[redacted]

## 1.2 Definitions of sensor and transducer

A *transducer* is here defined as an elementary device capable, within a given field of measurement, of converting a physical non-electrical input quantity (the measurand) into an electrical output quantity. The transducer itself does not contain any further processing beyond this energy conversion.

A *sensor* is here defined as a non-elementary device, usually based on a transducer, capable of converting a physical non-electrical input quantity into an electrical output quantity *and* of processing it, in accordance with a given algorithm, to provide an output suitable for interfacing to a process control system such as a computer.

The main difference lies therefore in the non-elementary nature of the sensor, that is in its capability to embody functions other than the basic energy conversion. This leads to a further classification of sensors, that of:

- intelligent sensors, those that can interact with the control computer to provide data manipulation (such as 'feature extraction' as in the case of vision sensors)
- non-intelligent sensors, those that can provide the computer with the output data only (and which therefore require longer communication times).

## 1.3 Generalities

Both sensors and transducers can be classified according to their input/output characteristics. With respect to their input physical quantity these devices can be termed:

*Absolute*—when, given a fixed origin, the electrical output signal can represent all the possible values of the input physical signal with no ambiguity

*Incremental*—when an origin cannot be fixed for all points within the field of measurement and each point is taken as the origin for the next one

The nature of the output function, on the other hand, determines whether the device is:

*Analogue*—when the output signal is continuous and proportional to the input physical quantity

*Digital*—when, given a continuous physical input quantity, the output signal can only take a number of discrete values

The nature of the electrical output quantity also determines the device performance characteristics, which can be divided into *static* and *dynamic* ones.

*Static characteristics* describe the device performance at room conditions (i.e. at a temperature of $25 \pm 10$ degrees Celsius, a relative humidity of 90% or less and a barometric pressure of 880–1080 mbar), with very slow changes in the measurand and in the absence of any mechanical shock (unless this latter happens to be the measurand). Static characteristics include: linearity, accuracy, stability, precision, sensitivity and resolution.

*Linearity*—can be defined as the variation in the constant of proportionality between the input physical quantity and the output electrical signal. A sensor or a transducer is therefore said to be linear when the constant of proportionality has the same value within the whole measurand range (i.e. when the graph relating input to output is a straight line). The linearity error is expressed as a percentage of the maximum electrical output value.

For example, in Figure 1.1 the dotted line shows the theoretical straight line of maximum linearity within the measurand range. Curve 'a' shows the output characteristic for a device which is linear up to 70% of the measurand range and then exibits increasing deviation from straight line linearity. This behaviour is often known as 'output saturation' and affects most transducers, particularly optical ones.

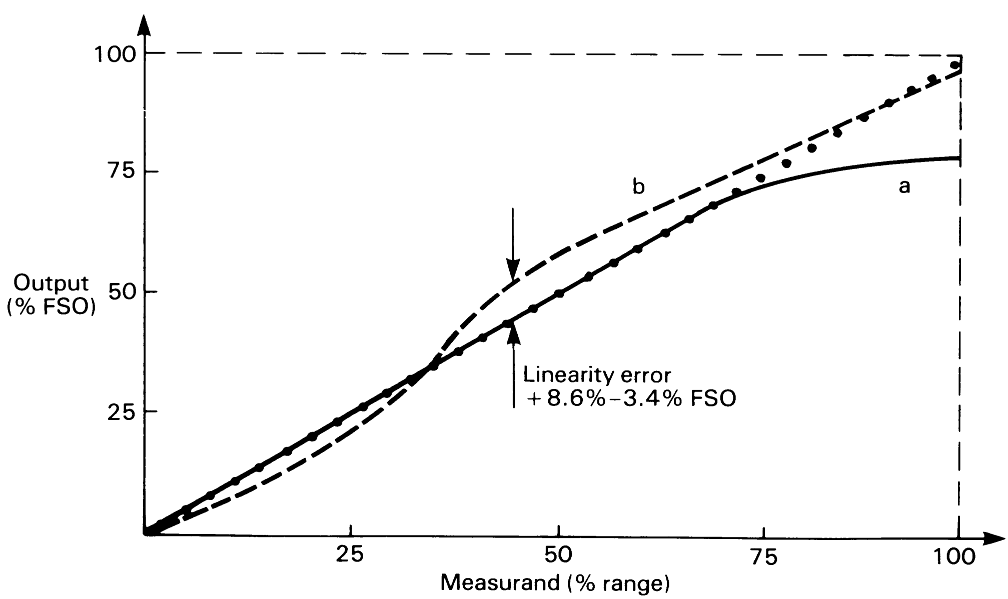


**Figure 1.1**

Curve 'b' shows the output characteristic of a transducer with a marked non-linear behaviour throughout the measurand range. The linearity error for device 'b' would therefore be +8.6%, −3.4% FSO (full-scale output) *with respect to the terminal linearity curve.* In fact it is meaningless to quote a linearity error without stating what sort of straight line it uses as reference. The choice of this straight line depends on the device output curve and its applications; as shown in Figures 1.2–1.5 there are four main types of curve used for linearity calculations:

