

Pressure Transducers

What They Are and How to Select One

This article shows how to select the proper pressure transducer or transmitter. It walks the reader through the key technical features explaining what they are and why they are important. The general discussion of sensor design and transducer construction will provide the reader with an understanding of the fundamentals.

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More than one hundred companies are in the business of designing and manufacturing pressure transducers in the United States. Worldwide, that number can probably be doubled. If you're in the market for one, here are some factors you should keep in mind.

First, consider what a transducer is. It's a device that converts a physical measurement into an electrical signal. They include strain gages for measuring relative strains, linear variable differential transformers (LVDTs) to measure linear displacements, pressure transducers for the measurement of differential, gauge or absolute pressures, and load cells to measure force.

The generic term "pressure transducer," or as used by many people, just "transducer," may refer to either a pressure transducer or pressure transmitter. The distinction is as follows:

- **Pressure Transducer:** A typically millivolt or voltage system which converts input pressure into low-level electrical/electronic

signals. These signals, however, are not suitable for transmission over long distances.

- **Pressure Transmitter:** A current loop instrument which incorporates an electronic amplifier and pressure sensor into one package, allowing measurement signals to be transmitted over long distances without loss of accuracy or the introduction of electrical noise. Transmitter output signals are typically 4-20 mA analog.

Pressure transducer systems are defined by their output signals: (1) non-amplified 0-30 and 0-100 millivolts, (2) amplified 5 and 10 volt, and (3) amplified 4-20 mA current-loop output. The characteristics of each system will be described.

MILLIVOLT SYSTEM

These ratiometric units are relatively low cost because the power supply, voltage regulator and signal conditioning functions are remote from the transducer. This allows the transducer to be smaller in size. Because

the signal conditioner is separate, these transducers are compatible with most instrumentation.

AMPLIFIED VOLTAGE SYSTEMS

While they have the same basic sensor technology as millivolt systems, amplified voltage systems are enhanced by instrumentation-grade amplifiers. An amplified voltage system is appropriate for many industrial applications. These systems are directly compatible with most older process control and computer interfaces.

CURRENT-LOOP SYSTEMS

These units are designed for industrial and process applications where the signal is processed remotely and when high noise immunity is required. Since they transmit a 4 to 20 mA output signal, these systems are able to operate over 1,000 feet without signal degradation. Current loop systems are used for direct interface with most computers, data acquisition systems and industrial process controllers.

THE OPERATING SYSTEM

A pressure measurement system has three primary components: (1) pressure transducer, (2) excitation power supply, and (3) signal processor which can include a digital or analog readout meter, oscilloscope, digital voltmeter, tape recorder, computer, chart recorder, X-Y plotter, controller or recorder (see Figure 1). A ratiometric transducer requires the user to select an accurate power source and signal conditioner. This is necessary because the ratiometric transducer's output voltage (V_o) is directly related to the supply voltage (V_s) by a ratio. The output voltage is $V_o = V_s \cdot S (P \div P_1)$, where P is the operating pressure, P_1 is the rated pressure, and S is the sensitivity. For a transducer where the sensitivity is 3 mV/V, with a unit rated for 100 psi and an input voltage of 10 volts, at an operating pressure of 50 psi the output voltage will be:

$$V_o = 10V \cdot 3mV/V \cdot (50 \text{ psi} \div 100 \text{ psi}) = 15 \text{ mV}$$

Should the input voltage fluctuate, then the output signal would change for the same pressure.

Voltage transducers and current-loop transmitters normally have amplifiers and signal conditioning built-in. They are capable of accepting either an unregulated or regulated power supply. This means the

excitation voltage can vary between limits, set by the manufacturer, and for a given pressure the output signal will not vary. Therefore, a more expensive regulated power supply and signal conditioner are not required.

SELECTING A TRANSDUCER

When selecting a transducer, one must consider *accuracy, system pressure, temperature, fluid compatibility, excitation, processor compatibility, noise, the type of basic sensor, and for transmitters, the system's loop resistance.*

Accuracy: How does one determine the accuracy needed in a transducer? For most, this is a daunting task. To do it right requires a complete analysis of how tightly the pressure should be controlled. Then the accuracy of each sensor and control element within the loop needs to be determined and the statistical accuracy of the control-loop calculated. Most applications, however, don't require this degree of sophistication. But accuracy will affect system performance and possibly the quality of the product. Therefore, a general rule-of-thumb is to select a transducer with a 0.25% FSO accuracy. Generally, less accuracy can cause problems, while the cost for greater accuracy is unjustified. However, make sure that the accuracy statement given by the manufacturer includes linearity, hysteresis and repeatability.

