SKN3022
PROCESS INSTRUMENTATION
CHAPTER III

INSTRUMENTATION CHARACTERISTICS

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INSTRUMENTATION CHARACTERISTICS

- Shows the performance of instruments to be used.
- Divided into two categories: static and dynamic characteristics.
- Static characteristics refer to the comparison between steady output and ideal output when the input is constant.
- Dynamic characteristics refer to the comparison between instrument output and ideal output when the input changes.

STATIC CHARACTERISTICS

1. ACCURACY

- **Accuracy is the ability of an instrument to show the exact reading.**
- **Always related to the extent of the wrong reading/non accuracy.**
- **Normally shown in percentage of error which of the full scale reading percentage.**

STATIC CHARACTERISTICS

Example :

A pressure gauge with a range between 0-1 bar with an accuracy of ± 5% fs (full-scale) has a maximum error of:

$$\frac{5}{100} \times 1 \text{ bar} = \pm 0.05 \text{ bar}$$

Notes: It is essential to choose an equipment which has a suitable operating range.

STATIC CHARACTERISTICS

Example :

A pressure gauge with a range between 0 - 10 bar is found to have an error of ± 0.15 bar when calibrated by the manufacturer.

Calculate :

a. The error percentage of the gauge.

b. The error percentage when the reading obtained is 2.0 bar.

STATIC CHARACTERISTICS

Answer :

a. Error Percentage $= \pm \frac{0.15 \text{ bar}}{10.0 \text{ bar}} \times 100 = \pm 1.5\%$

b. Error Percentage $= \pm \frac{0.15 \text{ bar}}{2.0 \text{ bar}} \times 100 = \pm 7.5\ \%$

- The gauge is not suitable for use for low range reading.
- Alternative : use gauge with a suitable range.

STATIC CHARACTERISTICS

Example :

Two pressure gauges (pressure gauge A and B) have a full scale accuracy of ± 5%. Sensor A has a range of 0-1 bar and Sensor B 0-10 bar. Which gauge is more suitable to be used if the reading is 0.9 bar?

Answer :

Sensor A :

Equipment accuracy (in bar) $= \pm \frac{5}{100} \times 1 \text{ bar} = \pm 0.05$

Equipment accuracy

@ 0.9 bar (in %) $= \pm \frac{0.05 \text{ bar}}{0.9 \text{ bar}} \times 100 = \pm 5.6\%$

STATIC CHARACTERISTICS

Sensor B :

Equipment accuracy (in bar) = $\pm \frac{5}{100}$ x 10 bar = ± 0.5 bar

Equipment accuracy

@ 0.9 bar (in %) = $\pm \frac{0.5 \text{ bar}}{0.9 \text{ bar}}$ x 100 = ± 55%

Conclusion :

Sensor A is more suitable to use at a reading of 0.9 bar because the error percentage (± 5.6%) is smaller compared to the percentage error of Sensor B (± 55%).

Example :

A temperature sensor has a span of 20-250°C. A measurement results in a value of 55°C for the temperature. Specify the error if the accuracy is (a) ±0.5% FS, (b)±0.75% span, and (c)±0.8% of reading. What is the possible temperature in each case.

Solution

(a) Error = (±0.005)(250°C) = ±1.25°C. Thus, the actual temperature is in the range of 53.75 to 56.25°C.

(b) Error = (±0.0075)(250-20)°C = ±1.725°C. Thus, the actual temperature is in the range of 53.275 to 56.725°C.

(c) Error = (±0.008)(55°C)= ±0.44°C. Thus, the temperature is in the range of 54.56 to 55.44°C.

