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STRAIN MONITOR SYSTEM FOR THE THREADED
CLOSURE ON A THIRTY-INCH
PRESSURE VESSEL

S. L. Chapman
J. A. Kowalewski
C. R. Olmstead

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June 1976

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OAK RIDGE, TENNESSEE

prepared for the **U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION**
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Physical Testing Department
Y-12 Product Certification Division

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ABSTRACT

A system has been designed and fabricated to remotely measure and automatically print voltages proportional to strains experienced by the internal threaded areas of the closure on a 30-inch pressure vessel in the Oak Ridge Y-12 Plant. This system was designed to provide continuous monitoring during pressure vessel use and thereby provide a faster response to possible vessel failure, should the data indicate a weakening of the pressure vessel closure. Standard 120-ohm foil strain gages in a wheatstone-bridge configuration are utilized with an integrated circuit instrumentation amplifier and multiplexing logic installed within the vessel closure to minimize the wiring problems. The system has performed satisfactorily and has provided data on 15 gages located within the closure.

CONTENTS

SUMMARY	4
INTRODUCTION	5
THREADED CLOSURE STRAIN MONITOR SYSTEM	6
System Design and Fabrication	6
Prototype Design	6
Prototype Modification	6
Final Design	7
System Fail Proofing	7
Debugging	8
Burn In	8
Site Preparation	8
Cleaning	8
Ultrasonic Inspection	9
Dye-Penetrant Inspection	9
System Installation	10
Gage	10
Lead Wire	11
Electronics	12
Calibration	17
Calculations for Instrumentation	17
Results	19
CONCLUSIONS AND RECOMMENDATIONS	20
REFERENCES	21
ACKNOWLEDGEMENTS	22
APPENDIX A	23
Program to Calculate System Calibration Data	23
APPENDIX B	24
Program to Convert System Output to Strain Data	24
APPENDIX C	25
Program to Output Data File from the Previous Test	25
APPENDIX D	26
Sample Strain Data	26
APPENDIX E	35
Program to Plot Comparison Data	35
APPENDIX F	36
Graphic Comparisons	36
APPENDIX G	46
Strain Gage System Drawings	46

SUMMARY

Pressure vessels used in autoclave work are subjected to large working pressures and are susceptible to catastrophic failure if conditions develop which might weaken the vessel components. The most probable area in which these conditions could arise is in the closure areas, due to fabrication techniques. A visual inspection is impossible without disassembly, thus the need arises for a dynamic testing technique which may be used to study the vessel while under operating conditions.

A system which monitors the dynamic conditions in a 30-inch pressure vessel closure area was installed and evaluated.

Results of the evaluation can be summarized as follows:

1. Electronic state of the art allows design and fabrication of a totally enclosed, remote monitoring system.
2. Generation and transmission of analog data to a remote analog/digital converter and printer over a line length of 200 feet is possible without line-loss errors.
3. Remote measurement and multiplexing of analog data in a closed environment is feasible.
4. Remotely acquired strain-gage data are accurate and repeatable.

INTRODUCTION

Recently, the gas autoclave (designated as PV-2) was taken off line for overhaul and maintenance. The autoclave's lower closure was previously instrumented for strain measurements in the thread roots. These measurements were previously taken manually on an infrequent basis to determine strain conditions at strategic vessel locations. Improvement of the strain monitoring system was requested prior to placing the vessel off line.

An automatic strain monitoring system was designed and installed to provide for: (1) a reduction in cabling, (2) remote sensing and display of strain conditions, (3) reduction of data acquisition and analysis time, and (4) on-call data acquisition by operating personnel.

This report deals with the design, fabrication, and installation of such a system in the Oak Ridge Y-12 Plant. (a)

(a) Operated by the Union Carbide Corporation's Nuclear Division for the US Energy Research and Development Administration.

THREADED CLOSURE STRAIN MONITOR SYSTEM

SYSTEM DESIGN AND FABRICATION

The 30-inch pressure vessel (PV-2), located in the Oak Ridge Y-12 Plant, was taken out of service for overhaul and modification in late 1973. During early planning discussions of work which would be required to reinstrument the threaded closure, a request was made to determine the feasibility of providing a monitoring system that was automatic in nature and would provide data faster than the manual reading system which was then in use.

As first presented, the request was for a radio-frequency telemetry system totally enclosed within the vessel closure area. However, this method was impossible due to the solid steel enclosure formed when the vessel was sealed; also, it was impossible to transmit through the steel walls. The method proposed and selected for installation was one which located wheatstone bridges and amplifier circuits with analog multiplexers internal to the closure area, but the display and printer were remotely located.

Prototype Design

A prototype of the required bridge and amplifier circuit was assembled and put under test to determine the functions, controls, and component requirements that must be given consideration in the final design. A simplified schematic of the circuit is given in Figure 1.

Figure 1. PROTOTYPE BRIDGE/AMPLIFIER.

Prototype Modification

The bridge halves in the initial circuit were formed by R_g , one half of R_b and R_z , and one half of R_b . In order to reduce sensitivity of the circuit to adjustment of R_b and R_z , the circuit was modified to that shown in the final circuit of Figure 2. These modifications provided the ability to very precisely establish V_a and V_b when initializing the circuit for measurements.

Figure 2. MODIFIED BRIDGE/AMPLIFIER.

An additional modification to the circuit was to replace the original potentiometers (R_b and R_z) with components having 50 ppm/ $^{\circ}$ C drift. This change was necessary due to the high gain of the amplifier stages.

Evaluation of the prototype circuit proved the feasibility of providing low-drift bridge and amplifier circuits to monitor strain. At this point, the concept was assigned to Y-12 Engineering for final design and fabrication.

Final Design

During final design, the only major circuit change was the use of Analog Device's AD520K instrumentation amplifier. This change reduced the circuit physical size by a factor of 5. Figure 3 presents the final circuit configuration as installed. Each bridge and amplifier circuit board contained four circuits for measuring strain.

Figure 3. DESIGN BRIDGE/AMPLIFIER SYSTEM.

