Calibration Essentials:
Pressure

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About the Author

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INTRODUCTION

Welcome to the fourth edition of Calibration Essentials, brought to you by the calibration team at Beamex. We are again partnering with the International Society of Automation to bring industrial automation professionals—executives and technicians alike—more advice, insights and tools for the efficient and effective calibration of industrial instruments in order to help facilitate continuous productivity for your facility.

Calibration Essentials: Pressure provides detailed resources for calibrating different types of pressure instruments, including transmitters, switches and gauges. It also explains how to set up calibration schedules, understand and convert units, how to ensure accuracy of measurement, and more.

With the Calibration Essentials series from Beamex and the International Society of Automation, you have all you need to ensure your calibration efforts remain as efficient and effective as possible. Both organizations are dedicated to helping to maintain a continuous automated production environment provide numerous resources.

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Pressure Calibration Basics: Pressure Types
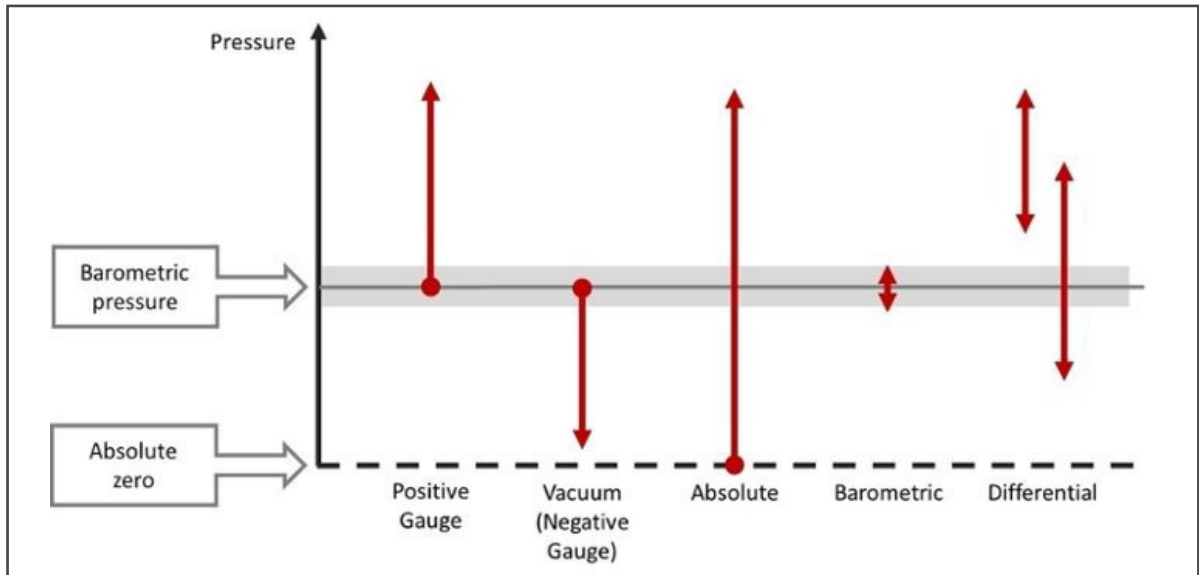
Pressure Types

In everyday situations, we do not usually talk much about different pressure types, but different types (sometimes also referred to as "modes") are available. Here is a short explanation of the different pressure types.

The two principal pressure types are gauge (or gage) and absolute pressure. Vacuum is sometimes considered its own pressure type, although it is a negative gauge pressure. Barometric pressure is also used in discussions; it is the atmosphere's absolute pressure.

Differential pressure is also considered a pressure type, being the difference of two separate pressures. In the end, all the pressure types are differential, with just a different point of comparison. Let's have a quick look at these different types.

Gauge pressure

Gauge pressure is the most commonly used pressure type. With gauge pressure we always compare the pressure we are measuring against the current atmospheric pressure. So it is the difference between the measured pressure and the current atmospheric pressure, meaning that we are that much above (or below) current atmospheric pressure. If our gauge pressure measurement device is open to atmospheric, it will always read zero, although the atmospheric pressure is different on any given day.

The two principal pressure types are gauge (or gage) and absolute pressure. Vacuum is sometimes considered its own pressure type, although it is a negative gauge pressure.

Gauge pressure can be indicated with the word "gauge" after the pressure unit (e.g., 150 kPa gauge). The abbreviation "g" is also used, although it is not fully legitimate and may cause confusion with the pressure unit. Because gauge is the default pressure type, often there is no indication of pressure type when it is gauge.

One practical example of gauge pressure is a car's tire pressure. Although we do not talk about "gauge" pressure, we measure and fill up the tire to a certain gauge pressure, i.e., a certain amount above atmospheric pressure, whether there is a low (rainy) or high (sunny) atmospheric pressure on that day.

Absolute pressure

Absolute pressure is the pressure compared to absolute vacuum, so it is the difference of the measured pressure and the absolute vacuum. An absolute vacuum is a state where the vacuum is so deep that there are no air molecules left, so there is no pressure. In practice a perfect absolute vacuum is impossible to achieve, but we can get pretty close. Also, in outer space, the pressure is absolute vacuum. An absolute pressure can never be negative, or in practice not even zero. If somebody tells you about a negative absolute pressure, you can ask him to check his facts.

Absolute pressure should be indicated with the word "absolute" after the pressure reading (e.g., 150 psi absolute). Sometimes you see the abbreviations "a" or "abs" being used, but the whole word "absolute" should be used if there is a risk that "a" or "abs" can cause confusion in combination with the pressure unit. It is important to remember to highlight that it is absolute pressure in question, otherwise it may be confused with gauge.

Vacuum pressure

Vacuum pressure is a (gauge) pressure that is below current atmospheric pressure. Being a gauge pressure, it is compared against the current atmospheric pressure and is often indicated as negative gauge pressure. The term vacuum is sometimes also used as a generic term to refer to a pressure that is below atmospheric pressure, even if it could also be measured as absolute pressure. In that case it is of course not a negative number, it is just an absolute pressure that is smaller than the current atmospheric absolute pressure. For example, if you pull a 40 kPa vacuum, it can be indicated as –40 kPa gauge, but it can also be indicated in absolute pressure as, for example, 60 kPa absolute, if the barometric pressure is 100.000 kPa absolute at the moment.

The basic conversion rule between gauge and absolute pressure is the following:

Absolute pressure = atmospheric pressure + gauge pressure

Differential pressure

As the name already hints, the differential pressure is a difference of two separate pressures. The value can be positive or negative (or zero) depending on which of the two pressures is higher.

A common industrial application is measuring flow by comparing a differential pressure over a constriction in the tubing (usually zero-based), or determining tank level by measuring the differential pressure between tank top and bottom. Another common measurement is the very low differential pressure difference between a clean room and surrounding areas.

Barometric pressure

The barometric pressure is the absolute pressure of the current atmospheric pressure at a specific location. The nominal barometric pressure has been agreed to be 101,325 Pa absolute (101.325 kPa absolute, 1013.25 mbar absolute, or 14.696 psi absolute). The barometric pressure is dependent on weather conditions, your location, and your elevation. It is highest at sea-level elevation and lowest at high mountains.

A weather forecast is one practical example of the use of absolute pressure to indicate high or low barometric pressure, roughly corresponding to sunny or rainy weather. If a weather forecast were to use gauge pressure, the air pressure would always be zero, so that would be a pretty useless forecast.
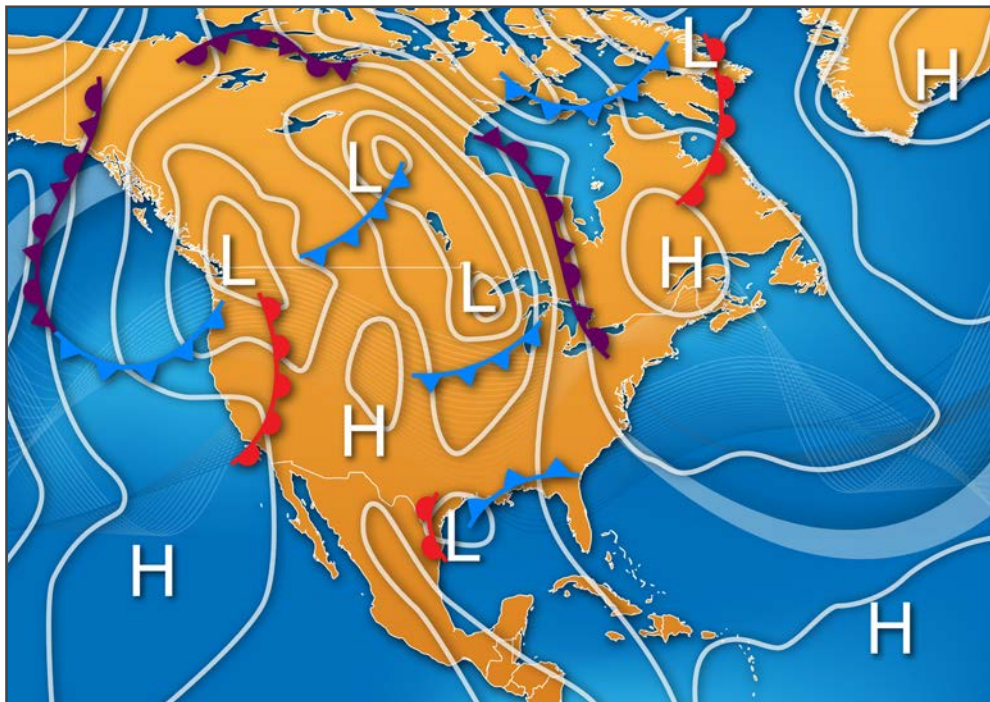
What is Barometric Pressure?

Barometric pressure, sometimes referred to as atmospheric pressure, is the pressure on Earth that is caused by the weight of the air above us. That definition sounds pretty simple, but let's take a deeper look into this subject.

What is pressure?

To start with, what is pressure? Pressure is defined as force per area ($p=F/A$), which means that pressure is a certain amount of force affecting an area. The International System of Units (SI) defines the base unit for pressure as a pascal, where 1 pascal equals 1 newton per square meter (N/m^2).

Whether we have realized it or not, many commonly used pressure units indicate the force and the area in their name. For example, psi is pound-force per square inch, and kgf/cm^2 is kilogram-force per square centimeter. However, most pressure units do not include this principle right in their name.

