DESIGN, CONSTRUCTION, AND CALIBRATION OF A DIFFERENTIAL PRESSURE GAGE FOR USE IN HIGH PRESSURE LOW VOLUME FLOW MEASUREMENT

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With respect to construction of the differential pressure gage, special recognition must go to Mr. J. R. Brown of Brown Oil Tools Inc., Houston, Texas. The material, machines, and much of the labor used in the construction of the gage was supplied by Mr. Brown at no charge to the writer.

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CHAPTER I

INTRODUCTION

The purpose of this thesis was to design, construct, and calibrate a differential pressure gage. The gage is to be used in conjunction with a venturi meter for measurement of fluid flow in small pipes and tubes. The pressure gage must withstand working pressures which are of the order of magnitude of 5,000 psig, while measuring differential pressures of up to 15 inches of mercury with a high degree of accuracy. One of the design requirements was that the gage should have an accuracy of $\pm$ 1.0%.

The high working pressures prohibited the use of standard manometers in such a system. Yet an accuracy equal to that of the manometer was needed to measure pressure differential in such a high pressure, low volume flow.

The degree of accuracy required for the differential pressure gage was not obtained. However, the results indicated several ways in which the accuracy of the gage could be improved. Further experimentation using the existing equipment and improved operating procedure should yield accuracy within the required $\pm$ 1.0%.

CHAPTER II

DIFFERENTIAL PRESSURE INDICATION

The first problem which was considered in the design of a differential pressure gage was to decide on the indicating device to be used for detecting pressure differential.

Existing differential pressure measurement gages employ mechanical indicator devices; that is, movement of a part of the gage is caused by a differential pressure acting on the gage. The movement is transmitted to a calibrated dial by a mechanical linkage. This type of gage, however, is used for relatively large values of differential pressure.

It was decided that the use of a mechanical linkage would present problems in design, and would result in inherent inaccuracies due to friction of sealing glands. Such a design would require a push rod or indicator arm to be brought out of the gage in order that the movement caused by the differential pressure could be observed. Such indicators would have to be sealed off to prevent pressure losses from within the gage.

Due to the apparent disadvantages of a mechanical linkage indicator, it was decided that such a system would not be satisfactory.

The next logical choice was some type of electrical indicator device. In such a device a mechanical movement would have to be transformed to an electrical signal.

The use of a strain gage or series of strain gages to sense the deflection of a body subjected to a differential pressure was selected as the best method for producing an electrical signal.

There are a number of ways that a pressure difference can result in a movement which could be sensed by a strain gage. Most pressure gages now in use operate by the elongation and contraction of a bellows. Using this principle a differential pressure introduced across a bellows with the high pressure introduced within the bellows and the lower pressure surrounding it would cause the bellows to expand. A strain gage attached to the body of this bellows would detect its movement. An alternate method would be to allow the bellows to push against a small beam or leaf spring, to which a strain gage would be attached.

Either of these two methods seems practical but slightly complicated. Another practical method which is less complicated would be to allow the differential pressure to act upon the two sides of a thin diaphragm. The electrical output of strain gages attached to the diaphragm could be calibrated to correspond to differential pressure.

It was decided that since diaphragm material was available in the form of shim stock, which comes in a wide range of thicknesses, the gage would be built using a diaphragm and a series of strain gages to indicate differential pressure.

From THEORY OF PLATES AND SHELLS by Timoshenko, the differential equation for deflection of circular plates or diaphragms is:

$$\frac{1}{r}\frac{d}{dr}\left\{r\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dw}{dr}\right)\right]\right\} = \frac{q}{D}$$

where r = radial distance

w = deflection of plate

q = unit load

D = flexural rigidity of plate

Since the edges of the diaphragm would have to be clamped to prevent communication of pressure across it, the slope $(\frac{dw}{dr})$ would equal 0 at the edges and the center. In the solution of the differential equation with these boundary conditions, the maximum stress occurring in the diaphragm is given by:

$$\sigma_{max} = \frac{3}{4}\frac{qa^2}{h^2}$$

where a = radius

h = plate thickness

Assuming that the maximum allowable yield stress is 30,000 psi, the maximum pressure differential which can be applied to the diaphragm for different thicknesses of shim stock is

0.003-in. thickness q = 0.65-in. of Hg

0.005-in. thickness q = 1.80-in. of Hg

0.010-in. thickness q = 7.24-in. of Hg

In the experiment diaphragms thicker than 0.005-in. did not give enough deflection to indicate on the strain gage meter without exceeding the metal's elastic limit. Therefore, diaphragms of 0.003-in. and 0.005-in. were used even though the metal was operated in the plastic range. This should not affect the reproducibility of data as long as the zero deflection reading of the strain gages is noted and taken as the base for each run.

CHAPTER III

CONSTRUCTION

The first model of the differential pressure gage proved unsuccessful. In order to use standard parts whenever available, heavy duty 2-in.-11½ bull plugs and flanges were used as the pressure vessel. The bull plugs and flanges were screwed together and then welded. The welding was a precaution against thread leaks. A diaphragm of 0.005-in. thickness was cut to fit the flanges and was clamped in place between the flanges by tightening the flange bolts. Pressure taps were drilled in the end of each bull plug and tapped with 1/8-in. pipe thread. A Conax packing gland was mounted in one flange. The gland was fastened by 1/8-in. pipe thread in a tapped hole drilled on a 30° angle, as seen in Figure 1. The Conax gland contained a teflon sealing element which prevented leaks around the electrical leads which connected the strain gage with the strain gage meter.

With the bull plugs welded in place and the flanges bolted together, a differential pressure introduced across the gage acted on the diaphragm held between the flanges. Pressure leaks around the diaphragm were checked by one "O" ring mounted in the face of each flange.

Immediately, a disadvantage of this arrangement was apparent.

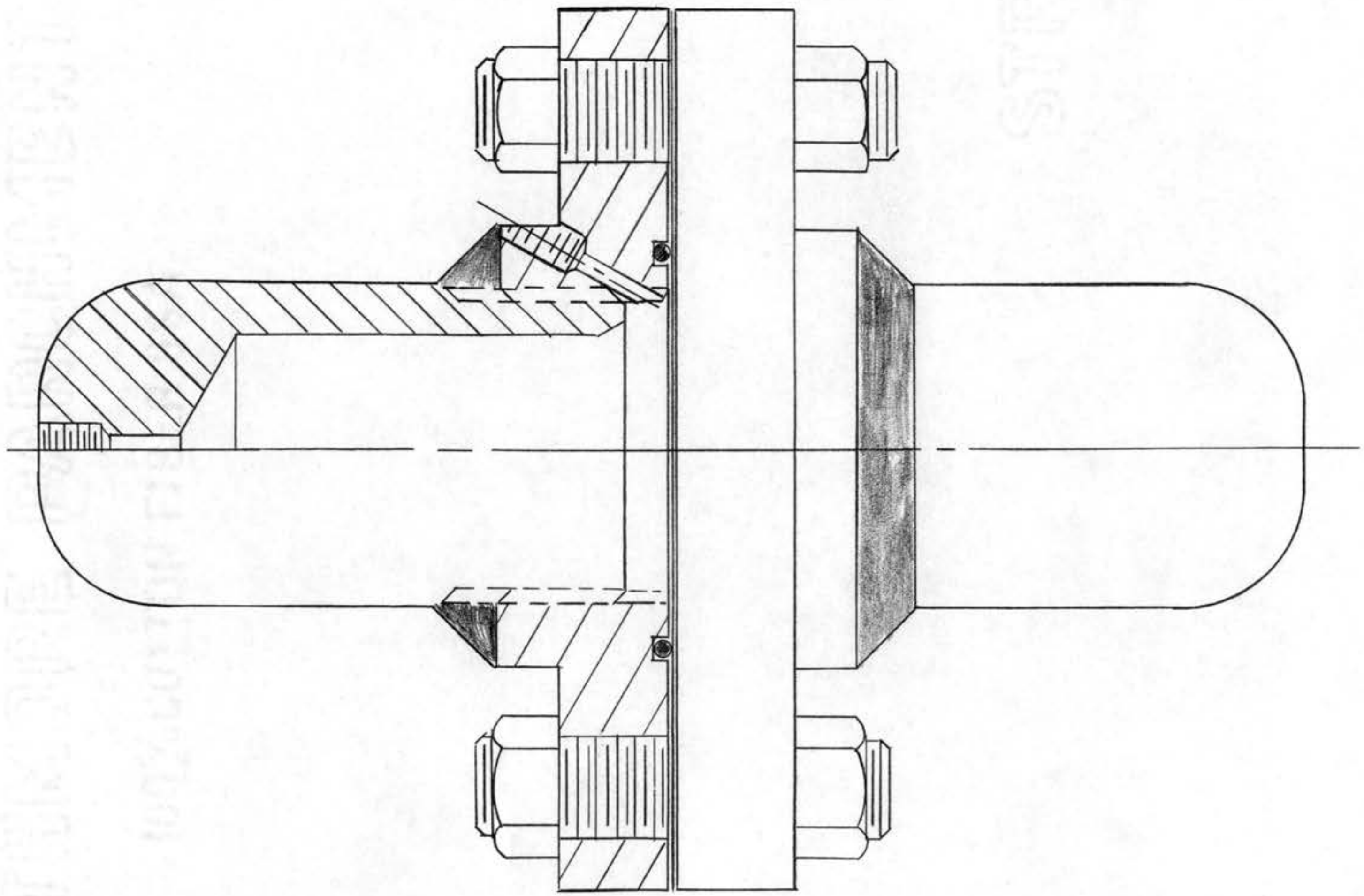

Figure 1. First Model Differential Pressure Gage

In order to attach the strain gage leads to the strain gage meter, which was used for measuring the output, the meter leads had to be pulled through the packing gland three to four inches. The strain gage leads were then soldered to the meter leads. To get the diaphragm in position the meter leads had to be pulled back through the gland until the diaphragm was flush with the flange. This procedure caused damage to the strain gage. It tended to tear the leads loose from the body of the gage.

