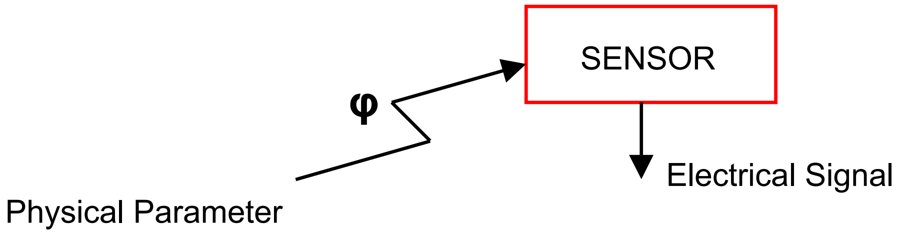
BASIC of PRESSURE MEASUREMENTS

1) What is a Pressure Sensor ?

Any kind of sensor is composed of 2 distinct elements :

¤ A body submitted to the Physical Parameter **φ** to be measured + many other parameters acting as undesirable perturbations.
Under the influence of the Parameter to be measured + the influence of undesirable parameters, the Body of the sensor gets a dimensional change (due to the stress induced generating an external strain) or a Temperature change or both.

¤ A Sensing Element which converts the Strain or the Temperature change into an electrical signal easy to measure by means of usual electronic devices.



Thus, the goal of the sensor is to catch the physical parameter and to convert it into an electrical signal, in such a way that the output signal is as high as possible regarding the desired parameter and as low as possible regarding the undesired parameters.
The design of a Sensor is a Specialist job and the resulting characteristics must be contained in a Data Sheet allowing the End-user to determine the performance of his measurement under the environmental conditions where the sensor is used.

Taking the example of a Pressure Sensor used on board a car, the external environmental conditions are usually :

¤ Temperature	Resulting in a S_T signal
¤ Humidity	Resulting in a S_{RH} signal
¤ Vibrations	Resulting in a S_V signal
¤ Acceleration or deceleration	Resulting in a $S_{A \text{ or } D}$ signal
¤ Others …	

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If the desired Pressure signal is named S_P, then the combined Output Signal is :

$S = S_P + S_T + S_{RH} + S_V + S_{A\ or\ D} + \ldots$

As it is impossible to separate the useful S_P signal from the others, one understands the concern regarding having S_P as high as possible and the others as low as possible.

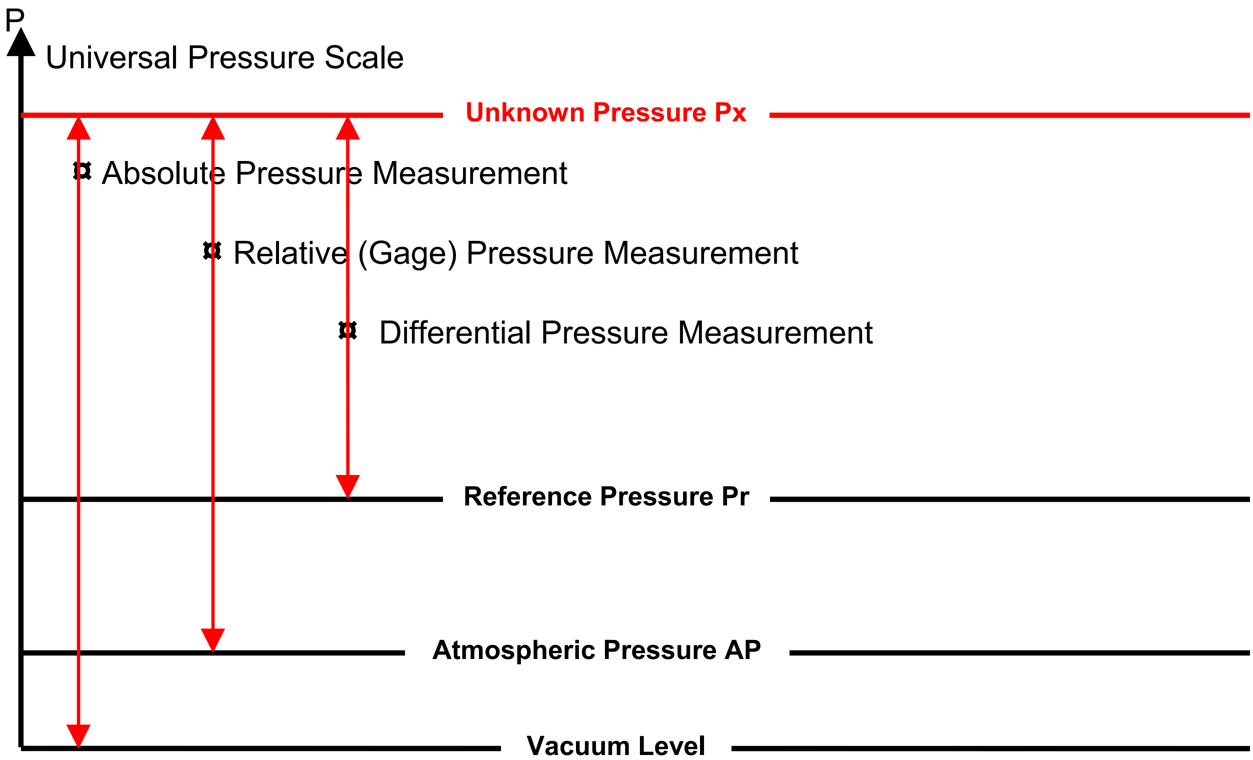
The undesired parameters generate errors as : E_T , E_{RH} , E_V ,$E_{A\ or\ D}$.