To learn more about pressure and the different pressure units, please see the article *Pressure Units and Pressure Unit Conversion.*

Absolute pressure

Barometric pressure is a so-called absolute pressure type. When measuring absolute pressure, the measured pressure is being compared to a perfect (absolute) vacuum, where there are no air molecules left and therefore no pressure. In comparison, the common gauge pressure is referred to as current barometric/atmospheric pressure.

For more detailed information about the different pressure types, please see the article *Pressure Calibration Basics – Pressure Types.*
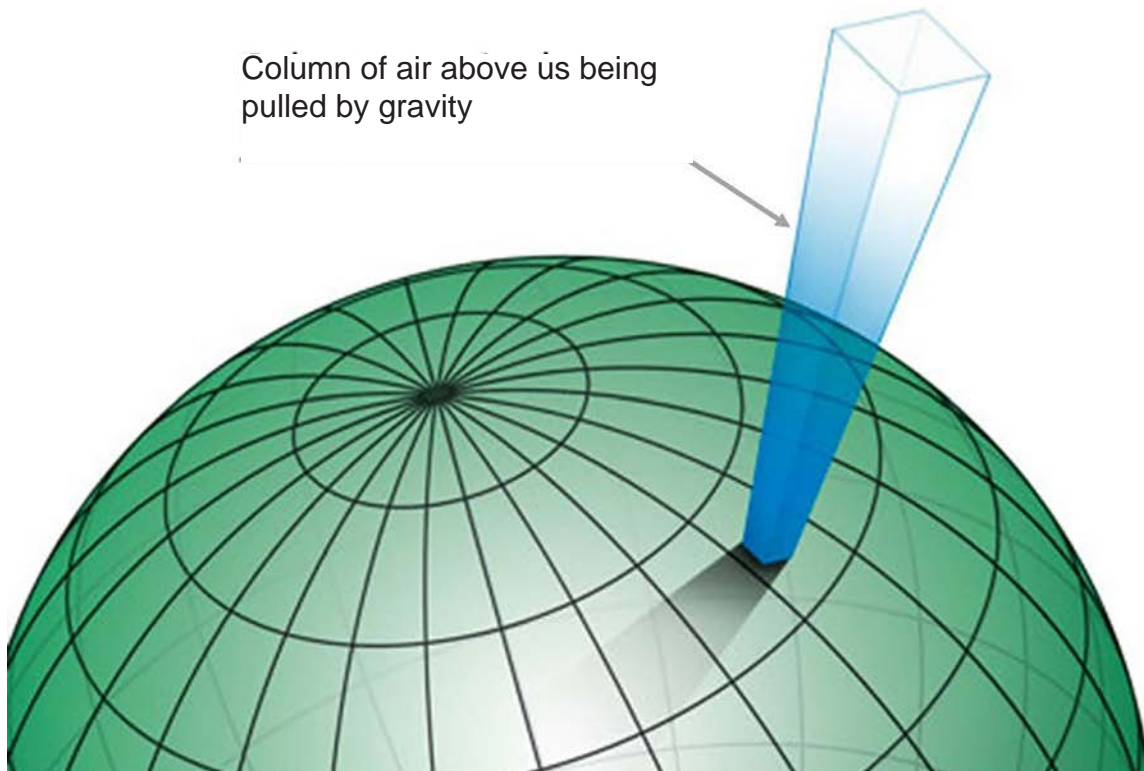
Barometric pressure

As mentioned, barometric pressure is the pressure caused by the weight of the air above us. The earth's atmosphere above us contains air, and although it is relatively light, there is so much of it that it starts to have some weight as gravity pulls the air molecules.

When I say "air," I mean the air around us, comprising about 78 percent nitrogen, 21 percent oxygen, less than 1 percent argon, and a small amount of other gases. The air gets thinner as we go higher because there are fewer molecules.

Approximately 75 percent of the atmosphere's mass is below the altitude of about 11 km (6.8 miles or 36,000 feet), a thick layer on Earth's surface. The border where atmosphere turns into outer space is commonly considered to be about 100 km (62 miles) above the earth's surface.

The column of air above us being pulled by gravity and causing barometric pressure is illustrated in the image.

Column of air above us being pulled by gravity

The agreed upon nominal barometric pressure on Earth is 101.325 kPa absolute (1013.25 mbar absolute or 14.696 psi absolute), which means that there is typically about 1.03 kilogram-force per every square centimeter (14.7 pound force per every square inch) on Earth's surface caused by the weight of the air. In practice, the barometric pressure very rarely is exactly that nominal value, as it is changing all the time and varies at different locations.

Barometric pressure depends on several things like weather conditions and altitude. For an example regarding the weather: during a rainy day, the barometric pressure is lower than it is on a sunny day.

The barometric pressure also varies based on altitude. The higher you are, the smaller the barometric pressure, which makes sense because when you move to a higher altitude, there is

less air on top of you. The air at higher altitudes also contains fewer molecules, making it lighter than it would be at a lower altitude. The gravity also decreases at these heights. Due to these reasons, the barometric pressure is smaller at higher altitudes.

You can actually use a barometric pressure meter to measure your altitude, which is how airplanes measure their height. The pressure drops as you go higher, but it does not drop exactly linearly. When you go all the way up to space, there is no pressure, and it is a perfect vacuum with no air molecules left.

The images illustrate how barometric pressure changes when altitude changes. The first image shows kPa versus meter, and the second psi versus feet.
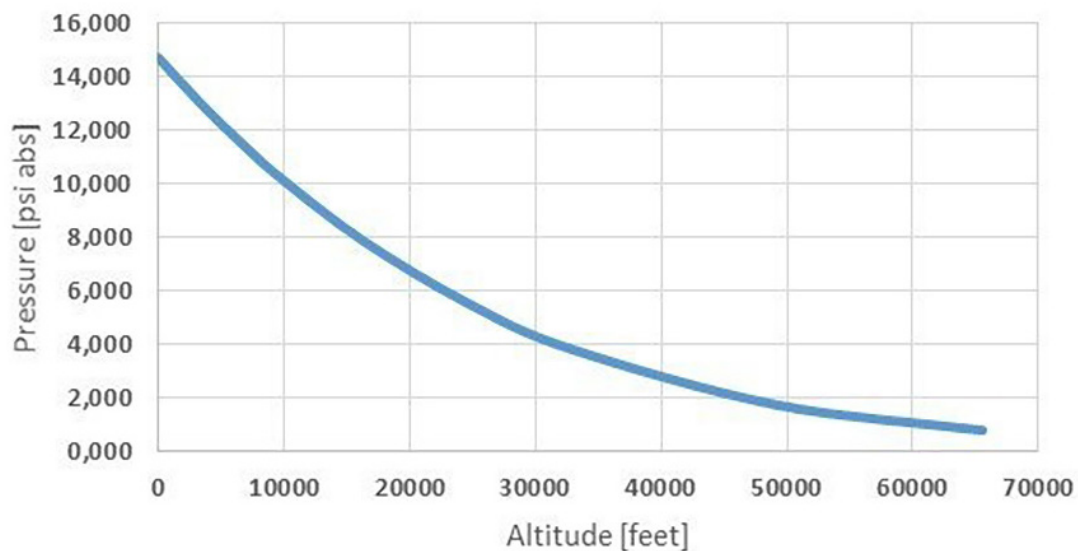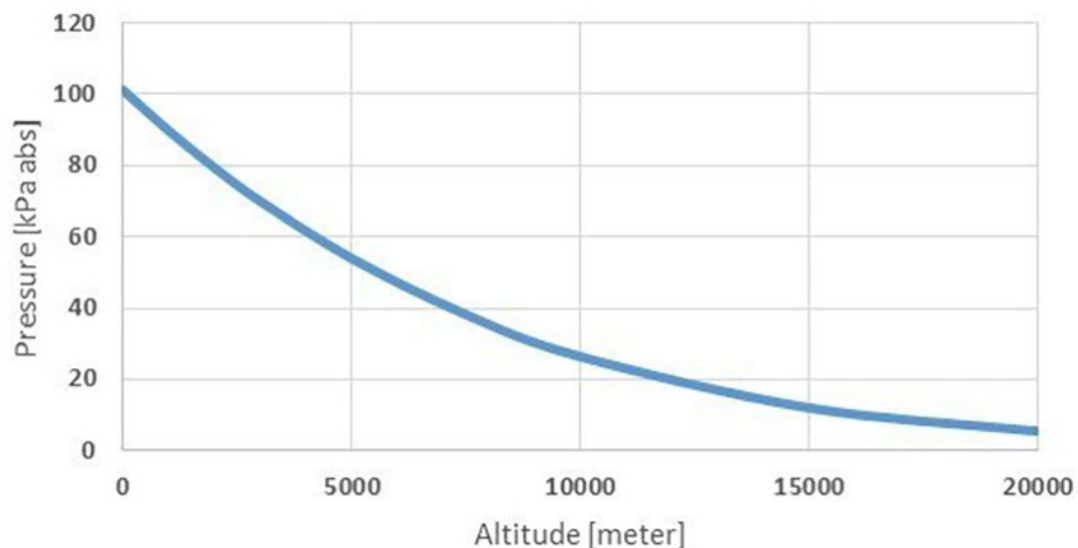
Barometric (atmospheric) pressure units

There are a few pressure units that have been created specifically to measure barometric pressure. One of these units is standard atmosphere (atm), which equals 101,325 pascal. There is also a unit called technical atmosphere (at), which is not exactly the same as atm (1 at = 0.968 atm).

Torr is also used to measure barometric pressure. It was originally equal to a millimeter of mercury, but later was defined slightly differently. Some SI units are also used, such as hPa (hectopascal), kPa (kilopascal), and mbar (millibar).

It is important to remember that we always talk about absolute pressure when we talk about barometric pressure.

Some practical considerations

We can easily feel the change in barometric pressure when we travel in an airplane. Even though there is pressure generated inside the airplane, the pressure still drops as the plane goes higher. You can especially feel the growing pressure in your ears as the plane starts to land and comes to a lower altitude. The change is so rapid that your ears do not always settle fast enough.

You may have also noticed how a yogurt cup is somewhat swollen when you are up in the air. The cup swells because it was sealed on the ground at a normal barometric pressure. As the plane ascends, the pressure inside the plane cabin decreases, causing the swelling because the pressure inside the cup is higher. Some people can feel the change in the barometric pressure in their bodies, experiencing headaches or aching in their joints.

