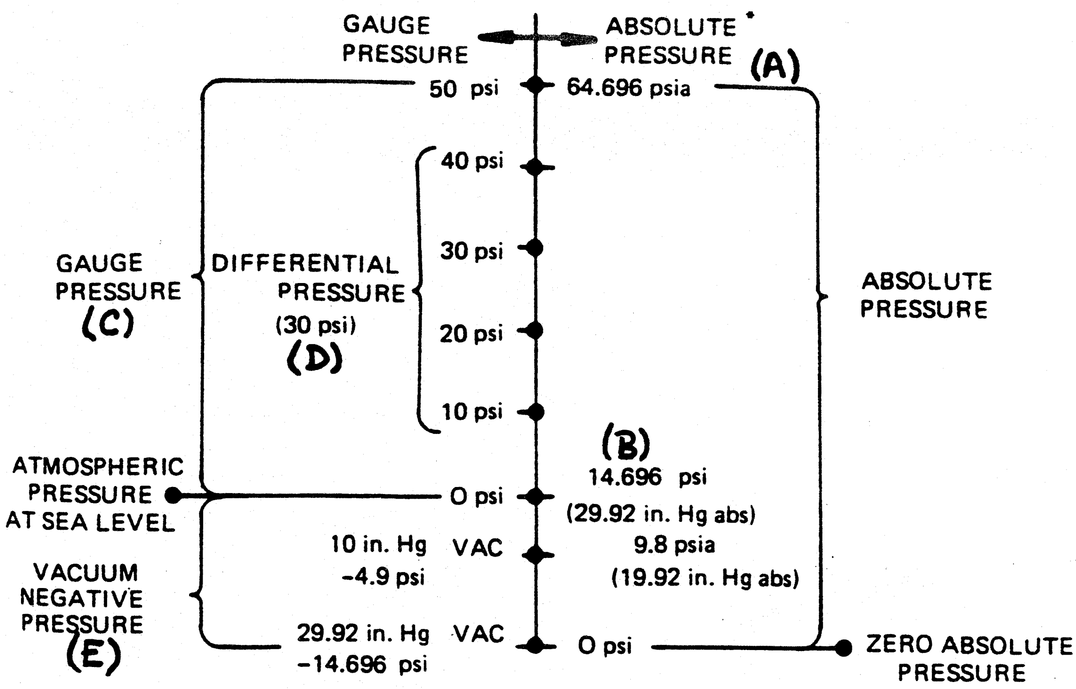
PRESSURE MEASUREMENT

Why?

- Safety
- Product Quality
- Stability

PRESSURE MEASUREMENT AND TRANSMISSION

TYPES OF PRESSURE:



* BASED ON STANDARD ATMOSPHERIC PRESSURE = 14.696 psia OR 29.92 in. Hg abs

A. Absolute Pressure measured above a perfect vacuum

B. Atmospheric Pressure exerted by the earth's atmosphere (≈ 14.7 psi)

C. Gauge Pressure measured above atmosphere

D. Differential Pressure is the difference between two pressures

E. Vacuum is a pressure less than atmosphere

Pressure Measurement

Pressure elements or pressure devices may be categorized in several different ways--on the basis of their design principles and their operating range, most of this discussion will be on element types, since signal transmission is essentially the same as that discussed for flows. Elements to be discussed are:

1. Bourdon Tubes
2. Bellows
3. Diaphragms
4. Strain Gauges

Bourdon tubes are among the group of pressure sensors that are known as elastic-deformation elements. They have been used in industry for over 100 years. There are three types of Bourdon elements, the "C", the spiral, and the helical. Bourdon tubes are simple to construct and are, therefore, relatively low in cost. Their measurement accuracy is good except at low ranges below 50 psig.

The C-Bourdon element, Figure 6-1, is used most frequently for local indication but is also used in pressure transmission and control applications. The tube is generally formed into an arc of 250°, thus deriving the term "C" because of its shape. It is secured at one end in a fixed socket where the sensed pressure is applied and the tip end is sealed. As internal pressure is applied, the tube tends to straighten. The motion of the tip is non-linear but linear response is obtained by the geared sector and pinion movement.

The accuracy of the "C" element Bourdon tube varies from ±0.5 percent to ±2 percent.

The spiral Bourdon element, Figure 6-2, is used when the free-end movement of the "C" type is not great enough to provide the needed motion. As pressure is applied to the spiral, it tends to uncoil producing the relatively long movement of the tip end. This longer movement provides greater accuracy's in the range of ±0.5 percent.

The helical Bourdon element, Figure 6-4, is similar to the spiral element except it is wound in the form of a helix. The tip travel increases considerably producing even greater amplification than the spiral element. Advantages of the helix element include the high overrange capabilities, its stability in fluctuating pressure services, and suitability for high pressure.

The number of coils used for helix elements varies depending on the pressure range. Low pressure spans may have as few as three coils while high spans may have as many as 16 or more. Accuracy's of the helix varies from ±1/2 to ±1.0 percent of span.

The bellows element is also an elastic member, usually formed from a thin seamless sheet. A simplified diagram of the element is shown in Figure 6-5. Bellows elements are used to measure absolute, gauge, or differential pressures. When measuring absolute pressure, top bellows are used. The evacuated bellows is used for atmospheric pressure compensation while the measuring bellows senses the process pressure. Since the evacuated bellows has negligible internal pressure and is surrounded by atmospheric pressure, any change in atmospheric pressure either adds to or subtracts from the movement of the measuring bellows. Bellows are used in controllers, receivers, and transmitters with accuracy's of ±1/2 percent of span.

The diaphragm element is similar to that of the bellows. Pressure is applied causing it to expand in direct proportion to the applied pressure.

The diaphragm element is essentially a flexible disk with either a flat or corrugated surface as shown in Figure 6-6. When measuring absolute pressure, evacuated capsules are required. Accuracy's of diaphragm elements range from ±1/2 to ± 1-1/4 percent of span. Applications are usually in low-pressure service except for button-type diaphragms which are used for pressures to 15,000 psig.

Most electronic pressure sensors incorporate one of the previously described elements as the primary pressure detector. Each of the devices can be used to vary a measurable electrical quantity to produce a proportionately variable electronic signal. Because the energy form is transferred from mechanical to an electrical signal, these devices are generally classified as transducers.

Among the electronic devices used to measure pressure is the strain gauge, which includes a sensing element (Bourdon tube, bellows, or diaphragm), a strain gauge attached to the element, a stable power supply, and a readout device.

The strain gauge changes a mechanical motion into an electrical signal when a wire length is changed by tension or compression, altering the wire diameter, which results in a resistance change. This change in resistance is measured by a Wheatstone bridge circuit in terms of pressure.

Generally, strain gauge accuracy's range from ±0.1 to ±2 percent of full scale depending on material and design. They are available in ranges from a few inches of water to 200,000 psig. Strain gauges are also used for measurements other than pressure such as torque and weight.

A pressure differential sensor is shown schematically in Figure 20. These devices are used in flow and level measurement and are generally called d/p cells (differential-pressure cells). A pair of diaphragms are welded to the d/p cell body and the space between them is liquid filled. The differential pressure to be detected is applied to the two sides of this diaphragm capsule. The difference (differential force) is results in a mechanical movement of the force bar. When a change occurs in the steady-state condition, the force bar changes its position relative to the nozzle, causing a change in the pneumatic output signal. The new air pressure is sensed by the feedback bellows and a state of equilibrium is established by the bar force being opposed by an equal force developed in the feedback bellows. As a results, the output signal is maintained proportional to the differential pressure sensed by the cell.

When electronic d/p transmitters are used, the force bar force is balanced against the magnetic force developed in a coil. In this instance, the coil replaces the feedback bellows and the output current flow replaces the output air signal. As the flowing current is changed, the force is changed, the force balance is reestablished by matching each bar force with an equal magnetic force and, therefore, the current output signal is proportional to the pressure differential in the d/p cell, Figure 31.

