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DIFFERENTIAL PRESSURE MERCURY MANOMETER

Technological Spinoff Report

March 1973

Bendix Corporation
Kansas City, Missouri

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DIFFERENTIAL PRESSURE MERCURY MANOMETER

Prepared by R. J. Russell

Bendix Kansas City Division has developed and evaluated a differential pressure mercury manometer for calibrating pressure transducers from 1 to 50 torr.

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SUMMARY

A mercury differential pressure manometer has been designed and constructed in the Bendix Kansas City Metrology Laboratory to calibrate absolute and differential pressure transducers from 1 to 50 torr. Manometer measurements have an uncertainty of less than ± 0.015 torr. The development of the manometer and an error analysis of the working system are described.

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DISCUSSION

Accurate calibration of absolute and differential pressure transducers within the range of 1 to 50 torr has long been a problem in the Bendix Kansas City Metrology Laboratory. Instruments used in the past to perform calibrations in this range--the McLeod gage, the Hass barometer, and the dead weight piston gage--each have inherent problems in providing an adequate standard in this range. The Bendix McLeod gage is limited to a maximum pressure of 5 torr, which is inadequate for calibrating most transducers. The Hass barometer covers the necessary range, but its accuracy of ± 0.2 torr is inadequate to support many calibration needs. The dead weight piston gage is ideal except for its limitation as an absolute pressure standard.

SCOPE AND PURPOSE

The purpose of this project was to develop an instrument for calibrating absolute and differential pressure transducers in the range of 1 to 50 torr. The accuracy desired was ± 0.015 torr.

National Bureau of Standards (NBS) Technical Note 420, used as a guide throughout this project, proved helpful. However, several modifications were made to the NBS design which increased accuracy and reduced problems in surface detection.

ACTIVITY

Design Considerations

It was necessary to solve four fundamental problems before the manometer could be effective. These problems were contact sensitivity, vibration, temperature, and sealing.

Contact Sensitivity

It is extremely important to determine the exact point of contact between the micrometer spindle and the mercury surface to achieve the necessary repeatability. Various optical methods and lighting techniques were tried but each proved unsatisfactory. The idea of using an optical method was then abandoned and other methods were investigated. The Veeko Roto-Point audio oscillator was tried and proved satisfactory for this application.

Vibration

The mercury pools in the cisterns proved to be excellent indicators of vibratory disturbances. These disturbances imposed a problem in the ability to null on the face of the mercury pool. Vibration isolators were first considered as a way to reduce vibration transmitted from a vibration source to the manometer by permitting relative motion. The more isolation required, the more relative motion was needed. Since the proper isolation material was not available for this application, the theory was applied another way.

The capacity of the system to respond to the excitation was reduced by eliminating a table between the vibration source and the manometer and locating the manometer directly on the floor. Other than being somewhat inconvenient for use, this location proved satisfactory and the disturbance was reduced to a tolerable limit.

Temperature

Temperature affects the density of mercury which, in turn, affects the pressure values being measured as shown in Equation 2. The desired accuracy requires that the mercury temperature be known within 0.1°C . This temperature is used to compute density by using Equation 3.

The location of the thermometer was selected to obtain the mercury temperature rather than the ambient temperature. Secondly, the surrounding air temperature should be controlled so as not to drift more than 1°C per 8 hours. This requirement was met by the temperature controllers in the laboratory. The thermometer location selected is shown in Figure 1.

Sealing

The plumbing and cisterns were made leaktight by using thin plastic seals between the glass cisterns and the stainless steel plates. Rubber O-rings and silicone lubricant were used to make the seals on the micrometer spindles. The system was tested for leaks with a mass spectrometer and the sealing techniques proved satisfactory. No detectable leaks were found in the system.

Calibration

The accuracy of each micrometer was determined by comparison with a laser interferometer. After the micrometer was tested, it was assembled as shown in Figure 1. The perpendicularity of the spindle travel to the top plate was determined. Then the bottom plate was tested for parallelism to the top plate. The results of these tests proved to be well within the design tolerances. The levels (Figure 1) were then adjusted to enable setting the face of the mercury pools perpendicular to the axis of the spindle travel (Table 1).

Figure 1. Assembled Micromanometer

The repeatability of the system was first determined with both cisterns at the same pressure. Secondly, the repeatability was determined with a differential pressure across the manometer. Both sets of data were consistent, and for evaluation purposes the first set was used in Table 1. The MKS Baratron was used to make the second evaluation. The data recorded has an uncertainty owing to hysteresis and repeatability of the MKS Baratron. This uncertainty was considered in evaluating the data and is estimated not to exceed ± 0.005 torr. Both sets of data are recorded in Tables A-1 and A-2.

Once repeatability was established, it was necessary to evaluate the system as a working instrument. This evaluation was conducted using a dual dead weight tester method for generating differential pressures. The estimated uncertainty in the applied differential pressure was less than 400 micro-inches of mercury. The results of this evaluation are recorded in Table A-3. These results revealed agreement of better than 100 microinches of mercury between the reference system and the micromanometer.

Evaluation of the Calibration Data

The following constituent errors were considered in arriving at a value of uncertainty for the dual cistern manometer (Bendix Number 11396).

Table 1. Error Analysis

Error Component	Uncertainty in Torr
Repeatability (2 σ value)	0.0063
Gravity	0.005
Density of mercury (temperature)	0.001
Meniscus of mercury	0.003
Expansion of mercury	0.0001
Micrometers (2)	0.0051
Nulling sensitivity	0.001
Cosine error	0.00005
Thermal expansion (dimensional)	(Negligible)

The root of the sum of squares of these component errors is 0.011 torr. The worst case error (0.022 torr) would result if the individual errors were added arithmetically. The errors are believed to be sufficiently independent that this worst case condition is improbable. Using these figures as limiting conditions, an uncertainty estimate of ± 0.015 torr is believed to be a realistic figure for this instrument.

