1. Introduction

This document has been prepared for individuals having moderate or little knowledge of marketing electronic pressure transmitters products and their applications.

The first part of this document provides some definitions of the basic terminology used in the specification of a pressure transmitter. While in the second part it is provided a guide to the selection of pressure transmitters, including calculations examples required for the most common pressure transmitter applications.

2. Pressure measurement

A pressure transmitter can be used to measure various form of pressure. It can be used to measure gauge pressure (barg, psig), absolute pressure (bara, psia), or vacuum pressure (cm or inches H_20 vacuum). Figure 1 shows the relationship of the various forms of pressure that can be measured with a pressure transmitter.

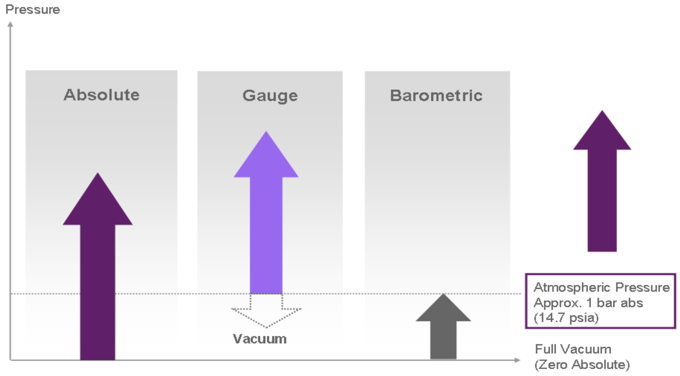


Fig. 1 Relationship between the various forms of pressure

2.1 Atmospheric Pressure

Atmospheric pressure is the force of pressure exerted by the earth's atmosphere. Atmospheric pressure at sea level is equivalent to 14.695 psia. The value of atmospheric pressure decreases with increasing altitude.

2.2 Barometric Pressure

Barometric pressure is the same as atmospheric pressure.

2.3 Hydrostatic Pressure

Hydrostatic, pressure is encountered in liquid level applications. Hydrostatic pressure is the pressure below the liquid surface exerted by the liquid above.

2.4 Line Pressure

Line pressure is simply the amount of pressure, or the force per unit area, exerted on a surface by the flow parallel to a pipe wall.

2.5 Static Pressure

Static pressure is the same as line pressure.

2.6 Working Pressure

Working pressure is also referred to as line or static pressure.

2.7 Absolute Pressure

Absolute pressure is a single pressure measurement with a reference to a full, or perfect vacuum. Absolute pressure is the measurement of the process pressure in excess of full vacuum or 0 psia. Zero absolute pressure (0 psia) represents a total lack of pressure- For example, space is considered to be a full vacuum.

2.8 Gauge Pressure

Gauge pressure is a single pressure measurement that indicates the pressure above atmosphere. Gauge pressure represents the positive difference between measured pressure and existing atmospheric pressure. You can convert gauge pressure to absolute pressure by adding the actual atmospheric pressure value to the gauge pressure reading. For example 10 psig is equivalent to 24-7 psia 0 psig is equivalent to 14.7 psia.

2.9 Vacuum

Vacuum pressure is a single pressure measurement, which also has a reference to atmospheric pressure. Vacuum pressure is the measure of the depression of process pressure below atmospheric pressure. Vacuum pressure is generally measured in cm or inches of H_20. For example, 14.7 psia is equivalent to 407.5 inches of H_20. Therefore, a pressure of 10 inches of H_20 vacuum implies process pressure is depressed 10 inches below atmosphere. Or 10 inches of H_20 vacuum is equivalent to 397.5 inches of H_20 absolute. Vacuum pressure is typically measured using a gauge pressure transmitter with an elevated zero calibration.

3. Pressure transmitter applications

Pressure is considered a basic measurement because it is utilized in several process applications: pressure and differential pressure, flow, level, density, etc. This section will briefly describe the following measurement applications that transmitters can be used for.

3.1 Differential Pressure

Differential pressure is the difference in magnitude between some pressure value and a reference pressure. In a sense, absolute pressure can also be considered a differential pressure, with full vacuum or zero absolute as the reference pressure. Gauge pressure too can be considered a differential pressure, since in gauge pressure the atmospheric pressure is the reference pressure.

3.2 Flow

A common application of a Differential Pressure transmitter is for sensing flow rate. A primary flow element such as the one shown in Figure 4-1 has an internal restriction. This restriction reduces the cross sectional area of the pipe through which the process flows. This restriction causes fluid velocity to increase as it passes by the restriction. Therefore, fluid immediately upstream from the restriction has a lower kinetic energy (speed) than the fluid immediately downstream from the restriction. This increase in kinetic energy across the restriction is balanced by a corresponding decrease in potential energy (static pressure). Taps placed on either side of the restriction sees a differential in static pressure produced as a result of this decrease in potential energy of the fluid.

The differential pressure transmitter subtracts the downstream or lesser pressure from the upstream pressure. This pressure difference is generally quite low, typically from 1" water column to 750" water column (0,24 to 186 KPa) depending on the fluid and flow rate. A generic representation of a differential pressure flow measurement is shown in Figure 2.

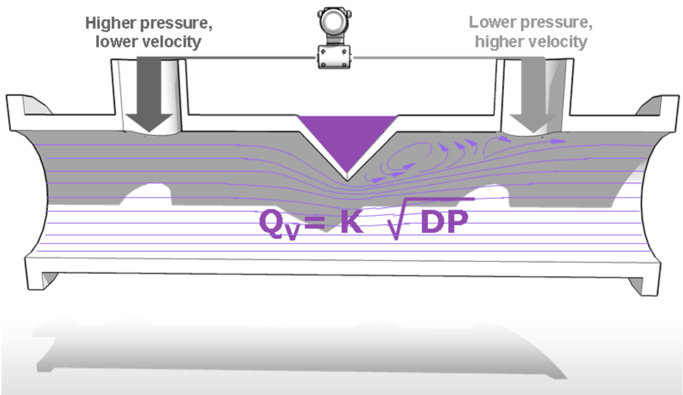


Fig. 2 Differential pressure flow measurement

The output of a transmitter measuring the flow rate by means of an obstruction in the stream is not linear with flow. To make the signal linear with flow, it is necessary to perform an arithmetic conversion by extracting the square root of the pressure difference signal.

Electronic differential pressure transmitters, are available with square root extraction electronics built into the instrument, if so ordered.

3.3 Liquid level

Liquid level measurements can be made using a differential pressure type transmitter or gauge pressure type transmitter. Typically, this is determined based upon whether the tank is open to the atmosphere or whether it is closed.

3.3.1 Open tank

Open tank liquid level measurement means that the tank is open to the atmosphere. In open tank applications, any change in atmospheric pressure affects the process fluid pressure within the tank. In this type of level measurement application, the low side of the transmitter measures atmospheric pressure, thus cancelling out the effects of atmospheric pressure on the tank fluid level. The high side of the transmitter is connected to the tank and thus measures the actual level of fluid in the tank.

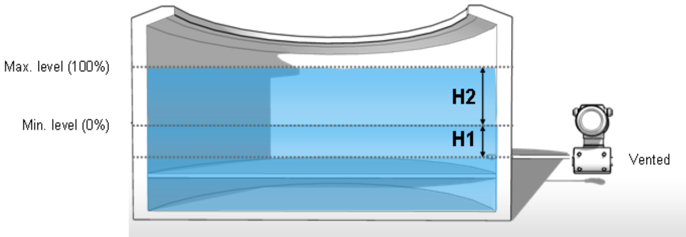


Fig. 3 Open tank liquid level measurement

3.3.2 Closed tank

A closed tank application is where the tank or vessel is sealed from the atmosphere. As process fluid fills or is emptied from the tank, the pressure inside the tank may go from positive to vacuum. This change in internal tank pressure has a direct effect on measured fluid level, unless it is compensated for. Piping the low side of a differential pressure transmitter to the top of the tank easily does this.

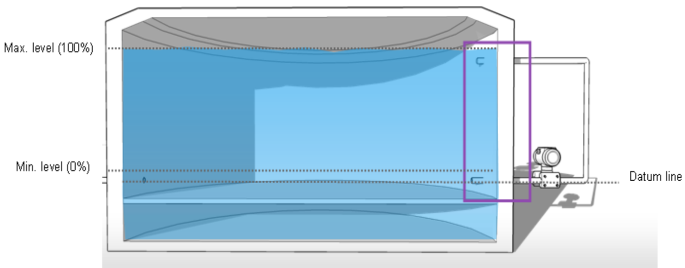


Fig. 4 Closed tank liquid level measurement

3.3.3 Calculations

To calculate the pressure at the bottom of the tank is necessary to know the value of 'h1' in cm or inches (Figure 5). For example, if 'h1' is 14", and the material in the tank is water, then we can express the pressure at the bottom as 14" $H_2 0$.

But if the liquid in the tank is not water, a conversion must be made to specify in "$H_2 0$. The formula to do this is:

h = (h") x (SG)

Where:
h = liquid head, $H_2 0$
h" = Actual liquid head, in inches
SG = Specific Gravity (dimensionless) of the fluid in the tank

Specific Gravity (SG) is the relative weight of a unit volume of liquid compared to the same volume of water. Gasoline, for example, has a SG of approximately 0.8. Therefore, a litre of gasoline weighs 8/10 or 80% of the weight of a litre of water.

Consequently, when specifying the pressure of the liquid column in a tank, it is necessary to identify the liquid and obtain its SG.

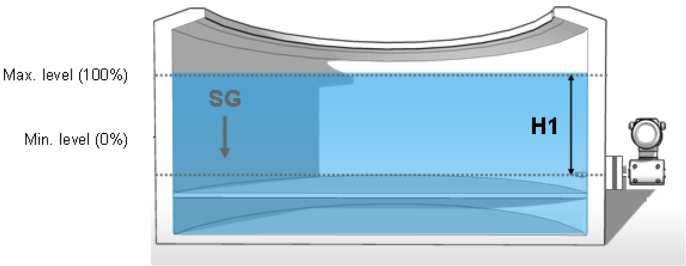


Fig. 5 Pressure calculation relationships

3.3.4 Bubble tube measurement

Another method of liquid level measurement is by means of a bubble tube or bubble pipe, Figure 6. This may be applied to either an open or closed tank.

