How To Measure Pressure with Pressure Sensors

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Overview

Learn how to measure pressure with pressure sensors. Understand the types of sensors available and the appropriate hardware to accurately take pressure measurements.

Return to the NI Measurement Fundamentals Main Page (http://zone.ni.com/devzone/cda/tut/p/id/4523)

Table of Contents

1. What is Pressure?

Pressure is defined as force per unit area that a fluid exerts on its surroundings.[1] For example, pressure, P, is a function of force, F, and area, A.

$$P = F/A$$

A container full of gas contains innumerable atoms and molecules that are constantly bouncing of its walls. The pressure would be the average force of these atoms and molecules on its walls per unit of area of the container. Moreover, pressure does not have to be measured along the wall of a container but rather can be measured as the force per unit area along any plane. Air pressure, for example, is a function of the weight of the air pushing down on Earth. Thus, as the altitude increases, pressure decreases. Similarly, as a scuba diver or submarine dives deeper into the ocean, the pressure increases.

The SI unit for pressure is the Pascal (N/m2), but other common units of pressure include pounds per square inch (PSI), atmospheres (atm), bars, inches of mercury (in Hg), and millimeters of mercury (mm Hg).

A pressure measurement can be described as either static or dynamic. The pressure in cases where no motion is occurring is referred to as static pressure. Examples of static pressure include the pressure of the air inside a balloon or water inside a basin. Often times, the motion of a fluid changes the force applied to its surroundings. Such a pressure measurement is known as dynamic pressure measurement. For example, the pressure inside a balloon or at the bottom of a water basin would change as air is let out of the balloon or as water is poured out of the basin.

Head pressure(or pressure head) measures the static pressure of a liquid in a tank or a pipe. Head pressure, P, is a function solely on the height of the liquid, h, and weight density, w, of the liquid being measured as shown in Figure 1 below.

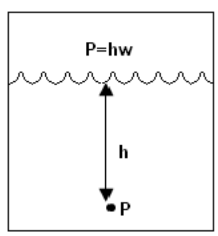

Figure 1. Head Pressure Measurement

The pressure on a scuba diver swimming in the ocean would be the diver's depth multiplied by the weight of the ocean (64 pounds per cubic foot). A scuba diver diving 33 feet into the ocean would have 2112 pounds of water on every square foot of his body. That translates to 14.7 PSI. Interestingly enough, the atmospheric pressure of the air at sea level is also 14.7 PSI or 1 atm. Thus, 33 feet of water create as much pressure as 5 miles of air! The total pressure on a scuba diver 33 feet deep ocean would be the combined pressure caused by the weight of the air and the water, that would be 29.4 PSI or 2 atm.

A pressure measurement can further be described by the type of measurement being performed. There are three types of pressure measurements: absolute, gauge, and differential. Absolute pressure measurement is measured relative to a vacuum (Figure 2). Often times, the abbreviations PAA (Pascals Absolute) or PSIA (Pounds per Square Inch Absolute) are used to describe absolute pressure.

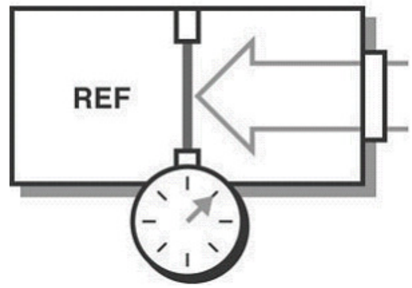

Figure 2. Absolute Pressure Sensor [3]

Gauge pressure is measured relative to ambient atmospheric pressure (Figure 3). Similar to absolute pressure, the abbreviations PAG (Pascals Gauge) or PSIG (Pounds per Square Inch Gauge) are used to describe gauge pressure.

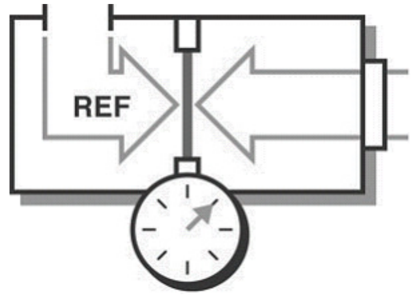

Figure 3. Gauge Pressure Sensor [3]

Differential pressure is similar to gauge pressure, but instead of measuring relative to ambient atmospheric pressure, differential measurements are taken with respect to a specific reference pressure (Figure 4). Also, the abbreviations PAD (Pascals Differential) or PSID (Pounds per Square Inch Differential) are used to describe differential pressure.