The second major portion of the system was the multiplexing and analog-to-digital conversion system which was used to select and digitize the appropriate amplifier output for display and printing. A block diagram of the clock and multiplexing circuit is given in Figure 4.

The signals between the control console and the enclosed circuit cards were transmitted for a distance of approximately 200 feet. For this reason, digital signals were transmitted with a DEC A 207 operational amplifier used as a line driver.

The analog signals representing strain, after conversion, are displayed on a LED display and printed on a Systron Donner Model 5013B strip printer, along with the channel number to indicate gage locations.

System Fail Proofing

As may be noted from the system drawings (Appendix G), there is duplication of circuit functions. This duplication was planned in order to provide methods for continued monitoring of strain should there be a loss of components or whole circuit cards after installation was complete. With four channels per card, a card loss would result in a loss of only one sixth of capability. The multiplexer card is duplicated so that a loss of a

Figure 4. STRAIN MONITOR SYSTEM.

multiplexer would not destroy the system's functions. The multiplexer outputs are supplied on two output lines so that loss of a lead during installation would not destroy the system's function. As the gages were connected to the bridges, a careful selection was made so that loss of a gage, an amplifier, or a multiplexer would not mean loss of data from a particular area on the thread root. A final attempt to prevent system failure from causing loss of all data was to extend leads from five of the active gages, plus two reference gages, through the bleeder holes, thus providing for manual measurement.

Debugging

The entire system was fabricated in the Y-12 Electronics Fabrication Shop, with fixed resistors as dummy gages and lead wire for each channel. The system was tested and calibrated to the dummy resistors to duplicate expected on-site operation. The amplifiers for each channel were tested for output linearity and span. Those amplifiers that were marginal or intermittent were replaced and that channel retested.

Burn In

Completion of the debugging stage left the system with all channels in operation at or near the design standards. The system was then put through a burn-in cycle of two weeks to detect any malfunctioning components during continuous operation. This test was deemed to be necessary since the system, once installed, would be approximately 90% inaccessible. Only two channels failed during this period and were left in an inoperative condition since several of the installed gages would be monitored with a manual backup.

SITE PREPARATION

Cleaning

Site preparation of the vessel for installation of the gages and instrumentation was extensive. Previously installed gages were removed and the thread roots examined by ultrasonic and

dye-penetrant inspection techniques. To perform these inspections, the thread roots were ground and honed to remove rust, scale, and small voids, seen in Figure 5.

Figure 5. THREAD ROOTS, SHOWING RUST, SCALE, AND SMALL VOIDS.

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Ultrasonic Inspection

Ultrasonic inspection used the contact-testing, pulse-echo method. The lower ID and plug threads were tested using a 5-MHz, Aerotech Miniature, transducer with an 80-degree plastic shoe that produced a shear wave in the threads. A standard ultrasonic model (Figures 6 and 7), with Elox slots of different dimensions, was used to calibrate the ultrasonic instrument. The first four threads were inspected. There was no indication of flaws observed during the inspection.

Dye-Penetrant Inspection

The first dye-penetrant inspection used Spotcheck Cleaner (SKC-5) as the solvent with penetrant (ZL-2) and developer (ZP-9), which is a nonaqueous wet developer. There were no

155672

Figure 6. STANDARD THREADS USED TO CALIBRATE THE ULTRASONIC INSTRUMENT.

cracks detected. However, there was considerable rust and pitting. There was a high amount of background fluorescence, making evaluation difficult.

The second inspection, performed after grinding and honing of the first four threads, as seen in Figure 5, differed only through the use of ZL-30A penetrant. There were no detectable cracks.

It should be noted that only the first four threads were inspected, based on statements by the stress analysts that this area is that which would result in catastrophic failure should cracking occur.

SYSTEM INSTALLATION

Gage

The gages were located in pairs due to the results received from gages previously installed. The gage pairs were located, as indicated in Figure 8, as follows: first thread - five pairs, second thread - three pairs, and third thread - two pairs. A pair of temperature and zero stress reference gages mounted on a steel block were located in the area near the printed circuit cards. Additionally, a pair of gages, which had been prestressed to approximately 2500 $\mu\text{m/in}$ were mounted on a steel block, and also located in the same area. These gages were installed to provide data on temperature compensation for the system.

Figure 7. CLOSEUP VIEW OF THE STANDARD-THREAD ASSEMBLY.

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Each gage location was further polished with emery cloth and passivated with metal conditioner and neutralizer. A catalyst was applied to the gage back and Eastman 910 cement to the attachment surface. Terminal tabs were similarly located at each gage site for attaching the gage and lead wires. A total of 24 gages (Micro-Measurements, Type EA-06-050SB-120) were mounted in the lower portion of the vessel. The gage resistance was $120.0 \pm 0.3\%$ ohms with a gage factor of $1.99 \pm 1.0\%$.

Twenty of the gages were installed in the root of the top three threads of the lower ID of the vessel. The gages were mounted in pairs at ten different locations, as noted in Figure 8. The remaining four gages were mounted in pairs to two compensator blocks. These compensator blocks were then mounted to the wall of the vessel above the threaded area.

Lead Wire

The lead wire from each pair of gage-terminal tabs was cut to 38 feet 9 inches. The lead wires of size 34 gage enamel wire, were cemented with Eastman 910 to the thread root at intervals of approximately six inches. The excess lead wire from the nearest gages was coiled and bonded to the surface of the vessel above the threaded area. The free ends of the lead were attached, by soldering, to a barrier strip (Cinch Jones, Type 141-10). Each gage-and-lead wire installation was completed by applying two coats of Gage Kote 2 and then applying two coats of Gage Kote 5 for waterproofing. Typical completed gage-and-lead wire installations can be seen in Figure 9.

Figure 8. LOCATIONS OF GAGE PAIRS. (View is from the Top of PV-2 Downward; Ch Indicates Channel of the Strain Monitor System; Pr Indicates Wire Pair of the Manual System)

Resistance readings of each gage and associated lead wires were taken after installation. These resistances are listed in Tables 1 and 2.