A constant pressure of air or a gas compatible with the tank contents is maintained on the pipe inserted into the tank. As the level changes, the backpressure measured by the transmitter is a direct level measurement. The advantage is that only the pipe material is exposed to the process - not the transmitter. However, the process cannot be sensitive to a gas bubbling through it.

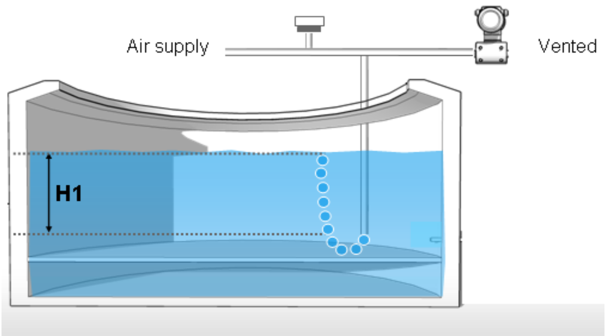


Fig. 6 Bubble tube measurement

3.4 Interface level measurement

Interface level measurement, i.e., measuring the liquid level of an interface between two separated liquids such as oil and water can be made also using the differential pressure transmitter shown in Figure 7.

Liquids 1 and 2 are of different densities and as long as the total level in the tank is above the top tap, and as long as the distance 'h' remains constant, the change in density, and hence the hydrostatic pressure, will change with interface level change.

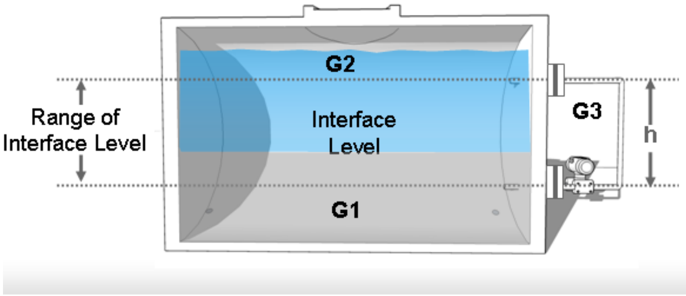


Fig. 7 Interface level measurement

3.5 Density measurement

The preceding principle leads to density measurement in a tank. In this case, a homogenous liquid of changing density in the tank will exert varying pressure on the transmitter depending on the change in density.

As long as the level remains above the top tap, and as long as "h" is constant the transmitter will respond to changes in density. Density is weight per unit volume, e.g., Kilograms per cubic meters. If the density increases, the pressure on the lower tap increases and so does the transmitter output. Typically, as in level measurement, a differential pressure transmitter is used because the spans are relatively low.

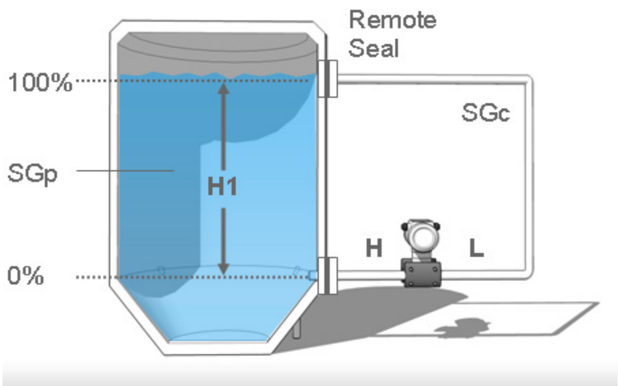


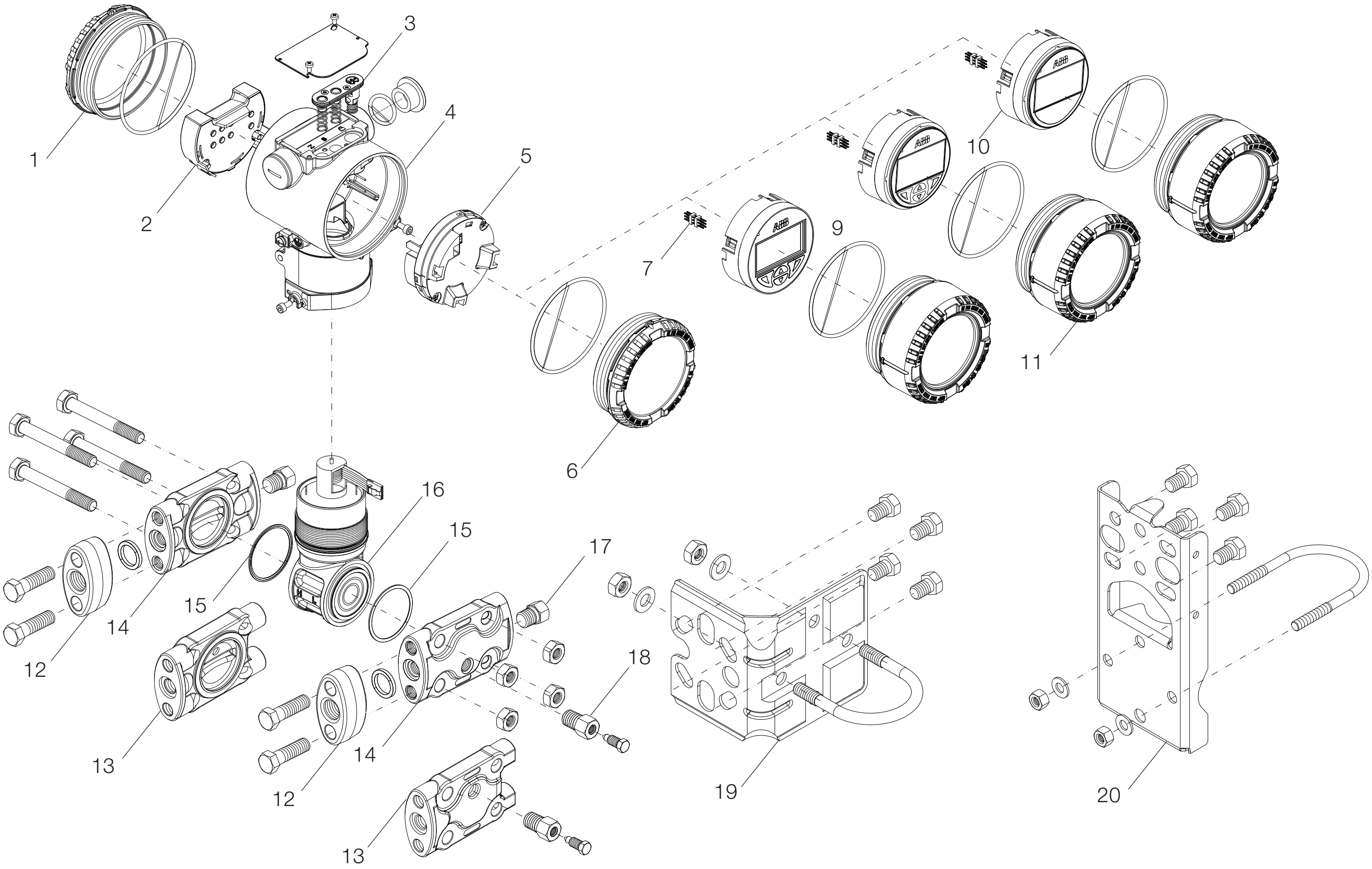
Fig. 8 Density measurement

4. Pressure transmitter features

As already mentioned, pressure is considered a basic measurement because it is utilized in several process applications: pressure and differential pressure, flow, level, density, volume, etc.

4.1 Main components

Pressure is measured by means of transmitters that generally consist of two main parts: a sensing element, which is in direct or indirect contact with the process, and a secondary electronic package which translates and conditions the output of the sensing element into a standard transmission signal.



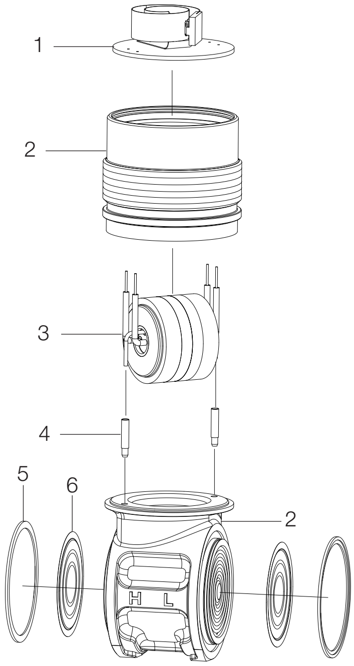
1 Rear cover | 2 Terminal block | 3 Push buttons | 4 Housing | 5 Communication board | 6 Front blind cover | 7 Display connector | 10 Standard LCD display | 11 Front windowed cover | 12 Flange adapter | 13 Low rating flanges | 14 Standard process flanges | 15 Transducer gasket | 16 Transducer | 17 Plug |
18 Vent/drain valve | 19 Bracket kit for pipe or wall mounting | 20 Flat type bracket kit for box

Fig. 9 Differential pressure transmitter components

At the heart of the transducer there is a sensor that creates a low level electronic signal in response to force applied against the sensing element.

Pascal's Law states that whenever an external pressure is applied to any confined fluid at rest, the pressure is increased at every point in the fluid by the amount of that external pressure. This is the basic principle employed in primary element design. The primary element is connected to the process piping in such a way that the process pressure is exerted against the isolation diaphragm(s). According to Pascal's Law, the fill fluid inside the primary element will reach the same pressure as that applied against the isolation diaphragm(s). The fill fluid hydraulically conveys this pressure to the sensor, which in turn produces an appropriate output signal.

The design of the primary element lets the user conveniently pipe the transmitter to the process and provide mechanical protection for the sensor against damage due to process transients like overpressure.



1 Primary electronic | 2 Transducer body | 3 Inductive sensor | 4 Idraulic circuit components | 5 Gasket | 6 Isolating diaphragm

Fig. 10 Transducer components

The design of the primary element lets the user conveniently pipe the transmitter to the process and provide mechanical protection for the sensor against damage due to process transients like overpressure.

