Chapter 16
Principles of Conventional Pressure transducers

An understanding of the correct principle according to which an invention operates may follow, instead of precede, the making of the invention.

Clemens Herschel (1837)

16.1 DEFINITIONS

In general, a transducer a device that, being actuated by energy from one system, supplies energy (in any form) to another system.

In particular, the essential feature of a conventional pressure transducer is an elastic element, which converts energy from the pressure system under study to a displacement in the mechanical measuring system.

An additional feature found in many pressure transducers is an electric element which, in turn, converts the displacement of the mechanicals system to an electric signal.

The popularity of electric element pressure transducers derives from the ease with which electric signals can be amplified, transmitted, controlled, and measured. Electrical pressure transducers can be delineated further as follows:

An active transducer is one that generates its own electrical output as a function of the mechanical displacement, whereas a passive transducer (i.e., one dependent on a change in electrical impedance) requires an auxiliary electrical input which it modifies (modulates) as a function of the mechanical displacement for its electrical output (Figure 16.1) [1]-[4].

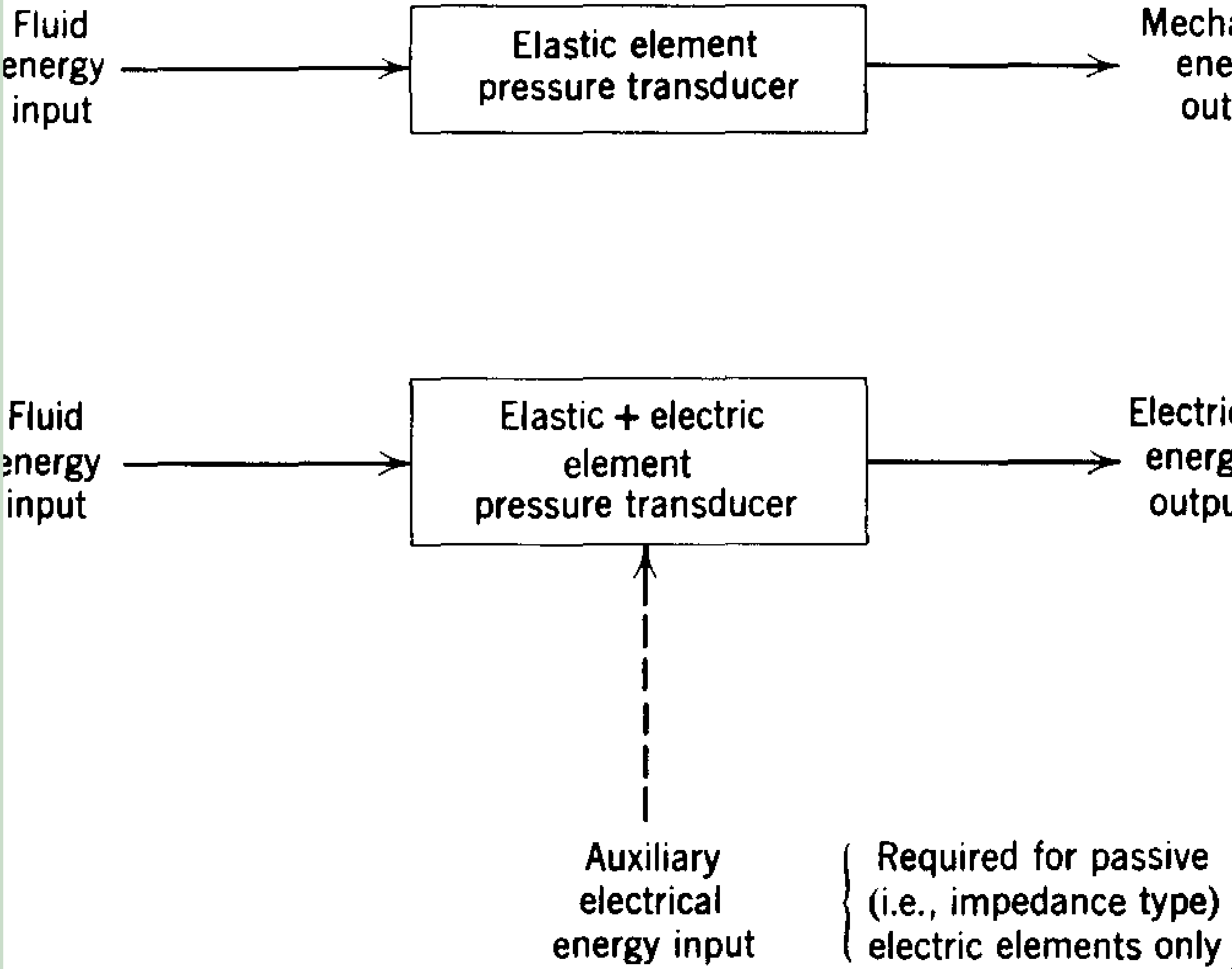


Figure 16.1 Block diagrams for pressure transducers.

Examples of mechanical pressure transducers having elements only are deadweight free-piston gauges, manometers, bourdon tubes, bellows, and diaphragm gauges.

An example of an active electrical pressure transducer, combining in one the elastic and electric elements, is the piezoelectric pickup.

Examples of electric elements employed in passive electrical pressure transducers include strain gauges, slide-wire potentiometers, capacitance pickups, linear differential transformers, variable reluctance units, and the like.

Some of the more commonly used mechanical and electrical pressure transducers are considered next.

16.2 MECHANICAL PRESSURE TRANSDUCERS

We have already described several types of mechanical pressure transducers in the discussion of manometer pressure standards.