Electronics

System electronics were installed in three sections. The control console, as seen in Figure 10, was located in the control room, approximately 200 feet from the pressure vessel, with the PV-2 control console. The power supply, as viewed in Figure 11, for the bridge/amplifier and multiplexer cards was located on the lower support base for the pressure vessel. The bridge/amplifier and multiplexer cards were located in the free volume of the pressure vessel closure, pictured in Figure 12.

The circuit cards and barrier strips were mounted on standoff pads of Micarta, indicated in Figure 13. Power and signal lines were brought from the barrier strips to the power supply and control console through bleeder holes in the pressure vessel bottom plug, as Figure 14 reveals.

(a) View 1.

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(b) View 2.

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Figure 9. TYPICAL GAGE AND LEAD WIRE INSTALLATIONS.

Table 1
SYSTEM CALIBRATION DATA

Shunt Resistance = 100000
Gage Factor = 1.99
Gage Resistance = 120

Channel Number	Measured Resistance	Gage Factor	Microstrain	Delta Volts	Microstrain Per Volt
2	141.9	1.6829	842.0049	1.6200	519.7561
5	141.5	1.6876	837.2579	1.5800	529.9164
4	141.9	1.6829	842.0049	1.7100	492.4006
7	141.9	1.6829	842.0049	1.5700	536.3089
3	142.3	1.6781	846.7553	1.6700	507.0391
18	141.9	1.6829	842.0049	1.6300	516.5675
10	141.8	1.6841	840.8194	1.6400	512.6948
20	142.1	1.6805	844.3785	1.6100	524.4587
15	141.8	1.6841	840.8194	1.6300	515.8402
19	141.8	1.6841	840.8194	1.5500	542.4642
14	141.8	1.6841	840.8194	1.6300	515.8402
13	141.7	1.6853	839.6348	1.6400	511.9724
17	141.7	1.6853	839.6348	1.6100	521.5123
21	141.8	1.6841	840.8194	1.6700	503.4847
16	141.6	1.6864	838.4509	1.6400	511.2506
9	141.7	1.6853	839.6348	1.6300	515.1134
8	141.7	1.6853	839.6348	1.5300	548.7809

Table 2
MANUAL GAGE CALIBRATION DATA
(Gage Factor for Manual Gages)

Manual Gage Number	Measured Resistance (ohms)	Gage Factor
31	153.11	1.5597
32	153.40	1.5567
33	153.03	1.5605
34	152.73	1.5635
35	153.30	1.5577
36	153.70	1.5537
Ref.	152.83

Figure 10. CONTROL CONSOLE FOR THE ELECTRONICS SYSTEM.

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Figure 11. POWER SUPPLY FOR THE ELECTRONICS SYSTEM.

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(a) View 1.

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(b) View 2. (to the right of View 1)

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(c) View 3. (to the right of View 2)

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Figure 12. THREE VIEWS OF THE BRIDGE/AMPLIFIER AND MULTIPLEXER CARDS INSTALLED IN THE PRESSURE VESSEL.

Figure 13. METHOD AND LOCATION FOR MOUNTING THE CIRCUIT CARDS AND BARRIER STRIPS.

Figure 14. BOTTOM FEEDTHROUGHS FOR THE PRESSURE VESSEL.

157367

Calibration

Each gage-and-lead wire pair were connected to a bridge circuit and the output placed near zero. A fixed resistor was used to shunt the gage to simulate the midrange compression strain. An output voltage was obtained for future use as a span factor when calculating strain. Before final vessel closure, this process was checked several times to check drift of the various channels. No appreciable drift was noticed.

CALCULATIONS FOR INSTRUMENTATION

The gage factor (GF) is defined as: (2)

$$GF_{\text{gage}} = \frac{\Delta R/R}{\Delta L/L}, \quad (1)$$

where:

ΔR represents the change in resistance,

R the gage resistance,

ΔL the change in gage length, and

L the gage length.

Similarly, for an installation having a lead resistance, R_L , a gage factor may be defined as:

$$GF_{\text{new}} = \frac{\Delta R/R_g + R_L}{\Delta L/L}, \quad (2)$$

where:

ΔR represents the change in resistance,

R_g the gage resistance,

R_L the line resistance,

ΔL the change in gage length, and

L the gage length.

Solving for $\frac{\Delta L}{L}$ in Equation 1 yields:

$$\frac{\Delta L}{L} = \frac{\Delta R/R_g}{GF_{\text{gage}}}. \quad (3)$$

By substitution in Equation 2:

$$GF_{new} = \frac{R_g}{R_g + R_L} GF_{gage}$$

Since the measured resistance, R_m , after installation was known, the equation may be rewritten as:

$$GF_{new} = \frac{R_g}{R_m} GF_{true}$$

The standard strain equation for any gage is:

$$\frac{\Delta R}{R_g} = GF_{true} \frac{\Delta L}{L}$$

With a compensating Gage Factor, this expression becomes:

$$\frac{\Delta R}{R_g} = GF_{new} \frac{\Delta L}{L}$$

The expression can now be written:

$$\frac{\Delta L}{L} = \frac{\Delta R}{R_g} \frac{1}{GF_{new}}$$

which resolves to:

$$\frac{\Delta L}{L} = \frac{\Delta R}{R_g} \frac{R_m}{R_g GF_{true}}$$

To calibrate the instrumentation, a shunt resistor of 100,000 ohms was placed across R_m to simulate a ΔR where:

$$\frac{\Delta L}{L} = \frac{(R_m)(100,000)}{100,000 + R_m} \frac{R_m}{R_g GF_{true}}$$

Application of the shunt resulted in a change in voltage, ΔV , at the instrumentation output.

A program was prepared for the HP 9830, a programmable desk-top calculator, to determine the GF_{new} , $\frac{\Delta L}{L}$, and $\frac{\Delta L}{L}$ per volt. The program is given in Appendix A and the program data

generated are shown in Table 1. These data are used as a calculation factor and applied to the readings taken during a pressure run of PV-2.

