INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad - 500 043

DEPARTMENT OF MECHANICAL ENGINEERING

Course: INSTRUMENTATION AND CONTROL SYSTEMS

IV B.Tech I Sem – JNTUH - R15

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Assistant Professor

UNIT-I

BASIC PRINCIPLES OF MEASUREMENT

MEASUREMENT PRINCIPLE

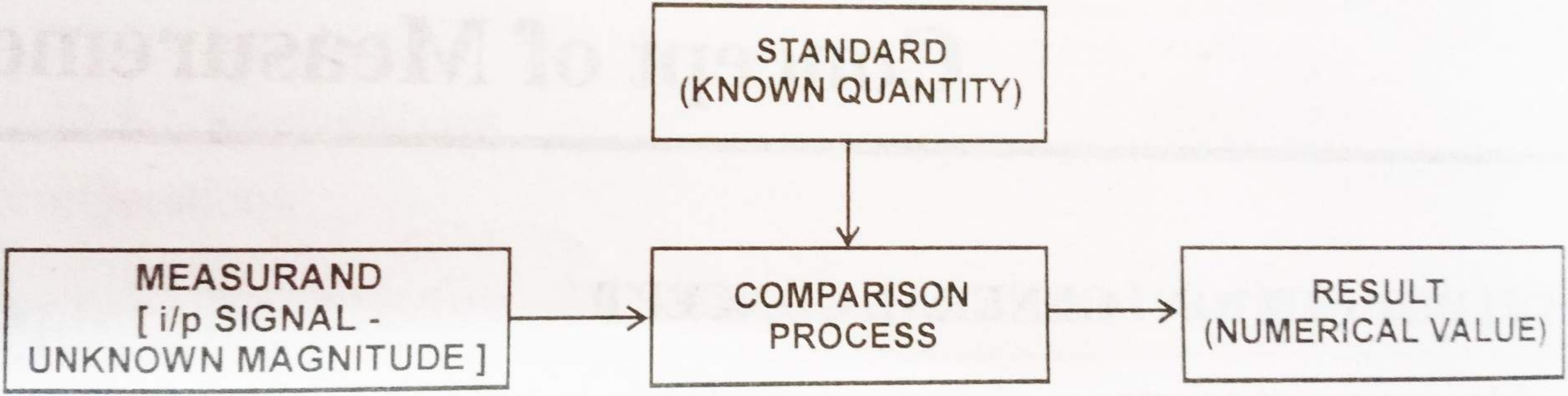


Figure 1.1: Measurement

MEASUREMENT PRINCIPLE

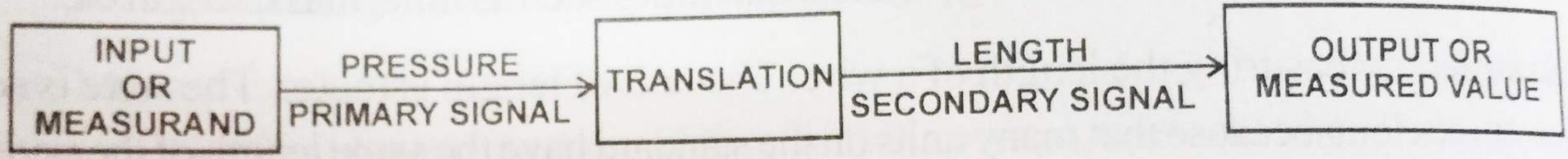


Figure 1.2: Secondary Measurement

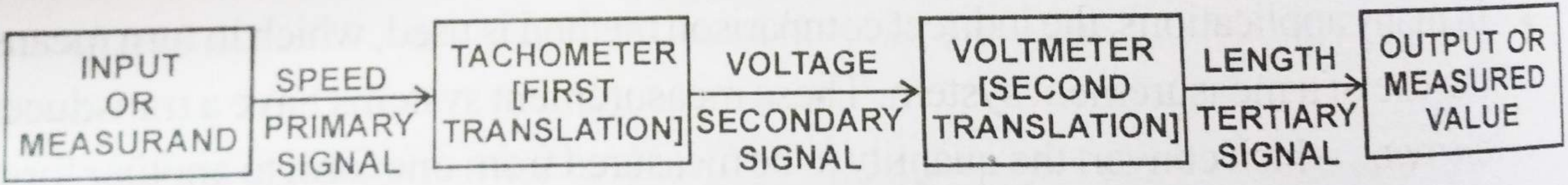


Figure 1.3: Tertiary Measurement (Electric Tachometer)

ELEMENTS OF MEASURING SYSTEM

ELEMENTS	STAGES
(a) Primary sensing element. (b) Variable conversion or transducer element	Detector - transducer stage.
(c) Variable manipulation element. (d) Data transmission element. (e) Data processing element.	Intermediate modifying stage.
(f) Data presentation element. (g) Data storage and playback element.	Terminating stage

ELEMENTS OF MEASURING SYSTEM

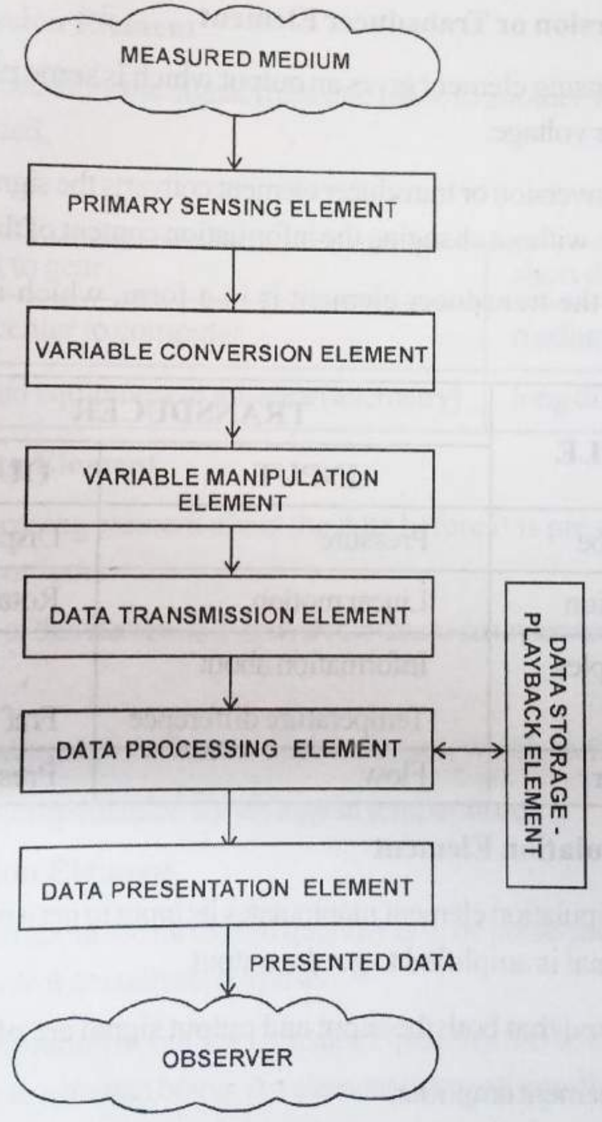


Figure 1.5: Generalised measurement system and its elements

EXAMPLE FOR MEASURING SYSTEM

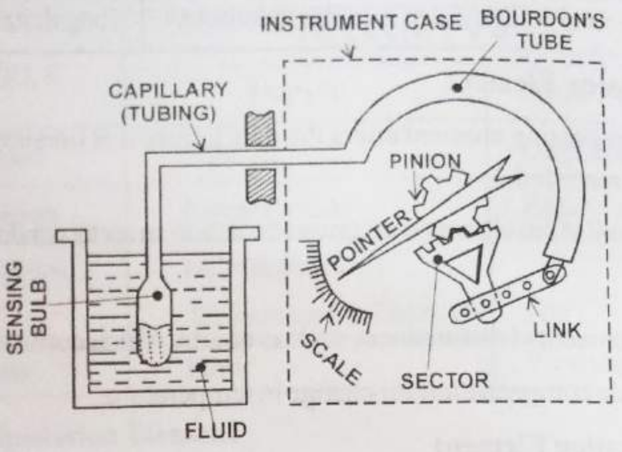


Figure 1.6: Pressure type thermometer

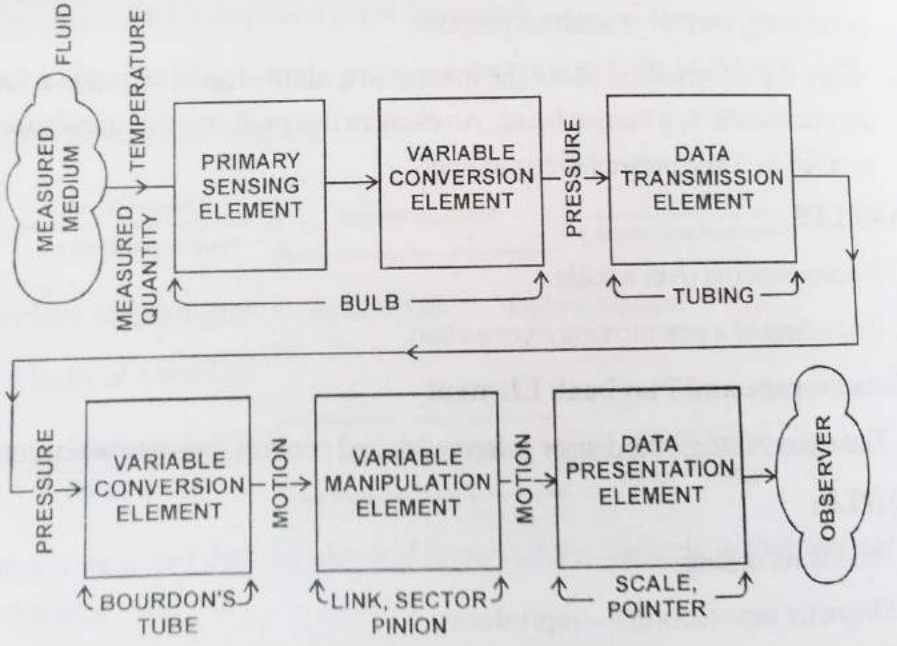


Figure 1.7: Flow diagram of elements

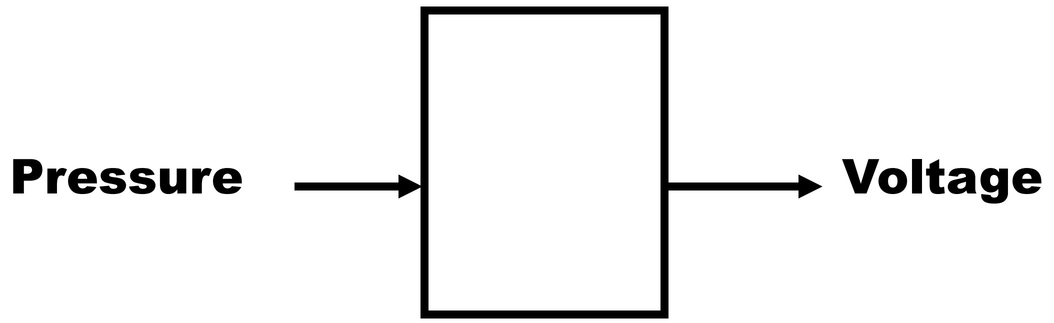
UNIT-II

Measurement of Displacement

Transducers

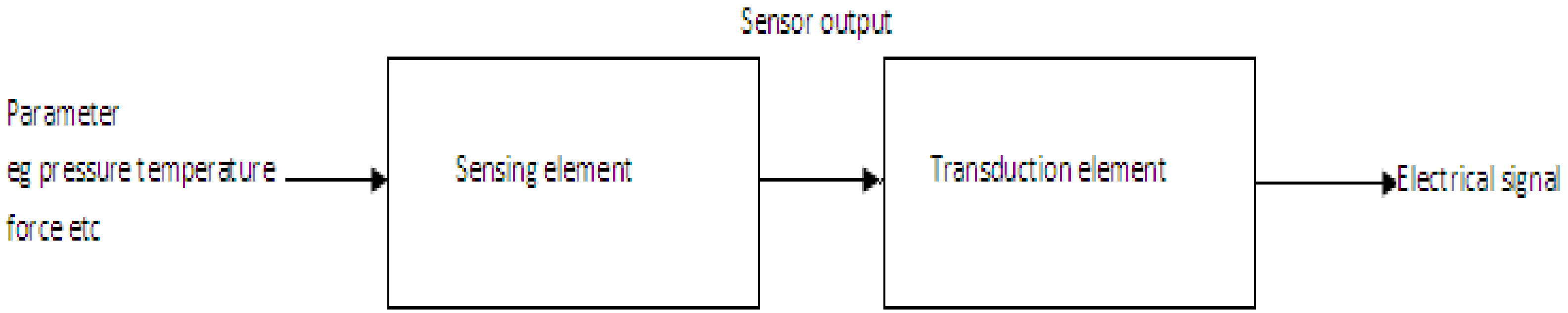
INTRODUCTION OF TRANSDUCERS

- A transducer is a device that convert one form of energy to other form. It converts the measurand to a usable electrical signal.
- In other word it is a device that is capable of converting the physical quantity into a proportional electrical quantity such as voltage or current.



BLOCK DIAGRAM OF TRANSDUCERS

- Transducer contains two parts that are closely related to each other i.e. the sensing element and transduction element.
- The sensing element is called as the sensor. It is the device producing measurable response to change in physical conditions.
- The transduction element convert the sensor output to suitable electrical form.



TRANSDUCERS SELECTION FACTORS

1. **Operating Principle:** The transducer are many times selected on the basis of operating principle used by them. The operating principle used may be resistive, inductive, capacitive , optoelectronic, piezo electric etc.
2. **Sensitivity:** The transducer must be sensitive enough to produce detectable output.
3. **Operating Range:** The transducer should maintain the range requirement and have a good resolution over the entire range.
4. **Accuracy:** High accuracy is assured.
5. **Cross sensitivity:** It has to be taken into account when measuring mechanical quantities. There are situation where the actual quantity is being measured is in one plane and the transducer is subjected to variation in another plan.
6. **Errors:** The transducer should maintain the expected input-output relationship as described by the transfer function so as to avoid errors.

Contd.

7. **Transient and frequency response :** The transducer should meet the desired time domain specification like peak overshoot, rise time, setting time and small dynamic error.
8. **Loading Effects:** The transducer should have a high input impedance and low output impedance to avoid loading effects.
9. **Environmental Compatibility:** It should be assured that the transducer selected to work under specified environmental conditions maintains its input- output relationship and does not break down.
10. **Insensitivity to unwanted signals:** The transducer should be minimally sensitive to unwanted signals and highly sensitive to desired signals.

CLASSIFICATION OF TRANSDUCERS

The transducers can be classified as:

I. Active and passive transducers.
II. Analog and digital transducers.
III. On the basis of transduction principle used.
IV. Primary and secondary transducer
V. Transducers and inverse transducers.

ACTIVE AND PASSIVE TRANSDUCERS

- **Active transducers :**
- These transducers do not need any external source of power for their operation. Therefore they are also called as self generating type transducers.

I. The active transducer are self generating devices which operate under the energy conversion principle.

II. As the output of active transducers we get an equivalent electrical output signal e.g. temperature or strain to electric potential, without any external source of energy being used.

