Chapter2 : Metrological Characteristics

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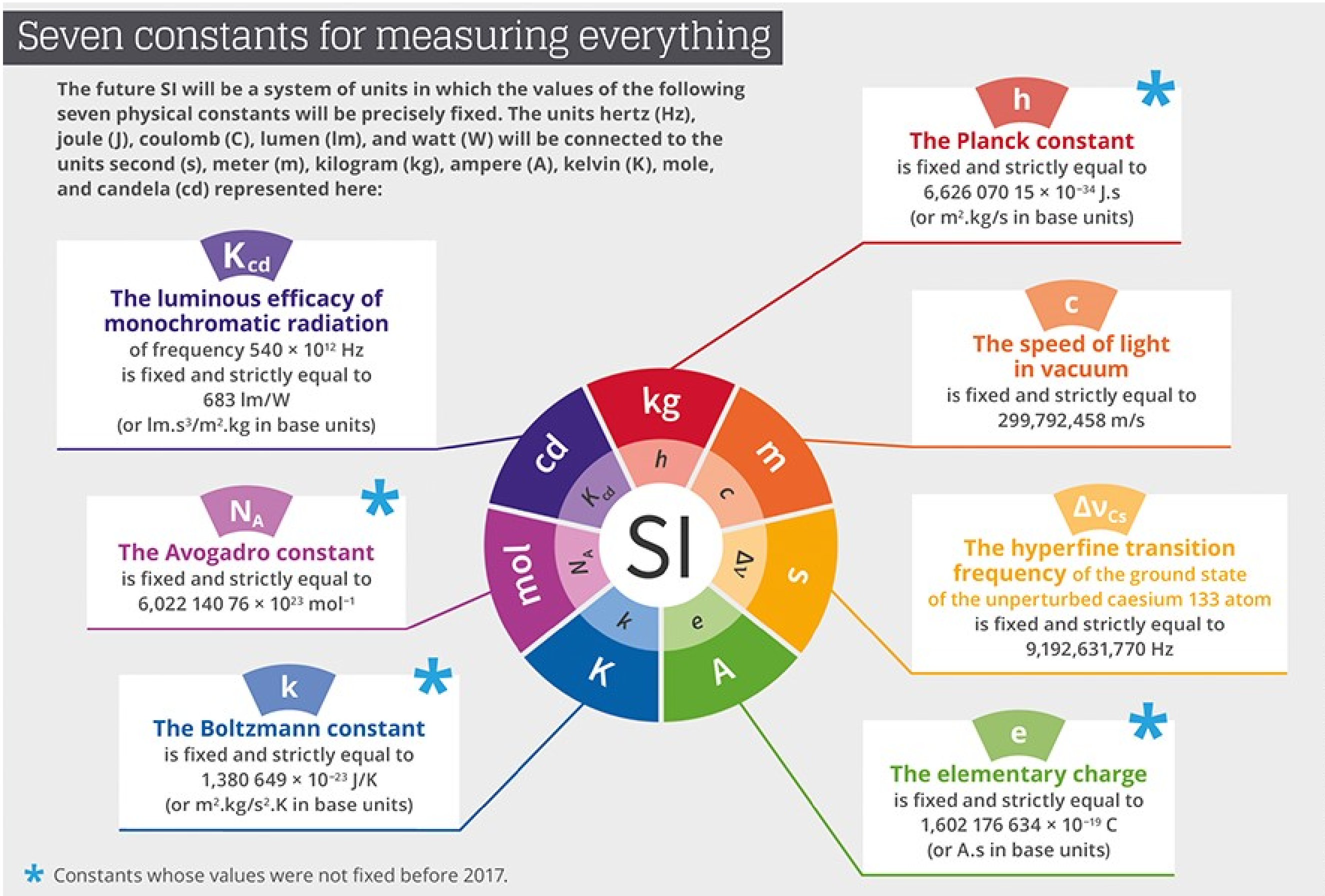
2.1 Measurement Errors

The sensor, the first element of the measurement chain, is the determining source of the electrical signal that the rest of the chain must process and exploit.