A program was prepared for the HP 9830 to reduce the data from a pressure run. This program determines the change in voltage and converts this change to microstrain. A copy of the program is given in Appendix B. Appendix C is a copy of a file output program.

RESULTS

Due to the large volume of data available from the system, the HP 9830 programmable calculator was programmed to analyze the resulting data and format the output for easy interpretation. Appendixes A through C contain programs to determine calibration data, strain conversion, and the file output programs, respectively. Sample data received from the system are contained in Appendix D.

Appendix E contains a program prepared to provide graphical comparisons, as shown in Appendix D, of the system data and data received from the pressure vessel in 1964. The graphical comparisons comprise Appendix F of this report. These data are duplicated in Table 3 for comparison purposes.

Stress analysis of the vessel is contained in a separate report.⁽³⁾

Engineering drawings of the strain gage system are contained in Appendix G.

Table 3
COMPARISON OF RECENT DATA WITH EARLIER DATA

Channel/ Gage Number	1974 Data							1964 Data			
	Pressure (psi)										
	0	5000	10000	15000	15000 ⁽¹⁾	10000 ⁽¹⁾	5000 ⁽¹⁾	0	5000	10000	15000
2	0	104	423	755	764	548	166	0	248	466	714
32	0	322	652	869	869	706	309	0			
5	0	1081	1777	2423	2297	1937	1270	0	852	1487	2086
4	0	918	1533	2100	2071	1715	1170	0			
7	0	257	695	1199	1171	764	278	0	525	1061	1675
36	0	202	623	1070	1070	706	233	0			
3	0	314	657	955	931	669	298	0	585	1120	1774
18	0	522	1104	1651	1613	1157	542 ⁽²⁾				
10	0	672	1094	1485	1474	1220	798	0	981	1388	1804
33	0	437	758	956	956	788	505	0			
20	0	-339	-336	-198	-189	-258	-280	0	-119	59	357
15	0	-265	-204	22	72	-91	-163	0			
19	0	638	855	1047	1013	949	745	0	615	852	1100
35	0	500	600	710	710	692	575	0			
14	0	-188	-75	36	33	-57	-191	0	506	525	615
13	0	-309	-258	-209	-222	-255	-317	0			
17	0	403	506	595	575	522	415	0	466	783	1080
21	0	424	606	776	769	657	459	0			
16	0	353	563	733	752	651	430	0	347	595	857
31	0	334	543	625	625	564	371	0			

(1) Vessel pressure was higher than indicated due to location of the pressure sensor.

(2) No sensitivity.

CONCLUSIONS AND RECOMMENDATIONS

Data received from the system compares favorably with that obtained manually in 1964 in both magnitude and direction of strains occurring during pressure vessel operation.

The system provides data in a repeatable fashion and with much greater ease than previously obtainable. Additionally, data may be obtained on each run, if desired, rather than once each year as was previously done, using a special equipment setup and requiring coordination between operating groups.

Worthy of special note is the detection by the system of the existence of a pressure differential between the actual vessel pressure and the pressure as indicated by the normal PV-2 monitoring equipment. This condition was corrected by relocation of the pressure transducer from the inlet lines of the vessel to a point as near the vessel as practical for better control of vessel pressure.

Where feasible, a system such as that described in this report should be installed on operating pressure vessels to provide operating data rather than static data as a means of observing strains in such vessels. Observation and historical data obtained in this manner will allow detection of potential failures long before actual failure occurs.

REFERENCES

- (1) Long, P. J. and Ross, W. D.; *Strain Gage Test at the Threaded Closure on a Thirty-Inch Pressure Vessel* Y-1471; Union Carbide Corporation-Nuclear Division, Oak Ridge Y-12 Plant, Oak Ridge, Tennessee; November 20, 1974.
- (2) Perry, C. C. and Lissner, H. R.; *The Strain Gage Primer*, Second Edition, pp 18-30, 55-73; McGraw-Hill Book Company, Inc, New York, N. Y.
- (3) Pohto, H. A.; *Brittle Failure of a Large High-Pressure Isostat and a Comparison Analysis of Its Twin Vessel*, Y-1989; Union Carbide Corporation-Nuclear Division, Oak Ridge Y-12 Plant, Oak Ridge, Tennessee; August 20, 1975.

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APPENDIX A

PROGRAM TO CALCULATE SYSTEM CALIBRATION DATA (Output Shown in Table 1)

```

10 DIM A[6],B[6],C[6],D[6],E[6],F[6],G[6],H[6],I[6]
20 A=100000
30 B=1.99
40 C=120
50 PRINT "SHUNT RESISTANCE = "A
60 PRINT "GAGE FACTOR = "B
70 PRINT "GAGE RESISTANCE ="C
71 PRINT LIN2
80 PRINT "CHANNEL";TAB13"MEASURED";TAB26"GAGE";TAB52"DELTA";TAB60"MICROSTRAIN"
90 PRINT "NUMBER";TAB12"RESISTANCE";TAB25"FACTOR";TAB36"MICROSTRAIN";
91 PRINT TAB52"VOLTS";TAB61"PER VOLT"
93 PRINT LIN2
100 DISP "CHANNEL NUMBER";
110 INPUT I
120 DISP "MEASURED RESISTANCE";
130 INPUT D
140 E=(C/D)*B
150 F=((D-((D*A)/(D+A)))/(E*D))*(1E+06)
160 DISP "DELTA VOLTS";
170 INPUT G
180 H=F/G
190 PRINT TAB2,I;TAB13,D;
191 FIXED 4
192 PRINT TAB24,E;TAB37,F;TAB50,G;TAB60,H
193 STANDARD
194 PRINT LIN1
200 GOTO 100
210 END

