Instrument Types and Performance Characteristics

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Active Instruments
- the quantity being measured simply modulates (adapts to) the magnitude of some external power source.

Passive Instruments
- the instrument output is entirely produced by the quantity being measured

Difference between active & passive instruments is the level of measurement resolution that can be obtained.
Instrument Types
Active Instruments-1

e.g. Float-type petrol tank level indicator

The change in petrol level moves a potentiometer arm, and the output signal consists of a proportion of the external voltage source applied across the two ends of the potentiometer.

The energy in the output signal comes from the external power source: the primary transducer float system is merely modulating the value of the voltage from this external power source.
Instrument Types

Active Instruments-2

- The change in petrol level moves a potentiometer arm, and the output signal consists of a proportion of the external voltage source applied across the two ends of the potentiometer.
- The energy in the output signal comes from the external power source: the primary transducer float system is merely modulating the value of the voltage from this external power source.

Instrument Types

Passive Instruments-1

e.g. Pressure-measuring device
Instrument Types
Passive Instruments

- The pressure of the fluid is translated into a movement of a pointer against scale.
- The energy expanded in moving the pointer is derived entirely from the change in pressure measured: there are no other energy inputs to the system.

Instrument Types
Analog and Digital Instruments

Analog Instrument

- An analogue instrument gives an output that varies continuously as the quantity being measured; e.g. *Deflection-type of pressure gauge*

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FIGURE 25 A thermocouple provides an analog signal for processing.
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Instrument Types
Analog and Digital Instruments

Digital Instrument

- A digital instrument has an output that varies in discrete steps and only have a finite number of values; e.g. Revolution counter

![Diagram of digital instrument components](image)

**FIGURE 1.6** A rotating shaft with a revolution counter produces a digital signal.

Smart and Non-smart Instruments

Smart Instrument

- An instrument with a microprocessor to do some operations during and after measurements

Non-Smart Instrument
**Static Characteristics**

**Definition**

- The **steady state** relationship between input and output of an instrument
- Measurement of quantities that are constant or vary quite slowly with respect to time.
- It does not involve differential equations.

**Important Parameters**

- Accuracy and Precision
- Repeatability/Reproducibility
- Tolerance
- Range or span
- Linearity
- Sensitivity of measurement
- Threshold
- Resolution
- Sensitivity to disturbance
- Hysteresis effects
- Dead space
The accuracy of an instrument is a measure of how close the output reading of the instrument is to the correct value.

Measurements that are close to each other are precise.

Measurements can be:

- Precise but inaccurate
- Neither precise nor accurate
- Precise and accurate

Three industrial robots were programmed to place components at a particular point on a table. The target point was the center of a circle shown below. The results are:

(a) Low precision, low accuracy
(b) Precise not accurate
(c) Precise and accurate
Static Characteristics
Repeatability/Reproducibility

- **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.

Static Characteristics
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**

- Electric circuit components such as resistors have tolerances of perhaps 5%. One resistor chosen at random from a batch having a nominal value 1000Ω and tolerance 5% might have an actual value anywhere between 950Ω and 1050 Ω.
Static Characteristics

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:
- 0-20 V range of a multimeter
- 0-1 V range of an oscilloscope.

Static Characteristics

Linearity

- It is highly desirable that the measurement system has a linear relationship between input and output means that the change in output is proportional to the change in the value of the measurand.
- Deviation from true linearity is called linearity error.
**Static Characteristics**

**Sensitivity of measurement**

- **Sensitivity** is the ratio of change in magnitude of the output to the change in magnitude of the measurand.

  \[
  \text{Sensitivity} = \frac{\Delta \text{(output)}}{\Delta \text{(input)}}
  \]

  **Example:**

  If the measured output is increased by 100 mV for a temperature change of 4°C, the sensitivity is

  \[
  S = \frac{\Delta V}{\Delta T} = \frac{100 \text{ mV}}{4 \text{°C}} = 25 \text{ V/°C}
  \]

**Static Characteristics**

**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.
**Static Characteristics**

**Resolution**

- Resolution is the lower limit on the magnitude of the change in the input measured quantity that produces an observable change in the instrument output.

**Example**

- 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.

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**Static Characteristics**

**Sensitivity to disturbance**

- 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.

- Sensitivity drift (also known as scale factor drift) defines the amount by which an instrument’s sensitivity of measurement varies as ambient conditions change.
Static Characteristics
Hysteresis effects

Examples: Iron core, spring

Static Characteristics
Dead space

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

In any linear, time-invariant measuring system, the following general relation can be written between input and output for time $t > 0$:

$$\frac{d^n q_0}{dt^n} + a_{n-1}\frac{d^{n-1} q_0}{dt^{n-1}} + \cdots + a_1 \frac{dq_0}{dt} + a_0 q_0 = b_n \frac{d^n q_i}{dt^n} + b_{n-1} \frac{d^{n-1} q_i}{dt^{n-1}} + \cdots + b_1 \frac{dq_i}{dt} + b_0 q_i$$

where $q_i$ is the measured quantity, $q_0$ is the output reading and $a_0 \ldots a_n$, $b_0 \ldots b_m$ are constants.

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

Dynamic Characteristics

Zero order instrument

- If all the coefficients $a_1 \ldots a_n$ other than $a_0$ are assumed zero, then
  $$a_0 q_0 = b_0 q_i \quad \text{or} \quad q_0 = b_0 q_i / a_0 = K q_i$$

where $K$ is a constant known as the instrument sensitivity.
Dynamic Characteristics
First order instrument

- If all the coefficients $a_1 \ldots a_n$ other than $a_0$ and $a_1$ are assumed zero, then

$$a_1 \frac{dq_0}{dt} + a_0 q_0 = b_0 q_i$$

![Graph showing the relationship between magnitude and time with the time constant](image1)

Dynamic Characteristics
First order instrument

- If all the coefficients $a_1 \ldots a_n$ other than $a_0$, $a_1$ and $a_2$ are assumed zero, then

$$a_2 \frac{d^2 q_0}{dt^2} + a_1 \frac{dq_0}{dt} + a_0 q_0 = b_0 q_i$$

![Graph showing the relationship between magnitude and time](image2)
Instruments
Calibration and Recalibration

- A new instrument will have been calibrated when it is obtained from an instrument manufacturer, and will therefore initially behave according to the characteristics stated in the specifications.
- During use, however, its behaviour will gradually diverge from the stated specification for a variety of reasons. Such reasons include mechanical wear, and the effects of dirt, dust, fumes and chemicals in the operating environment.
- The rate of divergence from standard specifications varies according to the type of instrument, the frequency of usage and the severity of the operating conditions.
- When the characteristics of the instrument will have drifted from the standard specification by an unacceptable amount, then it is necessary to recalibrate the instrument to the standard specifications.