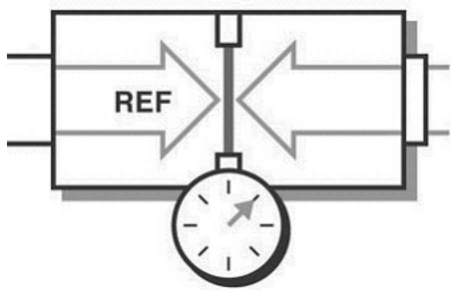

Figure 4. Differential Pressure Sensor [3]

2. The Pressure Sensor

Because of the great variety of conditions, ranges, and materials for which pressure must be measured, there are many different types of pressure sensor designs. Often pressure can be converted to some intermediate form, such as displacement. The sensor then converts this displacement into an electrical output such as voltage or current. The three most universal types of pressure transducers of this form are the strain gage, variable capacitance, and piezoelectric.

Of all the pressure sensors, Wheatstone bridge (strain based) sensors are the most common, offering solutions that meet varying accuracy, size, ruggedness, and cost constraints. Bridge sensors are used for high and low pressure applications, and can measure absolute, gauge, or differential pressure. All bridge sensors make use of a strain gauge and a diaphragm (Figure 4).

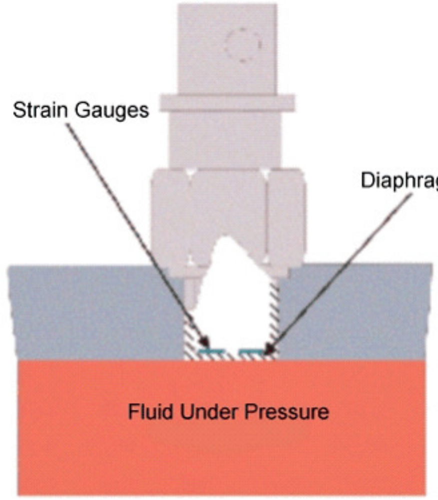

Figure 4. Cross Section of a Typical Strain Gauge Pressure Sensor [3]

When a change in pressure causes the diaphragm to deflect, a corresponding change in resistance is induced on the strain gauge, which can be measured by a Data Acquisition (DAQ) System. These strain gauge pressure transducers come in several different varieties: the bonded strain gauge, the sputtered strain gauge, and the semiconductor strain gauge.

In the bonded strain gauge pressure sensor, a metal foil strain gauge is actually glued or bonded to the surface where strain is being measured. These bonded foil strain gauges (BFSG) have been the industry standard for years and are continually used because of their quick 1000 Hz response times to changes in pressure as well as their large operating temperature.

Sputtered strain gauge manufacturers sputter a layer of glass onto the diaphragm and then deposit a thin metal film strain gauge on to the transducer’s diaphragm. Sputtered strain gauge sensors actually form a molecular bond between the strain gauge element, the insulating layer, and the sensing diaphragm. These gauges are most suitable for long-term use and harsh measurement conditions.

Integrated circuit manufacturers have developed composite pressure sensors that are particularly easy to use. These devices commonly employ a semiconductor diaphragm onto which a semiconductor strain gauge and temperature-compensation sensor have been grown. Appropriate signal conditioning is included in integrated circuit form, providing a dc voltage or current linearly proportional to pressure over a specified range.

The capacitance between two metals plates changes if the distance between these two plates changes. A variable capacitance pressure transducer (Figure 5), measures the change in capacitance between a metal diaphragm and a fixed metal plate. These pressure transducers are generally very stable and linear, but are sensitive to high temperatures and are more complicated to setup than most pressure sensors.

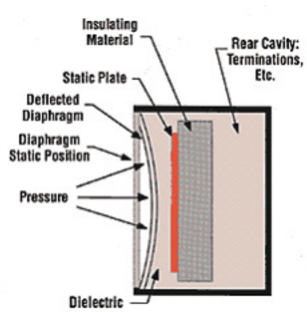

Figure 5. Capacitance Pressure Transducer [4]

Piezoelectric pressure transducer (Figure 6) take advantage of the electrical properties of naturally occurring crystals such as quartz. These crystals generate an electrical charge when they are strained. Piezoelectric pressure sensors do not require an external excitation source and are very rugged. The sensors however, do require charge amplification circuitry and very susceptible to shock and vibration.