Consequently the global Error on the Pressure measurement will be :

$$E_P = SQR\ [\ (E_T)^2 + (E_{RH})^2 + (E_V)^2 + (E_{A\ or\ D})^2\ ]$$

Thus, it appears why it is a nonsense to look for the indication of the Accuracy in the Manufacturer's Data sheet, as far as the result depends upon the conditions of use of the Sensor.

2) How to define the Pressure to be measured ?



¤ The first way to define the unknown pressure Px, is to relate it to the Absolute Vacuum (no trace of any residual molecule of any gas or liquid).
The **Absolute measurement** is the difference (Px – 0)

In practice, the Absolute measurements are quite rare in industrial applications as the generation of a good Vacuum Level (example 10^{-6} mm Hg) is long, complicated and expensive.

This kind of measurement concerns only a few percent of the industrial applications.

This is why the second following way is currently preferred.

¤ The second way to define the unknown pressure Px, is to relate it to the existing Atmospheric Pressure which is available everywhere (free of charge !).

The measurement **(Px – AP) is called a Gage (Relative) Pressure measurement.**

Relative means that the measurement is related to the AP at the time and place the measurement is performed, because the AP is not the same on the sea level or on top of a mountain. In addition, in a given place it varies all the time.

It must be consequently noticed that this kind of measurement normally means that the AP value must be known. In practice, it is not, most of the time.

¤ The third way to define the unknown pressure Px, is to relate it to a known Reference Pressure Pr (supposed to be known against the vacuum level).

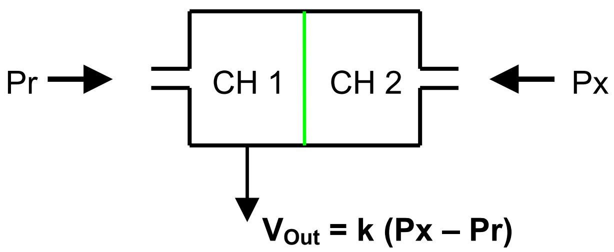
In that case, the measurement **(Px – Pr) is called a Differential Pressure measurement.**

Comparing the 3 ways to relate the unknown pressure to another one, it appears that the universal way to define a pressure is to make a Differential Pressure Measurement. Then a Gage measurement or an Absolute measurement become a special case of a Differential measurement where respectively the Reference Pressure is the AP or the vacuum.

This important remark drives us to the description of the corresponding 3 kinds of Pressure Sensors.

3) Pressure Sensors structures :