(a) *Theoretical slope*
The straight line between the theoretical end points. Usually 0–100% for both FSO and range—in which case it is called the 'terminal line' (see dotted line in Figure 1.2)—or it can purposely be offset to suit certain applications (see broken line).

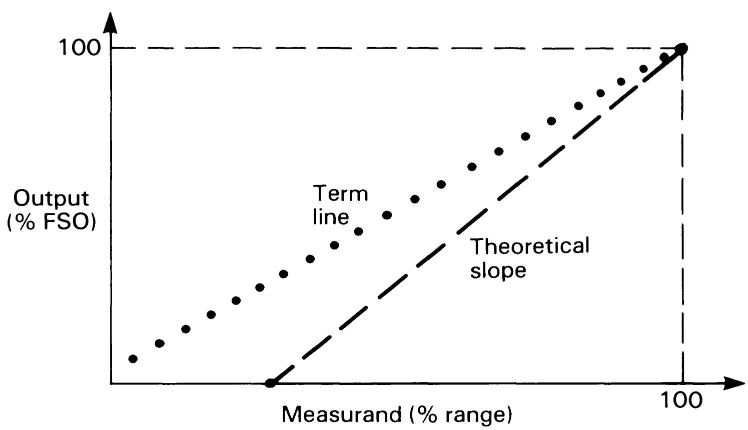


**Figure 1.2**

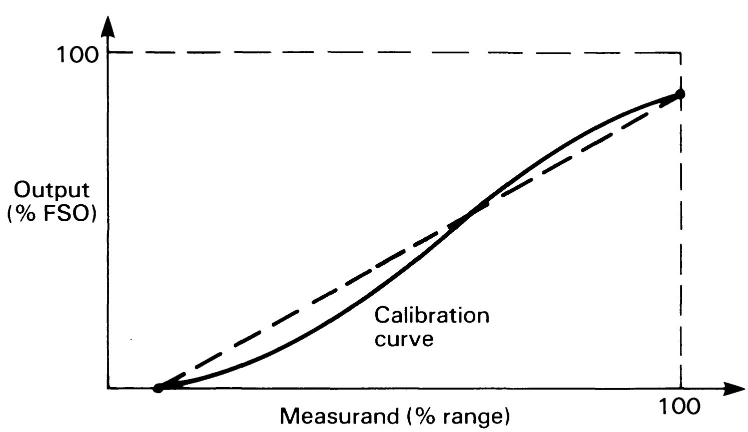


**Figure 1.3**

(b) *End-point line*
The straight line between the end points, namely the output values at the upper and lower measurand range limits obtained during any one calibration (see broken line in Figure 1.3).

(c) *Best straight line*
A line midway between the two parallel straight lines which are closest together and envelop all the output values obtained during calibration (see broken line in Figure 1.4).

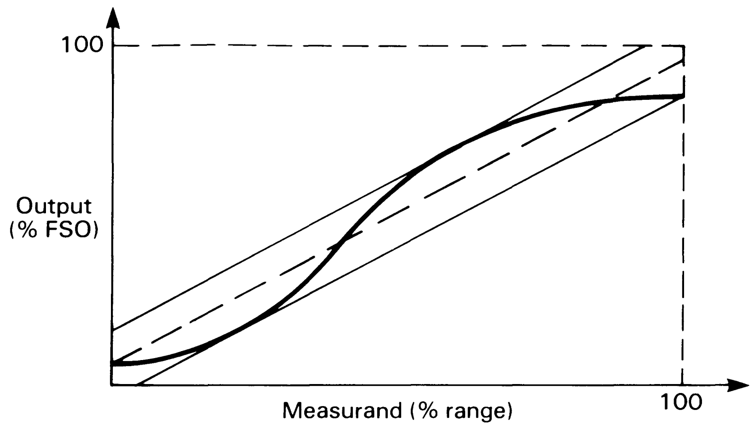


**Figure 1.4**

*Precision*—can be defined as the tolerance within which a measurement can be repeated (e.g. the ability of a device to give the same output value

