Example

Suppose that a standard mass is measured 30 times with the same instrument to create a reference data set, and the calculated values of s and a are σ = 0.46 and α = 0.08. If the instrument is then used to measure an unknown mass and the reading is 105.6 kg, how should the mass value be expressed?

Solution:

The estimation of random error in this single measurement

$1.96(\sigma + \alpha) = 1.06$. The mass value should therefore be expressed as

105.6 ± 1.1 kg.

CHAPTER TWO

2.1 Types of instruments

2.1.1 Active and Passive Instruments

* Instruments are divided into active or passive ones according to whether the instrument output is entirely produced by the quantity being measured or whether the quantity being measured simply modulates the magnitude of some external power source.

In active instruments, the external power source is usually in electrical form, but in some cases, it can be in other forms of energy such as a pneumatic or hydraulic one.

** One very important difference between active and passive instruments is the level of measurement resolution that can be obtained. In terms of cost, passive instruments are normally of a more simple construction than active ones and are therefore cheaper to manufacture. Therefore, choice between active and passive instruments for a particular application involves carefully balancing the measurement resolution requirements against cost.

2.1.2 Null-Type and Deflection-Type Instruments

* The accuracy of these two instruments depends on different things. For the first one it depends on the linearity and calibration of the spring, while for the second it relies on the calibration of the weights. The calibration of weights is much easier than careful choice and calibration of a linear-characteristic spring, which means that the second type of instrument will normally be the more accurate. This is in accordance with the general rule that null-type instruments are more accurate than deflection types.

** In terms of usage, the deflection-type instrument is clearly more convenient. It is far simpler to read the position of a pointer against a scale than to add and subtract weights until a null point is reached.

2.1.3 Analog and Digital Instruments

* **An analog instrument** gives an output that varies continuously as the quantity being measured changes. The output can have an infinite number of values within the range that the instrument is designed to measure.

** **A digital instrument** has an output that varies in discrete steps and so can only have a finite number of values.

*** The distinction between analog and digital instruments has become particularly important with the rapid growth in the application of microcomputers to automatic control systems. Any digital computer system, of which the microcomputer is but one example, performs its computations in digital form. An instrument whose output is in digital form is therefore particularly advantageous in such applications, as it can be interfaced directly to the control computer. Analog instruments must be interfaced to the microcomputer by an **analog-to-digital (A/D) converter**, which converts the analog output signal from the instrument into an equivalent digital quantity that can be read into the computer. This conversion has several disadvantages.

First, the A/D converter adds a significant cost to the system.

Second, a finite time is involved in the process of converting an analog signal to a digital quantity, and this time can be critical in the control of fast processes where the accuracy of control depends on the speed of the controlling computer.

2.1.4 Indicating Instruments and Instruments with a Signal Output

* The class of indicating instruments normally includes all null-type instruments and most passive ones. Indicators can also be further divided into those that have an analog output and those that have a digital display.

** One major drawback with indicating devices is that human intervention is required to read and record a measurement. This process is particularly prone to error in the case of analog output displays, although digital displays are not very prone to error unless the human reader is careless.

*** Instruments that have a signal-type output are commonly used as part of automatic control systems.

2.1.5 Smart and Nonsmart Instruments

The advent of the microprocessor has created a new division in instruments between those that do incorporate a microprocessor (smart) and those that do not.

2.2 Static Characteristics of Instruments

The various static characteristics are defined in the following paragraphs.

2.2.1 Accuracy and Inaccuracy (Measurement Uncertainty)

The accuracy of an instrument is a measure of how close the output reading of the instrument is to the correct value.

Inaccuracy or measurement uncertainty is the extent to which a reading might be wrong, and is often quoted as a percentage of the full-scale reading of an instrument.

2.2.2 Precision/Repeatability/Reproducibility

Precision is a term that describes an instrument's degree of freedom from random errors. If a large number of readings are taken of the same quantity by a high-precision instrument, then the spread of readings will be very small. Precision is often, though incorrectly, confused with accuracy. High precision does not imply anything about measurement accuracy. A high-precision instrument may have a low accuracy.

