

ME 226 - Mechanical Measurements (S2)

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1 Introduction

1.1 Why experiments?

- Test hypothesis, theories and models - We need to test the theory or model before it can be used to predict things. We test these by doing experiments.
- Exploratory research - Experiments are also used to explore the domains which we are not very well familiar.
- Measurement of properties - For example, if we are working with new material, we will need to use the material properties which can be found out by experiments.
- Field scale measurements - Non destructive testing. We want to know measure some properties without destroying the sample.
- Design of control systems - To design any thing, we need to measure somethings to behaviour of the system at those conditions.

1.2 Complexities in designing experiments

- Sound knowledge of engineering principles is required
- Should have a knowledge of governing principles
- Should have keen insight into the physical principles of the processes being investigated

2 Intrusive and Non intrusive based measurement techniques

Measurement techniques can be classified into intrusive and non intrusive.

- **Thermal inertia:**

- Intrusive techniques have thermal inertia, i.e, the probe takes some time to give the actual reading of the measurements.
- For example, a thermocouple used to measure the room temperature takes some time to give values near real temperature.
- Non-intrusive techniques are inertia free, i.e, they give near real value readings within negligible time.
- For example, light based/radiation based techniques take negligible time to give reading. It still takes finite time since speed of light is finite but this can be neglected.

- **Point measurement / Field measurement:**

- Intrusive techniques give point measurements, i.e, they take the measurement from a small region.
- For example, a thermocouple inserted in a water bath only measures temperature at which it is inserted. To measure temperatures at different points, we either need to change the position of the thermocouple or insert more number of thermocouples.
- Non intrusive based techniques give field measurement, i.e, they give the measurement of whole region in a single shot.

- **Representative Elementary Volume (REV):**

- Intrusive based techniques give the volume averaged reading of small finite region. This region is generally called representative elementary volume (REV).

- Non intrusive based techniques' REV is dependent on the resolution of the detector and lesser compared to intrusive based techniques.
- **Temporal and Frequency Response:**
 - As intrusive based techniques have thermal inertia, they have a poor temporal and frequency response, i.e, the rate at which they record data is low.
 - In the case of non intrusive based techniques, temporal and frequency response is only limited by the detector or camera.
- **Cost:**
 - Non intrusive based technique apparatus are generally costlier than intrusive based techniques.
 - Also non intrusive based techniques' data processing is also a bit difficult.

3 Transducers

- Transducers are devices that converts one physical effect to another by transforming one type of energy to another.
- Most used transducers are electrical transducers, i.e, devices which convert non-eletrical effects (quantities to be measured) into electrical effects. These types of transducers are prefered because the electrical signals can be easily measured and also that we can extract useful information from these signals using computers.
- Requirements of transuders:
 - **Linearity:** It is desired that the input signal and the output signal maintain linearity.
 - **Ruggedness:** Transducers are required to have high electrical and mechanical strength, so that when it gets overloaded it should not deterioate.
 - **Repeatability:** If we perform same experiment under same conditions multiple times, the results should be identical.
 - **High Signal to Noise Ratio:** The transducer should possess high SNR.
 - **Reliability:** It should be reliable.
 - **No hysteresis:** There should be no changes in output due to hysteresis, i.e, if we move from point A to point B or the other way around, there should be no change in the output. Hysteresis can occur due to thermal effects, magnetic effects etc.
- These can be classified into -

Active transducers:

- These do not require any external power source.
- They generate analog voltage or current when stimulated by some form of energy.
- For instance, thermocouples outputs an voltage that is related to temperature being measured without any external power source.
- Further amplification is required for active transducers as the output is usually low.

Passive transducers:

- These are extenally powered.
- They provide output in the form of some variation in resistance, capacitance or any other electrical parameter which has to being converted into equivalent electrical current or voltage using external energy.
- Passive transducers are complex than active transducers for getting required parameters.

4 Definitions in measurement

- **Validity:** It is the degree to which a measuring strategy (instrument, machine, or test) measures what is to be measured. A measurement is valid if it measures the required quantity accurately.
- **Reliability:** A measuring instrument is reliable if it is consistently gives same result for same experiment performed under identical conditions.

- **Readability:** Readability is the smallest difference between values that can be read from the instrument.
- **Least Count:** It is the smallest difference between indications that can be detected on the instrument scale.
- **Sensitivity:** It is the ratio of the linear movement of the pointer on an analog instrument to the change in the measured variable causing this motion
- **Hysteresis:** The system is said to exhibit hysteresis if there is a difference in reading depending on whether it is approached from above or below.
- **Accuracy:** Indicates the deviation of the reading from a known input. Accuracy is frequently expressed as a percentage of fullscale reading.
- **Precision:** Indicates its ability to reproduce a certain reading with a given accuracy.

5 Errors

- **Error in measurement:** It refers to difference between the measurement we obtain and true value of the variable.
- Sources of Error:
 - **Spacial resolution:** Probe is never a point, so the value we get is the volume averaged over some volume.
 - **Temporal error:** The reading is not measured instantaneously by the instrument, it requires some finite some time. This can lead to error.
 - **Dynamic errors:** Working with high frequency lead to this type of error. (//todo: complete this)
 - **Systematic and operational errors:** It is the difference between actual reading and the reading that instrument is showing.
 - **Hardware errors**
 - **Software errors:** Errors during data analysis using computer.
- If true value is possible to calculate, then error can be found using

$$Error = x_{measured} - x_{true}$$

- **Scatter :** If the values recorded from the a no of runs are taken, then the values deviate from the their mean, this is called scatter. The extent of scatter (standard deviation of the readings) is called uncertainty.
- **Confidence interval** is the percentage of the readings that lie in the range $mean \pm 2\sigma$ (or whatever we specify).
- Types of experimental errors
 - **Gross blunders :** The apparatus or instrument contruction invalidates the data, i.e, wrong construction.
 - **Fixed errors :** This will cause error to be shifted by a approximately same amount. This are also called as bias error or systematic error. We can model these types of errors and correct the measured values.
 - **Random errors :** Human errors, random electronic fluctuations in instruments. This *generally* a statistical distribution.

6 Uncertainty analysis

Let x_1, x_2, \dots, x_n be independent variables and they are used calculate $R(x_1, x_2, \dots, x_n)$. Let the uncertainties in the variables be w_1, w_2, \dots, w_n . Then the uncertainty in the calculated result is given by

$$w_R = \sqrt{\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \dots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2}$$

If R is of the form $R = x_1^{a_1} x_2^{a_2} \dots x_n^{a_n}$, then

$$\frac{\partial R}{\partial x_i} = x_1^{a_1} x_2^{a_2} \dots (a_i x_i^{a_i-1}) \dots x_n^{a_n}$$

$$\frac{1}{R} \frac{\partial R}{\partial x_i} = \frac{a_i}{x_i}$$

Using this,

$$\frac{w_R}{R} = \sqrt{\sum_{i=1}^n \left(\frac{a_i w_i}{x_i} \right)^2}$$