The awkward procedure of mounting the diaphragm was a minor disadvantage however. This became apparent after several test runs were made. No correlation could be made between runs. Reproducibility of data was poor; various runs differed by $\pm$ 30%. The major cause of the poor reproducibility seemed to be lack of pre-stress in the diaphragm. When the diaphragm was stressed by a pressure differential and then released, it assumed some position other than that of its original position. Its action was similar to that of the bottom of a large can or tub. When a force was applied, it would "pop" out and would not come back unless another force on the opposite side was applied.

A new gage had to be designed to overcome these two disadvantages. Plugs and mating flanges were made with a six-threads-per-inch Acme thread. This thread screws together quickly and is a very strong thread form. Two "O" ring grooves were cut in the plug bodies, as seen in Figure 2. In this arrangement all the pressure was held by the "O" rings which sealed between the plug and the flange. The plugs

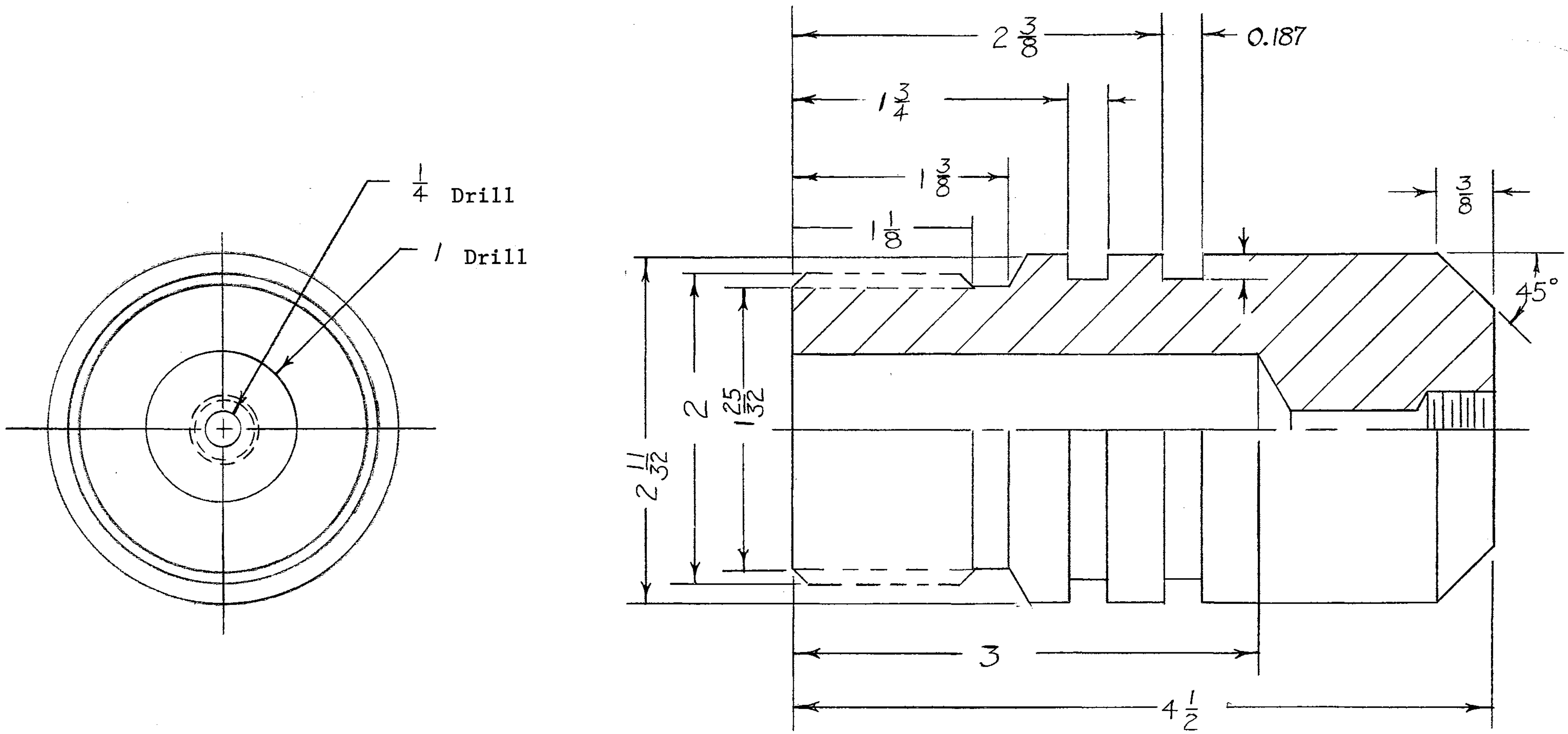

Figure 2. Bull Plug

were easily removable because the threads needed only to be screwed together hand tight. With the plugs removed, the strain gage meter leads could be connected to the strain gage leads after the diaphragm was in place.

To solve the second problem, two rings were machined with a 60° angle on the inside diameter. Figure 3 shows these rings. A mating groove was machined in each flange as shown in Figure 4. The groove in the flanges was machined 0.004-in. larger on the inside diameter than the rings. The diaphragm was then placed between the rings, held by six 5/16-in. Allen screws, and placed in the mating grooves of the flanges. As the flanges were pulled together, the rings were forced to expand, thereby stressing the diaphragm.

In this revised design only one flange was drilled and tapped for a Conax packing gland. In calibrating the gage, however, strain gages were placed on both sides of the diaphragm. For calibration, one side of the gage was exposed to atmospheric pressure while the other side was exposed to pressures ranging from 0 to 15 in. of Hg. Since only one side held pressure, the leads on the low pressure side were brought out of the pressure tap in the end of the plug. In actual running conditions the low pressure side flange would have to be drilled and tapped to accommodate a packing gland in the same manner as the high pressure side.

Figure 5 shows the assembly of the components which make up the differential pressure gage.

