Sensata
Technologies

PRESSURE TRANSDUCERS *TECHNICAL NOTE 2*

SPECIFYING A PRESSURE TRANSDUCER – HOW TO SELECT PRESSURE RANGE AND DEVICE TYPE

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When choosing a pressure transducer for a particular application, usually the first question which arises is: “For what pressure range should the transducer be rated?” This simple question begets a bevy of related ones, namely: “What is the pressure range in which the device typically operates? Does the device occasionally need to measure pressures outside this range? What pressure must the device withstand and still operate within specification when returned to its normal range? What pressure must the device withstand without failing even if it will function properly after returning to the normal operating range?”

Closely related to the pressure specification is the type of device to choose - absolute, gage or sealed gage. The following sections will first address pressure selection and then device type.

Pressure Specifications

Three pressure specifications typically appear on the data sheet.

Normal Operating Range

The device pressure range is the normal operating region for the device. This is the region in which the data sheet specifications are valid.

Proof Pressure

Proof pressure is the maximum pressure to which a device may be exposed after which it will return to its normal operating pressure range and perform within specification.

Proof pressure is specified as a multiple of the upper limit of the device’s operating (e.g., 1.5X for a 0-100 psi device would mean a proof pressure of 150 psi).

The typical testing performed by Sensata to verify proof pressure is for the pressure transducer to withstand 1000 cycles of exposure to the proof pressure, at room temperature, holding the pressure for 30 seconds each cycle, without degradation of performance.

Burst Pressure

Burst pressure is the maximum pressure to which a device may be exposed for two minutes without rupture that results in component separation from the transducer or application fluid leakage. It is not guaranteed that the device will function within specification when returned to its normal operating range after being exposed to a pressure above its proof pressure (even if that pressure is below its burst pressure). Like proof pressure, burst pressure is specified as a multiple of the upper limit of the device’s operating range.

Choosing Device Pressure

Proof pressure and burst pressure should be chosen based on potential over-pressure in the operating environment or regulatory requirement.

The highest system accuracy is attained only when the normal operating pressure of the pressure transducer is matched to the application. In order to understand the effect of using a device to measure pressures which are in a smaller range than the devices full span range, it is useful to examine an example.

Suppose that there is a requirement to measure pressures in the range 0-50 psia and a 0-100 psia sensor has been selected. There are two issues which affect the <u>theoretical</u> accuracy.

First, the device accuracy (static error and total error bands) is specified as a percentage of full span (%FS) and, in this example, is ±0.75% FS. If the full span of the application is only 0-50 psia the accuracy, as a percentage of the application’s full span would be (100psia / 50psia)* ±0.75% FS = ±1.5% FS. In general, the accuracy in an application is given by:

$$A_{app} = A_{dev} * (FS_{dev}/FS_{app})$$

where: A_{app} = application accuracy
A_{dev} = device accuracy
FS_{dev} = device full span
FS_{app} = application full span

The second aspect of using a pressure sensor for a smaller span than its rating is that of analog to digital converter (ADC) resolution. In many systems, an ADC is used to condition the output of the pressure sensor. An application might use a 10 bit ADC referenced to 0V and 5V. A 10 bit ADC has 1024 (2^{10}) possible outputs. Since the usual pressure sensor output is from 0.5V to 4.5V, only 80% (4V/5V) of the ADC range will be used. This reduces the number of possible ADC outputs to 819 (80*1024). Each least significant bit change corresponds to a voltage change of 4.9mV (4V span/818). Since the output of the ADC is discrete, it may be in error by ±1/2LSB, or in this example, ±2.4mV. The error due to AC quantization is ±0.06% (2.4mV/4V). Note that no mention has been made yet of the input pressure range of the pressure sensor.

