STUDY MATERIAL

Course code / Course Name: EI2251 / INDUSTRIAL INSTRUMENTATION - I
YEAR / Semester: II A / IV  Academic year: 2013-2014

COURSE CO-ORDINATOR: C.MAGESH KUMAR

COURSE AIM
To equip the students with relevant knowledge to suit the industrial requirements.

COURSE OBJECTIVES
• To provide sound knowledge about various techniques used for the measurement of industrial parameters.
• Discussion of load cells, torque meter and various velocity pick-ups.
• Exposure to various accelerometer pick-ups, vibrometers, density and viscosity pick-ups.
• To have an adequate knowledge about pressure transducers.
• To have an idea about the temperature standards, calibration and signal conditioning used in RTD's.
• To have a sound knowledge about thermocouples and pyrometry techniques.

PRE-REQUISITES:
• Fundamental Engineering knowledge

COURSE OUTCOMES (CO)
1. The students will acquire familiarity about various industrial instrumentation types, their parameters and different types of measurement techniques.
2. The students will understand the principles of industrial parameter standards and its calibration methodology.
3. The student will acquire extensive knowledge about pressure and temperature measurement, thermocouples and pyrometry techniques.

ASSESSMENT PLAN FOR THE COURSE:

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SYLLABUS

UNIT I
MEASUREMENT OF FORCE, TORQUE AND VELOCITY

UNIT II
MEASUREMENT OF ACCELERATION, VIBRATION AND DENSITY
Accelerometers:- LVDT, Piezo-electric, Strain gauge and Variable reluctance type accelerometer – Mechanical type vibration instruments – Seismic instruments as an accelerometer – Vibrometers : Calibration of vibration pickups – Units of density and specific gravity – Baume scale, and API scale- Pressure head type densitometers-Float type densitometers – Ultrasonic densitometer- Bridge type gas densitometer.

UNIT III
PRESSURE MEASUREMENT
Units of pressure-Manometers-Different types –Elastic type pressure gauges: Bourdon tube, bellows and diaphragms-Electrical methods: Elastic elements with LVDT and strain gauges – Capacitive type pressure gauge –Piezo-resistive pressure sensor-Resonator pressure sensor- Measurement of vacuum:-McLeod gauge-Thermal conductivity gauges-Ionization gauges:– Cold cathode type and hot cathode type-Testing and calibration of pressure gauges-Dead weight tester.

UNIT IV
TEMPERATURE MEASUREMENT
Definitions and standards-Primary and secondary fixed points –Calibration of thermometers -Different types of filled in system thermometer-Sources of errors in filled in systems and their compensation-Bimetallic thermometers – Electrical methods of temperature measurement-Signal conditioning of industrial RTDs and their characteristics-3 lead and 4 lead RTDs - Thermistors.

UNIT V
THERMOCOUPLES AND RADIATION PYROMETERS

TEXT BOOKS:

REFERENCES:

OTHER REFERENCE:
### Instrumentation:

“The art and science of measurement and control of process variable within a production or manufacturing area”

### Instrument:

“An instrument is a device that measures and/or regulates physical quantity, process variable such as flow, temperature, level, pressure”.

### Measurement:

“The act or result of comparison between a given quantity & a standard quantity (benchmark) chosen as a unit”

### Measurement methods:

- Direct method
  - Deflection type
  - Comparison type
- Indirect method

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UNIT I
MEASUREMENT OF FORCE, TORQUE AND VELOCITY

I. FORCE MEASUREMENT:

FORCE:

• **Force** is defined as “a mechanical quantity, an influence that causes an object to undergo a certain change, either concerning its movement, direction, or geometrical construction”.

• Force may be defined as “a cause that produces resistance or obstruction to any moving body, or changes the motion of a body, or tends to produce these effects”.

• Force measurement is also done by electric means in which the force is first converted into displacement at an elastic element and the displacement is measured. A vector quantity has both magnitude and direction.

• **Newton's second law** states that “the net force acting upon an object is equal to the rate at which its momentum changes with time.”

• If a force of magnitude, \( F \), is applied to a body of mass, \( M \), the body will accelerate at a rate, \( A \), according to the equation: \( F = MA \).

