Process Gauge Isolation
Diaphragm Seals and Isolator Rings

By David Gardellin, President Onyx valve Co

Pressure measurement on a compressed air or cooling water line is fairly straight foreword: simply tap a gauge at some point in the line. Fluids such as air and water have no adverse effects on the internal components of the gauge. Other fluids, however, may not be so benign. Many fluids subject to pressure measurement are corrosive, or they contain solids, or they crystallize or solidify.

Hard-to-measure fluids include strong acids and bases, adhesives, slurries, sewerage, sludge, pigments, food products such as cheese or ground meat, molten plastic and mine ore slurry.

For these fluids, we have to isolate the gauge from the process fluid with a barrier that transmits pressure while isolating the gauge from direct contact with the fluid being measured. The typical response is to apply a "chemical seal" like the one illustrated in figure 1.

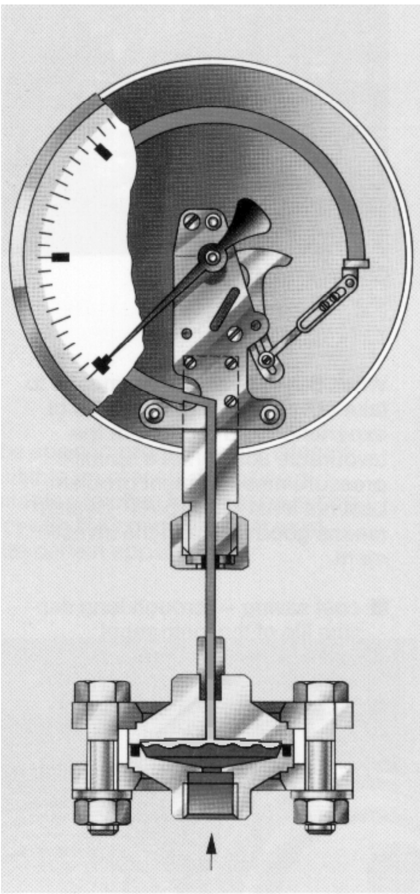


Figure 1
Typical Chemical Seal with Gauge

The pressure gauge is separated from the process fluid by a flexible diaphragm. The interior space between the diaphragm and pressure element is filled with an intermediate fluid that transmits the pressure applied to the diaphragm to the gauge.

It is critical that all the air is evacuated from the system prior to injecting the fill fluid. Any air bubbles entrained in the system will collapse under pressure, forcing the elastic membrane to over stretch. Air pockets introduce unacceptable errors in the gauge reading, or will cause the gauge to stop functioning completely. An air bubble as small as a grain of rice can cause the gauge to malfunction, so it is imperative that a vacuum pump be used to evacuate the system prior to filing. Once the system is evacuated and filed, if it is disassembled for any reason the evacuation and filling operation must be repeated for it to function properly.

The diaphragm and flange connection are exposed to the process fluid. The materials of diaphragm and flange must be suitable to withstand the temperature and chemistry of the process fluid.

Often, capillary tubing provides the connection between the diaphragm seal and the pressure-measuring instrument to bridge the distance or protect the gauge from hot process fluids.

Capillary tubing influences the response time of the system.

There are two ways to isolate the process fluid from a pressure-measuring instrument:

- A conventional diaphragm seal.
- An Isolator Ring.

The use of a chemical seal or isolator ring is not restricted to a pressure gauge as shown in the illustration, but works with transmitters and pressure switches as well.

Introducing either type of isolating device into a pressure measuring system protects the instrument from the process fluid but introduces errors in the reading.

Four factors determine the increased magnitude of the error in the gauge reading:

1. The **Required** Displacement Volume of the gauge: To drive the gauge mechanism and rotate the pointer around the dial, you have to inject a small but finite amount of fluid into the gauge Bourdon tube. The volume of fluid required to drive the pointer from zero to full scale is called the required displacement volume or control volume.
2. The **Available** Control Volume of the diaphragm seal or isolator ring: The amount of fluid which can be squeezed out of the diaphragm seal is the Maximum Available Displacement Volume.
3. Surface area of the isolating membrane.
4. Relative flexibility of the isolating membrane.