The adaptation of the sensor and the measurement chain implies that it does not add uncertainties or limitations to the initial signal greater than those provided by the sensor.

It is therefore on the quality of the sensor that the more or less agreement between the measured value and the true value of the measurand depends in the first place on the one hand; and on the other hand the limits of uncertainty on the measured value.

The only measurands whose value is perfectly known are the standard quantities since their value is fixed by convention.



The difference between the measured value and the true value is the measurement error.

The measurement error can only be estimated:

The value of the measurand cannot be known. However, a rigorous design of the measurement chain makes it possible to reduce the measurement error and therefore the uncertainty on the true value.

2.1.1 Systematic Errors

Systematic errors are generally caused by erroneous or incomplete knowledge of the measurement installation or its incorrect use.

Some of the causes of systematic errors include:

• errors on the value of a reference quantity (e.g. inaccurate value of the supply voltage of a bridge).

• errors in the characteristics of the sensor (e.g. error in sensitivity or calibration curve).

• errors due to the mode or the conditions of use (error in speed or speed of response).

• errors in the processing of raw measurement data (e.g. self-heating of a thermoelectric resistor).

2.1.2 Accidental (random) errors

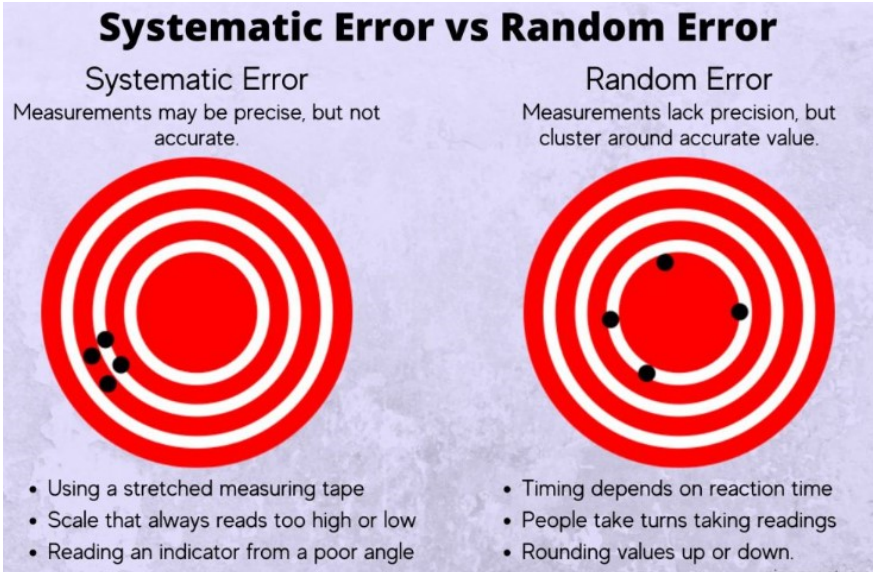
The appearance of these errors as well as their amplitude and their sign are considered as random. Some of the causes may be known but the values of the errors they cause at the time of the experiment are unknown.

Various possible causes of accidental errors are listed below:

• errors related to the intrinsic indeterminations of the instrumental characteristics (e.g. mobility error below a certain value).

• errors due to the taking into account by the measurement chain of spurious signals of a random nature (e.g. background noise).

• errors due to influence quantities (e.g. an apparatus having been developed at 20°C, any variation in temperature on either side of 20°C leads to errors).



2.2 Sensor Calibration

The calibration of the sensor includes all the operations which make it possible to explain, in graphic or algebraic form, the relationship between the values of the measurand and those of the output electrical quantity, and this, taking into account all the additional parameters likely to change the sensor response.

Additional parameters can be:

• or physical quantities linked to the measurand and to which the sensor is sensitive (direction and rate of variation of the measurand, physical properties of the material support of the measurand);

• either on physical quantities, independent of the measurand, to which the sensor is subjected during its use and which can modify its response:

- ambient influence quantities (temperature, humidity).

- power supply influence quantities (amplitude, frequency of the voltages necessary for the operation of the sensor).