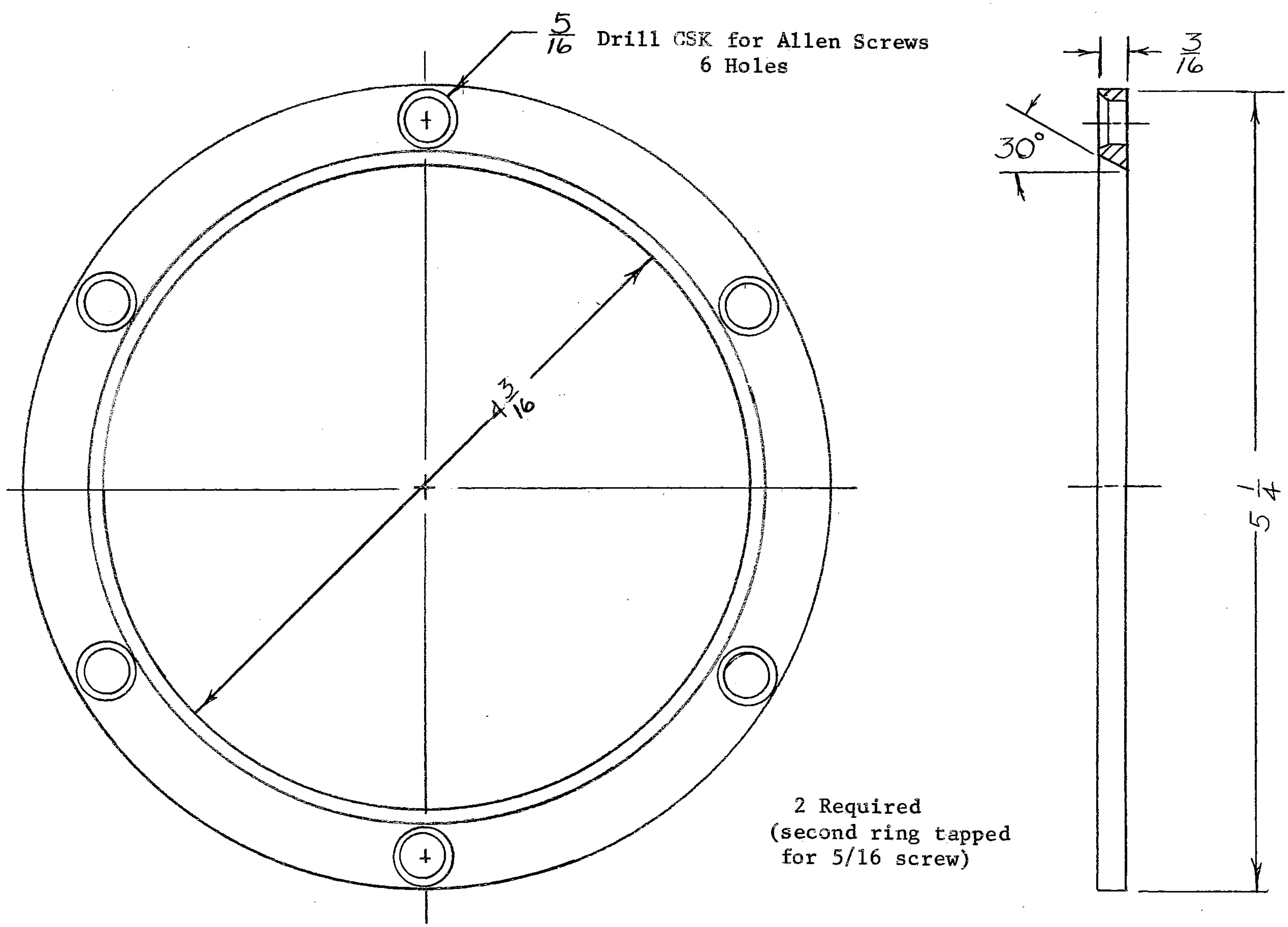

Figure 3. Holder Ring

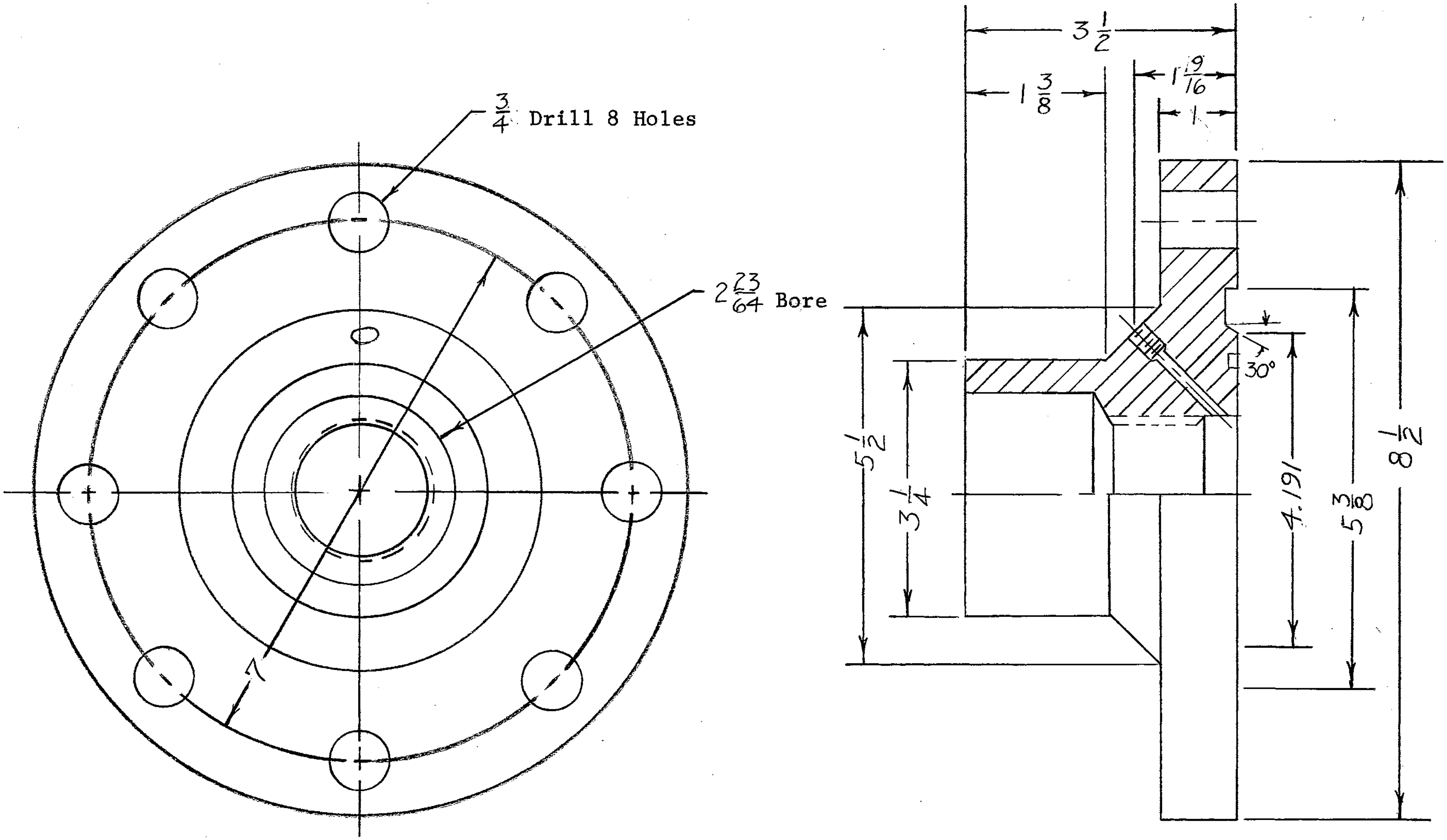

Figure 4. Flange

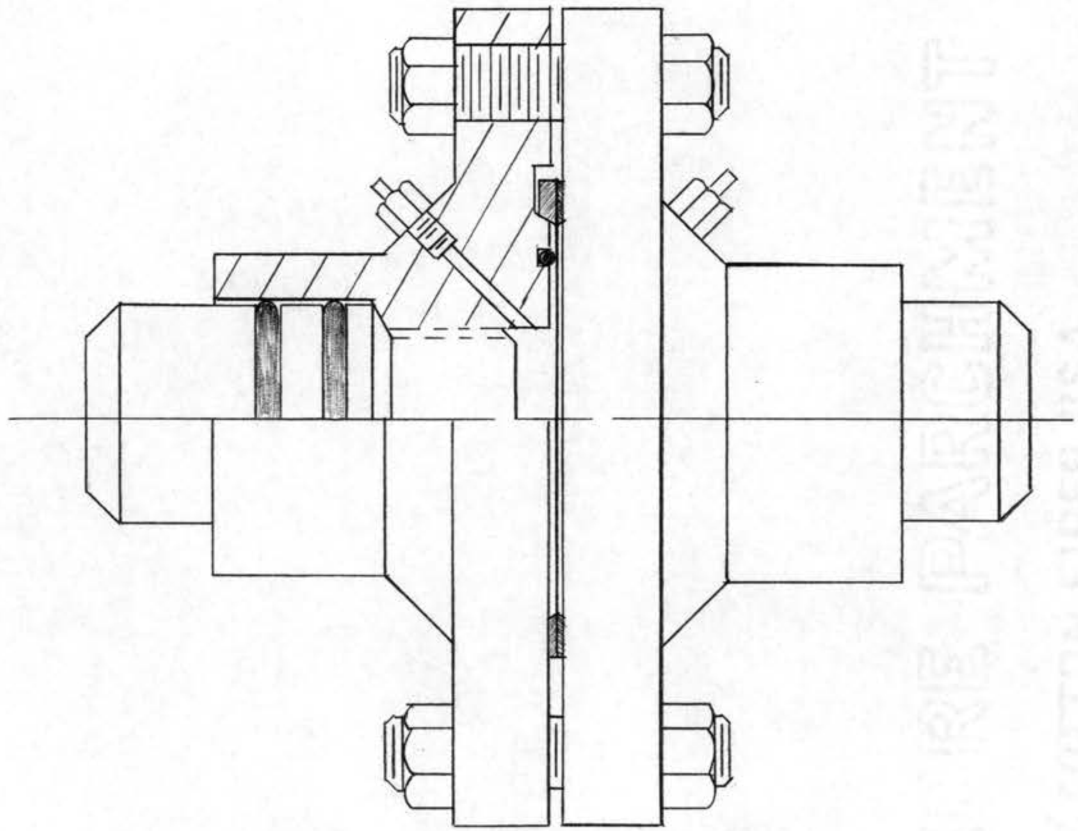

Figure 5. Assembled Differential Pressure Gage

CHAPTER IV

OPERATION

Since only differential pressure was measured, calibration of the gage was achieved by leaving the low pressure side open to the atmosphere and varying the high pressure side from 0 to 15 in. of Hg. The pressure was supplied by a hand pump which charged a storage tank connected to the high pressure side of the gage. A "U" tube manometer in the system measured the pressure on the high pressure side of the gage. This enabled the electrical output of the strain gages to be measured as a function of the pressure differential.