PRESSURE MEASURING INSTRUMENTS ARE EITHER:

- MECHANICAL
- ELECTRONIC

PRESSURE MEASUREMENT

Four basic types of primary elements:

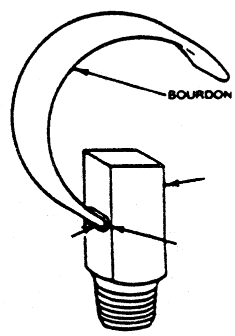
1. Bourdon Tube
2. Bellows
3. Diaphragm
4. Strain Gauge

BALANCE SENSORS

- Elastic Types - Any material will be deformed or distorted when a force is applied to it. The amount of deformation can be used as a measure of the pressure which created the force.

CHARACTERISTICS

- Deformation is proportional to the applied force
- Very little hysteresis
- Can do very little work (w = Fd) usually have mechanical gears etc. to increase mechanical advantage
- Bourdon Tube (Bronze, S.S., Alloys)
  - 30 psig < P < 100 k psig (si oil filled, sealed)
  - 1/4% - 5% of span accuracy



- Bourdon Spiral - Increased sensitivity due to greater movement
  - Usually max span to 400 psi
  - 1/4% - 5% of span accuracy

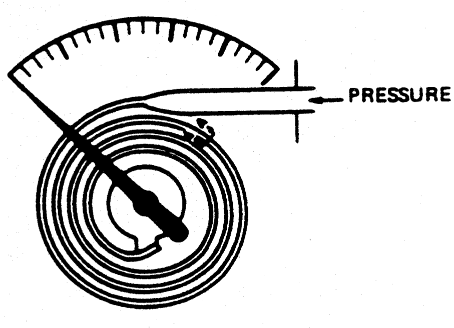


Figure 6-1
Pressure Gauge Components Drawing

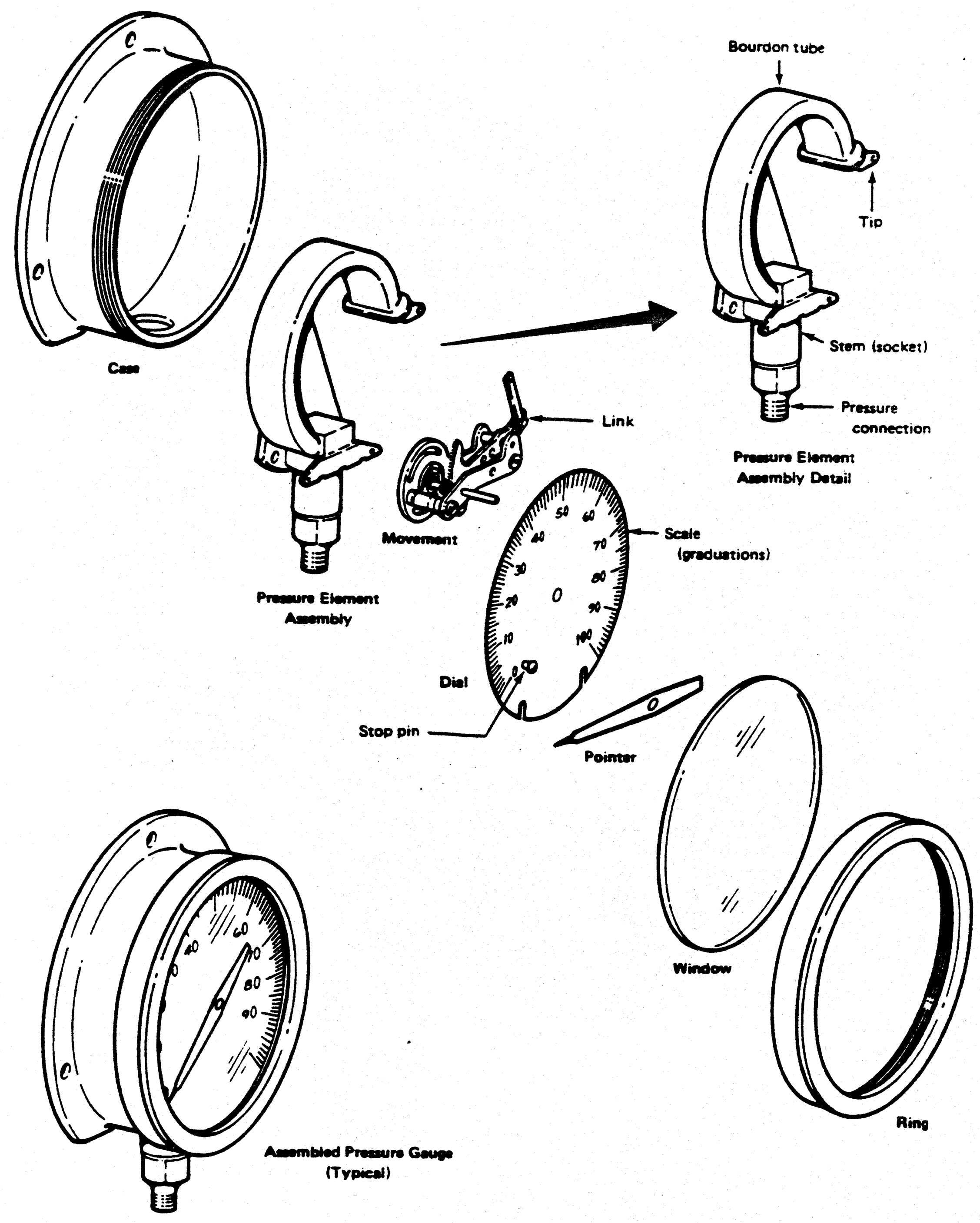
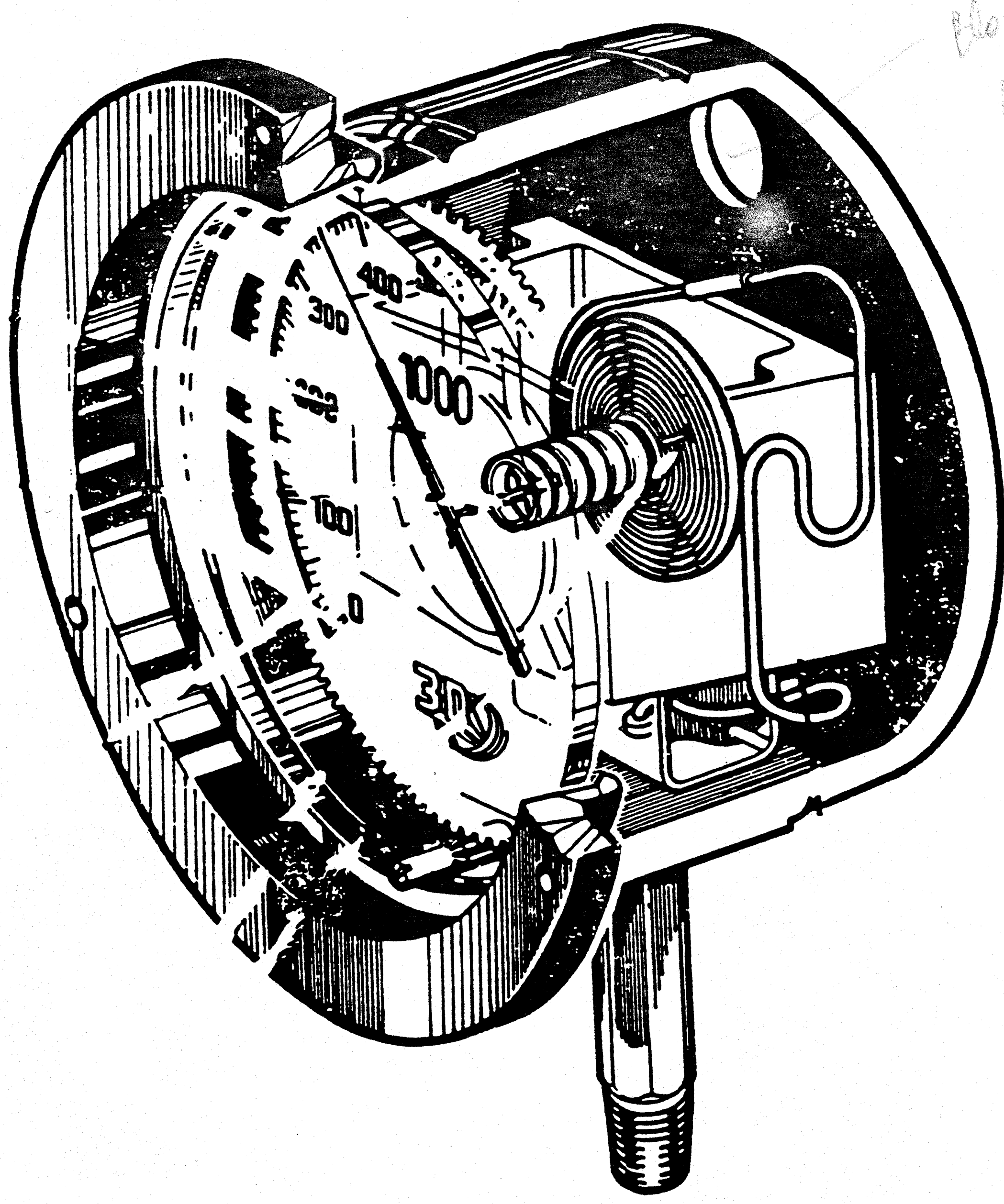