• Unit of force is the **Newton** (S I unit)

• **ONE NEWTON**: The force capable of giving a mass of one Kg an acceleration of one meter per second

• **Types of forces**
  • **Frictional force**: Friction is a surface force that opposes relative motion
  • **Tensional force**: Tension is the magnitude of the pulling force exerted by a string, cable, chain, or similar object on another object. Measured in newtons (or sometimes pounds-force)
  • **Compression force**: Opposite of tension
  • **Elastic force**: Elastic force is the physical property of a material that returns to its original shape after the stress

❖ **Various methods of measuring force:**
  1. Balancing on standard mass, either directly or through levers
  2. Measuring acceleration of the body if its mass is known on which the unknown force is applied
  3. Balancing against a magnetic force of a current-carrying coil and a magnet
  4. Transducing the force to fluid pressure and then measuring the pressure.
  5. Force to elastic member and measuring the resulting deflection
  6. Measuring the change in precession of a gyroscope caused by an applied torque due to applied force
  7. Measuring the change in natural frequency of a wire tensioned by the force.
 Balance
   - Electric / electronic Balance
   - Elastic Balance
   - Analytical balance.
   - Scale:
     » Pendulum ➔ equal arm balance
     » Lever ➔ equal arm balance
     » Spring ➔ spring balance
     » Hydrostatic plunger

1. ANALYTICAL BALANCE

1.a EQUAL ARM BALANCE:

- **PRINCIPLE: ➔ “MOMENT COMPARISON”**
- “The beam of equal arm balance is in equilibrium position when clockwise rotating moment is equal to anti clockwise rotating moment”.
- Clockwise rotating moment = anti clockwise rotating moment.
- Equal arm balance is shown in diagram.

- \[ M_1 L_1 = M_2 L_2 \]
  
i.e., the unknown force is balanced by known gravitational force.

  Where
  \[ M_1 \] – known standard mass
  placed at one end of beam
  \[ L_1 \] – length of beam from center (lever) of known mass
  \[ M_2 \] – unknown mass
  \[ L_2 \] – length of beam from center (lever) of unknown mass
  \[ g \] – gravitational force.

- **At equilibrium, \( M_1 L_1 = M_2 L_2 \)**
  if \( L_1 = L_2 \),
  then \( M_1 = M_2 \).
2. ELASTIC BALANCE: ELASTIC FORCE METER (PROVING RING) – use micrometer

**PRINCIPLE:**
- When a steel ring is subjected to force across its diameter, it deflects which is proportional to applied force.
  - The deflection can be measured by means of micrometer and a vibrating reed.
  - or
  - By means of using LVDT (Linear Variable Differential Transformer) principle which uses the principle of “Displacement caused by force resulting in a proportional voltage”.

**CONSTRUCTION & WORKING:**
- Elastic force meter also called as Proving ring consists of steel ring attached with external bosses on diameter of ring to apply force.
- A precision micrometer with one of its end mounted on a vibrating reed to measure the vibration which is calibrated in scale of force.
- When force is applied on bosses, the diameter of ring changes (deflection occurs). Due to deflection, the reed vibrates and it is measured by micrometer which indicates the ring deflection.
- The deflection is proportional to applied force.

3. ELECTRONIC LOAD CELL (ELECTRONIC BALANCE)
- The electronic load cell uses the physical principle that a “force applied to an elastic element produces a measurable deflection.”
- **ADVANTAGES:** Electronic load cells have significant advantages in terms of
  - Cost,
  - wide measurement range,
  - tolerance of dusty and corrosive environments,
  - remote measurement capability,
  - tolerance of shock loading
  - ease of installation.
The electronic balance is a device that contains several compression-type load cells. Commonly, either three or four load cells are used in the balance, with the output mass measurement being formed from the sum of the outputs of each cell.

**LOAD CELL:**
- LOAD CELL are also called as FORCE METER
- A load cell is a device that converts force into pressure. If the area on which the load is placed is known then the calibration of force can be done directly.
- Pressure is measured which is proportional to force.

\[ P \propto F \]
\[ P = x.F \text{ where } x \text{ – constant.} \]

- A load cell is a transducer that is used to convert a force into electrical signal. This conversion is indirect and happens in two stages.
  - **Stage-1:** The force being sensed deforms a strain gauge.
  - **Stage-2:** The strain gauge converts the deformation (strain) to electrical signals.