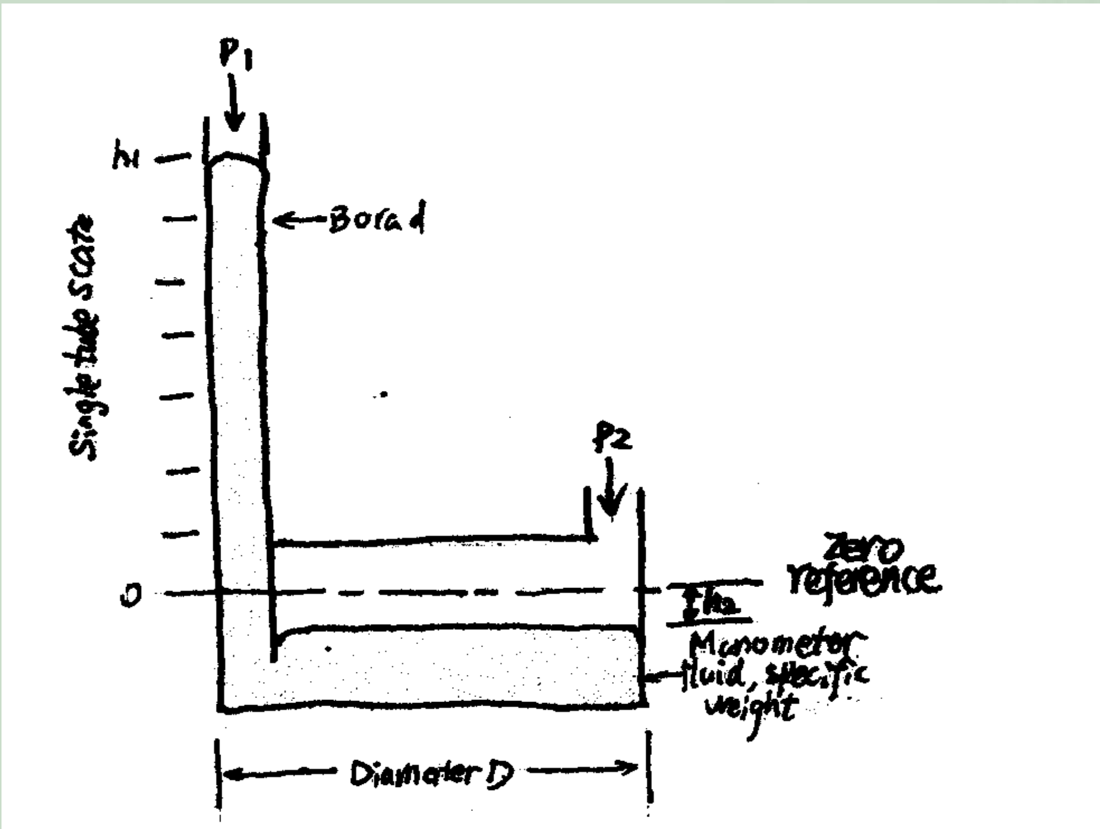
In addition, there are manometers not considered standards, yet used as conventional transducers.

These include the well, inclined, and Zimmerli types of manometers.

In these, as in all manometers, the elastic element is the manometric fluid itself, which is moved by an applied pressure difference

16.2.1 Well Type

The well-type manometer offers the advantage of a single-scale reading for the pressure difference, the hope being that the level variation in the well either is negligible or can be accounted for in the construction of the single-tube scale.



Following the notation of Figure 16.2, the pertinent equation is Figure16.2. A well-type manometer pressure transducer:

$$h_1 d = h_2 D \qquad p_2 - p_1 = w(h_1 + h_2)$$

$$p_2 - p_1 = wh_1(1 + d / D)$$

If D 》 d, (say on the order of 500 to 1), variations in the well level can be neglected.

16.2.2 Inclined Type

The inclined-type manometer provides a single scale reading that is expanded along the single tube (i.e., the scale has more graduations per unit vertical height than the equivalent vertical scale of the well-type manometer).

This allows for greater readability (on the order of ± 0.01 in.) than in the U-tube manometer.

The angle of incline (α) is generally about 10° from the horizontal (see Figure 16.3).

16.2.3 Zimmerli type

The Zimmerli-type manometer [5] is another special form of manometer that features high readability at the lower absolute pressures (range is 0 to 100 mm Hg within 0.1 mm Hg).

A mercury column is first separated by simultaneously applying the pressures to be measured to both sides of the mercury.

(which occurs at an applied pressure of about 140 mm Hg) produces a near-absolute zero reference for the measurement.

Any decrease in pressure beyond the separation point causes the mercury to drop in the reference leg and to rise in the measuring leg of the gauge until, at a pressure of about 0.1 mm Hg in the elevations of mercury in the two legs I apparent.

This, of course, represents the limit of usefulness of the Zimmerli manometer (Figure 16.4).

,

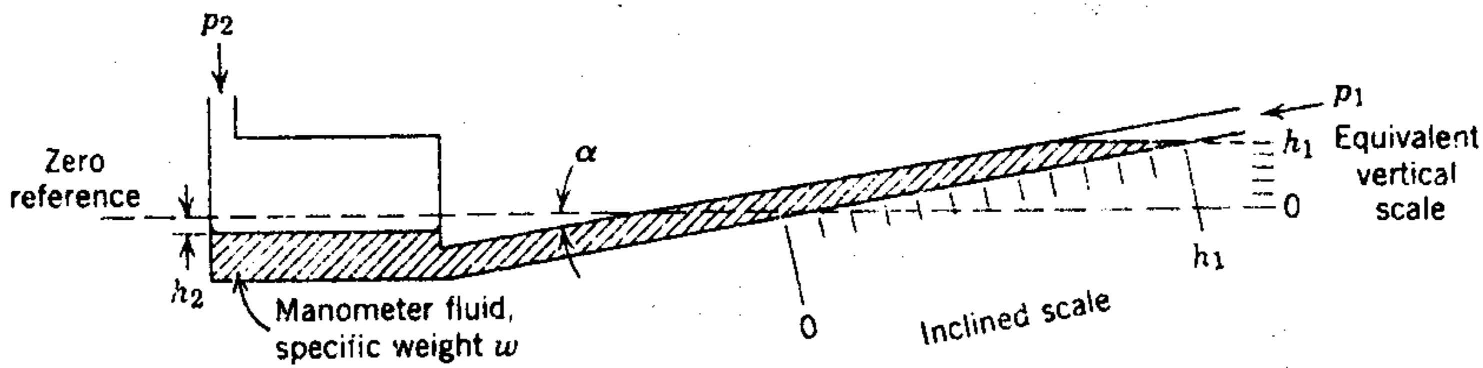


FIGURE 16.3 Inclined-type manometer pressure transducer.