Figure 6-2
<u>Pressure Gauge</u>



AN AMERICAN NATIONAL STANDARD

Gauges — Pressure Indicating Dial Type — Elastic Element

ASME B40.1-1991

(REVISION OF ANSI/ASME B40.1-1985)

The American Society of Mechanical Engineers

345 East 47th Street, New York, N.Y. 10017

Figure 6-3
Pigtail Siphon Drawing

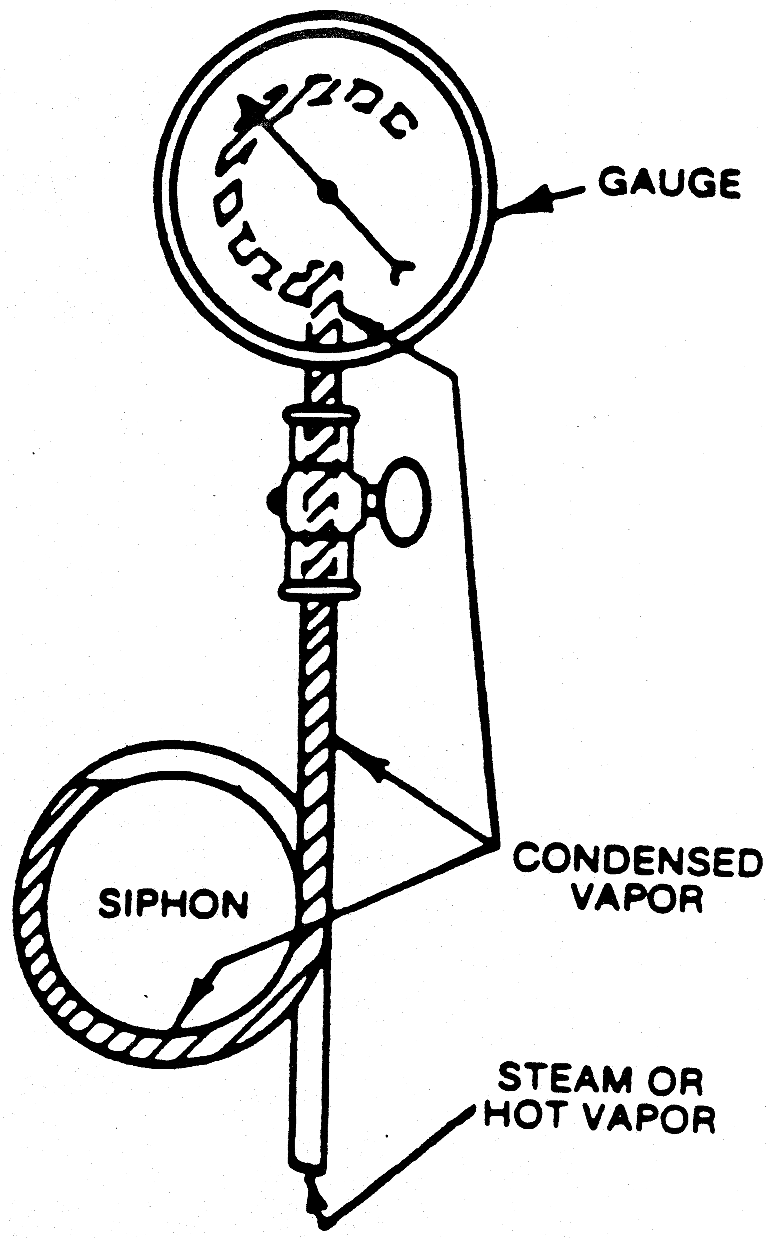


Table 6-1
Pressure Fill Fluids

Fill fluids should be selected so that in the event the diaphragm fails or a leak develops in the seal, mixing the fill fluid with the process fluid will not result in an explosion or other catastrophic failure, including contamination of the process medium. Contamination may be particularly serious in food processing applications. Other characteristics of the fill fluid that must be considered are its compatibility over the operating temperature range, including stability, vapor pressure, viscosity, and rate of expansion. Some of the more commonly used fill fluids and their properties are as follows:

1. Silicone DC-704

   (a) Usable from +70°F to +600°F. Not recommended for use below +70°F because crystallization can occur.

   (b) Will react violently with strong oxidizing agents such as (but not limited to) nitric acid, oxygen, chlorine, and hydrogen peroxide. Therefore, it should not be used for applications where such agents are present, as there is always the possibility that the seal will leak or be ruptured, allowing the fill fluid to mix with the process fluid.

   (c) Low change in viscosity with temperature.

2. Silicone DC-200

   (a) Usable from -60°F to +300°F.

   (b) Should not be used for applications involving chlorine. Use with other oxidizing agents, such as oxygen, nitric acid, and sulfuric acid, should be discussed with the seal manufacturer, since potential reaction is a function of pressure, temperature, and the concentration of the pressure medium.

   (c) Less expensive than DC-704.

   (d) Low change in viscosity with temperature.

3. Fluorolube FS-5

   (a) Usable from -50°F to +500°F.

   (b) Chemically stable with respect to oxidizing agents.

   (c) Reacts violently with diamines and aluminum compounds.

   (d) Expensive compared to other fluids.

4. Instrument oil

   (a) Usable from +30°F to +300°F.

   (b) General purpose filling fluid.

   (c) Larger change in viscosity than with the silicones. May cause sluggish indication in cold.

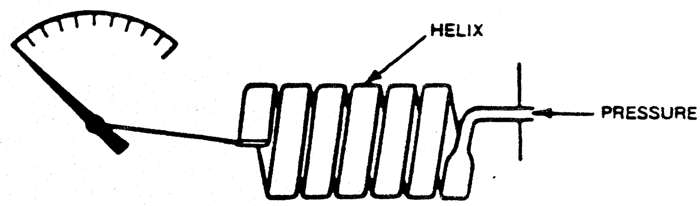
   (d) Least expensive of the fill fluids.

5. Sanitary filling fluids for food applications. Liquids such as water, vegetable oil, and pharmaceutical grade mineral oil may be used.

   (a) Usable temperature range is limited. Check with manufacturer.