4. **TYPES OF LOAD CELL:**

The types of load cells are as follows

I. HYDRAULIC LOAD CELL  
II. PNEUMATIC LOAD CELL  
III. MAGNETO – ELASTIC LOAD CELL  
IV. PIEZO ELECTRIC LOAD CELL  
V. STRAIN GAUGE LOAD CELL

4.i **HYDROSTATIC LOAD CELL:**

**PRINCIPLE:**
- Hydrostatic load cell works on the principle of “FORCE COUNTER BALANCE”.
- “Force is applied on liquid medium contained in closed space, the pressure of liquid will increase”.
- The increased pressure is proportional to applied force when calibrated in terms of force.”

**CONSTRUCTION & WORKING:**
- The block diagram of Hydrostatic load cell is shown below.
- Hydrostatic load cell is also called as plunger, used in static measurement.
- A piston with loading platform is placed on top of diaphragm. The force is made to apply on the load platform which is connected to the diaphragm.
- The diaphragm seals the chamber which is filled with fluid commonly oil (liquid medium under pre-loaded pressure) connected to pressure gauge commonly bourdon tube.
- When load is placed in piston, it forces the diaphragm in turn increases the oil pressure. During the measurement process the applied force pressurizes the oil which in turn activates the bourdon gauge and the needle connected to it indicates the magnitude of the pressure exerted.
- The increased pressure is proportional to applied force when calibrated in terms of force.
- These instruments are designed for measuring much larger masses.
- Hydraulic load cells are much more accurate with an inaccuracy figure of ±0.05% of full scale being typical. However, in order to obtain such a level of accuracy, correction for the local value of \( g \) (acceleration due to gravity) is necessary.
- A measurement resolution of 0.02% is attainable.
- Deflection = 0.05 mm at full load.
- Load range = 20 to 500 tons
- The force is well measured at 20 tons with good resolution & accuracy.
- Measurement range = (0 - 30000) to (0 - 5 million) Newton
- Tare compensation of 0.2MPa is done.
4.ii. **PNEUMATIC LOAD CELL**

**PRINCIPLE:**
- Pneumatic load cell works on the principle of “FORCE BALANCE”.
- “IF Force is applied to one side of a diaphragm (top side) and air pressure is applied on other side (bottom side) contained in closed space, there needs a particular pressure value to balance the force exactly. Measured Pressure is proportional to applied force”.

**CONSTRUCTION & WORKING:**
- The block diagram of Pneumatic load cell is shown below.
- It consists of corrugated diaphragm, air pressure regulator, flapper to apply load, nozzle to regulate air supply for balancing the applied force.
- The force is applied to the platform connected to the sealing diaphragm of air chamber.
- The applied force is measured by means of flapper nozzle principle described as follows.
  - The chamber is equipped with constant air supply.
  - The platform acts like a flapper and creates the backpressure on through the nozzle in the chamber according to the force applied on it
  - With increasing load, nozzle back pressure increases which in turn push the diaphragm upward and finally a balance is obtained.
  - The back pressure which is measured by the pressure gauge indicates the corresponding load if it is calibrated.
  - If the Applied mass = W, Output pressure=P, Diaphragm stiffness=k_s, Flapper-nozzle gain=k_f, Area of diaphragm=α,

\[
\text{Output = pressure } \Rightarrow P = \frac{W}{(k_s/k_f + \alpha)}
\]

If \( k_s/k_f << \alpha \), then \( P = \frac{W}{\alpha} \)

therefore, \( W = \alpha P \) implies a linear relationship between the load and the pressure.
- The force is made to exert on the load platform which in turn compresses the fluid closed by the diaphragm resulting in deflection of meter pointer.