2.2.1 Simple calibration

It applies to a measurand defined by a single physical quantity and to a sensor not sensitive to influence quantities.

These are in particular static measurements, i.e. at constant values:

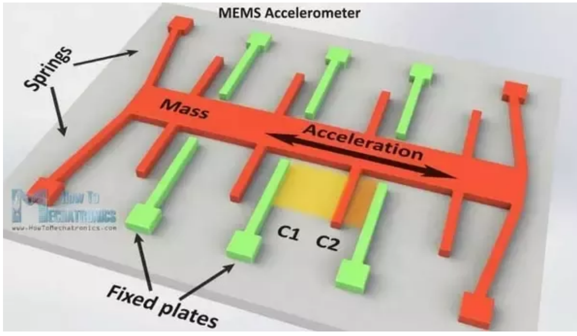
• measurement of fixed distances using a potentiometric sensor whose indication does not depend on the temperature (influence quantity).

• measurement of a temperature using a thermocouple.

Under these conditions, calibration consists of associating perfectly determined values of the measurand with the corresponding values of the electrical output quantity; the calibration is carried out by a single type of experiment and by one or the other procedure described below:

Direct or absolute calibration

The various values of the measurand are supplied either by standards or by reference elements whose value is known with an accuracy of the order of 100 times greater than those sought by the sensor.



Example: Laser interferometer for the displacement sensor or rectilinear movement (fig.1 absolute calibration of an accelerometer).

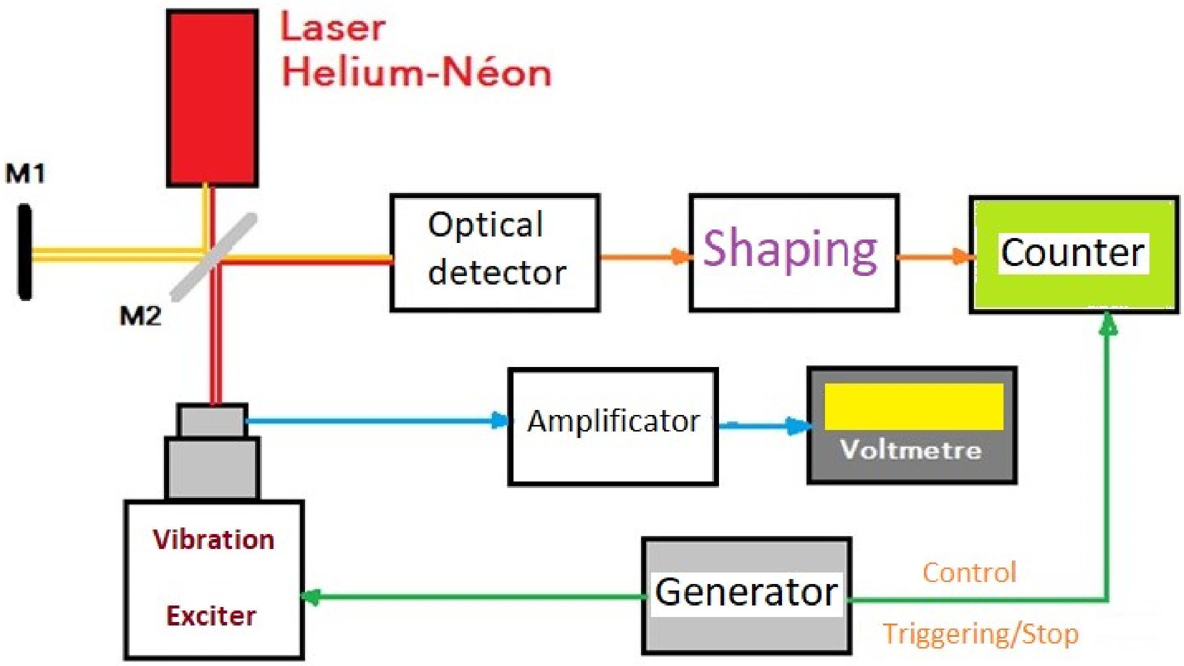
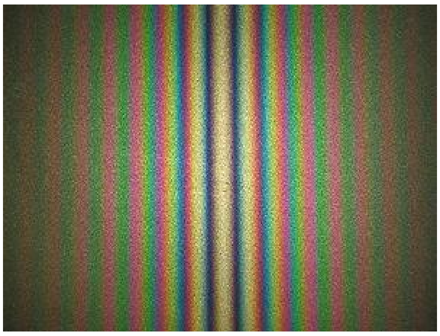


Fig.1: Absolute calibration of an accelerometer.

