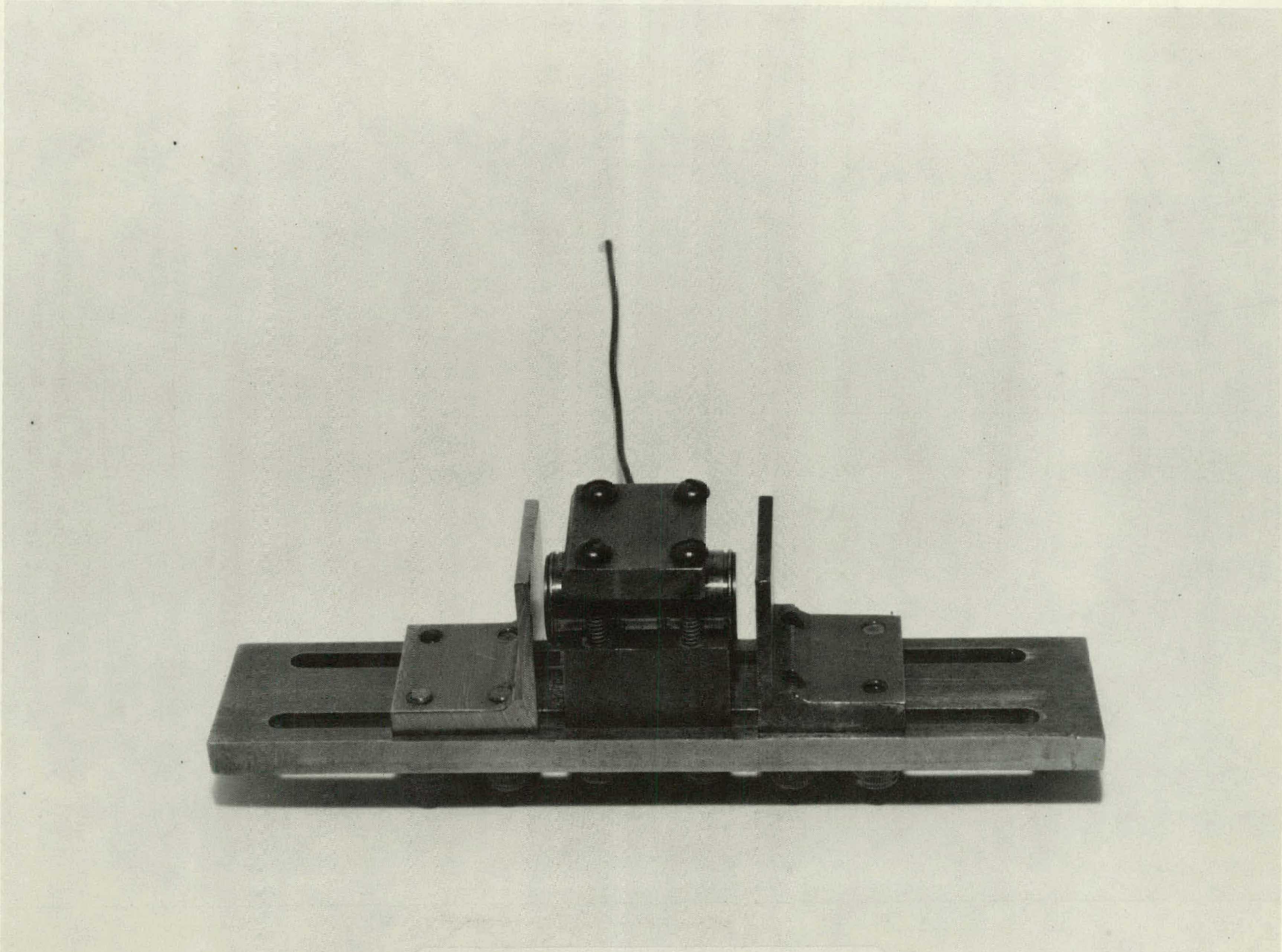


Figure 9B: Autoclave Test Fixture

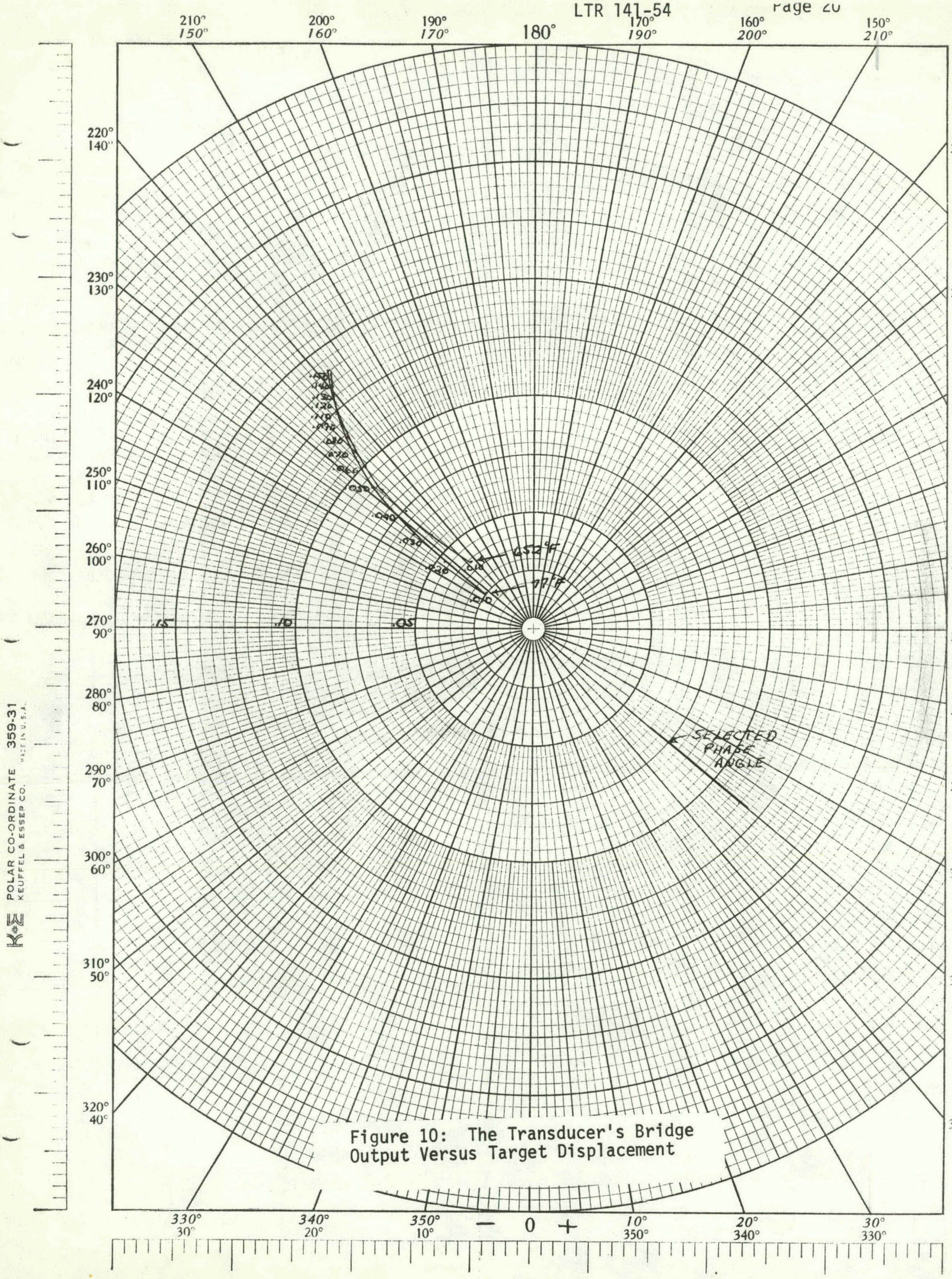


Figure 10: The Transducer's Bridge Output Versus Target Displacement

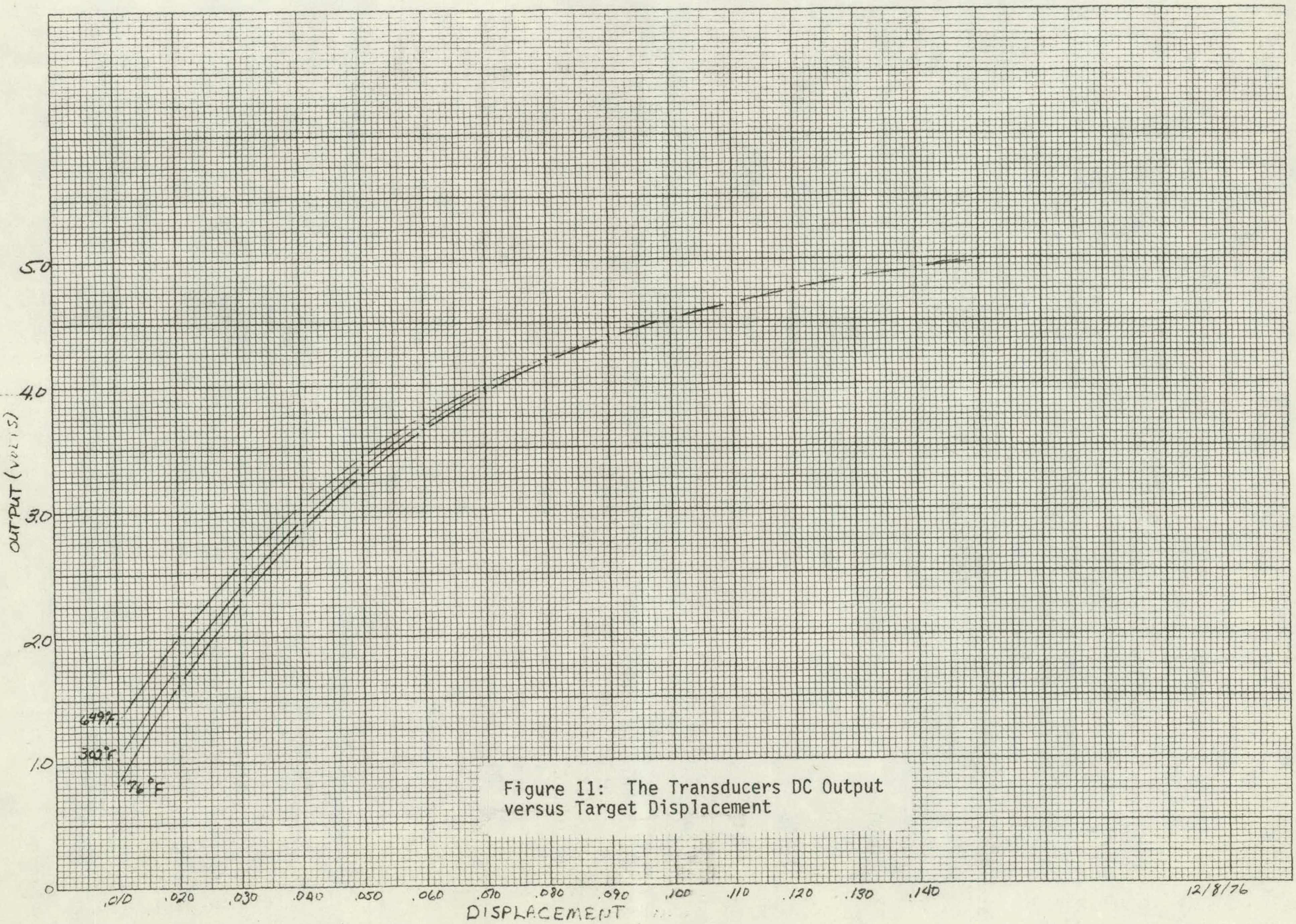


Figure 11: The Transducers DC Output versus Target Displacement

The total error in the displacement measurement which occurred as a result of variations in the temperature, pressure, and drift are tabulated in Table 1. In accumulating the total error resulting from these changes, an approximate sensitivity was determined for the various displacement ranges as indicated in the table. The percent of error, represented by the changes in total displacement resulting from a variation in temperature, pressure and drift, was calculated as a function of a ± 0.040 inch full scale range.

Range	Sensitivity	Temp Effects	Pressure Effects	Drift* Effects	Total Error	Percent Displacement
Mils	Volts/Mil	Mils	Mils	Mils	Mils	Error
10-30	0.068	3.5	1.14	0.36	5.00	±6.25
30-50	0.048	3.0	1.00	0.52	4.52	±5.65
50-70	0.029	2.0	0.78	0.85	3.63	±4.53
70-110	0.017	0-2.0	0.30	1.50	3.80	±4.75

* For 88 hour test.

As part of the first autoclave test the temperature and pressure were held at approximately 646^{o}F and 2240 psi for 5½ hours with a drift of 0.005 volt. This drift represents a displacement error of 0.18% at a displacement of 0.050 inch.

A series of three thermal shock tests were conducted in which the transducer was heated to approximately 650^{o}F and then submersed in ice water. The fixture in which the transducer was mounted for these tests consisted of a transducer mounting bracket and two targets located 0.050 inch from the ends of the transducer. The results of these tests are shown in Figure 12. Traces A and B resulted when the transducer was placed in the ice water such that one of the sensing ends were placed into the water before the other end. Trace C resulted when the transducer was submersed such that both sensing ends went into the water at the same time.