To compensate for any change of properties in the diaphragm due to temperature variation both the Young and Baldwin strain gage meters used in the calibration operate with two gages. One gage is called the active gage, the other, the compensating gage. Each of these gages act as one arm of the indicator bridge. During operation of the differential pressure gage, the active strain gage was placed on one side of the diaphragm and the compensating strain gage on the other side of the diaphragm. Figure 6 shows the wiring diagram of the bridge. By mounting one strain gage on one side of the diaphragm and the other strain gage on the opposite side, any change in the properties of the metal was canceled and the signal was doubled. The phenomenon of doubling the signal was due to the fact that when the

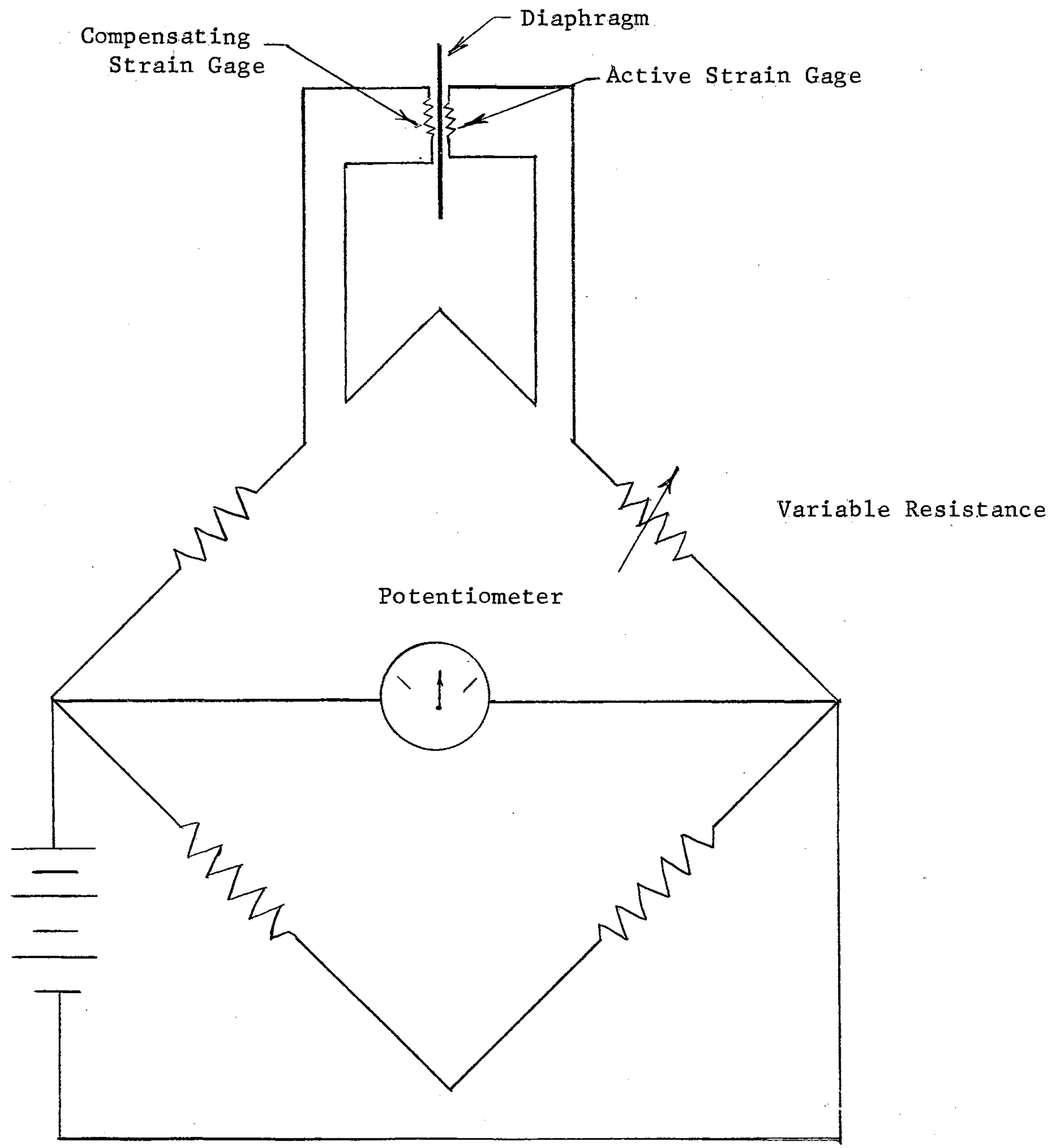

Figure 6. Wiring Diagram for Strain Gage Meter

diaphragm was stressed one side was in tension while the other side was in compression by the same amount. This doubling of the signal was a very desirable side effect because it allowed a more accurate reading from the strain gage meter. A temperature compensated strain gage could also have been used. A resistor could take the place of the compensating strain gage, but this would result in a reduction in the signal.

Figure 7 is a sketch of the apparatus used in the calibration operation.

Apparatus for Calibration Operation

Manometer - Standard 36-in. mercury "U" tube

Strain Gage Meter - Young's A-1 Strain Gage Meter and Baldwin Model K Strain Gage Meter

Strain Gages - SR-4, Type AD-7

Air Storage Tank - Three foot length of 4-in. pipe welded at each end

Tubing and Fittings - 1/4-in. copper

Calibration Procedure

1. The strain gage meter was balanced, and the dial reading was recorded, with zero pressure on the high side of the gage.

2. The valve on the air storage tank was opened and pressure was allowed to build up one increment in the high side of the pressure gage. This pressure was then recorded.

3. The strain gage meter was balanced, and the dial reading was recorded.

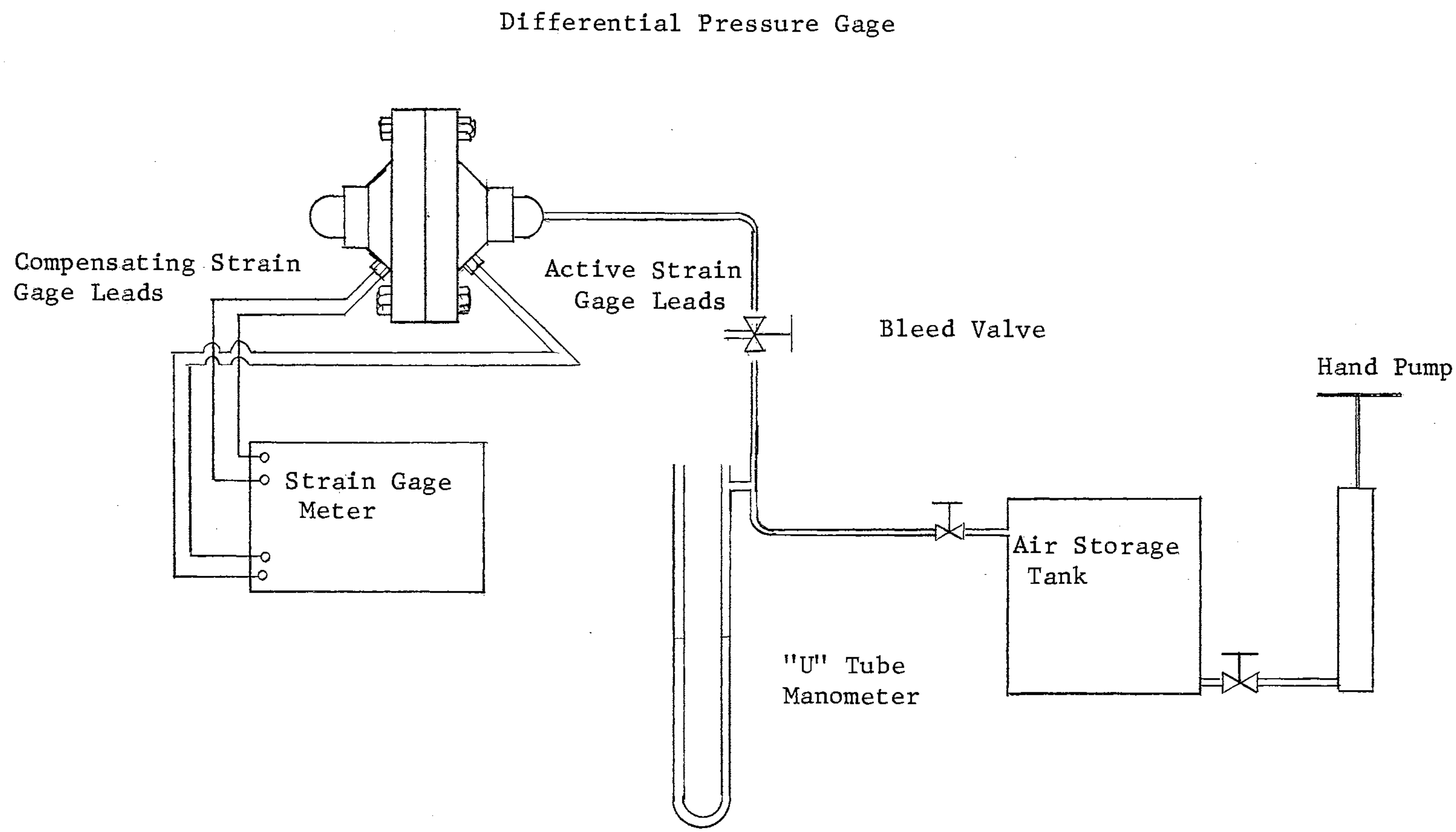

Figure 7. Apparatus Diagram

4. The bleed valve was opened and the pressure was bled from the pressure gage back to 0-in. of Hg.

5. The strain gage meter was balanced, and the dial reading was recorded.

6. The difference between the recorded readings in step one and step five was then entered in a difference column.

7. The procedure was then repeated for each increment until the desired maximum pressure was reached.

CHAPTER V

RESULTS

The first set of data was taken using a Young's A-1 strain gage meter. The results are shown in Table I. This machine was about twelve years old and tended to be unstable at certain times. It was not determined if the trouble was in the mechanical operation or in the electrical circuits. No circuit diagram was available on the machine so it could not be checked.