Calibrations under control

Pressure Units and Pressure Unit Conversion

It's a jungle out there! There are a lot of different pressure units in use around the world, and sometimes this can be very confusing and may cause dangerous misunderstandings. Here we will look at the basics of different pressure units and different pressure unit families.

What is pressure?

Pressure in this article does not refer to the stress you may be suffering in your work, but to the physical quantity. It is good to first take a quick look at the definition of pressure; this will also help us better understand some of the pressure units.

Most of us probably don't remember our studies of physics in school, so a short reminder is in order. Pressure is defined as force per area perpendicular to the surface. That is often presented as the formula $p = F/A$. Pressure is indicated with the letter "p," although capital letter "P" is also used on some occasions.

So what does this force per area mean in practice? It means that there is a certain force affecting a specified area. When we look at force, it is specified as mass × gravity. Because there are so many different engineering units used for both mass and area, the number of combinations of these is huge. Plus there are also a lot of pressure units that do not directly have mass and area in their names, even though it is in their definition.

Notice that in practice the "force" is not always included in the pressure unit names. For example, pressure unit kilogram force per square centimeter should be indicated as kgf/cm², but often it is indicated just as kg/cm² without the "f". Similarly, pound force per square inch (pfsi) is normally indicated as pounds per square inch (psi).

International System of Units/metric

Let's start to look at the pressure units by looking at the International System of Units (SI from the French Système international d'unités), derived from the metric system. Now that I mentioned the metric system, I can already see some of you taking a step back . . . but please stay with me! SI is the world's most widely used system of measurement. It was published in 1960, but had a very long history even before that.

SI unit of pressure

For pressure, SI's basic unit is pascal (Pa), which is N/m² (newton per square meter, while newton is kgm/s²). As a formula:

$$Pa = \frac{N}{m^2} = \frac{kg}{m \times s^2}$$

Pascal is a very small pressure unit; for example, the standard atmospheric pressure is 101,325 Pa absolute. Out of pascal's definition, the kg force can be replaced with different units like g (gram) force, and meter can be replaced with centimeter or millimeter. By doing that, we get many other combinations or pressure units, such as kgf/m², gf/m², kgf/cm², gf/cm², kgf/mm², gf/mm², just to list a few.

The unit "bar" is still often used in some areas. It is based on the metric system but is not part of SI. Because bar is 100,000 times pascal (100 times kPa), it is easy to convert. Some areas (like the National Institute of Standards and Technology in the U.S.) do not recommend using bar widely.

As we can for all pressure units, whether SI or not, we can use the common prefixes/coefficients in front of them. The most commonly used are milli (1/100), centi (1/10), hecto (100), kilo (1,000), and mega (1,000,000). To list a few examples, these different Pa versions are all commonly used: Pa, kPa, hPa, MPa. The unit bar is most commonly used without prefix or with the prefix milli: bar, mbar. But combining all mass units with all area units from SI gives us many combinations.

Although SI is used in most countries, there are still many other pressure units also being used. We will take a look at those next.

Imperial units

In countries using the Imperial system (like the U.S. and U.K.), the engineering units used for both mass and area are different from those used in the international system. Therefore, there is a whole new set of pressure units. Mass is commonly measured in pounds or ounces, and area and distance with inches or feet.

Some pressure units derived from these are lbf/ft², psi, ozf/in², iwc, inH$_2$O, and ftH$_2$O.

In the U.S., the most common pressure unit is pounds per square inch (psi). For process industries, a common unit is also inches of water (inH$_2$O), which is derived from level

measurement and the historical measurements of pressure differences with water in a column.

Liquid column units

The older pressure measurement devices were often made by using liquid in a transparent U-tube. If the pressure in both ends of the tube is the same, the liquid level in both sides are on the same level. But if there is a difference in the pressures, then there is a difference in the liquid levels. Level difference is linearly proportional to the pressure difference. In practice you can leave one side of the tube open to the room's atmospheric pressure and connect the pressure to be measured to the other side. Because it refers to the current atmospheric pressure, this is a gauge pressure type being measured.

The pressure scale is marked in the tube, so you read the pressure by reading the difference in liquid levels. When pressure is applied it will change the liquid level, and we can read the value. This sounds very simple, no electronics and no wearing parts, so what could possibly go wrong? Well, let's see about that.

The most commonly used liquid in the column is obviously water. But to be able to measure higher pressure with smaller U-tubes, heavier liquids are needed. One such liquid is mercury (Hg), as it is much heavier than water (13.6 times heavier). When you use heavier liquid you do not need to have that long column to measure higher pressure, so you can make a smaller and more conveniently sized column. For example, blood pressure was once (and still sometimes is) measured with a mercury column. Mercury is mainly used because a water column for the same pressure range would be so long it would not be practical to use in a normal room, because a water column is about 13.6 times longer than a mercury column. As a result of this, even today the pressure unit in which blood pressure is typically expressed is millimeter of mercury (mmHg).

A common industrial application for use of liquid column pressure units is to measure the liquid level in a tank. For example, if you have a water tank that is 20 feet (or 6 meters) high and you
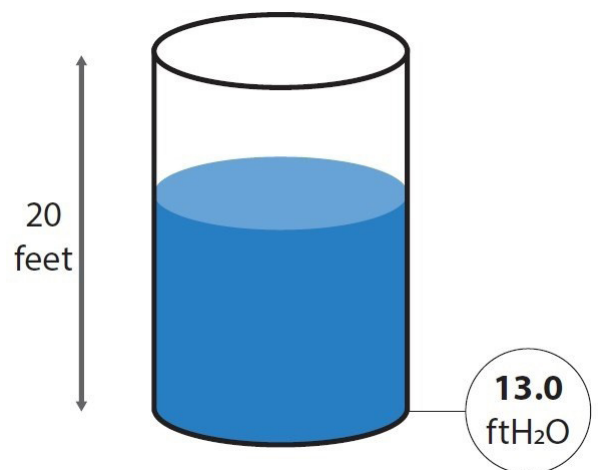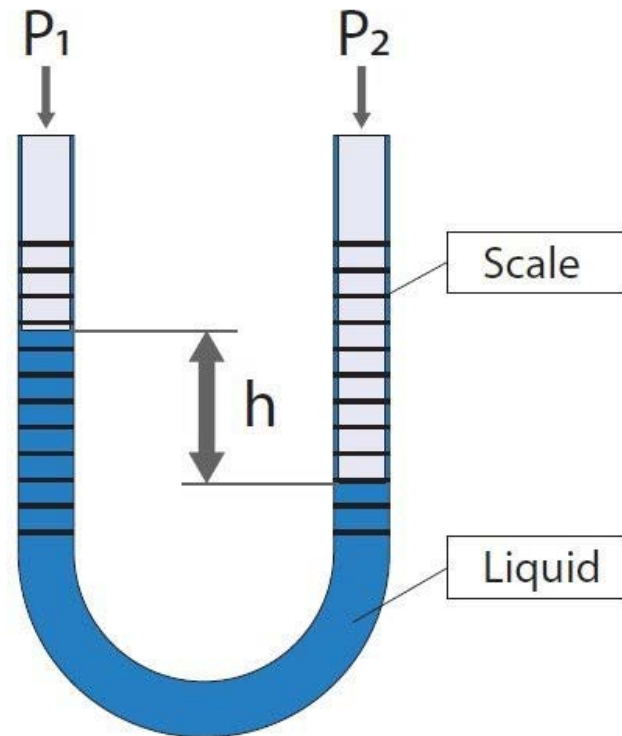
want to measure the water level in that tank, it sounds pretty logical to install a pressure indicator with a scale of 0 to 20 feet of water, which would tell straight what the water level is (13 feet in the example picture).

Back to the water column: It is clear that when the length indication has been made to a U column, many different length units have been used, both metric and nonmetric. This has generated many different pressure units.

Although a liquid column sounds very simple, it is important to remember that the weight of the liquid depends on the local gravity, so if you calibrate the column in one place and take it to another (distant, different elevation) place, the measurement may not be correct anymore. So you need to make a gravity correction to be precise.

Also, the temperature of the liquid affects the density of the liquid, and that also slightly affects the readings of a U-tube. There are various different liquid column–based pressure units available, where the liquid temperature is specified in the pressure unit. The most commonly used temperatures are 0 °C, 4 °C, 60 °F, and 68 °F.

But there are also water column units, which have no indication of the water temperature. These are based on a theoretical density of water at 1 kg/1 liter (ISO 31-3, BS 350). In practice, the water never has that high density. The highest density that water has is at +4 °C (39.2 °F), where it is approximately 0.999972 kg/liter. The density of water gets lower if the temperature is higher or lower than +4 °C. Temperature can have a pretty strong effect on the density, for example going from +4 °C to +30 °C changes the water density about 0.4 percent.

Finally, the readability of a mechanical liquid column is typically pretty limited, so you cannot get very accurate measurements. And due to the mechanical limitations, you cannot use a U-tube for high pressure. All of these above mentioned issues make a U-tube liquid column not very practical to use. Also, modern digital pressure measurement devices have replaced the liquid columns. But many of the pressure units created in the era of liquid columns have remained and are still used today. To shortly summarize liquid column–based pressure units:

- There are columns for different liquids, like water (H_2O) and mercury (Hg).
- For the length we have many units: mm, cm, m, inch, and feet
- There are water column units for different density at temperatures like 0 °C, 4 °C, 60 °F, and 68 °F and for theoretical densities.

By combining all of these, we get a long list of pressure units, to mention a few: mmH_2O, cmH_2O, mH_2O, mmHg, cmHg, mHg, iwc, inH_2O, ftH_2O, inHg, $mmH_2O@4°C$, $mmH_2O@60°F$, $mmH_2O@68°F$, $cmH_2O@4°C$, $cmH_2O@60°F$, $cmH_2O@68°F$, $inH_2O@60°F$, $inH_2O@68°F$, $inH_2O@4°C$, $ftH_2O@60°F$, $ftH_2O@68°F$, $ftH_2O@4°C$.

Atmospheric units

For measurement of the atmospheric absolute pressure, there are dedicated pressure units. One is the standard atmosphere (atm), which is defined as 101,325 pascal. To add confusion, there is also a technical atmosphere (at), which is pretty close to, but not quite the same as atm. The technical atmosphere is 1 kilogram force per square centimeter. So at 1, it equals about 0.968 atm.