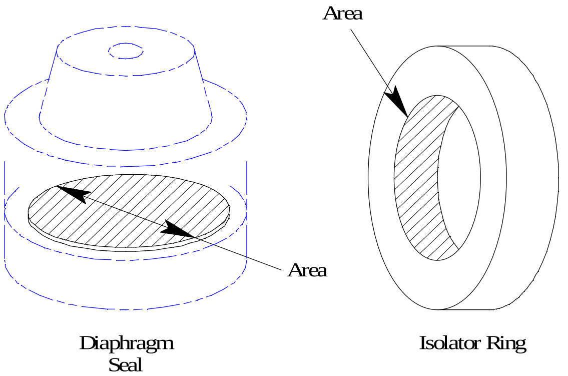
In order to function properly, the maximum available control volume in the seal must be greater than the required control volume of the gauge. Once the maximum available control volume has been extracted from the seal, the diaphragm hits the backstop and the gauge stops in its tracks. Isolator rings, even in small sizes, typically have more than 10 times the available control volume compared to any of the standard size diaphragm seals.

Diaphragm Seals Nominal size	Available Control Volume
1.375 inch	0.02 in^3
1.900 inch	0.03 in^3
2.500 inch	0.07 in^3

Isolator Rings	Available Control volume
½”	0.31 in^3
¾”	
1”	
2”	0.50 in^3
3”	1.23 in^3
4”	1.70 in^3

Surface Area of the Isolating Device:

The surface area and the modulus of elasticity (stiffness) of the flexible element affect the accuracy of the system.

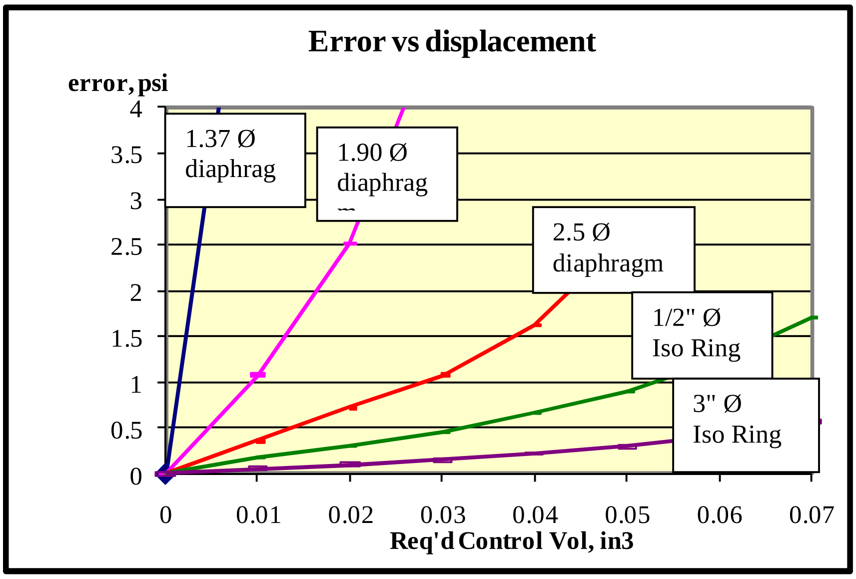


$A_{diaph} = \Pi * r^2$

$A_{Iso} = \Pi * d * L$

Diaphragm Seals Nominal size	Area
1.375 inch	1.48 in^2
1.900 inch	2.98 in^2
2.500 inch	4.90 in^2

Isolator Rings	Area
½”	4.32 in^2
¾”	
1”	
2”	8.64 in^2
3”	12.95 in^2
4”	17.27 in^2



The elastic membrane in an Isolator Ring has a lower Modulus of Elasticity (it's more flexible) than the material in the traditional chemical seal, which is usually stainless steel.