```

APPENDIX B

PROGRAM TO CONVERT SYSTEM OUTPUT TO STRAIN DATA (Example in Appendix C)

```
10 DIM A[6],B[6],C[6],D[6],E[6],F[6],G[6],A$[4]
20 PRINT LIN15
30 DISP "CHANNEL";
40 INPUT D
50 DISP "STRAIN/VOLT";
60 INPUT A
70 DISP "UNSTRESSED VOLTS";
80 INPUT B
90 PRINT "CHANNEL="D
100 PRINT "STRAIN/VOLT="A
110 PRINT "PRESSURE","UNSTRESSED","STRESSED","DELTA VOLTS","STRAIN"
120 DISP "PRESSURE";
130 INPUT G
140 DISP "STRESSED VOLTS";
150 INPUT C
160 E=B-U
170 F=E*A
180 PRINT G,B,C,E,F
190 DISP "DONE";
200 INPUT A$
210 IF A$="YES" THEN 230
220 GOTO 120
230 PRINT LIN16
240 END
```

APPENDIX C

PROGRAM TO OUTPUT DATA FILE FROM THE PREVIOUS TEST (Output Same as Appendix D)

```

10 DIM A[6],B[6],C[6],D[6],E[6],F[6],G[6],A#[4],H[20,20],K[6]
20 DISP "FILE NUMBER";
30 INPUT K
40 LOAD DATA K,H
50 FOR I=2 TO H[1,2]
60 PRINT LIN2
70 PRINT "CHANNEL="H[I,1]
80 PRINT "STRAIN/VOLT="H[I,2]
90 PRINT "PRESSURE","UNSTRESSED","STRESSED","DELTA","MICROSTRAIN"
100 PRINT " (PSI) "," (VOLTS) "," (VOLTS)","VOLTS","(IN/IN)"
110 FOR J=4 TO H[I,1]
120 E=H[I,3]-H[I,J]
130 F=E*H[I,2]
140 PRINT H[I,J],H[I,3],H[I,J],E,F
150 NEXT J
160 PRINT LIN2
170 NEXT I
180 GOTO 10
190 END

```

APPENDIX D

SAMPLE STRAIN DATA

CHANNEL= 5

STRAIN/VOLT= 530

UNSTRESSED VOLTS=-2.851

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.851	0	0	0
1000	-1.964	-0.887	-470.11	-464.071
2000	-1.712	-1.139	-603.67	-597.631
3000	-1.398	-1.453	-770.00	-765.149
4000	-1.099	-1.752	-928.56	-924.168
5000	-0.801	-2.05	-1086.5	-1081.01
6000	-0.521	-2.33	-1234.9	-1232.704
7000	-0.229	-2.622	-1389.66	-1387.464
8000	-0.057	-2.794	-1480.82	-1478.075
9000	0.254	-3.105	-1645.65	-1642.356
10000	0.512	-3.363	-1782.39	-1777.449
11500	0.859	-3.71	-1966.3	-1959.712
12000	1.024	-3.875	-2053.75	-2047.162
13000	1.282	-4.133	-2190.49	-2181.706
14000	1.513	-4.364	-2312.92	-2301.391
15000	1.749	-4.6	-2408	-2423.177

CHANNEL= 4

STRAIN/VOLT= 492

UNSTRESSED VOLTS=-4.401

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-4.401	0	0	0
1000	-3.627	-0.774	-380.808	-374.769
2000	-3.38	-1.021	-502.332	-496.293
3000	-3.091	-1.31	-644.52	-639.579
4000	-2.799	-1.602	-788.184	-783.792
5000	-2.525	-1.876	-922.992	-917.502
6000	-2.26	-2.141	-1053.372	-1051.176
7000	-1.985	-2.416	-1188.677	-1186.476
8000	-1.714	-2.687	-1322.004	-1319.259
9000	-1.525	-2.876	-1414.992	-1411.698
10000	-1.276	-3.125	-1537.5	-1532.559
11500	-0.946	-3.455	-1699.86	-1693.272
12000	-0.785	-3.616	-1779.072	-1772.484
13000	-0.535	-3.866	-1902.072	-1893.288
14000	-0.31	-4.091	-2012.772	-2001.243
15000	-0.084	-4.317	-2123.964	-2109.141

CHANNEL= 7
 STRAIN/VOLT= 536
 UNSTRESSED VOLTS=-2.677

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.677	0	0	0
1000	-2.56	-0.117	-62.712	-56.673
2000	-2.478	-0.199	-106.664	-100.625
3000	-2.381	-0.296	-158.656	-153.715
4000	-2.286	-0.391	-209.576	-205.184
5000	-2.188	-0.489	-262.104	-256.614
6000	-2.062	-0.615	-329.64	-327.444
7000	-1.899	-0.778	-417.008	-414.812
8000	-1.708	-0.969	-519.384	-516.639
9000	-1.564	-1.113	-596.568	-593.274
10000	-1.371	-1.306	-700.016	-695.075
11000	-1.109	-1.568	-840.448	-833.86
12000	-0.982	-1.695	-908.52	-901.932
13000	-0.781	-1.896	-1016.256	-1007.472
14000	-0.599	-2.078	-1113.808	-1102.279
15000	-0.413	-2.264	-1213.504	-1198.681

CHANNEL= 3
 STRAIN/VOLT= 507
 UNSTRESSED VOLTS=-2.801

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.801	0	0	0
1000	-2.706	-0.095	-48.165	-42.126
2000	-2.609	-0.192	-97.344	-91.305
3000	-2.463	-0.338	-171.366	-166.425
4000	-2.318	-0.483	-244.881	-240.489
5000	-2.17	-0.631	-319.917	-314.427
6000	-2.031	-0.77	-390.39	-388.194
7000	-1.882	-0.919	-465.933	-463.737
8000	-1.735	-1.066	-540.462	-537.717
9000	-1.634	-1.167	-591.669	-588.375
10000	-1.495	-1.306	-662.142	-657.201
11000	-1.313	-1.488	-754.416	-747.828
12000	-1.229	-1.572	-797.004	-790.416
13000	-1.107	-1.694	-858.858	-850.074
14000	-0.99	-1.811	-918.177	-906.648
15000	-0.888	-1.913	-969.891	-955.068