ACTIVE AND PASSIVE TRANSDUCERS

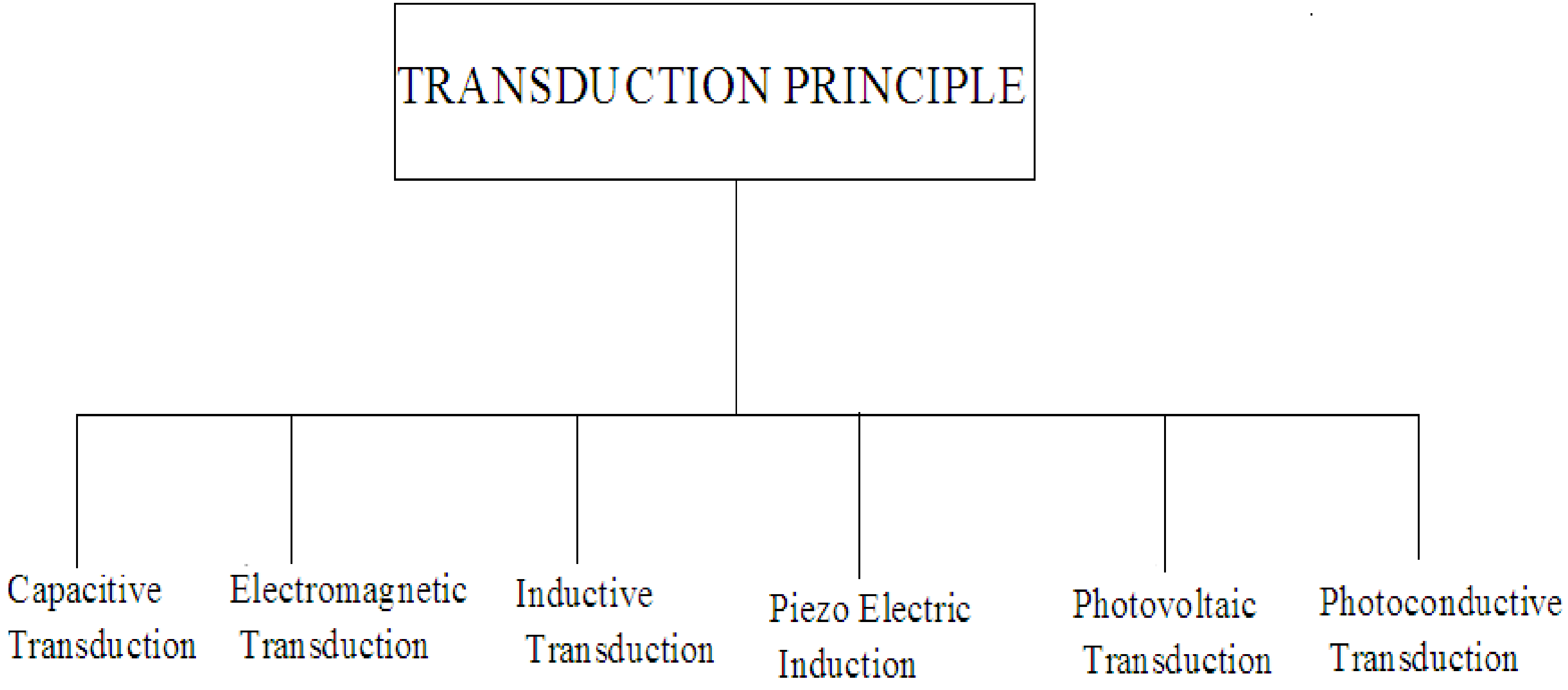
- **Passive Transducers :**

I. These transducers need external source of power for their operation. So they are not self generating type transducers.

II. A DC power supply or an audio frequency generator is used as an external power source.

III. These transducers produce the output signal in the form of variation in resistance, capacitance, inductance or some other electrical parameter in response to the quantity to be measured.

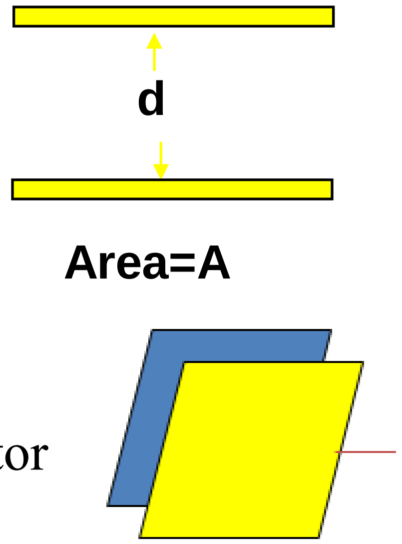
CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle



CLASSIFICATION OF TRANSDUCERS According to Transduction Principle

CAPACITIVE TRANSDUCER:

- In capacitive transduction transducers the measurand is converted to a change in the capacitance.
- A typical capacitor is comprised of two parallel plates of conducting material separated by an electrical insulating material called a dielectric. The plates and the dielectric may be either flattened or rolled.
- The purpose of the dielectric is to help the two parallel plates maintain their stored electrical charges.
- The relationship between the capacitance and the size of capacitor plate, amount of plate separation, and the dielectric is given by



$C = \varepsilon_0 \varepsilon_r A / d$

d is the separation distance of plates (m)

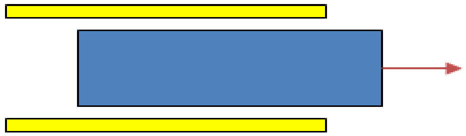
C is the capacitance (F, Farad)

ε_0 : absolute permittivity of vacuum

ε_r : relative permittivity

A is the effective (overlapping) area of capacitor plates (m2)

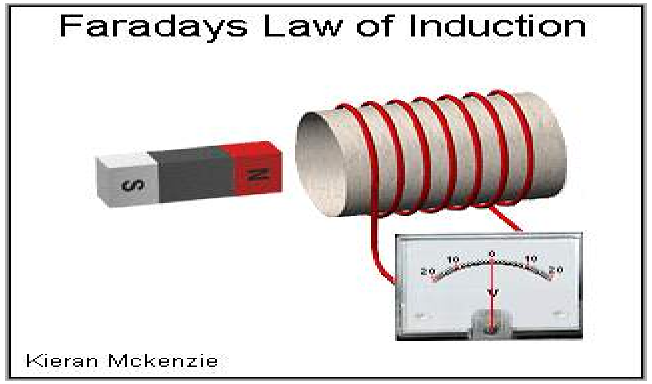
Either A, d or ε can be varied.

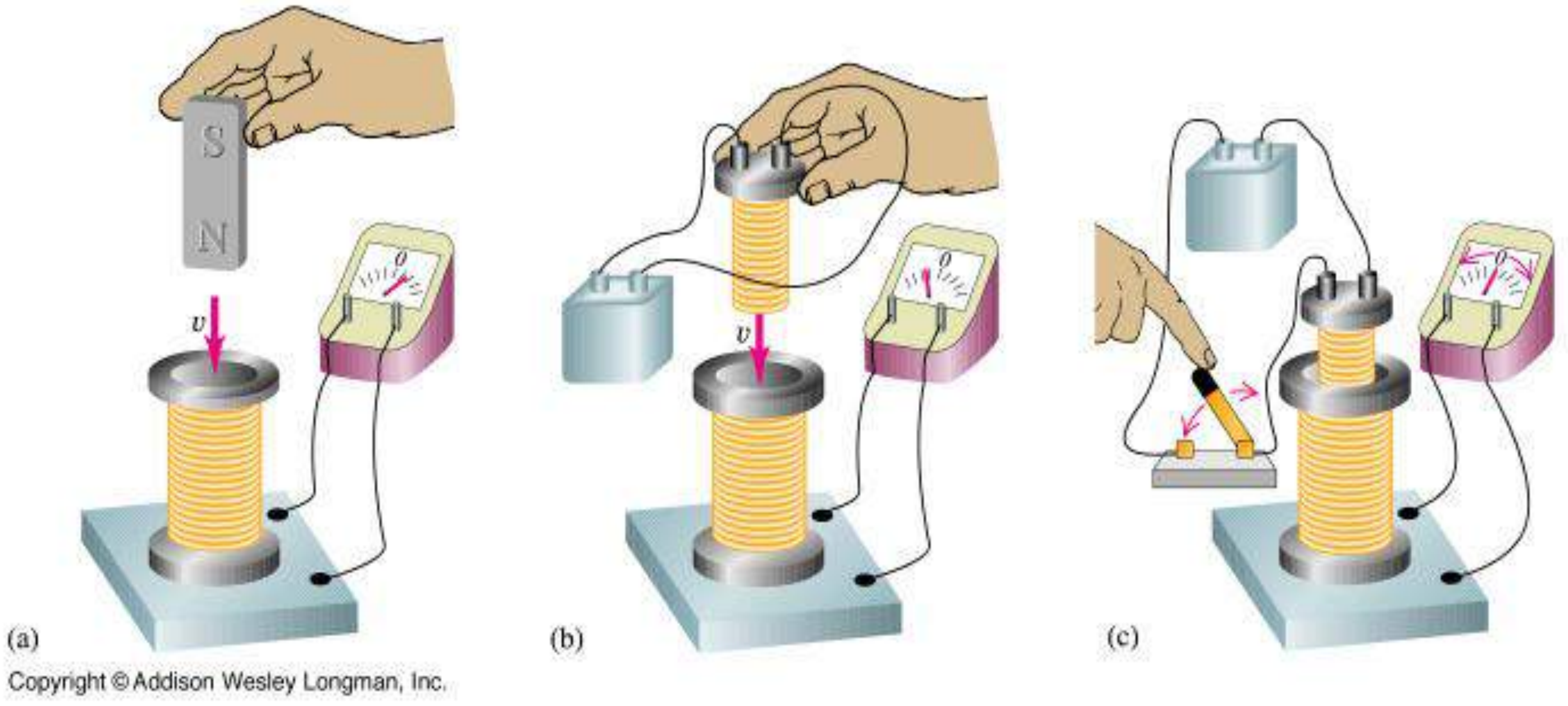


CLASSIFICATION OF TRANSDUCERS According to Transduction Principle

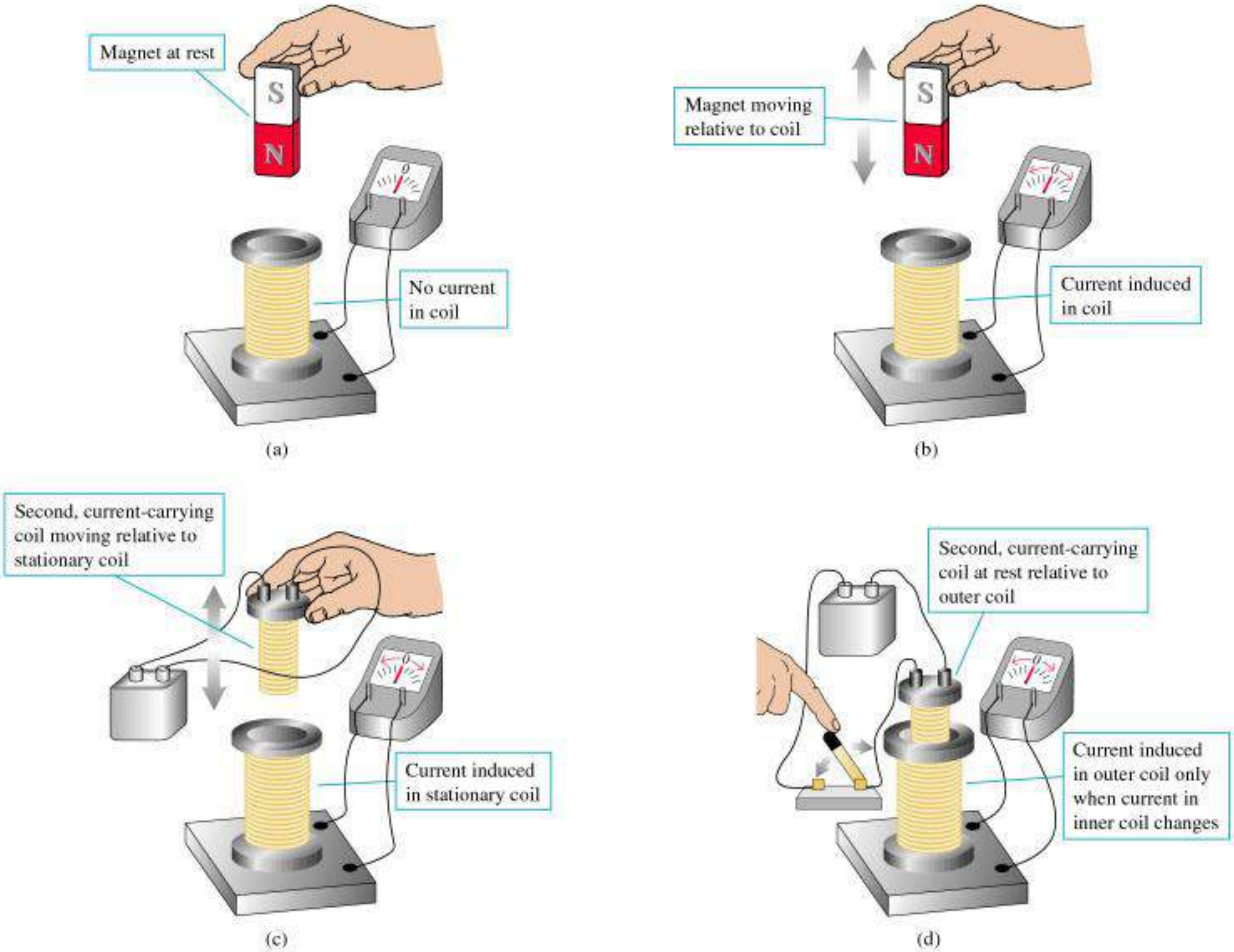
ELECTROMAGNETIC TRANSDUCTION:

- In electromagnetic transduction, the measurand is converted to voltage induced in conductor by change in the magnetic flux, in absence of excitation.
- The electromagnetic transducer are self generating active transducers
- The motion between a piece of magnet and an electromagnet is responsible for the change in flux





Current induced in a coil.


Magnet at rest
S
N
No current in coil
(a)
Magnet moving relative to coil
S
N
Current induced in coil
(b)
Second, current-carrying coil moving relative to stationary coil
Current induced in stationary coil
(c)
Second, current-carrying coil at rest relative to outer coil
Current induced in outer coil only when current in inner coil changes
(d)

CLASSIFICATION OF TRANSDUCERS According to Transduction Principle

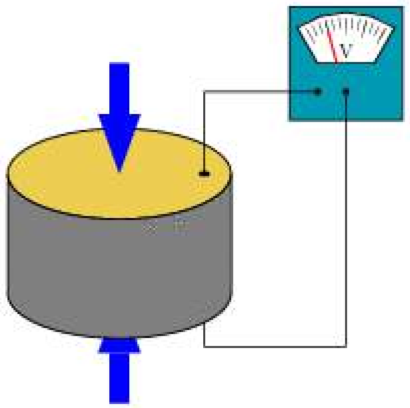
INDUCTIVE TRANSDUCER:

•In inductive transduction, the measurand is converted into a change in the self inductance of a single coil. It is achieved by displacing the core of the coil that is attached to a mechanical sensing element

CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle

PIEZO ELECTRIC INDUCTION :

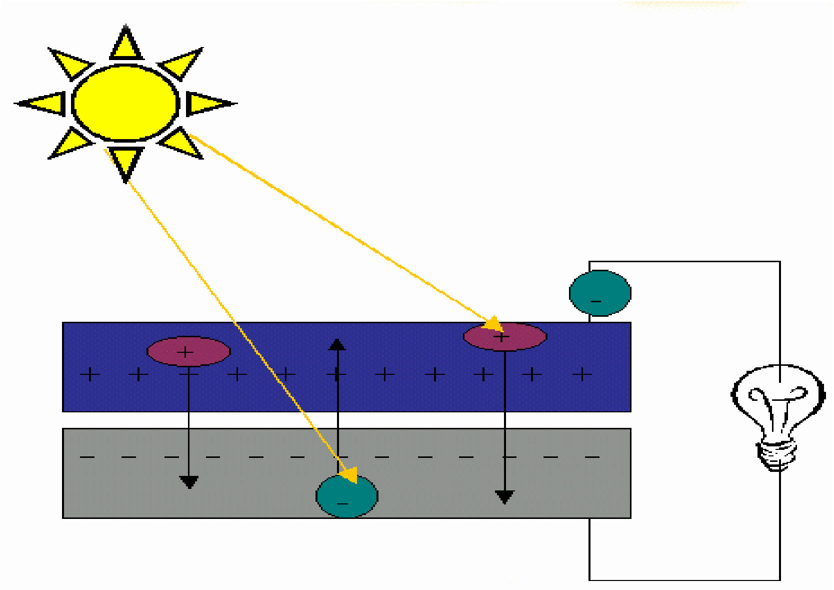
•In piezoelectric induction the measurand is converted into a change in electrostatic charge q or voltage V generated by crystals when mechanically it is stressed as shown in fig.