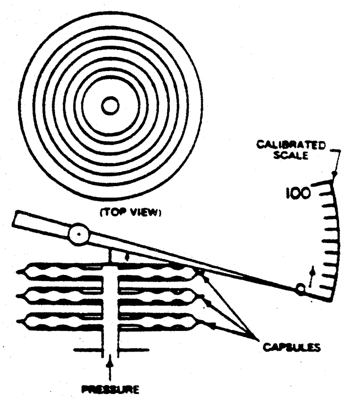
   (b) Not for use with strong oxidizing agents (see discussion under DC-704 above).

- Bourdon Helix - More movement than spiral



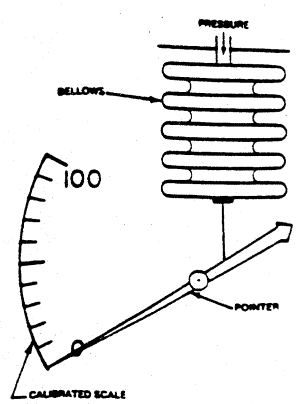
  - High over range (1000%)
  - High Pressure (≈ 20 coils → 80 k psi)
  - Low Pressure (≈ 3 coils → 30 psi)
  - Accuracy: 1/4% - 5% span
  - Quite often used in filled thermal systems

- Diaphragm (Bronze, S.S., BeCu, etc.)



  - Pressure can be applied to the inside or outside
  - Sensitivity increases proportional to diameter (≈ 1-6")
  - Diaphragms may be stacked for greater movement
  - Range: 0 - 5 mm Hg to 0-200 psig
  - Accuracy: 1/2% - 1% span

- Bellows (Brass, S.S., BeCu, Monel)



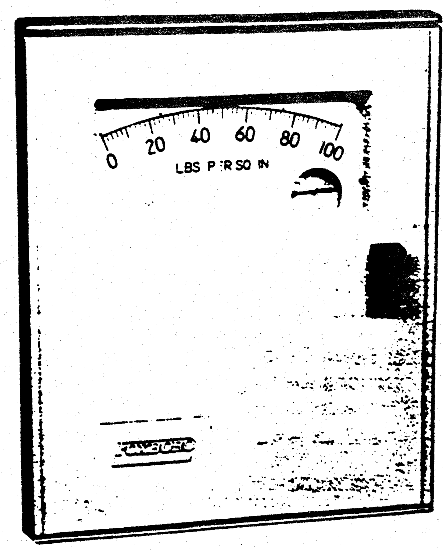
  - Movement proportional to # of convolutions
  - Pressure may be applied to inside or outside
  - Sometimes a spring is added to increase precision
  - Sensitivity proportional to size
  - In general, a bellows can detect a slightly lower pressure than a diaphragm
  - Range: ≈ 0 - 5 mm Hg < P < 0-2k psi
  - Accuracy: 1% span

Figure 6-7
Pneumatic Indicating Controller

43AP SERIES PNEUMATIC INDICATING CONTROLLERS

- **Wide Selection of Direct Connected Measurement Elements**
- **Broad Choice of Control Modes**
  - on/off, proportional, proportional plus derivative, proportional plus integral (reset), proportional plus integral (reset) plus derivative, differential gap, and automatic shutdown.
- **Internal Bumpless Auto/Manual Transfer**
  - smooth internal switching.
- **Weatherproof**
  - glass-fiber reinforced case, gasketed door.
  - NEMA Type 3 protection.
- **Accuracy Unaffected by Mounting**
  - measurement element and control unit mounted on rigid steel plate.

For complete specifications, refer to Product Specification Sheet PSS 3-1B3 A.



The 43AP Series Pneumatic Indicating Controllers continuously indicate and control pressure, vacuum, temperature, or flow.

FUNCTIONAL SPECIFICATIONS

Control Modes: See "HOW TO ORDER."

Measurement Elements: See "HOW TO ORDER."

Output Gauge: 0 to 200 kPa, 0 to 30 psi, or 0 to 2 bar or kg/cm^2, as specified.

Set Point Adjustment: By means of a knob mounted inside the case.

Controller Action: Output signal either increases or decreases with increasing measurement, as specified; action is reversible in the field.

Supply Pressure: 140 kPa, 20 psi, 1.4 bar or kg/cm^2.

Output Signal: See "HOW TO ORDER."

Ambient Temperature Limits: -40 and +80°C (-40 and +180°F).

PERFORMANCE SPECIFICATIONS

Accuracy (When used with the elements as listed under "HOW TO ORDER"): ±0.5% of calibrated span.

Repeatability: 0.2% of calibrated span.

PHYSICAL SPECIFICATIONS

Mounting: Panel, surface, pipe, or yoke.
Panel: Flush in a panel up to 16 mm (0.6 in) thick.

Surface: Suitable for all controllers having internally mounted elements. This mounting is not available with heavy duty helical elements. (These elements extend through the back of the case.)

Pipe: A kit of parts to fit a DN 50 or 2 in vertical pipe.

Yoke: Kit of parts to fit a vertical DN 50 or 2 in pipe stub. This mounting scheme is designed specifically for controllers having rear mounted differential pressure elements.

Enclosure: The case and door are glass-fiber reinforced polyester moldings, compounded for superior corrosion resistance. The door has a shatterproof polycarbonate window, ultraviolet-resistant. The overall construction is weatherproof, meets IEC IP53, and provides the environmental protection of NEMA Type 3.

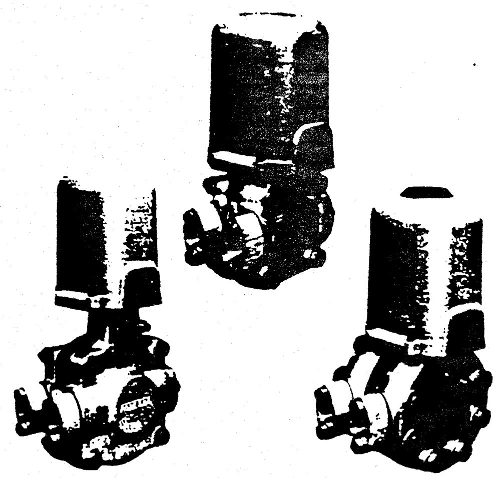
Scale: Black markings on a white background, sector-shaped with nominal effective length of 150 mm (6 in). Refer to Chart and Dial Catalog 600 for available ranges.

Figure 6-9
Typical Pneumatic Pressure Transmitters

15A, 13A, 13H SERIES PNEUMATIC d/p Cell TRANSMITTERS

- **15A** — low range transmitter adjustable for ranges from 0-1.3 to 0-6 kPa (0-5 to 0-25 inH_2O) ΔP at static pressures up to 3.5 MPa (500 psi).
- **13A** — adjustable for ranges from 0-5 to 0-210 kPa (0-20 to 0-850 inH_2O) ΔP at static pressures up to 14 MPa (2000 psi).
- **13H** — adjustable for ranges from 0-5 to 0-210 kPa (0-20 to 0-850 inH_2O) ΔP at static pressures up to 40 MPa (6000 psi).

For complete specifications, refer to Product Specification Sheet PSS 2B-1C1 A.



15A 13H

The 15A, 13A, 13H Series Pneumatic d/p Cell Transmitters measure differential pressure and transmit a proportional pneumatic output signal.

FUNCTIONAL SPECIFICATIONS

Static Pressure, Span, and Range Limits:

Series	Static Pressure Limit	
	MPa	psi
15A	3.5	500
13A	14	2000
13H	40	6000

Series	Span Code	Span Limits	
		kPa ΔP	inH_2O ΔP
15A	L	1.3 and 6	5 and 25
13A and 13H	M	5 and 62	20 and 250
	H	50 and 210	200 and 850

Series	Span Code	Range Limits (a)	
		kPa ΔP	inH_2O ΔP
15A	L	±12.5	±50
13A and 13H	M	±62	±250
	H	±210	±850

(a) Nonzero-based ranges require optional zero elevation or suppression kit. See "HOW TO ORDER." Upper and lower range values must not exceed range limits. Negative numbers indicate a higher pressure on the normal "Low Side" of the transmitter, such as may occur in closed tank application with a wet leg.