Pressure: Typical systems can have pressure described in a number of ways (e.g., operating pressure, design pressure, system pressure, etc.). But when selecting a transducer, *one must determine the maximum pressure the transducer will see.* First, determine the system's maximum operating pressure, determine if pressure spikes or pressure surges are likely to occur, and if they are, estimate their magnitude. To prevent damage to the transducer; select the maximum pressure including spikes and surges, add 20%, then select a transducer with a proof pressure greater than this value. There is a short cut to this process. If there are safety reliefs built into the system, then, in most cases, it will be acceptable to select a transducer with a proof pressure based on the safety's setting.

Figure 2 illustrates the selection procedure. Should the system be subjected to negative pressure, even during a cleaning operation, consult the manufacturer as it

may affect transducer selection. Remember, as the overall range increases, sensitivity of the unit will decrease; therefore, it is inadvisable to add too many safety factors. A prudent precaution is to add a pressure snubber in order to minimize the impact of surges and spikes.

If a pressure snubber is used, the column of gas or liquid will alter the frequency response and rise-time characteristics of pressure spikes and surges. It should be noted that the pressure transducer's response time to changes will change from approximately 1 millisecond to 10 milliseconds. For most systems this degree of dampening will have no effect.

Temperature: The temperature rating of the transducer should match the normal temperature range of the process. In the case of many pressure transducers, three temperature ranges are given: operating, compensated and storage.

The *operating* range defines the maximum temperature range in which the pressure transducer should be operated. If the operating range is exceeded, the transducer's ability to provide accurate pressure readings is greatly compromised. At extremely low temperatures the unit may be unable to energize. The *compensated* temperature range establishes the extent to which the thermal shift is accurately predicted. Outside this range the thermal shift will change by an unpredictable amount. The *storage*

temperature limit should not be exceeded for a powered or unpowered transducer. If the storage temperature is exceeded, the instrument electronics can be permanently damaged.

Pressure transducers can be used in applications where the process fluid temperature exceeds the upper/lower temperature limits given in the specifications. For these applications, the solution is to install a short (12 inches) length of pipe or tubing between the process piping and transducer. This should protect the transducer from -400° to 1000°F fluid temperatures. Remember, don't exceed the maximum operating temperature of the electronics. If there is any doubt about the temperature seen by the electronics, a thermocouple placed on the transducer will verify that the temperature is within the manufacturer's limits.

Fluid Compatibility: Make certain that diaphragm and process fittings are compatible with the process fluid. For example, 316 stainless-steel diaphragms and 17-4 PH stainless-steel process fittings are standard materials on many pressure transducers. Most manufacturers are able to make material substitutions for unique applications.

Isolating the transducer from the fluid is desirable in some applications due to material compatibility or sanitary concerns. This can be accomplished by adding a chemical seal and vacuum filling with oil or water. The filling is

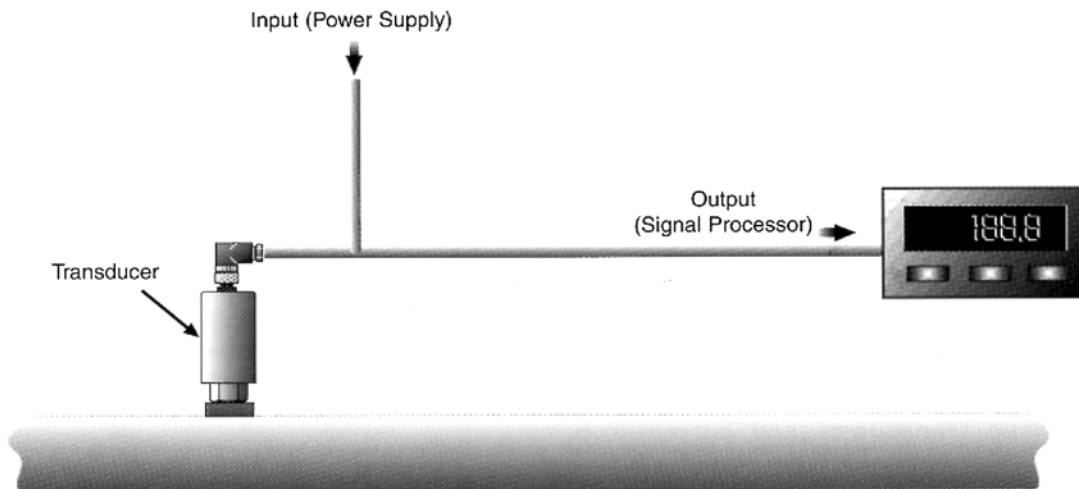


FIGURE 1. Typical pressure measurement system.