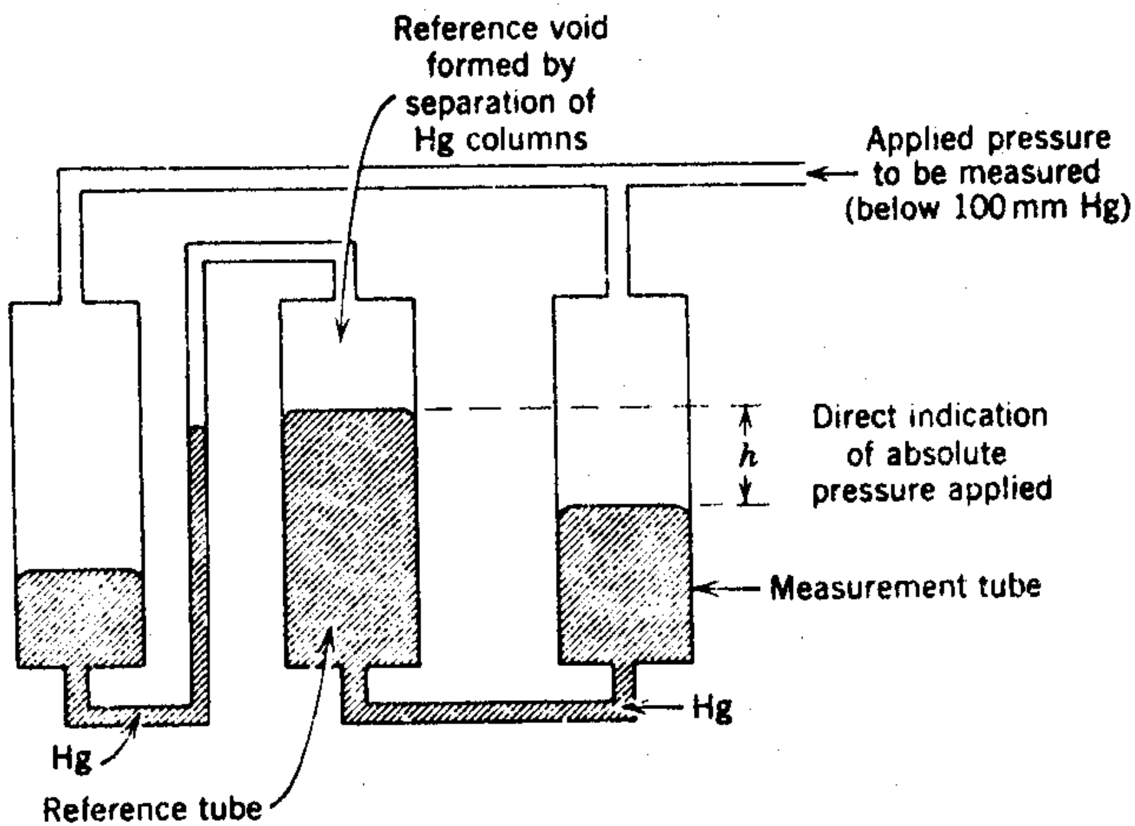


FIGURE 16.4 Zimmerii-type manometer pressure transducer.

16.2.4 Bourdon Tube

In the bourdon tube transducer, the elastic element is a small-volume tube, fixed at one end, which is open to accept the applied pressure, but free at the other end, which is closed to allow displacement under the deforming action of the pressure difference across the tube walls.

In the most common model, a tube of oval cross section is bent in a circular arc.

Under pressure, the oval-shaped tube to become circular, with a subsequent increase in the radius of the circular arc.

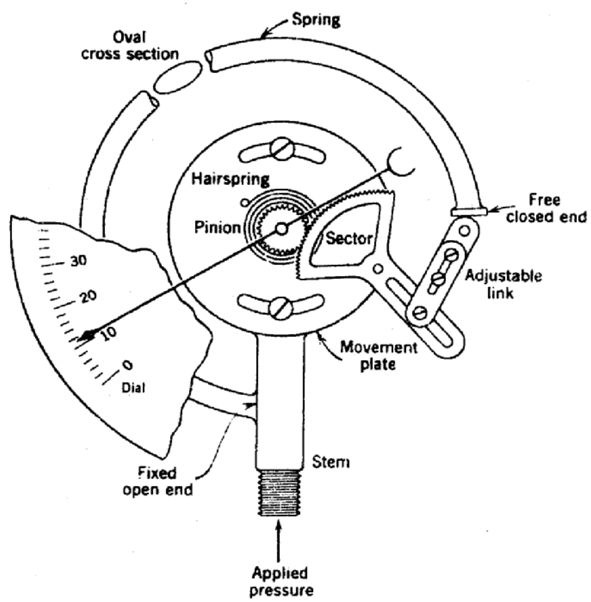


FIGURE 16.5 Common bourdon tube transducer. (*Source:* After ASME PTC 19.2 [3].)

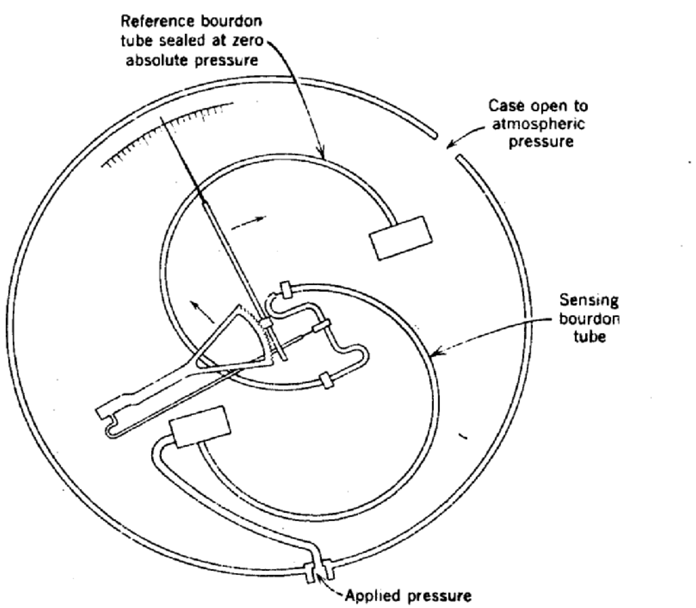


FIGURE 16.6 Bourdon tubes arranged for absolute-pressure measurements (*Source:* After Wallace and Tiernan.)

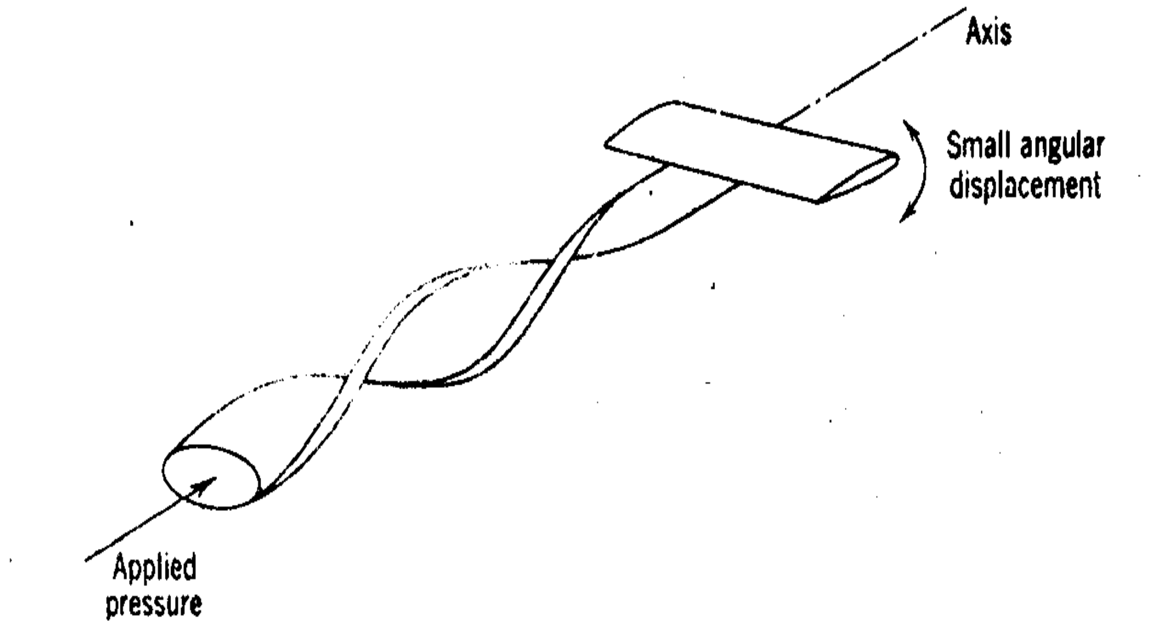


FIGURE 16.7 Twisted bourdon tube for use with passive electric elements.