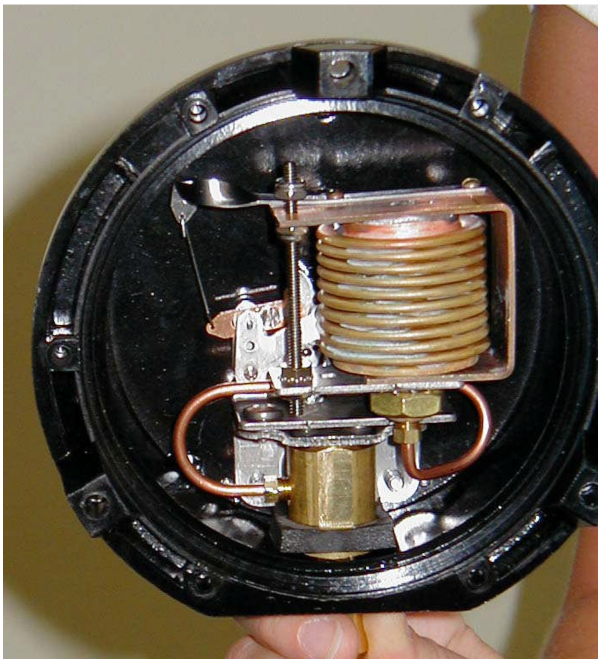


Fig-4 Bellows type measuring instrument

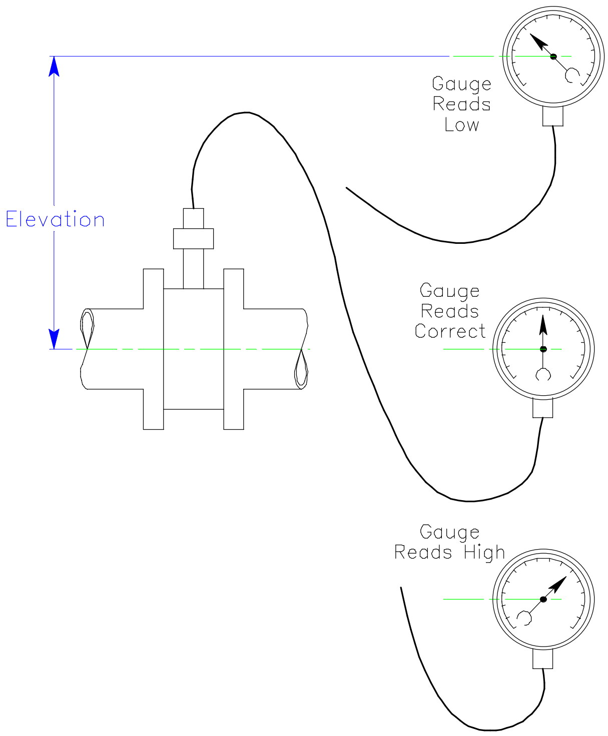
There is more surface area in an Isolator Ring than there is in a traditional chemical seal.

Some pressure instruments have relatively large control volumes. For example, a turret case gauge designed to measure low pressure in the range of 5 psi or less, uses a convoluted bellows as the pressure measuring element. (See figure-4 at left.)

This type of instrument has a control volume more than ten times the volume of a typical bourdon tube. This type of gauge can not be used with a diaphragm seal. However, isolator rings 6” and larger have enough displacement volume to operate this kind of instrument and still provide accurate readings.

Elevation effects of Caused by Capillary Tubing:

As you change the elevation of the gauge with respect to the isolator ring, you introduce an elevation error. This error is due to the static pressure of the liquid in the capillary tube.



The change in gauge reading caused by elevation changes of the pressure sensing instrument can be calculated in advance (and compensated for by re-calibrating the instrument) using the following equation:

$$P_{gauge}\{psi\} = P_{actual} + \frac{Elevation\,\{feet\} * sp\ gr}{2.31}$$

The Onyx standard fill fluid is silicone oil with a specific gravity = 0.967 at 77°F.

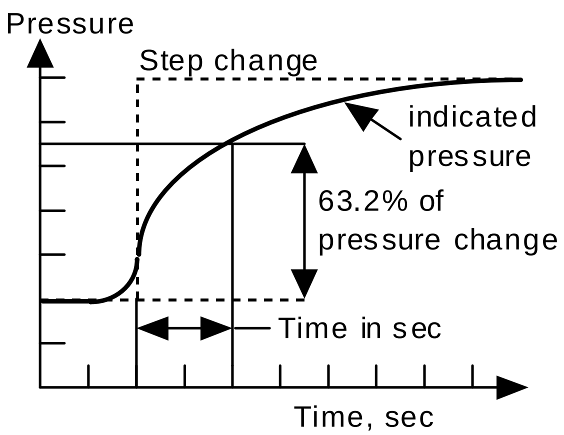
Observe polarity: If the gauge is below the isolator ring, then the elevation term in the above equation is positive; if the gauge is above the isolator ring, the elevation term is negative.