¤ Differential Pressure Sensors

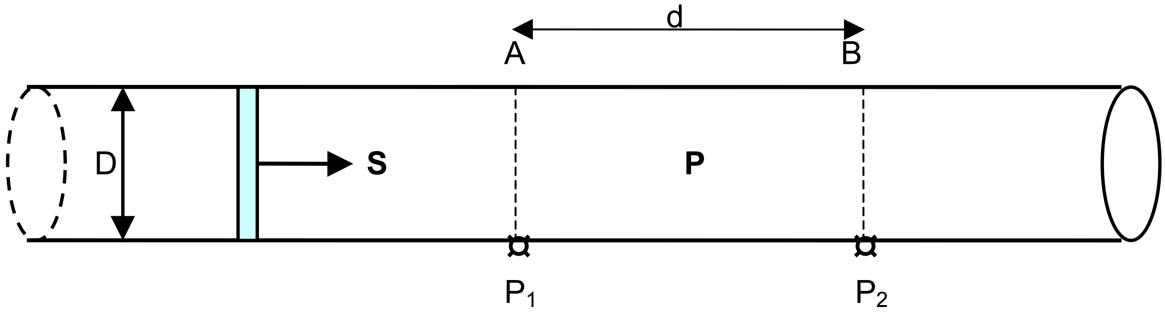


$V_{Out} = k\,(Px - Pr)$

The sensor comprises 2 chambers : CH1 is the Reference Chamber where Pr is applied
CH2 is the Measuring Chamber where Px is applied.
The 2 chambers are separated by means of a deformable element (a membrane or any other classical element used in sensors design).
The sensing elements are located in the Reference Chamber (strain gages, capacitive system, any other classical element used in sensors design).

The Output signal is proportional to (Px – Pr).

A Differential Pressure sensor is commonly used in order to measure a Flow rate in a pipe :



It is well known that if a fluid (having a η viscosity) flows through a pipe (having a certain Diameter D) at a S speed, it appears between 2 points A and B at a ''d'' distance a Delta P = P1 – P2 proportional to the speed ''S'' and consequently proportional to the Flow rate.

If the 2 holes corresponding to the A and B sections are connected to a Differential Pressure Sensor, then its output is directly proportional to the flow rate.

2 concepts are extremely important :

¤ The average Pressure P in the pipe (called **Line Pressure**) is usually high in comparison with the differential pressure **ΔP** representing the flow rate. For example if the Line Pressure is 100 bar, the ΔP can be as low as 100 mbar.
It means that if, for any reason, one of the 2 connecting tubes breaks (driving the pressure back to the Atmospheric Pressure), the Line Pressure is only applied on one side of the sensor : Either it has been selected to withstand that configuration, or it explodes. Danger.

So, a selection of a Differential Pressure sensor must be made considering :
- The Maximum admissible Line Pressure.
- The ΔP Pressure Range.
- The protection in case of rupture.

¤ The fluid can be a gas or a liquid. It can be aggressive or not.

When the application concerns a dry and non corrosive gas, on both sides, the Differential Pressure Sensor can be selected as a **''Dry-Dry''** unit.
When the application concerns a liquid on only one side, the Differential Pressure Sensor can be selected as a **''Wet-Dry''** unit.
If both sides are connected to a liquid, the selection must be a **''Wet-Wet''** unit.

When the fluid is aggressive on both sides, the selection must be a ''Wet-Wet'' unit, even for a gas application, so that the internal sensing elements are protected.

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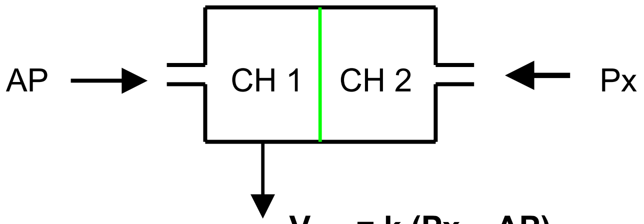
Before making a selection for a Differential Pressure sensor, it is strongly recommended to consult a Specialist.

¤ Gage (Relative) Pressure Sensors

As said before, a Gage Pressure Sensor is a special case of a Differential Pressure Sensor. It has consequently the same basic structure :



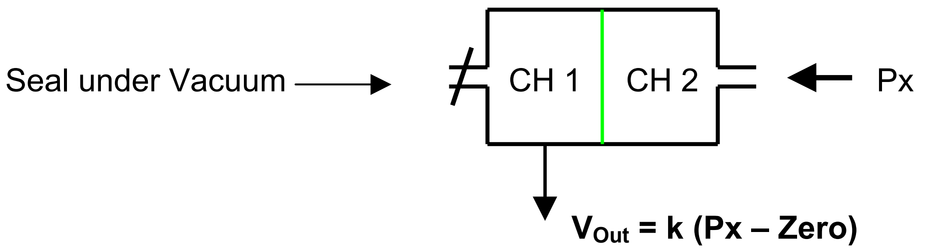
$V_{Out} = k\,(Px - AP)$

In the present case, the reference pressure is the Atmospheric Pressure AP, so that the internal chamber CH 1 is left open at the Atmosphere.

