Journal of Research of the National Bureau of Standards Vol. 48, No. 1, January 1952 Research Paper 2283

Sensitive Mercury-Level Detecting Unit for Manometers

W. E. Williams, Jr.

An electronic instrument has been developed to determine the differential height of the two arms of a mercury manometer. The instrument has a sensitivity corresponding to 0.0005-inch height differential, and the pickup units are designed to provide this performance at absolute pressures up to 35,000 pounds per square inch. Use is made of a high-frequency mutual-inductance micrometer, with the tops of the mercury columns serving as the reference surfaces.

1. Introduction

The sensitive level-detecting unit was primarily developed to locate the mercury surface in an opaque, closed system of an 8-m manometer to be used in calibrating working standards for high pressure. The detecting unit described here was developed in the Electronic Instrumentation Section of the Bureau for inclusion in a manometer that was designed and is now being constructed by the Bureau's Mechanical Instruments Section.

The application of the high-pressure manometer as an accurate primary standard will be facilitated by the desirable characteristics of the detector, particularly in the precise determination of certain "fixed points" usable in the calibration of piston gages used as working standards and other instruments. Such fixed points of pressure may include melting or freezing points of pure substances, equilibrium points in multiphase systems, or other phenomena.[1]

A simplified schematic diagram of the manometer, figure 1, shows the two pressure chambers, or manometer cells, connected by tubing. The two manometer cells are separated by a vertical height, h, of approximately 8 m. The lower half of the 1½-in.-diameter cavity in each cell is filled with a mercury pool, which is part of the mercury column. The remainder of the cavity is filled with oil from the two oil lines connecting the cells with points A and B. The electric pickups, or probes, are mounted in the oil above the surface of the mercury. The difference in pressure between A and B is obtained from calculations based upon an accurate measurement of distance H.

The height of the mercury column is determined in two ways. The distance between visible reference marks on the two cells is determined by a suitable means. The height of the mercury surface within the cell in relation to the applicable reference mark is determined by the mercury-surface-sensing unit. The sensitivity of this unit (about 0.00008 in. for the smallest division on the meter) is ample, and it is expected that this unit will not be the limiting factor in the accuracy of the pressure measurements.

As this manometer is for use at pressures up to 35,000 lb/in.^{2} it is to be constructed of steel, and the usual optical methods of observing the mercury were not considered practicable. A capacitive system was rejected because of the presence of oil, which is used as the pressure-transmitting fluid in the manometer. In addition, the low-level output of a capacitive-measuring system would have been masked by the capacitance of the long leads required in this application.

After consideration of several possible methods of locating the mercury columns, a version of the mutual-inductance micrometer [2] was decided upon. This instrument utilizes the variation in mutual inductance between two fixed coils to provide an indication of distance. The two fixed coils are wound on a single form in planes parallel to the face of the pickup assembly, or probe. One coil serving as the primary is excited with a current at radio

[1] W. G. Brombacher, Some problems in the precise measurement of pressure' Instruments 22, 355 (1949).

[2] Technical details of electronic micrometer, Electronics 20, 172 (Nov. 1947).

