Measurement
(Motion Measurement-1)

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Introduction

- Motion is one of the most fundamental quantities in nature (length, mass, time)
- Other quantities (such as force, pressure, temperature, etc) are often measured by transducing them to motion and then measuring their resulting motion

Fundamental Standards

- Four fundamental quantities for which independent standards have been defined are: length, time, mass and temperature
- Units and standards for all other quantities are derived from these
- Before 1960: standard of length was carefully preserved platinum-iridium International Meter Bar at Sevre, France
- In 1960: Redefined as 1,650,763.73 times wavelengths of krypton-86 lamp in vacuum
- This standard is reproducible to 2 parts in 10^8 with precision level of 0.25 nm in 1 m

Fundamental Unit of Time

- 1956-1964: One second = 1/31,556,925.9747 of the tropical year at 12^h ephemeris time, 0 Jan 1900
- Implemented through lengthy astronomical observations over several years to define the basic standard, and then relate it to the mean solar second
- A direct comparison of an interval of time with this standard is not possible – a serious flaw
- Leads to an estimated probable error of 1 part in 10^9 – poor compared to the precision required
- In 1964: Redefined in terms of frequency of atomic resonators. Now, second is the interval of time corresponding to 9,192,631,770 cycles of atomic resonant frequency of cesium 133

Fundamental Standards *(contd.)*

- Such standards cannot be used for routine calibration work
- To protect such top-levels standards from deteriotation, labs such as NIST (National Institute of Standards and Technology), USA and NPL, New Delhi (National Physical Lab) develop *National Reference Standards*
- Below *National Reference Standards* we have *Working Standards* and further below *Interlaboratory Standards*
- These *Interlaboratory Standards* are sent to labs and factories for calibration and certification

Relative Displacement: Translational and Rotational

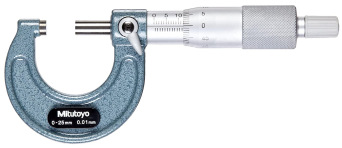
- Interest is in measuring translation along a line of one point relative to another
- Also, plane rotation about a single axis of one line relative to another
- Such displacement measurements form the basis for transducers measuring pressure, force, acceleration, temperature, etc

- Static calibration can be accomplished with micrometers (reads to the nearest 0.01 mm)
- For smaller increments, use lever arrangement (10:1) or wedge-type mechanisms (100:1) can be employed for motion reduction

Translational Measurement Units

- One micrometer unit has minimum graduation of 0.25 μm and accuracy of +/- 0.25 μm
- Another micrometer has resolution of 0.07 μm and minimum graduation of 0.5 μm.
- Using levers and wedges, it can be used to control motion with resolution of 1 nm (and thermal sensitivity of 0.00017 nm/K)

- More complex and expensive micrometers employ linear encoder scales or laser interferometers for greater accuracy, longer range and digital readouts. Laser interferometers have now become quite common, easy to use, and available over a range of specifications and cost



Translational Measurement Units
(*contd.*)

- One such micrometer has a range of 0.45 m, resolution of 0.0254 μm, and an accuracy of 0.7 μm over the full range
- Another system has a range of 51 m, resolution of 0.635 μm, and accuracy of 1.5 μm over 1 m of travel
- Such systems used to automate the calibration of mechanical gauges

- Measurement of microscopic-scale devices can be facilitated by development of small-scale pitch standards – such as that developed by Mikrokator (a totally mechanical displacement gauge) with a resolution of 0.0254 μm which produces motion magnification up to 200,000:1 between the sensing tip and indicating needle

Dimension Measurement Units

- A physical object whose dimension we can rely on for checking various instruments
- Gauge blocks are small blocks of hard, dimensionally stable steel (or other material) made in sets that can be stacked to provide accurate dimensions over a wide range and in small steps

- For example, a 25 mm block typically has an accuracy of +/- 0.05 μm. If this tolerance is too large, calibrate against light wavelengths to 0.003 μm
- Note that to achieve very high accuracy, it is extremely important to control all interfering and/or modifying inputs (such as ambient temperature)

Rotational or Angular Displacement Measurement Units

- Since angular displacement measurement is based on length measurement, a fundamental standard is not necessary
- However, reference and working standards for angles (and angular displacement) are desirable
- Basic standards are angle blocks, made of steel, 16 mm wide x 76 mm long, with a specific angle between the two contact surfaces. The blocks can be calibrated to an accuracy of 0.1 second of arc

- These blocks can be stacked to build-up any desired angle accurately and in small increments

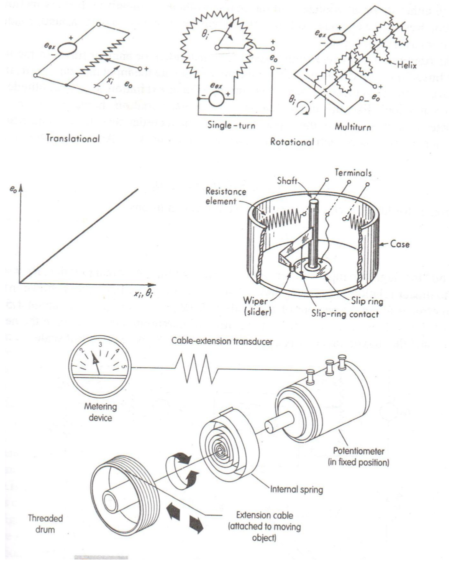
Rotational or Angular Displacement Measurement Units *(contd.)*

- Typically such high accuracy is not required, and calibration can be carried out using more convenient and readily available equipment
- A precision dividing head can produce angular motion and also measure it
- Units with a resolution of 0.0001° and repeatability of 1 arc second are available
- Digital absolute shaft angle encoders, with electronic angle readouts, are also available in a wide range. They can have resolution of 22 bits and accuracy of 0.3 arc second