- Pneumatic load cell is used in static measurement.
- Example of closed loop control system
- Measurement range = (0 - 35) to (0 - 12250) Newton.
- The advantage with this system is easy accommodation of a flapper-Nozzle assembly so that an amplified output signal is derived and measurement becomes more convenient.
4.iii. **MAGNETO – ELASTIC LOAD CELL**

**PRINCIPLE:**
- Magneto-elastic load cell works in principle of “Magneto elastic principle” called as Villari effect.
- “When a ferromagnetic material undergoes a mechanical stress, it changes the magnetic permeability of the material. The level of change in permeability property is proportional to applied force / stress.”
- Depends on permeability property of magnet defined as “The measure of the ability of a material to support formation of magnetic field within itself”

**CONSTRUCTION & WORKING:**
- Magneto-elastic load cell is also called as “Pressductor”.
- The laminated sheets of ferromagnetic material bonded together to form transducer body.
- Primary and secondary windings are wounded at right angles through the holes as shown in block diagram.
- When AC current is supplied to primary windings, secondary windings remain undisturbed under no load condition.
- On load condition the angle between the primary and secondary changes from 90° to θ° degree and when load is applied at 45° degree the resulting flux linkage is given by

\[ \Phi = \alpha B \cos \theta \]

Where \( \alpha = \) Cross Sectional Area of material  
\( \Phi = \) Total flux linkage  
\( B = \) Magnetic flux density  
\( \cos \theta = \) change in angle

if \( n = n_2/n_1 = \) turn ratio  
\( es = -n \, d\Phi /dt \)
4. iv. PIEZO ELECTRIC LOAD CELL

**PRINCIPLE:**

- “If dimension of crystal is altered, an electronic potential appears across certain surface of crystal material due to displacement of charges that induces a output voltage and induces a voltage proportional to the force applied”.

**CONSTRUCTION & WORKING:**

- Piezoelectric materials used:
  - Lithium sulphate,
  - Dipotassium titrate,
  - Rochelle salt,
  - Ammonium dihydrogen phosphate.
- In a typical quartz-based force sensor, a charge-collection electrode is sandwiched between quartz-crystal element. The quartz elements are oriented to supply the same polarity voltage to the electrode when compressed, while the opposite polarity is applied to the sensor housing.
- Any force applied to the piezoelectric sensing element produces a separation of charges within the atomic structure of the material, generating an electrostatic output voltage. The polarity of the voltage generated depends on the atomic structure of the material and the direction in which the force is applied.
- When a force is applied to surface of electrode, the quartz elements generate an output voltage which can be routed directly to a charge amplifier.
- The magnitude and polarity of induced surface charges are proportional to magnitude and direction of applied force.
- Piezoelectric force sensors are mostly used for dynamic- force measurements such as oscillation, impact, or high speed compression or tension.
4.v. STRAIN GAUGE LOAD CELL

PRINCIPLE:

- Strain gauge load cell is also called electromechanical transducer.
- “Change in applied force is converted into change in voltage”.
- When a steel cylinder is subjected to a force, it tends to change in dimension. If the strain gauges are bounded on the cylinder, when force is applied strain gauge is stretched or compressed causing a change in strain gauge dimension along length and diameter. If dimension of strain gauge is changed, its resistance also changes. The change in resistance is a measure of applied force.

CONSTRUCTION & WORKING:

- Strain gauge load cell is shown below.
- A cylinder made of steel on which 4 identical strain gauge are mounted on sides of the cylinder.
- The gauges are connected to a wheat stone bridge circuit.
- The 4 strain gauge are arranged at right angles to each other.
- Under no load condition on cylinder, all 4 gauge will have same resistance. Hence the wheat stone bridge is balanced and the output voltage will be zero.
- When force is applied, the gauges along axis Y1 & Y2 will be compressed and resistance will decrease and the gauges along axis X1 & X2 will be stretched and resistance will increase.
- When a steel cylinder is subjected to a force, it tends to change in dimension. If the strain gauges are bounded on the cylinder, when force is applied strain gauge is stretched or compressed causing a change in strain gauge dimension along length and diameter. If dimension of strain gauge is changed, its resistance also changes. The change in resistance is a measure of applied force.
- Hence variation in resistance of strain gauge unbalance the wheatstone bridge. The change in resistance is proportional to applied force when calibrated in terms of force.