Process Temperature Limits: -40 and +120°C (-40 and +250°F) at capsule.

Ambient Temperature Limits: -40 and +120°C (-40 and +250°F).

Output Signal and Supply Pressure:

Output Signal	Supply Pressure
20 to 100 kPa	140 kPa
3 to 15 psi	20 psi

PERFORMANCE SPECIFICATIONS

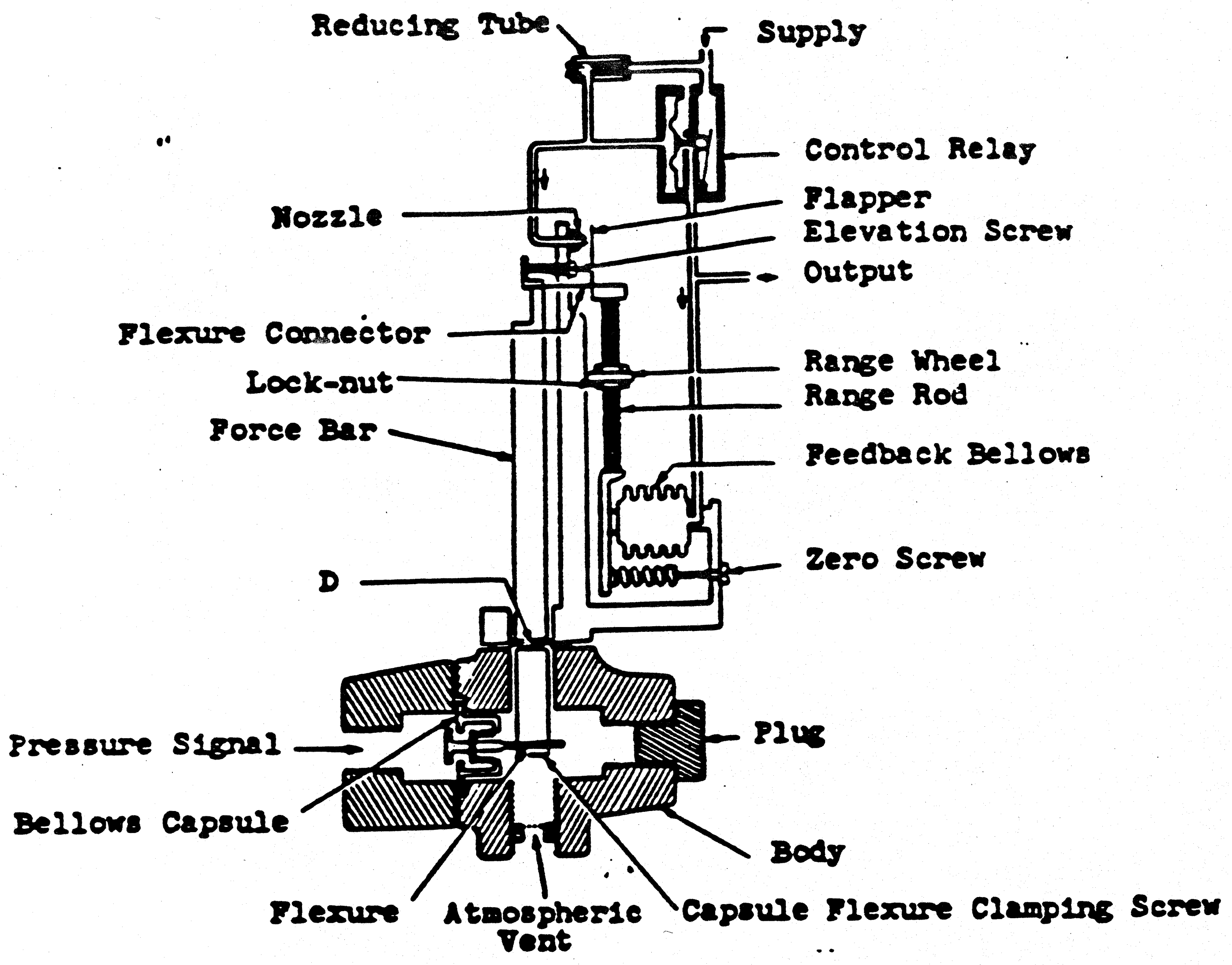
Accuracy:
15A Series: ±0.5% of calibrated span.

13A and 13H Series: ±0.5% of calibrated span except ±0.75% of calibrated span for calibrated spans greater than 130 kPa or 525 inH_2O ΔP.

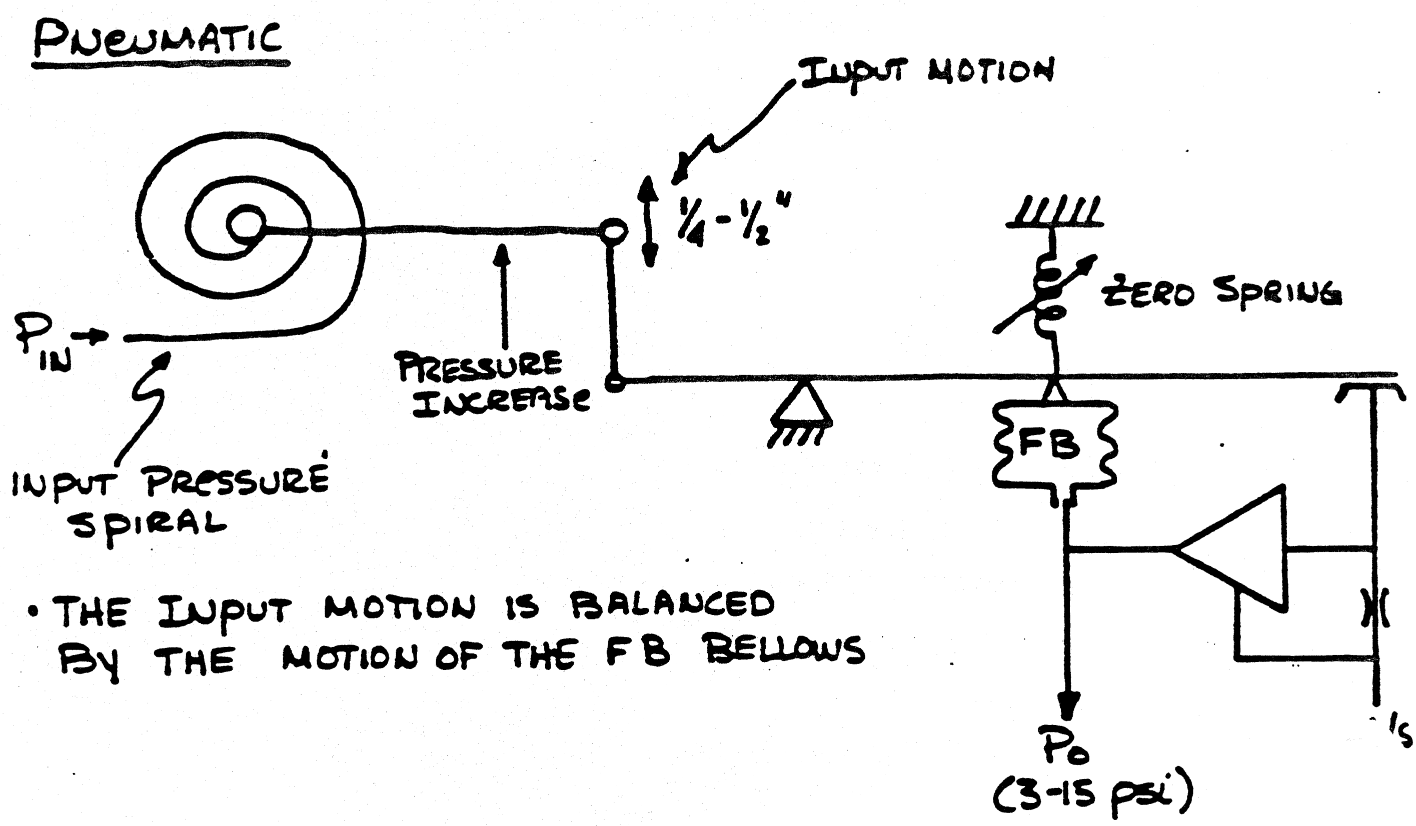
Repeatability: 0.1% of calibrated span.