The secondary electronics of the transmitter filter, amplify, condition, and convert the sensor signal into a standard 4-20 mA dc output signal. The secondary electronics are highly sophisticated and perform many functions. The output of the sensor is compensated for variations in process and ambient conditions before being converted to a 4-20mA signal. This minimizes unwanted measurement errors due to temperature effects, for example, and gives the transmitter a very stable output. The electronics also let the user calibrate the transmitter over a range of input pressures. For example, transmitter can be calibrated to measure a span as low as 0-150 psig, or it can be calibrated to measure a span as high as 0-600 psig. Therefore, the user doesn't have to stock as many versions of transmitters to handle the same range of applications. In addition, the secondary electronics allow the user to bias the output of the transmitter to measure special applications (e.g., elevation/suppression).

The secondary electronics are contained in a housing that is integrally mounted to the primary element. This housing is suitable for installation in the plant or in the field. The housing helps protect the electronics from the effects and changes of the environment. The housing also provides convenient termination for the sensor wires coming from the primary element, and for the field wiring.

4.2 Measuring principle

Pressure transmitters have undergone significant improvements during the past decade, largely through electronically oriented primary sensing techniques several approaches are being used that result in lower power consumption, smaller size and weight, and fast response with high reliability, accuracy and repeatability.

The most common effective sensing methods used today are Electromechanical Strain Gauge, Variable Capacitance, Variable Reluctance and Piezoresistive. Each of them having certain advantages and disadvantages,includes various types of sensors, offering the combination the best performances of each of them.

4.2.1 Electromechanical strain gauge

Electromechanical Strain Gauge Strain gauge sensors convert pressure into relatively small resistivity changes. The change in resistance typically affects the four legs of a Wheatstone bridge circuit, Figure 11.

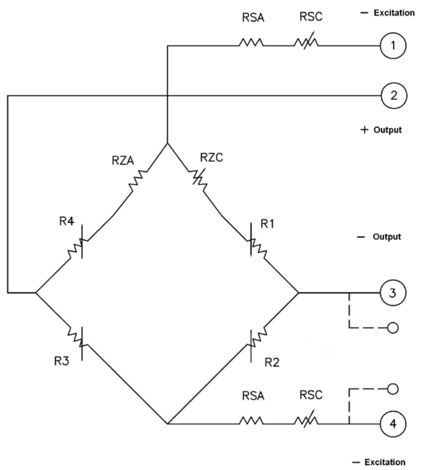


Fig. 11 Wheatstone bridge circuit

When all the resistive legs of the bridge circuit are balanced, and when the circuit is energized, the voltages read at test points 2 and 3 are equal. Strain gauge sensors located in the primary sensor usually take the place of two of the resistor legs in a Wheatstone bridge circuit. Fixed resistor networks in the transmitter electronics take the place of the other two legs. When there is zero pressure applied to the transmitter, the resistance of the strain gauges balances the fixed resistors in the transmitter electronics and there is no voltage differential across the test points. However, when a pressure is applied to the transmitter, the resistance of the strain gauges changes, unbalancing the bridge, and creating a proportional differential voltage across the test points. The transmitter electronics converts this voltage signal into a 4-20 mA signal for transmission. Strain gauge transducers are extremely sensitive to temperature effects. This is because the resistance of the strain gauge element can be affected by temperature as well as applied stress. Extreme care must be taken in the design of the primary element to minimize the ambient temperature effects or process temperature effects on the sensor. It is also essential to be able to compensate the sensor output for temperature changes, otherwise stability problems will occur.

4.2.2 Variable Capacitance

Variable capacitance transducers sensor operates as follows. An increase in pressure on the process diaphragm is transmitted through the fill fluid to the ceramic diaphragm in the capacitance sensor. The pressure increase causes the diaphragm to bulge, thus changing the distance between the diaphragm and the reference plate. This change in distance is very small. The change in the ratio of the C- and C+ capacitance feeds the logic circuit of the transmitter. Increased output from the logic circuit is converted to dc voltage and amplified by the gain and summation circuit. The signal from the gain and summation circuit is applied to the output current regulator through the zero and span circuit. The output current regulator produces an increase in transmitter output current, which is proportional to the increase in process pressure.

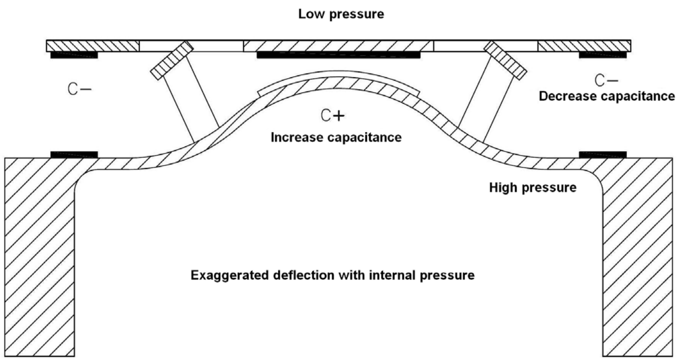


Fig. 12 Variable capacitance sensor operation

The advantages of capacitance sensing for pressure measurement include:

- good accuracy, linearity, hysteresis, repeatability and stability
- excellent resolution

The disadvantages of capacitance sensor technology can be:

- potentially high impedance output
- sensitivity to temperature changes; requires ambient temperature compensation
- requires custom electronics to produce a stable output
- since it is an analog sensor design, it may be susceptible to long term drift.

4.2.3 Variable Reluctance

Variable reluctance elements are being employed to detect small displacements of capsules or other sensors for direct coupling between pressure sensitive elements and amplifier circuits, Figure 13.

The variable reluctance pressure sensor, the inductance in a pair of coils is affected by changes in the magnetic coupling of the diaphragm, which is mounted between the two coils. With applied pressure, the sensing diaphragm will deflect towards one coil and away from the other. The position of the sensing diaphragm enhances the magnetic flux density of the closest coil, while decreasing the flux density of the furthest coil. Increasing the magnetic flux density of a coil will increase the induction and impedance of the coil.

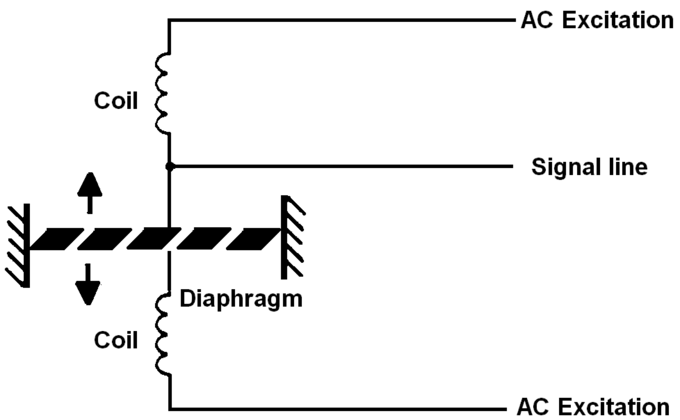


Fig. 13 Variable reluctance elements

Typical advantages of variable reluctance technology are:

— Very low or very high pressure ranges.

— High output signal level.

— Fairly rugged construction

Disadvantages of this type of sensor include:

— Limited overpressure capability.

— Since it is an analog sensor, it may be susceptible to long term drift.

4.2.4 Piezoresistive

Piezoresistive sensors have come into wide use in recent years, they can be considered the semiconductor technology version of the Electromechanical Strain Gauge that we have already described.

The Piezoresistive sensor consists of a semiconductor element that has been doped to obtain a piezoresistive effect. Its Conductivity is influenced by a change (compression or stretching of the crystal grid) that can be produced by an extremely small mechanical deformation. As a result, the sensitivity of monocrystalline sensors is higher than that of most other types. In particular higher than the standard strain gauges, whose resistance changes only with geometrical changes in the structure.

Therefore Piezoresistive sensors are 10 to 100 times more sensitive than metal strain gauges. A semiconductor element in a wafer format provides very high mechanical strength and elastic behaviour up to the point of mechanical breakdown, yielding sensors that exhibit only minor response to mechanical aging and hysteresis. But strain sensitivity in semiconductors is temperature dependent and they must be compensated accordingly.

Specific advantages are:

— High sensitivity, >10mV/V

— Good linearity at constant temperature

— Ability to track pressure changes without signal hysteresis, up to the destructive limit

Disadvantages are:

— Strong non linear dependence of the full-scale signal on temperature (up to 1%/kelvin)

— Large initial offset (up to 100% of full scale or more)

— Strong drift of offset with temperature

These disadvantages can be compensated with electronic circuitry.

The piezoresistive sensors must not be confused with the piezoelectric sensors. These one produce a surface voltage potential difference when stressed in certain directions. Quartz, Rochelle salt, barium titanate, lead-zirconate, and tourmaline are some of the common piezoelectric crystals. The piezoelectric sensors are a dynamic type of transducer that is incapable of measuring steady-state pressures. They have, however, the highest frequency response of any sensor, so they are used for vibration, acceleration and alternating forces, or pressures such as those produced by a vortex flow meter. They can be used in resonant transmitters.

4.3 Signal Transmission

As already mentioned, the secondary electronics of a transmitter amplifies and conditions the weak electrical signals generated by the sensor, so that the signals can't be sent long distances without being degraded by noise, and so the signals can be used to drive devices such as indicators, recorders, and controllers. Transmitters use several techniques to transmit their signal. This section describes four different types of signal transmission: four-wire transmitter, two wire transmitter, "Smart" transmitter and Fieldbus transmitter.

4.3.1 Four-Wire Transmission

In four-wire transmitters, two wires are used for power to the instrument, and the other two wires are used for signal transmission. They are used in special cases such as in remote areas where commercial power is not readily available. In these cases, the transmitter will be powered by an alternate power source such as a battery or perhaps even a solar cell.

For most applications where commercial power is readily available, the two-wire transmitter is the practical instrument, because of the added cost to install and run four wires to a transmitter compared to two wires.