Operation

The micromanometer may be used to make either absolute or differential pressure measurements to 50 torr. The instrument is not to be used above 1 atmosphere on the reference port. The following procedure may be used in operating this instrument.

- Carefully level the instrument using the leveling feet and the attached levels. This action will eliminate cosine error within the limits shown on Table 1.
- Expose both cisterns to the reference pressure and obtain a zero reading from both micrometers. This is accomplished by lowering each micrometer separately until an audio signal is produced by the Veeco audio oscillator.
- Observe and record the micrometer zero readings (h_1, h_2).
- Raise the micrometer spindles and apply the pressure to be measured on the test port of the manometer. Measure this change in pressure by taking the reading as outlined. Record the micrometer readings (H_1, H_2). Using Equation 1, determine the height (h) of the liquid column displaced by the unknown pressure. Apply temperature and gravity corrections to obtain the value of pressure as shown in Equation 2.

$$h = (h_1 - H_1) + (h_2 - H_2) \quad (1)$$

$$\Delta P = \frac{\rho g h}{g_s} \quad (2)$$

$$\text{where } \rho = 1/[V_o(1 + 0.0001818t)] \quad (3)$$

t = temp. in $^{\circ}\text{C}$

V_o = specific volume of mercury at $t = 0^{\circ}\text{C}$

ΔP = differential pressure

h = height in cm

ρ = density of mercury (gm/cm^3)

g = local acceleration of gravity (cm/sec^2)

$g_s = 980.665 \text{ cm}/\text{sec}^2$ = standard acceleration of gravity

h_1 = height read on Micrometer 1 (zero reading)

h_2 = height read on Micrometer 2 (zero reading)

H_1 = height read on Micrometer 1 (test reading)

H_2 = height read on Micrometer 2 (test reading)

CONCLUSION

The micromanometer is a significant addition to the pressure standards in the Bendix Metrology Laboratory. This micromanometer has wide application in calibration of pressure devices and bridges a gap (from 0 to 30 torr) that has caused many problems in the past. A measuring uncertainty of ± 0.015 torr can be expected in use of this standard.

Appendix
DEVELOPMENT DATA

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Table A-1. Repeatability Determination With Both Cisterns at the Same Pressure.

Reading Number	R ₁ Micrometer 1 (in.)	R ₂ Micrometer 2 (in.)	R ₁ + R ₂ (in.)
1	0.97200	0.98035	1.95235
2	0.97215	0.98035	1.95250
3	0.97200	0.98030	1.95230
4	0.97205	0.98030	1.95235
5	0.97210	0.98015	1.95225
6	0.97205	0.98030	1.95235
7	0.97200	0.98020	1.95220
8	0.97200	0.98035	1.95235
9	0.97185	0.98015	1.95200
10	0.97200	0.98030	1.95230
11	0.97220	0.98005	1.95225
12	0.97210	0.98010	1.95220
13	0.97220	0.98020	1.95240
14	0.97210	0.98020	1.95230
15	0.97215	0.98025	1.95240
16	0.97205	0.98030	1.95235
17	0.97210	0.98000	1.95210
18	0.97200	0.98005	1.95205
19	0.97210	0.98010	1.95220
20	0.97210	0.98025	1.95235
Maximum spread = 0.0005 inch Hg = 0.01270 torr δ = 0.000124 inch Hg = 0.00315 torr 3 δ = 0.000372 inch Hg = 0.00945 torr			

Table A-2. Comparison Evaluation Using MKS Baratron

Test 1						
Reading MKS Baratron (Torr)	Manometer Reading in Torr					Spread In Readings
	Reading 1	Reading 2	Reading 3	Reading 4	Average	
0						
1	1.018	1.013	1.005	1.009	1.011	+0.007 -0.006
2	2.008	2.008	2.009	2.019	2.011	+0.008 -0.003
5	5.019	5.014	5.019	5.023	5.019	+0.004 -0.005
10	10.035	10.028	10.033	10.031	10.032	+0.003 -0.004
20	20.017	20.010	20.019	20.021	20.017	+0.004 -0.007
30	30.085	30.095	30.092	30.093	30.092	+0.003 -0.007

Table A-2 Continued. Comparison Evaluation Using MKS Baratron

Test 2						
Reading MKS Baratron (Torr)	Manometer Reading in Torr					Spread In Readings
	Reading 1	Reading 2	Reading 3	Reading 4	Average	
0						
1	1.018	1.018	0.011	1.008	1.014	+0.004 -0.006
2	2.022	2.004	2.003	2.010	2.010	+0.012 -0.007
5	5.025	5.024	5.031	5.035	5.029	+0.006 -0.005
10	10.050	10.070	10.051	10.053	10.056	+0.014 -0.005
20	20.061	20.062	20.063	20.050	20.059	+0.004 -0.009
30	30.145	30.148	30.162	30.145	30.150	+0.012 0.005

Table A-3. Evaluation of the Micromanometer as a Working System

Reference (Inch Hg at 0°C)	Micromanometer Reading (Inch Hg at 0°C)	Deviation (Inch Hg at 0°C)
1.32235	1.43346	0
	1.32244	+0.00010
	1.32229	-0.00005
0.91549	0.91540	0.00009
	0.91550	+0.00001
	0.91545	-0.00004
0.40688	0.40688	0
	0.40688	0
	0.40690	+0.00002