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If a 0-50 psia application uses a 0-100 psia sensor, the output range will be between 0.5V and 2.5V for a range of 2V. In this case quantization error is 2.4VmV/2V = ±0.12% FS. In general, the quantization error of an application is given by:

$$E_q(\pm\%FS) = \frac{1}{2 \times (2^n - 1) \times \dfrac{FS_{app}}{(ADC_{HI} - ADC_{LO})}} x100$$

Where: E_q = quantization error
n = ADC bits
FS_{APP} = application full span
ADC_{HI} = ADC high reference voltage
ADC_{LO} = ADC low reference voltage

The quantization error is a function solely of the ADC resolution and reference voltages, and the full span voltage range of the device as used in the application. By using as much of the pressure sensor's input pressure range as possible, quantization error is minimized.

These two aspects of theoretical accuracy for a pressure transducer should be kept in mind. It is important to note that this discussion is more about resolution than actual transducer accuracy when in application. Sensata transducers are always calibrated to have as little as possible error and 100% checked for accuracy tolerances through out the entire operating pressure range. In applying transducers to an application, there will be an upper limit where the resolution of the sensor starts to affect the accuracy. This is the case with a large transducer pressure range and the small application range. This large mismatch will result in a slight change of application pressure causing an out of specification output.

It is also important to note that if other mechanical aspects of a higher full scale pressure transducer are desirable (such as proof pressure) then a device can be configured with this sense element and calibrated down to include a higher degree of accuracy with a lower pressure range.

Measuring Pressures Outside Normal Device Range

In some applications, there is a requirement to detect pressures above or below the normal operating range of the pressure sensor. One example is if the system requires alarms ("diagnostic bands")at points outside the normal operating range. In this situation, it may be undesirable to use a sensor with a range encompassing the alarm points since this will reduce the resolution in the normal operating range in order to accommodate infrequent incursions to the alarm pressures. Application note ***AN3 - Useful Pressure Transducer Performance Outside Normal Operating range*** describes how far outside the normal operating range the pressure transducer will function and its performance in these regions.

Device Type – Gage or Sealed

The pressure sensing element in Sensata pressure transducers is a pair of parallel plates which form a capacitor. One plate is fixed to a ceramic diaphragm which flexes in response to pressure changes. The other plate is attached, with a rigid glass seal, to a ceramic substrate which is insensitive to pressure changes. As the pressure varies, the diaphragm flexes and the distance between the capacitor plates changes.

In typical transducers, only one side of the diaphragm is accessible to the application and the other inaccessible side, is permanently referenced to some other pressure. The pressure on the inaccessible side can fall into one of two categories: gage (or vented) and sealed. In a gage sensor, the inaccessible side of the diaphragm is vented to the atmosphere. In a sealed sensor, there is no way for the atmosphere to move in or out of contact with the inaccessible side of the diaphragm.

It is possible to manufacture a sealed sensor with different pressures sealed in. Typically the sealed pressure is atmospheric. Depending on the associated electronics, a transducer can be built to operate within a specified accuracy regardless of the sealed pressure. The two transducer types are illustrated schematically in Figure 1.