In order to determine the effects of pressure as a function of displacement a series of tests were conducted in which the pressure was changed at 500 psi intervals for various displacements. The results of these tests are plotted in Figure 13. The maximum change in the output for a pressure change of 2250 psi was 1.25% of the full scale range.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the testing performed on the eddy current transducer indicates that the transducer has a useful range of approximately a 0.140 inch. The maximum error which occurred in the displacement range

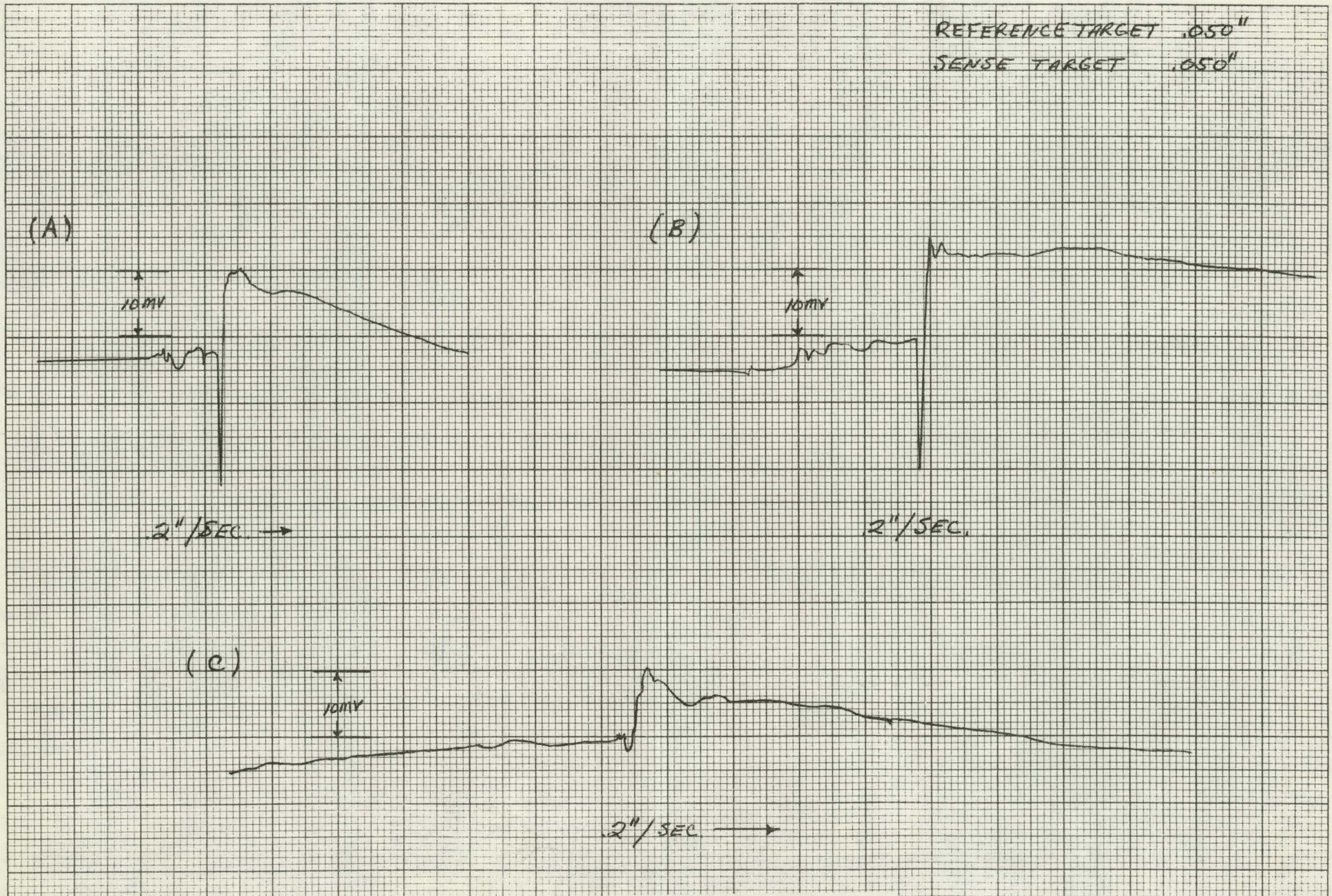


Figure 12: The Transducer's Response to Thermal Shock

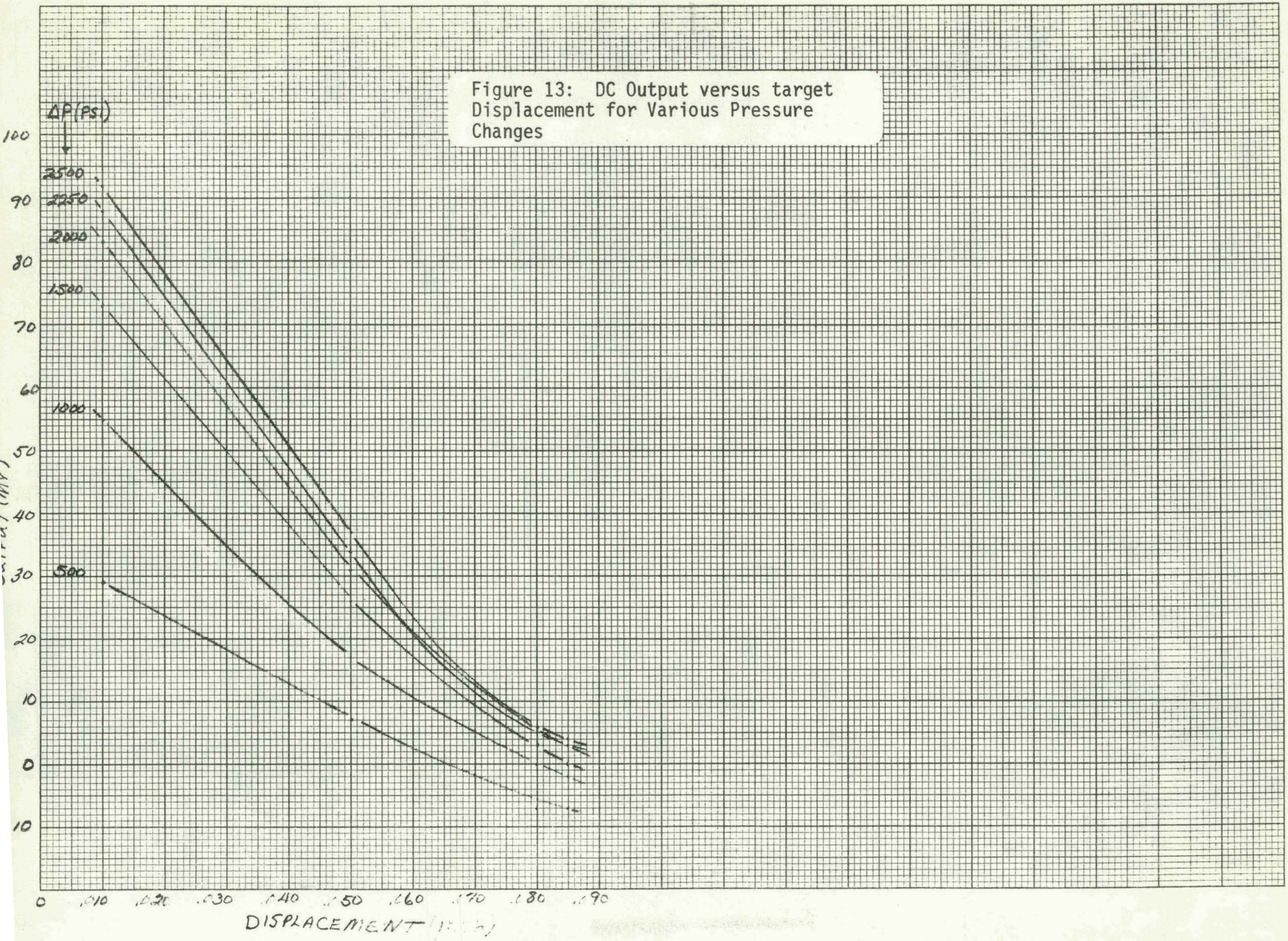


Figure 13: DC Output versus target Displacement for Various Pressure Changes

from 0.030 to 0.110 inch as a result of temperature, pressure and drift variations was ± 5.65% of the specified ±0.040 inch operating range. The results of the tests conducted in the autoclave and the oven indicate that the transducer should operate satisfactorily in the LOFT environment. Additional testing will be necessary to determine the cause of the shift in the optimum phase angle setting which occurred in the test program.