4.3.2 Two-Wire Transmission

Two wires transmitters are designed to provide a current transmission signal of 4 to 20 mA dc. The majority of electronic pressure transmitters available today are two-wire devices. A two-wire transmitter uses part of the 4 mA bias current to operate its electrical circuitry. Both power and signal are carried over the same two wires. Current transmission is used because a current signal can be carried over long distances without being affected by circuit resistance that can change depending on length and temperature, as well as the quality and number of connections.

4.3.3 "Smart" Transmission

Intelligent or "Smart" transmitters transmit both digital and analog signals over the same two wires. A digital signal is superimposed over the traditional 4 to 20 mA.

Digital signal transmission is faster and more accurate than analog. More information can be carried between the instrument and the control room using the same two wires with two-way digital transmission, including configuration and diagnostic information.

Two-way communications means that a value cannot only be read from the end device but it is possible to write to the device. For example, the calibration constants associated with a particular sensor can now be stored directly in the device itself and changed as needed. This often makes it possible to remotely diagnose a field device problem, thus saving a costly trip to the field. The most widespread digital communication is HART® based on Bell 202 FSK standard, there are millions of instruments in the world using this standard, it is simple and well understood.

4.3.4 Fieldbus Transmission

Fieldbus is a digital, two-way, multi-drop communication link among intelligent control devices that can be used only instead of the 4-20 mA standard.

Multi drop communication means that over the same two wires can take place a digital communication among several field devices (like valves, pressure transducers, etc.) and computers, programmable logic controllers (PLCs) or remote terminal units (RTUs). The multi-drop capability of a fieldbus will perhaps result in the most immediate cost saving benefit for users, since one single wire pair is shared among several devices. While with analog or smart devices, a separate cable needs to be run between each end device and the control system.

Currently the main disadvantage to the user, however, is that there are more accepted fieldbus standard , among which Profibus and Fieldbus Foundation (FF) are probably the most widespread. The main advantage of FF is that it allows the relocation of control functions (like the PID) from the central control room out to the fieldbus devices. In this way a loop can e realized through the direct communication between a sensor and a control valve. This results in better, more reliable control as well as a less complex centralized control system. The current limitation is on communication speed and the limited maximum number of instrument linked to the same communication "segment".

The main advantage of Profibus is that it is well suited also for digital signal transmission. Therefore it is often selected in processes with a high number of digital signals (like batch processes or manufacturing industries). It can reach higher communication speed in the traditional master slave configuration, where a controller acquired data from the transmitter and sets the values of the valve. In case of failure of the main master a reserve master can take over the communication.

4.3.5 Loop Load Capacity

Two-wire transmitters must have a certain minimum voltage at the terminals in order to function. Typically this value is 12Vdc. Figure 14 shows a two-wire circuit.

With a 24V dc power supply, and the transmitter requiring 12Vdc at its terminals, this leaves only the difference, or 12Vdc, for voltage drops around the loop.

In terms of resistance, by applying Ohm's Law of R = E/I, and noting that the maximum analog signal is 20 mA or .020 Amps, we can compute the maximum resistance allowed in the loop:

R = E/I = 12 Vdc / 0.02 A = 600 Ohms

Note that, according to Namur standards, the maximum current output can be conventionally set to 22 mA. The transmitter in case of main transmitter failure conditions detected by self-diagnostic sets this output. If this feature is to be used, the maximum current value in the above calculation has to be modified accordingly with a 0.22 A instead of 0.20 A.

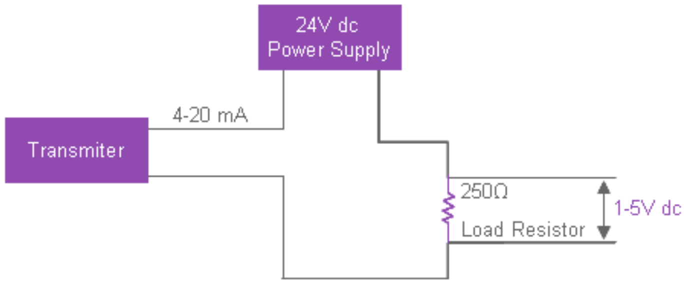


Fig. 14 Load loop capacity

To derive the total loop resistance we add:

250	Ohms Typical Load Resistor
45	Ohms Line Resistance (varies with length and size, but this value is typically used for design purposes)
70	Ohms Surge Protector
———	
365	Ohms Total Loop Resistance (Loop Load)

This loop will operate satisfactorily having a 235 Ohm surplus load capability. (600 - 365 = 235 Ohms).

The transmitters can operate with up to a 55Vdc power supply. This increases the load carrying capability of the loop to

R = (55-12)/0.020 = 2150 Ohms

In case the DC power supply is increased, a minimum load resistance has to be present in order to avoid damages to the electronic circuitry. The addition of other resistances, such as barriers in an intrinsically safe loop, must be carefully considered in determining the total loop resistance. You may find specification sheets use the term impedance for dc resistance. This is a convention in the instrument business.

4.4 Remote seals

Remote seals have been developed in order to widen the applicability of pressure transmitter beyond their limitations in terms of maximum temperature, dirty process fluids, etc..

This section describes the features of remote seal transmitters and the impact on their response time and the temperature effect on its precision. For some guidelines on the selection of the appropriate remote seal, see the following chapter on applications.

A remote seals consists of a remote element made up of a flange connection, a stem, and a seal diaphragm with a membrane connected through a capillary to the flanged chamber of the transmitter.

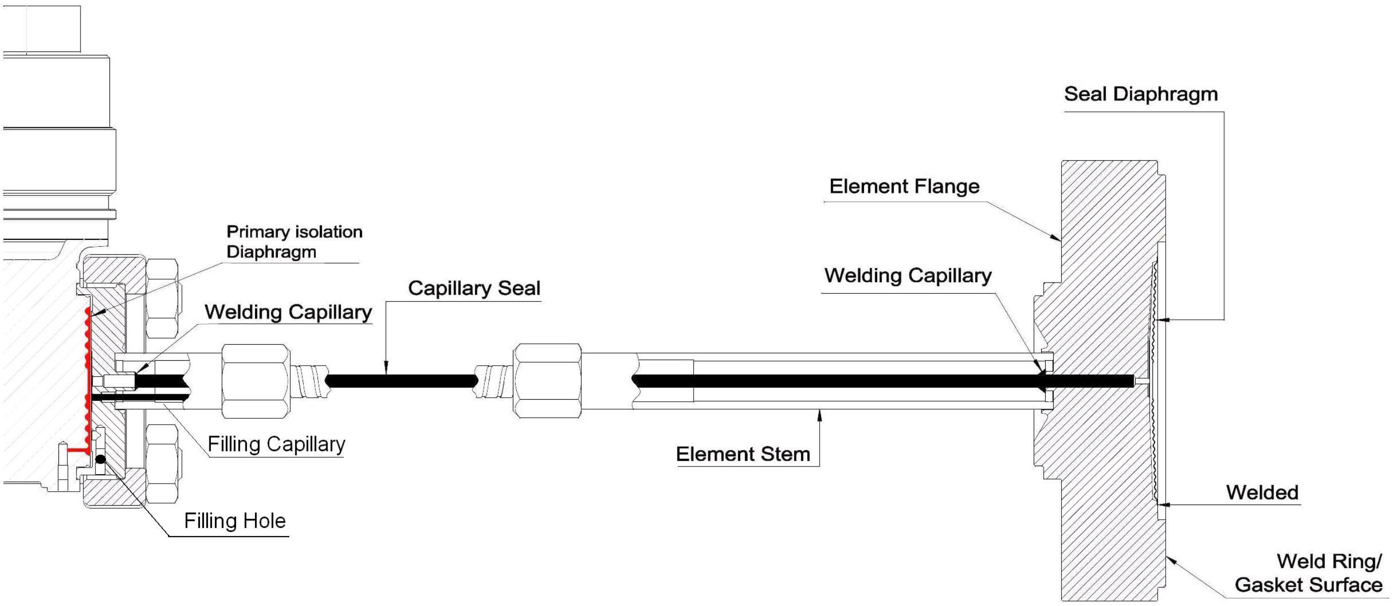


Fig. 15 Seal system structure

The remote seal can be integral with the transmitter or remote with a capillary length up to some meters. In this case the capillary is protected with suitable armour. Once connected the individual components, the system is evacuated from the air and filled with an incompressible fluid.

In this way when process pressure is applied to the seal diaphragm, this one deflects and exerts a force against the fill fluid. Since the liquid is incompressible, this force is transmitted hydraulically to the sensing diaphragm in the transmitter body, causing it in turn to deflect. The deflection of the sensing diaphragm of the transmitter is the basis for the pressure measurement. For a proper dimensioning of a remote seal system some features has to be considered. The first one is the displacement capacity (i.e. the volume displacement in the transmitter resulting from a full scale deflection of the seal). It must exceed the displacement capacity of the transmitter; otherwise the seal element cannot drive the transmitter to full-scale measurement.The second one is the volume of the cavity between the flange and the primary isolation diaphragm of the transmitter. The total volume of fill fluid has to be minimized in order to minimize the ambient / process temperature effect (see the paragraph on temperature effect in the following). Special flanges are available for the transmitters that minimize the cavity volume when connected to a remote seal.

4.4.1 Remote seal response time

The response time is qualified by means of the time constant, i.e. the amount of time required for an instrument output to reach the 63% of the amount it will ultimately change in response to a step change in input. Normally an instrument will reach 99.9 % of full response within a length of time equal to four times the time constant. The response time of a transmitter can be significantly increased when connected to a remote seal. This response time is affected by:

- The total length of capillary connecting the seal element to the transmitter body. The response time is directly proportional to the length of capillary. Therefore the length of capillary has to be minimized provided that the application requirements are satisfied.
- The inside diameter of the capillary. The response time of the instrument is inversely proportional to the fourth power of the capillary diameter. A smaller capillary section “delays” the response.
- The fluid viscosity. It is intuitive that a high viscosity of the fluid increases the time it will take that fluid to transmit an applied force through the system. Also the temperature effect on viscosity (generally the viscosity increases as temperature decreases) has to be considered, in particular it is important the temperature along the length of the capillary. The lower this average temperature, the slower the response time of the system.