CHANNEL= 18
 STRAIN/VOLT= 517
 UNSTRESSED VOLTS=-2.918
 PRESSURE STRESSED

(PSI)	(VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.918	0	0	0
1000	-2.759	-0.159	-82.203	-76.164
2000	-2.604	-0.314	-162.338	-156.299
3000	-2.375	-0.543	-280.731	-275.79
4000	-2.137	-0.781	-403.777	-399.385
5000	-1.897	-1.021	-527.857	-522.067
6000	-1.671	-1.247	-644.699	-642.503
7000	-1.429	-1.489	-769.813	-767.617
8000	-1.185	-1.733	-895.961	-893.216
9000	-1.012	-1.906	-985.402	-982.108
10000	-0.774	-2.144	-1108.448	-1103.507
11500	-0.469	-2.449	-1266.133	-1259.545
12000	-0.323	-2.595	-1341.615	-1335.027
13000	-0.098	-2.82	-1457.94	-1449.156
14000	0.105	-3.023	-1562.891	-1551.362
15000	0.305	-3.223	-1666.291	-1651.468

CHANNEL= 10
 STRAIN/VOLT= 513
 UNSTRESSED VOLTS=-0.102
 PRESSURE STRESSED

(PSI)	(VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-0.102	0	0	0
1000	0.079	0.401	240.750	240.714
2000	0.608	-0.71	-364.23	-358.191
3000	0.832	-0.934	-479.142	-474.201
4000	1.032	-1.134	-581.742	-577.35
5000	1.219	-1.321	-677.673	-672.183
6000	1.392	-1.494	-766.422	-764.226
7000	1.569	-1.671	-857.223	-855.027
8000	1.746	-1.848	-948.024	-945.279
9000	1.871	-1.973	-1012.149	-1008.855
10000	2.04	-2.142	-1098.846	-1093.905
11500	2.204	-2.060	-1210.750	-1207.17
12000	2.369	-2.471	-1267.623	-1261.035
13000	2.535	-2.637	-1352.781	-1343.997
14000	2.674	-2.776	-1424.008	-1412.559
15000	2.821	-2.923	-1499.499	-1484.676

CHANNEL= 2
 STRAIN/VOLT= 520
 UNSTRESSED VOLTS=-2.608

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.608	0	0	0
1000	-2.501	-0.107	-55.64	-49.601
2000	-2.458	-0.15	-78	-71.961
3000	-2.485	-0.123	-63.96	-59.019
4000	-2.466	-0.142	-73.84	-69.448
5000	-2.398	-0.21	-109.2	-103.71
6000	-2.294	-0.314	-163.28	-161.084
7000	-2.166	-0.442	-229.84	-227.644
8000	-2.027	-0.581	-302.12	-299.375
9000	-1.923	-0.685	-356.2	-352.906
10000	-1.786	-0.822	-427.44	-422.499
11500	-1.605	-1.003	-521.56	-514.972
12000	-1.515	-1.093	-568.36	-561.772
13000	-1.378	-1.23	-639.6	-630.816
14000	-1.256	-1.352	-703.04	-691.511
15000	-1.128	-1.48	-769.6	-754.777

CHANNEL= 20
 STRAIN/VOLT= 524
 UNSTRESSED VOLTS=-2.224

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.224	0	0	0
1000	-2.593	0.369	193.356	199.395
2000	-2.661	0.437	228.988	235.027
3000	-2.732	0.508	266.192	271.133
4000	-2.803	0.579	303.396	307.788
5000	-2.861	0.637	333.788	339.278
6000	-2.908	0.684	358.416	360.612
7000	-2.938	0.714	374.136	376.332
8000	-2.929	0.705	369.42	372.165
9000	-2.909	0.685	358.94	362.234
10000	-2.856	0.632	331.168	336.109
11500	-2.908	0.584	306.016	312.604
12000	-2.773	0.549	287.676	294.264
13000	-2.714	0.49	256.76	265.544
14000	-2.653	0.429	224.796	236.325
15000	-2.574	0.35	183.4	198.223

CHANNEL= 13
 STRAIN/VOLT= 516
 UNSTRESSED VOLTS=-2.435

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.435	0	0	0
1000	-2.786	0.351	181.116	187.155
2000	-2.804	0.369	190.404	196.443
3000	-2.874	0.439	226.524	231.460
4000	-2.909	0.474	244.584	248.976
5000	-2.938	0.503	259.548	265.038
6000	-2.957	0.522	269.352	271.548
7000	-2.966	0.531	273.996	276.192
8000	-2.943	0.508	262.128	264.873
9000	-2.908	0.473	244.068	247.362
10000	-2.821	0.386	199.176	204.117
11500	-2.711	0.276	142.416	149.004
12000	-2.656	0.221	114.036	120.624
13000	-2.557	0.122	62.952	71.736
14000	-2.501	0.066	34.056	45.585
15000	-2.364	-0.071	-36.636	-21.813

CHANNEL= 19
 STRAIN/VOLT= 542
 UNSTRESSED VOLTS=-2.749

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.749	0	0	0
1000	-2.179	-0.57	-308.94	-302.901
2000	-1.951	-0.798	-432.516	-426.477
3000	-1.778	-0.971	-526.282	-521.341
4000	-1.656	-1.093	-592.406	-588.014
5000	-1.561	-1.188	-643.896	-638.406
6000	-1.475	-1.274	-690.508	-688.312
7000	-1.389	-1.36	-737.12	-734.924
8000	-1.304	-1.445	-783.19	-780.445
9000	-1.243	-1.506	-816.252	-812.958
10000	-1.165	-1.584	-858.528	-853.587
11500	-1.058	-1.691	-916.522	-909.934
12000	-1.01	-1.739	-942.538	-935.95
13000	-0.93	-1.819	-985.898	-977.114
14000	-0.859	-1.89	-1024.38	-1012.851
15000	-0.79	-1.959	-1061.778	-1046.955