Hysteresis: 0.1% of calibrated span.

Figure 6-8
Pneumatic Force Balance Transmitter



MOTION BALANCE (Earliest Type of Transmitter, Display)

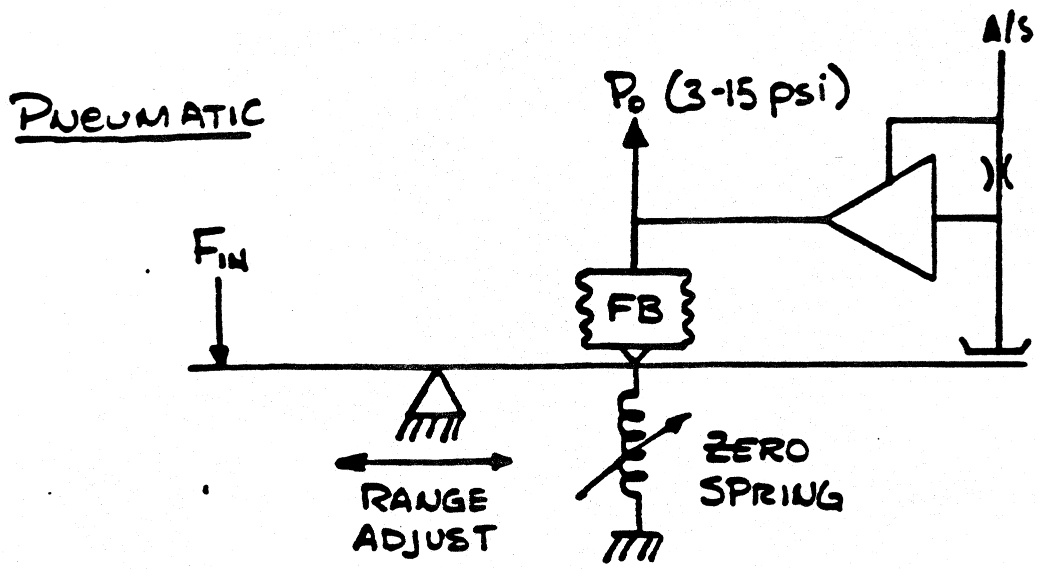


- The input motion is balanced
  by the motion of the FB bellows

Advantages	Disadvantages
• Lower cost than F/B	• Because of motion:
• Simpler Mechanism	- Friction
• Local Indicator	- Wear
• Easier to service	• Possible non-linearity due to large motion
	• More difficult to calibrate
	• More susceptible to vibration

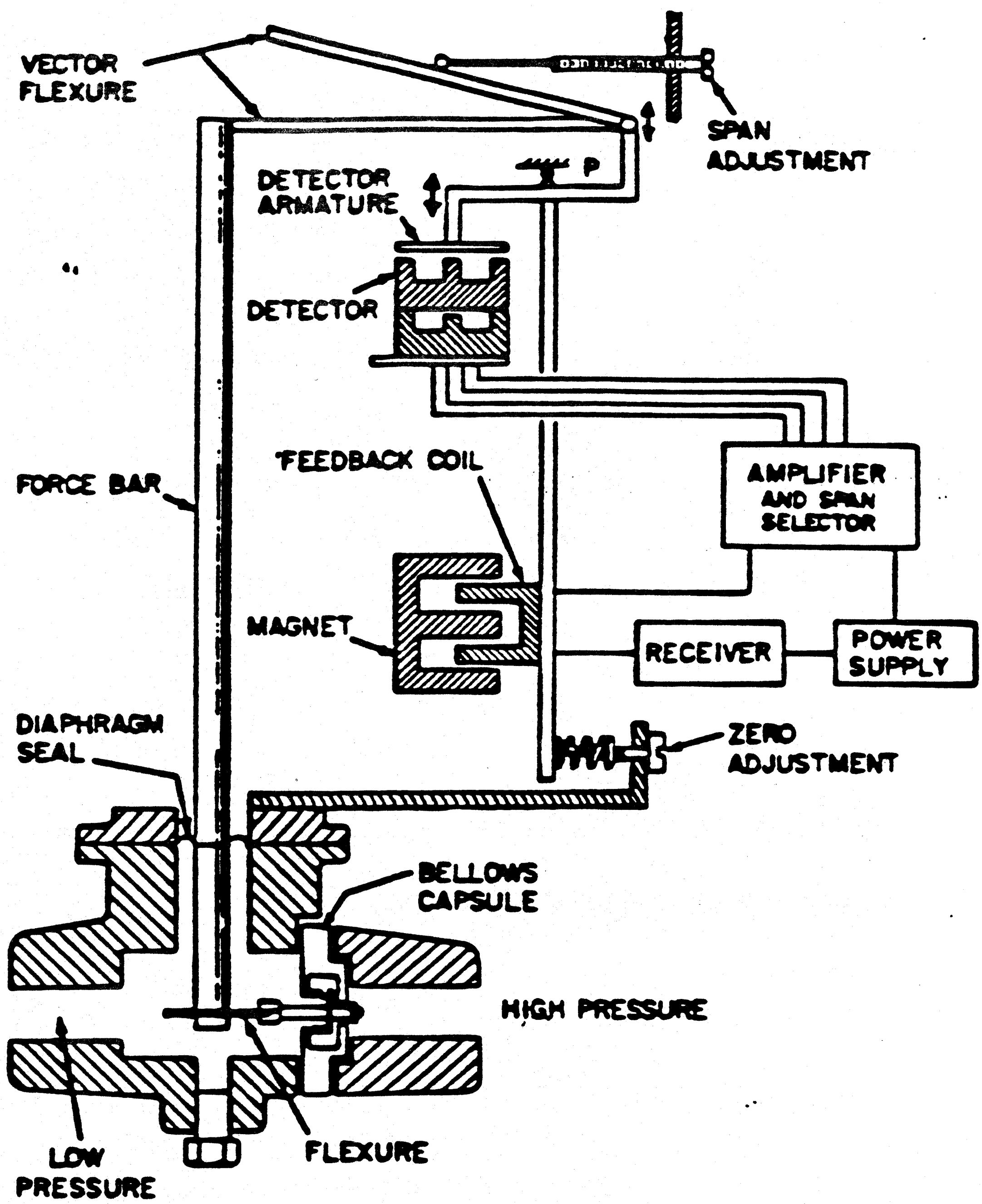
Electronic - A coil replaces the balance bellows; electronic M/B XMTRS are not too common

FORCE BALANCE PRESSURE TRANSMITTER



- Fin is balanced by the force generated by the feedback bellows
- Generally, F/B transmitters are replacing motion balance devices

Figure 6-10
Electronic Force Balance Transmitter



Advantages	Disadvantages
• Essentially no motion ∴ - No friction - No wear	• Relatively expensive
	• Generally no internal local indicator. Must be added externally
• Low maintenance	
	• Large and heavy
• Inherently linear	• Shock and vibration sensitive (although not as great as M/B)
• Relatively simple to calibrate	
• High accuracy (< .5%)	