Application:

- Used in vehicle load measurement.
- Used in force dynamometers.
- Used to measure force when the load is unsteady.
II. DIFFERENT METHODS OF TORQUE MEASUREMENTS:

**Torque:**
- “The force which tends to change the linear motion or rotation of a body”.
- “It is also defined as the turning or twisting moment of a force about an axis”.
- “The force that tends to cause rotation”
- Unit: Radian /sec

  - \( T = F D \)
    - Where \( T \) = Torque
    - \( F \) = Force
    - \( D \) = perpendicular distance from the axis of rotation of the line of action of the force

**METHODS OF MEASUREMENT:**

1. **In-Line Rotating torque sensor**
   - **strain gauge**
   - **Relative angular twist** (Proximity torque sensor)
     1. Magnetic pick up type
     2. Optical stroboscopic type
   - In-Line stationary torque sensor

**1. IN-LINE ROTATING TORQUE SENSOR - STRAIN GAUGE**

**PRINCIPLE:**
- When a strain gauge is stretched its resistance will change. The change in resistance is proportional to applied torque. Due to unbalance in bridge (change in resistance) an A.C voltage is developed in output side.
- When torque is applied to shaft, there will be twist in shaft in turn which changes the dimension of strain gauge that results in change in resistance. The change in resistance will be proportional to the applied torque.

**CONSTRUCTION & WORKING:**

- Strain gauge (In-Line Rotating torque sensor) block diagram is shown below
- Input Supply is given via A.C oscillator
- Output is taken via transformer.
- A shaft on which torque is to be applied is made of steel on which 4 identical strain gauge are mounted on sides of the cylinder.
- The gauges are connected to a wheat stone bridge circuit.
- The 4 strain gauge are fixed to shaft at right angles to each other.
- Under no load condition on shaft, all 4 gauges will have same resistance. Hence the wheat stone bridge is balanced and the output voltage will be zero.
- When torque is applied, the gauges along axis Y1 & Y2 will be compressed and resistance will decrease and the gauges along axis X1 & X2 will be stretched and resistance will increase.
- When the shaft is subjected to torque, it tends to change in dimension. If the strain gauges are bounded on the shaft, when torque is applied strain gauge is stretched or compressed causing a
change in strain gauge dimension along diameter. If dimension of strain gauge is changed, its resistance also changes. The change in resistance is a measure of applied torque.

- Hence variation in resistance of strain gauge unbalance the wheatstone bridge. The change in resistance is proportional to applied torque when calibrated in terms of torque.

2. RELATIVE ANGULAR TWIST METHOD (Proximity torque sensor)

- The torque is measured between a driving engine and driven load.
- Proximity and displacement sensors also can detect torque by measuring the angular displacement between a shaft's two ends.
- By fixing two identical toothed wheels to the shaft a some distance apart, the angular displacement caused by the torque can be measured. Proximity (closeness) sensors located at each toothed wheel produce output voltages whose phase difference increases as the torque twists the shaft.

\[
\varepsilon = \pm 8TD_0 / [\pi C (D_0^4 - D_i^4)]
\]

Where

- T = applied torque
- \(D_0\) = outer diameter
- \(D_i\) = inner diameter
- \(C\) = shear modulus (Rigidity)
2.a. MAGNETIC PICK-UP TYPE

PRINCIPLE:
- When shaft rotates due to applied torque, the tooth of wheel passes the magnetic pick-up sensor due to which there exists a phase shift between the pulses. The phase difference is converted to time difference of two pulses which is proportional to applied torque.

CONSTRUCTION & WORKING:
- The shaft is connected between driving engine and driven load.
- Two slotted disc (toothed wheels) are attached on either side of the shaft.
- Proximity sensors also can detect torque by measuring the angular displacement between a shaft's two ends is placed under the slotted disc as shown in block diagram.
- Proximity (closeness) sensors located at each toothed wheel produce output voltages whose phase difference increases as the torque twists the shaft.
- When torque is not applied on shaft, the teeth of both discs perfectly align. Hence the voltage pulse produced will have zero time difference.
- When torque is applied on shaft, the teeth of both discs will be get disaligned. Hence the voltage pulse produced will have some time difference.
- The time difference between two pulses is proportional to applied torque.
2.b. OPTICAL STROBOSCOPIC TYPE

PRINCIPLE:
- When a shaft is connected between a driving engine and driven load, a twist occurs on shaft between the ends. The angle of twist is measured and calibrated in terms of torque.