STATIC CHARACTERISTICS

2. PRECISION

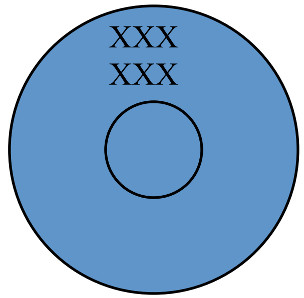
- **An equipment which is precise is not necessarily accurate.**
- **Defined as the capability of an instrument to show the same reading when used each time (reproducibility of the instrument).**

STATIC CHARACTERISTICS

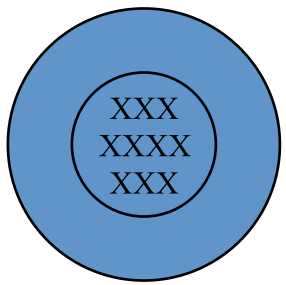
Example :

X : result

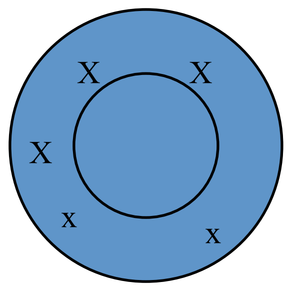
Centre circle : true value



Low accuracy, high precision



High accuracy, high precision



Low accuracy, low precision

Comparison of accuracy and precision

STATIC CHARACTERISTICS

3. TOLERANCE

- **Closely related to accuracy of an equipment where the accuracy of an equipment is sometimes referred to in the form of tolerance limit.**
- **Defined as the maximum error expected in an instrument.**
- **Explains the maximum deviation of an output component at a certain value.**

STATIC CHARACTERISTICS

4. RANGE OF SPAN

- **Defined as the range of reading between minimum value and maximum value for the measurement of an instrument.**
- **Has a positive value e.g..:**

  The range of span of an instrument which has a reading range of –100°C to 100 °C is 200 °C.

STATIC CHARACTERISTICS

5. BIAS

- Constant error which occurs during the measurement of an instrument.
- This error is usually rectified or corrected through calibration.

Example :

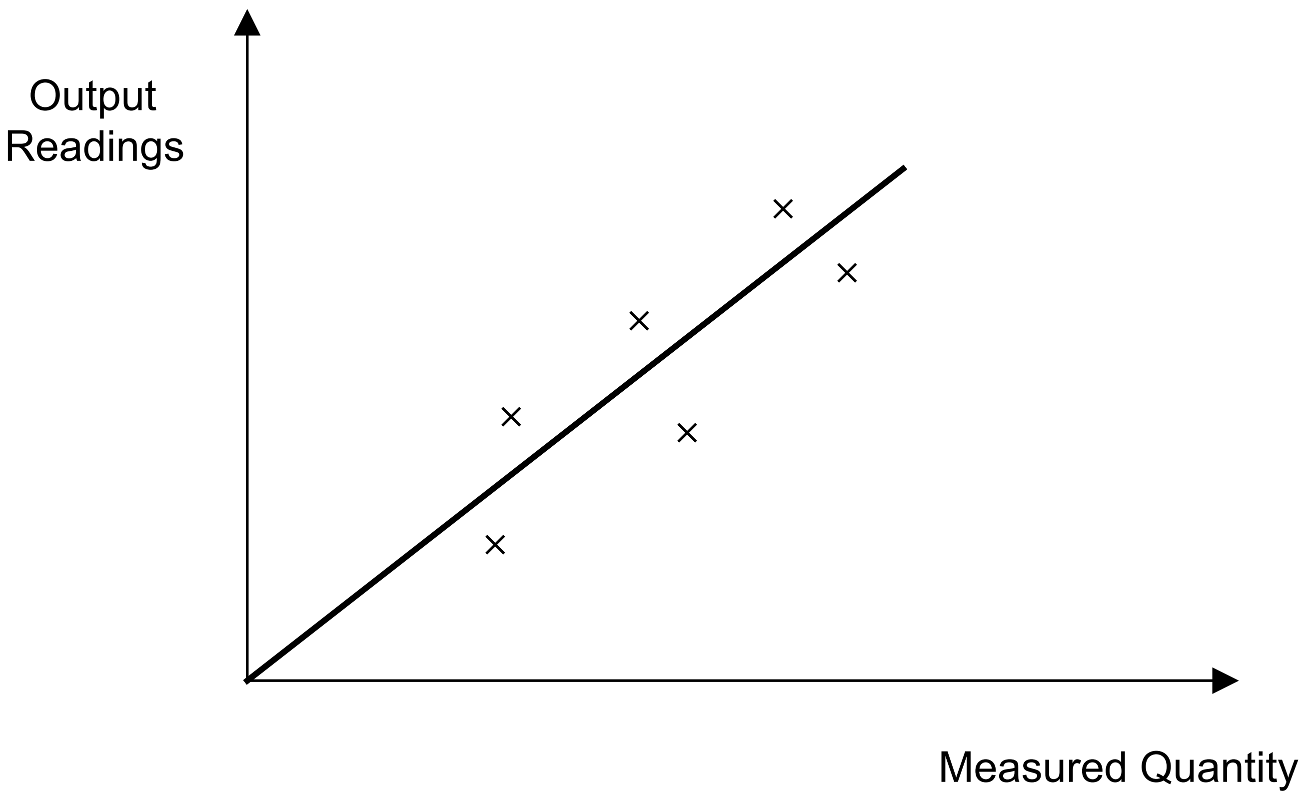
A weighing scale always gives a bias reading. This equipment always gives a reading of 1 kg even without any load applied. Therefore, if A with a weight of 70 kg weighs himself, the given reading would be 71 kg. This would indicate that there is a constant bias of 1 kg to be corrected.