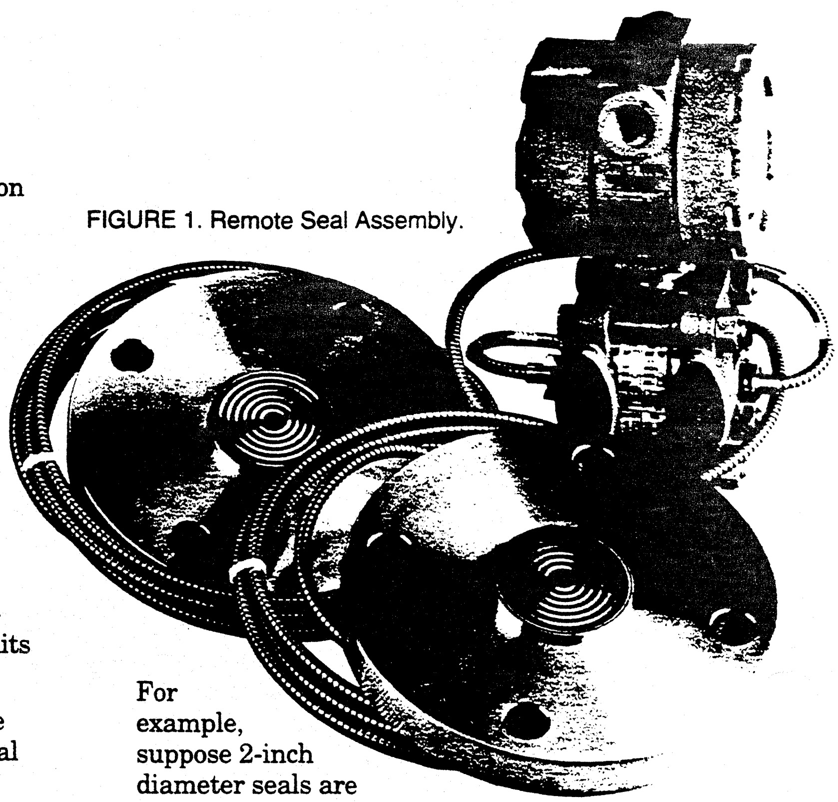
- Both the pneumatic and electronic D/P cells are mechanical in nature, the difference being the form of the output, 3-15 psi vs. 4-20 ma.

Figure 6-11
Remote Seal Pressure Transmitters

What is a remote seal system?

A remote seal system consists of a pressure transmitter, one or two remote seals, a connection between the remote seal(s) and the transmitter, and a fill fluid. See Figure 1. Seal systems act as a pressure transport medium between the process and the sensor of the transmitter.

FIGURE 1. Remote Seal Assembly.



When are remote seals used?

Remote seals are used when it is necessary to isolate the transmitter from the process. Remote seals help in the following conditions:

- The process **temperature** is outside of the normal operating ranges of the transmitter and cannot be brought into those limits with impulse piping.
- The process is **corrosive** and would require frequent transmitter replacement or unusual materials of construction.
- The process contains a lot of **solids** or is **viscous** and could plug the impulse piping.
- The application requires the use of **sanitary connections**.
- There is a need for easier cleaning of the process from the connections to **avoid contamination** between batches.
- There is a need to **replace wet legs** to reduce maintenance on applications where the wet leg is not stable or often needs to be refilled.
- There is a need to make **density** or **interface measurements**.

Use remote seals when one of the above conditions requires their use. A common example where seals are used unnecessarily is boiler drum level measurements or steam flow. In most of those applications, the high temperatures can be reduced with the use of impulse piping and condensate legs.

For example, suppose 2-inch diameter seals are attached to a transmitter with narrow-diameter 25-foot capillaries and D.C. 200 fill fluid. If these are used in an indoor application where the ambient and process temperatures are in a fairly stable, but cool environment, then this combination may contribute a small error. It may also be fairly easy to zero the system at the temperature and eliminate most of the error. In a large tank where the level changes very slowly, the time response associated with the 25-foot capillaries may not be a problem.

However, if the tank is outside and the temperature frequently changes by 50 °F (28 °C), then the error could be five times higher. If the level of the tank changes very fast, then the error could be aggravated by the extended time response associated with the 25-foot capillaries. It is therefore prudent to examine the application conditions and select the seal configuration accordingly.