In order to increase the accuracy of the data, a Baldwin Model K strain gage meter was borrowed from the Civil Engineering department. Operation of this machine proved to be superior to that of the Young's meter. It is this writer's opinion that the results obtained using the Baldwin meter were more reliable than the results obtained from the Young's meter.

Two sets of data were obtained using a diaphragm thickness of 0.005-in, one set using the Young's meter and the other set using the Baldwin meter. One set of data was obtained using a diaphragm thickness of 0.003-in. and the Baldwin meter. These results using the Baldwin meter are shown in Tables II and III.

Graphs were plotted to show the data and were coded as follows: Run 1, •, Run 2, ○, Run 3, □, Run 4, △.

TABLE I

ELECTRICAL OUTPUT VS DIFFERENTIAL PRESSURE

Two SR-4, Type AD-7 Strain Gages
Diaphragm thickness 0.005 in.
Young's A-1 Strain Gage Meter

	Hg	Gage (Pressured)	Gage (Unpressured)	△
RUN 1				
	0	29.4	29.4	0
	1.05	28.4	29.6	1.0
	2.1	25.7	29.9	3.9
	3.0	24.3	30.3	5.6
	4.05	22.8	30.3	7.5
	5.0	21.4	30.6	8.9
	6.0	20.0	30.6	10.6
	7.0	18.5	30.6	12.0
	8.0	17.3	30.8	13.3
	9.0	16.3	30.9	14.5
	10.0	15.2	30.9	15.7
RUN 2				
	0	29.9	29.9	0
	1.0	28.9	29.9	1.0
	2.1	26.2	30.2	3.7
	3.1	24.6	30.4	5.6
	4.0	23.2	30.4	7.2
	5.0	22.8	30.6	8.6
	6.0	20.3	30.7	10.6
	7.0	19.0	30.8	11.7
	8.0	17.8	30.9	13.0
	9.0	16.5	31.1	14.4
	10.0	15.3	31.3	15.8
RUN 3				
	0	30.3	30.3	0
	1.2	28.2	30.4	2.1
	2.0	26.7	30.6	3.7
	3.0	25.3	30.8	5.3
	4.0	23.8	31.0	7.0
	5.0	22.4	31.0	8.6
	6.0	20.8	31.1	10.2
	7.0	19.5	31.3	11.6
	8.0	18.0	31.5	13.3
	9.0	17.0	31.6	14.5
	10.0	15.8	31.7	15.8

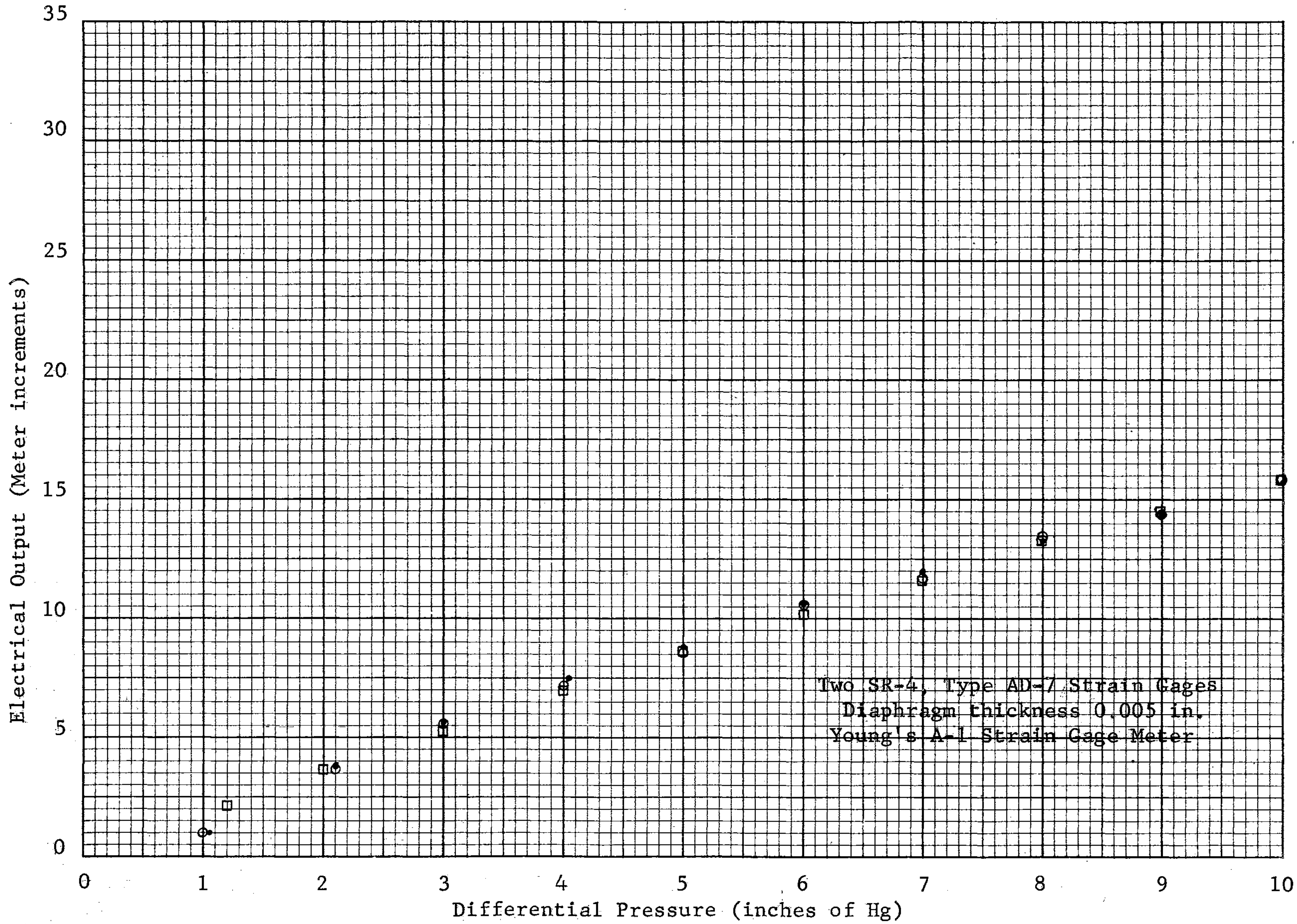

Figure 8. Electrical Output Vs Differential Pressure

TABLE I (Continued)

ELECTRICAL OUTPUT VS DIFFERENTIAL PRESSURE

Two SR-4, Type AD-7 Strain Gages
Diaphragm thickness 0.005 in.
Young's A-1 Strain Gage Meter

	Hg	Gage (Pressured)	Gage (Unpressured)	△
RUN 4				
	0	31.0	31.0	0
	6.1	20.2	30.8	10.8
	7.1	19.0	31.0	11.8
	8.0	17.8	31.8	13.2
	9.0	16.6	31.2	15.2
	10.0	15.5	31.5	15.7
	11.0	14.5	32.0	17.0
	12.0	12.8	30.9	18.2
	13.0	11.7	31.3	19.2
	14.0	10.9	31.2	20.4
	15.0	10.0	31.1	21.2
RUN 5				
	0	30.7	30.7	0
	6.0	19.7	30.4	11
	7.0	18.5	30.8	11.9
	8.0	17.8	30.9	13.0
	9.0	16.5	31.4	14.5
	10.0	15.2	31.2	16.2
	11.0	14.2	31.9	17.0
	12.0	13.6	32.0	18.3
	13.0	12.8	32.3	19.2
	14.0	12.0	32.4	20.3
	15.0	11.3	32.4	21.1
RUN 6				
	0	32.5	32.5	0
	6.0	21.9	32.5	10.6
	7.0	20.7	32.6	11.8
	8.0	19.4	32.6	13.2
	9.0	17.8	32.4	14.8
	10.0	16.6	32.6	15.8
	11.0	15.8	32.6	16.8
	12.0	14.5	32.8	18.1
	13.0	13.7	32.7	19.1
	14.0	12.5	32.7	20.2
	15.0	10.9	32.3	21.3