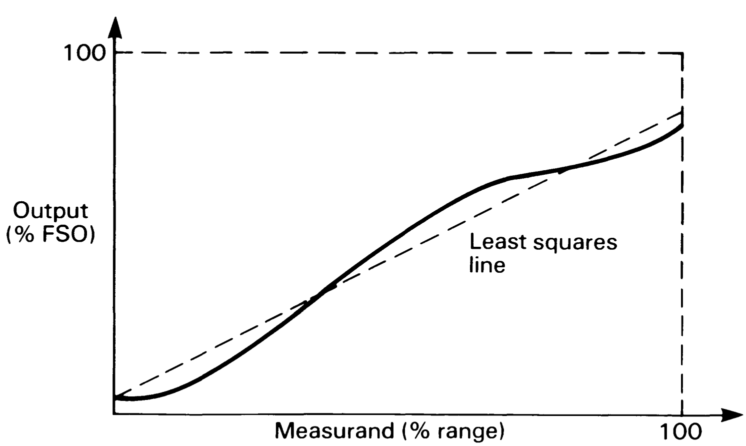


**Figure 1.5**

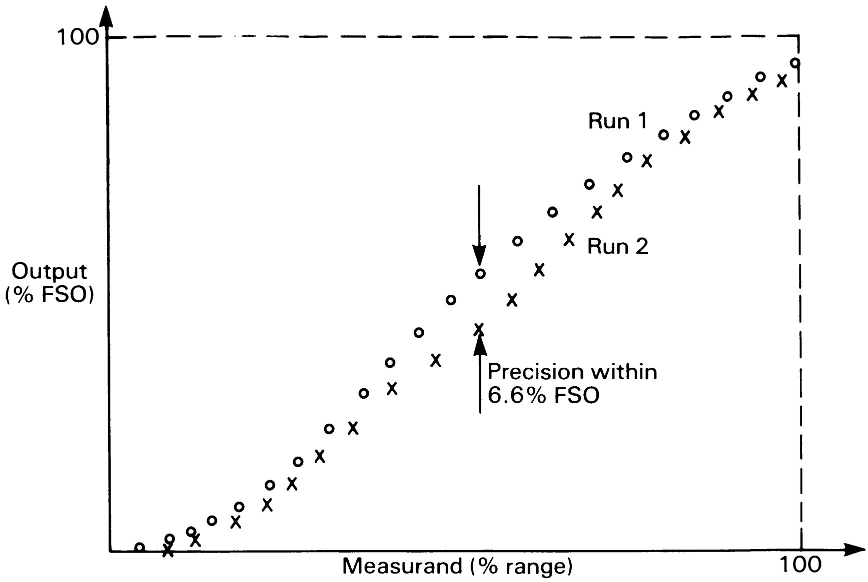


**Figure 1.6**

when the same input value is applied to it). Precision is normally expressed as a percentage of FSO and is sometimes referred to as *repeatability*. Note that the measurement must be carried out always in the same way to avoid hysteresis problems. See Figure 1.6.