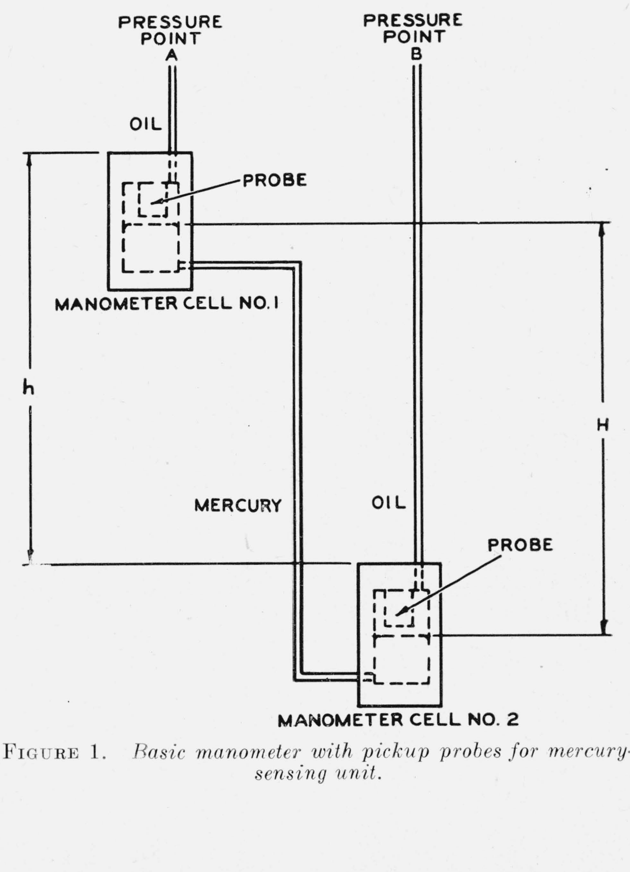

FIGURE 1. *Basic manometer with pickup probes for mercury-sensing unit.*

frequency, and the resultant voltage induced in the second or secondary coil provides the indication of distance. The mutual inductance between the two coils, and hence the voltage induced in the secondary, is proportional to the distance between the coils (or probe face) and a conducting surface. This system has several advantages over other systems. The output of the secondary is high level and easily usable with the long leads required with the 8-m manometer. The instrument-output readings are unaffected by the dielectric constant of any substance between the probe face and the conducting surface. Contact with the surface of the mercury is unnecessary, thus avoiding errors due to loading or deformation of the surface.

2. Description of Instrument

The instrument comprises two cabinets shown in figures 2 and 3, two pickups, and interconnecting cables. The mercury-sensing unit contains the major part of the circuitry and provides meter indication of the height of column one and the differential column heights. The meter box provides remote indication, duplicating the differential-height indication and indication of the height of the second mercury column. The two units are required to be located within 3 ft of the manometer cells, but the two unit-and-cell combinations may be separated by approximately 35 ft. Scale-factor adjustments for all meters are located on the front panel of the two units directly below their respective meters. The zero-adjust control for the differential height indication is located on the back of the mercury-sensing-unit chassis.