Another pressure unit used for measuring atmospheric absolute pressure is torr, which is 1/760

of standard atmosphere. Torr is an absolute pressure, although that is typically not mentioned; you just need to know it, which can cause confusion. Torr was initially meant to be the same as 1 millimeter of mercury, although the later definitions show a very small difference. Torr is not part of SI.

cgs unit of pressure

The abbreviation "cgs" comes from "centimeter-gram-second." As these words hint, the cgs system is a variation of the metric system, but instead of using meter it uses centimeter as the unit for length, and instead of kilogram it uses gram as the unit for mass. Different cgs mechanical units are derived from using these cgs base units.

The cgs is a pretty old system and has been mostly replaced. It was replaced by the MKS (meter-kilogram-second) system, which was then replaced by the international system. Yet, you still sometimes run into cgs units of pressure. The cgs base pressure unit is barye (Ba), which equals 1 dyne per square centimeter. Dyne is the force needed to accelerate a mass of one gram to a rate of 1 centimeter per second per second. As a pressure unit conversion, 1 barye (Ba) equals 0.1 pascal (Pa).

Pressure unit conversions standards

If you work with pressure, you know it is very common for a pressure to be indicated with one pressure unit that you need to convert into another pressure unit. Pressure units are based on standards, and the conversion between units should also be based on standards. Most common standards for pressure units are:

- International System of Units (SI)
- ISO 31-3
- ISO 80000-4:2006
- BS 350
- PTB-Mitteilungen 100 3/90
- Perry's Chemical Engineer's Handbook, 6th ed, 1984

Online pressure unit converter

With this converter you can easily convert a pressure reading from one unit into other units.

www.beamex.com/resources/pressure-unit-converter/

Calibrating a Square Rooting Pressure Transmitter
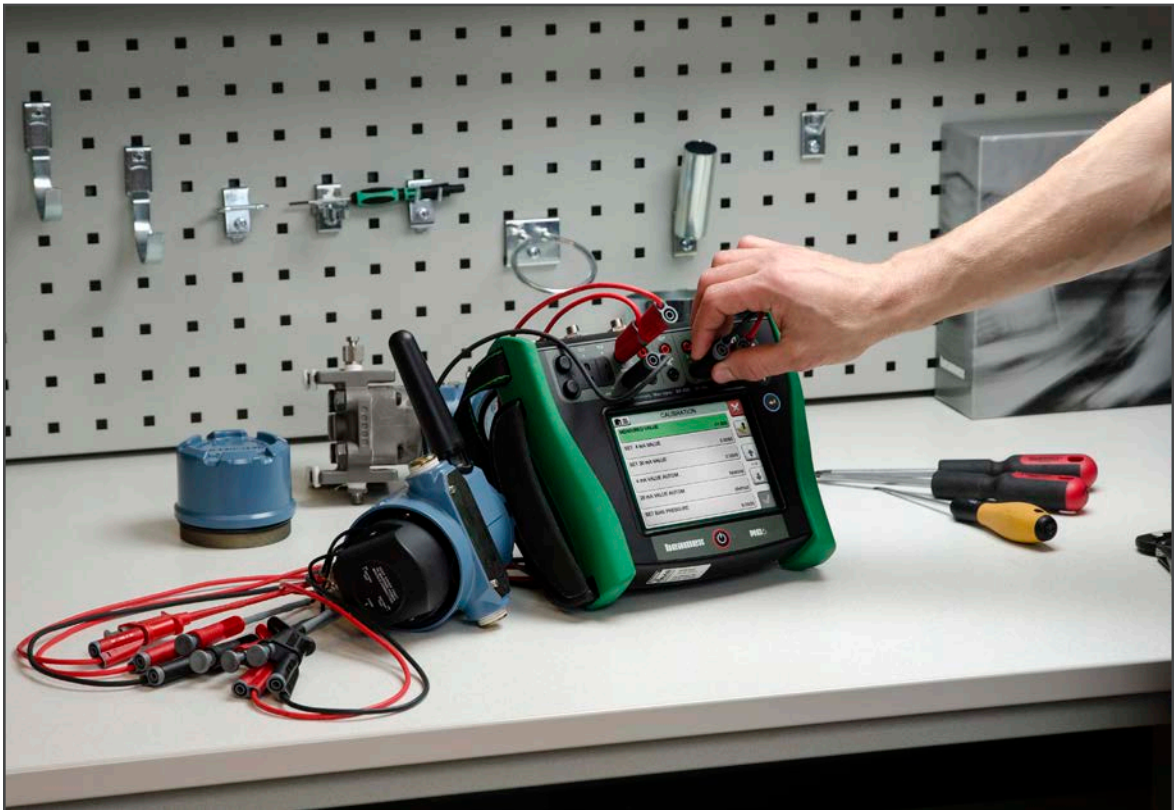
There are a lot of questions regarding the calibration of a square rooting pressure transmitter. Most often the concern is that the calibration fails too easily at the zero point. There is a reason for that, so let's find out what that is.

First, when we talk about a square rooting pressure transmitter, it means a transmitter that does not have a linear transfer function; instead, it has a square rooting transfer function. When the input pressure changes, the output current changes according to a square rooting formula. For example, when the input is 0 percent, the output is 0 percent of the range, just as when input is 100 percent, output is 100 percent. But when the input is only 1 percent, the output is already 10 percent, and when the input is 4 percent, output is 20 percent. The image on page 19 explains this graphically.

So, when would you use that kind of transmitter? It is used when you are measuring flow with a differential pressure transmitter. If you have some form of restriction structure (orifice/venturi) in your pipe, the bigger the flow is, the more pressure is generated over that structure. When the flow grows, the pressure does not grow linearly; it grows with a quadratic correlation.

If you want to send a mA signal to your control room, you use a square rooting pressure transmitter that compensates for the quadratic correlation—and as a result, you have a mA signal that is linear to the actual flow signal. You could also use a linear pressure transmitter and make the conversion calculation in your distributed control system; ISO 5167 gives more guidance.

So, what about when you start calibrating this kind of square rooting transmitter?

You can, of course, calibrate it in a normal way, by injecting a known pressure to the transmitter's input and measuring the mA output. Anyhow, you should remember that the output current does not change linearly when the input pressure changes. Instead, the mA output grows according to the rooting transfer function. This means that in the beginning, when you are at zero input and you have 4 mA output, the transfer function is very steep. Even the smallest change in the pressure will cause the output to change a lot. I have illustrated this in the simple figure below. The red curve shows the transfer function of a square rooting transmitter, and the blue line shows the function of a linear transmitter.

In practice, this means that if your input pressure measurement fluctuates just one or a few digits, the output should change a lot in order for the error to be zero. What happens is that if the measured values fluctuate even in the least significant digit, the error calculation will say that the point fails. In practice, it is just about impossible to make that zero point a "pass" calibration point within the allowed tolerance.
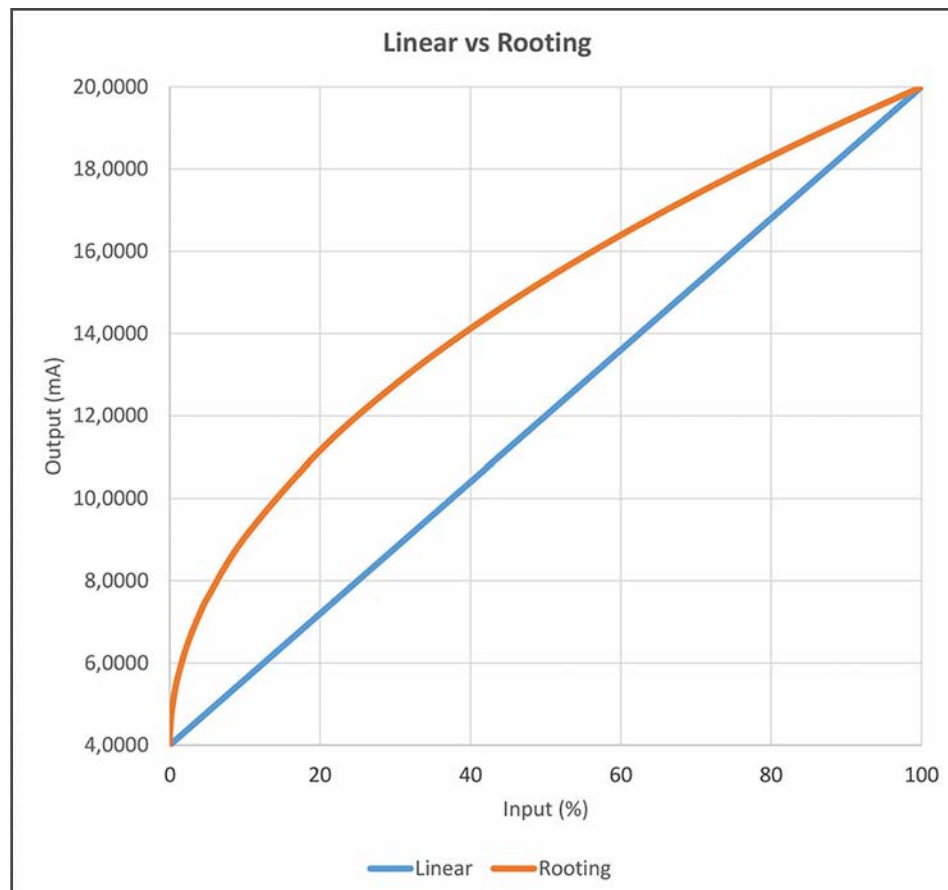
Figure 1. Linear versus square rooting

So what to do? To calibrate, you should simply move the first calibration point a bit higher than 0 percent of the input range. If the first calibration point is at 5–10 percent of the input range, you are already out of the steepest part of the curve, and you can get reasonable readings and error calculation. Of course, then you do not calibrate the zero point, but your process is normally not running at zero point either.

How to calculate the output?

Use the formula below to calculate what the output current should be at a given input point:

Where:

O_{ideal} is the theoretical output value at the measured input for a calibration point (I).

I is the measured input for a calibration point.

I_{zero} is the theoretical input value at input 0 percent.

I_{fs} is the theoretical input value at input 100 percent (full scale).

O_{fs} is the theoretical output value at output 100 percent (full scale).

O_{zero} is the theoretical output value at output 0 percent.

$$O_{ideal} = \sqrt{\frac{(I - I_{zero})}{(I_{fs} - I_{zero})}} \; x \; (O_{fs} - O_{zero}) + O_{zero}$$

Pressure Transmitter Accuracy Specifications: The Small Print

Environment Temperature

Power Supply

Vibration

Mounting Position

Long-term Stability

Pressure Transmitter Accuracy

Reference Accuracy

Pressure Range

Re-ranging

Static (line) Pressure

Media Temperature

Pressure transmitters are widely used in the process industry, and the advertised accuracy specification of modern pressure transmitters has become more and more accurate. However, often the advertised accuracy specification is only part of the truth. It includes only some of the accuracy components affecting the total transmitter accuracy that you can expect in practice in your application.