CONSTRUCTION & WORKING:
- The shaft is connected between driving engine and driven load.
- Two drums one with torque calibrated scale and another with pointer are attached on either side of the shaft.
- A stroboscope is arranged to measure the rotating shaft.
- Due to applied torque, an angle of twist is experienced by the shaft which is proportional to torque when calibrated.
- The angular twist is observed on torque calibrated scale corresponding to position of the pointer.

Advantage:
- Direct measurement of torque is possible.
- Power of shaft is also calculate along with torque using flashing frequency of stroboscope.

Disadvantage:
- Applicable only on shafts rotating at a constant speed.
- Accuracy decreases for small displacement of pointer.
III. SPEED MEASUREMENT

- **MOTION MEASUREMENT** – displacement, velocity (speed) and acceleration measurement.
- **Speed** is defined as rate of change of position of an object with respect to time. Speed = velocity
- **Velocity** is the rate of change of displacement, \( V = \frac{dx}{dt} \)

**Units of speed**
- Meters per second (ms\(^{-1}\) or m/s), the SI derived unit;
- Kilometers per hour (km/h);
- Miles per hour (mph);
- Knots (nautical miles per hour, kn or kt);
- Feet per second (fps or ft/s);
- Mach number, speed divided by the speed of sound;
- The speed of light in vacuum (c) is one of the natural units;
- Revolution per minute (rpm)

**TYPES OF VELOCITY:**
1. **Linear velocity** *(along the axis of movement)*
2. **Angular velocity** *(along the axis)*

1. **LINEAR VELOCITY** *(ALONG THE AXIS OF MOVEMENT):*
   - Velocity of a body moving in linear fashion (m/s).
   - The conventional type for linear velocity measurement is by using **electromagnetic transducer**. A permanent magnet core moves as a result of velocity in core and depending on magnitude of velocity of core a voltage is induced in coil which is given by
   \[
   V = a \frac{d\phi}{dt}
   \]
   \[V = -Na \frac{d\phi}{dt}\]
   where \( V \) – velocity of core, \( \frac{d\phi}{dt} \) – rate of change of flux.

**Application:**
1. Velocity measurement of vehicle in highways
2. Missile targeting
3. Tracking movement of aircraft.

2. **ANGULAR VELOCITY** *(ALONG THE AXIS):*
   - Velocity of a body moving in rotational fashion
   - Measured in Revolution per minute (rpm) or radian / sec.

**Measuring methods (Angular velocity):**
Generally speed is calculated using tachometers which calculates the angular speed in revolution per minute (rpm) of the object and converted into required form.

**Types of Tachometer:**
1. **Mechanical tachometer**: Associated only with mechanical units to measure speed
2. **Electric tachometer**: Associated with transducer for converting rotational speed to electrical quantity. The electric signal is proportional to speed.
**Tachometer**

- **Mechanical tachometer**
  - 1. Revolution counter with time counter
  - 2. Centrifugal force tachometer
  - 3. Resonance tachometer

- **Electric tachometer**
  - 1. Eddy current/drag cup type/magnetic drag
  - 2. Electric generator tachometer
    - a. DC TACHO
    - b. AC TACHO
  - 3. Contactless tachometer
  - 4. Frequency type tachometer
  - 5. Ignition type tachometer
  - 6. Stroboscopic tachometer
  - 7. Capacitive Tachometer

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**1. CAPACITIVE TACHOMETER:**

**PRINCIPLE:**

- Capacitor – charges & discharges.
  - The principle of charging a capacitor and discharging through a meter continuously.
  - If charging and discharging is controlled by speed of the device which is to be measured, then the average discharge current would be proportional to the speed.
  - Average discharge current \( I \) is given by \( I = RC\omega \)
  
  where \( R \) – resistance, \( C \) – capacitance,
  \( \omega \) - speed of rotation (rpm)