The materials used in the fabrication of the transducer were selected because of their ability to withstand the environmental conditions. The ceramic cement used in the fabrication process was a 100% inorganic compound and should have excellent radiation resistance. It is recommended that an irradiation evaluation be conducted on this ceramic cement as well as the other ceramic material used in fabrication of the transducer.

It would be desirable to produce several of these transducers and evaluate them in order to obtain better statistical data on their performance characteristics.

6.0 REFERENCE

1. SDD 1.4.1 - LOFT Program Division System Design Description for the Test Assembly Experimental Measurements System.

2. W. A. Simpson, J. W. Luguire, C. V. Dodd and W. G. Spoeri, Computer Programs for Some Eddy Current Problems, 1970, ORNL-TM-3295, June, 1971.

3. R. G. Bearden, Design Requirements for the Eddy Current Sensor RGB-24-76.

APPENDIX A

LOFT PRIMARY COOLANT SYSTEM CHEMISTRY CONTROL SPECIFICATION [(a)]

pH @ 25°C	4.2 - 10.5
Conductivity μmhos/cm @ 25°C	1 - 40
Boron ppm	100 - 3000
Lithium ppm	0.2 - 2.2
Oxygen ppm	0.10 max
Hydrogen cc/kg @ STP	15 - 60
Total Gas cc/kg @ STP	100 max.
Hydrazine ppm (At temp. <250°F)	1.0 min. (prenuclear operation)
Chloride ppm	0.15 max.
Flouride ppm	0.10 max.
Undissolved Solids ppm	1.0 max.
Total Gross Activity μCi/ml	250 max.
Gross Alpha	
Gross Beta	
Gross Gamma	
Iodine - 131 μCi/ml	2.45×10^{-1} max.
Iodine - 133 μCi/ml	5.04×10^{-1} max.
Tritium - μCi/ml	1.6 max.

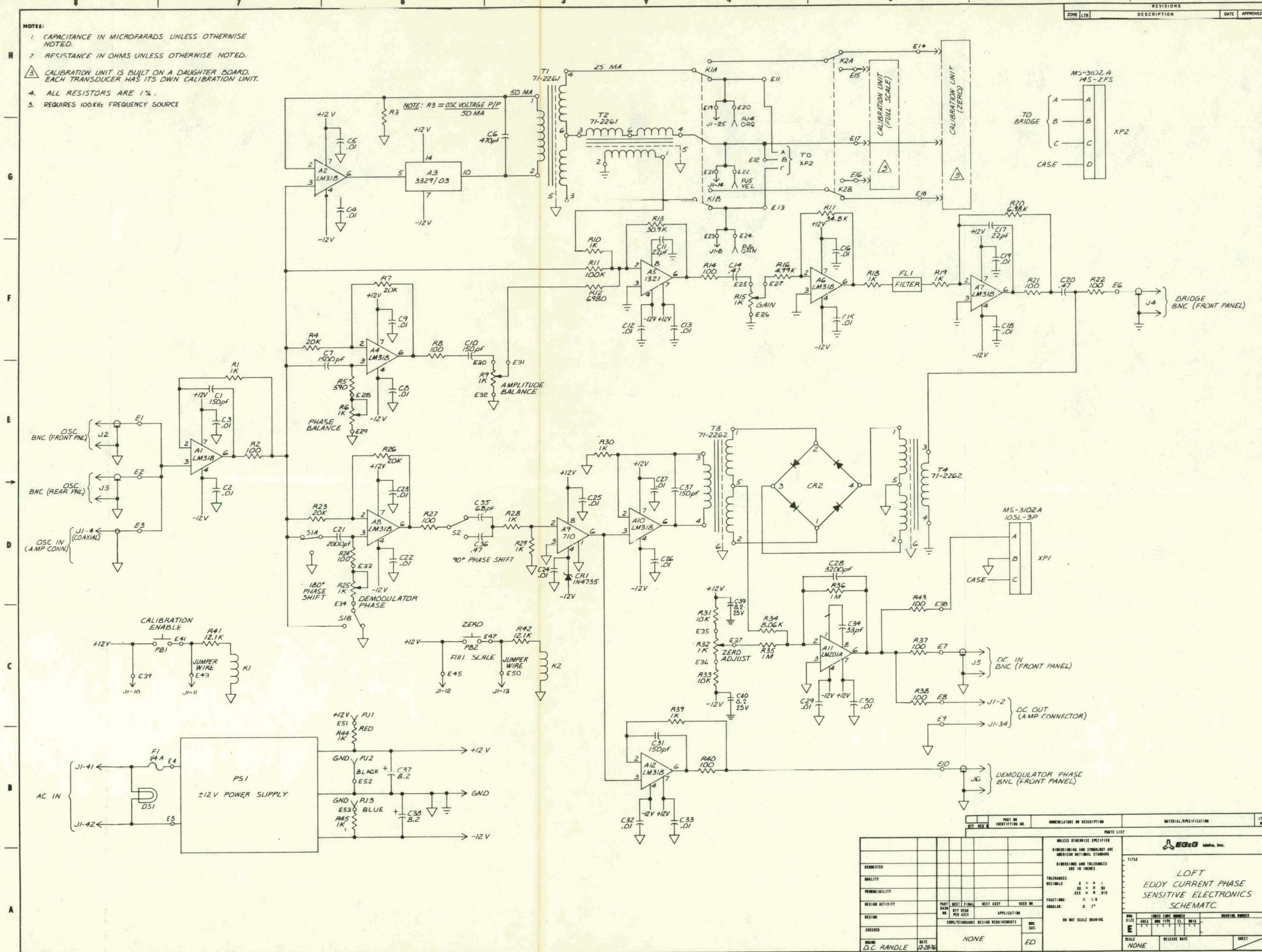
(a) Aerojet Nuclear Company, LOFT Facility Division, Plant Operating Manual, Volume II, Chapter 8.