*Hysteresis*—can be defined as the maximum difference in the output values

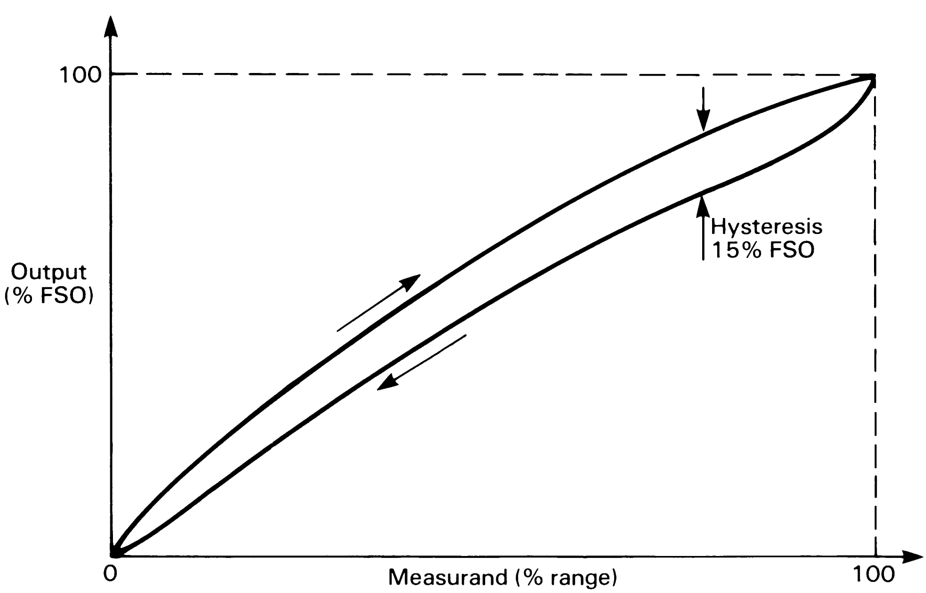


**Figure 1.7**

obtained by covering the measurand range first in the increasing direction (i.e. from zero to 100%) and then in the decreasing direction (i.e. from 100% to zero). See Figure 1.7.

*Sensitivity*—can be defined as the relationship between the variations in the output electrical quantity and the corresponding variations in the input physical quantity.

*Resolution*—can be defined as the magnitude of the output step changes produced by a continuously varying measurand. Normally expressed as a percentage of FSO. For digital output devices resolution is given by the number of bits in the output data word(s) or, in the case of incremental position transducers, by the number of states obtained per unit measurand change. Figure 1.8 shows the output for a wirewound potentiometer with a very poor resolution of 2.5% FSO.

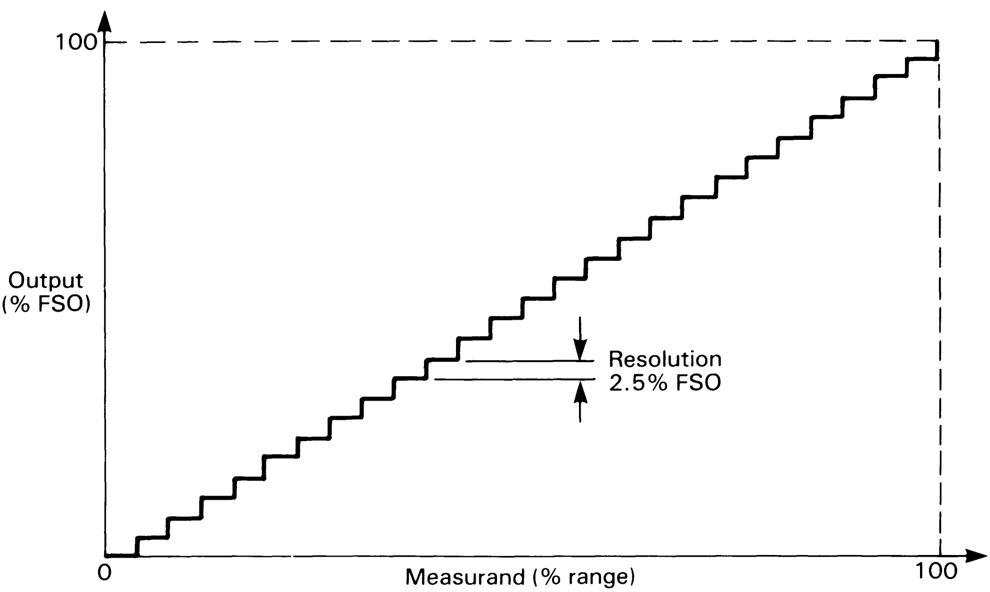


**Figure 1.8**

*Dynamic characteristics* relate the response of the device to variations of the measurand with respect to time. The most important ones are the frequency- and step-response characteristics.

*Frequency response*—can be defined as the variations in the output curve given a sinusoidally varying, constant amplitude, input measurand, see Figure 1.9. Please note that the output is normally shown as a ratio of the output amplitude divided by measurand amplitude, expressed in percentage.