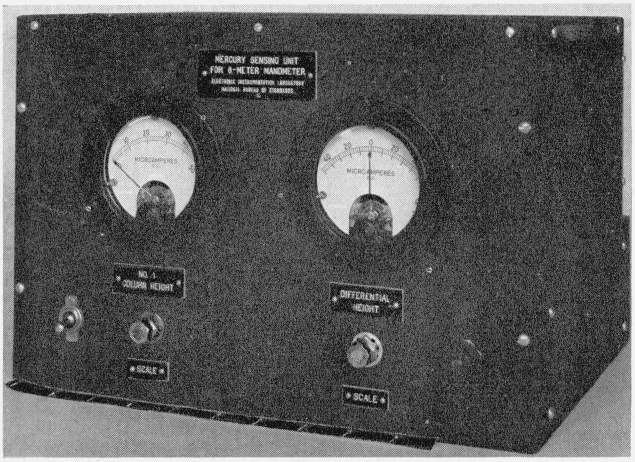

FIGURE 2. *Mercury-sensing unit for 8-meter manometer.*

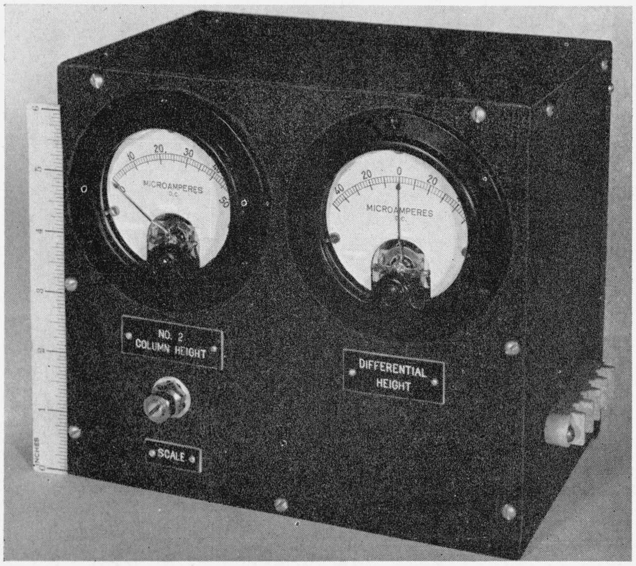

FIGURE 3. *Meter box of mercury-sensing unit.*

3. Design Details

A version of the electronic micromanometer [3] is used to measure the displacement of the two mercury columns. A 480-kc amplitude-regulated oscillator is used to excite the primaries of two micrometer pickups. The outputs from the secondaries are compared with the use of a vibrating relay and the difference in outputs amplified. This amplified signal is then rectified for indication as differential height on a d-c meter.

Full-scale meter deflection for the difference between the probe-to-mercury distance ("differential height") is ±0.002 in. on a zero-center scale meter. In this instrument a 50–0–50 microampere meter was used, but the scale may be calibrated to read directly in inches. The direction of deflection is indicative of which column is the higher and the magnitude of deflection of the distance. Figure 4

[3] M. L. Greenough and W. E. Williams, An electronic circuit for measuring the displacement of pressure-sensitive diaphrams. J. Research NBS **46**, 1 (1951) RP2168.

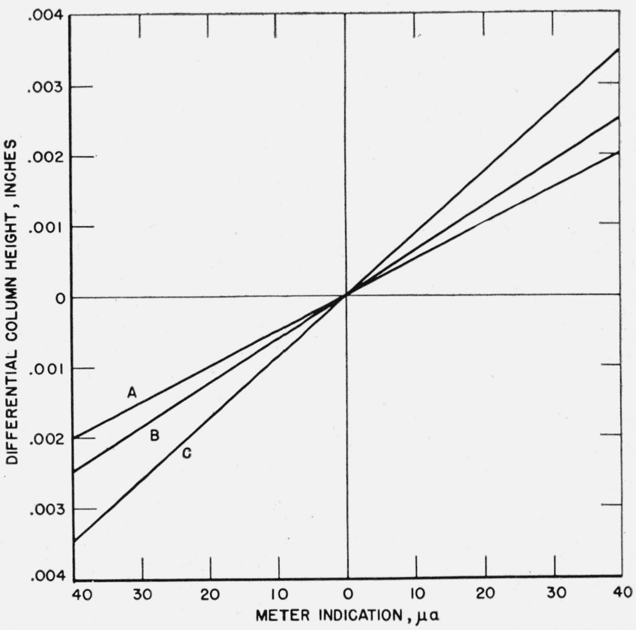

FIGURE 4. *Sensitivity of unit as a function of initial probe-to-mercury distance.*

A, Probe to mercury, 0 to 0.025 inch; B, probe to mercury, 0.04 inch; C, probe to mercury, 0.065 inch.

gives the linear range of operation of the instrument. The graph is a plot of differential-height meter indication against the differential height in inches for several values of the initial pickup-to-mercury distance. For any pickup-to-mercury distance from 0 to 0.025 in., curve A is applicable. At greater distances the response is nonlinear and may be approximated by reference to the other two curves.

The individual probe-to-mercury distances (column heights) are indicated on separate meters with a sensitivity of 0.3-in. full scale. As the outputs of the electric pickups are nonlinear for large distances, these heights must be obtained from a graph (fig. 5).