By an almost frictionless linkage, the free end of the tube rotates a pointer over a calibrated scale to give a mechanical indication of pressure (see Figure 16.5) ranges of absolute, gauge, and differential pressure measurements within a calibration uncertainty of 0.1% of the reading.

In contrast to the large angular displacements encountered in the mechanical-output bourdon gauges already described, the elastic element most often used in conjunction with electric elements (to yield electrical outputs) takes the form of a flattened tube that is twisted about its own longitudinal axis and exhibits very small angular displacements (Figure 16.7) .

16.2.5 Bellows

Another elastic element used in pressure transducers takes the form of a bellows.

In one arrangement, pressure is applied to one side of a bellows , and the resulting deflection is partly counterbalanced by a spring (Figure 16.8).

In another differential arrangement, one pressure is applied to the inside of one scaled bellows while the other pressure is led to the inside of another sealed bellows.

By suitable linkages, the pressure difference is indicated by a pointer.

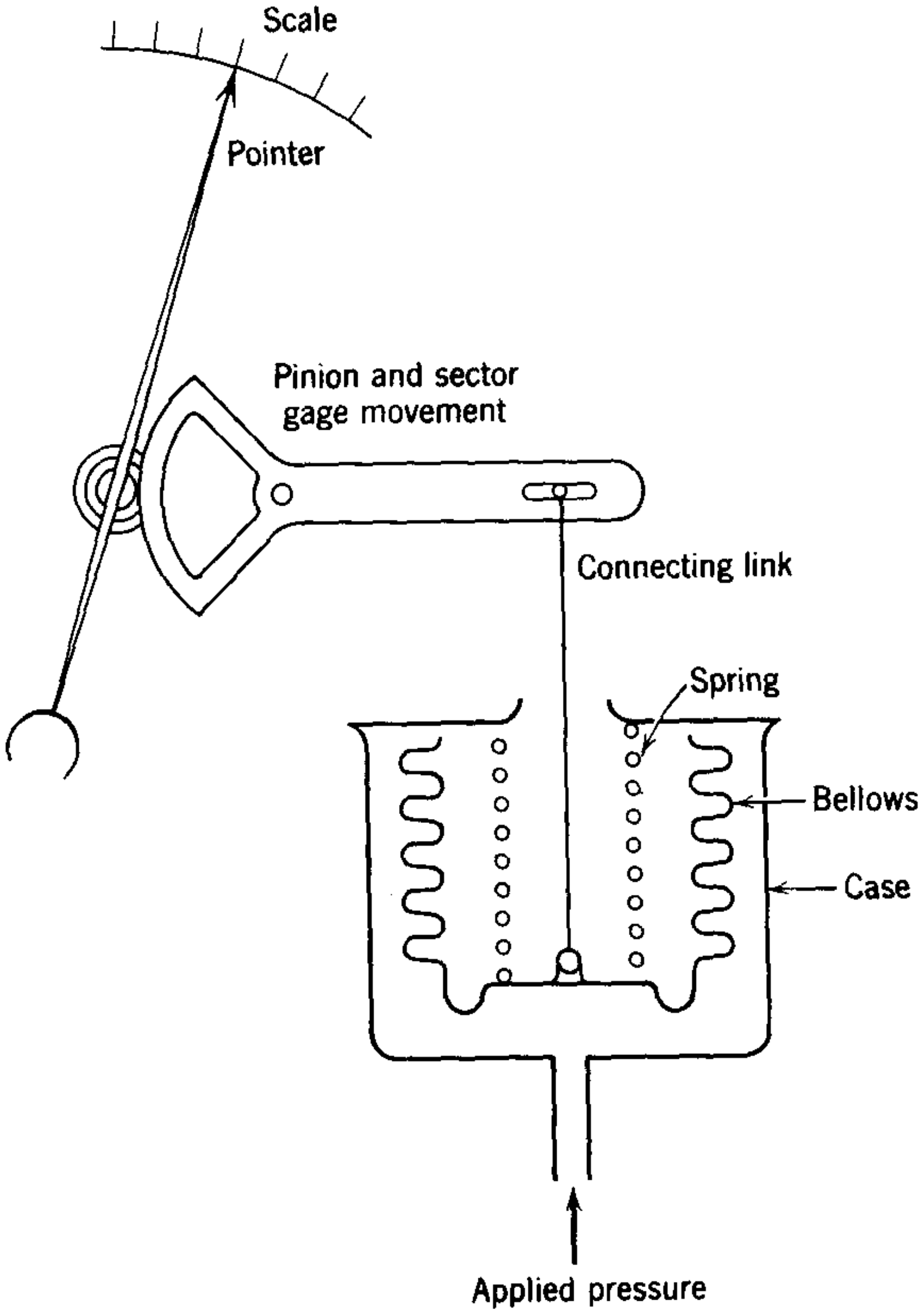


Figure 16.8 Common bellows gauge. (After ASME PTC Supplement 19.2, 1964.)

