CHAPTER I

REVIEW OF BASIC INSTRUMENTATION

Definition: ***instrument*** is a device that transforms a physical variable of interest (the measurand) into a form that is suitable for recording (the measurement). In order for the measurement to have broad and consistent meaning, it is common to employ a standard system of units by which the measurement from one instrument can be compared with the measurement of another.

An example of a basic instrument is a ruler. In this case the measurand is the length of some object and the measurement is the number of units (meters, inches, etc.) that represent the length.

1.1 General Principles of Instrumentation

Since we have said an instrument is used to transform a physical variable into a suitable measurement or record it needs some element to do so.

The key functional element of the instrument model are:

1. ***Primary sensor:*** this gives an output that is a function of the measurand (the input applied to it). For most but not all sensors, this function is at least approximately linear. Some examples of primary sensors are a liquid-in-glass thermometer, a thermocouple and a strain gauge. In the case of the mercury-in-glass thermometer, the output reading is given in terms of the level of the mercury, and so this particular primary sensor is also a complete measurement system in itself. However, in general, the primary sensor is only part of a measurement system.
2. ***Variable conversion elements:*** are needed where the output variable of a primary transducer is in an inconvenient form and has to be converted to a more convenient form. For instance, the displacement-measuring strain gauge has an output in the form of a varying resistance. The resistance change cannot be easily measured and so it is converted to a change in voltage by a *bridge circuit*, which is a typical example of a variable conversion element.

In some cases, the primary sensor and variable conversion element are combined, and the combination is known as a transducer.

3. ***Signal processing elements:*** exist to improve the quality of the output of a measurement system in some way.
   A very common type of signal processing element is the electronic amplifier, which amplifies the output of the primary transducer or variable conversion element, thus improving the sensitivity and resolution of measurement. This element of a measuring system is particularly important where the primary transducer has a low

output. For example, thermocouples have a typical output of only a few millivolts. Other types of signal processing element are those that filter out induced noise and remove mean levels etc.

In some devices, signal processing is incorporated into a transducer, which is then known as a transmitter.

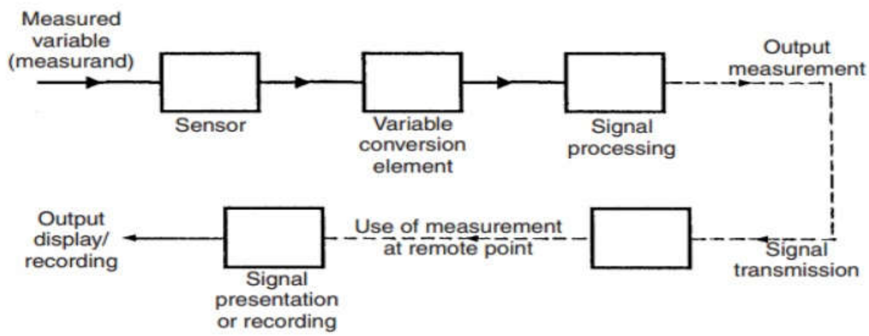


Figure 1.1: Elements of a measuring instrument

<u>Choosing appropriate measuring instruments</u>

The starting point in choosing the most suitable instrument to use for measurement of a particular quantity in a manufacturing plant or other system is

1. The specification of the instrument characteristics required, especially parameters like the desired measurement ***accuracy, resolution, sensitivity and dynamic performance***.
2. It is also essential to know the environmental conditions that the instrument will be subjected to, as some conditions will immediately either eliminate the possibility of using certain types of instrument or else will create a requirement for expensive protection of the instrument. It should also be noted that protection reduces the performance of some instruments, especially in terms of their dynamic characteristics (for example, sheaths protecting thermocouples and resistance thermometers reduce their speed of response).
3. The extent to which the measured system will be disturbed during the measuring process is another important factor in instrument choice. For example, significant pressure loss can be caused to the measured system in some techniques of flow measurement.
4. Generally, the better the characteristics, the higher the cost. However, in comparing the cost and relative suitability of different instruments for a particular measurement

situation, considerations of ***durability, maintainability and constancy*** of performance are also very important because the instrument chosen will often have to be capable of operating for long periods without performance degradation and a requirement for costly maintenance. Cost is very strongly correlated with the performance of an instrument, as measured by its static characteristics.