*Step response*—can be defined as the variation in the output value given a

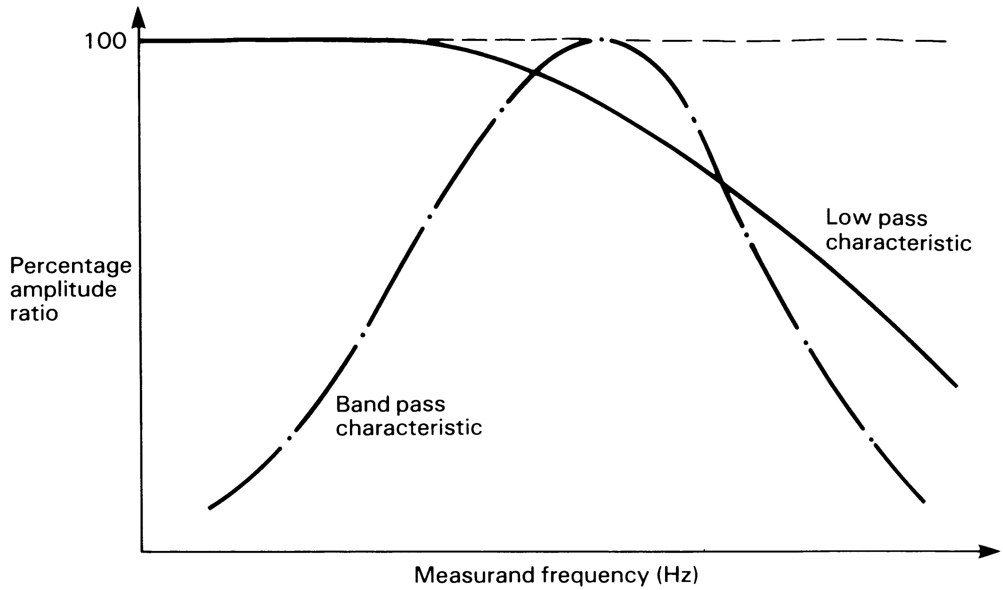


**Figure 1.9**

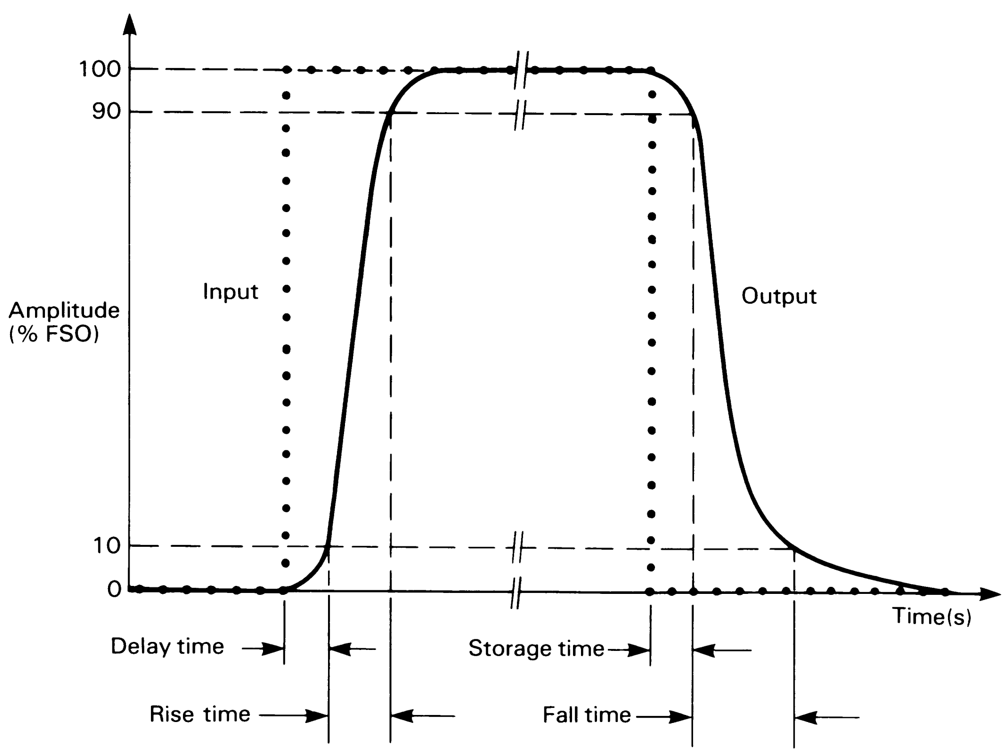


**Figure 1.10**

step change in the input measurand value. The time required for the output to reach a specified percentage of the final value is termed the 'response time'. These specified percentages are usually 10% and 90% of the final value.

As shown in Figure 1.10 there are four main types of response time:

- *Delay time*—the time taken for the output to rise to 10% of the final value once the input step has been applied.
- *Rise time*—the time taken for the output to rise from 10% to 90% of the final value.
- *Storage time*—the time taken for the output to fall to 90% of the final value once the input step has been removed.
- *Fall time*—the time taken for the output to fall from 90% to 10% of the final value.

Other important elements of the output characteristic are noise and noise margins, which can be defined as:

*Noise*—the level of any spurious signal(s) appearing at the output of the device due to any cause other than the driving input physical quantity.

*Noise margin*—the maximum noise level that can be tolerated by the device before it has any significant effect on the output signal.