A Differential unit could do the job, but it would be far too expensive. A Gage (Relative) unit must be selected, as its internal structure is much simpler compared to a Differential one.

¤ Absolute Pressure sensors

In the present case, the Reference Chamber must be related to the vacuum. It means that the Manufacturer must pump the CH 1 chamber down to vacuum.

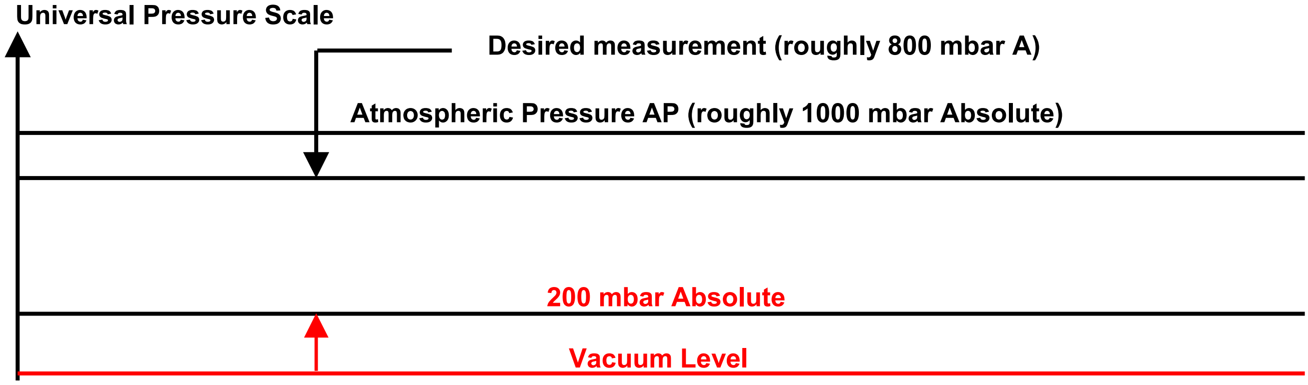


$V_{Out} = k\,(Px - Zero)$

The vacuum level being in theory Zero Pressure, the above formula applies and consequently an Absolute Pressure Sensor gives a direct reading of an Absolute Pressure.
In practice, the industrial Absolute Sensors are pumped down to a Primary Vacuum (roughly 10^{-3} mm Hg) generated by means of a simple stage pump.

Notice : When the CH 2 chamber is at the AP, the Absolute Pressure Sensor gives the value of the Atmospheric Pressure (obvious) !
It means that a 1 bar Absolute Sensor is saturated at the AP. Consequently in order to read the Zero value set-up for the sensor, it is necessary to pump down to vacuum before making the reading.

Example : In order to make a measurement of a pressure roughly equal to 200 mbar under the AP, do not select a 200 mbar Absolute Sensor, because that one is only acting between the vacuum and 200 mbar Absolute !



The right solution consists in selecting either a Relative unit allowing negative pressure measurement (below the AP) or an Absolute unit 1 bar range which will indicate 800 mbar A.

¤ Sealed Gage Pressure Sensors : Warning !

Sometimes, a Gage Pressure measurement has to be performed in a wet or aggressive environment : In that case, the Humidity inside can generate a condensation when the temperature varies, or the sensing elements inside can be destroyed versus time.

In order to avoid that kind of trouble, it is possible to select either an Absolute unit (in that case the sensing elements are perfectly protected inside the sealed under vacuum reference chamber) or it is possible to seal the sensor at the AP. This configuration is called a **Sealed Gage** unit.

The drawback of that cheap solution compared to an Absolute unit, is that :

a) If the temperature varies, the Avogadro Law applies :

$$PV = P_0V_o\,(1 + \alpha\,T) \;\Rightarrow\; \Delta P = \alpha\,\Delta T$$

As α = 1/273 it generates a variation of the internal reference pressure of 0.37 % /°C. If the temperature remains constant the solution is valid.
If the temperature varies, the sensor is acting as a Thermometer !

b) Even if the temperature is constant, the variations of the AP (currently from 950 to 1050 mbar) generate an error.
If the range of the measurement is high enough to ensure the required accuracy, the solution is OK. The utmost care must be taken for low ranges applications.

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