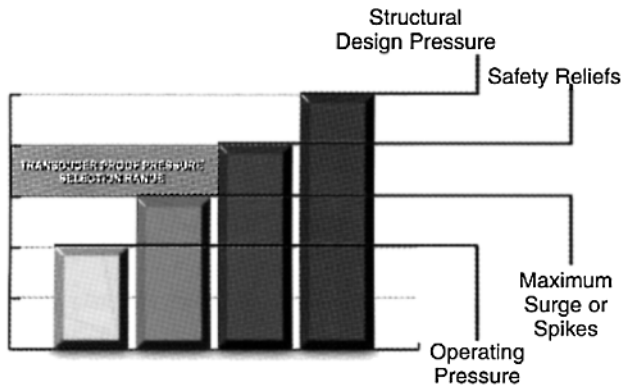


FIGURE 2. Factors to consider when selecting a pressure rating.

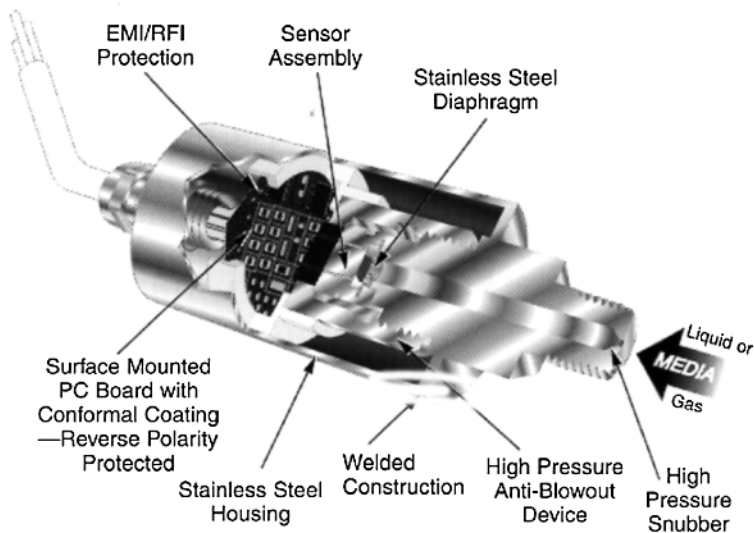


FIGURE 3. High-pressure transducer cutaway (Barksdale Models 423, 425, 426).

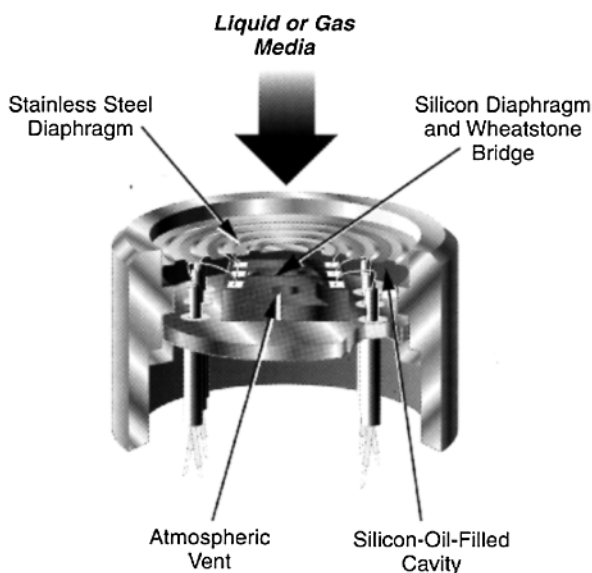


FIGURE 4. Typical transducer sensor cutaway; open cell design.

done under vacuum to eliminate air which would affect frequency response and accuracy.

Excitation: All transducers require electrical excitation in order to function. Excitation power can be provided from an independent power supply or from process instrumentation which includes excitation capabilities. The power supplies can be divided into regulated and unregulated. All millivolt output transducers require a regulated power supply, while voltage and current loop pressure transducers can normally use either type of power supply. Any transducer which can accept an unregulated power supply can also accept a regulated supply.

Processor Compatibility: When selecting a transducer, make sure its output matches the input requirements of the processor. To make certain that the user knows his unit is operating even when there is no process pressure on the transducer, most voltage output units have a zero offset. This, of course, is the same rationale used for a 4 to 20 mA transmitter. If a true zero is used, one can never be sure if the system pressure is zero or if the transducer is inoperable. However, many processors and recorders still specify a 0 to 5 volt or a 0 to 10 volt input signal, but their span can normally be adjusted to accept a standard offset such as 0.5 to 5.5 volt or 1 to 11 volt input signal.