This article will examine some popular pressure transmitters' accuracy specifications and the different accuracy components, such as the effects of re-ranging, ambient temperature, mounting position, static pressure, long term drift, vibration, power supply, and more.

Later we will explain what these components are and what they mean with a few examples.

Background

We see "number games" being played with some transmitters' specifications, where the advertised accuracy number is just part of the truth, i.e., it is just one of the many accuracy components that you should consider. In some cases, these advertisements are confusing and give the wrong impression of the total practical accuracy you will get in your application.

Maybe the competition and race for the best accuracy numbers have led to this situation, where some manufacturers make a "limited" accuracy figure and put that on the cover of the brochure and advertise that on their website, while the full specifications are found in the user manual.

Typically, a pressure transmitter's specifications include several accuracy components that you

should take into account when considering the total accuracy. As mentioned, this article will review some popular pressure transmitter's specifications to give you an idea of the kind of important factors you should consider and be aware of. Also, it will list some typical specification numbers for the different partial accuracy components. This content is by no means trying to put down or depreciate any transmitter.

Because the transmitter accuracy affects the accuracy of your calibration equipment, we do get these accuracy questions from customers. Certainly, the calibrator should be more accurate than the transmitter you calibrate with it, but different people have different opinions on the accuracy ratio between these two. Anyhow, you should be aware of the total uncertainty of the calibration and document that during the calibration.

The selection of your process transmitter's tolerance should be based on the process requirements, not on the specifications of the transmitter that is installed in that location.

Time to dive in.

Pressure transmitter accuracy components

Reference accuracy

Often there is a separate, "limited" accuracy statement, typically on the cover of the brochure or on the website. This may be called "reference accuracy" or something similar; it includes only some parts of the accuracy, not all parts. It includes, for example only linearity, hysteresis, and repeatability.

This "best-case accuracy" does not include all the practical accuracy components you should consider (mounting position, ambient temperature, etc.). So, do not think that this specification is what you can expect in practice from the transmitter when you install it in your process. This "best-case accuracy" may be, for example, 0.04 percent or even 0.025 percent of range for the most accurate pressure ranges for the most accurate transmitters.

Different pressure ranges

Often the best (reference) accuracy is valid only for certain pressure ranges, not for all the ranges available. Also, it may vary on the pressure type, i.e. an absolute range may be different than a gauge range.

While the best ranges can have, say even a 0.04 percent of range accuracy, some other range of that same transmitter model may have, for example, a 0.1 percent accuracy.

Accuracy specifications may be doubled or tripled for the different pressure ranges available. So, make sure you know what the accuracy is for the exact pressure ranges/models that you are using.

Re-ranging

HART (smart) transmitters can be re-ranged with a wide ratio. Often you can re-range a transmitter with a turndown ratio of 100:1 or even more. Accuracy specifications are commonly given to the full range, or with a limited turndown ratio.

If the HART transmitter (with a mA output) is re-ranged for a smaller range than the full range, the

accuracy typically worsens. So, if you re-range your transmitter to a smaller range than the max range, please make sure you find out how much error that adds to the accuracy.

Ambient temperature effect

Most pressure transmitters are used in varying environmental conditions in the processes. Also, the temperature of the pressure media may vary widely during usage. Like most measurement devices, pressure transmitters typically have some kind of temperature coefficient, i.e., there is an accuracy component that depends on the environmental temperature.

The temperature dependency often seems to be specified in a pretty difficult-to-understand format. But try to understand it, and ask the supplier if you cannot figure it out.

Anyhow, looking at different transmitters, this value may vary from say 0.01 percent of range to even up to 0.5 percent of range. The worst models seem to specify the temperature effect as more than 1 percent of the range.

If the temperature in your process varies a lot, you should take this into account.

Static (line) pressure effect

Differential pressure transmitters can be used under static line pressure conditions. This means that both inputs have a certain pressure, and the transmitter is measuring the difference between the two inputs. Compare this to a gauge transmitter that measures pressure against the atmospheric pressure or an absolute transmitter that measures pressure against full vacuum.

An ideal differential transmitter would measure only the difference between the inputs, but in practice, the common-mode static line pressure has some effect on the output.

If you have both inputs open to atmospheric pressure, the differential pressure is naturally zero. Also, if you have the same pressure (say 50 bar/psi) applied to both inputs, the differential pressure is still zero. In practice, that static pressure has some effect on the transmitter output. So, the output changes a little when the line pressure changes. Typically, the line pressure effect can go from 0.025 percent of range up to 0.4 percent of range, depending on the transmitter model.

Commonly, the line pressure mainly changes the zero of the transmitter, but does not make a significant change to the span. So, in calibration, you can test this effect by applying the same pressure (a low pressure and a high pressure) to both inputs and see how much the zero changes.

Line pressure may also have some effect on the span of the transmitter, which makes it far more difficult to handle and to calibrate. It requires a differential pressure standard for the calibration.

Long-term stability

All measurement devices will slowly lose their accuracy over time. Some more, some less. That also goes for pressure transmitters.

Some pressure transmitters specify a one-year stability; some have a five- or 10-year specification, or even longer. For example, a transmitter that has a reference accuracy of 0.04 percent of range can have one-year stability of 0.2 percent of range. Some other models have a

similar 0.2 percent of range level of specification valid for five or even 10 years. The best one I found was as low as 0.01 percent of range as a one-year stability.

Depending on how often you recalibrate your pressure transmitters, you should consider the long-term stability effect, as the transmitter may drift that much before the next recalibration (and possible trim).

Mounting position (orientation) effect

The mounting position typically has some effect on the accuracy of the pressure transmitter. Most pressure transmitters have a specification for the mounting position.

Typically, a change in the orientation changes the zero and does not affect the span accuracy. In practice, the orientation of the transmitter does not change during normal usage. The orientation should, however, be considered if you first calibrate the transmitter in a workshop and then install it to the process, or if you remove the transmitter from the process for recalibration.

Certainly, if a transmitter has a remote seal, the location of the capillary tubes will have a big effect on zero value. Again, this is something that does not change during normal usage, but it may affect the calibration if the transmitter is removed from its install location.

Vibration effect

Many pressure transmitters have a specification for the effect of vibration. Naturally, this needs to be considered only if the transmitter is installed in a vibrating location.

The vibration effect to accuracy is often relatively small and can be, for example, specified as being "less than 0.1 percent of range."

Power supply effect

A two-wire transmitter needs an external power supply to work. Typically, the power supply is a 24 VDC supply. Transmitters can commonly work on a wide supply voltage range, going even down to 10 VDC.

A supply voltage change during the operation can have a small effect on the accuracy of the transmitter.

The effect of the power supply voltage is typically small and can be specified as being "smaller than 0.01 percent of span per 1 volt change," for instance.

In practice, if you have a normal good power supply, this is not an issue.

Total accuracy specification

Some transmitters have some kind of "total accuracy" specification that includes several of the common accuracy components. This can include the earlier mentioned "reference accuracy," the ambient temperature effect, and the static/line pressure effect. This kind of total accuracy has a more user-friendly value, as it is closer to the real accuracy you can expect from a transmitter. As an example, the "total accuracy" specification can be 0.14 percent of range, while the reference is 0.04 percent.

So as soon as you include the temperature and line pressure effects, the reference accuracy is multiplied by a factor of 3 to 4.

Another example model offers a 0.075 percent of range reference accuracy, and when the temperature effect is included, it increases to 0.2 percent. When static pressure effects are also included, it goes up to 0.3 percent of range.

If the transmitter has this kind of "total" accuracy specification, it helps you to get a more realistic picture of what kind of accuracy you can expect in practice. Even though the "total" accuracy is often still missing, some accuracy components are listed here.

Contamination in usage

When a pressure transmitter is used in a process to measure pressure, there is a big risk of the pressure media or some dirt contaminating the transmitter's membrane. This kind of contamination can have a huge effect on the transmitter's accuracy.

This is, of course, not something that can be specified, but is anyhow a big risk in normal use, especially if you decide to have a very long recalibration period, such as several years. So, in addition to the transmitter's long-term drift specification, this should be considered in the risk analysis.

If the transmitter gets very dirty and starts to measure significantly incorrectly, you will normally see that in the measurement results. But if it only starts to measure a slightly incorrectly, it is difficult to notice in normal usage.

Best-case and worst-case examples

When you add up all the different accuracy specifications listed above, you come to the real total accuracy specification you can expect in practice. Generally, when you combine independent uncertainty components, the common rule is to use the "root sum of the squares" (RSS) method. Just adding all components together as a straight sum would be a worst-case scenario, and statistically it is not very likely that all components will be in the same direction at the same time. Therefore, this statistical RSS method is used.

To get a best-case summary, take all the smallest accuracy components and neglect the ones that may not be relevant. For the worst-case scenario, take all the accuracy components as their max and assume they are all present.

After reviewing the specifications for several different transmitters, the smallest combined accuracy I can find takes me down to about 0.15 percent of range. For most other models it seems that the best case is double that, so about 0.3 percent of range at best.

There are also many models that have bigger best-case accuracy.

Best-case accuracy

To get the best-case accuracy, the following assumptions were used:

- Pick the best reference accuracy.
- Choose the most accurate model and range.
- Do not do any re-ranging ➡ no effect on the accuracy.
- Use the transmitter in a limited temperature range, close to ambient temperature. Pick the smallest available temperature effect.
- Assume no static/line pressure effect (used for gauge measurement) ➡ no effect.
- Assume no vibration effect ➡ no effect.
- Assume a good power supply ➡ no effect.
- Include a one-year drift.

Again, looking at the different specifications, it seems that adding these worst-case accuracy specifications brings us somewhere around **1 percent to 1.5 percent** of range accuracy with the most accurate transmitters. But this figure can also go higher with some models.

Worst-case accuracy

To find the worst-case accuracy, the following assumptions were used:

- Pick a model/pressure range with the biggest accuracy specification.
- Assume some re-ranging happens.
- Use the range with bigger temperature effect.
- Assume static/line pressure is being used.
- Assume a small vibration effect.
- Assume a small power supply effect.
- Include a one-year drift.