The accelerometer is subjected to a sinusoidal vibration of known frequency f; as a function of the amplitude X1 of the displacement, the acceleration has the amplitude

$$A_1 = 4\pi^2 f^2 X_1$$

The value of X_1 is deduced from the number of interference fringes passing in front of an optical detector during an excitation period: for each value of A_1 the output signal of the accelerometer is deduced from the indication of a precision voltmeter .



Fringes of interference

Indirect calibration (by comparison)

We use a reference sensor for which we have the calibration curve and whose stability we are sure of (fig.2).

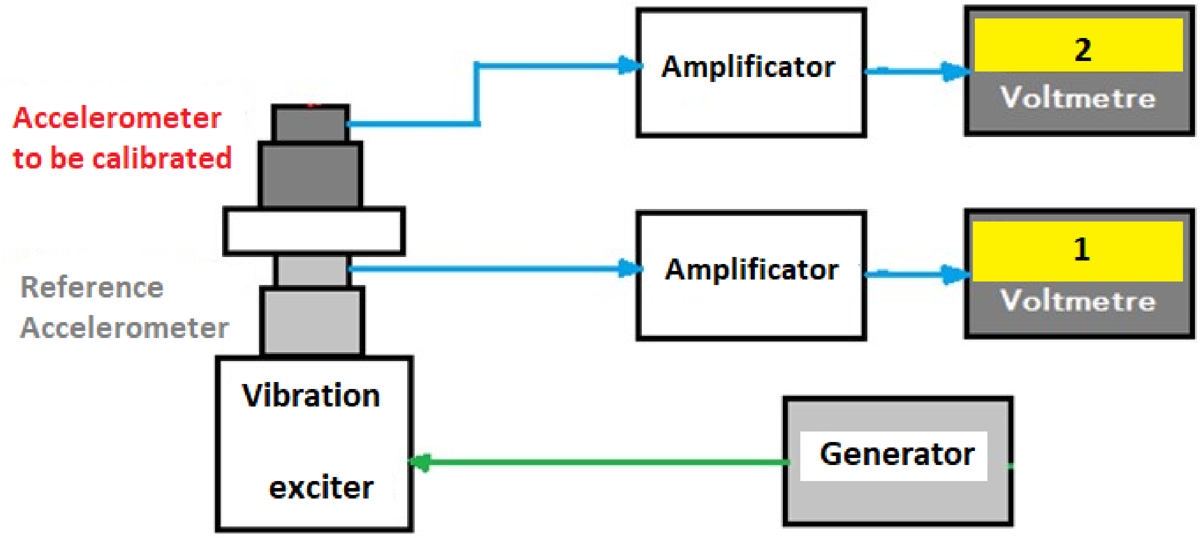
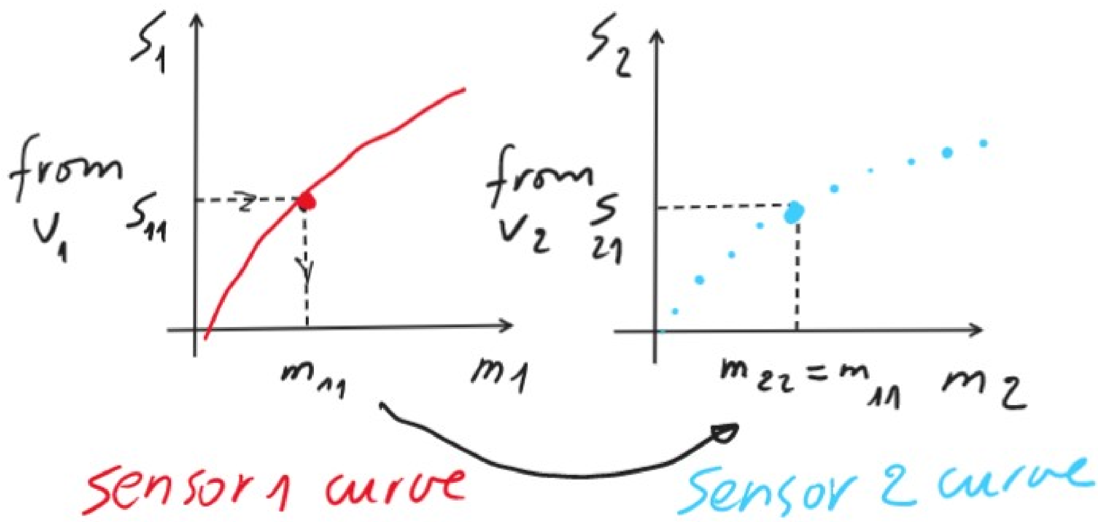