STATIC CHARACTERISTICS

6. LINEARITY

- Maximum deviation from linear relation between input and output.
- The output of an instrument has to be linearly proportionate to the measured quantity.
- Normally shown in the form of full scale percentage (% fs).
- The graph shows the output reading of an instrument when a few input readings are entered.
- *Linearity* = maximum deviation from the reading of x and the straight line.

Linearity



STATIC CHARACTERISTICS

7. SENSITIVITY

- **Defined as the ratio of change in output towards the change in input in steady state.**
- Sensitivity (K) = $\dfrac{\Delta \theta_o}{\Delta \theta_i}$

$\Delta \theta_o$: *change in output;* $\Delta \theta_i$: *change in input*

Example 1:

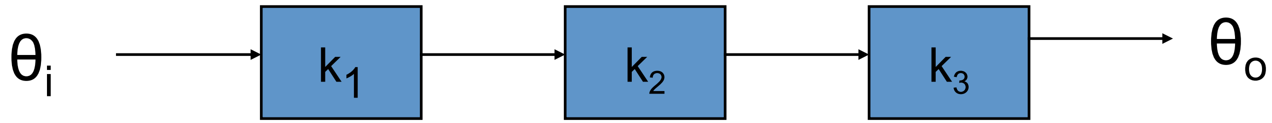
The resistance value of a Platinum Resistance Thermometer changes when the temperature increases. Therefore, the unit of sensitivity for this equipment is Ohm/°C.

STATIC CHARACTERISTICS

Example 2:

Pressure sensor A with a value of 2 bar caused a deviation of 10 degrees. Therefore, the sensitivity of the equipment is 5 degrees/bar.

- **Sensitivity of the whole system is (k) = $k_1 \times k_2 \times k_3 \times .. \times k_n$**



STATIC CHARACTERISTICS

Example:

Consider a measuring system consisting of a transducer, amplifier and a recorder, with sensitivity for each equipment given below:

Transducer sensitivity	**0.2 mV/°C**
Amplifier gain	**2.0 V/mV**
Recorder sensitivity	**5.0 mm/V**

Therefore,

Sensitivity of the whole system:

$$(k) = k_1 \times k_2 \times k_3$$

$$k = 0.2\,\frac{mV}{°C} \times 2.0\,\frac{V}{mV} \times 5.0\,\frac{mm}{V}$$

$$k = 2.0\ mm/°C$$

Example :

The output of a platinum resistance thermometer (RTD) is as follows:

Input(°C)	Output(Ohm)
0	0
100	200
200	400
300	600
400	800

Calculate the sensitivity of the equipment.