Noise: EMI and RFI compatibility with electrical and electronic equipment is an international concern. The IEC and ISO standards were implemented in January 1996 by the European Community. The EC requires that all electrical and electronic products delivered after this date be qualified in conformance with these standards. A manufacturer's amplified transducers and transmitters should be tested and qualified to meet or exceed these standards. The product's specification sheets should state the IEC standards the unit meets or exceeds. Look for "CE qualified" marked on the specification sheet.

THE PRESSURE SENSOR

The pressure sensor is inherently incomplete. It is simply a subcomponent of the transducer which must be normalized, temperature compensated, and output conditioned to produce a usable product. A signal conditioning circuit is generally required to provide temperature compensation, excitation, offset and

span adjustment. This, in addition to the construction of the sensor, is important to the overall performance of the pressure transducer. A cutaway illustration of a transducer designed to provide EMI/RFI protection, shock and vibration resistance, and a NEMA 4 environmental enclosure is shown in Figure 3.

Many types of sensor technologies are on the market today, each offering potential benefits and shortcomings. Barksdale, for example, has chosen the diffused semiconductor piezoresistive-type sensor because it offers shock and vibration resistance, the capability of handling a wide range of system pressures, wide response frequency, compact size, and long-term stability.

BASIC SENSOR STRUCTURE

The basic diffused semiconductor pressure sensor consists of a homogeneous silicon measuring cell with two vacuum-welded silicon plates. A four-arm Wheatstone bridge is diffused into the silicon plate. Pressure is applied to the stainless-steel diaphragm and transmitted through the silicon-oil-filled chamber to each leg of the bridge (see Figure 4). Then, by means of the piezoresistive effect, the individual resistor's values change proportional to the measured pressure.

Absolute (vacuum) pressure sensors are made by hermetically sealing a vacuum reference chamber on one side of the integrated circuit sensing element. Pressures are measured relative to this vacuum reference. Sealing in a nearly perfect vacuum of, say, 0.0005 psia as a reference eliminates potential thermal errors. If gas is used in the reference chamber, it would exert pressure during thermal expansion and contraction, causing error.

Gauge pressure sensors are referenced to barometric pressure through a vent port which is open to atmospheric pressure. At high pressures a closed sensor is used which is referenced to the local atmospheric pressure where it is manufactured. If a vented transducer is submerged, special venting precautions must be considered. Due to the vent port, the sensor automatically compensates for changes in altitude, making it ideal for mobile applications.

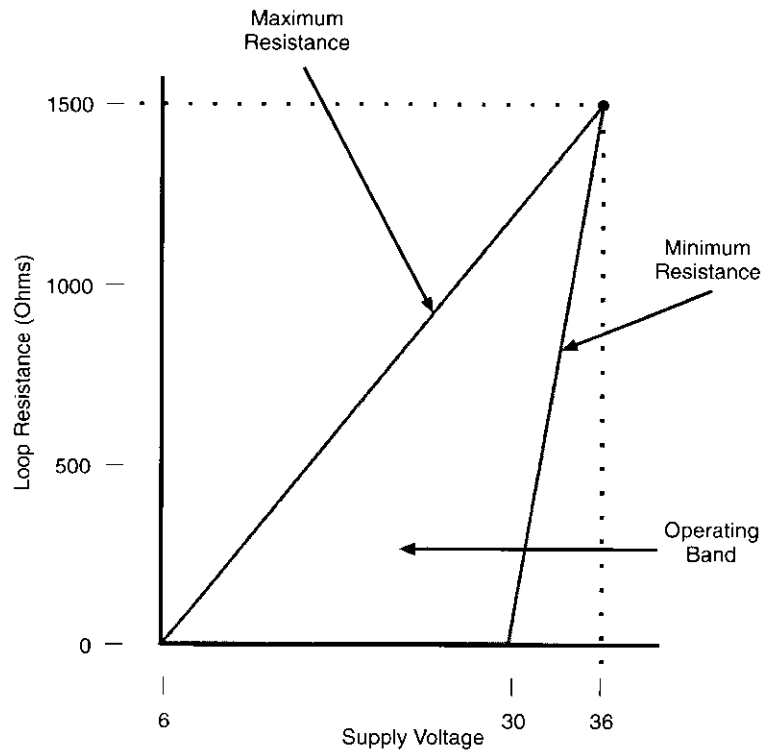


FIGURE 5. Loop resistance curve.