Figure 6 - 11A
Differential Capitance Cell

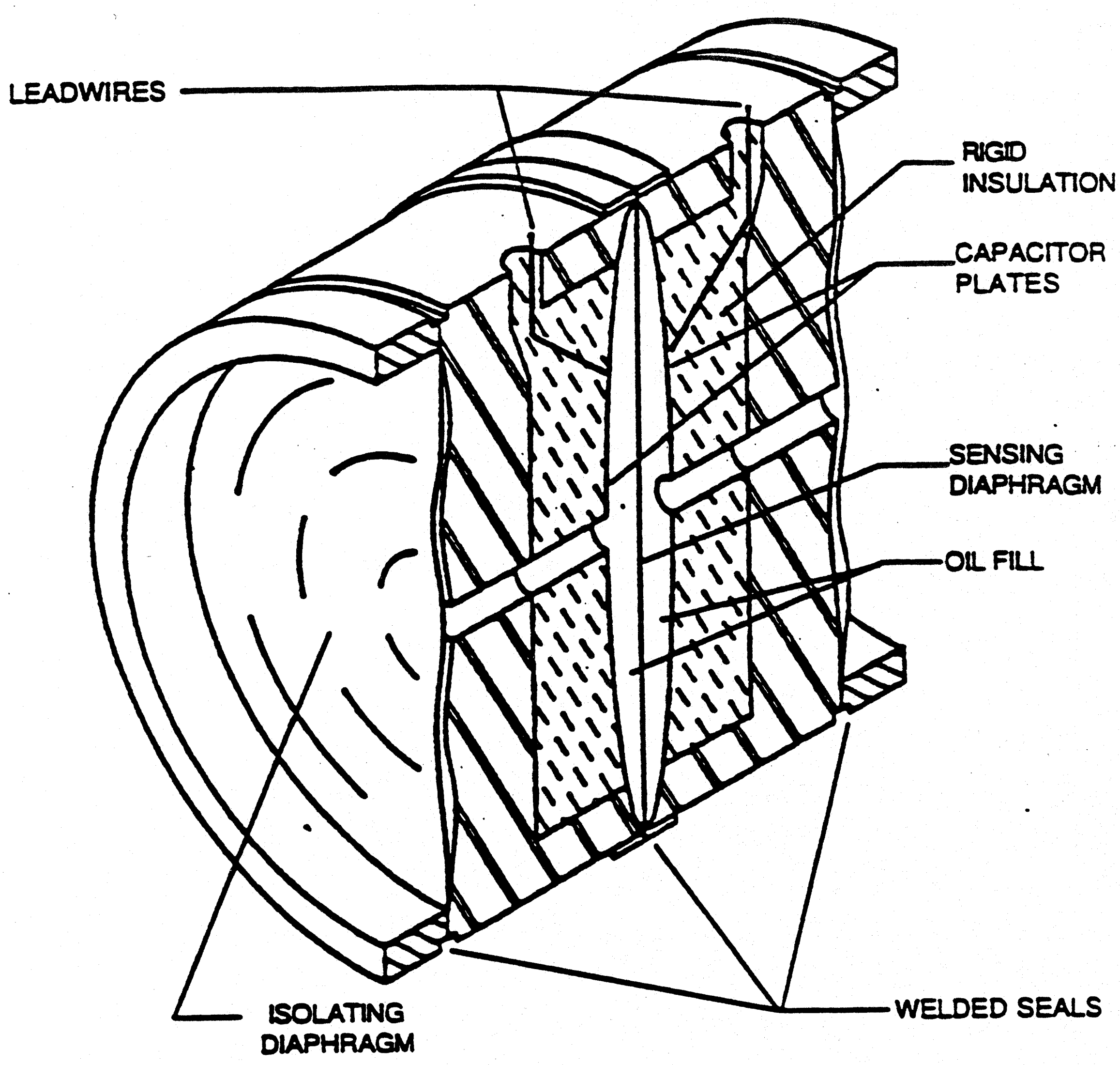


Figure 6-12
Types of Remote Seals

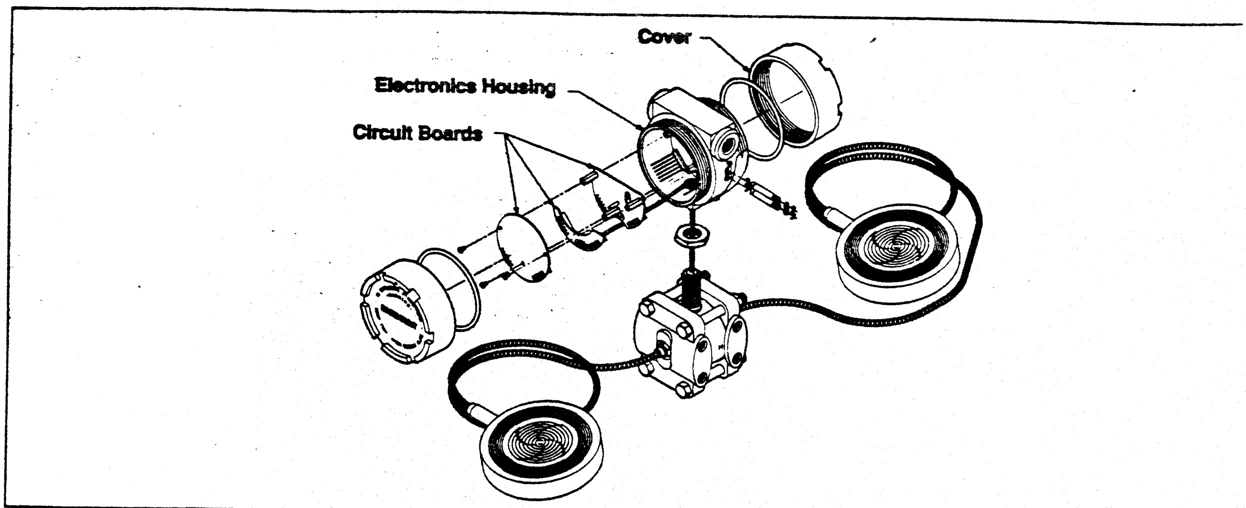
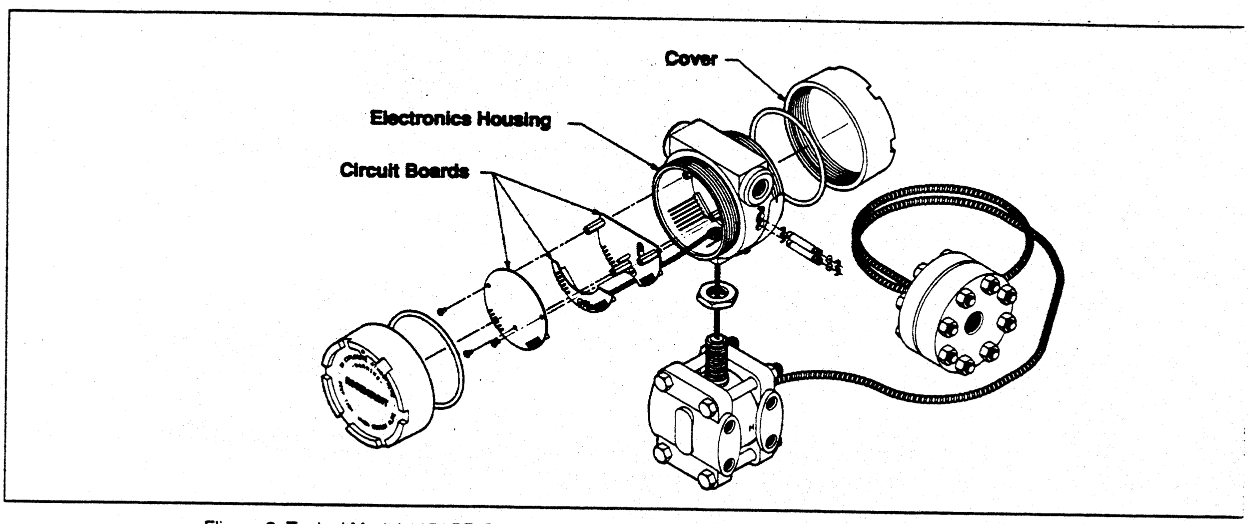


Figure 1. Typical Model 1151DP Differential Pressure Transmitter with Two Remote Diaphragm Seal Assemblies



Fligure 2. Typical Model 1151GP Gage Pressure Transmitter with Remote Diaphragm Seal Assembly

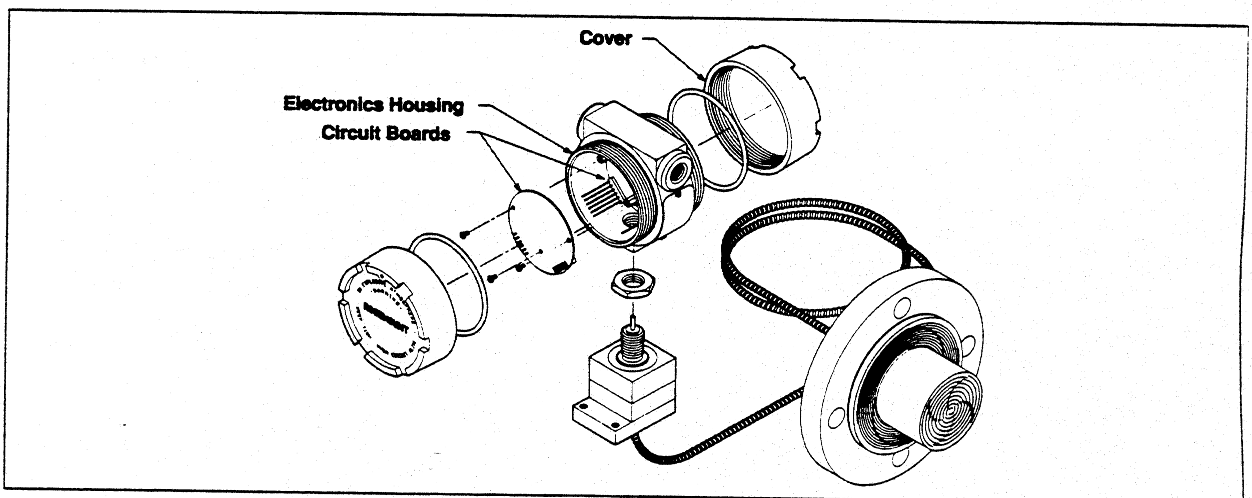
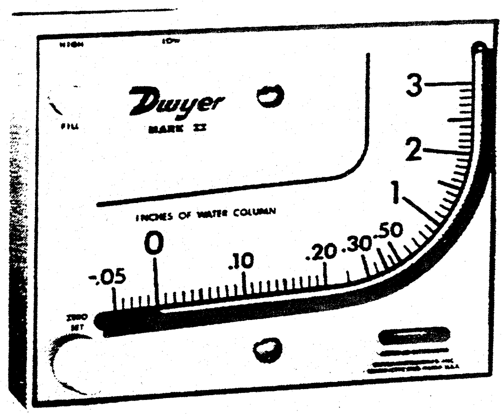


Figure 3. Typical Model 1144 Transmitter with Remote Diaphragm Seal Assembly

Figure 6-13
Low Pressure Instruments



Mark II Model No. 25
Molded Plastic Manometer

water column