To summarize therefore, instrument choice is a compromise between performance characteristics, ruggedness and durability, maintenance requirements and purchase cost.

Instrument types and performance characteristics

Instruments can be subdivided into separate classes according to several criteria. These sub classifications are useful in broadly establishing several attributes of particular instruments such as ***accuracy, cost, and general applicability*** to different applications.

1. Active and Passive Instruments

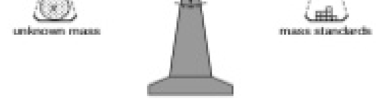
- ***Passive element:*** when instrument's output is entirely produced by the quantity being measured. Less cost and simple construction.
- ***Active element:*** when an instrument's quantity being measured simply modulates the magnitude of some external power source. In active instruments, the external power source is usually in electrical form, but in some cases, it can be other forms of energy such as a pneumatic or hydraulic one.

Therefore, choice between active and passive instruments for a particular application involves carefully balancing the measurement resolution requirements against cost.

2. Null-type and deflection-type instruments

Null-type

The purpose of any null mode instrument is to act like a laboratory balance scale, indicating when the two quantities are equal. The laboratory scale balance beam doesn't actually weight anything; rather, it simply indicates *equality* between the unknown mass and a pile of standard (calibrated) known masses. Balance beam acts as a "null detector", its scale need not be accurately calibrated, but it must accurately indicate the "null" or balance condition.



Deflection-type

While a null-mode instrument is as accurate as its known standard value that the unknown quantity is balanced against, it is an iterative process that can take time to complete. The deflection-mode instrument is faster but less accurate. The best example of a deflection mode instrument is a spring-loaded scale that measures weight.

3. Analogue and digital instruments

An analogue 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.

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 ***analogue output*** and those that have a ***digital display***.

A common analogue indicator is the liquid-in-glass thermometer. Another common indicating device, which exists in both analogue and digital forms, is the bathroom scale. The older mechanical form of this is an analogue type of instrument that gives an output consisting of a rotating pointer moving against a scale (or sometimes a rotating scale moving against a pointer).

Instruments that have a signal-type output are commonly used as part of automatic control systems. In other circumstances, they can also be found in measurement systems where the output measurement signal is recorded in some way for later use.

5. Smart and non-smart instruments

Instruments those that do incorporate a microprocessor (smart) and those that don't is non-smart.

<u>Static characteristics of instruments</u>

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. In practice, it is more usual to quote the *inaccuracy* figure rather than the accuracy figure for an instrument.

Inaccuracy is the extent to which a reading might be wrong, and is often quoted as a percentage of the full-scale (f.s.) reading of an instrument. If, for example, a pressure gauge of range 0–10 bar has a quoted inaccuracy of ±1.0% f.s. (±1% of full-scale reading), then the maximum error to be expected in any reading is 0.1 bar. This means that when the instrument is reading 1.0 bar, the possible error is 10% of this value. The term *measurement uncertainty* is frequently used in place of inaccuracy.

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. Low accuracy measurements from a high precision instrument are normally caused by a bias in the measurements, which is removable by recalibration.

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.*

The degree of repeatability or reproducibility in measurements from an instrument is an alternative way of expressing its precision.

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.

Whilst it is not, strictly speaking, a static characteristic of measuring instruments, it is mentioned here because the accuracy of some instruments is sometimes quoted as a tolerance figure. When used correctly, tolerance describes the maximum deviation of a manufactured component from some specified value.

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.

5. Linearity

It is normally desirable that the output reading of an instrument is linearly proportional to the quantity being measured. ***The non-linearity*** is then defined as the maximum deviation of any of the output readings. Non-linearity is usually expressed as a percentage of full-scale reading.