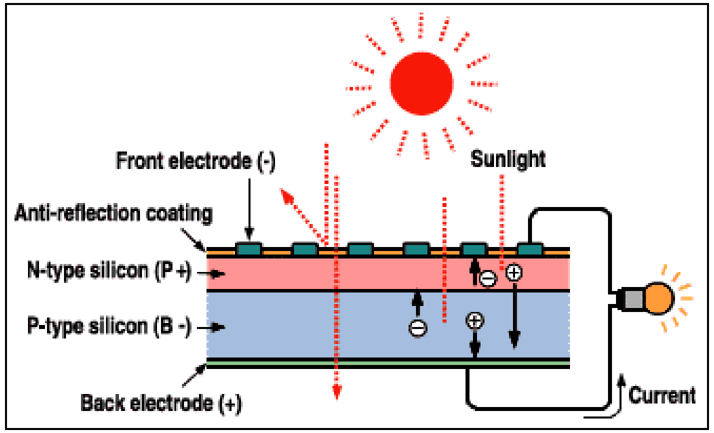


CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle

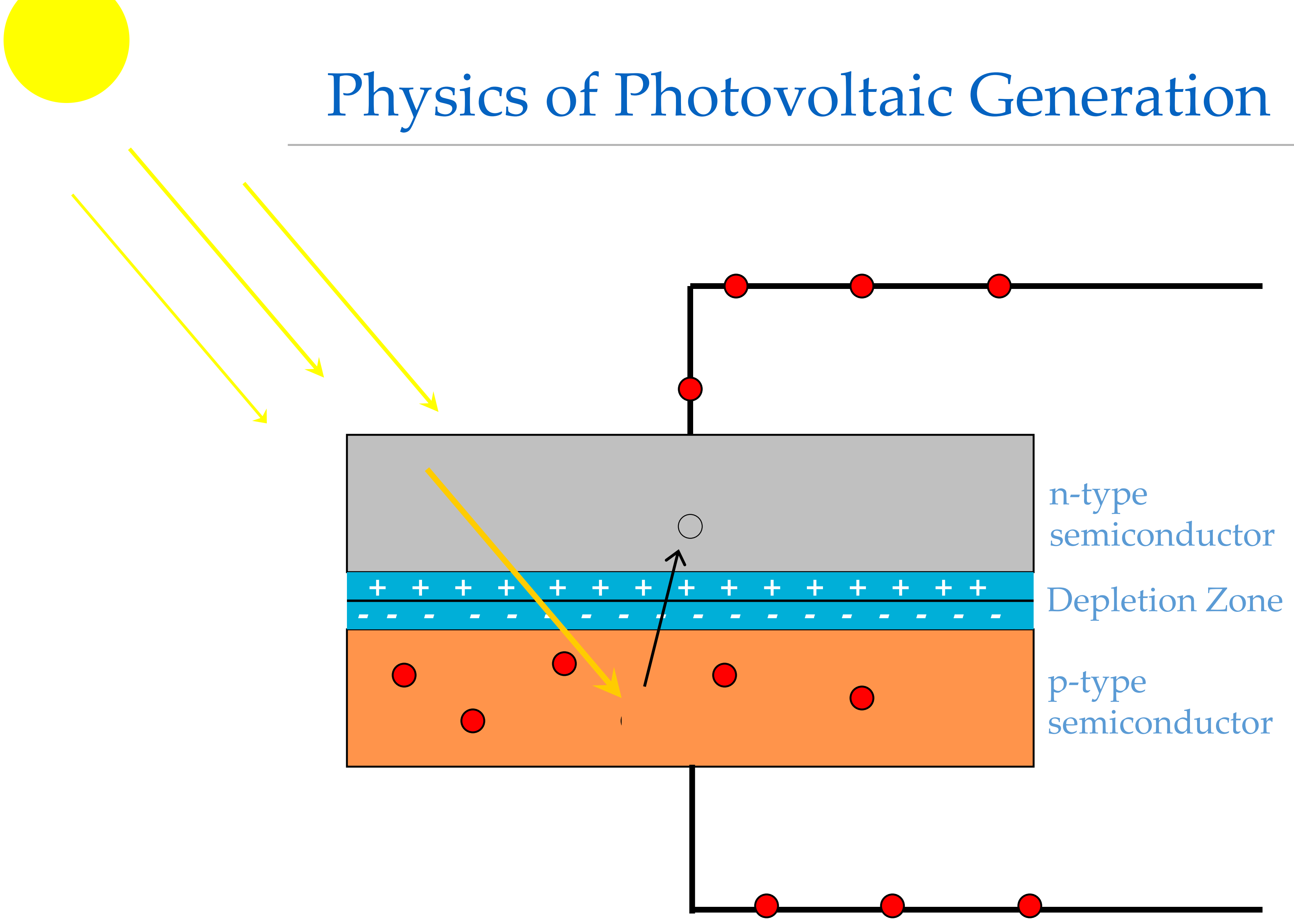
PHOTOVOLTAIC TRANSDUCTION :

•In photovoltaic transduction the measurand is converted to voltage generated when the junction between dissimilar material is illuminated as shown in fig.





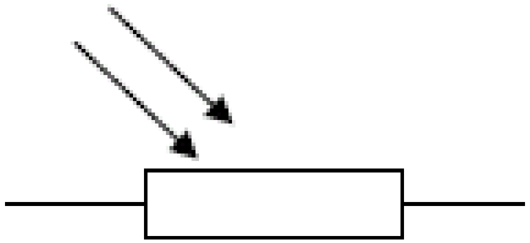
Physics of Photovoltaic Generation



CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle

PHOTO CONDUCTIVE TRANSDUCTION :

•In photoconductive transduction the measurand is converted to change in resistance of semiconductor material by the change in light incident on the material.



PASSIVE TRANSDUCERS

- **Resistive transducers** :
  - Resistive transducers are those transducers in which the resistance change due to the change in some physical phenomenon.
  - The resistance of a metal conductor is expressed by a simple equation.
  - $R = \rho L/A$
  - Where R = resistance of conductor in Ω

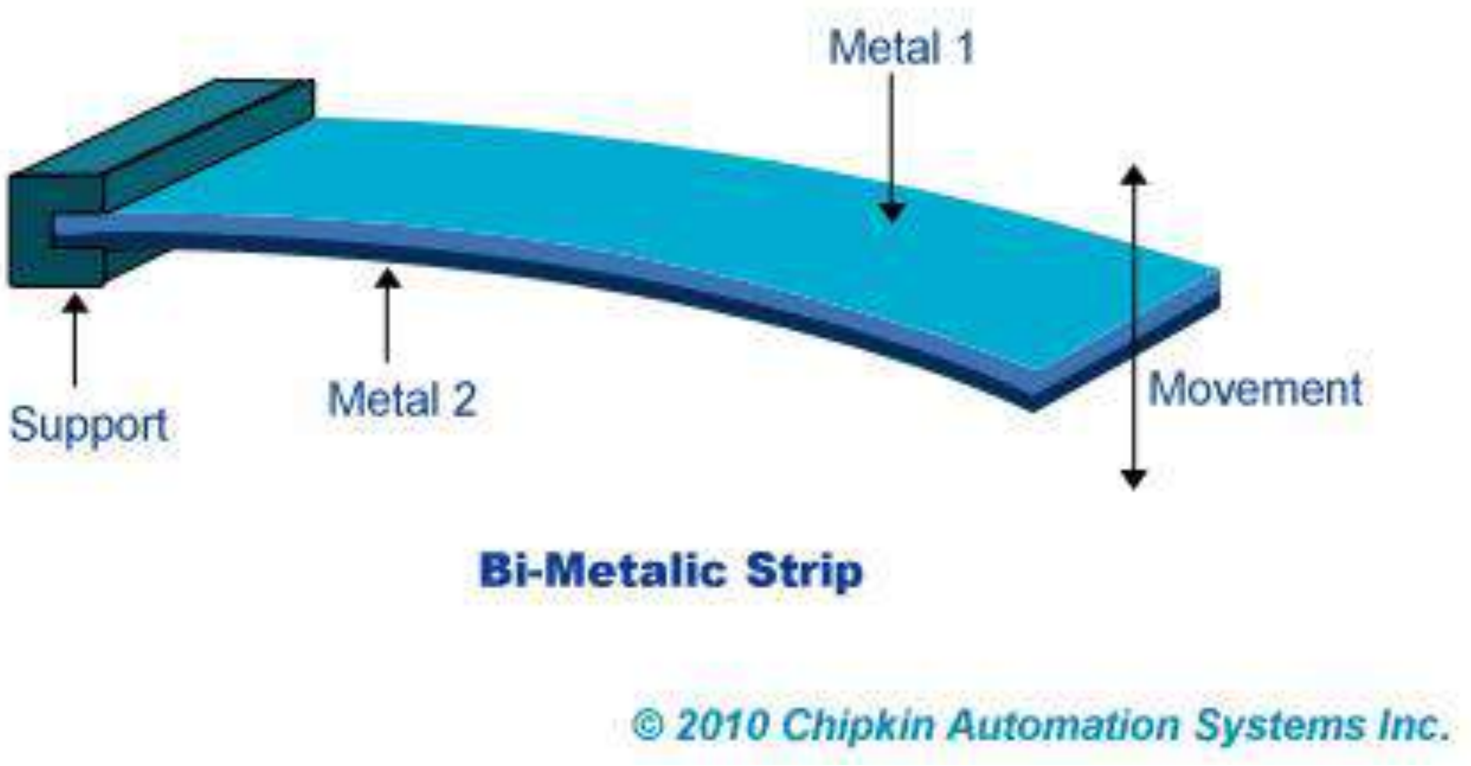
    L = length of conductor in m

    A = cross sectional area of conductor in m^2

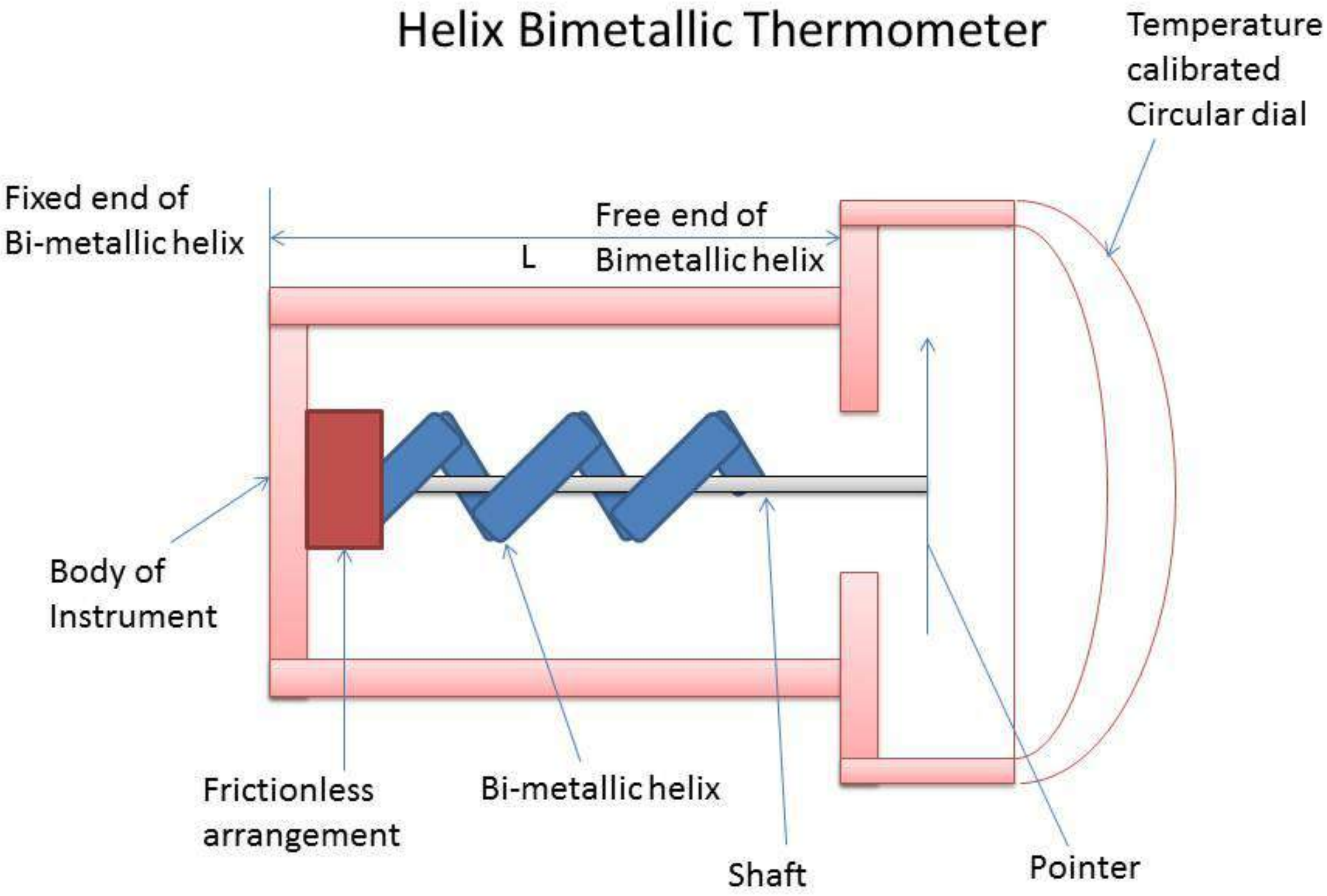
    ρ = resistivity of conductor material in Ω-m.