Accuracy in practice

As mentioned earlier, modern pressure transmitters are very accurate instruments. However, it is good to read the accuracy specifications carefully, including all the different components that affect accuracy. It is easy to miss these and just look at the one accuracy (e.g., "reference accuracy") that is shown in marketing and other materials.

The purpose of this article is to raise your awareness about the different things that have an effect on the total accuracy that you can expect in practice. Of course, the same goes for all measurement equipment, not only for pressure transmitters. It is always good to read all specifications, including all the footnotes with small print.

How to Calibrate Pressure Gauges: 20 Things to Consider

Pressure gauges are very common instruments in the process industry. As with any measurement device, pressure gauges need to be calibrated at regular intervals to ensure they are accurate.

There are many things to consider when calibrating pressure gauges.
This article lists 20 things you should consider when calibrating pressure gauges:

20 things you should consider

1. Accuracy classes
2. Pressure media
3. Contamination
4. Height difference
5. Leak test of piping
6. Adiabatic effect
7. Torque force
8. Calibration/mounting position
9. Generating pressure
10. Pressurizing/exercising the gauge
11. Reading the pressure value (resolution)
12. Number of calibration points
13. Hysteresis (direction of calibration points)
14. "Tapping" the gauge
15. Number of calibration cycles (repeatability)
16. Adjustment/correction
17. Documentation – calibration certificate
18. Environmental conditions
19. Metrological traceability
20. Uncertainty of calibration (TUR/TAR)

What is pressure?

Before we discuss each of the things to consider when calibrating pressure gauges, let's take a quick look into a few more basic concepts. Pressure is the force that is perpendicular to the surface divided by the area it is affecting. So, pressure equals force per area, or $p = F / A$.

There are many different pressure units used around the world, and this can be sometimes very confusing. The engineering unit for pressure, according to the SI system, is Pascal (Pa), being a force of one Newton per one square meter area, $1\ Pa = 1\ N/m^2$. Because Pascal is a very small unit, it is most often used with coefficients, such as hecto, kilo, and mega.

Pressure types

Several different pressure types exist, including gauge, absolute, vacuum, differential, and barometric. The main difference between these pressure types is the reference point against which the measured pressure is being compared. Pressure gauges are also available for all these pressure types. Also, compound gauges are available, including a combined scale for both positive gauge pressure and vacuum (negative gauge) pressure.

Pressure gauges

When talking about pressure gauges, it is normal to refer to analog pressure indicators that are provided with a pointer needle and a pressure scale. These are normally manufactured according to the EN 837 or ASME B40.100 standards. Often these kinds of analog pressure gauges are built with a Bourdon tube, diaphragm, or capsule. There is a mechanical structure that moves the pointer as pressure increases, causing the pointer to move across the scale.

Pressure gauges are divided into different accuracy classes that specify the accuracy of the gauge as well as other attributes. Available pressure ranges are typically divided in steps with coefficients 1, 1.6, 2.5, 4, 6 continuing into the next order of magnitude (10, 16, 25, 40, 60) and so on. The different gauge diameters (of scales) are typically 40, 50, 63, 80, 100, 115, 160, and 250 mm (1½, 2, 2½, 4, 4½, and 6 inches). More accurate gauges typically have a bigger diameter.

Pressure connectors are normally parallel pipe threads (G) according to ISO 228-1, or taper pipe threads (NPT) according to ANSI/ASME B1.20.1.

There are also digital pressure gauges that have a numeric pressure indication instead of an analog pointer. This article focuses on analog gauges, but most of the principles are valid for both.

Pressure gauges are commonly used in all industries and are a very common instrument to calibrate. As with any process measurement device, they should be calibrated at regular intervals to make sure that they are measuring correctly. Gauges are mechanical instruments, which adds to the risk for them to drift due to mechanical stress.

For more general information on why you should calibrate instruments, please see the blog post Why calibrate? For more information on how often instruments should be calibrated, please see post How often should instruments be calibrated?

The basic principle of calibration

If we simplify the principle of pressure gauge calibration to its minimum, we can say that when we calibrate a pressure gauge, we provide a known accurate pressure input and read the indication on the gauge, and then document and compare them. The difference in the values is the error, and the error should be smaller than the required accuracy for the gauge.

This section lists the 20 most common things you should consider when you are calibrating pressure gauges.

20 things you should consider

1 Accuracy classes

Pressure gauges are available in many different accuracy classes. Accuracy classes are specified in the ASME B40.100 (accuracy classes from 0.1–5 percent range) and EN 837 (accuracy classes from 0.1–4 percent range) standards. The accuracy class specification most often being "percent of range" means that if the accuracy class is 1 percent and if the scale range is zero to 100 psi, then the accuracy is ±1 psi. Make sure you know the accuracy class of the gauge you are going to calibrate, as this will naturally specify the acceptable accuracy level, but it will also have other effects on the calibration procedure.

2 Pressure media

When calibrating pressure gauges, the most common pressure media are gas or liquid. Gas is most often regular air, but in some applications, it can be different gases, such as nitrogen. Most commonly, the liquid is water or oil. The pressure media during the calibration depend on the media that is used in the process that the gauge is connected to. Media also depend on the pressure range. Low pressure gauges are practical to calibrate with air/gas, but as the pressure range gets higher it is more practical and also safer to use liquid as the media.

3 Contamination

While installed in a process the pressure gauge uses a certain type of pressure media; this should be considered when selecting the media for the calibration. You should not use a media during the calibration that could cause problems when the gauge is installed back to the process. Also, the other way around, sometimes the process media could be harmful to your calibration equipment.

Dirt inside the gauge can get into the calibration equipment and cause harm. With gas-operated gauges, you can use a dirt/moisture trap, but for a liquid-operated gauge, you should clean the gauge prior to calibration.

One of the most extreme process situations is if the gauge is used to measure the pressure of oxygen. If any grease goes into a high-pressure oxygen system during the calibration of the gauge, it can be very dangerous and could cause an explosion.

4

Height difference

If the calibration equipment and the gauge to be calibrated are at different heights, the hydrostatic pressure of the pressure media in the piping can cause errors. This normally is not an issue when gas is used as the media, as gas is light compared to liquid. But when liquid is used as the media, the liquid in the piping will have a weight due to hydrostatic pressure and can cause errors. The magnitude of the error depends on the density of the liquid and the
difference in height, because gravity is pulling the liquid inside the tubing. If it is not possible to have the calibrator and gauge at the same height, then the effect of the height difference should be calculated and taken into account during the calibration.

An example of the effect of hydrostatic pressure:

Hydrostatic pressure is calculated as follows: $$Ph = p \times g \times h$$

Where:

Ph   is the hydrostatic pressure
p   is the density of liquid (kg/m³)
g   is the local gravity (m/s²)
h   is the height difference (m)

For example, if water is the media (density 997.56 kg/ m³), local gravity is 9.8 m/s², and there is a 1 meter (3.3 feet) difference between the DUT and the reference equipment, this will cause an error of 9.8 kPa (98 mbar or 1.42 psi).

Note that depending on the pressure to be measured, the error caused by the height difference can be significant.

5

Leak test of piping

If there are any leaks in the piping during the calibration, unpredictable errors can occur. Therefore, a leak test should be done before calibration. The simplest leak test is to pressurize the system, let the pressure stabilize for some time, and monitor that the pressure does not drop too much. Some calibration systems (pressure controllers) may be able to maintain the pressure even in case of a leak, if there is a continuous controller adjusting the pressure. In that case, it is difficult to see a leak, so the controller should be closed to enable a closed system for a leak test. Adiabatic effect should also always be considered in closed systems, especially with gas media, as explained in the next item.

6

Adiabatic effect

In a closed system with gas as the pressure media, the temperature of the gas effects the volume of the gas, which has an effect on the pressure.

When pressure is increased quickly, the temperature of the gas will rise, and this higher temperature makes the gas expand, so it has a bigger volume and higher pressure. When the temperature starts to cool down, the volume of the gas becomes smaller, and this will cause the pressure to drop. This pressure drop may seem like a leak in the system, but it is actually caused by the adiabatic effect due to the change in the gas temperature. The faster the pressure is changed, the bigger the effect is. The pressure change caused by this effect will gradually get smaller as the temperature stabilizes. So, if you change the pressure quickly, make sure you let it stabilize before judging whether or not there is a leak in the system.

7

Torque force

Especially for torque-sensitive gauges, do not use excessive force when connecting pressure connectors to the gauge, as it may damage the gauge. Follow the manufacturer's instructions for the allowed torque force. Take the time to use proper tools and appropriate adapters and seals.

8

Calibration/mounting position

Because pressure gauges are mechanical instruments, their position will affect the reading. Therefore, calibrating the gauge in the same position as it is used in the process is recommended. The manufacturer's specifications for the operation/mounting position should also be taken into account.

A typical specification for a mounting position is that a change of 5 degrees in position should not change the gauge indication by more than half (0.5 times) of the accuracy class.

9

Generating pressure

To calibrate a pressure gauge, you need to source the pressure applied to the gauge. There are different ways to do that: you can use a pressure hand pump, a pressure regulator with a bottle, or even a dead weight tester. A dead weight tester will provide a very accurate pressure, and you do not need a separate calibrator to measure the pressure, but a dead weight tester is expensive, not very mobile, requires a lot of attention to use, and is sensitive to dirt. It is more common to use a pressure calibration hand pump to generate pressure and an accurate pressure measurement device (calibrator) to measure the pressure. A pressure controller can also be used to supply the pressure.

10

Pressurizing/exercising the gauge

Due to its mechanical structure, a pressure gauge will always have

The left indicator in the picture is difficult to read accurately, because the indicator is between scale marks. The one on the right is easy to read, since the applied pressure is adjusted so that the pointer is exactly on a scale mark.

To get an accurate reading, it is important to look at the gauge perpendicularly/straight.

some friction in its movement, and may change its behavior over time; therefore you should exercise it before calibration. This is especially the case if the gauge has not been applied with pressure for a while. To exercise, supply the nominal max pressure and let it stay for a minute, then vent the pressure and wait a minute. You should repeat this process two or three times before starting the actual calibration cycle.

11 Reading the pressure value (resolution)

The scale in pressure gauges has limited readability. It has major and minor scale marks, but it is difficult to accurately read the pressure value when the indicator is in between the scale marks. It is much easier to see when the needle is exactly at a scale mark. Therefore, the recommendation is to adjust the input pressure so that the needle is exactly at an indication mark, and then record the corresponding input pressure. If you just supply a certain accurate input pressure and then try to read the indicator, it will cause errors due to limited reading accuracy.