Fig.2: calibration of an accelerometer by comparison

with a reference accelerometer.

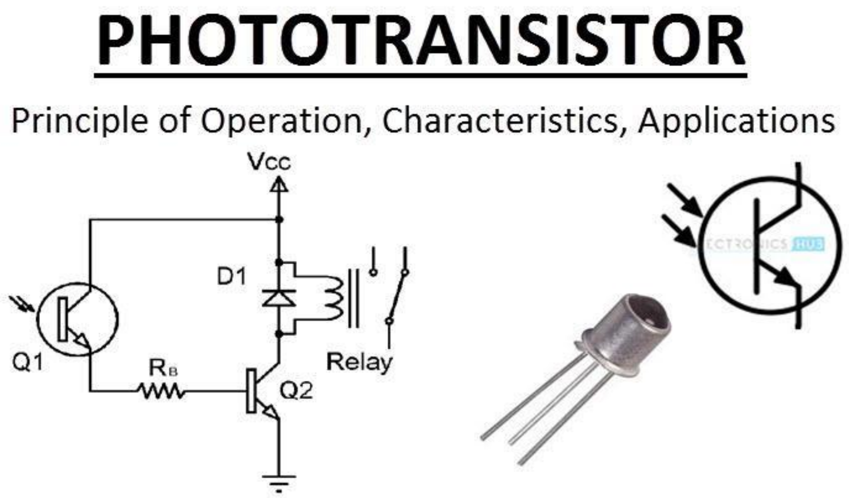


Note: *the relationship between measurand and output quantity can be in graphical form (the calibration curve), or in algebraic form (characteristic equation of the sensor).*

2.2.2 Multiple calibration

When the measurand alone does not make it possible to define the response of the sensor, it is necessary to specify, by a series of successive calibrations, the influence of each of the additional active parameters.

E.g. the Phototransistor



This is an optical sensor whose output quantity, the collector current Ic depends on:

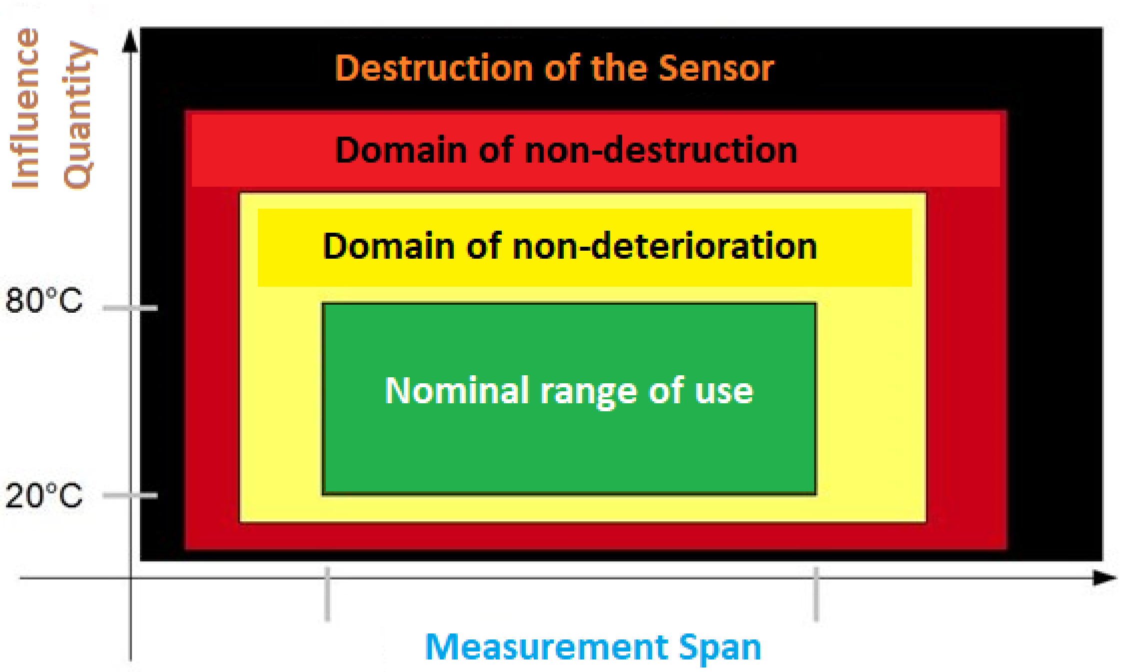
- - the incident radiation flux φ, as well as its wavelength λ, the angle α between the incident radiation and the normal to the illuminated surface;
- - the collector-emitter voltage V_{CE};
- - load resistance *Rm*;
- - and temperature.

For each of the parameters indicated, the manufacturer provides the corresponding calibration, obtained by noting the influence on Ic of the parameter considered.

From these curves, the user can, in his own experimental conditions, determine the response of the sensor by interpolation.

2.3 Limits of use of the sensor

The mechanical, thermal or electrical stresses to which a sensor is subjected lead, when their levels exceed defined thresholds, to a modification of the characteristics of the sensor, as they were known by prior calibration or manufacturer's specifications.



- *Nominal range of use: It corresponds to the normal conditions of use of the sensor.*
- *Non-deterioration domain: When the values of the measurand or influence quantities exceed the limits of the nominal range of use but remain below the limits of the non-deterioration range, the metrological characteristics of the sensor risk being modified.*
- *Non-destruction domain: When the values of the measurand or the influence quantities exceed the limits of the non-deterioration domain while remaining below the limits of the non-destruction domain, the characteristics of the sensor are irreversibly modified. Reuse requires recalibration.*
- Measurement Span (MS): It is defined by the difference between the extreme values of the range of the measurand in which the operation of the sensor satisfies given specifications (nominal range in general).

2.4 Sensibility

This is a decisive specification in the choice of sensor; in general, the sensitivity *S* is defined, around a constant value m_i of the measurand, by the ratio Δs of the output quantity to the variation Δm of the measurand which gave rise to it:

$$S = \left(\frac{\Delta s}{\Delta m}\right)_{m=mi}$$

The sensitivity value is provided by the manufacturer; it allows the user:

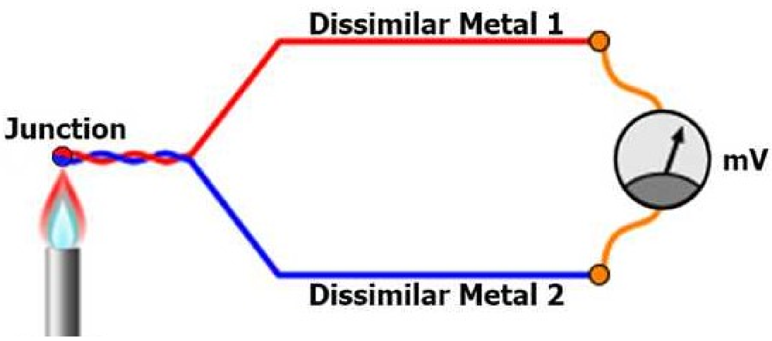
• To estimate the order of magnitude of the response of the sensor, knowing the order of magnitude of the variations of the measurand.