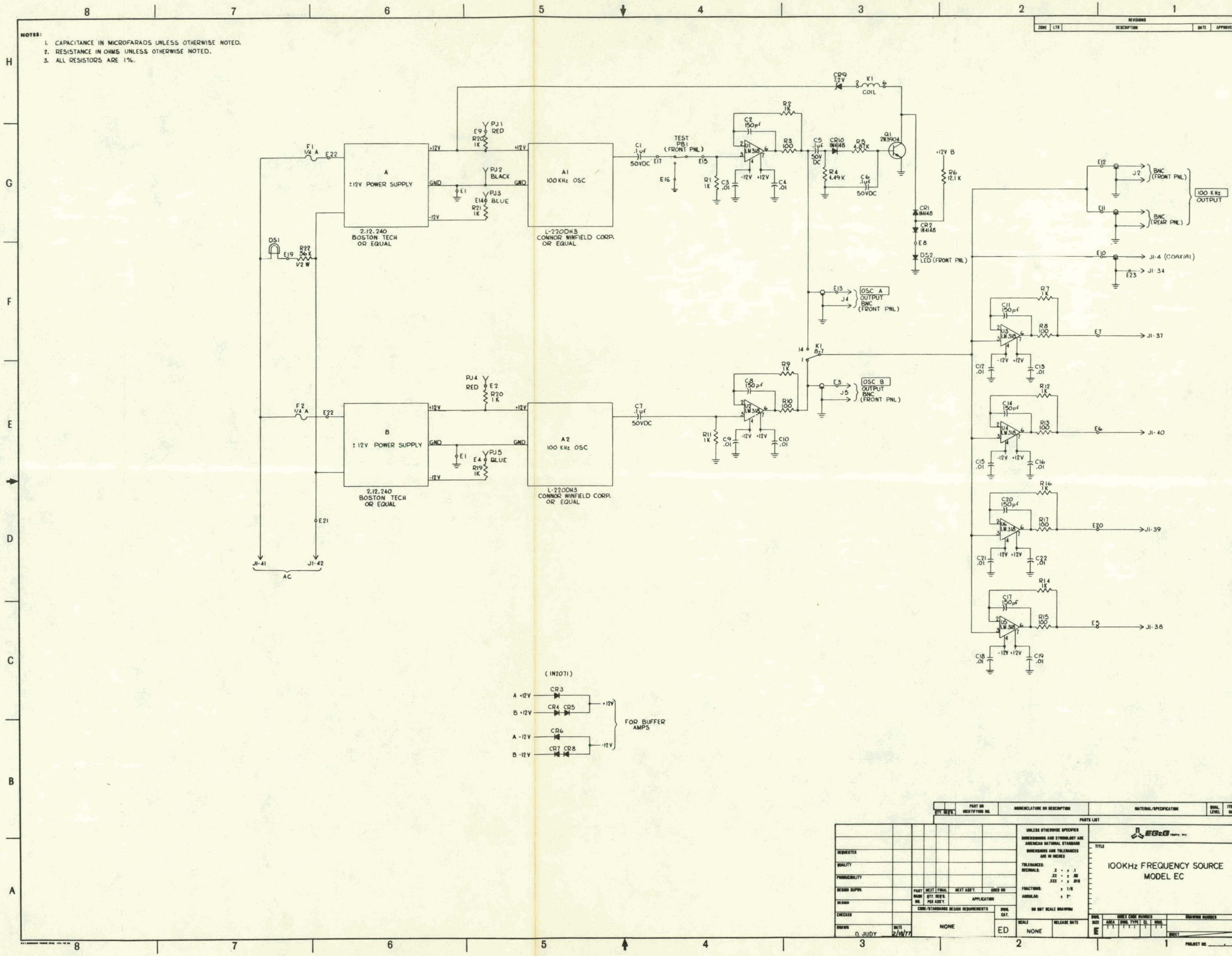
APPENDIX B

LOFT EDDY CURRENT PHASE SENSITIVE ELECTRONICS SCHEMATIC

AND

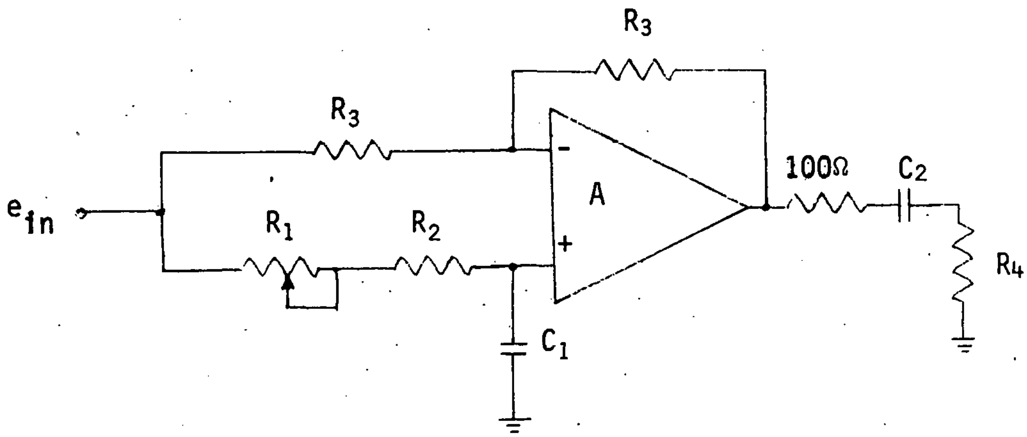
100 KHZ FREQUENCY SOURCE SCHEMATIC


NOTES:
1. CAPACITANCE IN MICROFARADS UNLESS OTHERWISE NOTED.
2. RESISTANCE IN OHMS UNLESS OTHERWISE NOTED.
3. CALIBRATION UNIT IS BUILT ON A DAUGHTER BOARD. EACH TRANSDUCER HAS ITS OWN CALIBRATION UNIT.
4. ALL RESISTORS ARE 1%.
5. REQUIRES 100KHz FREQUENCY SOURCE
NOTE: R3 = OSC VOLTAGE P/P / 50 MA
CALIBRATION UNIT (FULL SCALE)
CALIBRATION UNIT (ZERO)
MS-3102A 14S-2FS
TO BRIDGE
XP2
PHASE BALANCE
AMPLITUDE BALANCE
GAIN
FILTER
BRIDGE BNC (FRONT PANEL)
OSC BNC (FRONT PNL)
OSC BNC (REAR PNL)
OSC IN (AMP CONN)
90° PHASE SHIFT
180° PHASE SHIFT
DEMODULATOR PHASE
MS-3102A 10SL-3P
XP1
ZERO ADJUST
DC IN BNC (FRONT PANEL)
DC OUT (AMP CONNECTOR)
DEMODULATOR PHASE BNC (FRONT PANEL)
CALIBRATION ENABLE
JUMPER WIRE
FULL SCALE
AC IN
PS1 ±12 V POWER SUPPLY
EG&G Idaho, Inc.
LOFT
EDDY CURRENT PHASE SENSITIVE ELECTRONICS SCHEMATIC
DRAWN D.C. RANDLE
SCALE NONE