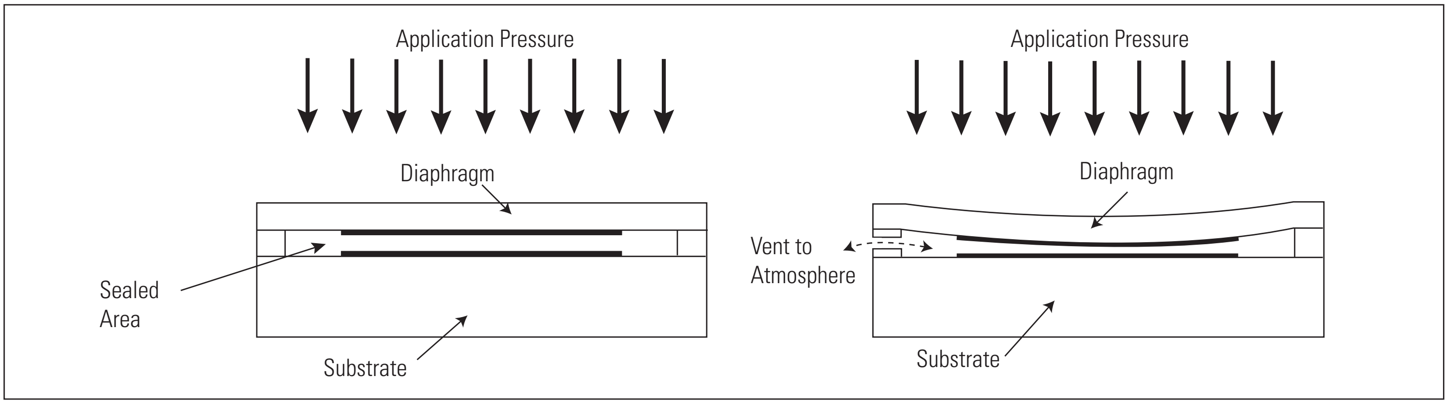

Figure 1. Different types of pressure transducers

Figure 2. Gage vs. sealed device for measuring open or closed pressure vessels

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Pressure Scales

Since the measurement of pressure is always differential (i.e., the pressure being measured is always compared to some other pressure), the nomenclature used to describe a pressure measurement includes information about the pressure reference.

The following abbreviations are commonly used:

psi = pounds per square inch
psia = psi **a**bsolute (i.e., relative to vacuum)
psig = psi **g**age (i.e., relative to atmospheric pressure)

Psi (without the "a" or "g") should generally be avoided as it is unclear to what pressure the measured pressure is referenced. An exception is when a pressure increment is being discussed - since a 10 psia pressure change is the same as a 10 psig pressure change, the term psi could be used unambiguously in this context.

Depending on the pressure of the application, the distinction between psia and psig may be negligible. This is generally true in high pressure applications. The difference in measurement between an absolute and a gage device depends on atmospheric pressure. (At sea level, is approximately 14.7 psi.) For a 1000 psi full span application this is a 1.5% FS difference.

Performance of the Transducer Types

In order to understand how the two device types differ in performance, it is necessary to change their environment while keeping the applied pressure constant.

What is the effect of increasing atmospheric pressure on each of the device types? The gage device is the only one which changes in response to an atmospheric pressure change since it is the only one with a diaphragm surface exposed to the atmosphere. When the atmospheric pressure increases, the gage device will indicate a lower measured pressure since it is measuring with respect to atmospheric pressure.

How do these different operational characteristics influence the choice of device type? The only way to be unaffected by altitude or barometric pressure changes with a single sensor is to use a gage device. Conversely, if the application requires measurement of the environmental pressure, a gage device cannot be used.

Altitude Example

Ambient atmospheric pressure decreases with increasing altitude by approximately 0.5 psi for every 1,000 foot increase.
At the typical mountain pass in Colorado of 10,000 feet, the ambient pressure is 14.7 psia - 5 psia = 9.7 psia.

When a sealed sensor (either absolute or sealed gage) with its pressure port open to the atmosphere is brought to higher elevations, the output will decrease because the pressure applied to its diaphragm is being reduced. The error due to altitude is calculated by finding the pressure change for the altitude range and dividing by the full scale range of the sensor to get error in % FS.

Example (note: psi is used in some places in this example when pressure changes or differences are being considered): A 0-50 psia sealed sensor is being used to measure the height of an open container of liquid by measuring the pressure at the bottom of the tank. The system is moved from sea level to Denver, Colorado at 5,000 feet. So 5,000' * (0.5 psi/1,000') = 2.5 psi change. 2.5 psi/50 psi * 100% = 5% FS altitude error. This error is due to the decreased pressure of the atmosphere on the liquid. If a gage part were used, the decrease in pressure on the liquid would be compensated by a decrease in pressure on the side of the diaphragm exposed to the atmosphere and the error would be zero.

Depending on the pressure of the application, the error contributed by changes in the ambient atmospheric pressure may be negligible. In the example above, if the full span were 1,000 psia, the error contributed by the altitude change would be 2.5 psi/1,000 psi * 100% = 0.25% FS.

In some systems (e.g., refrigeration), the fluid being measured is shielded from the effect of atmospheric pressure by the system construction If in the previous example the container were closed so that changes in atmospheric pressure had no effect on the fluid, then there would be no error due to the atmospheric pressure changes even if a sealed device were used. In this situation, using a gage device would cause an error since atmospheric pressure changes experienced by the vented, inaccessible side of the diaphragm would not be offset by pressure changes on the application side. See illustration in Figure 2.