CHANNEL= 14
 STRAIN/VOLT= 516
 UNSTRESSED VOLTS=-1.781

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-1.781	0	0	0
1000	-2.131	0.35	180.6	186.639
2000	-2.188	0.407	210.012	216.051
3000	-2.193	0.412	212.592	217.533
4000	-2.169	0.388	200.208	204.6
5000	-2.135	0.354	182.664	188.154
6000	-2.099	0.318	164.088	166.284
7000	-2.052	0.271	139.836	142.032
8000	-2.003	0.222	114.552	117.297
9000	-1.966	0.185	95.46	98.754
10000	-1.917	0.136	70.176	75.117
11500	-1.858	0.077	39.732	46.32
12000	-1.827	0.046	23.736	30.324
13000	-1.776	-5.00000E-03	-2.58	6.204
14000	-1.73	-0.051	-26.316	-14.787
15000	-1.682	-0.099	-51.084	-36.261

CHANNEL= 13
 STRAIN/VOLT= 512
 UNSTRESSED VOLTS=-2.584

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.584	0	0	0
1000	-3.059	0.475	243.2	249.239
2000	-3.143	0.559	286.208	292.247
3000	-3.178	0.594	304.128	309.069
4000	-3.182	0.598	306.176	310.568
5000	-3.176	0.592	303.104	308.594
6000	-3.161	0.577	295.424	297.62
7000	-3.138	0.554	283.648	285.844
8000	-3.117	0.533	272.896	275.641
9000	-3.101	0.517	264.704	267.998
10000	-3.078	0.494	252.928	257.869
11500	-3.053	0.469	240.128	246.716
12000	-3.04	0.456	233.472	240.06
13000	-3.013	0.429	219.648	228.432
14000	-2.991	0.407	208.384	219.913
15000	-2.965	0.381	195.072	209.895

CHANNEL= 17
 STRAIN/VOLT= 522
 UNSTRESSED VOLTS=-1.816

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-1.816	0	0	0
1000	-1.625	-0.191	-99.702	-93.663
2000	-1.465	-0.351	-183.222	-177.183
3000	-1.283	-0.533	-278.226	-273.285
4000	-1.125	-0.691	-360.702	-356.31
5000	-1.034	-0.782	-408.204	-402.714
6000	-0.986	-0.83	-433.26	-431.064
7000	-0.949	-0.867	-452.574	-450.378
8000	-0.911	-0.905	-472.41	-469.665
9000	-0.883	-0.933	-487.026	-483.732
10000	-0.838	-0.978	-510.516	-505.575
11500	-0.789	-1.027	-536.094	-529.506
12000	-0.765	-1.051	-548.622	-542.034
13000	-0.728	-1.088	-567.936	-559.152
14000	-0.692	-1.124	-586.728	-575.199
15000	-0.648	-1.168	-609.696	-594.873

CHANNEL= 21
 STRAIN/VOLT= 503
 UNSTRESSED VOLTS=-2.091

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.091	0	0	0
1000	-1.937	-0.154	-77.462	-71.423
2000	-1.76	-0.331	-166.493	-160.454
3000	-1.549	-0.542	-272.626	-267.685
4000	-1.361	-0.73	-367.19	-362.798
5000	-1.238	-0.853	-429.059	-423.569
6000	-1.158	-0.933	-469.299	-467.103
7000	-1.086	-1.005	-505.515	-503.319
8000	-1.011	-1.08	-543.24	-540.495
9000	-0.967	-1.124	-565.372	-562.078
10000	-0.876	-1.215	-611.145	-606.204
11500	-0.784	-1.307	-657.421	-650.833
12000	-0.737	-1.354	-681.062	-674.474
13000	-0.663	-1.428	-718.284	-709.5
14000	-0.595	-1.496	-752.488	-740.959
15000	-0.519	-1.572	-790.716	-775.893

CHANNEL= 16
 STRAIN/VOLT= 511
 UNSTRESSED VOLTS=-2.681

PRESSURE (PSI)	STRESSED (VOLTS)	DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.681	0	0	0
1000	-2.531	-0.15	-76.65	-70.611
2000	-2.375	-0.306	-156.366	-150.327
3000	-2.222	-0.459	-234.549	-229.608
4000	-2.097	-0.584	-298.424	-294.032
5000	-1.979	-0.702	-358.722	-353.232
6000	-1.885	-0.796	-406.756	-404.56
7000	-1.801	-0.88	-449.68	-447.484
8000	-1.712	-0.969	-495.159	-492.414
9000	-1.643	-1.038	-530.418	-527.124
10000	-1.569	-1.112	-568.232	-563.291
11500	-1.472	-1.209	-617.799	-611.211
12000	-1.423	-1.258	-642.838	-636.25
13000	-1.347	-1.334	-681.674	-672.89
14000	-1.282	-1.399	-714.889	-703.36
15000	-1.217	-1.464	-748.104	-733.281

CHANNEL= 9
 STRAIN/VOLT= 515
 UNSTRESSED VOLTS=-3.121
 PRESSURE STRESSED
 (PSI) (VOLTS)

		DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-3.121	0	0	0
1000	-3.103	-0.018	-9.27	-3.231
2000	-3.103	-0.018	-9.27	-3.231
3000	-3.102	-0.019	-9.785	-4.844
4000	-3.102	-0.019	-9.785	-5.393
5000	-3.103	-0.018	-9.27	-3.78
6000	-3.105	-0.016	-8.24	-6.044
7000	-3.103	-0.018	-9.27	-7.074
8000	-3.101	-0.02	-10.3	-7.555
9000	-3.097	-0.024	-12.36	-9.066
10000	-3.093	-0.028	-14.42	-9.479
11500	-3.09	-0.031	-15.965	-9.377
12000	-3.079	-0.042	-21.63	-15.042
13000	-3.09	-0.031	-15.965	-7.181
14000	-3.073	-0.048	-24.72	-13.191
15000	-3.07	-0.051	-26.265	-11.442

CHANNEL= 8
 STRAIN/VOLT= 549
 UNSTRESSED VOLTS=-2.343
 PRESSURE STRESSED
 (PSI) (VOLTS)