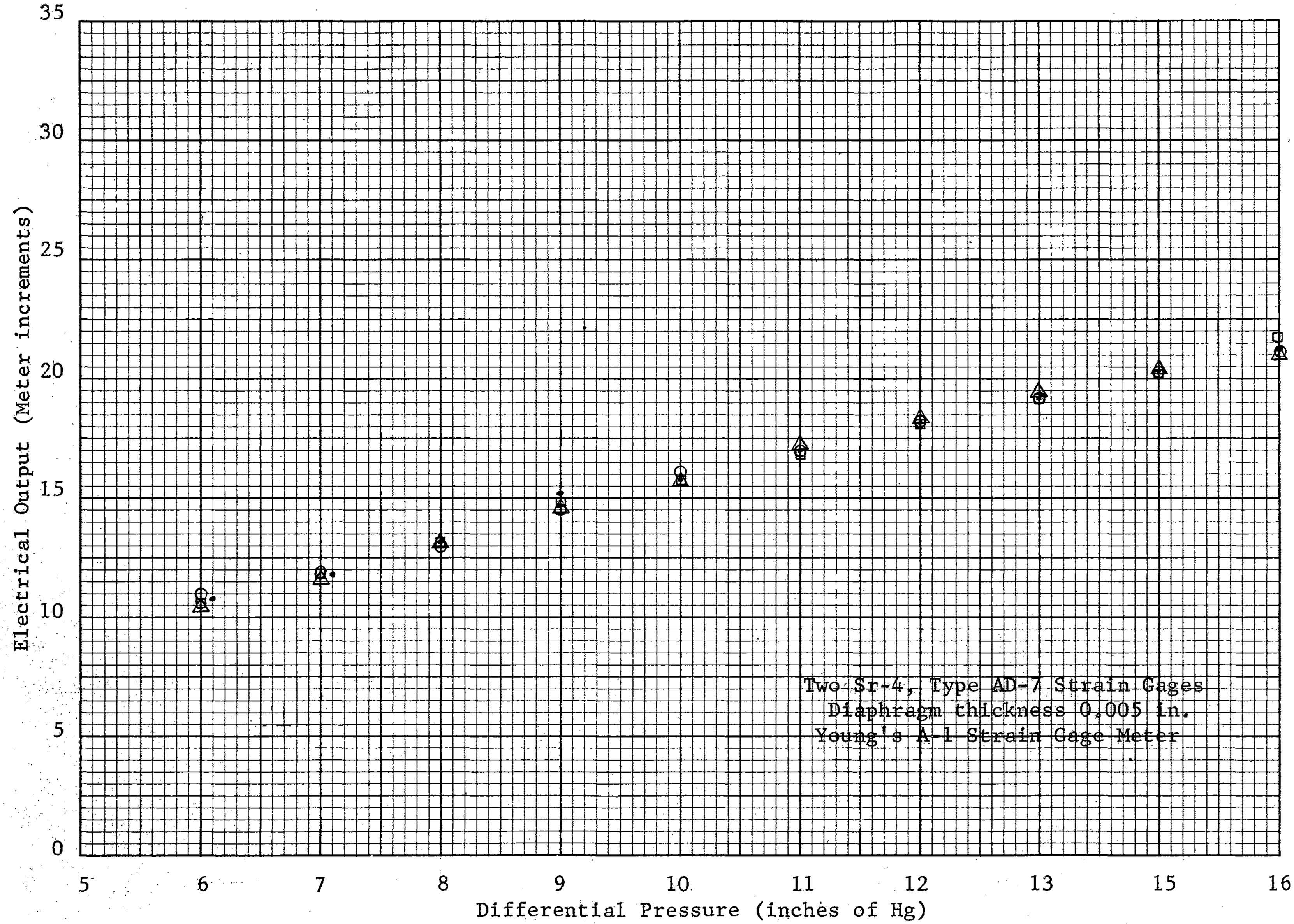

Figure 9. Electrical Output Vs Differential Pressure

TABLE II

ELECTRICAL OUTPUT VS DIFFERENTIAL PRESSURE

Two SR-4, Type AD-7 Strain Gages
Diaphragm thickness 0.005 in.
Baldwin Model K Strain Gage Meter

	Hg	Gage (Pressured)	Gage (Unpressured)	Δ
RUN 1				
	0	1066	1066	0
	1.0	1050	1070	16
	2.0	1036	1070	34
	3.0	1020	1072	50
	4.0	1005	1075	67
	5.0	991	1076	84
	6.0	979	1079	97
	7.0	967	1080	112
	8.0	952	1080	128
	9.0	940	1081	140
	10.0	930	1080	151
RUN 2				
	0	1080	1080	0
	1.2	1069	1090	14
	2.1	1058	1096	32
	3.0	1049	1100	47
	4.0	1030	1100	70
	5.0	1020	1101	80
	6.0	1008	1106	93
	7.0	995	1109	111
	8.0	982	1110	127
	9.0	971	1110	139
RUN 3				
	0	1100	1100	0
	1.0	1080	1100	20
	2.0	1069	1102	31
	3.0	1055	1109	47
	4.0	1046	1111	63
	5.0	1032	1119	78
	6.0	1021	1120	99
	7.0	1011	1122	109
	8.0	1000	1126	122
	9.0	990	1130	136

TABLE II (Continued)

ELECTRICAL OUTPUT VS DIFFERENTIAL PRESSURE

Two SR-4, Type AD-7 Strain Gages
Diaphragm thickness 0.005 in.
Baldwin Model K Strain Gage Meter

	Hg	Gage (Pressured)	Gage (Unpressured	Δ
RUN 4				
	0	1113	1113	0
	1.1	1099	1128	14
	2.05	1090	1130	38
	3.0	1080	1130	50
	4.0	1064	1130	66
	5.0	1050	1101	80
	6.0	1012	1110	89
	7.0	1001	1116	109
	8.0	991	1119	125
	9.0	981	1120	139

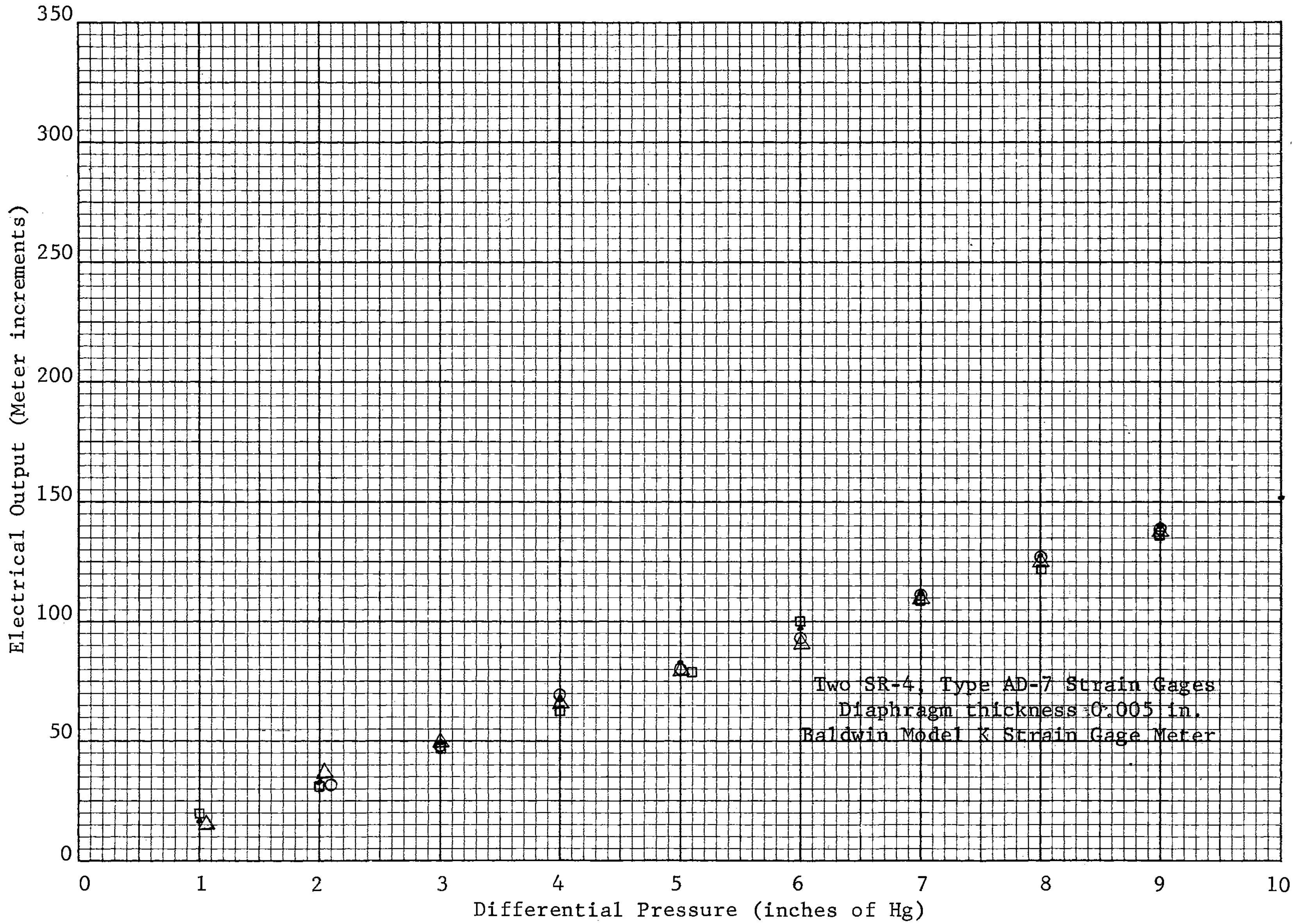

Figure 10. Electrical Output Vs Differential Pressure

TABLE II (Continued)

ELECTRICAL OUTPUT VS DIFFERENTIAL PRESSURE

Two SR-4, Type AD-7 Strain Gages
Diaphragm thickness 0.005 in.
Baldwin Model K Strain Gage Meter

	Hg	Gage (Pressured)	Gage (Unpressured)	△
RUN 5				
	0	1089	1089	0
	6.0	991	1091	98
	7.0	980	1098	111
	8.0	974	1100	124
	9.0	960	1100	140
	10.0	950	1101	150
	11.0	941	1101	160
	12.0	932	1104	169
	13.0	923	1105	181
	14.0	917	1108	188
	15.0	909	1109	199
RUN 6				
	0	1102	1102	0
	6.0	1007	1104	95
	7.0	993	1106	111
	8.0	981	1106	125
	9.0	970	1107	136
	10.0	959	1100	148
	11.0	942	1100	158
	12.0	932	1100	168
	13.0	920	1101	180
	14.0	910	1100	191
	15.0	902	1101	198
RUN 7				
	0	1095	1095	0
	6.0	1000	1096	95
	7.0	984	1095	112
	8.0	970	1095	125
	9.0	959	1093	136
	10.0	946	1092	147
	11.0	933	1093	159
	12.0	922	1092	171
	13.0	911	1091	181
	14.0	901	1092	190
	15.0	891	1095	201