If the gauge or transmitter has a zero adjust capability, the elevation error can be eliminated completely by re-setting the zero adjust to compensate for the elevation change.

Response Time with Capillary Tubing

Capillary tubing introduces a response time lag in the instrument reading. This delayed reaction time is influenced by:

- Length of the capillary tube
- Internal diameter of the capillary tube
- Control volume of the pressure-sensing instrument
- Viscosity of the fill fluid, including temperature effects fill fluid viscosity



Response time is defined as the time, in seconds, for the pressure-sensing instrument to register 63.2% of a step change in pressure.

The reason the definition is not based on a 100% change is because, theoretically, it takes an infinite amount of time for any pressure-sensing instrument to respond to a step change in pressure. That's because the gauge pointer moves slower and slower as it gets closer to the actual pressure.

The control volume of a pressure-sensing instrument such as a gauge or transmitter is defined as the change in volume required to deflect the bourdon tube or sensing diaphragm from zero to 100% reading.

The smaller the control volume, the better the performance. Instruments with smaller control volumes exhibit less temperature error and time lag than instruments with greater volume. As a general rule, higher range instruments have a smaller control volume than lower range instruments; for example a 100-psi gauge has a much smaller control volume than a 15-psi gauge.

Another general rule is that electronically amplified devices have a smaller control volume than mechanical devices; again, to use an example, an electronic transmitter has about 1/100th the control volume of a bourdon tube gauge of the same range.

Onyx isolator rings are supplied with capillary tubes with ID = 0.075 inches, and the fill fluid is Silicone with a viscosity = 100 centistokes. Typical time lag with 5 feet of capillary and a 4 ½" turret case gauge with a 60 psi range is about 2 seconds.

Apart from the geometrical configuration of the measuring system, the temperature rating of the viscosity of the fill liquid also influences the response time. A fill liquid of low viscosity reduces the response time.

Temperature Effects on Accuracy with Capillary Tubing:

The complete isolating assembly, consisting of a chemical seal (with or without capillary) and pressure measuring instrument is filled with a certain amount of filling liquid at a specified temperature (in general 20° ± 2 ˚C), referred to as the filling temperature.

Temperature changes cause the liquid inside the capillary tube to expand and contract, changing the volume of the fill fluid. The resulting error is a function of the total volume of the tubing, pressure instrument, and isolator ring. Because the rubber sleeve in the isolator ring has a much lower modulus of elasticity compared to a diaphragm seal, it can absorb most of the volumetric change resulting from temperature differences throughout the usable temperature range for isolator rings. A typical error in gauge reading through a temperature swing from 0°F to 120°F is about ½ psi depending on isolator ring size and gauge type. This is roughly a quarter the error expected with a standard 60 mm stainless steel diaphragm seal

Users who want a more accurate prediction of performance for a measuring system consisting of an isolator ring, capillary tube and pressure sensing element can bring the full capability of mathematics to bear on the problem. For calculating the volume inside the capillary tube: Onyx isolator rings are supplied with capillary tubes with ID = 0.075 inches.

$$Err = \left[\left(\Delta T_{process} * Vol_{iso\ ring}\right) + \left(\Delta T_{amb} * Vol_{capil}\right) + \left(\Delta T_{amb} * Vol_{gage}\right)\right] * E * R_S$$

Where:

Err = Error in reading expressed in inches H_2O water column.