• To choose the sensor so that the measurement chain as a whole satisfies the imposed measurement conditions.

The unit of S results from the principle which is the basis of the sensor and the orders of magnitude involved, example:

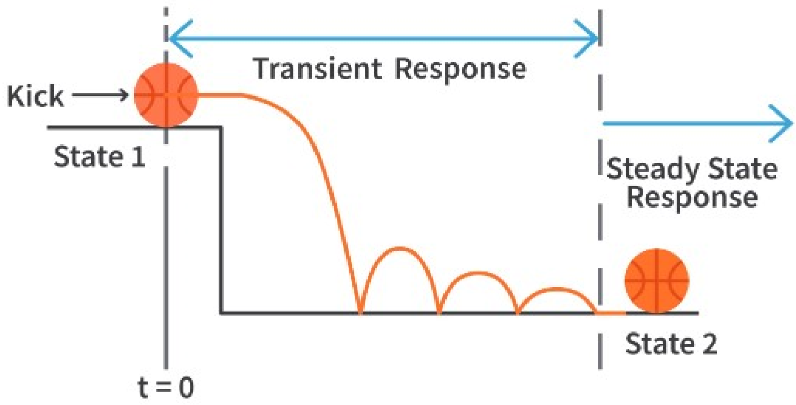
Ω/°C for a thermometric resistance;

µV/°C for a thermoelectric gauge.



2.5 *Speed – Response time*

The frequency response of a sensor applies to the steady state of the output quantity in the presence of a periodic measurand.



As soon as the measurand is applied to the sensor or undergoes a sudden variation, the establishment of the steady state is preceded by a transient state, the importance of which must be able to be assessed for correct performance of the measurements.

The function of time which determines this transitory regime results from the differential equation of the system: it is the general solution of the equation without second member.

2.6 *Smoothness*

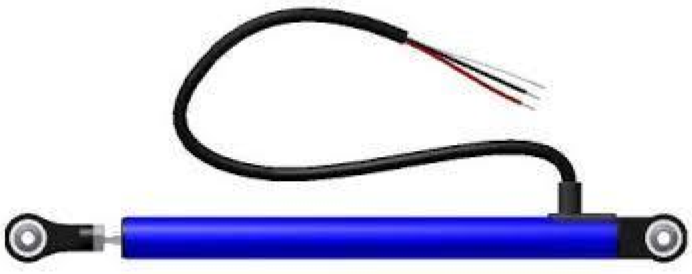
It is a specification that allows the user to estimate the influence that the presence of the sensor and its connections can have on the value of the measurand.

Smoothness is defined by the value of a physical quantity which depends on the nature of the sensor and which determines its reaction on the measurand.

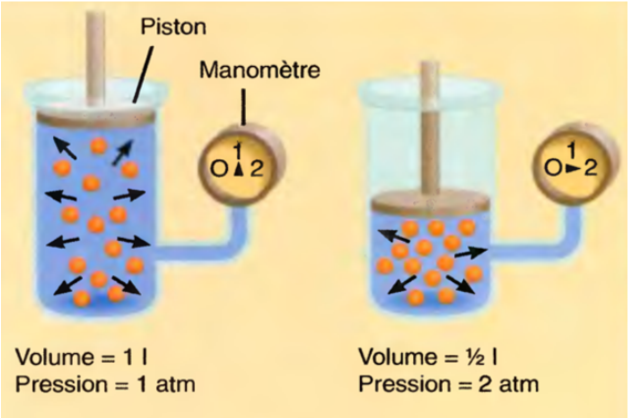
The influence of the sensor on the measurand depends not only on the characteristics of the sensor but also on those of the medium or the structure which are the support of the measurand.

Examples:

• A linear displacement sensor has smoothness all the greater as its mobile mass and the effort necessary for its displacement are .... relative to the mass of the moving object and the forces applied to it.



• The smoothness of a pressure sensor is all the greater when its dead volume and its breathing volume are more .... compared to the volume of the enclosure whose pressure must be measured.



Weak, reduced