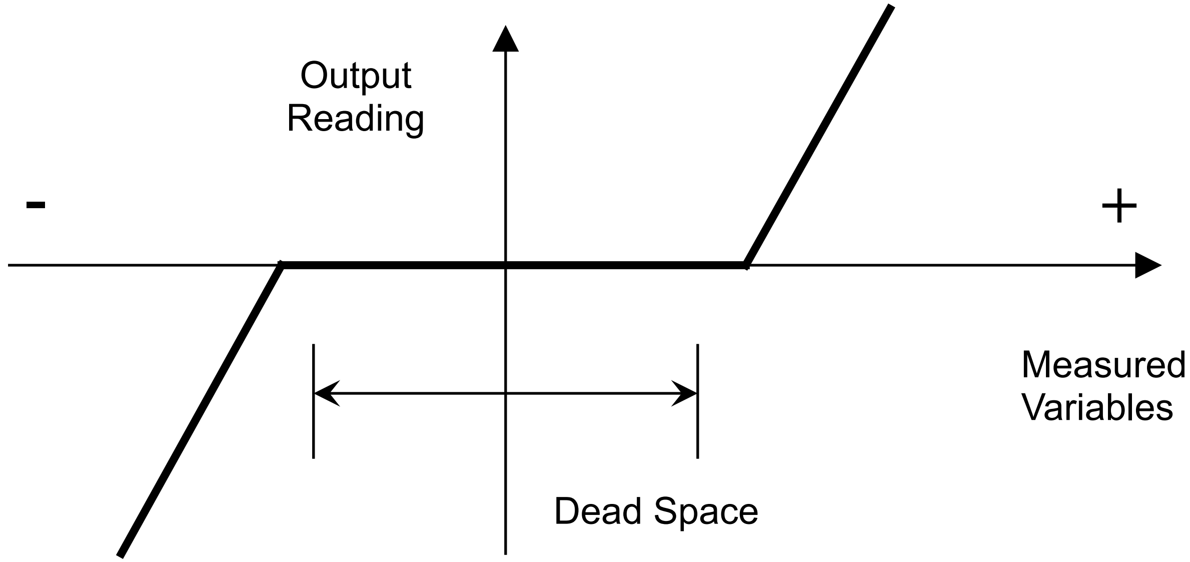
Answer :

Draw an input versus output graph. From that graph, the sensitivity is the slope of the graph.

$$K = \frac{\Delta R}{\Delta T} \qquad \text{graph slope} = \frac{(400-200)\ \text{Ohm}}{(200-100)\ °C} = 2\ \text{Ohm/°C}$$

STATIC CHARACTERISTICS

8. DEAD SPACE / DEAD BAND



- **Defined as the range of input reading when there is no change in output (unresponsive system).**

STATIC CHARACTERISTICS

9. RESOLUTION

- The smallest change in input reading that can be traced accurately.
- Given in the form '% of full scale (% fs)'.
- Available in digital instrumentation.

Example:

A force sensor measures a range of 0 to 150N with a resolution of 0.1% FS. Find the smallest change in force that can be measured.

Solution:

Because the resolution is 0.1% FS, we have a resolution of (0.001)(150N) = 0.15N, which is the smallest measurable change in force.

STATIC CHARACTERISTICS

10. THRESHOLD

- When the reading of an input is increased from zero, the input reading will reach a certain value before change occurs in the output.
- The minimum limit of the input reading is ‘threshold’.

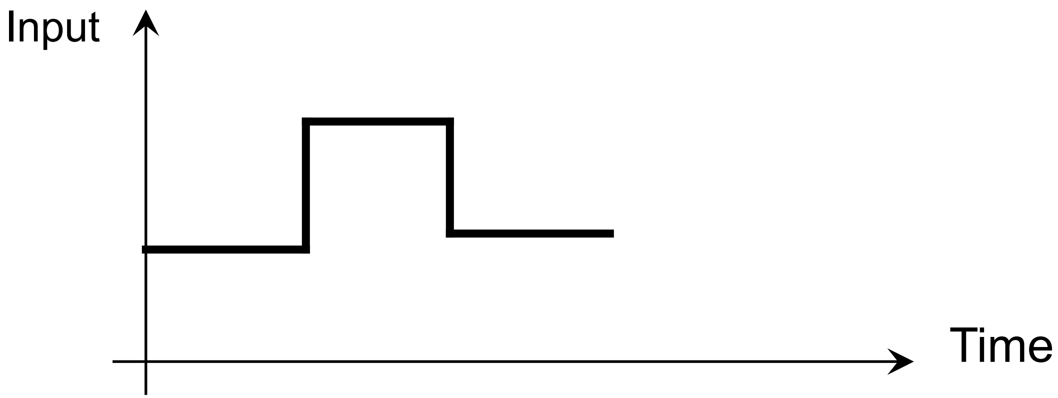
DYNAMIC CHARACTERISTICS

- **Explains the behaviour system of instruments system when the input signal is changed.**
- **Depends on a few standard input signals such as 'step input', 'ramp input' and 'sine-wave input'.**