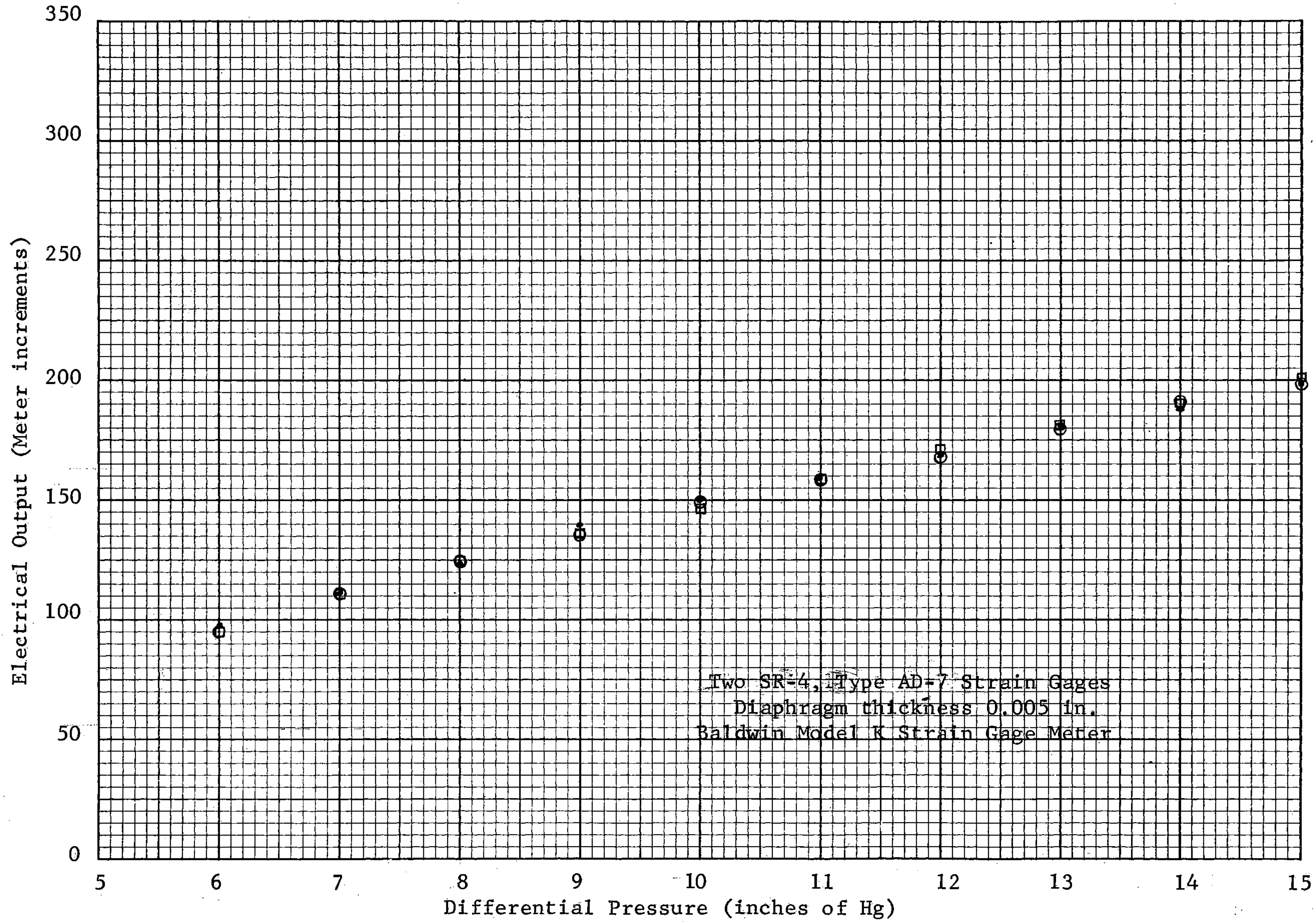

Figure 11. Electrical Output Vs Differential Pressure

TABLE III

ELECTRICAL OUTPUT VS DIFFERENTIAL PRESSURE

Two SR-4, Type AD-7 Strain Gages
Diaphragm thickness 0.003 in.
Baldwin Model K Strain Gage Meter

	Hg	Gage (Pressured)	Gage (Unpressured)	Δ
RUN 1				
	0	210	210	0
	1.0	195	210	15
	2.0	180	213	30
	3.0	165	216	48
	4.0	150	218	66
	5.0	133	220	85
	6.0	118	220	102
	7.0	104	222	116
	8.0	88	229	134
	9.0	70	229	159
	10.0	50		170
RUN 2				
	0	225	225	0
	1.0	210	225	15
	2.0	192	225	33
	3.0	179	228	46
	4.0	160	228	68
	5.0	145	230	83
	6.0	128	230	102
	7.0	110	230	120
	8.0	90	232	140
	9.0	70	232	162
	10.0	51		181
RUN 3				
	0	230	230	0
	1.0	215	230	15
	2.0	200	230	30
	3.0	182	230	48
	4.0	167	232	63
	5.0	150	232	82
	6.0	130	235	102
	7.0	115	236	120
	8.0	95	236	141
	9.0	77	238	159
	10.0	60		178

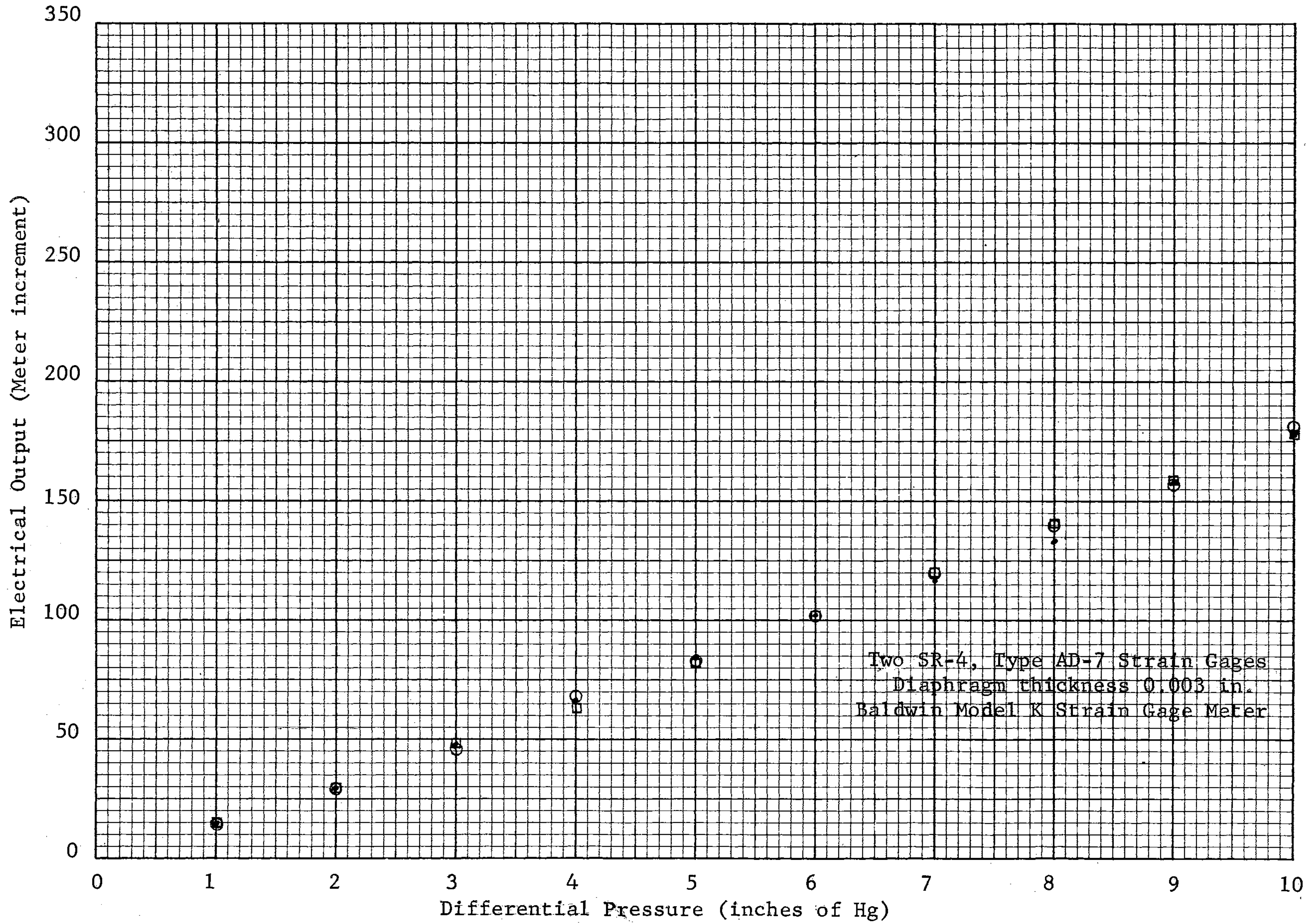

Figure 12. Electrical Output Vs Differential Pressure

TABLE III (Continued)