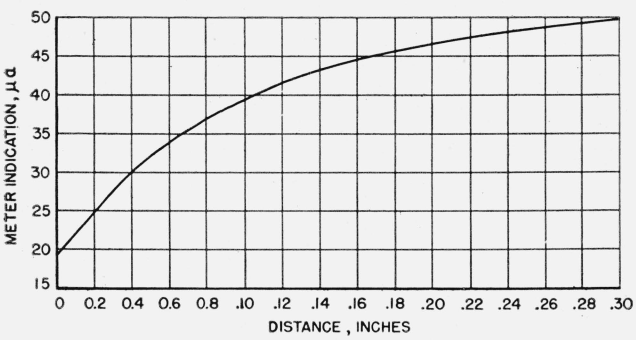

FIGURE 5. *Probe output as a function of distance.*

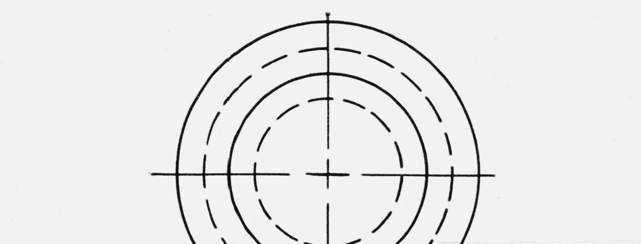

FIGURE 6. *Constructional details of probe.*
Material: Lava A.

This height is the distance from the face of the pickup to the surface of the mercury.

The probe elements are two mutual-inductance pickups (fig. 6) $\frac{3}{4}$ in. in diameter, made of Lava A. The primary, 25 turns of No. 34 copper wire with Formex insulation, is wound in the outer slot. The inner slot is used for the secondary, 40 turns of No. 38 Formex insulated copper wire. Formex insulation was chosen because it was unaffected by the mercury and oil in the pressure chamber. Bare copper wire and solder at the terminals on the end of the windings were completely covered with glyptal. Feed-throughs with screw terminals and Lucite insulation were provided to bring the signal out of the pressure chamber.

The primaries of these pickups are excited in parallel with 0.5 amp of current at 480 kc passing through each probe. The mutual inductance between the two coils, and hence the voltage induced in the secondary, is a function of the distance between the coils and the surface of the mercury. Power dissipation in the pickup was held to 0.65 w to prevent excessive heating of the manometer cell.

The complete circuit schematic is given in figure 7. A 480-kc amplitude-regulated oscillator, *V3*, is used to excite the primaries of the two pickups. A portion of the oscillator radio-frequency (r-f) output is rectified by *V4* and compared with a fixed reference potential. The difference between this reference potential and the rectified oscillator output is amplified by the one-stage amplifier, *V1*. A voltage-regulator tube, *V9*, is used as the source of reference potential for the amplifier. The amplifier output drives a cathode follower, *V2*, which in turn controls the screen of the oscillator. Hence, any change in oscillator output causes a corresponding and correcting change in oscillator screen voltage. That is, an increase in the oscillator output will cause a decrease in screen voltage, resulting in a decrease of oscillator output to its original value. An equivalent change will result for a decrease in oscillator output.

Loading coil *L3* is used to match the load impedance to the oscillator output. Variable inductance *L4*, the instrument zero set, is a center-tapped coil, one-half of which is in series with each pickup primary. A powdered-iron core is adjustable so that the inductance of one-half of the coil is increased at the same time the other half is decreased. This core is adjusted for zero difference in probe outputs for equal column displacements.

A portion of the r-f secondary voltage of each pickup is rectified by the crystal diodes *D1* and *D2*. The resulting d-c voltage is measured on meters *M2* and *M4*, indicating the individual column heights.

The unrectified portions of the outputs of the pickups are applied to opposite contacts of the vibrating relay. A 60-cycle vibrating contactor, or relay, with mercury-wetted contacts was used to minimize switching noise. The relay output at the contactor is then a 480-kc carrier with a 60-cycle square-wave modulation proportional to the difference in probe outputs, or difference in column heights. This modulated carrier is passed through a diode detector, *V5*, resulting in a 60-cycle square wave proportional to the difference in height of the two mercury columns. This signal is amplified in a square-wave amplifier, *V6*, and used to drive the cathode follower, *V7*. The output from the driver transformer, *T2*, in series with the cathode of *V7*, is fed back to the relay contacts through *1K* wire-wound resistors, *R14* and *R15*, providing synchronous rectification for indication on the d-c output meters, *M1* and *M3*.