4.4.2 Remote seal temperature effect

A change in temperature from the temperature under which the system was filled (we can call it the reference temperature) will cause the fill fluid to expand or contract. The resulting effect depends on the physical properties of the actual fill fluid being used. The change in volume causes the internal pressure of the system to change. This will in turn cause a deflection in the diaphragm, which leads to zero shifts and unwanted measurement errors. After installation this effect can be “zeroed out”. However each time there is a temperature variation in the process or ambient temperature, which affects the temperature of one or more components of the remote seal, a measurement error will be induced. A simplification factor applies in case of differential pressure measurement with two remote seals that have the same dimensions, including the capillary length. If the temperature of both branches of the transmitter is the same, the effect on the differential pressure transmitter will compensate each other, minimizing the error.

Another feature of the remote seals that attenuates the temperature effect is low seal diaphragm stiffness. This is measured as a spring rate, i.e. a pressure variation applied divided by the resulting volumetric displacement. Less stiff diaphragms will have lower values of spring rate and will produce a small increase of the pressure applied to the transmitter as a result of a temperature increase.

Increasing the diameter of the diaphragm decreases its spring rate. Low spring rate are also recommended for measuring very low pressure spans, as they can withstand only small volumetric changes in fill fluid. The length of capillaries is dictated by the installation, they could be better accomplished in terms of response time by means of larger internal diameters. But this, together with the length of capillary increases the total volume of the filling fluid, with a negative temperature. Hence a trade-off between response time and optimal temperature performance has to be accepted.

4.4.3 The all-welded construction technology

Another critical source of error for the remote seal is the possibility that any gas enter the capillary system. Because of gas compressibility even a small quantity of gas prevents the principle upon which the seal operate (i.e. absolute constant fill fluid volume at any pressure). Therefore special care must be paid during the filling operations in order to carefully avoid any gas penetration, i.e. fill fluid is de-aerated, the dry remote seal system is emptied at full vacuum prior to filling, then the system is sealed and a leak test is carried out.

Nevertheless during the operation of the transmitter, a slow gas penetration is possible through gasket connections or threaded joints. This is even more critical because the system fails “slowly” and larger errors occur prior to failure.

An innovative technology that consists in welding all the capillary connections including a filling capillary welded shut (see the above figure). This technology has proven to really guarantee that no air enters system even after years of continuous service. These features are absolutely mandatory for high vacuum service application where even some microscopic amount of gas tends to expand their volume tremendously as a pressure close to absolute zero is reached.

4.4.4 Remote seal applications

In pressure transmitter directly connected to process piping by the use of impulse lines, the process fluid leaves the piping, fills the impulse lines and enters the body of the transmitter. Remote seals are recommended for all applications where it is necessary to prevent the fluid to leave the piping, or to enter the transmitter because of:

- The process fluid is highly corrosive
- The process fluid is dirty, solid laden, or viscous and can foul the impulse line
- The process fluid can solidify in impulse line or the transmitter body, because of temperature decrease
- The process fluid is too hazardous to enter the area where the transmitter is located
- The transmitter body must be located away from the process for easier maintenance
- The process temperature exceeds the recommended maximum limits for the transmitter

The latter can also be accomplished using impulse lines of sufficient length. Remote seals are employed when required impulse line length becomes impractical for the installation.

5. Selection of transmitter's features

In the following paragraph are listed some additional criteria in order to select some transmitter features according to the particular requirements of a specific plant.

5.1 Materials selection

One of the most important factors for the selection of suitable material is their resistance to corrosion, but also their compatibility to specific applications must be considered. As an example, toxic filling-fluids of the transmitter cannot be utilized for food applications, because in case of leakage they could poison the process fluid.

Corrosion is the gradual destruction of a metal by chemical or electrochemical means. It is affected by several factors, from the combination of chemicals, even if present in small amounts, to temperature. As an example if the temperature goes above 40 °C (104 °F) in seawater, then pitting corrosion is a threat for stainless steel.

Therefore cannot guarantee that a material is suited to a particular application under all possible process conditions. It is the user's responsibility to make a careful analysis of all process parameters when specifying materials.

Other process fluids not discussed here are listed in the attached corrosion table where some further information are presented, but only as a reference intended only to make the user aware of the most common problems of materials incompatibility for a given application.

Further materials (like Titanium, Nickel, Gold Plating) may be asked to local representatives. Local representative cooperation may be asked also to assess the suitability of some material for specific applications by field test, which is the most recommended approach for critical service applications.

5.1.1 Wetted parts material

316 L Stainless Steel.

The 316 L SST is the standard material for the wetted parts of it has a good resistance to corrosion, including low concentrations of nitric acid and most salt solutions with some exception like no oxidizing acids such as Hydrochloric, Hydrofluoric, Sulphuric and Phosphoric. The resistance of 316 L SST to alkaline solutions, organic acids, and other organic compounds may depend on temperature. Concerning salts, the halide salts (fluorine, chlorine, bromine, iodine) can cause severe pitting and possibly stress-corrosion cracking.

In case of Hydrogen Sulphide (H2S) that is often present in oil/gas production, the 316 L SST may be available with a specific certificate: NACE MR0175, see the applicable data sheets. This standard applies in case of sufficient partial pressure of H2S in gas, i.e. as an example a total process pressure of 400 KPa and a concentration of H2S at least above 700 PPM, or a process pressure of 26 MPa and a concentration of H2S above 10 PPM. This standard assures the prevention of sulphide stress corrosion cracking, by reducing the stress, i.e. by means of a low hardness of the construction material and a suitable manufacturing process of the transmitter. Non wetted part like bolts are also covered by this standard since they affect the effectiveness of containment of the whole instrument even if they are exposed to H2S far below the limit of applicability of the mentioned NACE standard. The NACE certificate is also available for Monel and Hastelloy C. For UREA grade applications, a specific certificate is available for 316 L SST: ASTM A262, practice C, Huey test.

Monel

Monel (67Ni-33Cu) has good resistance at ambient temperatures to most of the no oxidizing acids, such as hydrofluoric, sulphuric, and phosphoric acids. Monel is also considered the best choice in case of parts in contact with Sea Water. It also resists no oxidizing salts. The nickel in the alloy improves its resistance toward alkalises.

Hydrogen may penetrate Monel in high hydrogen concentration applications. When used as a diaphragm material, hydrogen atoms may permeate the diaphragm allowing hydrogen bubbles to form within the fill fluid. Therefore, Monel should not be used as a diaphragm material when the process is hydrogen gas.

Hastelloy C

In Hastelloy C (54Ni-16Mo-16Cr), chromium and molybdenum are added to nickel to improve the alloy's resistance to oxidizing conditions. Hastelloy C is well suited to provide protection against alkalises, organic acids, and other organic compounds.

This alloy also retains a considerable degree of resistance to no oxidizing conditions like Phosphoric acid and also the acid salts such as Nickel and Copper chlorides. At moderate temperatures Hastelloy C withstands Hydrochloric and sulphuric acids in most concentrations. Both Monel and Hastelloy C have good corrosion resistance against atmospheric conditions and fresh water.

Gold-Plated Hastelloy C or Monel or SST

Hastelloy C, like Monel and SST allows the permeation of Hydrogen therefore should be avoided as a diaphragm material for Hydrogen service. Indeed Hydrogen atoms can diffuse through the transmitter diaphragms, which are very thin, once reached the fill fluid, they can combine to form molecular hydrogen. Because molecular hydrogen is too large to permeate back through the diaphragm it gets trapped and forms bubbles in the fill fluid. These bubbles can severely affect transmitter performance. Plating these materials' diaphragm with gold provides protection against hydrogen permeation in all cases of high process pressure and temperature, which increase the permeation rate.

Tantalum

Tantalum has proved to be a useful material in corrosive applications where 316 L SST does not perform satisfactorily, like hydrochloric, hydrobromic, boiling hydrochloric, nitric, phosphoric, and sulphuric acids. There are a few exceptions to this rule such as Aluminium Fluoride, Potassium Carbonate and Sodium Sulphide, where Monel results more suitable. Tantalum has also a good resistance to most acids, chemical solutions, and organic compounds. Liquid metals generally do not affect Tantalum. However Tantalum can suffer severe embrittlement if in service with high-temperature oxygen or nitrogen, or with hydrogen at any temperature. Also, it is attacked by strong alkaline solutions and by fused alkalises like Sodium Hydroxide. Tantalum has a high melting point and good strength even at elevated temperatures, this allows thin sections to be used since it is very expensive.

PFA

another unique solution to corrosive application consists of a PFA coating of an AISI 316 L SS remote seal transmitter. The PFA corrosion suitability is really outstanding and a coating of 0,2-0,3 mm can solve severe corrosion application in a cost-effective way, i.e. without recurring to the use of more expensive metals.

The only limitation is the recommended process temperature of 200 °C (392 °F) and a minimum increase of the temperature effect on accuracy.

5.1.2 Housing

For marine environment there is a corrosion risk, related to the presence of chloride, an ion that gives place to an accelerated galvanic corrosion of aluminium housing because of the copper content of aluminium alloy. transmitter housings are copper free (copper content of aluminium less than 0,03 %).

5.1.3 Fill fluid

The type of fill fluid selected can limit the working temperature that the transmitter can stand. Therefore the fill fluid shall be selected on the fluid table according to the applicable temperature. This temperature can be considered the ambient one, because even with higher process temperature, this sharply decreases along the piping connection to the transmitter.
The most utilized fill fluid is Silicone Oil DC200 because of its high stability over a wide range of operating temperatures: -40 °C to 200 °C (-40 °F to 392 °F). Other fluids may be selected, whenever their temperature range is compatible with the application, in order to take advantage of a lower viscosity or a lower thermal expansion factor. In particular this could be very useful to improve the response time in case of remote seal application with long capillaries. For some food or pharmaceutical application the fill fluid must not to be toxic in order to prevent problems in case of diaphragm rupture and product contamination. In this case a food sanitary fill fluid shall be selected. Another special case that impacts the fill fluid is the application of a transmitter on Oxygen service, since Siliconee oil could fire in case of fluid losses, an inert fluid shall be selected.