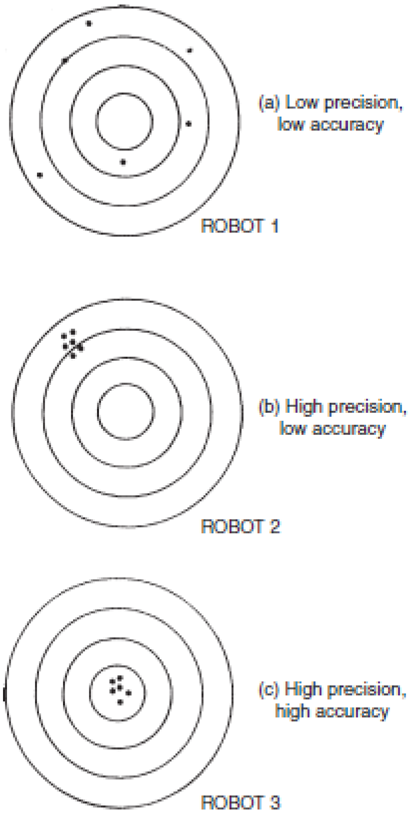

Figure 2.5
Comparison of accuracy and precision.

The terms repeatability and reproducibility mean approximately the same but are applied in different contexts as given below. ***Repeatability*** describes the closeness of output readings when the same input is applied repetitively over a short period of time, with the same measurement conditions, same instrument and observer, same location, and same conditions of use maintained throughout. ***Reproducibility*** describes the closeness of output readings for the same input when there are changes in the method of measurement, observer, measuring instrument, location, conditions of use, and time of measurement.

Both terms thus describe the spread of output readings for the same input. This spread is referred to as repeatability if the measurement conditions are constant and as reproducibility if the measurement conditions vary.

2.2.3 Tolerance

Tolerance is a term that is closely related to accuracy and defines the maximum error that is to be expected in some value.

Example 2.1

A packet of resistors bought in an electronics component shop gives the nominal resistance value as 1000Ω and the manufacturing tolerance as ±5%. If one resistor is chosen at random from the packet, what is the minimum and maximum resistance value that this particular resistor is likely to have?

Solution

The minimum likely value is 1000Ω - 5% = 950 Ω.

The maximum likely value is 1000Ω + 5% = 1050 Ω.

2.2.4 Range or Span

The range or span of an instrument defines the minimum and maximum values of a quantity that the instrument is designed to measure.

Example 2.2

A particular micrometer is designed to measure dimensions between 50 and 75 mm. What is its measurement range?

Solution

The measurement range is simply the difference between the maximum and minimum measurements.

Thus, in this case the range is

75 - 50 = 25 mm.

2.2.5 Threshold

If the input to an instrument is gradually increased from zero, the input will have to reach a certain minimum level before the change in the instrument's output reading is of a large enough magnitude to be detectable. This minimum level of input is known as the threshold of the instrument.

2.2.6 Resolution

When an instrument is showing a particular output reading, there is a lower limit on the magnitude of the change in the input measured quantity that produces an observable change in the instrument output. Like threshold, resolution is sometimes specified as an absolute value and sometimes as a percentage of the full scale deflection.

2.2.7 Linearity

It is normally desirable that the output reading of an instrument is linearly proportional to the quantity being measured. The X's marked on Figure below show a plot of the typical output readings of an instrument when a sequence of input quantities are applied to it.