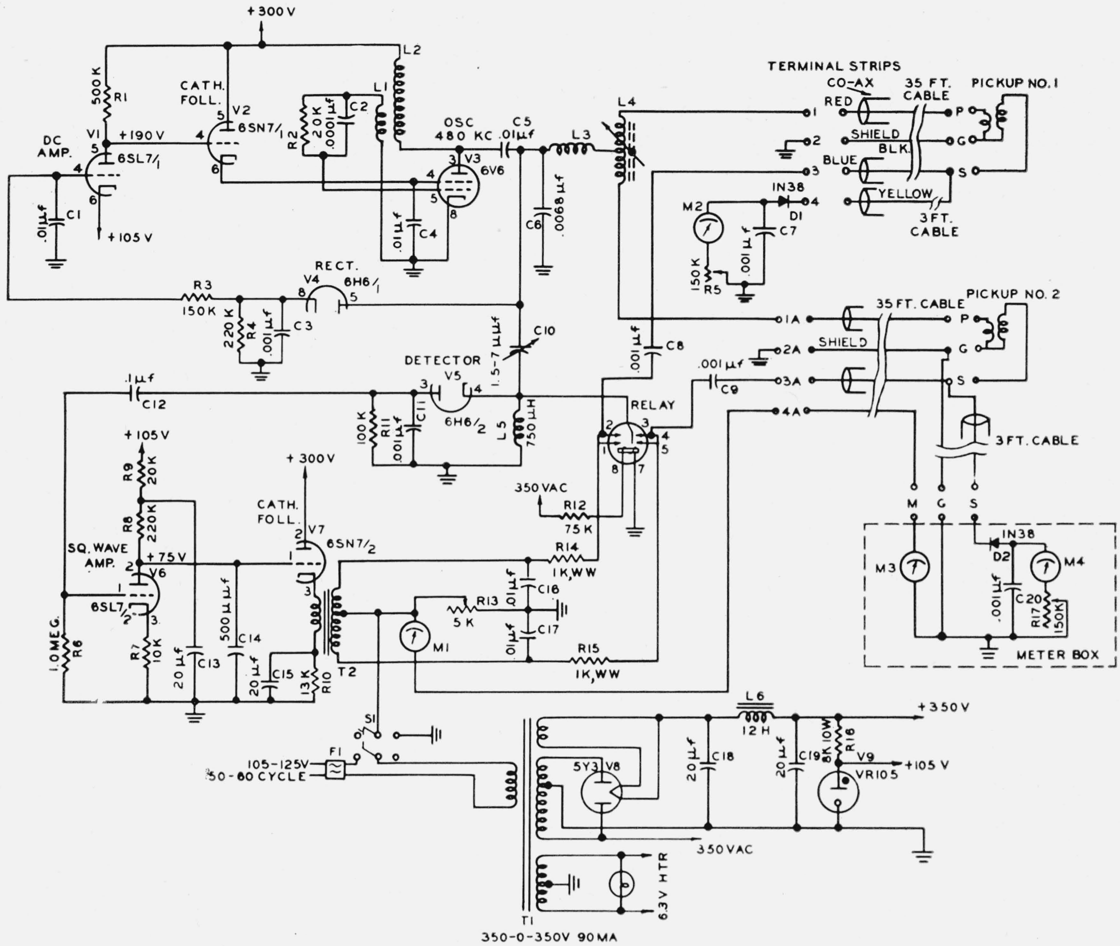

FIGURE 7. *Circuit diagram of mercury-sensing unit.*

Values of circuit components

Part number	Description
C1, C4, C5, C16, C17	0.01-µf paper condenser, 500 v.
C2	0.0001-µf mica condenser, 200 v.
C3, C7, C8, C9, C11, C20	0.001-µf paper condenser, 200 v.
C6	0.0068-µf mica condenser, 400 v.
C10	1.5 to 7-µµf ceramic variable condenser.
C12	0.1-µf paper condenser, 200 v.
C13, C15, C18, C19	20-µf electrolytic condenser, 450 v.
C14	500-µµf mica condenser, 400 v.
D1, D2	Crystal diode 1N38, or equivalent.
F1	Two 1-amp fuses.
L1	35 turns No. 27 copper Formex wire, wound over L2.
L2	90 turns No. 27 copper Formex wire, wound on 1-in.-diameter form.
L3	23 turns No. 29 copper Formex wire, wound on ¾-in.-diameter form.
L4	40 turns No. 29 copper Formex wire, wound on Millen coil assembly No. 74001.
L5	750 µh r-f choke.
L6	12-h 80-ma filter choke.
M1, M3	50 to 0 to 50 µa d-c, meters, 600-ohm resistance.
M2, M4	0 to 50 µa d-c meters.
R1	500K ½-w resistor.
R2, R9	20K ½-w resistor.
R3	150K ½-w resistor.
R4, R8	220K ½-w resistor.
R5, R17	150K wire-wound potentiometer.
R6	1.0-megohm ½-w resistor.
R7	10K ½-w resistor.
R10	13K 1-w resistor.
R11	100-K ½-w resistor.
R12	75K 5-w resistor.
R13	5K wire-wound potentiometer or Allen Bradley type AB.
R14, R15	1K wire-wound 1-w resistor.
R16	8K 10-w resistor.
S1	DPDT switch.
T1	Power transformer, 350 to 0 to 350 v, 90 ma.
T2	Driver transformer, Thordarson T20D77, or equivalent.
Relay	Western Electric 276–E.
Pickups	Primary—25 turns No. 34 copper Formex wire. Secondary—40 turns No. 38 copper Formex wire.
Cable	Coaxial cable RG 71/U, Amphenol No. 21–029.
V1, V6	½–6SL7 tube.
V2, V7	½–SN7 tube.
V3	6V6 tube.
V4, V5	½–6H6 tube.
V8	5Y3 tube.
V9	VR–105 tube.

R14 and *R15* are wire wound and have sufficient inductance to serve as r-f chokes to prevent the 480-kc signal on the relay contacts from being shorted to ground.

The relay used in this instrument is a type that opens from the first contact before it makes with the second, leaving the contactor open for a brief period during each switching cycle. While the contactor is thus open, or floating, a large spike is placed on the square wave. To eliminate this large signal, by providing a bias for the contactor arm during this open period, a part of the oscillator output is applied to the contactor through variable condenser *C10*. The value of this condenser is adjusted for minimum spike amplitude.