5.1.4 Gasket

The most widespread material for the transmitter gasket is PTFE because of its general corrosion suitability with several materials. A known limitation is in case of process which temperature can periodically vary of several degrees, compromising the tightness because of the limited elasticity of this material. In these cases special materials may be asked to local representatives.
Other special cases are the food or pharmaceutical applications that require an approved material listed by the American Food and Drug Administration (FDA) or other national equivalent bodies.

5.2 Overpressure limits

The maximum pressure that a transmitter can withstand without damages (i.e. no recalibration is required) is called Overpressure. For Differential Pressure transmitter, the overpressure is also called Static Pressure and is usually applied to both side of the transmitter (High and Low). This pressure depends on the mechanical features of the transmitter and in particular on the type of sensor and of process flanges. Sensors suitable for low ranges of pressure can stand lower overpressure.

The standard Maximum Withstanded Pressure (MWP) of a pressure transmitter is of 21 MPa, but it may differ according to the sensor selected. In case of higher process pressure requirements, are available specific versions of sensors and of process connections sensor (the latter in combination with temperature) with an overpressure limit of 60 MPa, 8700 psi (these models are called "High Static").

The exposure of a transmitter to a very high pressure, above the maximum operating pressure rating, can lead to a mechanical modification of the diaphragm, or to leakage or even a dangerous rupture (resulting in flying fragments outside the device). The capability of the transmitter to avoid leakage and dangerous rupture is certified according to the SAMA PMC 27.1 standard at a pressure of 48 MPa (6960 psi), 90 MPa (13054 psi) for High Static models.

In order to identify the real overpressure limit requirement, it is usually enough to check the conditions at the border of the application, some example are provided in the following:

closed vessel

- maximum pressure of the lines connected (filling fluids or inert gas),
- reflux from downstream equipment
- max pressure generated from a chemical reaction

Pipeline

- design rating of the line (to be checked on the P&ID if available)
- max prevalence of the upstream pump

5.3 Temperature limits

Most electronic transmitters are rated for operation at ambient temperature from as low as – 20 ° to – 40 °C (– 4 ° to – 40 °F) to a high temperature between 60° to 85°C (140 ° to 185 °F), depending on the filling materials that are used within the transmitter.

However the ambient temperature fluctuations has also to be carefully considered. For example, consider a transmitter that is installed in a measurement loop and which is located outdoors in an unprotected location where it receives sunlight from 9:00 AM to 4:00 PM. The transmitter output, will most likely show some zero shift during the hours of sunlight, even when the air temperature is constant. The zero shift is caused by an increase of the internal temperature of the transmitter due to the radiant heat effect of the sun. A sudden rain shower, or a strong cooling wind could have similar effects on the transmitter output. Furthermore high temperatures accelerate any degradation of electrical components, so high temperature (above 60 °C, 140 °F) should be avoided whenever practical.

5.4 Accuracy

For the family of transmitter there is the possibility to select among various base accuracy from 0,025% to 0,10%. This depends on the application requirements.

As an example the highest accuracy may be required for flow measurement and totalisation for transfer or fiscal metering.

6. Transmitter terminology

The terms used to describe various elements in transmitter applications are many and they are often misunderstood and misused. The following explanations of some of the most-used terms should prove helpful.

6.1 Accuracy

Manufacturers publish performance specifications such as accuracy, so that customers can evaluate a transmitter and compare the various brands available. There are few industry-accepted standards, like the Scientific Apparatus Makers Association (SAMA) that published a Control Terminology Standard, this help customers and manufacturers alike to come to some agreement on the definition of terms.

As a performance specification, accuracy is assumed to mean reference accuracy unless otherwise stated. Accuracy does not include any mention of a time base. Accuracy also does not include the effects of temperature Accuracy is basically the type of performance you can expect to receive on a bench calibration.

6.2 Reference Accuracy

Reference accuracy is a number or quantity, which defines the limit that errors will not exceed when the transmitter is used under reference operating conditions. Reference accuracy includes the combined linearity, hysteresis, and repeatability errors. The units being used to express accuracy are to be stated explicitly, and it is preferred that a ± sign precede the number or quantity. Reference accuracy is expressed in a number of forms:

— ±1 % of upper range value

— ±1 % of calibrated span

— ±1 % of actual output reading

It is important to understand how these statements differ in describing performance. Let's consider a fictional instrument to illustrate reference accuracy specifications. Lets' assume an instrument which has an upper range value of 100 and is calibrated at 0 to 50 (units are not important). We will calculate the absolute accuracy predicted by each of the above statements for full span (a reading of 50) and 50% of span (a reading of 25).

± 1% of Upper Range Value

The absolute error is determined at the upper range value and is then used to determine the absolute accuracy at various readings. For example, the absolute error is ± 1% of 100, or ± 1. The absolute accuracy at full span is ± l/50, or ± 2%. The absolute accuracy at 50% of span is ± 1/25, or ± 4%.

± 1% of Calibrated Span

The absolute error is determined at the 100% or full span reading, and is then used to determine the absolute accuracy at various readings. For example, the absolute accuracy at full span is ± 1%, meaning the absolute error is ± 1% of 50, or ± 0.50. The absolute accuracy at 50% of span is ± 0.50/25, or ± 2%.

± 1% of Actual Reading

The absolute accuracy at any reading is the same for this specification, and the absolute error varies with the reading. The absolute error at full span is ± 1 % of 50, or ± 0.50. The absolute error at 50% of span is ± 1% of 25, or ± 0.25.

6.3 Damping

Damping is the progressive reduction or suppression of oscillation in the output of a transmitter. There are applications where the transmitter can detect pumps or other process noise pulses. At maximum sensitivity (minimum damping), the output of the transmitter would "paint" a band on a recording device because of this noise. Damping allows the user to filter out unwanted noise by adjusting the transmitter by increasing the damping in the above example; the oscillations in the output of the transmitter would be greatly reduced or eliminated completely.

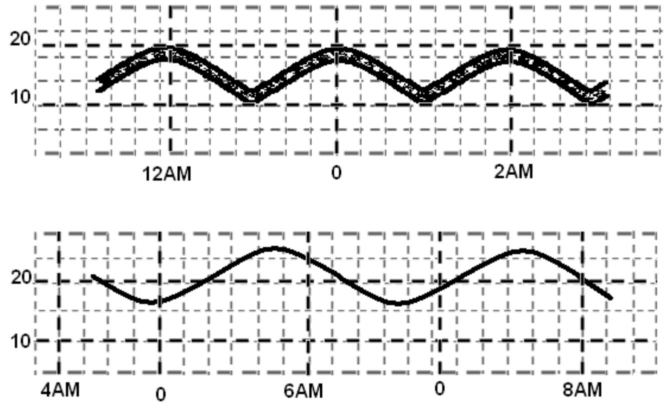


Fig. 34 Damping

On the other side, the more the transmitter is damped, the slower its response to step changes in the process. In cases where the system dynamics require a fast transmitter response time, damping should be kept to a minimum.

6.4 Dead band

Dead band is the range through which an input can be varied without initiating a response. Dead band is usually expressed in percent of span.

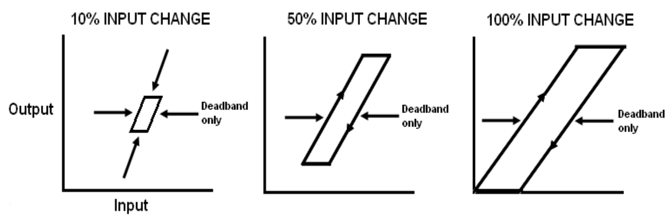


Fig. 35 Deadband

6.5 Drift

Drift refers to the change in the output-input relationship over a period of time.

6.6 Elevation and suppression

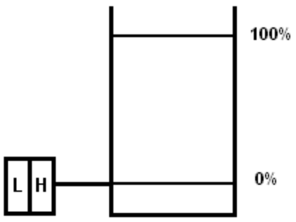
One of the most misunderstood concepts when dealing with transmitters is zero elevation and suppression. Figure 6-3. Elevation and suppression adjustments are frequently necessary in liquid level measurement when the transmitter cannot be installed on a level with the zero level of the tank. The definition is following, but to understand elevation and suppression, its easiest if you look at it from a mathematical viewpoint, that is described in the second part of this paragraph.

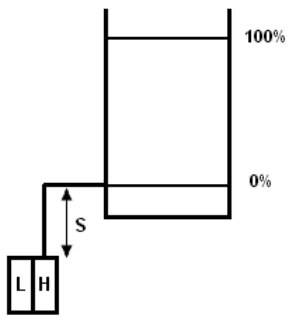
Zero Elevation—for an elevated zero range, the amount the measure variable zero is above the lower range value. It may be expressed either in units of measured variables or in percent of span.

Zero Suppression—for a suppressed zero range, the amount the measured variable zero is below the lower range value. It may be expressed either in units of the measured variable, or in percent of span.

Mathematically you can develop equations that will let you calibrate the transmitter for any given application requiring zero elevation or suppression. It's important to understand some basic facts about differential pressure transmitters. First, in order to obtain an increasing output, the high side of the transmitter must always be increasing in pressure relative to the low side. Therefore, to achieve a 20 mA output, the net result of all forces on both the high and low sides of the transmitter must be such that the high side is greater than the low side by an amount equal to the calibrated span of the transmitter. Second, the purpose of the calibration biases (elevation and suppression) is to apply a differential pressure to those situations where a 4 mA output is desired at some point other than 0 differential pressure.

Open tank

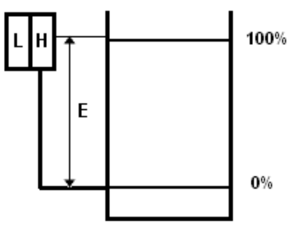




Suppression = SG

Where S = Height of leg (inches)

G = Specific gravity of fluid in leg



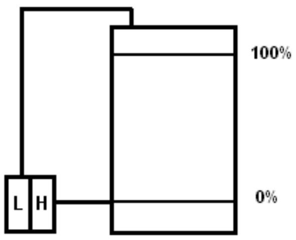
Elevation = EG

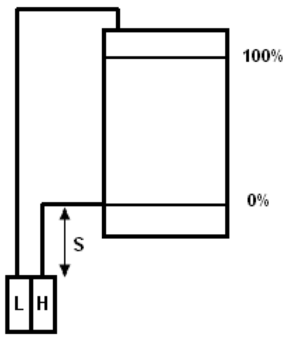
Where E = Height of leg (inches)

G = Specific gravity of fluid in leg

Note: this type of installation is very seldom successful - not recommended.