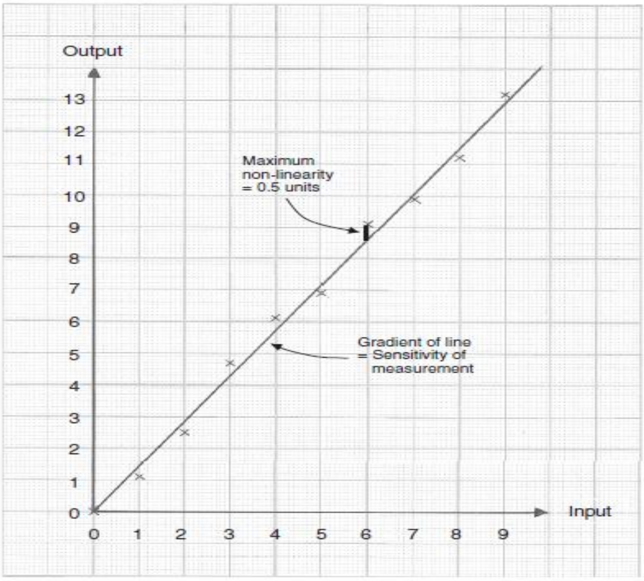

Figure 2.2 Instrument output characteristic

The nonlinearity is then defined as the maximum deviation of any of the output readings marked X from this straight line. Nonlinearity is usually expressed as a percentage of full-scale reading.

Example 2.3

Suppose that the instrument characteristic shown in Figure 2.6 is that of a pressure sensor, where the input units are expressed in bars from 1 to 9 bars and the output units are expressed in volts from 1 to 13 V.

(a) What is the maximum nonlinearity expressed as a percentage of the full scale deflection?

(b) What is the resolution of the sensor as determined by the instrument characteristic given?

Solution

(a) The maximum nonlinearity is the maximum deviation of any data point on Figure above away from the straight line drawn through the data points. This is shown by the thick line drawn on Figure 2.6. The length of this line is 0.5 units, which translates to 0.5 V. The full scale deflection (calculated for the fitted straight line) is 13.0 units, which translates to 13.0 V.

The maximum nonlinearity can therefore be expressed as

$$\frac{0.5}{13} \times 100 = 3.8\% \text{ of the full scale deflection.}$$

(b) The resolution of the sensor as determined from the graph in Figure above is the smallest change in input that is detectable. For the graph paper illustrated, the naked eye cannot determine anything smaller than one small square, which is one tenth of a unit or 0.1 bar. This figure of 0.1 bar pressure is therefore the resolution of the sensor as determined from the graph.

2.2.8 Sensitivity of Measurement

The sensitivity of measurement is a measure of the change in instrument output that occurs when the quantity being measured changes by a given amount. Thus, sensitivity is the ratio:

$$\frac{\text{scale deflection}}{\text{value of measurand producing deflection}}$$

The sensitivity of measurement is therefore the slope of the straight line drawn on Figure 2.2. If, for example, a pressure of 2 bar produces a deflection of 10 degrees in a pressure transducer, the sensitivity of the instrument is 5 degrees/bar (assuming that the deflection is zero with zero pressure applied).

Example 2.4

The following resistance values of a platinum resistance thermometer were measured at a range of temperatures. Determine the measurement sensitivity of the instrument in Ω /°C.

Resistance (Ω)	Temperature (°C)
307	200
314	230
321	260
328	290

Solution

If these values are plotted on a graph, the straight-line relationship between resistance change and temperature change is obvious.

For a change in temperature of 30 ^{o}C, the change in resistance is 7 **Ω**. Hence the measurement sensitivity = 7/30 = 0.233 Ω/^{o}C.

2.2.9 Sensitivity to Disturbance

All calibrations and specifications of an instrument are only valid under controlled conditions of temperature, pressure, etc. These standard ambient conditions are usually defined in the instrument specification. As variations occur in the ambient temperature, etc., certain static instrument characteristics change, and the sensitivity to disturbance is a measure of the magnitude of this change. Such environmental changes affect instruments in two main ways, known as ***zero drift*** and ***sensitivity drift***. Zero drift is sometimes known by the alternative term, bias.

Zero drift or Bias describes the effect where the zero reading of an instrument is modified by a change in ambient conditions. This causes a constant error that exists over the full range of measurement of the instrument.

The typical unit by which such zero drift is measured is V/^{o}C. This is often called the ***zero drift coefficient*** related to temperature changes. If the characteristic of an instrument is sensitive to several environmental parameters, then it will have several zero drift coefficients, one for each environmental parameter.

Sensitivity drift (also known as scale factor drift) defines the amount by which an instrument's sensitivity of measurement varies as ambient conditions change. It is quantified by sensitivity drift coefficients that define how much drift there is for a unit change in each environmental