NOTES:
1. CAPACITANCE IN MICROFARADS UNLESS OTHERWISE NOTED.
2. RESISTANCE IN OHMS UNLESS OTHERWISE NOTED.
3. ALL RESISTORS ARE 1%.
A ±12V POWER SUPPLY
2.12.240 BOSTON TECH OR EQUAL
B ±12V POWER SUPPLY
2.12.240 BOSTON TECH OR EQUAL
A1 100 KHz OSC
L-2200H3 CONNOR WINFIELD CORP. OR EQUAL
A2 100 KHz OSC
L-2200H3 CONNOR WINFIELD CORP. OR EQUAL
F1 1/4 A
F2 1/4 A
DS1
R22 56K 1/2 W
PJ1 RED
PJ2 BLACK
PJ3 BLUE
PJ4 RED
PJ5 BLUE
TEST PB1 (FRONT PNL)
Q1 2N3904
K1 COIL
CR9 12V
CR10 1N4148
CR1 1N4148
CR2 1N4148
DS2 LED (FRONT PNL)
+12V B
R6 12.1 K
OSC A OUTPUT BNC (FRONT PNL)
OSC B OUTPUT BNC (FRONT PNL)
BNC (FRONT PNL)
BNC (REAR PNL)
100 KHz OUTPUT
J1-4 (COAXIAL)
J1 34
J1-37
J1-40
J1-39
J1-38
J1-41
J1-42
AC
(1N2071)
A +12V
B +12V
A -12V
B -12V
FOR BUFFER AMPS
EG&G
100KHz FREQUENCY SOURCE MODEL EC
D. JUDY
2/16/77

APPENDIX C

Constant Amplitude Phase Shifter



The constant amplitude phase shifter has a phase shift (ϕ) which varies according to the following relationship:

$$\phi = -2 \arctan [2\pi f(R_1+R_2)\ C_1]$$

By interchanging C_1 and (R_1+R_2) the following phase shift is obtained:

$$\phi = -180 + (-2 \arctan [2\pi f(R_1+R_2)\ C_1])$$

The C_2 and R_4 combination can be used to produce another 90^0 phase shift. With $|^1/sC_2| < 0.1R_4$ the phase shift of the circuit is approximately centered on the imaginary axis while $|^1/sC_2| > 10R_4$ approximately centers the adjustment range on the real axis.

Table C1 lists the range of phase adjustment available as R_1 varies from 1K Ω to 0 Ω for the following values of R_2, C_1, C_2, R_4.

R_2 = 100 Ω

C_1 = 2000 pf

R_4 = 2K Ω

R_3 = 20K Ω

Table C1. Range of Phase Adjustment Available in the Demodulator Phase Shifter.

Circuit Conditions	Phase Range (Degrees)
C_2 = 68pf, input to R_1 C_1 to ground	(-14.3 to -108) + 85 = -23 to 70.7
C_2 = .47µf input to C_1 R_1 to ground	(-194 to -288) = 72 to 166
C_2 = 68pf, input to C_1 R_1 to ground	(-194 to -288) + 85 = 157 to 251
C_2 = .47 µf, input to R_1 C_1 to ground	(-14.3 to -108) = 252 to 346

The phase shifter associated with the bridge balance network has the following values:

C_1 = 1500 pf
C_2 = 150 pf
R_1 = 1KΩ
R_2 = 590Ω
R_3 = 20KΩ
R_4 = 1KΩ

APPENDIX D

TEST PLAN

LOFT EXPERIMENTS INSTRUMENTATION

Test Plan

531312

LOFT-FM-008

Prototype DTT Eddy Current Transducer Evaluation

LOFT PROJECT: [signature] DATE: 15 Sept 76

LOFT PROJECT: [signature] DATE: 14 Sept 76

I&M ENGINEER: [signature] DATE: 13 Sept 76

PREPARED BY: R. W. [signature] DATE: 13 Sept 76

1.0 SCOPE

An eddy current transducer is being developed for use in sensing drag disk displacement. The transducer will be used in a prototype drag disk unit.

The objectives of the testing include:

1.1 Selection of the optimum phase angle for the phase sensitive demodulator.

1.2 Determination of both the temperature and the pressure sensitivities.

1.3 Determination of useful range, long term stability and repeatability.

2.0 REFERENCE

2.1 Drawing: FEFPL EDDY CURRENT MODULE (for prototype testing)

2.2 Manual

3.0 FACILITIES AND EQUIPMENT

3.1 This test shall be performed at ARA III by ANC personnel.

3.2 Equipment

a. Oven Test Fixture
b. Autoclave Test Fixture
c. 100K FEFPL Eddy Current Module
d. Blue M Oven
e. Autoclave

The following equipment requires current calibration:

f. Wavetek Model 740 Phasemeter or Equivalent
g. Fluke Model 8120A Digital Multimeter or Equivalent
h. HP Model 3400A RMS Voltmeter
i. Oscilloscope Tektronic 321 or Equivalent
j. Thermocouple with Digital Readout
k. Two Dual Pen Strip Chart Recorder

4.0 TEMPERATURE EVALUATION

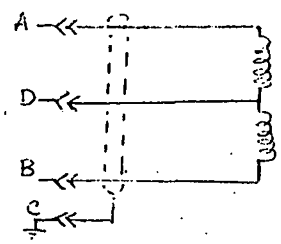
4.1 Installation of Transducer

4.1.1 Install test fixture through the hole on the side of the oven.

4.1.2 Mount the transducer in the test fixture and bring the sheath cable lead out through hole in the side of the oven. Install insulation in the holes around this lead and test fixture.

4.1.3 Adjust the micrometer on the test fixture for a zero reading. Position the transducer against the movable target and tighten it is place. Adjust the reference target at the required displacement from the transducer. Record the setting on data sheet 1. Note: a 50 mil reference displacement may be used to begin the evaluation. It may be desirable to try other settings. Install thermocouple on test fixture near the transducer.

4.2 Connect the transducer to connector J1-2 on the rear of the NIM bin.



4.3 Test Equipment (Figure 1)

4.3.1 Connect the oscilloscope, RMS voltmeter and phasemeter (Input B) to the AC output (bridge) connector.

4.3.2 Connect the phasemeter (Input A) to the oscillator reference signal connector.

4.3.3 Connect the multimeter to the dc output connector.

4.3.4 Connect phasemeter (Input B) to demodulator reference signal as required to set the demodulator phase angle.

4.4 Test Procedure

4.4.1 With the transducer connected to the electronics, adjust the amplitude and phase balance potentiometer for a null at the ac output. The movable target should be set at zero mils displacement.

4.4.2 Set the demodulator phase angle as required (see section 4.3.4). Record this setting on Data Sheet 1. An initial phase angle of +50° (i.e. Input B leads Input A by 50°) may be used for the evaluation. See section 4.4.7 for a procedure to use to determine possible phase angle if an acceptable phase angle is not known.

4.4.3 Adjust the gain and zero potentiometers as required. For evaluation these settings are not critical. Suggested gain: 5V/140 mil displacement.

4.4.4 Obtain transducer displacement data at the following temperatures: room temperature, approximately 300°F and approximately 650°F. Record the exact temperature on Data Sheet 1. Record the rms voltage, phase and dc output for 10 to 150 mil displacement.

4.4.5 Plot the dc output vs displacement and determine the transducers temperature coefficient

$$\frac{\Delta D \times 100}{D} / \Delta T$$

Where:

D = Displacement

T = Temperature

If the temperature coefficient is not acceptable $(\frac{.01\%}{^{\circ}F})$ repeat section 4.4.4 with a different phase angle. See section 4.4.7 for a method of determining a new phase angle.