Open cell designs (see Figure 4) are normally used to measure gauge pressure up to 150 psi. Changes in atmospheric pressure have no effect on the accuracy of open-cell sensors. Closed-cell sensors are used to measure absolute pressure, gauge pressure over 150 psig, or vacuum to 30" Hg.

LOOP RESISTANCE, 4 TO 20mA TRANSMITTERS

When designing a control system one must determine the system's loop resistance and operate within a specific band defined by the transmitter's maximum/minimum supply voltage (Figure 5). The following details the methodology to be followed:

(1) **Maximum Total Loop Resistance:** The maximum loop resistance, $R_{loop\ max}$, of the system must first be determined. $R_{loop\ max}$ is the maximum resistance the system is capable of handling regardless of the magnitude of the supply voltage, V_s . The maximum loop resistance, using a Barksdale 425 Series transmitter as an example, is 1200 ohms. The calculation for determining the loop resistance for the 425 transmitter is as follows:

$$R_{loop\ max} = (V_{s\ max} - V_{s\ min}) \div I_{FS}$$

where:

$V_{s \max}$ = maximum supply voltage.

$V_{s \min}$ = minimum supply voltage.

I_{FS} = full scale current.

Using the Series 425 data sheet, we have $V_{s \max}$ = 30 VDC, $V_{s \min}$ = 6 VDC, and I_{FS} = 20mA.

(2) Maximum Supply Voltage: One must determine the maximum supply voltage, V_s , in order to define the intercept with $R_{loop \max}$. Once this intercept is known, the minimum and maximum slopes of the operating band can be determined. The maximum supply voltage, V_s , is the intercept between the minimum and maximum loop resistance curves — i.e., where $R_{\min} = R_{\max}$.

$$((V_s - V_{s \min}) \div I_{FS}) = ((V_s - V_{s \max}) \div I_{zero})$$

$$((V_s - 6) \div 20) = ((V_s - 30) \div 4)$$

Solving for V_s yields $V_s = 36$ volts.

(3) Plotting the Curve: The loop resistance curve in Figure 5 is plotted as follows:

Y axis: $R_{loop \max} = 1200$ ohms

X axis: $V_{s \min} = 6$ V, $V_{s \max} = 30$ V, and $V_s = 36$ V.

Operating Band: The area defined by the intersection of the four curves identified above.

(4) How to Use the Loop Resistance Chart:

- Determine the power supply excitation voltage.
- Determine the total system resistance to include R_w (external wiring resistance) plus R_r (internal resistance) in your receiver.
- Compare the excitation voltage to the operating band given in the chart. If the sum of $R_w + R_r$ falls within the band, then nothing further is required. If it falls outside the band, then add resistance to the loop until it falls within the limits. □

Barksdale 1-800-835-1060

Series 425N1

4-20 mA



CE Qualified

Features

- Field Adjustable Zero and Span
- 2:1 turn down, Optional
- Integral Conduit Connection
- Reverse Polarity Protected
- Surface Mounted Conformal Coated Circuit
- Nema 4 Enclosure
- EMI, ESD & RFI Protection
- 0.25% Accuracy
- Internal Terminal Strip
- High Pressure Snubber

Performance Characteristics*

Accuracy (LH & R)	±0.25% FSO
Long Term Stability	±0.5% FSO of calibration curve
Typical Life	100 million cycles
Proof Pressure	2 times rated pressure or 13000 psi max. (884 bar), whichever is less
Warranty	3 years
Input	
Excitation Voltage	12 to 32 VDC (unregulated)
Loop Resistance	1250 ohms (max.)
Output	
Output	4 to 20 mA
Full Scale Output	16 mA ± 0.4%
Zero Output	4 mA ± 0.2%
Zero Adjustment Range	3.0 to 5.0 mA
Span Adjustment Range	15.0 to 17.0 mA
Physical	
Weight	23.7 oz. (672 grams) to 1000 psi 24.2 oz. (686 grams) from 2000 psi
Wetted Parts	17-4 PH & 300 series stainless steel
Enclosure	NEMA 4, cast aluminum, anodized
Pressure Connection	7/16-20 UNF female.
Electrical Connection	4-pole terminal strip and integral 1/2" NPT female conduit connection
Environmental	
Temperature Ranges	
Operating	0 to 160°F (-18 to 71°C)
Compensated	30 to 160°F (1 to 71°C)
Storage	-40 to 185°F (-40 to 85°C)
Temperature Shift	
Zero & Span	±1.0% FSO (max.) over compensated range
Vibration	15 g's, 10-2000 Hz, MIL-STD 202
Shock	50 g's, 11 mS, MIL-STD 202 Method 213, Cond. G.

* Definitions are in accordance with ANSI/ISA S37.1-75