Also, it is important to look at the indication perpendicular to the gauge scale. Many accurate gauges have a reflecting mirror along the scale, behind the needle pointer. This mirror helps you read it, and you should read it so that the mirror reflection of the needle is exactly behind the actual needle. Then you know that you are looking perpendicularly/straight at the gauge.

If the gauge has a digital indicator, then the resolution (reading accuracy) is totally different. You can read the digital indicator equally accurately at any point of its range.

12 Number of calibration points

The different accuracy classes of gauges will determine the different number of calibration points. For the most accurate gauges (better than 0.05 percent), you should use the "comprehensive calibration procedure." The calibration should be performed 11 calibration points across the range (zero point plus 10 percent steps) with three cycles in rising and falling pressure. For the medium-accuracy class gauges (0.05–0.5 percent), use a "standard calibration procedure" with 11 points, but fewer repeated cycles. The less accurate gauges (class equal or greater than 0.5 percent) are to be calibrated with the "basic calibration procedure" with six calibration points (zero point plus 20 percent steps) with rising and falling pressure.

In practice, gauges are sometimes calibrated with fewer calibration points. Hysteresis is discussed later, but to find the hysteresis, the calibration should be done with increasing and decreasing pressure points. Naturally, the number of calibration points and cycles also depends on the application, criticality, and accuracy requirement.

13 Hysteresis (direction of calibration points)

Again, due to its mechanical structure, a pressure gauge may have some hysteresis. This means that the indication is not exactly the same when a pressure point is approached with an increasing pressure compared to a decreasing pressure. To find the amount of hysteresis, you should calibrate the gauge with increasing and decreasing calibration points, i.e., to first go up and then go down with pressure. While doing this, it is important to make sure that the pressure moves only in the desired direction. For example, when you calibrate with increasing pressure you must make sure that you do not decrease the pressure at any point when fine adjusting the pressure, as this will cause you to lose the hysteresis information. If you overshoot the target point with increasing pressure, you need to come way back down and then increase the pressure again to the target point.

14

"Tapping" the gauge

Sometimes a mechanical pressure gauge may need a gentle tapping in order to make sure that it is released from any friction or lost flexibility, especially if it has not been exercised in normal use. During the calibration, once the input pressure is stabilized, you can gently tap the gauge to see if the indication changes. Of course, you need to tap gently so you do not damage the gauge.

15

Number of calibration cycles (repeatability)

During calibration, the calibration cycles are repeated several times to determine the repeatability of the gauge under calibration. If the gauge to be calibrated has bad repeatability, it will give different results during different calibration cycles. If you only calibrate it with one cycle, you will miss the repeatability information and part of the truth. As mentioned earlier, the most accurate gauges should be calibrated with three calibration cycles. In practice the repeatability is often tested as a type test for certain instrument types (make/model), and once the typical repeatability is known, the actual calibration is carried out in practice with just a one-calibration cycle, taking the typical repeatability into consideration.

16

Adjustment/correction

If the As Found calibration shows that the gauge is not within the accuracy requirements, something needs to be done. In most cases the gauge should be adjusted so that it will be within the allowed tolerance levels. After adjustment, the gauge needs to be calibrated again (As Left) to verify the condition it was left in.

If it is not possible to adjust the gauge in question, then a correction coefficient can be calculated, and this coefficient must be taken into account in normal usage. This will, of course, make the usage more difficult.

If the gauge has a big error, then it is best to repair/replace it and not try to adjust it, as most likely it will not stay stable in the future.

17

Documentation – Calibration certificate

One crucial aspect for calibration is, of course, to document calibration results in a calibration certificate. The certificate should document the applied pressure and the indication of the gauge as well as an error calculation (difference of applied pressure and indication). Certainly, the certificate needs to contain other information also, as stipulated by standards/regulations, including calibration uncertainty.

If you make the certificate manually, it means that you write the gauge's indication and the applied pressure on paper and then calculate the error manually. You can also use automated calibration equipment that will perform the documentation and calculations automatically and transfer the results to the computer for calibration software to store/print the results.

For more information on what a documenting calibrator is, please read the blog post What is a documenting calibrator and how do you benefit from using one?

18

Environmental conditions

Most gauges specify temperature effect, and this should be taken into account. Most often you

calibrate the gauge in the normal room temperature, but the gauge may be used at a different temperature in the process. This difference in temperatures may cause differences in gauge accuracy between calibration and process usage.

Environmental conditions (temperature and humidity) during the calibration should be recorded in the calibration certificate.

19

Metrological traceability

As with any calibration, you must ensure that the reference standard you are using to measure the applied pressure to the pressure gauge has a valid calibration certificate and that its calibration is traceable to the appropriate national standards (metrological traceability).

20
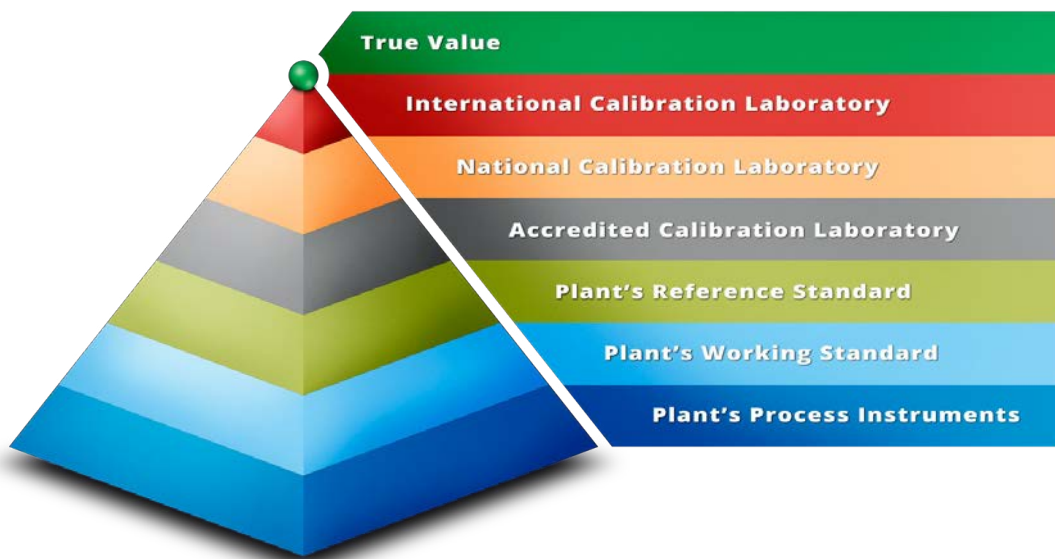
Uncertainty of calibration (TUR/TAR)

With any calibration, you should be aware of the total uncertainty of the calibration measurements, otherwise the result will not have much value. Awareness of calibration uncertainty seems to be rising, and it is also included more frequently in relevant standards and regulations. In some areas the test uncertainty ratio (TUR) or test accuracy ratio (TAR) is used instead of the uncertainty calculation. The concept of this is to make sure that you have a calibrator (or reference standard) that is several times more accurate than the instrument to be calibrated, and if you know this, you do not need to calculate uncertainty. One of the most commonly used ratios is 1:4, meaning that the calibrator's specs are four times better than the specs of the gauge to be calibrated.

It is good to notice, anyhow, that when using this TUR/TAR ratio method, you are not aware of all the relevant uncertainty components of your calibration process and you do not know how good the calibration really is. Therefore, calculating the total uncertainty of the calibration is the more recommended method.

Pressure Switch Calibration

Pressure switches are very common instruments in the process industry, and various kinds of pressure switches are available. Like many instruments, pressure switches need to be calibrated to ensure their accuracy and reliability. Switches are a bit more difficult to calibrate than transmitters. The wrong kind of calibration can cause many errors in the calibration result. In this article, we will look at how to properly calibrate pressure switches.

Before rushing into the calibration process, let's discuss some fundamental characteristics and terminology of pressure switches.

How does a pressure switch work?

Briefly stated, a pressure switch is an instrument that measures pressure and that has an electrical switch function programmed to operate at a certain pressure. For example, the pressure switch can be set so that when no pressure is connected (open to atmosphere) the switch is closed, but when pressure exceeds 10 psi, the switch opens. Again, when the pressure drops below 10 psi, the switch closes.

Pressure switch terminology

Let's very briefly discuss the related terminology:

Normally open/Normally closed

Some switches have the switch terminals open when no pressure is connected, called normally open (NO) or a closing switch. The opposite is a normally closed (NC) or opening switch. The selection depends on the kind of circuit you want to drive with the switch.

What is "normally"? There is some debate about the definition of the normally open/closed switch. Most commonly, it is defined as the state of the pressure switch output when it is not connected to any pressure, i.e., it has no physical stimulation. Some may define the "normal" state as the state of the switch during the normal operation of the process (untripped).

A normally open switch is open when no pressure is connected. When enough pressure is applied, the switch closes.
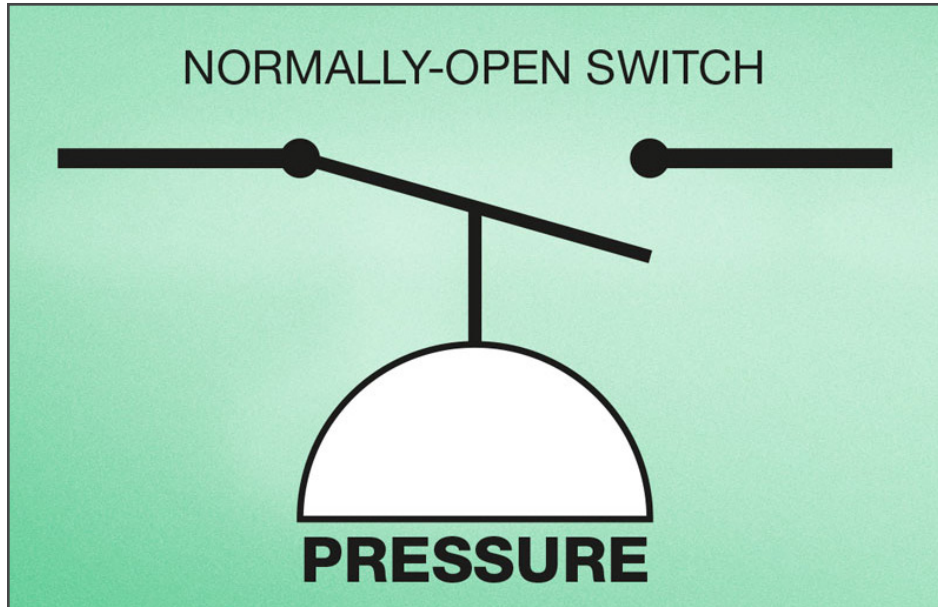
Normally-open switch