4.4.6 Monitor the dc output of the electronics and the oven temperature on a dual pen recorder. Set the reference target and sense target at 50 mils displacement from transducer. Record the initial dc output and increase temperature to approximately 650°F. Record dc output and temperature. Maintain this temperature for four hours, then record the dc output. Allow the temperature to return to room temperature and record the dc output of the electronics. Allow the transducer to remain at room temperature for at least 24 hours. Record the final dc output. Refer to Data Sheet 2.

4.4.7 Phase Angle Determination

Plot the RMS voltage and phase data from the data sheet on polar co-ordinate paper. By visual examination of this plot pick a phase angle for maximum displacement sensitivity and minimum sensitivity to temperature variation. It may be necessary to try several angles in order to obtain an optimum setting. Repeat section 4.4.4 as required.

5.0 AUTOCLAVE TEST

5.1 Mount the transducer in the autoclave test fixture. Set the reference and sense targets 50 mils from the ends of the transducer.

5.2 Use LOFT chemistry water in the autoclave.

5.3 Connect the electronics as indicated in sections 4.2 and 4.3. All electronic settings should remain the same as in the final test of section 4.0.

5.4 Test Procedure

5.4.1 Record the autoclave pressure and the dc output of the electronics on a dual pen strip chart recorder. Also record both autoclave temperature and pressure on a dual pen strip chart recorder.

5.4.2 With the autoclave at room temperature, increase the pressure from 0 to 2500 psi and record the dc output for pressure increments of 500 psi on Data Sheet 3. Include also the dc output at 2250 psi. Then release the pressure slowly. Monitor both pressure and the dc output of the electronics on the recorder.

5.4.3 Repeat 5.4.2 for various displacements in the range required.

5.4.4 While monitoring the items indicated in section 5.4.1 increase the autoclave temperature and pressure to 650°F and 2250 psi. Maintain this condition for four hours then allow the autoclave to cool down. To determine repeatability, again increase the autoclave temperature and pressure to 650°F and 2250 psi and maintain this condition for at least 15 minutes for the system to stabilize.

6.0 THERMAL SHOCK TEST

6.1 Mount the transducer in the autoclave test fixture. Set the reference and sense targets 50 mils from the ends of the transducer.

6.2 Place the transducer and test fixture in the oven. Monitor the dc output on the recorder.

6.3 Heat the transducer approximately 650°F. Remove the transducer and test fixture from the oven and immerse in water to determine response to thermal shock.

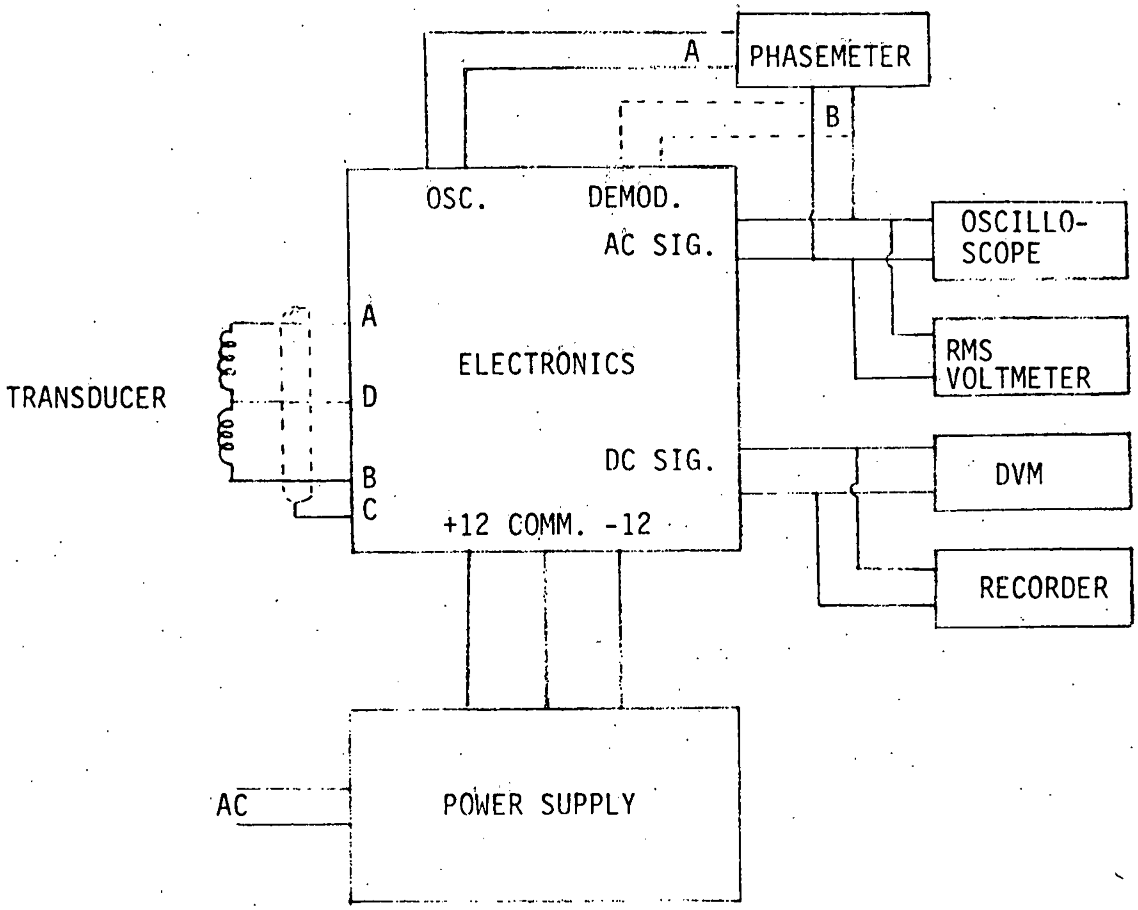


FIGURE 1: TEST SET-UP

DATA SHEET 1

1. Transducer S/N ____________________
2. Signal Conditioner S/N ______________
3. Reference target position ____________
4. Demodulator Phase Angle______________
5. Gain Setting__________________________

TEMP	______ °F			______ °F			______ °F		
MILS	RMS	Ø	DC	RMS	Ø	DC	RMS	Ø	DC
0									
10									
20									
30									
40									
50									
60									
70									
80									
90									
100									
110									
120									
130									
140									
150									

COMMENTS:

PERFORMED BY:______________________________ DATE:__________________

DATA SHEET 2

1. Transducer S/N ____________________

2. Signal Conditioner S/N ____________________

3. Reference Target Position ____________________

4. Demodulator Phase Angle ____________________

5. Gain Setting ____________________

Condition	Temperature	1st Cycle	2nd Cycle
Initial at R.T.			
After return to R.T.			
After 24 hrs at R.T.			
Initial at 650°F			
After 4 hrs at 650°F			
Max Drift at R.T.			
Max Drift at 650°F			

Comments: (Drift and Repeatability)

Performed by: ____________________ Date: ____________________

DATA SHEET 3

1. Transducer S/N ____________________
2. Signal Conditioner S/N ____________________
3. Reference Target Position ____________________
4. Demodulator Phase Angle ____________________
5. Gain Setting ____________________