E = Expansion factor. If you use degrees F and inches for all the terms in the above equation, then E for Silicone fluid = 0.000600

Rs = Spring rate. For isolator rings, R_S is related to nominal size such that:

$$R_S = \frac{100}{Nom\ size,\ in}$$

The error as a percent of reading is therefore:

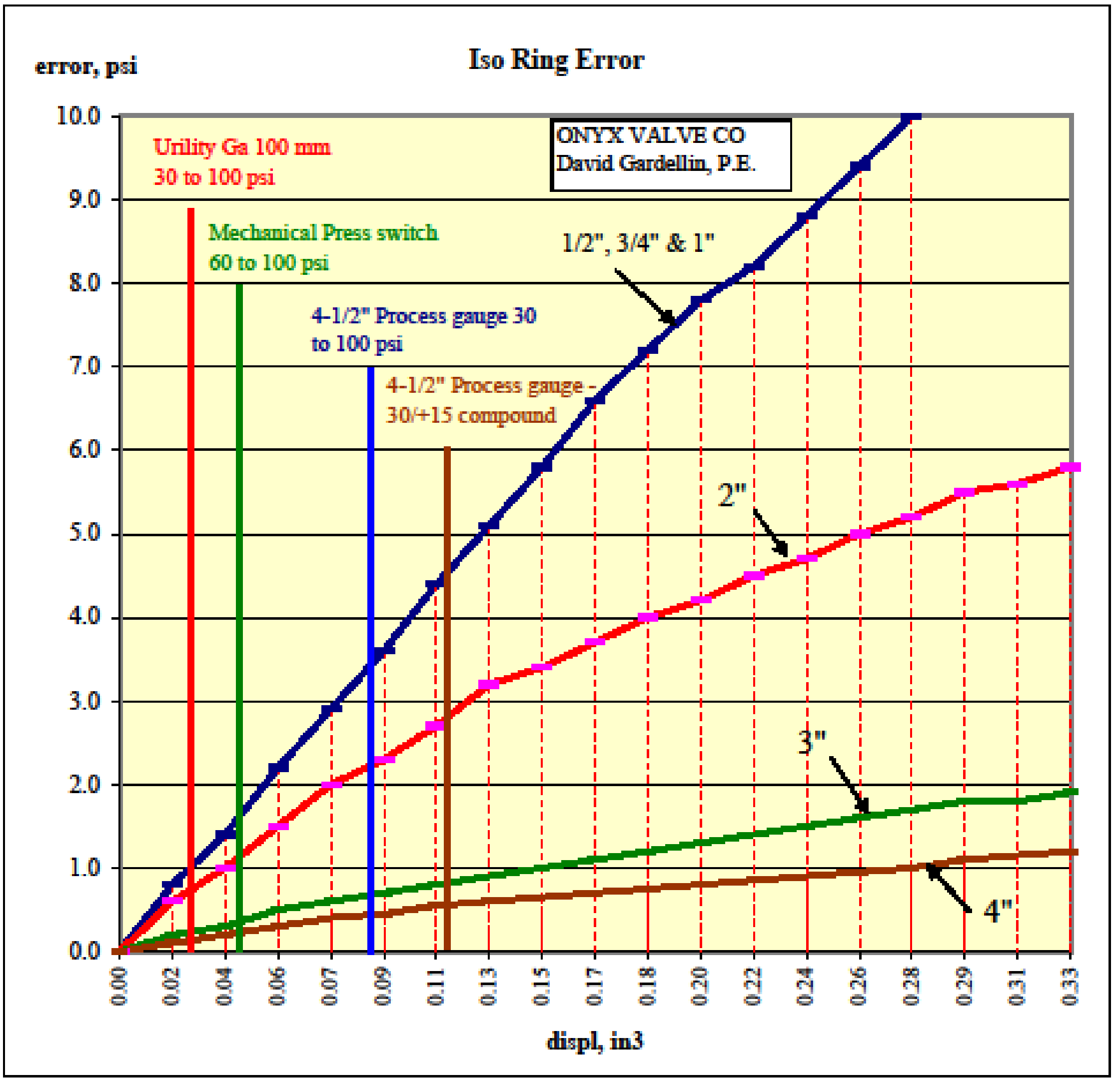
$$Error\% = \frac{Err}{Measured\ Span\ in\ inches\ H2O} * 100$$

Volume of Onyx Isolator Rings:

size	Vol, CC	Vol, in3
1	10.0	0.61
1.5	11.0	0.67
2	15.8	0.97
2.5	19.8	1.21
3	25	1.53
4	33	2.01
5	40	2.44
6	47	2.87

size	Vol, CC	Vol, in3
8	60	3.66
10	79	4.83
12	95	5.80
14	111	6.76
16	137	8.36
18	170	10.37
20	192	11.72

Iso Ring Error 1-3.xls



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