Resistive Potentiometers

- A resistive potentiometer consists of a resistance element with a movable contact
- The contact can be translation, rotation, or combination of the two (helical motion)
- Translatory devices have range from 2 – 500 mm
- Range of rotational devices 10° – 60 full turns

Resistive Potentiometers *(contd.)*



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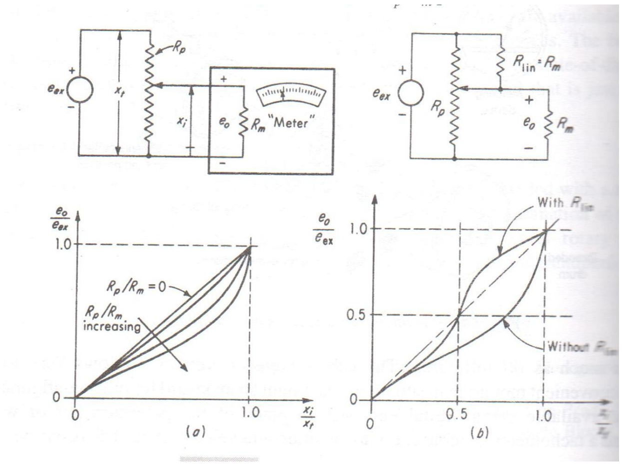
Resistive Potentiometers *(contd.)*

- Linear relation between input and output is expected
- However, since the potentiometer output voltage is input to a meter or recorder, some current is drawn from the potentiometer. This distorts the input-output relationship, to

$$\frac{e_0}{e_{ex}} = \frac{1}{1/(x_i/x_t + R_p/R_m)(1-x_i/x_t)}$$

Resistive Potentiometers *(contd.)*



Resistive Potentiometers *(contd.)*

- Note that to achieve good linearity, for a given R_m, want R_p to be small
- Low R_p however means poor sensitivity
- How about increasing e_{ex} to get better sensitivity?
- Increasing e_{ex} increases the power to be dissipated
- e_{ex} is therefore dictated by power dissipating (P) capacity of potentiometer: max(e_{ex}) = sqrt(P R_p)
- So for a given P, if R_p is low, e_{ex} will also be small

Noise in Resistive Potentiometers
(contd.)

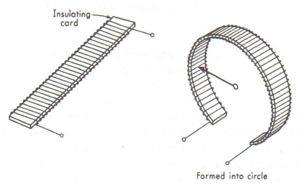


Fig. 4.6 *Construction of wirewound resistance elements.*

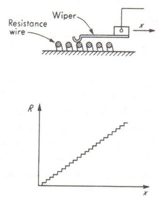


Fig. 4.7 *Resolution of wirewound potentiometers.*

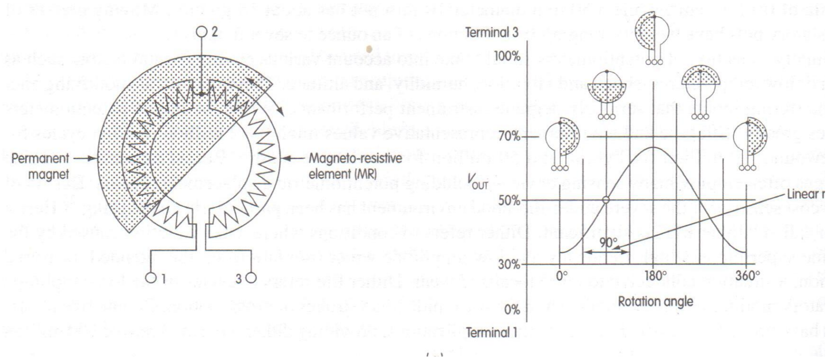
Noise in Resistive Potentiometers
(contd.)

- Noise refers to spurious input-output fluctuations due to motion of slider
  - For example, bouncing of slider during motion
  - Dirt and wear products can come between contact and winding
- Speed and wire spacing can be such so to produce bouncing at resonance frequency, leading to intermediate contact
  - By using two contacts, with different resonant frequencies, this problem can be overcome
  - Can also add damping fluid to limit the resonant amplitude
- Noise can also result from other mechanical and electrical defects
- Environmental factors such as high/low temperature, shock, vibration, humidity can act as modifying/interfering inputs
- Design for "under the hood" environment is particularly challenging

Magnetoresistive displacement transducer

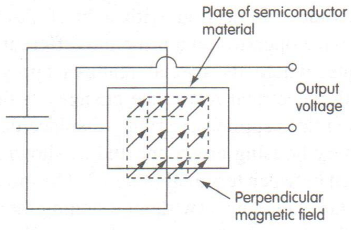
- Idea: Certain materials exhibit change in electrical resistance in presence of magnetic field
- Figure shows a rotary displacement sensor
  - Two magnetoresistive elements mounted in a stationary housing
  - Input shaft rotates a specially designed permanent magnet over the resistance elements (without touching them)
  - The movement of the magnet causes change in the resistances
  - Known voltage (say 10 V) supplied between terminals 1 and 3
  - Output voltage taken between terminals 1 and 2
- Disadvantage: Device is temperature sensitive
- Advantage: Non-contact feature gives excellent resolution, torque smoothness, long life, high speed capability

Magnetoresistive displacement transducer



Magnetoresistive displacement transducer based on Hall effect

- Construction
  - A thin semiconductor material excited with a DC voltage across two terminals, is placed in a magnetic field (applied perpendicular to the plate)
  - An output voltage proportional to the field strength appears at two other terminals
  - Position sensing is accomplished by moving a permanent magnet relative to the Hall plate



- Issues: Problems of linearity and temperature sensitivity