Vent Path

All gage devices must have a vent path to atmospheric pressure. In competitive devices, the vent path is wide open to dirt and moisture and is a frequent cause of field failures. In Sensata gage devices, the internal workings of the sensor are protected from moisture and dirt by the connector as well as some patented features in the sensing element. The vented air travels from the sensing element, through the standard electrical wire and exits at the end of the wire. The wire end must remain in a clean environment to avoid plugging of the vent (i.e., not plugged with solder or water or oil). The size and length of the leads for venting affect the response time of the sensor. For a 10 psi atmospheric pressure drop, a device with standard 18 AWG wire leads will have a response time of less than one minute. This is significantly faster than the atmospheric pressure changes unless the sensor is rapidly changing altitudes. This response time does not affect the sensor's output response time to changes in working fluid pressure.

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Sealed Gage Device

Some users of sealed sensors find it more convenient for the transducer to output a value of 0 psi at atmospheric pressure (14.7 psia) rather than at 0 psia. For these cases an absolute transducer is calibrated to output 0 psi at a standard sea level pressure of 14.7 psia. To make it clear that an absolute reference pressure is being used but with a gage scale calibration, the industry uses the term "sealed gage" which is denoted by psis.

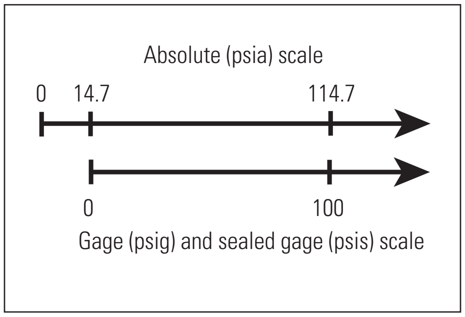

Figure 3. Absolute vs. Gage and Sealed Gage Pressure Scales

A sealed gage part behaves the same as an absolute; its output is affected by changes in atmospheric pressure. They differ in output by a 14.7 psi offset as shown in Figure 3.

Selection Summary

The following three rules can be used to decide whether a sealed or gage device should be used:

Rule 1: If the pressure being measured changes when atmospheric pressure changes AND that is considered an error AND that error is too high, use a gage device

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Rule 2: If the pressure being measured changes when atmospheric pressure changes and that should result in a change in device output, use a sealed (absolute or sealed gage) device.

Rule 3: If the pressure being measured does not change when atmospheric pressure changes, use a sealed device (absolute or sealed gage).

The flow chart in Figure 4 can be used to decide whether a gage, sealed gage or absolute part should be used in an spplication.

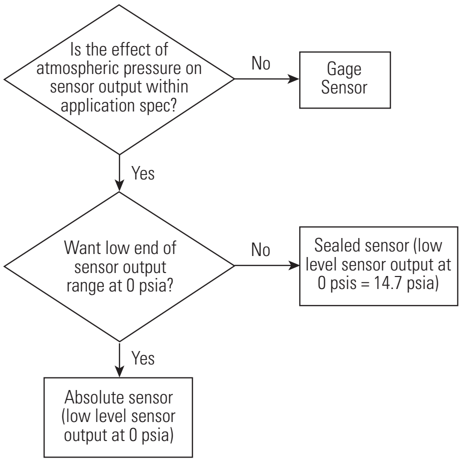

Figure 4. Transducer Type Selection Flow Chart

Company Description

Sensata Technologies is one of the world's leading suppliers of sensing, electrical protection, control and power management solutions across a broad array of industries and markets. Our products improve safety, efficiency and comfort for millions of people every day in automotive, appliance, aircraft, industrial, military, heavy vehicle, heating, air conditioning, data, telecommunications, recreational vehicle and marine applications.

For more information, please visit our web site at: **www.sensata.com/pressure or call toll free at 1-888-438-2214 or email us at sensors@sensata.com.**

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