MEASUREMENT OF TEMPERATURE

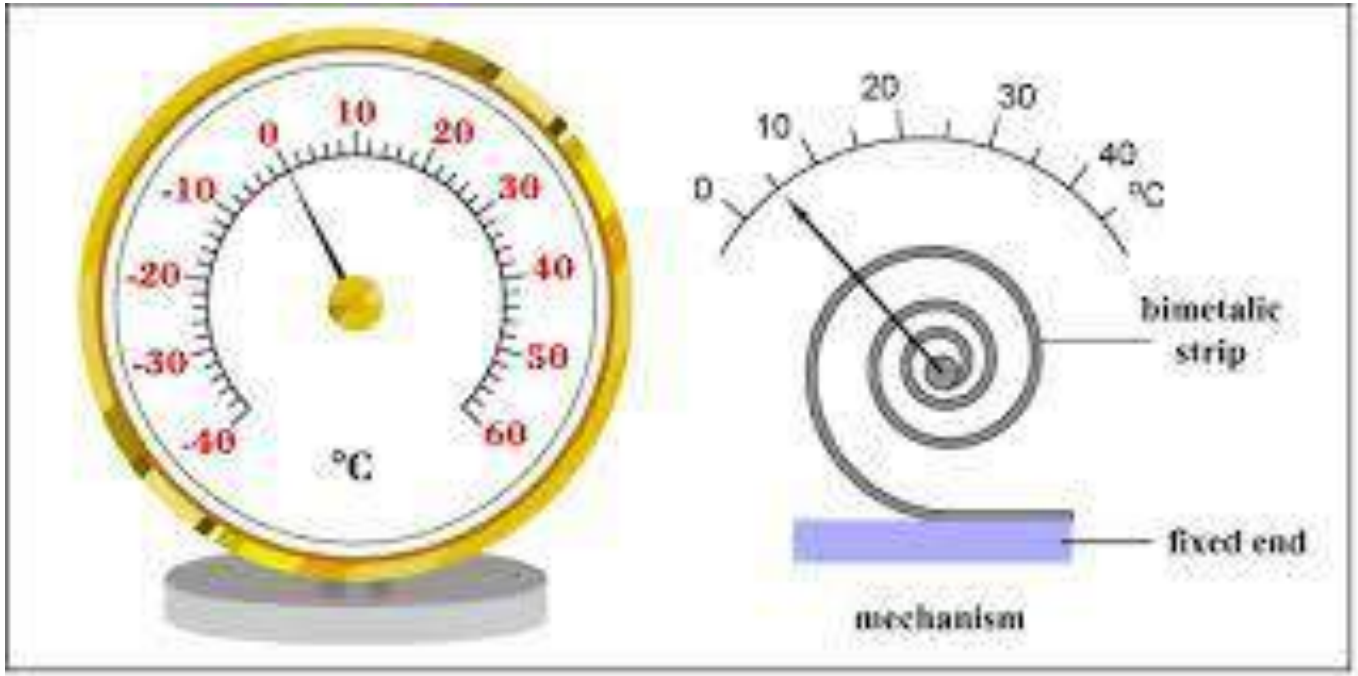
BIMETALLIC STRIP



HELIX BIMETALLIC THERMOMETER



SPIRAL BIMETALLIC THERMOMETER



Resistance Thermometer

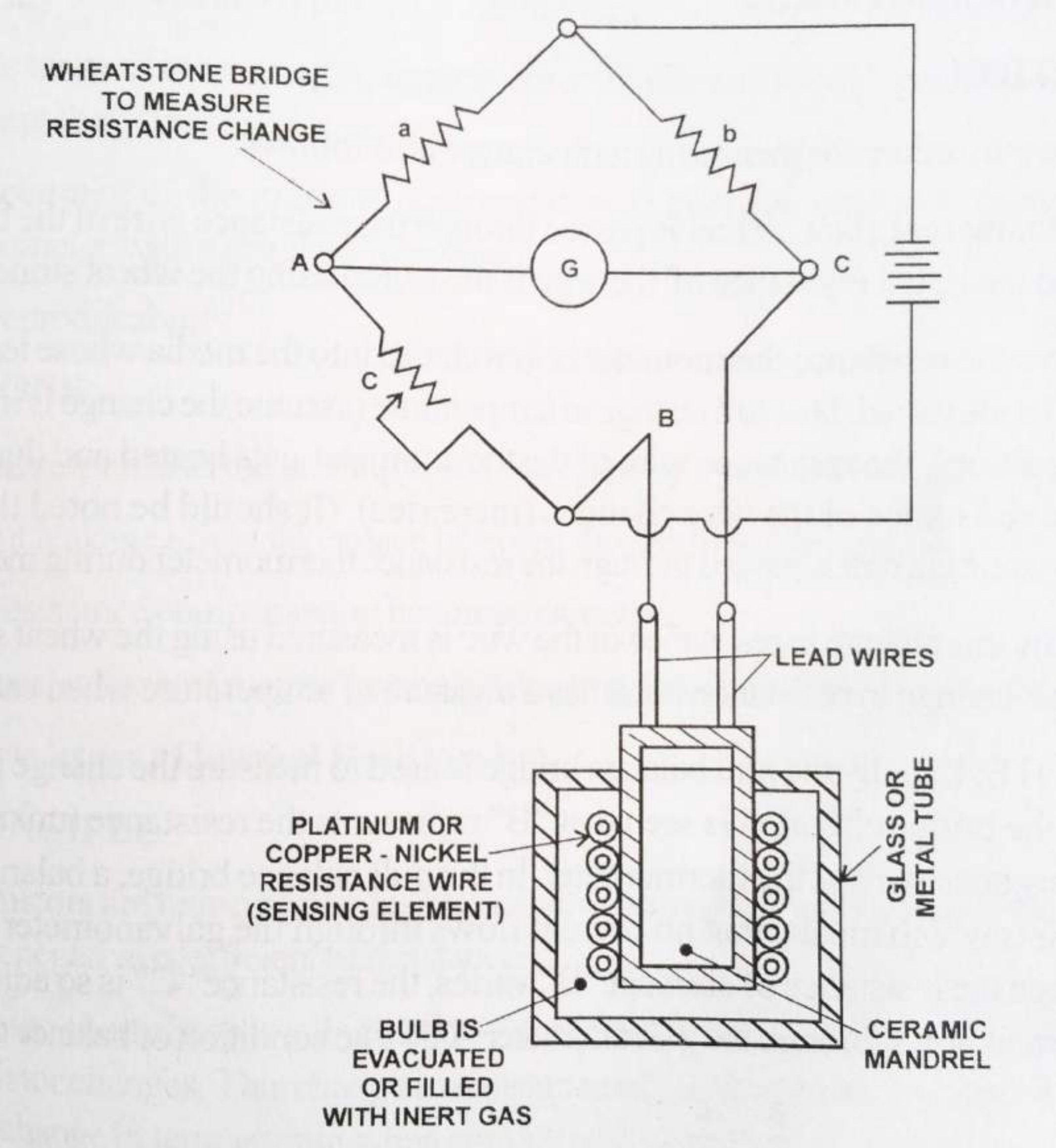


Figure 20.6: Resistance thermometer

THERMISTOR

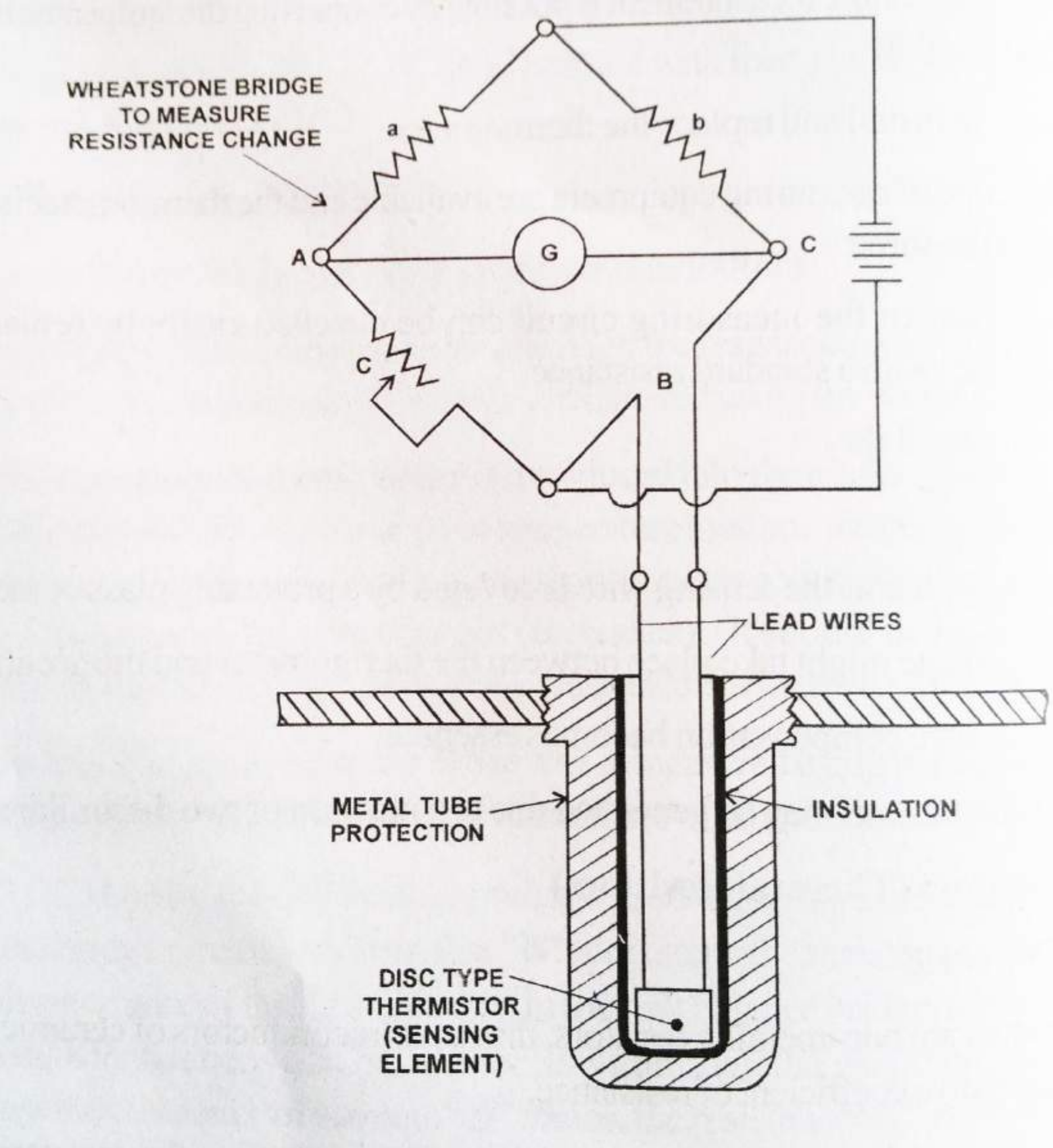


Figure 20.7: Thermistor

THERMOCOUPLE

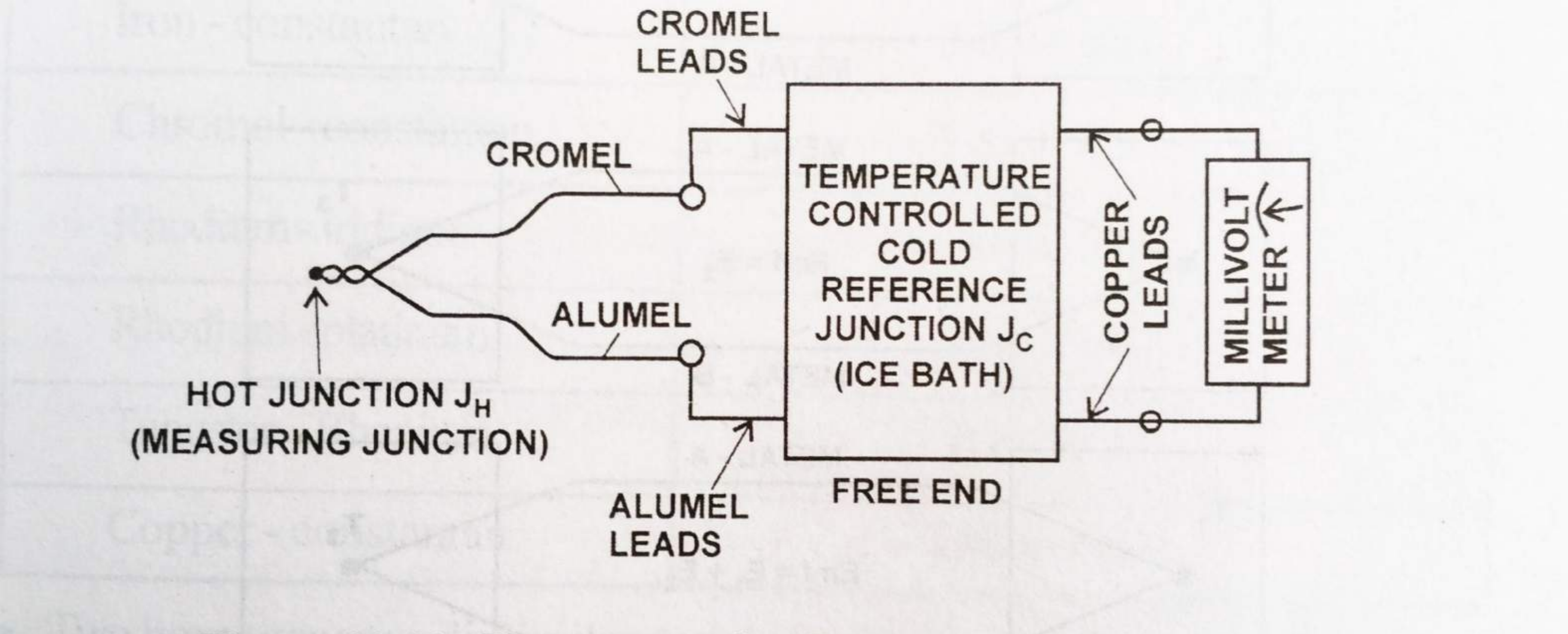


Figure 20.10: Thermocouple - Temperature measurement

Alumel is an alloy consisting of approximately 95% nickel, 2% manganese, 2% aluminium and 1% silicon

Chromel is an alloy made of approximately 90 percent nickel and 10 percent chromium