Displacement	____mils		____mils		____mils		____mils	
Pressure PS	Pressure	DC	Pressure	DC	Pressure	DC	Pressure	DC
0								
500								
1000								
1500								
2000								
2250								
2500								

6. Displacement ____________ mils ____________

CYCLE 1			CYCLE 2		
Temp	Pressure	DC	Temp	Pressure	DC
After Four Hours					

Comments:

Performed by: ____________

Date: ____________

APPENDIX E

TEST DATA

EFFECTS OF REFERENCE TARGET LOCATION ON BRIDGE OUTPUT

	Ref Target At 0 Mils		Ref Target At 10 Mil		Ref Target At 50 Mil		No Target	
	RMS	Ø	RMS	Ø	RMS	Ø	RMS	Ø
0 mils	-	-	-	-	-	-	-	-
10	.051	14.6	.043	-150	.286	-150	.480	-148
20	.138	15.8	.0455	+12	.197	-154	.400	-154
30	.210	14.1	.166	+13.7	.125	-156	.335	-158
40	.265	12.2	.173	+12.4	.0675	-157	.284	-163
50	.310	10.2	.220	+10.5	.0205	-150	.240	-167
60	.348	+8.5	.253	+9.0	.0206	-1.0	.205	-171
70	.378	+7.2	.282	+7.6	.051	+6.0	.175	-175
80	.40	+5.9	.31	+6.2	.0785	+6.3	.150	-178
90	.42	+4.7	.33	+5.1	.10	+5.4	.128	16
100	.438	+3.7	.350	+4.0	.118	+4.4	.111	13.1
110	.45	+2.8	.361	+3.0	.134	+3.4	.0965	10.3
120	.462	+1.95	.373	+2.2	.147	+2.4	.0845	+ 7.6
130	.472	+1.2	.382	+1.4	.158	+1.5	.0735	+ 5.0
140	.480	+ .6	.392	+ .7	.168	+ .7	.064	+ 2.4
150	.488	+41° ref	.40	+36 ref	.177	+6.0 ref	.056	+164 ref

All data was taken without readjusting the bridge balance.

The phase values Ø recorded were measured relative to the ref. value.

EFFECTS OF DEMODULATOR PHASE SETTING ON D.C. OUTPUT

Phase / Displacement	70°	60°	50°	30°
0 mils				
10	-.283	-.276	-.184	-.202
20	-.934	-.927	-.830	-.754
30	-1.446	-1.456	-1.365	-1.225
40	-1.847	-1.875	-1.796	-1.621
50	-2.165	-2.211	-2.148	-1.948
60	-2.413	-2.480	-2.433	-2.223
70	-2.609	-2.699	-2.669	-2.458
80	-2.767	-2.875	-2.859	-2.651
90	-2.892	-3.017	-3.016	-2.813
100	-2.992	-3.132	-3.146	-2.950
110	-3.071	-3.228	-3.253	-3.063
120	-3.137	-3.305	-3.343	-3.161
130	-3.188	-3.369	-3.417	-3.243
140	-3.230	-3.421	-3479	-3.312
150	-3.263	-3.464	-3.530	-3.371

Note: A phase setting of 50° yields the best overall sensitivity.

DATA SHEET 1

1. Transducer S/N Prototype
2. Signal Conditioner S/N #9
3. Reference target position 50 mils
4. Demodulator Phase Angle 35°
5. Gain Setting 5 volt

TEMP	76 °F			302 °F			649 °F		
MILS	RMS	Ø	DC	RMS	Ø	DC	RMS	Ø	DC
0									
10	.0455	-136	.82	.0565	-145°	1.04	.072	-150	1.33
20	.0899	-138	1.62	.098	-142	1.80	.109	-145.8	2.01
30	.126	-139.8	2.30	.133	-143	2.43	.135	-145.3	2.59
40	.155	-144.7	2.85	.160	-143	2.94	.165	-145.7	3.06
50	.178	-143.3	3.29	.182	-144.2	3.37	.186	-146.5	3.44
60	.197	-145	3.65	.200	-145.4	3.69	.204	-147.5	3.76
70	.213	-146.4	3.95	.215	-146.7	3.98	.217	-148.4	4.01
80	.225	-147.7	4.18	.226	-147.6	4.19	.229	-149.3	4.22
90	.236	-148.9	4.37	.236	-148.6	4.38	.238	-150.3	4.40
100	.245	-150	4.52	.245	-149.7	4.53	.245	-151	4.54
110	.252	-150.8	4.65	.251	-150.5	4.65	.253	-151.8	4.66
120	.258	-151.6	4.76	.257	-151.3	4.76	.258	-152.4	4.76
130	.263	-152.4	4.85	.263	-151.9	4.84	.262	-153	4.85
140	.266	-153	4.92	.266	-152.5	4.91	.267	-153.6	4.91
150	.270	-153.6	4.98	.270	-153.1	4.97	.270	-154.1	4.97

COMMENTS:

PERFORMED BY: R. W. Shurtliff DATE: 12/8/76

DATA SHEET 2

1. Transducer S/N Prototype
2. Signal Conditioner S/N #9
3. Reference Target Position .050"
4. Demodulator Phase Angle 35°
5. Gain Setting 5 volts

Condition	Temperature	1st Cycle	2nd Cycle
Initial at R.T.	76°F	3.15 volts	
After return to R.T.	76°F	3.16	
After 24 hrs at R.T.		*	
Initial at 650°F	688°F	3.37	
After 4 hrs at 650°F	685°F	3.39	
Max Drift at R.T.		*	
Max Drift at 650°F		.020	

Comments: (Drift and Repeatability)
*A long term drift test was conducted at room temperature as a separate test. The sense target was located at .010". The following results were obtained:

24 hrs - .022 volt
88 hrs - .025 volt

Performed by: M. E. Yancey Date: December, 1976

DATA SHEET 3

1. Transducer S/N Prototype
2. Signal Conditioner S/N #9
3. Reference Target Position 50 mils
4. Demodulator Phase Angle 35°
5. Gain Setting 5 volts

Displacement	10 mils		50 mils		80 mils		85 mils	
Pressure PS	Pressure	DC	Pressure	DC	Pressure	DC	Pressure	DC
0								
500	500	.030	500	.007	500	-.007	500	-.007
1000	1000	.005	1000	.017	1000	.000	1000	-.002
1500	1500	.073	1500	.026	1500	.003	1500	.000
2000	2000	.083	2000	.031	2000	.006	2000	.003
2250	2250	.089	2250	.034	2250	.005	2250	.003
2500	2500	.093	2500	.037	2500	.006	2500	.004

6. Displacement 50 mils

CYCLE 1			CYCLE 2		
Temp	Pressure	DC	Temp	Pressure	DC
63°F	0 psi	.000V	61°F	1813 psi	.000V
63	1803	.021	132	1822	-.003
301	1870	.055	300	1890	.034
506	1997	.110	617	2143	.109
635	2166	.133	650	2216	.118
646	2238	.134	650	2241	.120
After Four Hours			650	2500	.134
646	2241	.139			

Comments:

Drift was 5mV for 5½ hours. (.134 to .139mV)

Performed by RWShurtliff

Date: 12/8/76