DYNAMIC CHARACTERISTICS

Step Input

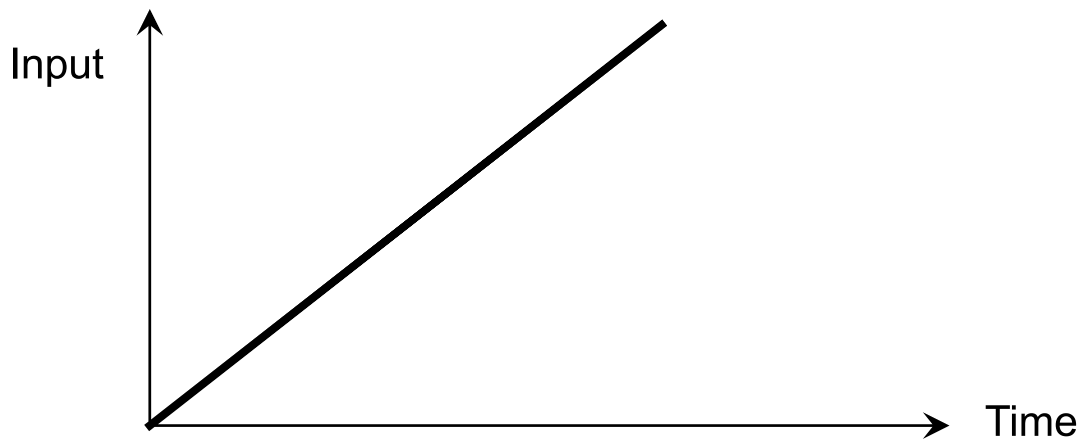
- Sudden change in input signal from steady state.
- The output signal for this kind of input is known as 'transient response'.



DYNAMIC CHARACTERISTICS

Ramp Input

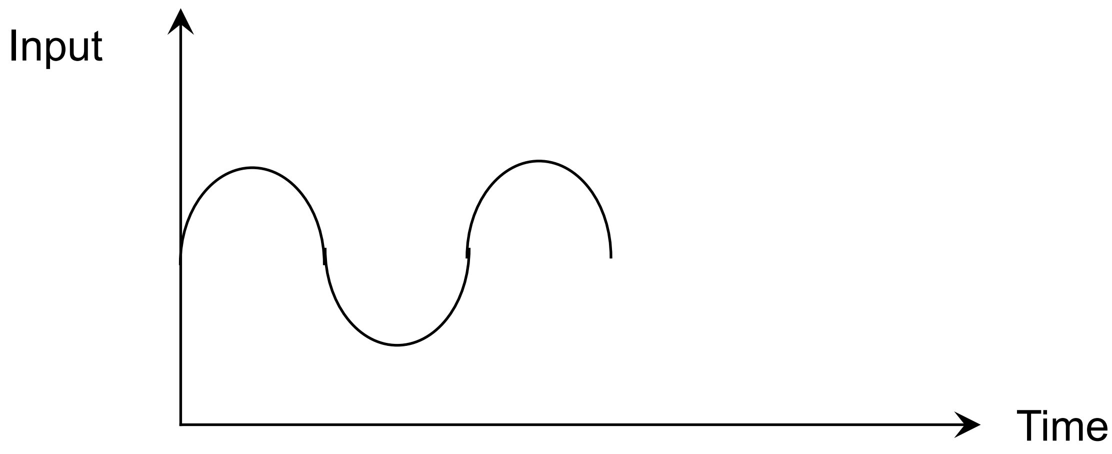
- The signal changes linearly.
- The output signal for ramp input is 'ramp response'.