MEASUREMENT
OF
PRESSURE

DEAD WEIGHT TESTER

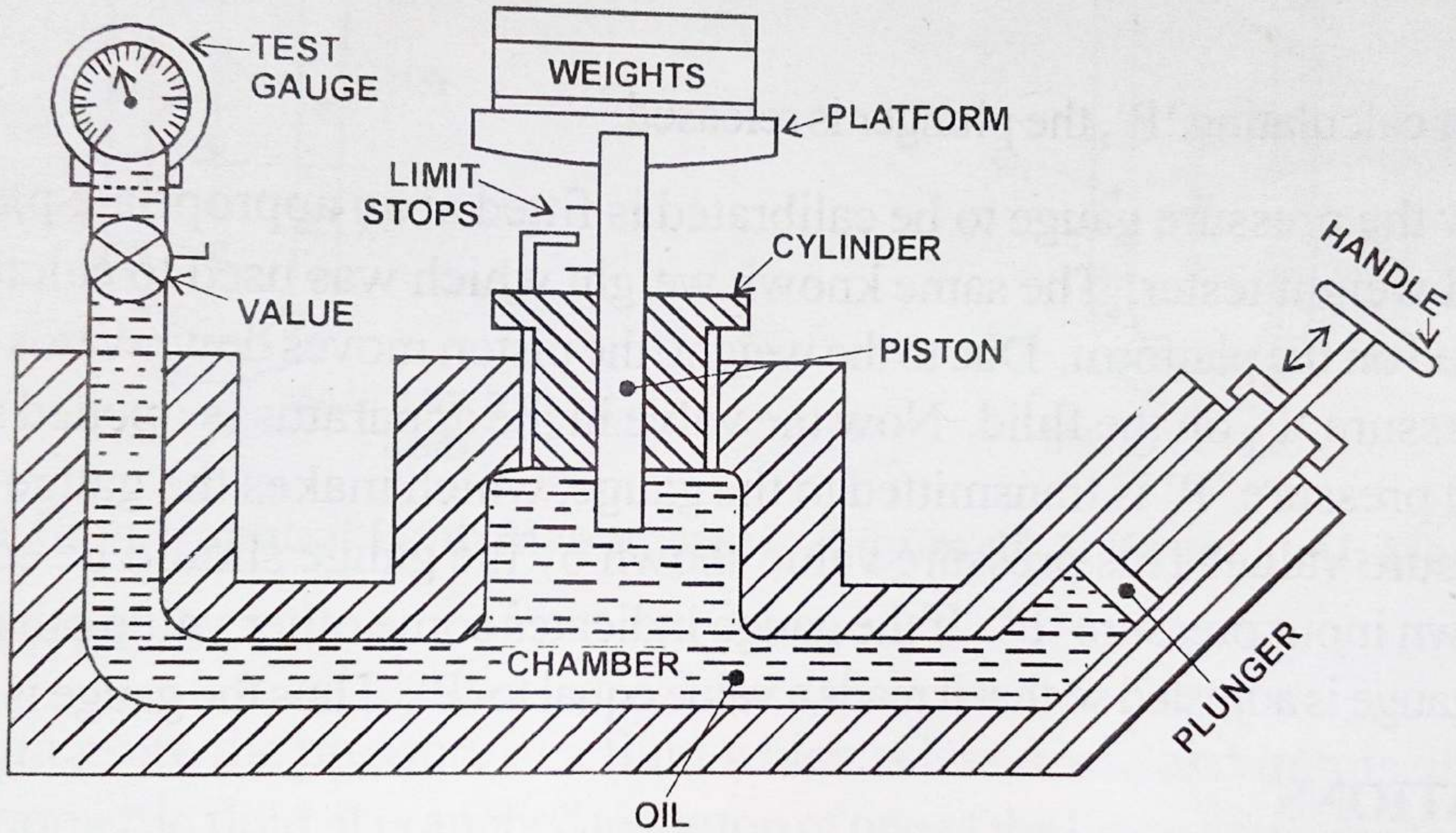


Figure 18.3: Dead Weight Tester

BOURDON TUBE PRESSURE GAUGE

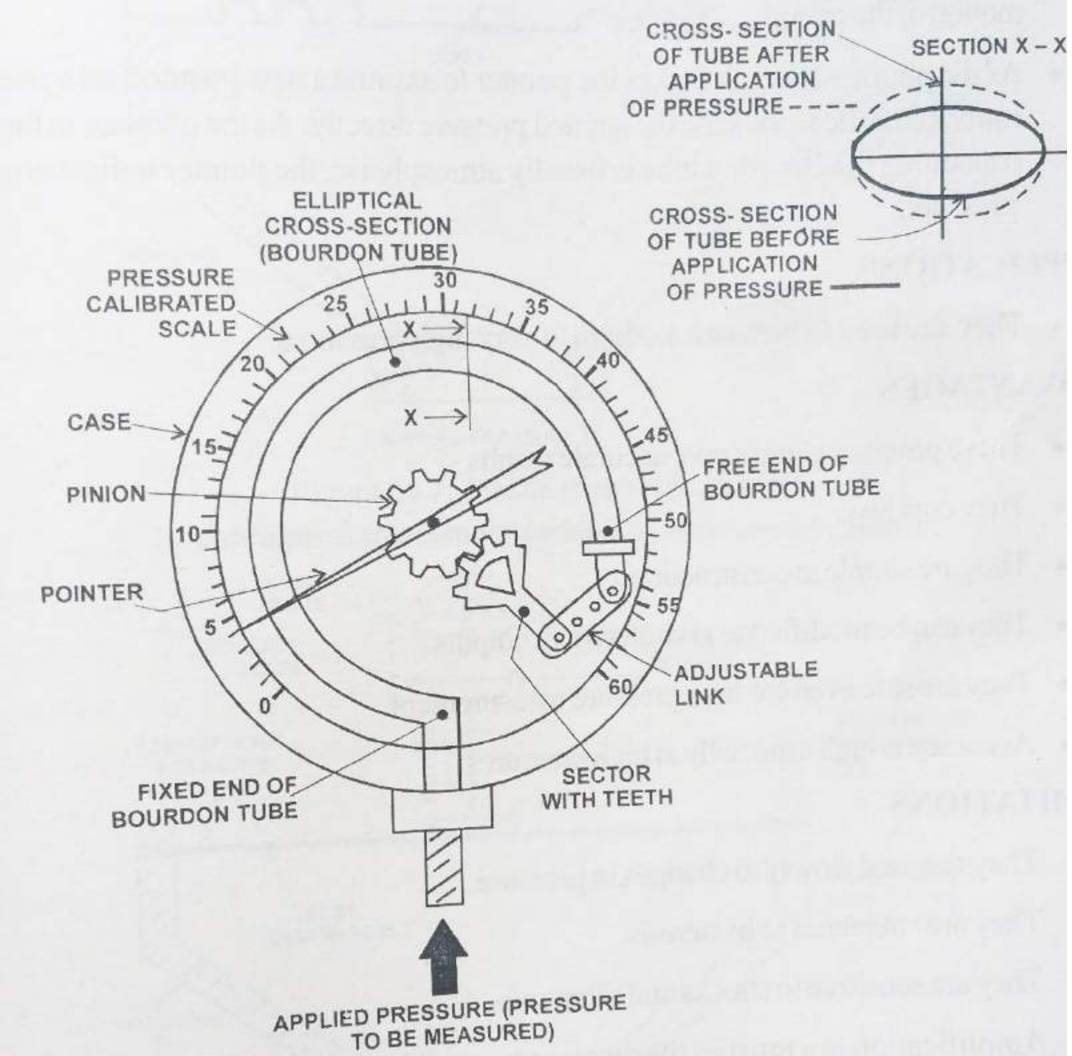


Figure 18.6: Bourdon tube pressure gauge

DIAPHRAGM GAUGE

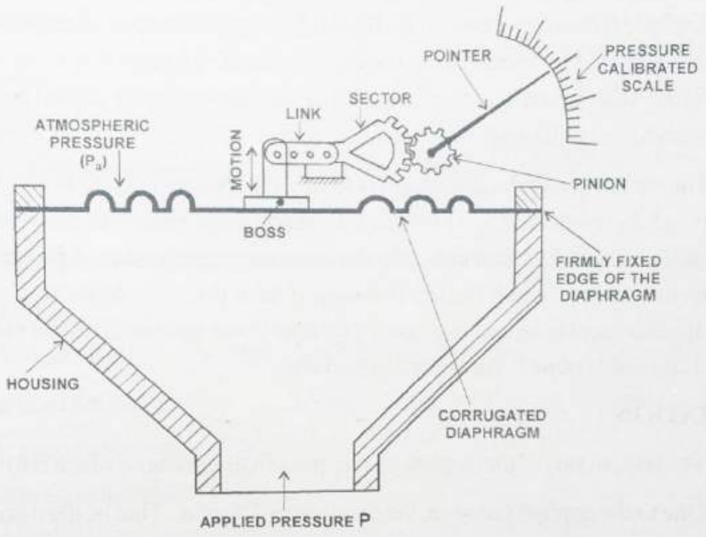


Figure 18.7: Elastic diaphragm gauge
(Diaphragm displacement sensed by mechanical means)

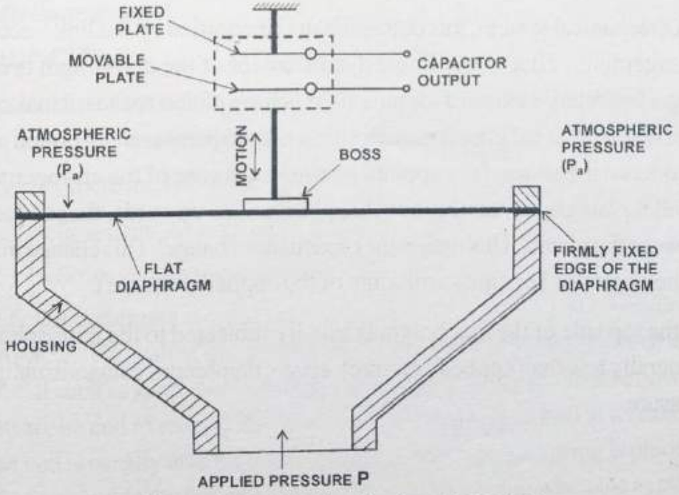


Figure 18.8: Elastic diaphragm gauge
(Diaphragm displacement sensed by Secondary Transducer)