**CONSTRUCTION & WORKING:**

- The circuit diagram for capacitive tachometer is shown below.
- The circuit diagram 1 is used to measure the rotational speed.
- The circuit diagram 2 is used to measure the direction of rotation along with rotational speed.
- It consist of a capacitor (C), rotary switch with rotary positions P1 and P2, a milli ammeter to indicate the discharge current, power supply (E), resistor (R).
- The capacitor is charging when the rotary switch is in position P1, and due to rotation the rotary switch will go to position P2 where discharging of current takes place through ammeter.
- This mechanism is repeated as rotation takes place continuously. Thus the charging and discharging activity depends on the speed of rotation of the device.
- Thus discharging current indicates the average speed of the device, average discharge current \( I \) \( (I) = RC\omega \)
- Measurement of direction of rotation along with rotational speed is possible (diagram 2) when the direction of rotation reverses, the direction of current also gets changed since the polarity of capacitor changes.
- The range of instrument can be changed by changing the range supply voltage and capacitor.
2. **EDDY CURRENT / DRAG CUP TYPE / MAGNETIC DRAG TACHOMETER**

**PRINCIPLE:**
- “An emf is induced due to change in magnetic flux”
- An analog signal is produced in form of continuous drag due to eddy current induced in the cup which is proportional to speed.

**CONSTRUCTION & WORKING:**
- The diagram for drag cup type tachometer is shown below.
- A permanent magnet is connected to the shaft whose speed is to be measured.
- An Aluminium disc or drag cup is fixed closer to rotating magnet.
- The drag cup is self-possessed by a control spring and pointer arrangement as shown in diagram.
- Due to angular rotation of shaft, the magnet also rotates continuously. Thus the magnetic flux cuts the drag cup and in turn emf is produced.
- The emf generates an eddy current in the drag cup. This eddy current oppose the magnetic flux and a torque is produced which tend to drag or rotate the drag cup along the rotation of magnet.
- Due to this action the angular rotation is indicated by the pointer via spring setup which is proportional to angular speed \(\omega\).
3. ELECTRIC GENERATOR TACHOMETER

- The transducer that converts rotation speed directly into electrical signal is an induction pick-up type.
- Such types of tachometers are used for speed control of rotating equipment.
- Electric generator tachometer are 2 types as follows
  - D.C tacho generators
  - A.C tacho generators

Pre-requisite: Knowledge about working of AC and DC motor.

3a. D.C TACHO GENERATOR:

PRINCIPLE:

- “Electromagnetic induction”.
- “An emf is induced due to change in permanent magnetic flux. The induced emf is proportional to flux and rotational speed”

CONSTRUCTION & WORKING:

- The diagram of D.C tacho generator is shown below.
- It consists of small armature which is coupled to machine whose speed is to be measured.
- This armature rotates in the magnetic field of permanent magnet.
- The rotating armature cuts the permanent magnetic flux, so an emf is produced which is proportional to flux and rotational speed.
- Since the magnetic flux is constant, the generated voltage is proportional to speed.
- The polarity of output voltage indicates the direction of rotation. The emf measured with moving coil voltmeter having uniform scale and calibrated directly in terms of speed.
- The output voltage of a DC generator \( e_0 \) is given by
  \[ e_0 = \frac{n_p n_c \omega \phi_p \times 10^8}{(60 n_{pp})} \]
  where
  - \( n_p \) – number of poles,
  - \( n_c \) – number of conductors in armature
  - \( \omega \) – rotational speed to be measured (rpm)
  - \( \phi_p \) - flux per pole
  - \( n_{pp} \) – parallel paths between positive & negative brushes

D.C tacho generator

Advantages:

- Polarity of output voltage indicates direction of rotation directly.
- Normally \( e_0 = 10 \text{ mV per rpm} \) which can be measured using conventional type DC voltmeter.

Disadvantages:
The brush noise and ripples (commutator) are source of disturbance. They need periodic maintenance.

The magnet flux is changed non-linearly if the armature current is large.