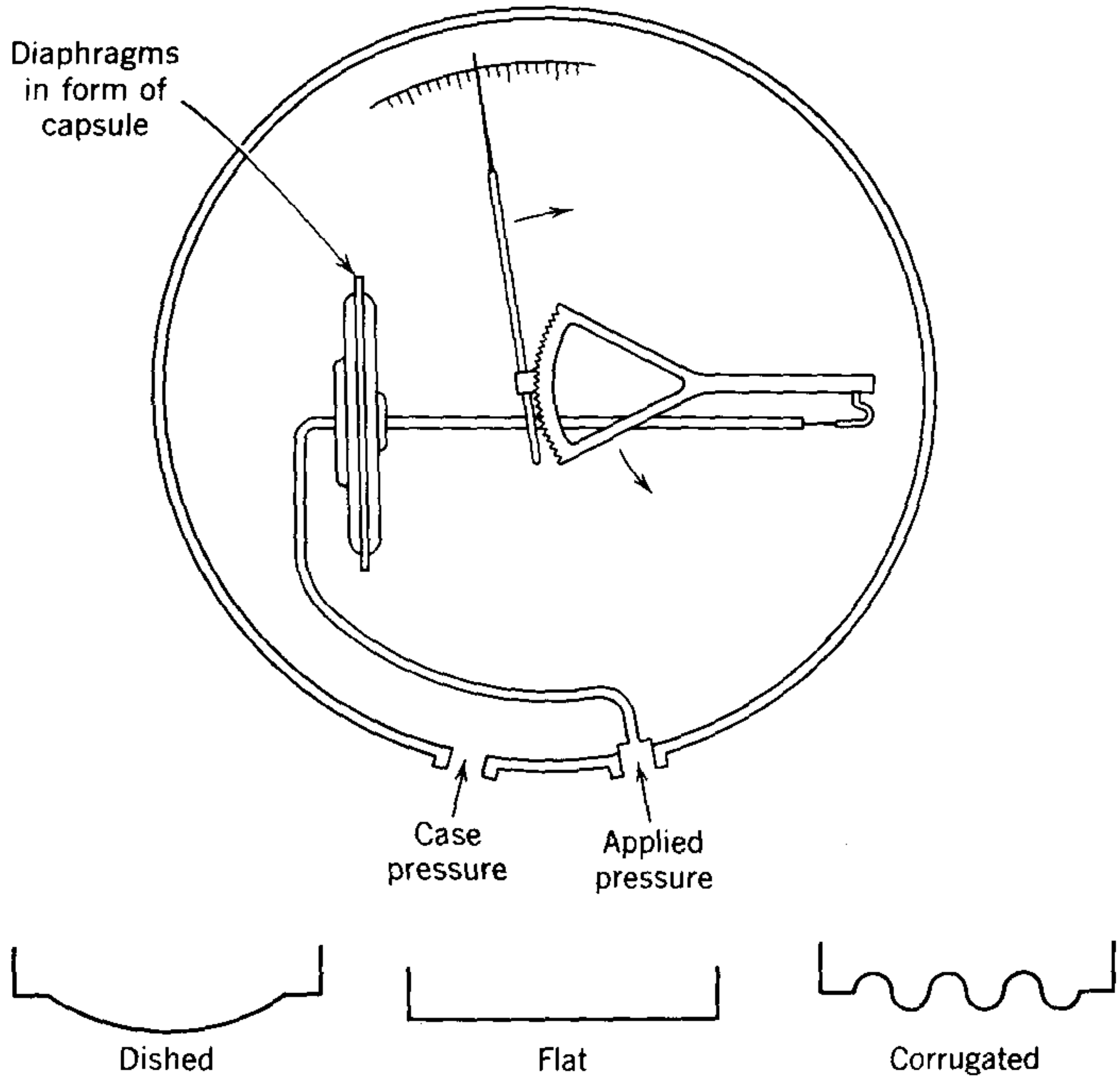


Figure 16.9 Precision capsule gauge. Diaphragm may be dished, flat, or corrugated. (Afte
Wallace and Tiernan, Instruction Book F1A-101-1-1*a*.)

16.2.6 Diaphragm

A final elastic element to be mentioned because of its widespread use in pressure transducers is the diaphragm (Figure 16.9).

Such elements can appear in the form of flat, corrugated, or dished plates.

The choice depends on the strength and amount of deflection desired.

The literature on diaphragms is quite extensive and should be consulted for detailed information on diaphragm characteristics and on diaphragm-type pressure transducers [6], [7].

In high-precision instruments, a pair of diaphragms is used back to back to form an elastic capsule.

One Pressure is applied to the inside of the capsule, which is surrounded on the outside by the other pressure.

Such a differential pressure transducer exhibits the unique feature of a calibration that is almost independent (within 0.1 %) of pressure level effects .

16. 3 Electrical Pressure transducers

An Active Electrical Pressure transducer

A piezoelectric element provides the basis for the only active electrical pressure transducer in common use. It operates on a principle discovered in the 1880s by the Curie brothers that certain crystals (i.e, those not possessing a center of symmetry) produce a surface potential difference

When they are stressed in appropriate directions [8],, [9] . Quartz, Rochelle salt , barium-titanate , and lead-zirconate-titanate are some of the common crystals that exhibit usable piezoelectricity .

Pressure pickups designed around such active elements have the crystal geometry oriented to give maximum piezoelectric response in a desired direction with little or no response in other directions.

Sound pressure instrumentation makes extensive use of piezoelectric pickups in such forms as hollow cylinders, disks, and so on.

Piezoelectric pressure transducers are also used in measuring rapidly fluctuating aerodynamic pressures or for short-term transients such as those encountered in shock tubes.

Although the emf developed by a piezoelectric element may be proportional to pressure, it is nonetheless difficult to calibrate by normal static procedures.

An attractive technique called “electrocalibration “has been described in the recent literature [10]. In this procedure, the piezoelectric pressure transducer is excited by an electric field rather than by an actual physical pressure to obtain the calibrations.

Passive Electrical Pressure transducers

Of the passive electrical pressure transducers, none are more common than the variable resistance types.

STRAIN GAUGE Types .

Electric elements of this type operate on the principle that the electrical resistance of a wire varies with its length under load (i. e., with strain).

In the unbounded type, four wires run free between four electrically insulated pins located two on a fixed frame and two on a movable armature.

The wires are installed under an initial tension and form the active legs of a conventional bridge circuit (see Figure 16. 10).

Under pressure, the elastic element (usually a diaphragm) displaces the armature, causing two of the wires to elongate while reducing the tension in the remaining two wires.

This change in resistance causes a bridge imbalance proportional to the applied pressure , and these quantities can be related by calibration.

The use of four wires in the manner indicated makes for increased bridge sensitivity , and allowing the wires to run free between the pins causes a high natural frequency for the transducer [11] .

In the bonded type , the strain gauge takes the form of a fine wire filament , set in cloth , paper , or plastic , and fastened by a suitable cement to a flexible plate that takes the load of the elastic element (see Figure 16 . 11) .

Often two strain gauge elements are connected to the bridge in an attempt to nullify unavoidable temperature effects.

The electrical energy input, required for all passive transducers, is in the case the excitation voltage of the bridge.

The nominal bridge output impedance of most strain gauge pressure transducers is 350

The nominal excitation voltage is 10V (ac or dc.) The natural frequency can be as high as 50, 000 cps.

Transducer resolution is infinite, and the usual calibration uncertainty of such gauges is within 1 % of full scale.