DYNAMIC CHARACTERISTICS

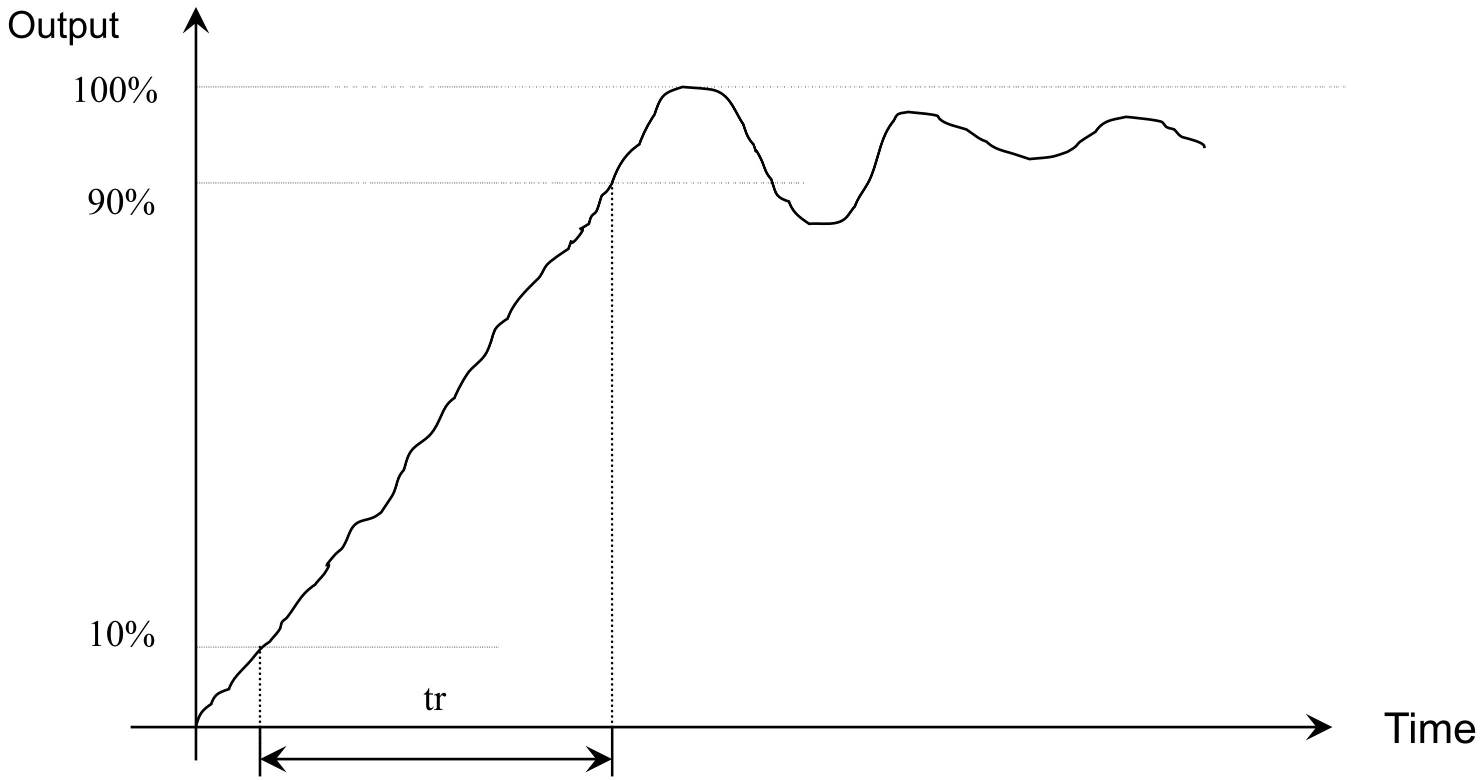
Sine-wave Input

- **The signal is harmonic.**
- **The output signal is 'frequency response'.**



EXAMPLE OF DYNAMIC CHARACTERISTICS

Response from a 2nd order instrument:



EXAMPLE OF DYNAMIC CHARACTERISTICS

Response from a 2nd order instrument:

1. <u>Rise Time (tr)</u>

- Time taken for the output to rise from 10% to 90 % of the steady state value.

2. <u>Settling time (ts)</u>

- Time taken for output to reach a steady state value.

Problems

1. A sensor resistance changes linearly from 100 to 180Ω as temperature changes from 20 to 120°C. Find a linear equation relating resistance and temperature.

2. Suppose the temperature range 20 to 120°C is linearly converted to the standard current range of 4 to 20 mA. What current will result from 66°C? What temperature does 6.5 mA represent?