BELLOWS GAUGE

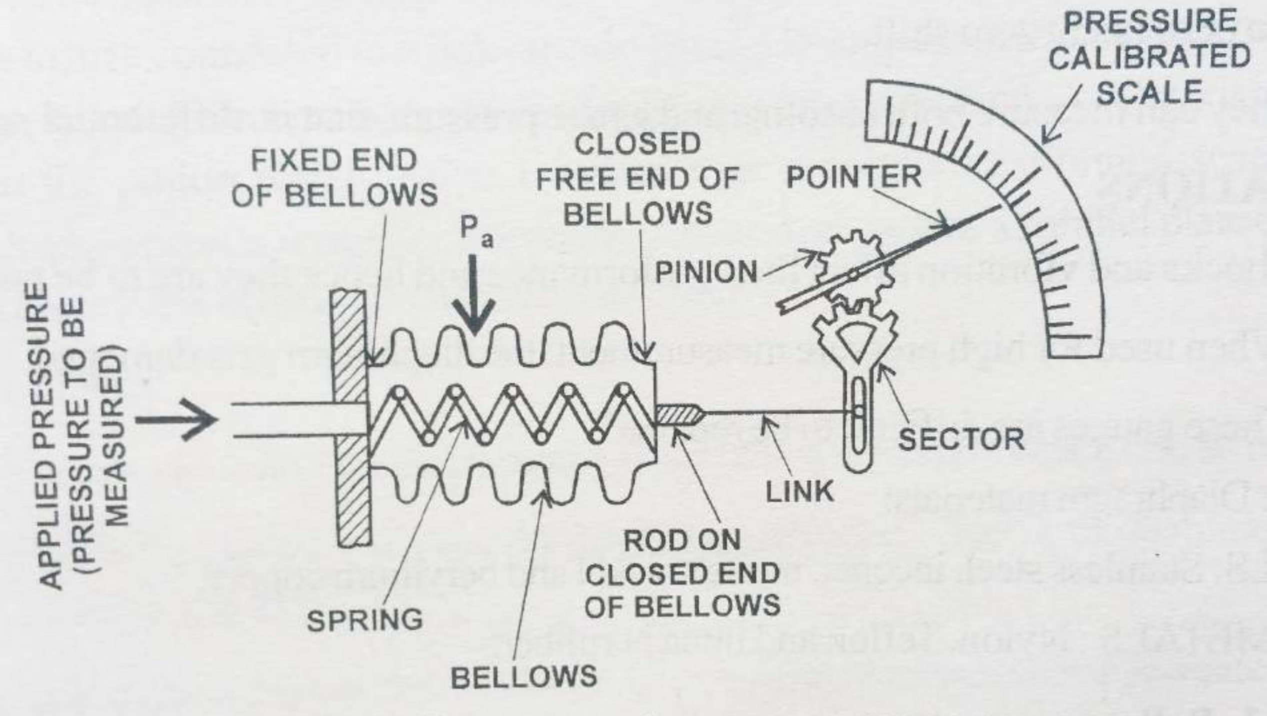


Figure 18.9: Bellows gauge to measure gauge pressure

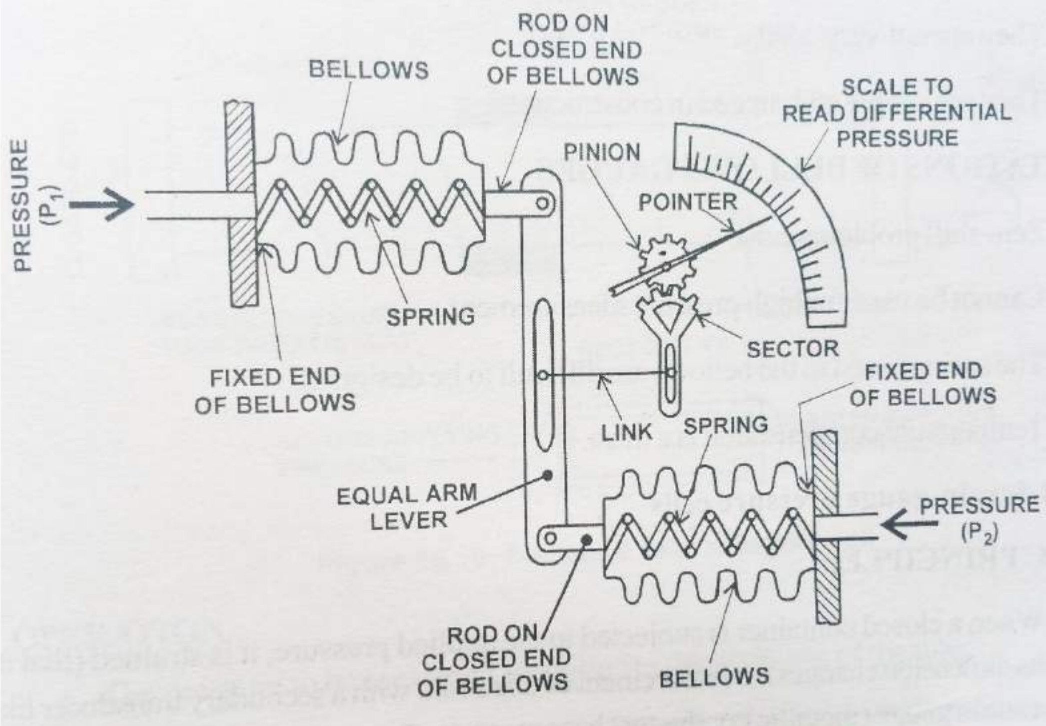


Figure 18.10: Bellows gauge to measure differential pressure

MCLEOD VACUUM GAUGE

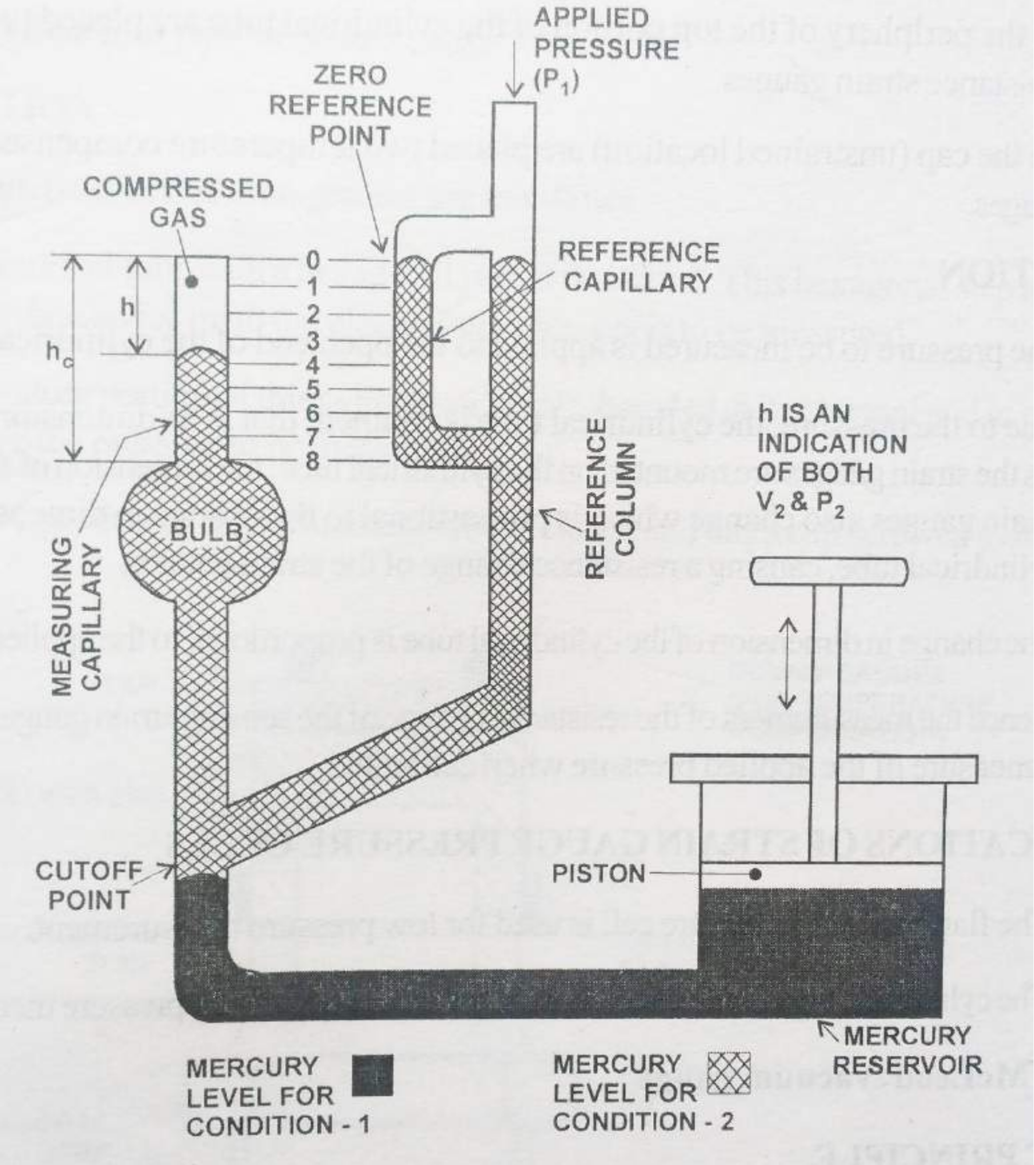


Figure 18.12: McLeod vacuum gauge

PIRANI GAUGE

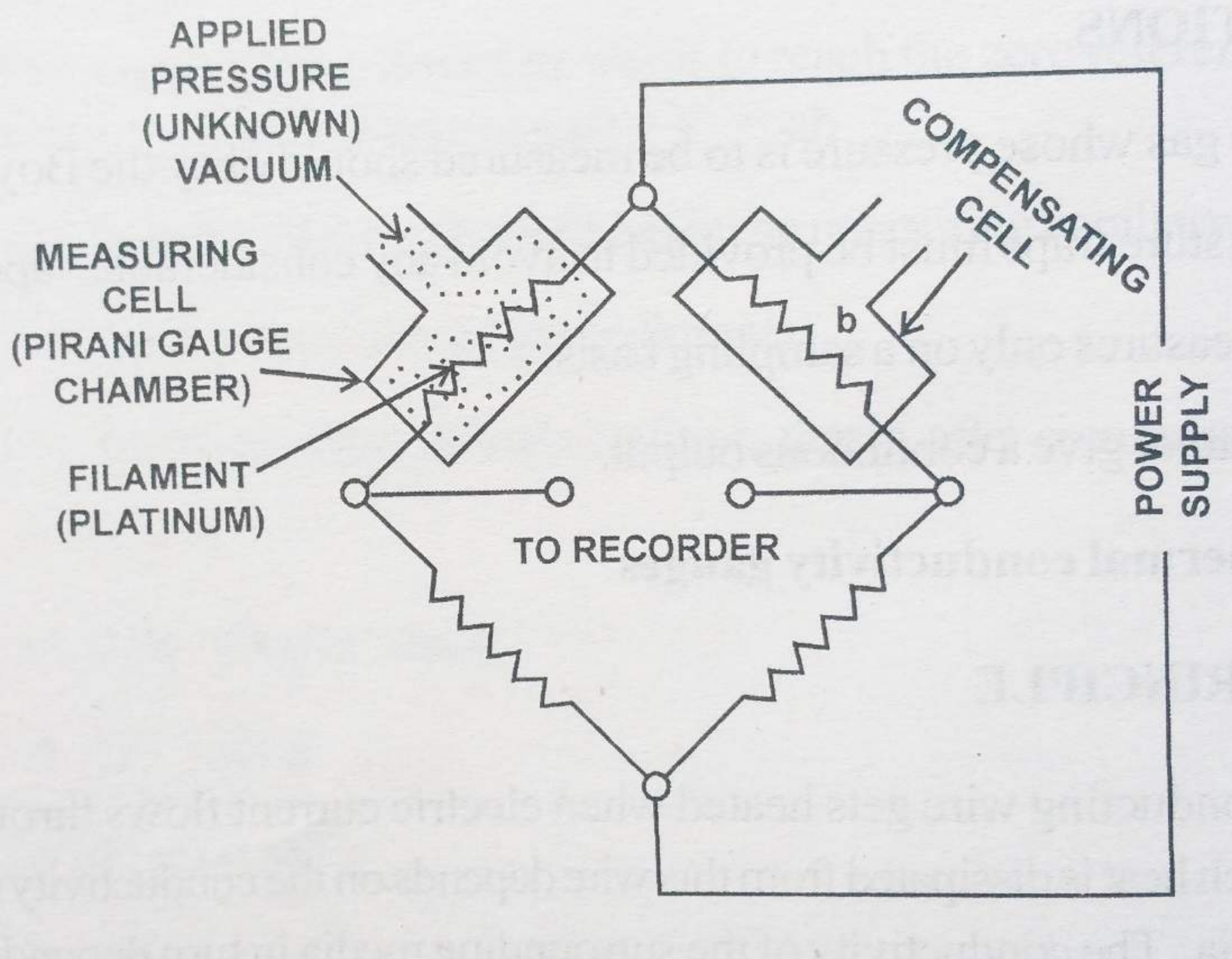


Figure 18.13: Pirani gauge

THERMOCOUPLE TYPE CONDUCTIVITY GAUGE

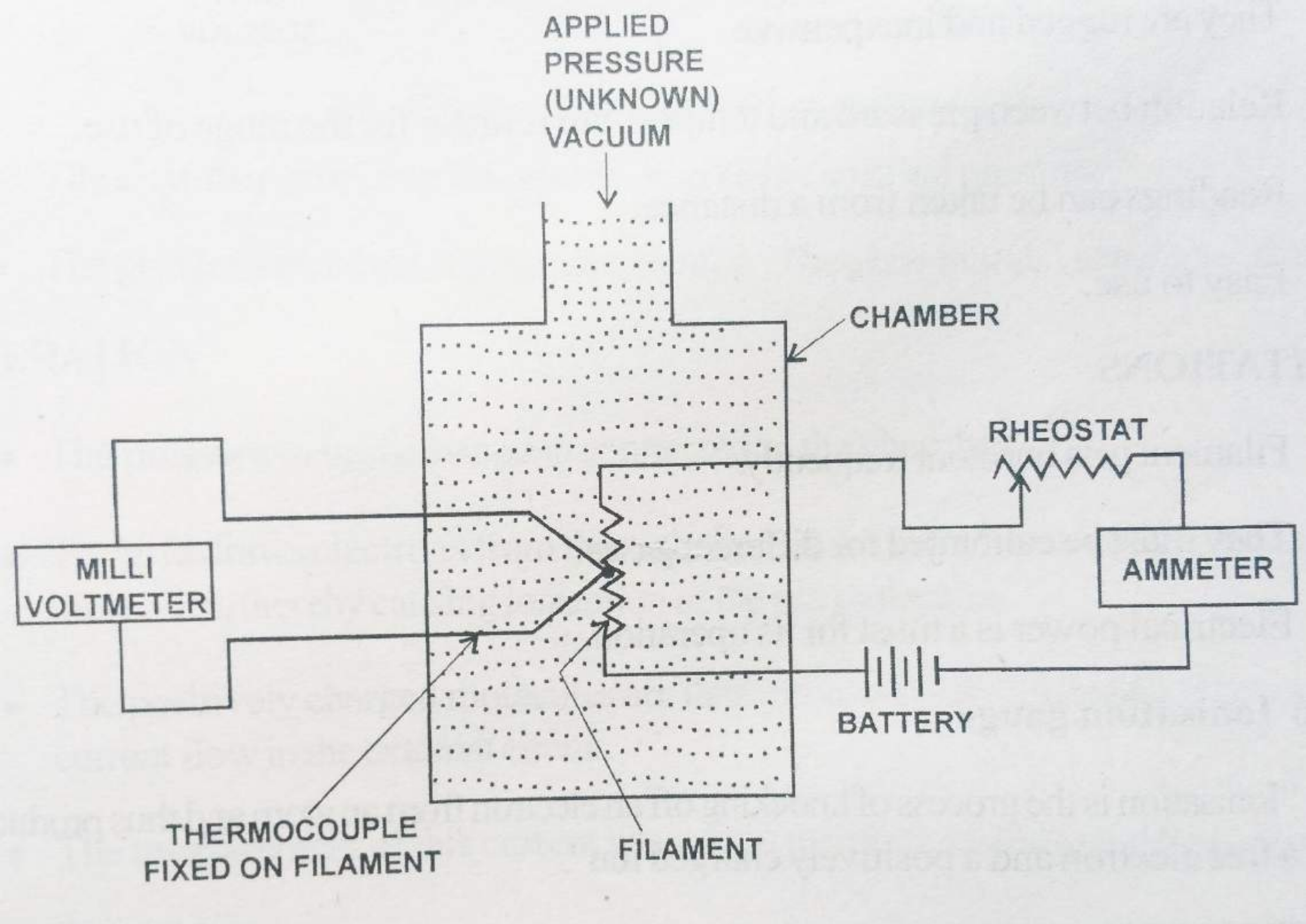


Figure 18.14: Thermocouple type conductivity gauge

IONIZATION GAUGE

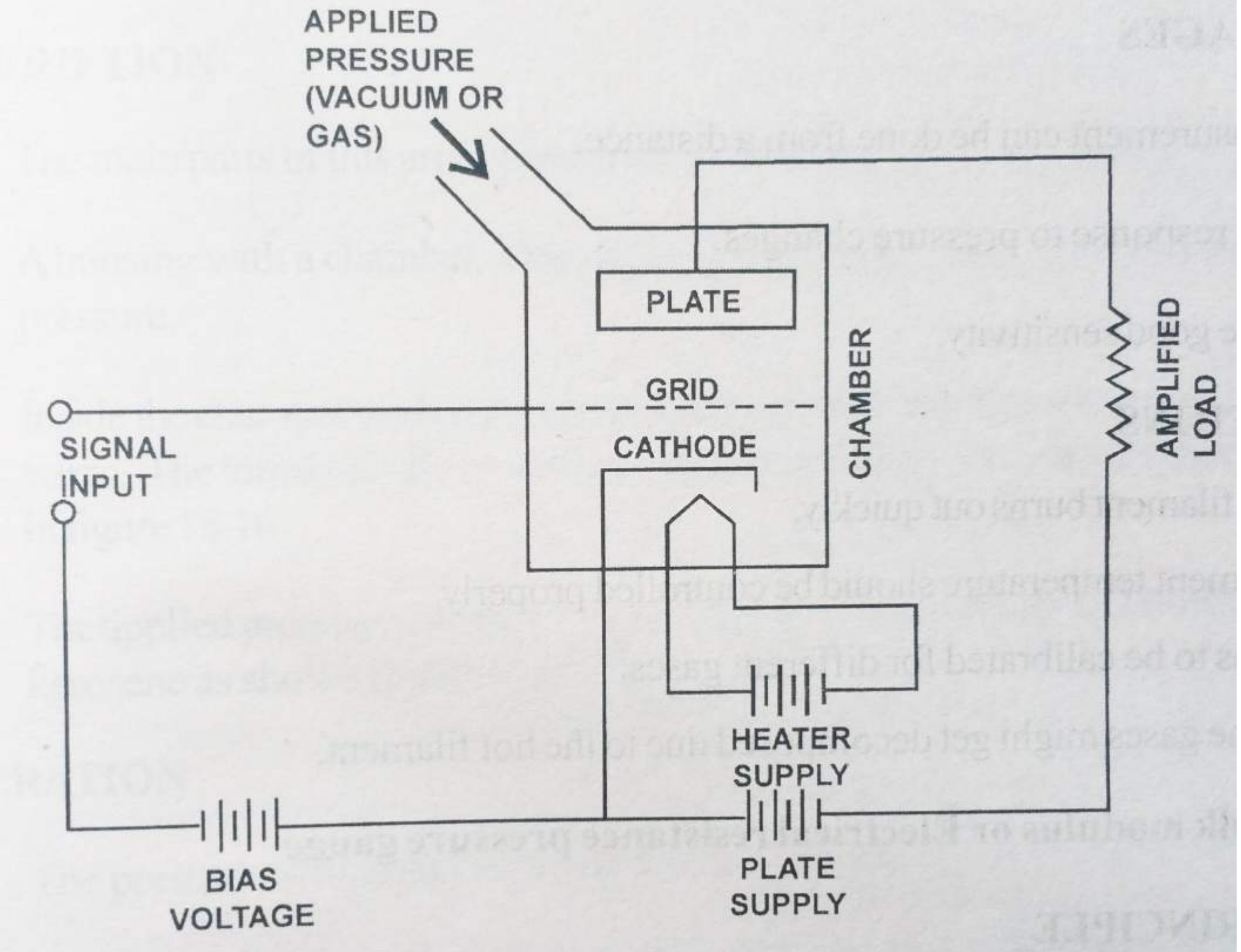


Figure 18.15: Ionization gauge

UNIT-III

MEASUREMENT
OF
LIQUID LEVEL

DIRECT LIQUID LEVEL MEASUREMENT DEVICES

SLIGHT GLASS

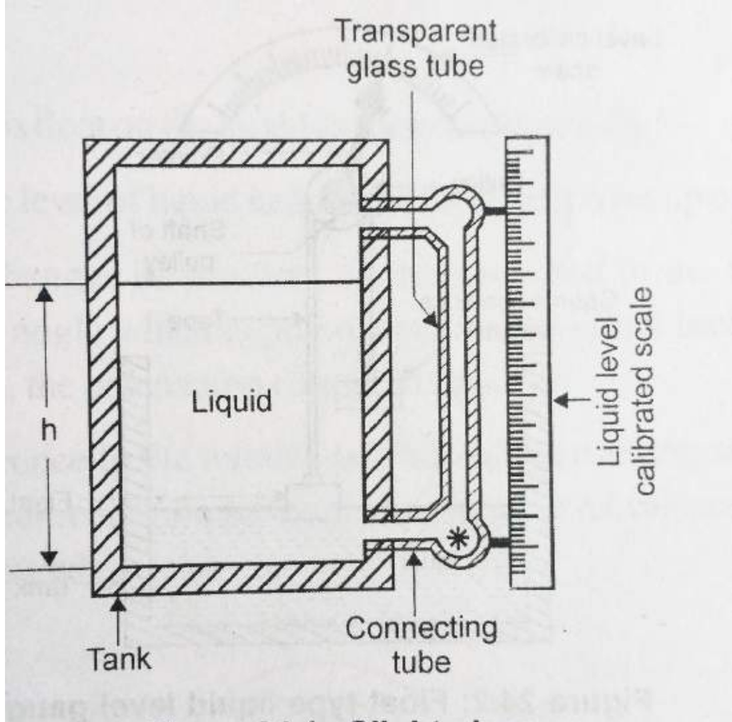


Figure 24.1: Slight glass

FLOAT GAUGES

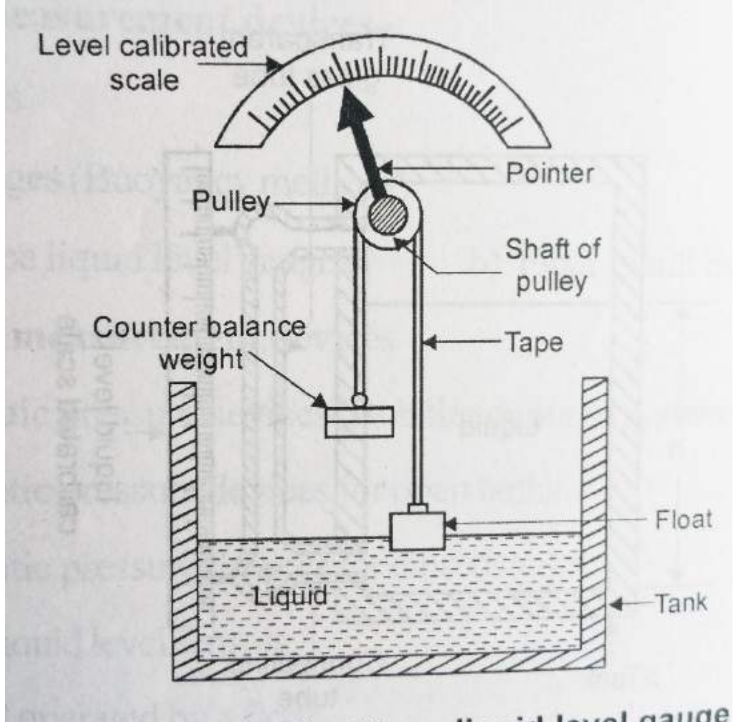


Figure 24.2: Float-type liquid level gauge

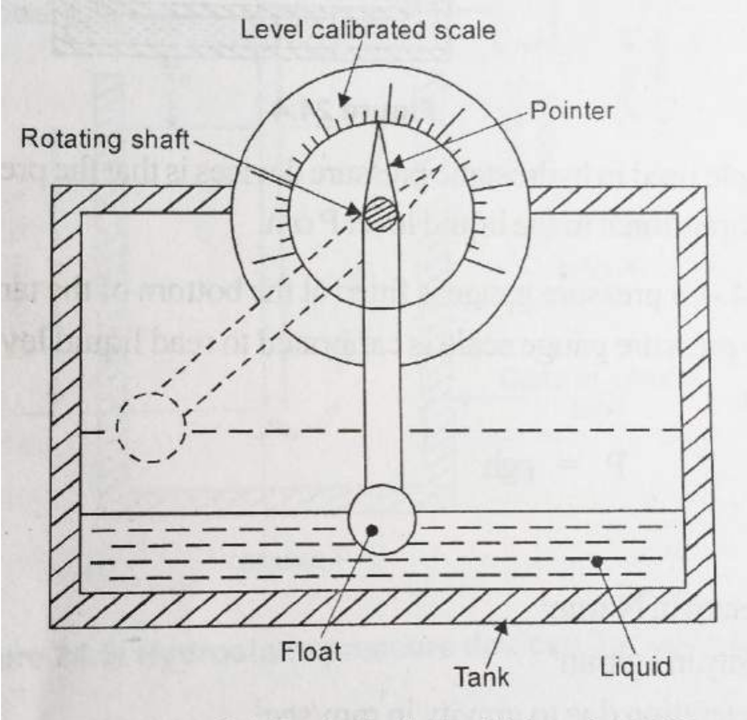


Figure 24.3: Float-shaft liquid level guage

INDIRECT LIQUID LEVEL MEASUREMENT DEVICES

HYDROSTATIC PRESSURE DEVICES (BUBBLER OR PURGE SYSTEM)