		DELTA VOLTS	MICROSTRAIN (IN/IN)	MICROSTRAIN (IN/IN)
0	-2.343	0	0	0
1000	-2.332	-0.011	0.000	0
2000	-2.332	-0.011	-6.039	0
3000	-2.334	-9.00000E-03	-4.941	0
4000	-2.335	-8.00000E-03	-4.392	0
5000	-2.333	-0.01	-5.49	0
6000	-2.339	-4.00000E-03	-2.196	0
7000	-2.339	-4.00000E-03	-2.196	0
8000	-2.338	-5.00000E-03	-2.745	0
9000	-2.337	-6.00000E-03	-3.294	0
10000	-2.334	-9.00000E-03	-4.941	0
11500	-2.331	-0.012	-6.580	0
12000	-2.331	-0.012	-6.588	0
13000	-2.327	-0.016	-8.784	0
14000	-2.322	-0.021	-11.529	0

APPENDIX E

PROGRAM TO PLOT COMPARISON DATA (Graphical Output is Provided in Appendix F)

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10 DIM A[6],B[6],C[6],D[6]
20 DEG
30 DISP "SCALE";
40 INPUT A,B,C,D
50 SCALE A,B,C,D
60 PLOT A,C
70 PLOT B,C
80 PLOT B,D
90 PLOT A,D
100 PLOT A,C,-1
110 PLOT 10000,C+(D-C)/100,0
120 CPLOT -4.5,2,3
130 LABEL (*,2,1.7,0,1)"PRESSURE"
140 FOR I=1 TO 3
150 X=5000*I
160 PLOT X,C,-2
170 PLOT X,C+(D-C)/100,-1
180 CPLOT -3,+0.3
190 LABEL (*,2,1.7,0,1)X
200 NEXT I
210 PLOT A+250,((D-C)/2)+C,0
220 CPLOT 10,-2
230 LABEL (*,2,1.7,90,1)"MICROSTRAIN"
240 LABEL (*,2,1.7,0,1)
250 FOR I=1 TO ((D-C)-200)/200
260 Y=(100*I)*2+C
270 PLOT A,Y,-2
280 PLOT A+250,Y,-1
290 CPLOT 0.6,-0.3
300 LABEL (*,2,1.7,0,1)Y
310 NEXT I
320 DISP "DATA SET ONE";
330 INPUT E,F,G
340 PLOT 5000,E,-2
350 CPLOT -0.3,-0.3
360 LABEL (*)"X"
370 PLOT 5000,E,-2
380 PLOT 10000,F
390 CPLOT -0.3,-0.3
400 LABEL (*)"X"
410 PLOT 10000,F,-2
420 PLOT 15000,G
430 CPLOT -0.3,-0.3
440 LABEL (*)"X"
450 DISP "DATA SET TWO";
460 INPUT E,F,G
470 PLOT 5000,E,-2
480 CPLOT -0.3,-0.3
490 LABEL (*)"X"
500 PLOT 5000,E,-2
510 PLOT 10000,F
520 CPLOT -0.3,-0.3
530 LABEL (*)"X"
540 PLOT 10000,F,-2
550 PLOT 15000,G
560 CPLOT -0.3,-0.3
570 LABEL (*)"X"
580 DISP "DATA SET THREE";
590 INPUT E,F,G
600 PLOT 5000,E,-2
610 CPLOT -0.3,-0.3
620 LABEL (*)"0"
630 PLOT 5000,E,-2
640 PLOT 10000,F
650 CPLOT -0.3,-0.3
660 LABEL (*)"0"
670 PLOT 10000,F,-2
680 PLOT 15000,G
690 CPLOT -0.3,-0.3
700 LABEL (*)"0"
710 DISP "DATA SET FOUR";
720 INPUT E,F,G
730 PLOT 5000,E,-2
740 CPLOT -0.3,-0.3
750 LABEL (*)"0"
760 PLOT 5000,E,-2
770 PLOT 10000,F
780 CPLOT -0.3,-0.3
790 LABEL (*)"0"
800 PLOT 10000,F,-2
810 PLOT 15000,G
820 CPLOT -0.3,-0.3
830 LABEL (*)"0"
840 DISP "DATA SET FIVE";
850 INPUT E,F,G
860 PLOT 5000,E,-2
870 CPLOT -0.3,-0.3
880 LABEL (*)"+"
890 PLOT 5000,E,-2
900 PLOT 10000,F
910 CPLOT -0.3,-0.3
920 LABEL (*)"+"
930 PLOT 10000,F,-2
940 PLOT 15000,G
950 CPLOT -0.3,-0.3
960 LABEL (*)"+"
970 A=0
980 B=20000
990 C=0
1000 D=1200
1010 SCALE A,B,C,D
1020 PLOT 4000,1150,0
1030 LABEL (*)"X"
1040 PLOT 4000,1100,0
1050 LABEL (*)"0"
1060 PLOT 4000,1050,0
1070 LABEL (*)"+"
1080 END

```

APPENDIX F

GRAPHIC COMPARISONS

APPENDIX G

STRAIN GAGE SYSTEM DRAWINGS

Figure G-1. MULTIPLEXER SCHEMATIC.

Figure G-2. STRAIN GAGE SCHEMATIC.

ITEM	QTY	DESCRIPTION
13	47EA	TERMINAL WIRE LUG.
12	1EA	R9 POT, TRIM, 10K
11	EA	C3, C4, C6, C8, C9 CAP, 0.1UF
10	3EA	C1, C2, C5 CAP, 1UF
9	1EA	R7 RES, .00K, 1/2W
8	3EA	R5, R6 & R8 RES, 10K, 1/2W
7	4EA	R1, R2, R3 & R4 RES, 5K 1/2W
6	1EA	INTEGRATER CKT SU72741
5	1EA	INTEGRATER CKT SU7493
4	1EA	INTEGRATER CKT SU7472
3	1EA	INTEGRATER CKT SU7413
2	1EA	INTEGRATER CKT SU7401
1	2EA	MULTIPLEXER, HI 506A

1/16" DRILL

TERMINAL WIRE LUGS (TYPICAL)

ALL COMPONENT HOLES WILL
BE $\frac{7}{16}$ DRILL.

Figure G-3. PRINTED CIRCUIT BOARD ASSEMBLY.

Figure G-4. CONTROL CABINET SCHEMATIC.

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