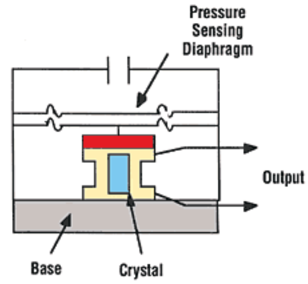

Figure 6. Piezoelectric Pressure Transducer [4]

A common cause of sensor failure in pressure measurement applications is dynamic impact, which results in sensor overload. A classic example of overloading a pressure sensor is known as the water hammer phenomenon. This occurs when a fast moving fluid is suddenly stopped by the closing of a valve. The fluid has momentum that is suddenly arrested, which causes a minute stretching of the vessel in which the fluid is constrained. This stretching generates a pressure spike that can damage a pressure sensor. To reduce the effects of “water hammer”, sensors are often mounted with a snubber between the sensor and the pressure line. A snubber is usually a mesh filter or sintered material that allows pressurized fluid through but does not allow large volumes of fluid through and therefore prevents pressure spikes in the event of water hammer. A snubber is a good choice to protect your sensor in certain applications, but in many tests the peak impact pressure is the region of interest. In such a case you would want to select a pressure sensor that does not include overprotection. [3]

3. Pressure Measurement

As described above, the natural output of a pressure transducer is a voltage. Most strain based pressure transducers will output a small mV voltage. This small signal requires several signal conditioning considerations that are discussed in the next section. Additionally, many pressure transducers will output a conditioned 0-5V signal or 4-20 mA current. Both of these outputs are linear across the working range of the transducer. For example both 0 V and 4 mA correspond to a 0 pressure measurement. Similarly, 5 volts and 20 mA correspond to the Full Scale Capacity or the maximum pressure the transducer can measure. The 0-5V and 4-20 mA signals can easily be measured by National Instruments Multi-function Data Acquisition (DAQ) hardware.

4. Signal Conditioning Used To Measure Pressure

As with any other bridge based sensor, there are several signal conditioning considerations in order to accurately measure pressure. It is important to consider the following:

- Bridge completion
- Excitation
- Remote sensing
- Amplification
- Filtering
- Offset
- Shunt Calibration

Each of these considerations are addressed thoroughly in the Measuring Strain with Strain Gauges tutorial linked below.

Once you have obtained a measurable voltage signal, that signal must be converted to actual units of pressure. Pressure sensors generally produce a linear response across their range of operation, so linearization is often unnecessary, but you will need some hardware or software to convert the voltage output of the sensor into a pressure measurement. The conversion formula you will use depends on the type of sensor you are using, and will be provided by the sensor manufacturer. A typical conversion formula will be a function of the excitation voltage, full scale capacity of the sensor, and a calibration factor.

$$\text{Pressure} = \left(\frac{C_{fs}}{V_{ex}}\right)\left(\frac{V_{meas}}{CF}\right), \text{where}$$

C_{fs} = Full Scale Capacity - the maximum pressure which the transducer should receive
V_{ex} = Excitation Voltage - the recommende d input voltage
V_{meas} = Measured Voltage - the raw voltage returned by the sensor
CF = Calibratio n Factor - the output of the transducer ,usually expressed in mV per input V

For example, a pressure transducer with a full scale capacity of 10,000 PSI and a calibration factor of 3mv/V and given an excitation voltage of 10V DC produces a measured voltage of 15 mV, the measured pressure would be 5000 PSI.

After you have properly scaled your signal, it is necessary to obtain a proper rest position. Pressure sensors (whether absolute or gauge) have a certain level that is identified as the rest position, or reference position. The strain gauge should produce 0 volts at this position. Offset nulling circuitry adds or removes resistance from one of the legs of the strain gauge to achieve this "balanced" position. Offset nulling is critical to ensure the accuracy of your pressure measurement and for best results should be performed in hardware rather than software.

See Also:
Measuring Strain with Strain Gauges (http://zone.ni.com/devzone/cda/tut/p/id/3642)

5. References

[1] Johnson, Curtis D, “Pressure Principles” Process Control Instrumentation Technology, Prentice Hall PTB.
[2] Daytronic.com, “Strain Gauge Pressure Transducers”, http://www.daytronic.com/products/trans/t-presstrans.htm (http://www.daytronic.com/products/trans/t-presstrans.htm) (current November 2003).
[3] Sensotec.com, “Honeywell Sensotec Frequently Asked Questions”, http://www.sensotec.com/pdf/FAQ_092003.pdf (http://www.sensotec.com/pdf/FAQ_092003.pdf) (current November 2003).
[4] Sensorsmag.com, "Pressure Measurement: Principles and Practice", http://www.sensorsmag.com/articles/0103/19/main.shtm (http://www.sensorsmag.com/articles/0103/19/main.shtm)l (current January 2003).

6. Next Steps

For more in-depth guidance on making pressure and load measurements, visit the how-to guide (http://zone.ni.com/devzone/cda/tut/p/id/7138).

Watch the 13-minute Introduction to Data Acquisition (http://zone.ni.com/wv/app/doc/p/id/wv-169)to learn the fundamentals of acquiring, analyzing and visualizing data -- from sensors such as pressure -- using your PC.