PRINCIPLE

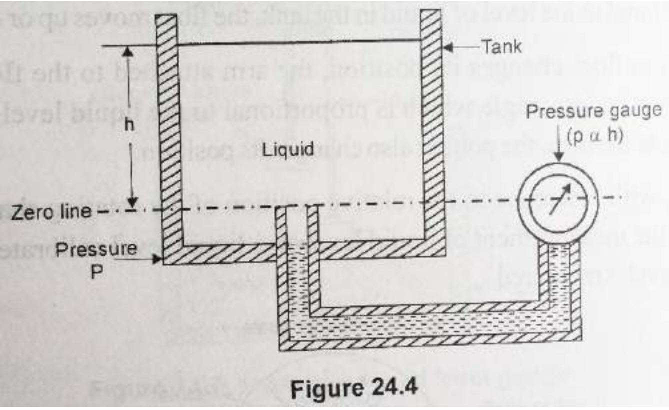


Figure 24.4

FOR OPEN TANK

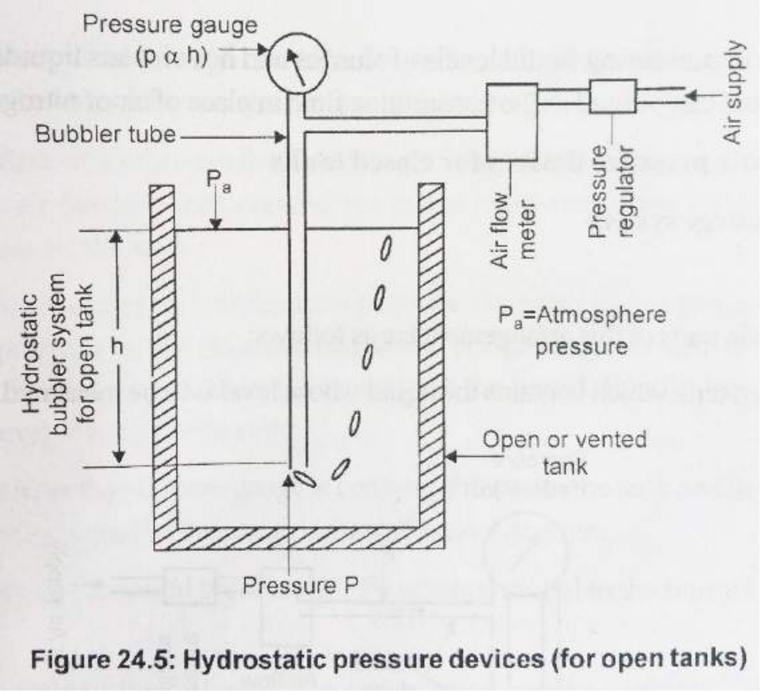


Figure 24.5: Hydrostatic pressure devices (for open tanks)

FOR CLOSED TANK

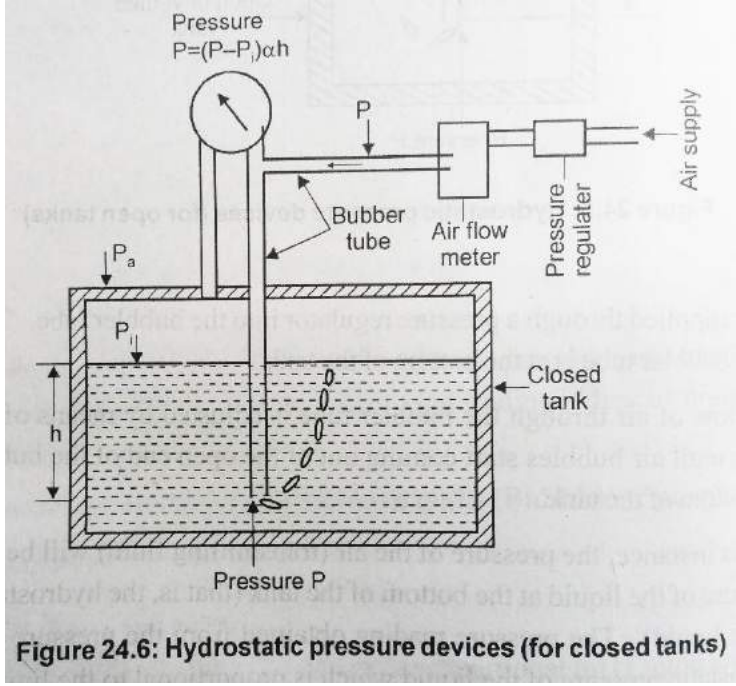


Figure 24.6: Hydrostatic pressure devices (for closed tanks)