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

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). The sensitivity of measurement is therefore the slope of the straight line drawn on Figure 1.2

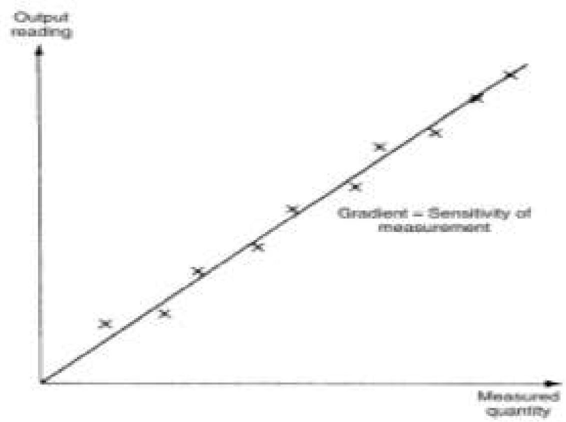


Figure 1.2: Instrument output characteristic.

7. 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 output reading is of a large enough magnitude to be detectable. *This minimum level of input is known as the threshold of the instrument.* Manufacturers vary in the way that they specify threshold for instruments. Some quote absolute values, whereas others quote threshold as a percentage of full-scale readings. As an illustration, a car speedometer typically has a threshold of about 15 km/h. This means that, if the vehicle starts from rest and accelerates, no output reading is observed on the speedometer until the speed reaches 15 km/h.

8. 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 f.s. deflection. One of the major factors influencing the resolution of an instrument is how finely its output scale is divided into subdivisions. Using a car speedometer as an example again, this has subdivisions of typically 20 km/h. This means that when the needle is between the scale markings, we cannot estimate speed more accurately than to the nearest 5 km/h. This figure of 5 km/h thus represents the resolution of the instrument.

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.

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 parameter that the instrument characteristics are sensitive to.

10. Dead space

Dead space is defined as the range of different input values over which there is no change in output value.

Dynamic characteristics of instruments

The static characteristics of measuring instruments are concerned only with the steady state reading that the instrument settles down to, such as the accuracy of the reading etc.

The dynamic characteristics of a measuring instrument describe its behavior between the time a measured quantity changes value and the time when the instrument output attains a steady value in response. As with static characteristics, any values for dynamic characteristics quoted in instrument data sheets only apply when the instrument is used under specified environmental conditions. Outside these calibration conditions, some variation in the dynamic parameters can be expected.

Based on a dynamics characteristics of instruments may be:

- Zero order instrument
- First order instrument
- Second order instrument

1.2 Structure of measurement systems

The measurement system consists of several elements or blocks. It is possible to identify four types of element, although in a given system one type of element may be missing or may occur more than once. The four types are shown in Figure 1.3 and can be defined as follows

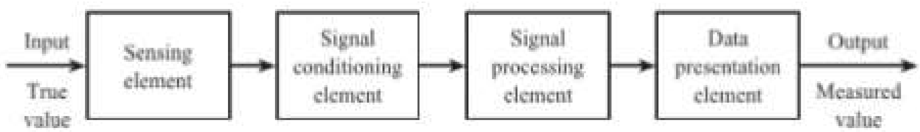


Figure 1.3: General structure of measurement system.

Sensing element

This is in contact with the process and gives an output which depends in some way on the variable to be measured. Examples are:

- Thermocouple where millivolt e.m.f. depends on temperature
- Strain gauge where resistance depends on mechanical strain
- Orifice plate where pressure drop depends on flow rate

If there is more than one sensing element in a system, the element in contact with the process is termed the primary sensing element, the others secondary sensing elements.

Signal conditioning element

This takes the output of the sensing element and converts it into a form more suitable for further processing, usually a d.c. voltage, d.c. current or frequency signal.

Examples are:

- Deflection bridge which converts an impedance change into a voltage change
- Amplifier which amplifies millivolts to volts
- Oscillator which converts an impedance change into a variable frequency voltage.

Signal processing element

This takes the output of the conditioning element and converts it into a form more suitable for presentation. Examples are:

- Analogue-to-digital converter (ADC) which converts a voltage into a digital form for input to a computer
- Computer which calculates the measured value of the variable from the incoming digital data.

Typical calculations are:

- Computation of total mass of product gas from flow rate and density data
- Integration of chromatograph peaks to give the composition of a gas stream
- Correction for sensing element non-linearity.

Data presentation element

This presents the measured value in a form which can be easily recognized by the observer. Examples are:

- Simple pointer–scale indicator
- Chart recorder
- Alphanumeric display
- Visual display unit (VDU).