Closed tank (dry leg)

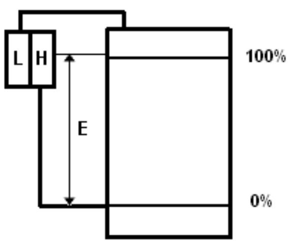




Suppression = SG

Where S = Height of leg (inches)

G = Specific gravity of fluid in leg



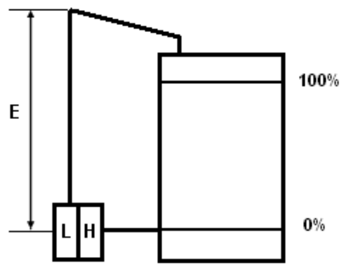
Elevation = EG

Where E = Height of leg (inches)

G = Specific gravity of fluid in leg

Note: this type of installation is very seldom successful - not recommended.

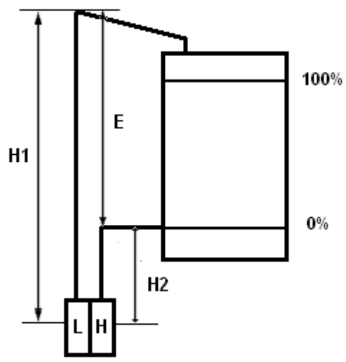
Closed tank (wet leg)



Elevation = EG

Where E = Height of leg (inches)

G = Specific gravity of fluid in leg



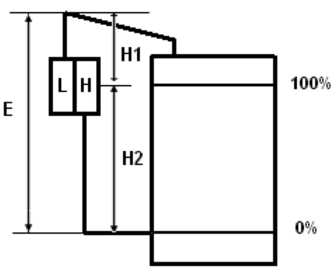
Elevation = $H_1G_1 - H_2G_2$

Where H_1 = Height of wet leg (inches)

G_1 = Specific gravity of fluid in leg

H_2 = Height of measuring leg (inches)

G_2 = Specific gravity of fluid in leg



Elevation = $H_1G_1 + H_2G_2$

Where H_1 = Height of wet leg (inches)

G_1 = Specific gravity of fluid in leg

H_2 = Height of measuring leg (inches)

G_2 = Specific gravity of fluid in leg

Note: this type of installation is very seldom successful - not recommended.

We know that for any situation, the sum total of effects on a transmitter should be zero for a 4 mA output.

Therefore at the desired 4 mA condition:

H — L+ B = O

Where:

H = is the pressure (relative to atmosphere) applied at the high side of the transmitter in inches $H_2 0$

L = is the pressure (relative to atmosphere) applied at the low side of the transmitter in inches $H_2 0$.

B = is the bias factor, in inches $H_2 0$, which can be either positive or negative.

At a 20 mA condition:

H — L+ B = S

Where:

S = is the calibrated span of the transmitter, which can never be zero or negative.

So this gives us two equations:

H — L + B = O at 4 mA

H — L + B = S at 20 mA

With these two equations, it is now possible to determine the calibration for any situation according to the following procedures:

- Analyse the specific application to identify all fluid forces on both sides of the transmitter at the point where you want 4 mA Output and the point where you want 20 mA output.
- Using the 4 mA condition, solve for B in: H — L+ B = O
- Using the 20 mA condition, and the value of B obtained from the above calculation, solve for S: H — L+ B = S
- Calibrate the transmitter to a range of: (— B) to (— B + S)

For example, Figure 36 represents a closed tank application where we want a 4 mA output when the level is at the bottom tap and 20 mA output at the top tap.

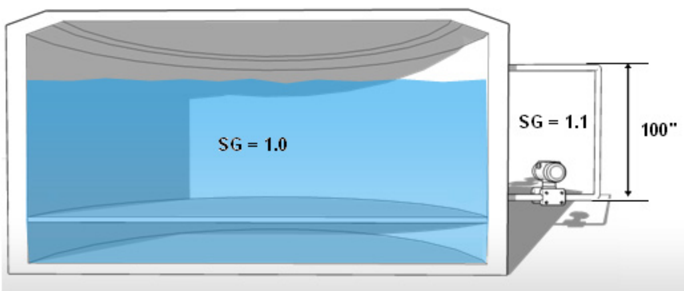


Fig. 36 Closed tank application

We also know that the low side leg is always filled with material whose specific gravity is 1.1.

If the specific gravity of the fluid in the tank is 1.0, what is the calibration?

At 4 mA: H = 0

L = 100” x 1.1 = 110” $H_2 0$

So that:

H — L + B = 0

0 —110 + B = 0

B = 110

At 20 mA: H = 100. x 1.0 = 100” $H_2 0$

L= 100. x 1.1 = 110” $H_2 0$

So that:

H — L + B = S

100 -110 + 110 = S

S = 100” $H_2 0$

So our calibration for this application is: (— B) to (— B + S)

So: — 110 to (— 110 + 100)

calibration is: — 100 to -10” $H_2 0$

6.7 Hysteresis

Hysteresis represents the maximum difference for the same input between the upscale and downscale output values during a full range traverse in each direction.

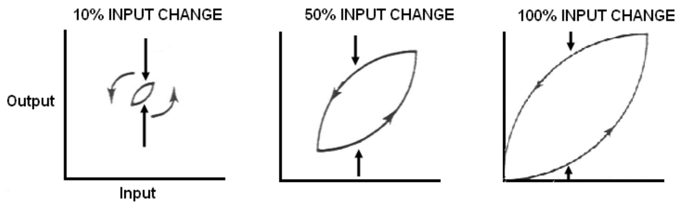


Fig. 37 Hysteresis

6.8 Linearity

Linearity is the closeness to which a curve approximates a straight line. It is expressed as independent linearity, terminal based linearity, or zero based linearity. When expressed as simply linearity, it is assumed to mean independent linearity.

6.8.1 Independent linearity

Figure 38 depicts an independent linearity curve. Independent linearity represents the maximum deviation of the actual characteristic from a straight line so positioned as to minimize the maximum deviation.

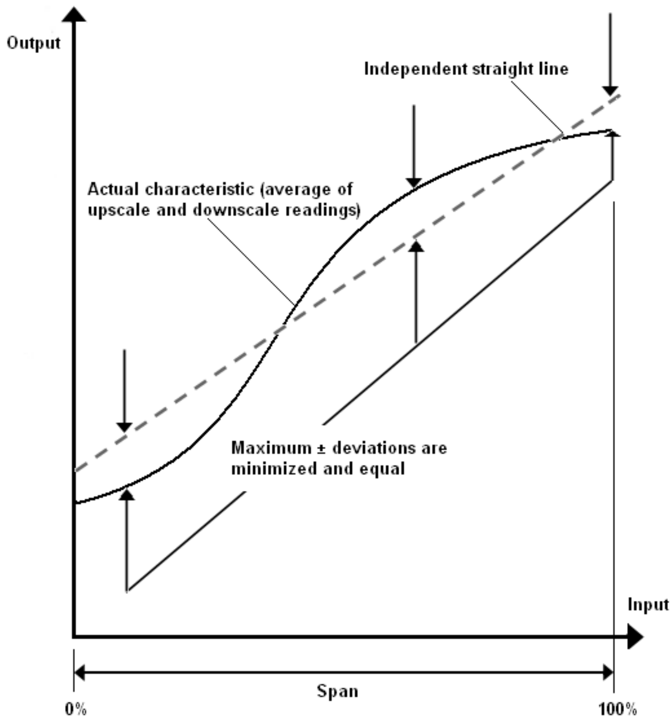


Fig. 38 Independent linearity

6.8.2 Terminal-based linearity

Terminal based linearity, Figure 39, is the maximum deviation of the actual characteristics from a straight line coinciding with the actual characteristic at upper and lower range values.

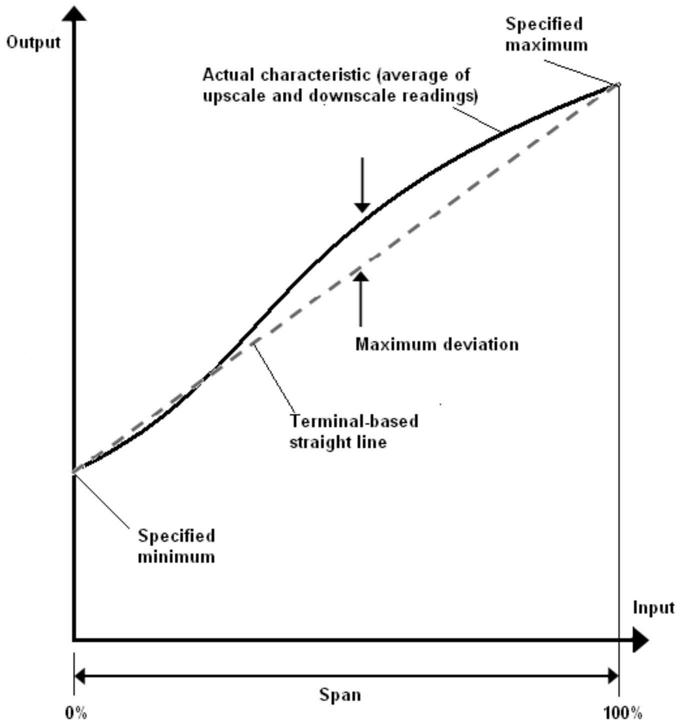


Fig. 39 Terminal-based linearity

6.8.3 Zero-based linearity

The maximum deviation of the actual characteristic from a straight line so positioned as to coincide with the actual characteristic at the lower range value and to minimize maximum deviation is referred to as zero based linearity.