3b. **A.C TACHO GENERATOR**

**PRINCIPLE:**
- “An emf is induced due to change in permanent magnetic flux. The induced emf is proportional to flux and rotational speed”

**CONSTRUCTION & WORKING:**
- The diagram of A.C tacho generator is shown below.
- To overcome the brush & commutator problem A.C tacho generators are used.
- Here the operation is similar to the DC tachometer but the magnet rotates in the stationary coil proportional to the speed which is to be measured in a stationary coil and generates a A.C voltage which is calibrated in the units of speed.
- Due to rotation of shaft, the magnet also rotates which induces an emf in stator coil.
- Since the AC voltage is in form of pulse (the polarity of pulse changes when north pole passes the coil and the polarity of pulse changes in opposite direction when south pole passes the coil.)
- When speed of shaft changes it changes the amplitude and rise time of output voltage which should be conditioned using a rectifier circuit for direct measurement of speed.
- For negligible load current, output voltage \(e_0 = k\omega\).

![A.C tacho generator diagram](image)

A.C tacho generator
IV. STROBOSCOPE

PRINCIPLE:

- A stroboscope having a scale that reads in flashes per minute or in revolutions per minute; the speed of a rotating device is measured by directing the stroboscopic lamp on the device, adjusting the flashing rate until the device appears to be stationary, then reading the speed directly on the scale of the instrument.

CONSTRUCTION:

- Stroboscopes are simple, portable manually operated device used to measure the speed of rotation or frequency of vibration of a mechanical system.
- Used to measure periodic or rotary motions without making contact with rotating body or disturbing the equipment under test.
- A stroboscope, also known as a strob, is an instrument used to make a cyclically moving object appear to be stationary. The principle is used for the study of rotating, reciprocating, oscillating or vibrating objects.
- The frequency is set by operator. The speed is measured by adjusting the frequency so that the moving objects are visible only at specific intervals of time.
- The most advanced stroboscopic instruments for industrial use are of the electronic type. They consist of an oscillator that controls the pulse frequency and of a gas-discharge tube that serves as the source of the light pulses.
- The shaft doesn't stop turning, but the strobe flashes and it illuminates the same spot on the shaft with every rotation, and that's what makes it (the shaft) appear to stop moving.
- If the strobe is flashing at exactly half the speed of the shaft, it will be illuminating the same spot on the shaft each time it flashes, but the shaft will actually have turned twice instead of once.
- The frequency of the oscillator and, consequently, of the flashes can be smoothly adjusted by varying the parameters of the electric circuit, usually between 2 and 2,500 Hz with accuracy rate - 1 to 2%.

Source of light:

- An electronic stroboscope uses a (variable frequency flashing light) multivibrator type circuit to produce flashes of light at known and adjustable rates.
- The variable frequency flashing light source is called strobotron.
- Neon lamps or light emitting diodes are commonly used for low-intensity strobe applications. Neon lamps were more common before the development of solid-state electronics, but are being replaced by LEDs in most low-intensity strobe applications.
- Xenon flash lamps are used for medium- and high-intensity strobe applications. Sufficiently rapid or bright flashing may require active cooling such as forced-air or water cooling to prevent the xenon flash lamp from melting.

WORKING: (to measure rotational speed)

- A simple stroboscope circuit is shown below.
- A distinctive mark is made on the shaft whose rotational speed is to be measured.
- A stroboscope is made to flash directly on the mark. The flashing is adjusted until the mark appears stationary even though the shaft rotates.
- At this condition, the speed of shaft (n in rpm) is equal to frequency (f in Hertz) of light flashed on shaft. i.e., \( n = f \)
  - In general, if no. of marking in shaft is ‘m’, then \( n = f/m \).
  - If no. of marking is 1, then \( n = f \).
- If no. of marking is 2, then \( n = \frac{f}{2} \)
- If no. of marking is 3, then \( n = \frac{f}{3} \)

- Typically a gas-discharge or solid-state lamp is used, because they are capable of emitting light nearly instantly when power is applied, and extinguishing just as fast when the power is removed.

**Advantage:**
- Used to measure periodic or rotary motions without making contact with rotating body or disturbing the equipment under test.
- Mechanical equipment may be observed under actual operating conditions with the aid of stroboscopes.
- Parasitic oscillations, flaws, and unwanted distortion at high speeds are readily detected.
- The flashing-light stroboscopes employ gas discharge tubes to provide a brilliant light source of very short duration.

![A simple stroboscope circuit](image1)

![A simple Stroboscope arrangement](image2)