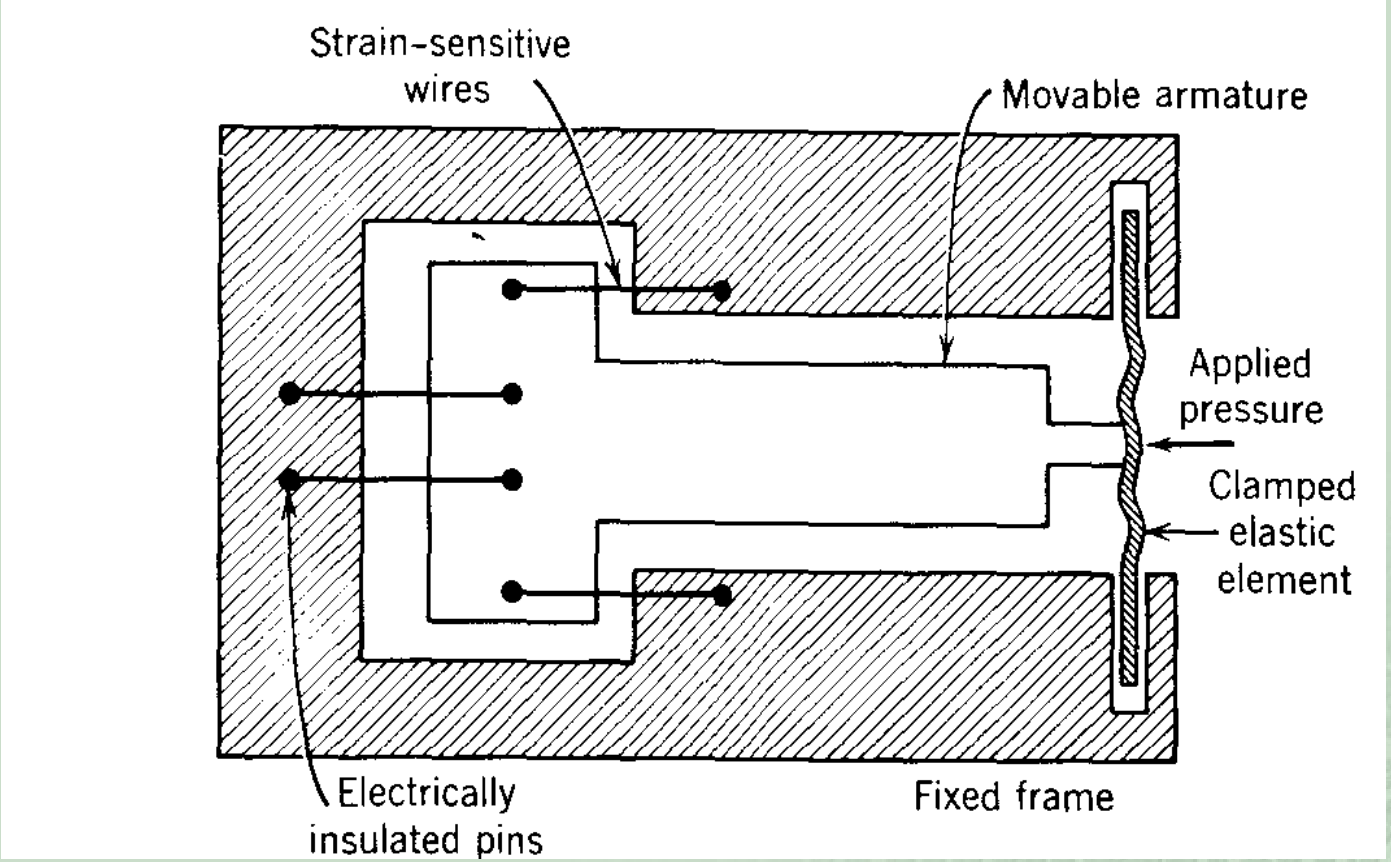


Figure 16. 10 Typical unbonded strain gauge.

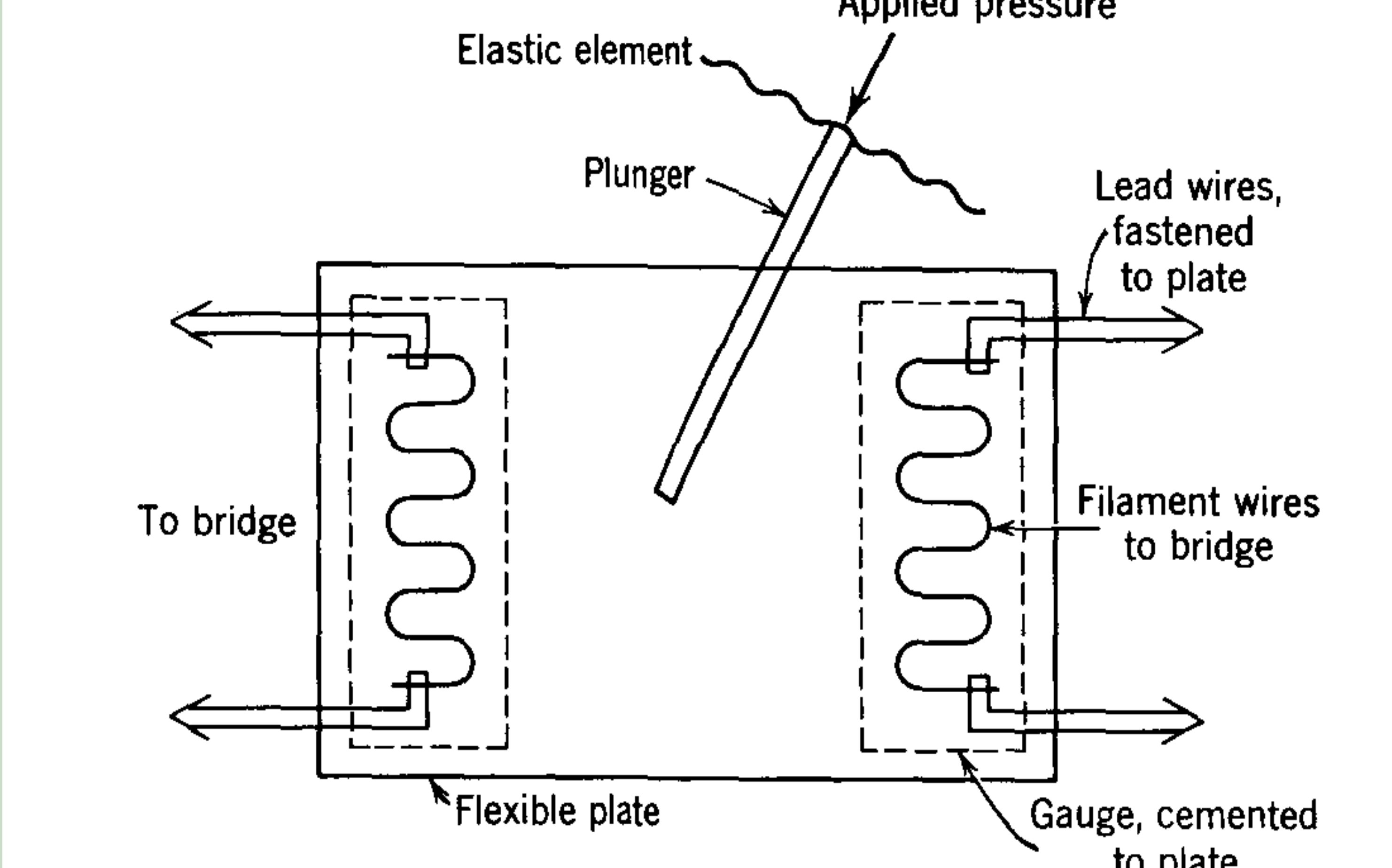


Figure 16.11 typical bonded strain gauge .