A normally closed switch is closed when no pressure is connected. When enough pressure is applied, the switch opens.
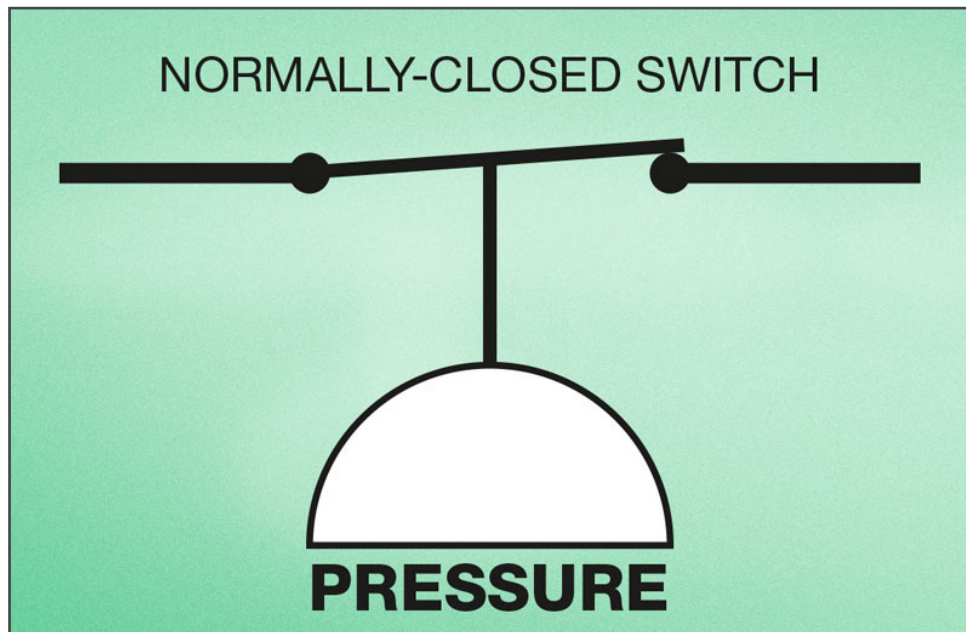
Normally-closed switch

A switch always has some deadband, which is the difference between the two operating points (opening and closing points). Deadband is required, because if a switch opens and closes at the same point, it could start oscillating when the pressure is on that limit. Also, if there was no deadband, the switch could control the circuit on and off with a high frequency. For example, a closing (NO) pressure switch may close at 10 psi pressure and open again at 9.5 psi pressure, so there is a 0.5 psi deadband.

Some switches operate at rising pressure, others with falling pressure. Sure, you always get one of the functions with rising and the other with falling, but the primary desired function happens in one direction.

There are pressure switches that operate with different pressure types: gauge, absolute, differential, or vacuum pressure.

Some older switches are mechanical (or even pneumatic), so inside the switch the pressure causes the switch to change its state. Most newer types are electronic or digital, so they measure the pressure and control the switch output accordingly. Many modern switches are programmable, so it is easy to set the desired operating points. While mechanical switches do not need a power supply, the electrical ones do.

When selecting the switch type, consider the state, so that if the power supply fails or a cable becomes loose, the switch status remains safe. And in the case of a safety switch, configure it so that if a cable comes loose, the alarm goes on. For example, if it is normally open (closing switch), you will not notice anything if the cable comes loose. The switch is still open, but it will not make the desired action when the switch closes. So all in all, you should design it to be fail safe.

There are also dry and wet switches. A dry switch has the connections open or closed, so it works like a mechanical switch. A wet switch has two different voltage values representing the two output states. The output of an electrical wet switch can be a voltage signal with two levels, a current signal, or an open collector type signal.

Sometimes the switch function can also be done in the control system, by measuring the current signal from a transmitter and programming the switch-like function to control something based on the signal level.

In practice, industrial switches often have double switch contacts that can be programmed separately.

This can be the normal "Lo" and "Hi" points, but also "Lo Lo" and "Hi Hi" points. Although the Lo and Hi are the normal control points, the Lo Lo and Hi Hi are alarm limits that will control for more serious alarm activities.

Safety pressure switches

Safety switches are switches used in safety instrumented systems. These switches have certain safety classifications, and the calibration of the switches is regulated.

A big difference with these switches is that they stay static most of the time without ever functioning. So, they do not toggle open and closed in normal usage. They just wait until the safety alarm level is met, and then they operate.

Because these switches rarely operate, there is a risk that they will get stuck and not work when they should.

When calibrating, do not exercise these safety switches prior to calibration; instead, capture the very first point when the switch operates.

Sometimes the first operation requires more pressure than the operations after a few exercises. Normal switches are typically exercised a few times before calibration, but that should not be done for the safety switches.

In a safety switch, the operation point is critical, but often the return point is not relevant and may not require calibration.

How to calibrate pressure switches

Now, let's discuss how to calibrate pressure switches.

Preparations and safety

If the switch is installed in the process, it is very important to make sure it is isolated from the pressure line. You also need to make sure to disconnect any circuit that the switch is controlling—you do not want to generate a safety alarm or for big valves to start opening/closing or pumps to start operating.

Some switches may have mains voltage, or another dangerous voltage, across the switch terminals when they open, so make sure that it is isolated.

Pressure ramp

To calibrate a pressure switch, you need to provide a slowly changing pressure ramp, moving across the operating points of the switch. Depending on the switch type, you need to first supply a suitable pressure to start the calibration.

Often you can start from atmospheric pressure, but in some cases, you need to pump a high pressure and start slowly decreasing the pressure toward the operation point. Or you may need to provide a vacuum to start from. This depends on the switch to be calibrated.

There are different ways to provide the input pressure. You can use a calibration hand pump with a fine adjustment control; you can use shop air supply with a precise pressure controller; or you can use an automatic pressure controller.

It is vital to provide a slow pressure ramp, so that you can see the precise pressure whereby the switch operated. If the pressure changes too quickly, you cannot accurately capture the pressure point when the switch operated. However, some tools (like the Beamex MC6) can automatically capture the exact pressure during the very moment when the switch changed its status.

Anyhow, remember to change the pressure very slowly when you are approaching the operation points of the switch! You may change the pressure faster when you are not yet close to the operation points.

Measuring the switch output

You need a tool to measure the switch terminals. If it is a dry switch, with an open and close output, you may use an ohm meter. If the output is electrical, you will need to find a tool that can measure the output. In some cases, it may be a voltage meter, or a current meter. For electrical outputs, it is sometimes a bit difficult to find how to measure the output. You should be able to recognize the two states of the output and to see when the state changes.

With some tools, you can program a trigger level that suits the switch in question, which enables the status change to be captured automatically. This is how the Beamex MC6 works.

Capturing the operation points

In the switch calibration, you need to capture the input pressure at the very moment when the output state changes.

You can try to capture the input pressure manually. For example, when the switch state changes, you stop the ramp and check the input pressure (on the device/calibrator that is measuring the input pressure). Most likely there is some delay in your reflexes, so the pressure is already different from what it was during the switch operation moment. That is the main reason you should provide a very slow input pressure, so it does not change that much during the delay of your reflexes.

Some devices can capture the input pressure automatically at the very same moment when the switch output changes its state. These devices can interpolate between the pressure measurement readings. Let me explain: a digital pressure measurement device measures the pressure a few times every second. It may happen that the switch operates in between the two consecutive pressure measurement readings. In that case, the calibrator looks at the time stamp of the switch operation and interpolates between the two consecutive pressure measurement results to get the exact pressure value during the switch operation moment.

Delayed output

Some industrial switches have a delay added to the output so that it does not work too quickly. You should find out if your switch has delay. If it does, the calibration needs to be done even slower than normally.

With some added delay, by the time the output toggles, the input pressure is already far away from the point that actually triggered the output to toggle.

Here is a condensed list of steps in pressure switch calibration:

1. Depressurize and disconnect for safety.
2. Connect the pressure source and the pressure calibrator to the switch input.
3. Connect the device to measure the switch output status.
4. Exercise the switch a few times—pump full pressure and back to zero. Do not do this with safety switches!
5. Pump normal pressure close to operation point.
6. Move pressure very slowly across the operation point, until the switch output toggles. Record the operation pressure.
7. Move pressure very slowly toward the return point, until the switch status toggles. Record the return pressure.
8. Make required number of repeats—repeat the two previous steps.
9. Vent pressure.
10. Disconnect the test equipment.
11. Return switch back to service.

Naturally, you need to document the switch calibration results. Also, you need to calculate the errors found in the calibration and compare them to the max allowed tolerance for that switch to see if it passed or failed calibration. If the switch fails the calibration, then you need to either adjust the switch or replace it. Even if it passes the calibration, you should still analyze how big the error was. If the error was close to the tolerance limit, or if it had drifted much since the last calibration, it is good to adjust it to avoid a fail result in the next calibration.

And as with every calibration, based on the calibration result history, you should consider if the calibration period should be changed. You do not want to waste resources on calibrating too often, but you also do not want to calibrate so seldom that you get a failed calibration result. A failed calibration result should anyhow always start an investigation of the consequences. This can be expensive and work intensive.

Documentation, metrological traceability, calibration uncertainty

As documentation is included in the formal definition of calibration, it is a vital part of every calibration. This is also valid for pressure switch calibration, typically in the form of a calibration certificate.

The calibration equipment used should have a valid metrological traceability to the relevant standards, otherwise the calibration does not ensure traceability in the switch calibration.

The calibration uncertainty is a vital part in every calibration. If the calibration equipment (and calibration method and process used) is not accurate enough for the pressure switch calibration, then the calibration does not make much sense. What is the point in using a 2 percent accurate calibrator to calibrate a 1 percent accurate instrument?

About BEAMEX

BEAMEX is a leading worldwide provider of calibration solutions with the sole purpose to create better ways to calibrate for the global process industry. Beamex offers a comprehensive range of products and services — from portable calibrators to workstations, calibration accessories, calibration software, industry-specific solutions and professional services. Through Beamex's subsidiaries, branch offices and an extensive network of independent distributors, their products and services are available in more than 80 countries. Beamex has more than 12,000 customers worldwide.

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