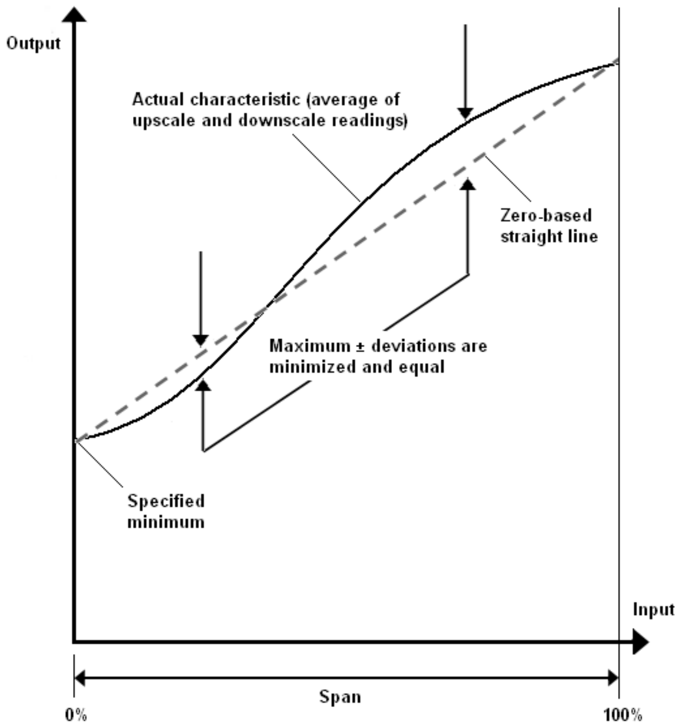


Fig. 39 Zero-based linearity

6.9 Maximum Withstanded Pressure (MWP)

See Overpressure

6.10 Output

The standard output for a two-wire transmitter is 4-20 mA dc.

6.11 Pressure

7.11.1 Pressure definition from physic

Pressure is force distributed over, a surface. The pressure P of a force F distributed over an area A is defined as:

$P = \frac{F}{A}$

6.11.2 Atmospheric pressure

The pressure exerted by the earth's atmosphere. Atmospheric pressure at sea level is about 100 KPa or 1 Bar or 15 psi. The value of atmospheric pressure decreases with increasing altitude.

6.11.3 Overpressure

It is the maximum pressure withstanded without damage by the transmitter. It is also indicated as Maximum Withstanded Pressure (MWP). See also the relevant considerations in the "Overpressure limits" paragraph in the "transmitter features selection" chapter.

6.11.4 Proof pressure

It is the Maximum Pressure withstanded without leaking by the transmitter.

6.11.5 Absolute pressure

Measured above total vacuum or zero absolute. Zero absolute represents total lack of pressure.

6.11.6 Barometric pressure

See atmospheric pressure.

6.11.7 Differential pressure

It is the difference in magnitude between some pressure value and some reference pressure. In a sense, absolute pressure could be considered as a differential pressure with total vacuum or zero absolute as the reference. Likewise, gauge pressure (defined below) could be considered similarly with atmospheric pressure as the reference.

6.11.8 Gauge pressure

It is the pressure above atmospheric. Represents positive difference between measured pressure and existing atmospheric pressure. Can be converted to absolute by adding actual atmospheric pressure value.

6.11.9 Hand Held Terminal

Hand Held Terminal (HHT) is a device usually made up of a Liquid Crystal Display (LCD) and of a keyboard. It is used to configure and calibrate the transmitters (via Hart or other Field Bus Protocols).

6.11.10 Hydrostatic pressure

The pressure below a liquid surface exerted by the liquid above.

6.11.11 Line pressure

Force per unit area exerted on a surface by a fluid flowing parallel to a pipe wall.

6.11.12 Static pressure

See line pressure.

6.11.13 Vacuum

Pressure below atmospheric.

6.11.14 Working pressure
See line pressure.

6.12 Range
Range is the region of units between the limits within which a quantity is measured, received or transmitted, expressed typically by stating the upper range and lower range value, (ISA S51.1)

6.12.1 Lower Range Value (LRV)
The lower range value is the lowest quantity that a transmitter is adjusted to measure.

6.12.2 Upper Range Value (URV)
The upper range value is the highest quantity that a transmitter is adjusted to measure.

Typical range	Name	Range	LRV	URV	Span	Other data
0 +100	–	0 to 100	0	100	100	–
20 +100	Suppressed zero range	20 to 100	20	100	80	Suppression = 0.25
-25 0 +100	Elevated zero range	-25 to 100	-25	100	125	–
-100 0	Elevated zero range	-100 to 0	-100	0	100	–
-100 -20	Elevated zero range	-100 to -20	-100	-25	80	–

6.12.3 Lower Range Limit (LRL)
The lower range limit is the lowest quantity that a transmitter can be adjusted to measure (ISA S51.1).

6.12.4 Upper Range Limit (URL)
The upper range limit is the highest quantity that a transmitter can be adjusted to measure (ISA S51.1).

6.12.5 Overrange
Overrange is simply any excess of the input signal to the transmitter that exceeds its upper range value or that is below the lower range value.

6.13 Reference operating conditions
The reference operating condition is the range of operating conditions for a transmitter within which operating influences are negligible. The range is usually narrow. It does not include the effects of ambient temperature, humidity, vibration, or shock.

6.14 Repeatability
Repeatability is the closeness of agreement among a number of consecutive measurements of output for the same value of the input over the same operating conditions and being approached from the same direction, figure 40. Repeatability does not include hysteresis.

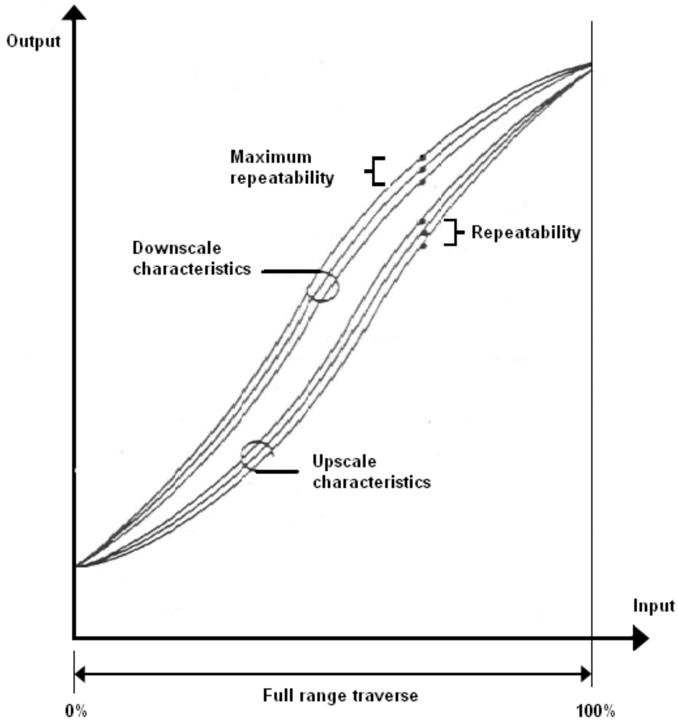


Fig. 40 Repeatability

6.15 Reproducibility
Reproducibility is the closeness of agreement among repeated measurements of the output for the same value of input under the same operating conditions over a period of time and being approached from both directions. Normally this implies long periods of time. Reproducibility includes hysteresis, drift, and repeatability.

6.16 Static pressure effect
Static pressure effect is the effect of -line pressure applied to both the high and low sides of the transmitter. It is typically: 0.25% of upper range limit for 2000 psi

Zero errors due to static pressure can be found in most manufacturers' literature. Span error information is less readily available. The span error on high line pressure systems is more pertinent than the zero error, since zero error can be easily calibrated out on-line.

6.17 Span
Span is the algebraic difference between the upper range value (URL) and the lower range value (LRL) (ISA S51.1).

6.18 Span error
Span error is the difference between the actual span and the ideal span.

6.19 Temperature effect

The temperature effect, unless otherwise stated, is assumed to include both the zero error and the total effect. It can be expressed as:

- ± 1-0% of maximum span per 100 °F
- ± 1-0% of maximum span per 100 °F between 50 °F and 150 °F

± 1-0% of Maximum Span per 100 °F.
This specification implies that the temperature effect is ± 1-0% of the upper range value for any 100 °F change in temperature within the operating limits of the transmitter.

± 1.0% of Maximum Span per 100°F between 50°F and 150°F.
This specifically calls out a specific range of temperature over which the statement applies. This range is generally a subset of the operating range of the transmitter. The specification does not apply if you are operating within the operating range of the transmitter, but outside the specification limits.

Temperature effect is generally defined in specifications at the maximum span. As the transmitter is turned down and smaller spans than maximum are measured, the temperature effect is magnified. This is true for all transmitters. As a rule of thumb, the worst-case temperature effect is magnified to the same extent as the transmitter turn down ratio. The following example shows how to determine temperature effect for span settings less than the maximum limit.

On Zero:

Temperature Effect Statement: ± 0.5% /100 °F (50 °C) at maximum span.

Span Limit: 0-25” w.c. to 0-150” w.c.

Calibrated Range: 0-25” w.c.

Temperature Change: 80° up to 180 °F (26 °C up to 82 °C), a 100 °F (56 °C) change.

Turn Down Ratio: 150/25 = 6:1

Temperature Effect at Calibrated Span: 6 x ± 0.5% = 3%/100 °F

Zero on transmitter may shift by (3% x 150”) = ± 4.5”

Because of the magnified effects of temperature at low span settings, most users will select a transmitter that works as close to maximum range conditions as possible. In addition, users try to eliminate the effects on ambient and process temperature changes on the transmitter installation. For example, a transmitter should not be installed outdoors where it is unprotected from direct sunlight, especially if it is being used near its minimum span limit.

6.20 Turn Down

The Turn Down Ratio of a transmitter is the ratio between its Upper Range Limit and the minimum recommended span. Some time it is also called rangeability. It represents the capability of the transmitter to cover several pressure ranges, without deteriorating the transmitter performance: accuracy, etc.

6.21 Vibration effect

Most specifications associated with vibration refer to sinusoidal vibration, which may or may not be the type of vibration exhibited in service. The ability of the transmitter to withstand shock is often as important as the vibration considerations. It is difficult to perform laboratory tests that relate well to the ruggedness of a unit in a given environment, so that trial installations tend to be much more reliable.

6.22 Zero error

Zero error is the difference between the actual zero and the ideal zero.