ELECTRICAL OUTPUT VS DIFFERENTIAL PRESSURE

Two SR-4, Type AD-7 Strain Gages
Diaphragm thickness 0.005 in.
Baldwin Model K Strain Gage Meter

	Hg	Gage (Pressured)	Gage (Unpressured)	△
RUN 4				
	0	260	260	0
	6.0	143	260	117
	7.0	125	260	135
	8.0	104	260	156
	9.0	85	260	175
	10.0	65	260	195
	11.0	49	262	211
	12.0	30	262	232
	13.0	10	262	252
	14.0	0.99	1260	261
	15.0	968		282
RUN 5				
	0	1258	1258	0
	6.0	1140	1260	118
	7.0	1121	1260	139
	8.0	1101	1260	159
	9.0	1084	1260	176
	10.0	1068	1261	192
	11.0	1057	1260	213
	12.0	1028	1260	232
	13.0	1009	1261	252
	14.0	990	1260	271
	15.0	970		290
RUN 6				
	0	1257	1257	0
	6.0	1142	1260	115
	7.0	1124	1260	136
	8.0	1103	1260	157
	9.0	1084	1260	176
	10.0	1068	1260	192
	11.0	1046	1260	214
	12.0	1028	1260	232
	13.0	1009	1260	251
	14.0	989	1260	271
	15.0	969		291

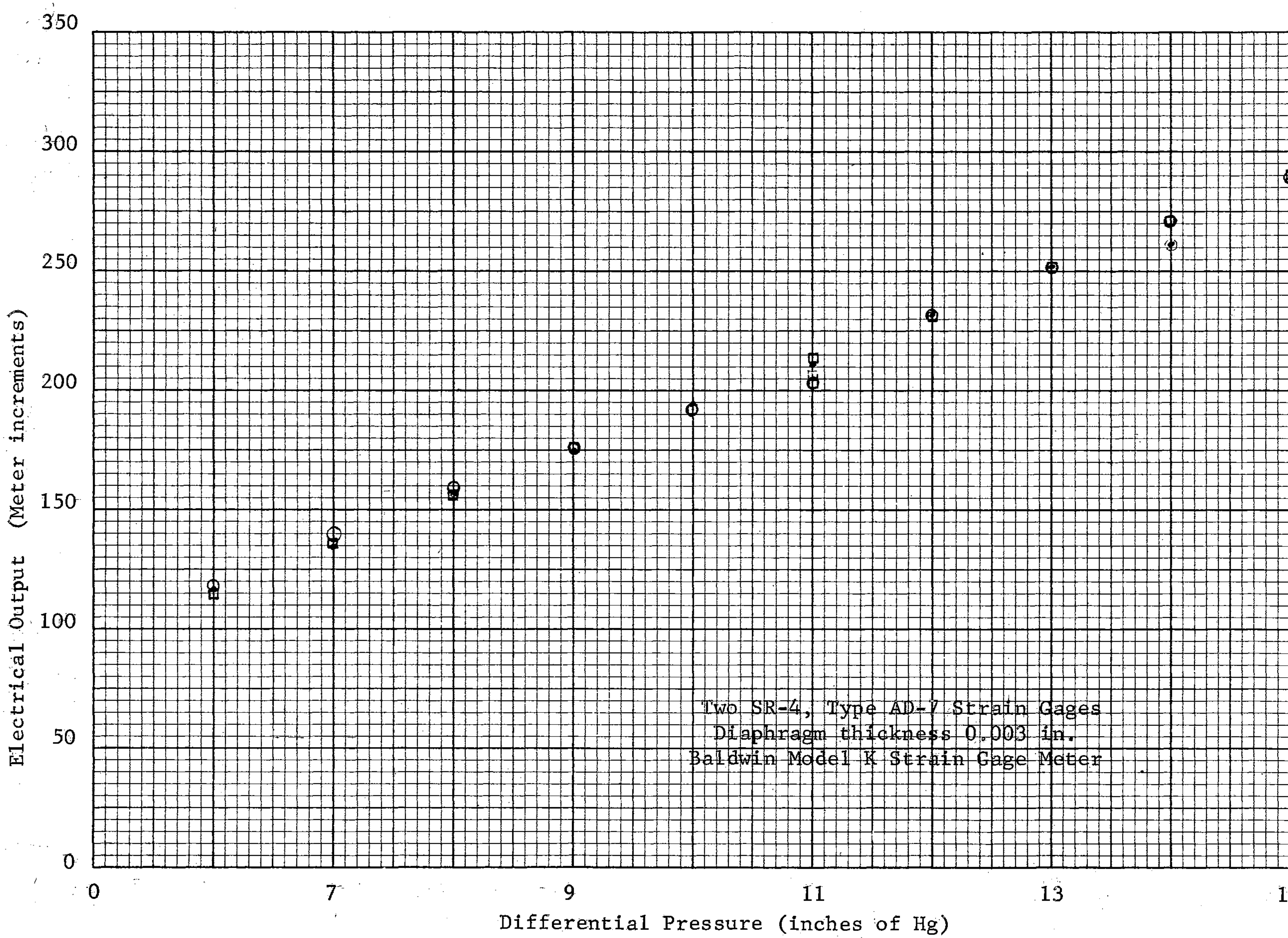

Figure 13. Electrical Output Vs Differential Pressure

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

The reproducibility of data did not seem to be within the limits of accuracy required for the differential pressure gage. There was some problem in the way in which the accuracy could best be expressed.

The data points, when plotted, followed very nearly a smooth curve, with the exception of an occasional wild point. A curve drawn as close as possible to the mean of the data points by sight could then be assumed correct. It is this writer's opinion that the accuracy of the data points do not warrant mathematical curve fitting. Assuming such a mean curve to be correct, the accuracy of reproducibility could be expressed as the per cent deviation of a point away from the mean.

Another method of measuring accuracy would be to take the difference of the maximum and minimum values of deflection at a given pressure and divide by twice the average value of the deflection. This method would give an accuracy based on reproducibility of the data.

Such a definition would give less accurate results at low values of electrical output and higher accuracy at large values of electrical output.

Example:

From the data taken with the Young's strain gage meter with a 0.005-in. thick diaphragm, the largest difference in electrical output on Figure 8 occurs at 4 in. of Hg.

$$\frac{7.5 - 7.0}{2(7.25)} \times 100 = \pm 3.0\%$$

while at 2-in. Hg.,

$$\frac{3.9 - 3.7}{2(3.8)} \times 100 = \pm 2.6\%$$

It may be seen from these examples that the accuracy is not too good a representation of the actual reliability of the data. At 4-in. of Hg. the difference in maximum and minimum values of electrical output is 0.5 while at 2-in. Hg. the difference is only 0.2. Yet the readings at 2-in. Hg. are only $\pm$ 0.4% more accurate than the readings at 4-in. Hg.

The accuracy on the upper end of the pressures improves very rapidly. From Figure 9 at 15-in. of Hg.,

$$\frac{21.8 - 21.2}{2(21.5)} \times 100 = \pm 1.4\%$$

At this range, a difference in electrical output of 0.6 gives a $\pm$ 1.4% accuracy while a difference in electrical output of 0.2 at 2-in. of Hg. gives an accuracy of $\pm$ 2.6%.

Defining accuracy in this way should give a conservative estimate of any pressure picked off the graph for some given value of deflection.

Through the use of this definition of accuracy it should be easy to increase the accuracy of data. By attaching several strain gages to a diaphragm and connecting them in series, the deflection read from the strain gage meter would be greatly magnified. If the difference in maximum and minimum deflection at a given pressure were not increased by the same factor, a more accurate reading would occur. Observation of the operation of the meters showed a tendency for instability at the smaller readings of deflection. Hence, it is believed that increasing the signal will result in more stable results and a higher degree of accuracy.

It is also possible to increase the accuracy by other means. The standard manometer used in the calibration process cannot be read with any accuracy beyond 0.05-in. of Hg. This fact alone gives a 5% error in reading 1-in. of Hg. The accuracy of calibration would be greatly increased with a manometer which could be read within 0.01-in. of Hg.

The thin diaphragms used in producing the data of this thesis were operated almost altogether in the plastic range of the metal. It is possible that using a thicker diaphragm which would operate below the yield point of the metal would give more accurate data. The only disadvantage to this is the fact that the signal would have to be amplified. If two standard SR-4, type AD-7 strain gages were used, the signal would be too weak to record. Here again several strain gages could be connected in series to give a readable electrical output.

When using the differential pressure gage for actual flow measurement each new diaphragm constructed should be calibrated individually. This is due to any variation in the thickness of the metal and the placement of the strain gages. Through the assumption that the metal had a uniform thickness and some method existed to locate each gage exactly, individual calibration would not be necessary.

With improvement in the accuracy of the calibration curves the differential pressure gage should give reliable static pressure measurement. If variable pressures were encountered, a recording device could be incorporated into the system to plot deflection vs time. From such a plot an overall average pressure could be obtained and an average flow rate calculated.

VITA

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