To prevent damage to meters *M1* and *M3* from an overload, when the power to the instrument is turned off, the power switch *S1* shorts the meter at the same time it opens the a-c line.

4. Discussion

Pressures in the chambers are expected to reach 35,000 lb/in.^{2}, and the electric pickups were constructed to withstand this pressure. In addition to the high pressure, the pickups must be unaffected by contact with the oil and mercury inside the chamber.

The differential distance, probe to mercury level, of the two columns is indicated with a sensitivity of 0.004-in. full scale on a zero-center scale meter within a range of 0.025 in. Meters are also provided to indicate the approximate height of each column over a range of 0.3 in. The primary function of the instrument is to indicate the difference in height of the two surfaces, and the individual surface heights are used primarily to determine when the instrument is within the proper operating range.

High zero stability was required, as in this application it is impractical to check the zero except at extended intervals.

During the operation the instrument mechanical vibration of the pressure chambers from time to time will cause small ripples on the surface of the mercury. These ripples will be visible as vibration of the needles on the differential-height meters.

Another possible application to mercury micromanometers used to measure low pressures with high sensitivity is of particular interest. The readings of the detecting units would be a direct function of the pressures without the need of an auxilliary scale. If long leads are unnecessary, the sensitivity can be increased to 0.0005-in. full scale, and adjustment provided to secure higher pressure ranges.

The instrument was developed in the Electronic Instrumentation Laboratory of the National Bureau of Standards.

The author acknowledges the aid of M. L. Greenough in the development of the circuitry, and of C. H. Meyers and D. P. Johnson, who designed the high-pressure mercury manometer.

WASHINGTON, September 14, 1951.