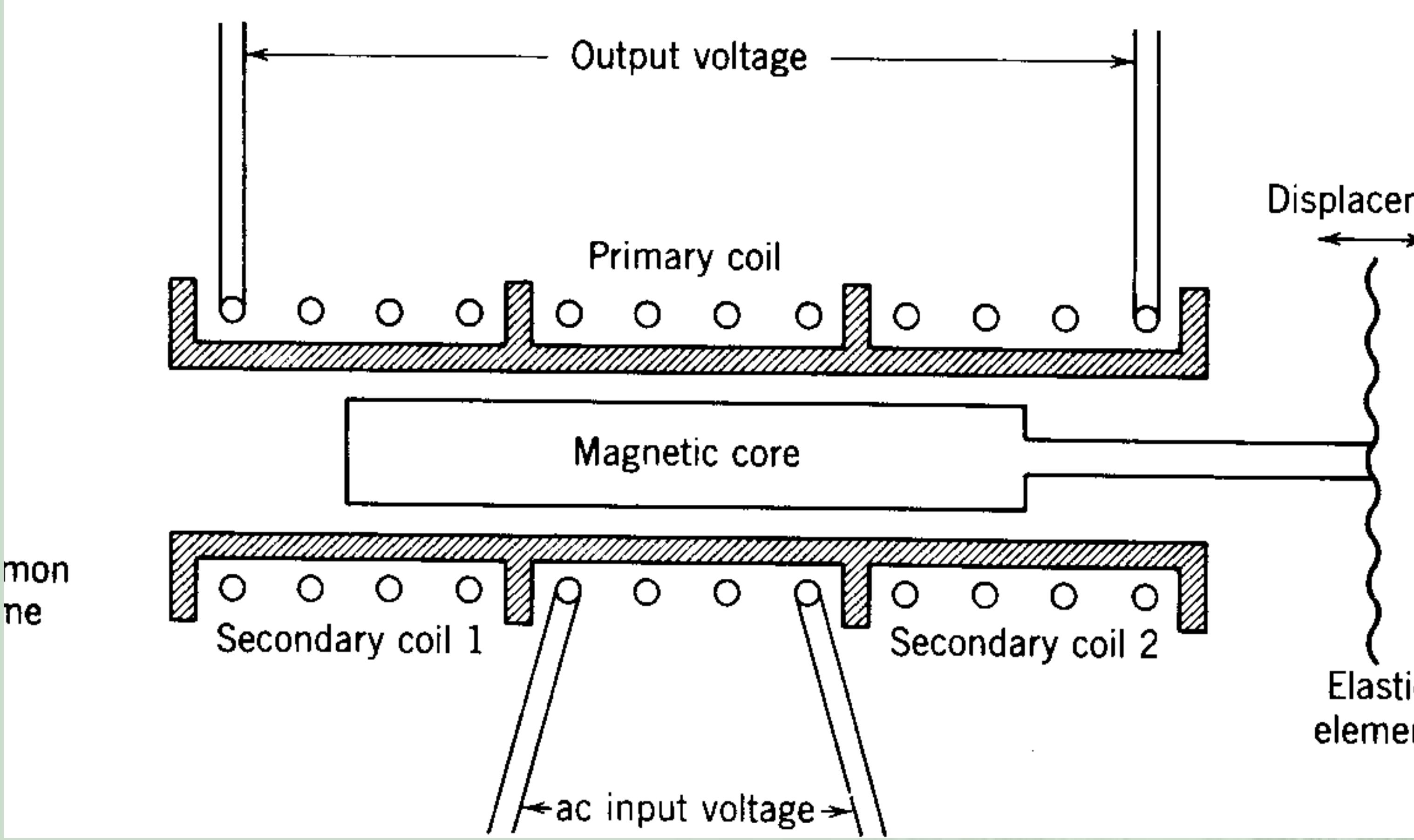


Figure 16.12 Linear variable differential transformer (LVDT.)

Potentiometer Type

Other pressure transducers of the variable resistance type operate on the principle of movable contacts such as those found in slide-wire rheostats or potentiometers.

In one arrangement, the elastic element is a helical bourdon tube, and a precision wire-wound potentiometer serves as the electric element.

As pressure is applied to the open end of the bourdon, it unwinds and causes the wiper (which is connected directly to the closed end of the bourdon) to move over the potentiometer, thus varying the resistance of a suitable measuring circuit.

Capacitance TYPE

In the variable capacitance-type pressure transducer, the elastic element is usually a metal diaphragm that serves as one plate of a capacitor.

If pressure is applied, the diaphragm moves with respect to a fixed plate to change the thickness of the dielectric between the plates.

By means of a suitable bridge circuit, the variation in capacitance can be measured and related to pressure by calibration.

Several variable inductance types of pressure transducers are considered next.

LINEAR VARIABLE Differential Transformer TYPE (LVDT)

The electric element in a LVDT is made up of three coils mounted in a common frame.

A magnetic core centered in the coils is free to be displaced by an elastic element of either the bellows, bourdon, or diaphragm type (see Figure 16. 12).

The center coil is the primary winding of the transformer and as such has an ac excitation voltage impressed across it. The two outside coils form the secondaries of the transformer.

When the core is centered, the induced voltages in these two outer coils are equal and out of phase; this represents the zero pressure-position.

However, when the core is displaced by the action of an applied pressure, the voltage induced in one secondary increases, whereas that in the other decreases. This output voltage difference varies essentially linearly with pressure for the small core displacements allowed in LVDT pressure transducers; this voltage difference is measured and related to the applied pressure by calibration.

In one variation of the above [12], a servo-amplifier operates on the electrical output of the LVDT and causes the core to return to its null position for each applied pressure.

Simultaneously it produces an appropriate electrical output signal (see Figure 16 · 13) .

Variable Reluctance Types

Another class of pressure transducers whose electrical output signals are ultimately derived from variable inductances in the measuring circuits operates on the principle of a movable magnetic vane in a magnetic field.

In one type, the elastic element is a flat magnetic diaphragm located between two magnetic output coils.

Displacement of the diaphragm , caused by the applied pressure , changes the inductance ratio between the output coils and results in an output voltage proportional to the applied pressure (see Figure 16 . 14) .

In a final type , the elastic element is a flat twisted tube such as already described in the section on bourdon tubes (see Figure 16.7) .

A flat magnetic armature, connected directly to the closed end of the bourdon, rotates slightly when a pressure is applied.

The accompanying small changes in the air gap between the armature and electromagnetic output coils alter the inductances in a bridge-type circuit.

This variation in circuit inductance is used to modulate the amplitude or frequency of a carrier voltage, with the net result being an electrical response that is proportional to the applied pressure [13].

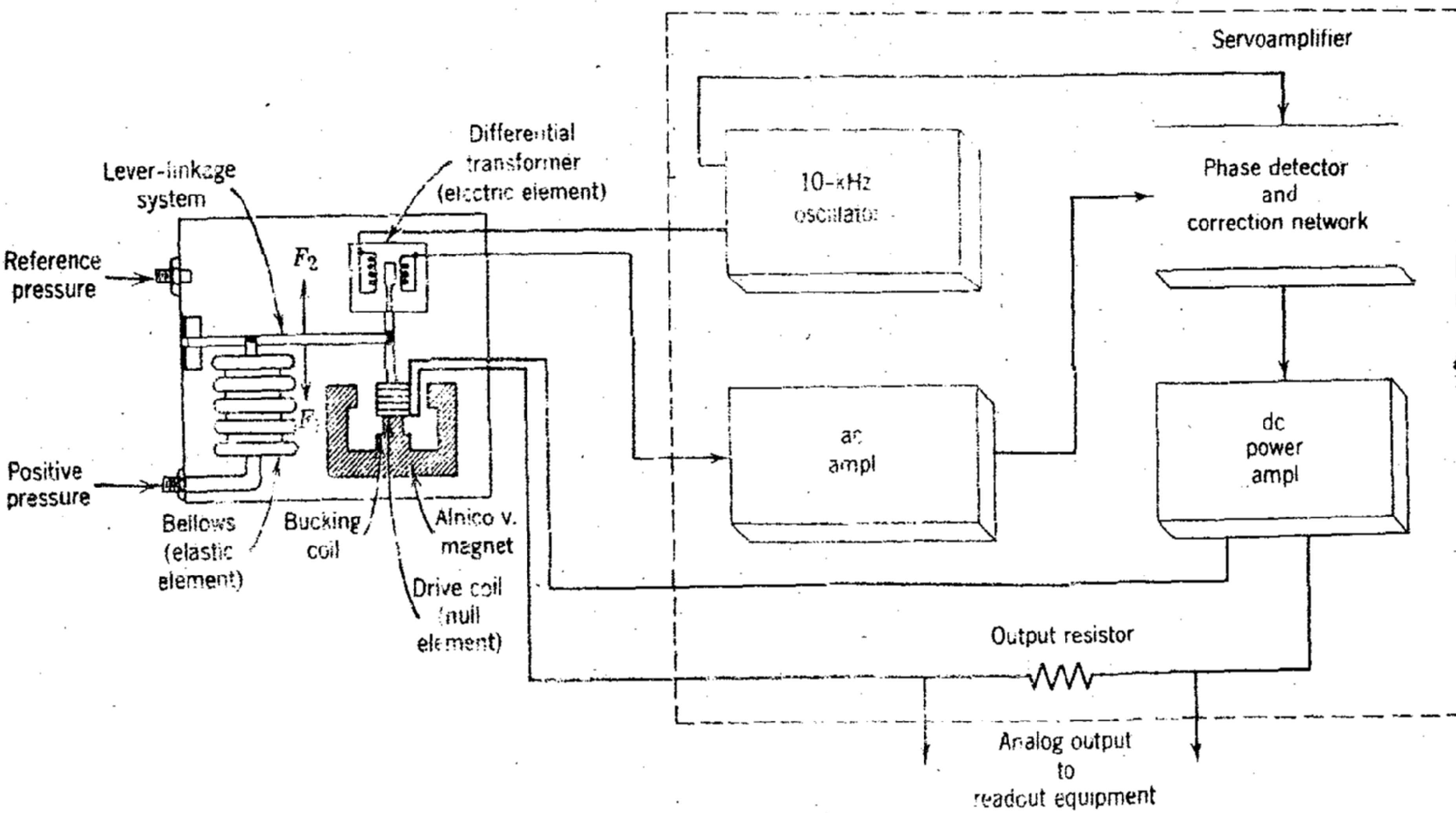


FIGURE 16.13 Block diagram and schematic of null-balance type LVDT pressure transducer. (*Source:* From Consolidated Electrodynamics Corp., [12].)

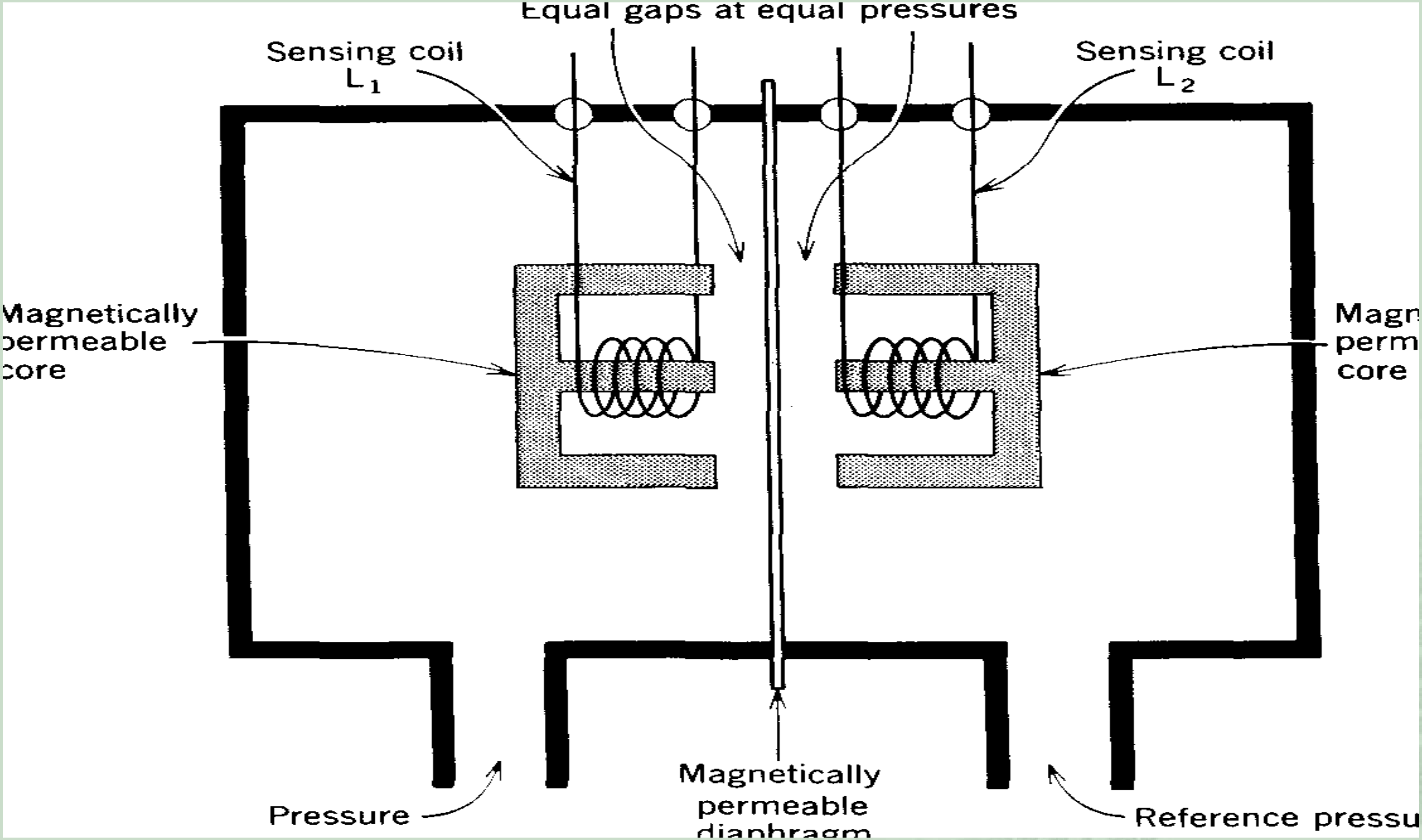


Figure 16.14 Magnetic reluctance differential pressure transducer (after Pace Wiancko literature.)