INDIRECT LIQUID LEVEL MEASUREMENT DEVICES

ELECTRIC LIQUID LEVEL SENSORS

RHEOSTAT OPERATED BY FLOAT

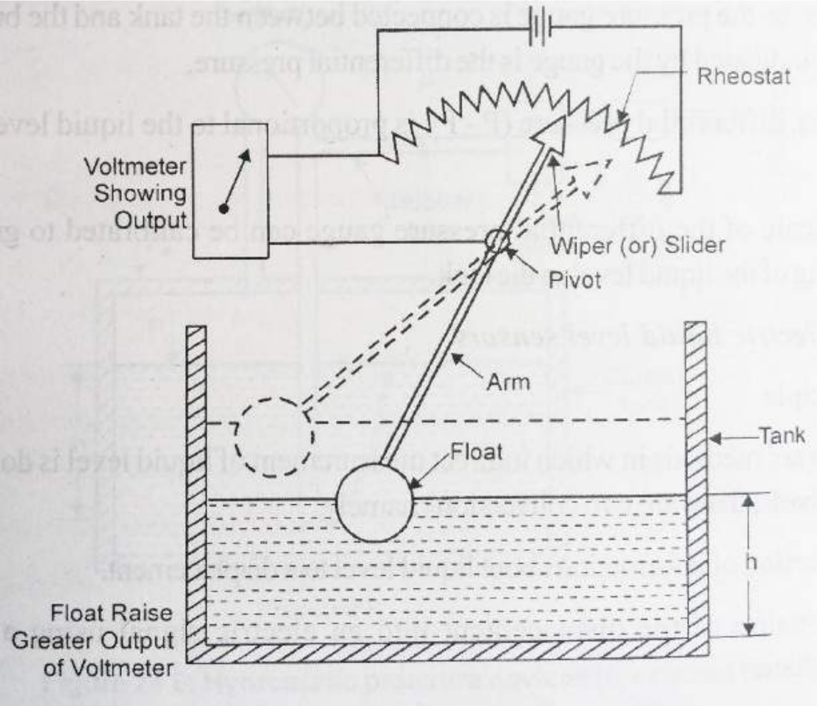


Figure 24.7: Rheostat operated by a float

CAPACITIVE LIQUID LEVEL SENSOR

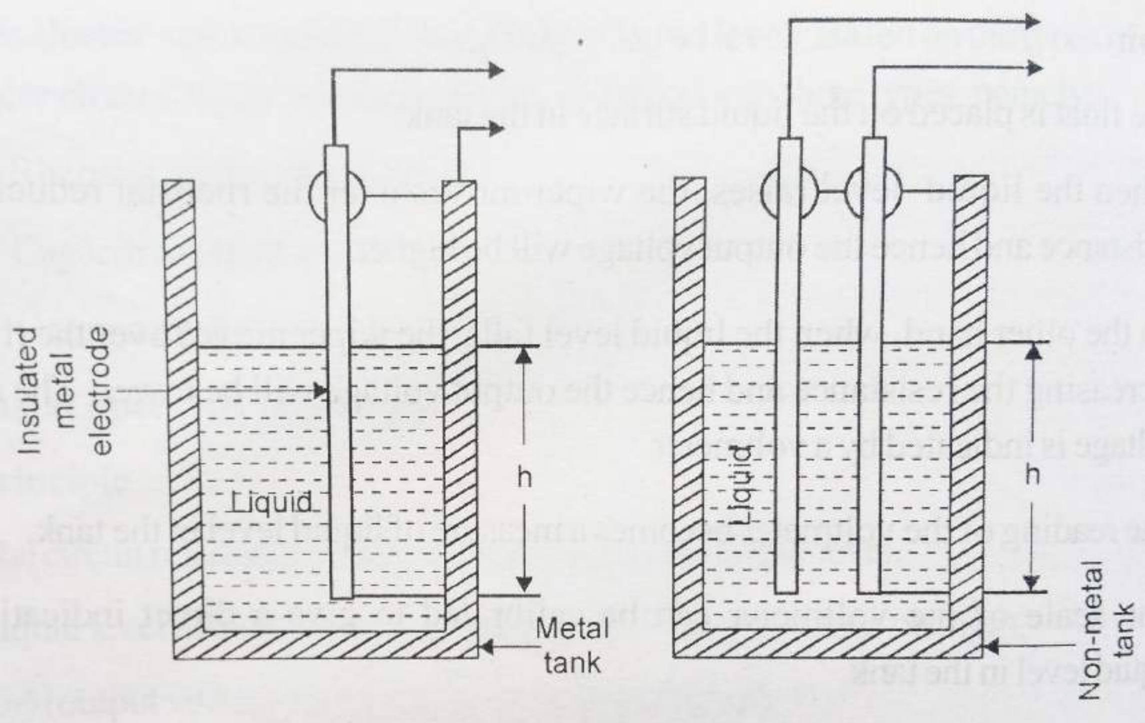


Figure 24.8: Capacitive liquid level sensor

GAMMA RAY LIQUID LEVEL SENSOR

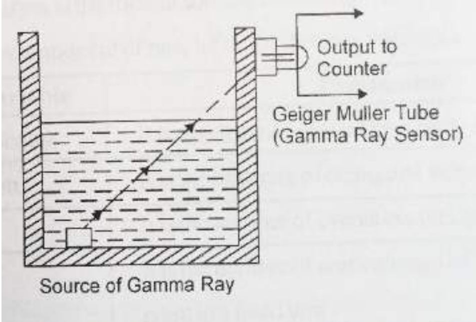


Figure 24.9: Gamma ray liquid level sensor

MEASUREMENT
OF
SPEED

MECHANICAL TACHOMETERS

(a) REVOLUTION COUNTER AND TIMER

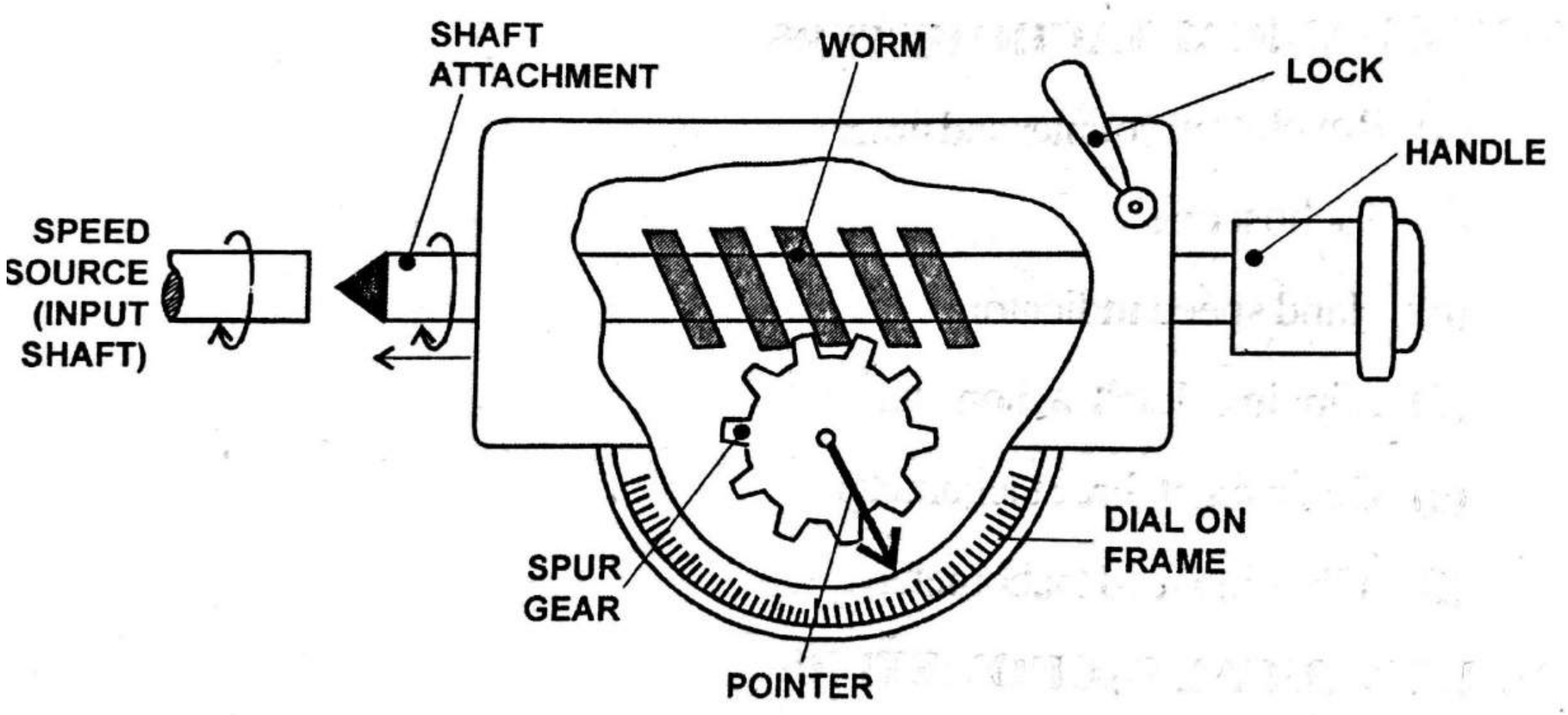


Figure 15.3: Revolution Counter and Timer

MECHANICAL TACHOMETERS

(b) TACHOSCOPE

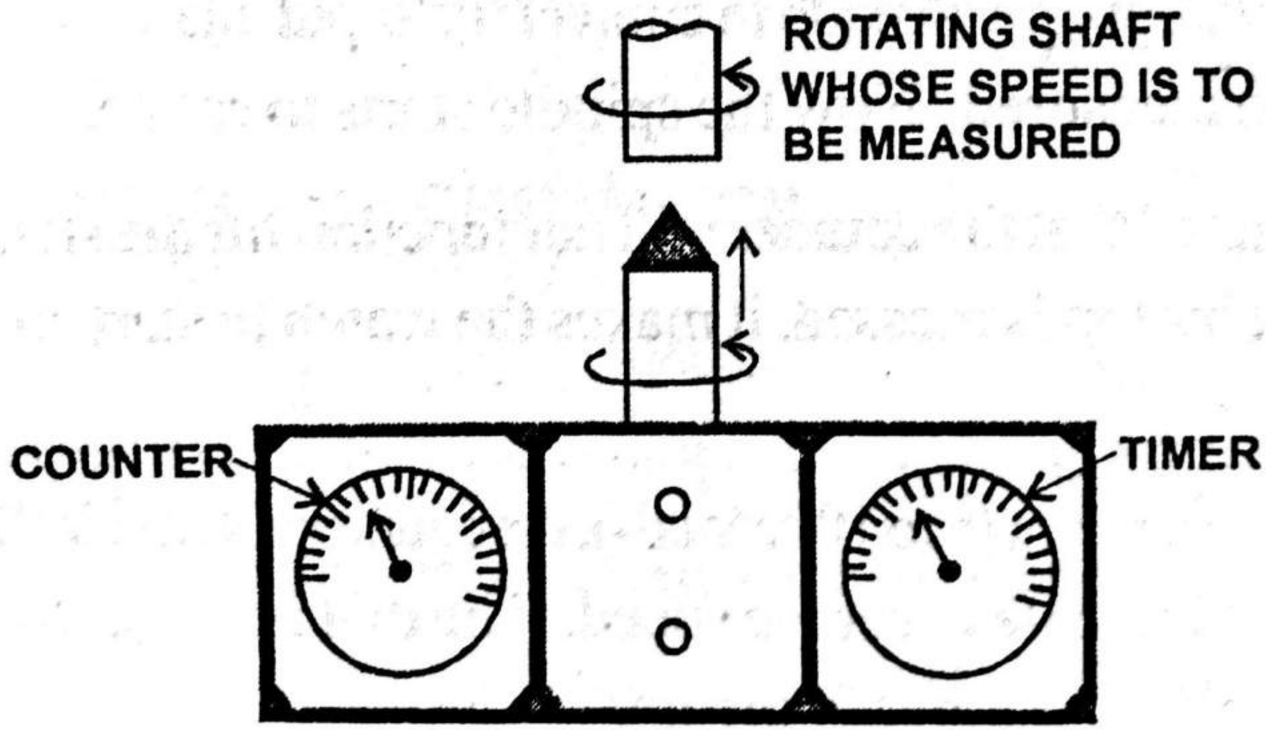


Figure 15.4: Tachoscope

MECHANICAL TACHOMETERS

(c) HAND SPEED INDICATOR

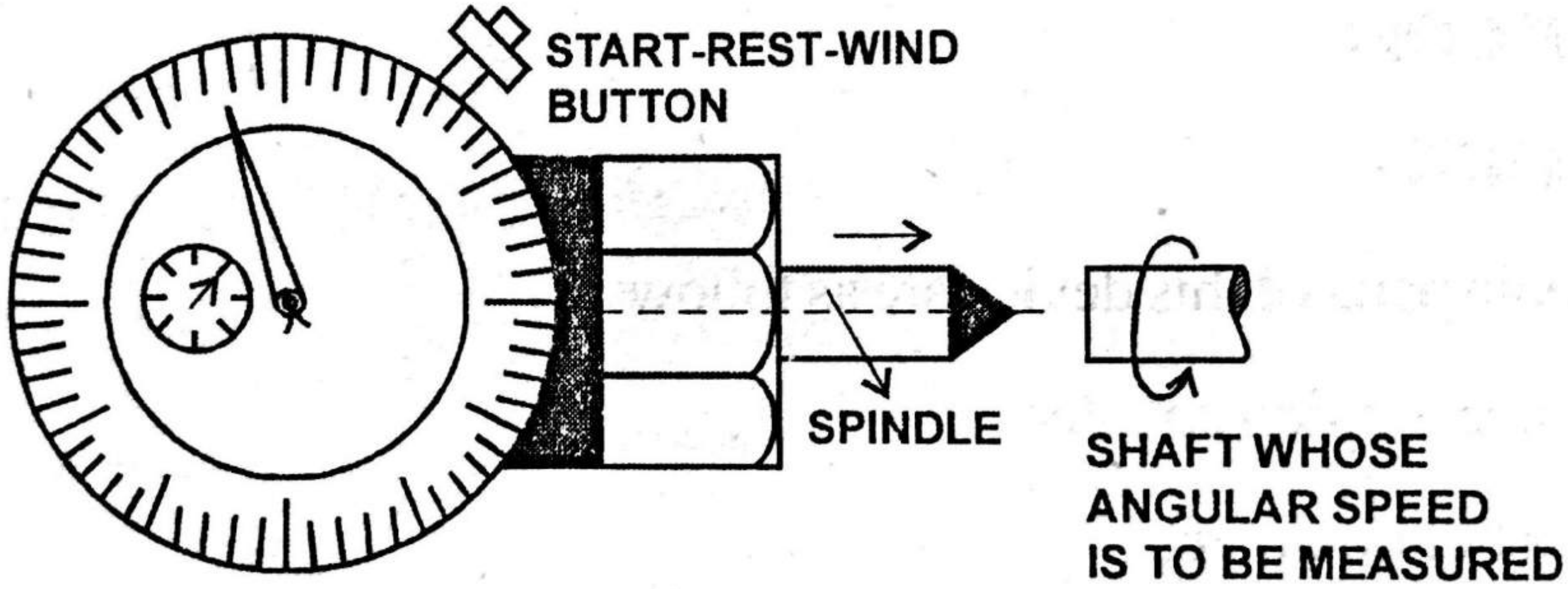


Figure 15.5: Hand speed indicator

MECHANICAL TACHOMETERS

(d) SLIPPING CLUTCH TACHOMETER

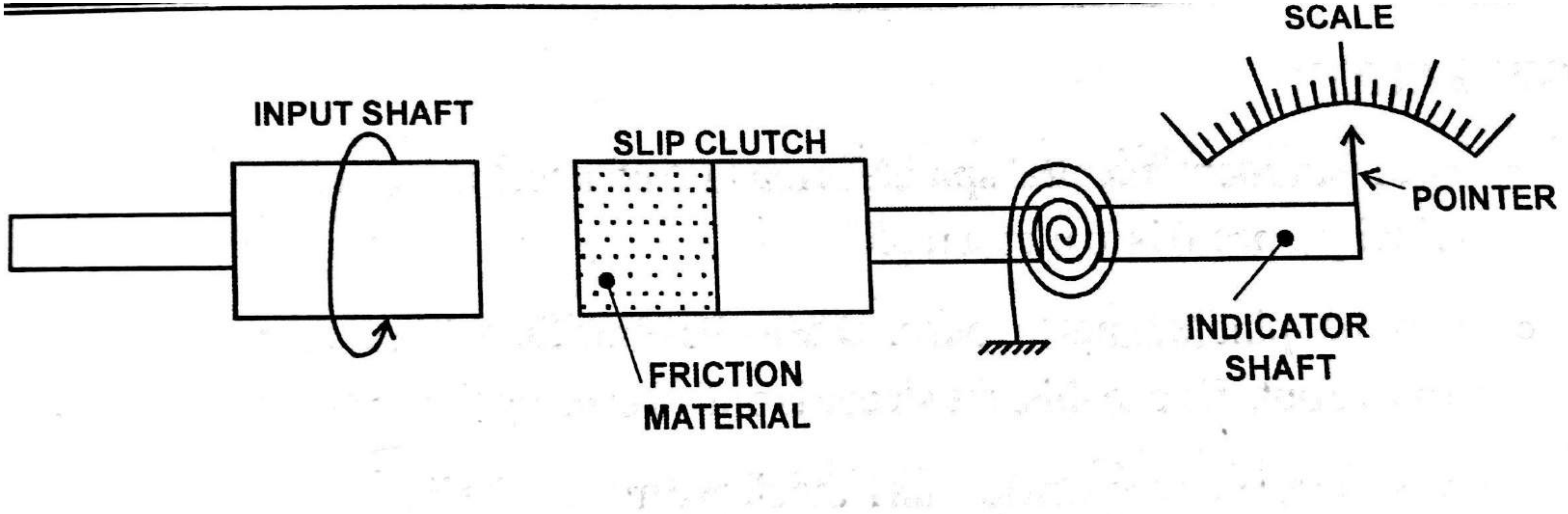


Figure 15.6: Sliping clutch tachometer

MECHANICAL TACHOMETERS

(e) CENTRIFUGAL FORCE TACHOMETER

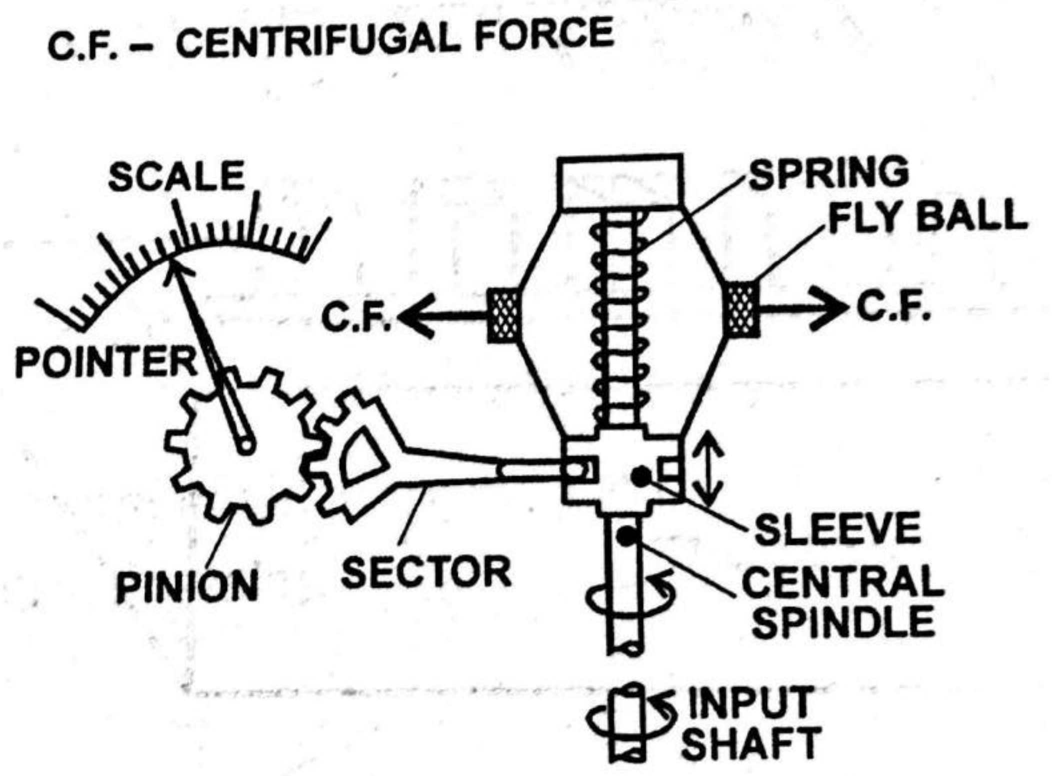


Figure 15.7: Centrifugal force tachometer

MECHANICAL TACHOMETERS

(f) VIBRATION REED TACHOMETER

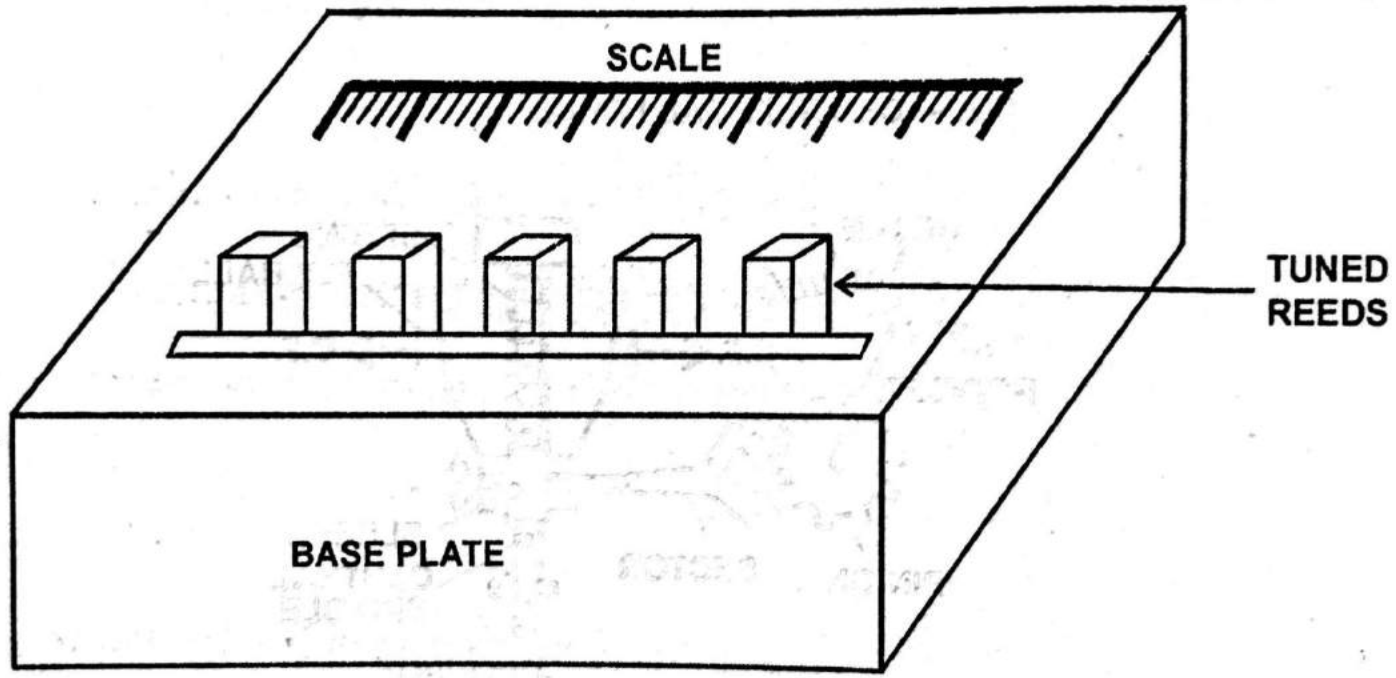
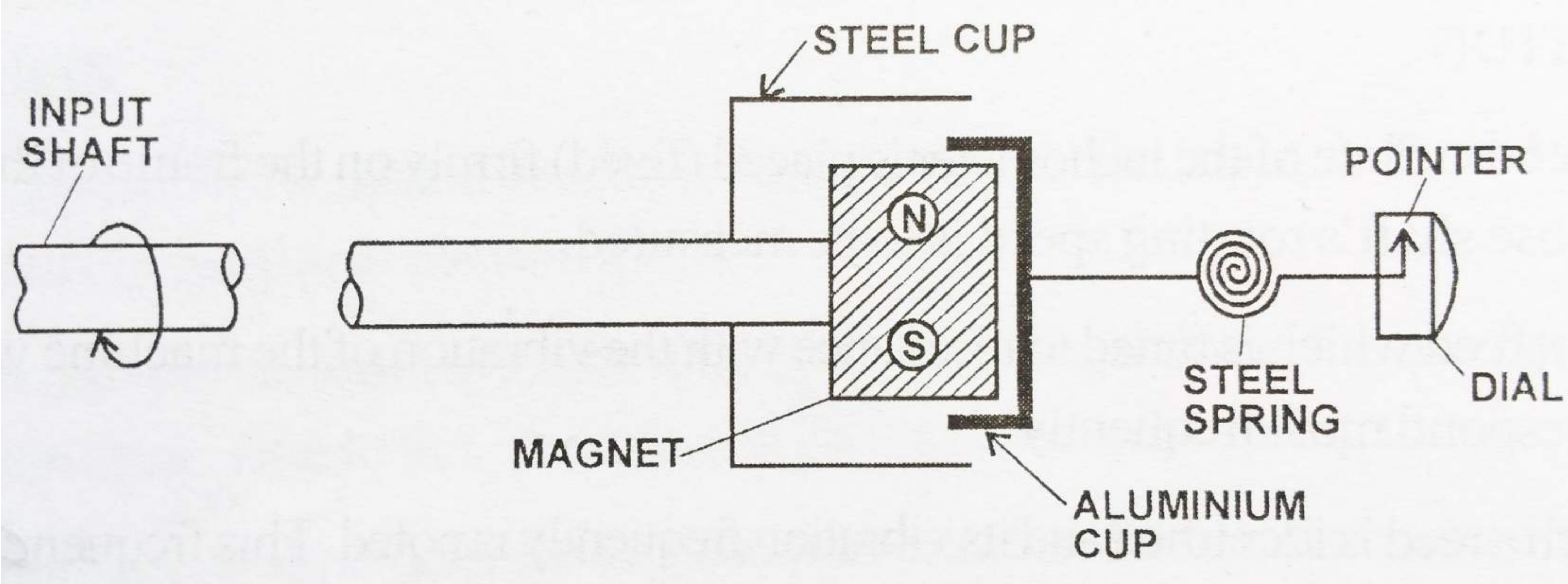


Figure 15.8: Vibrating reed tachometer

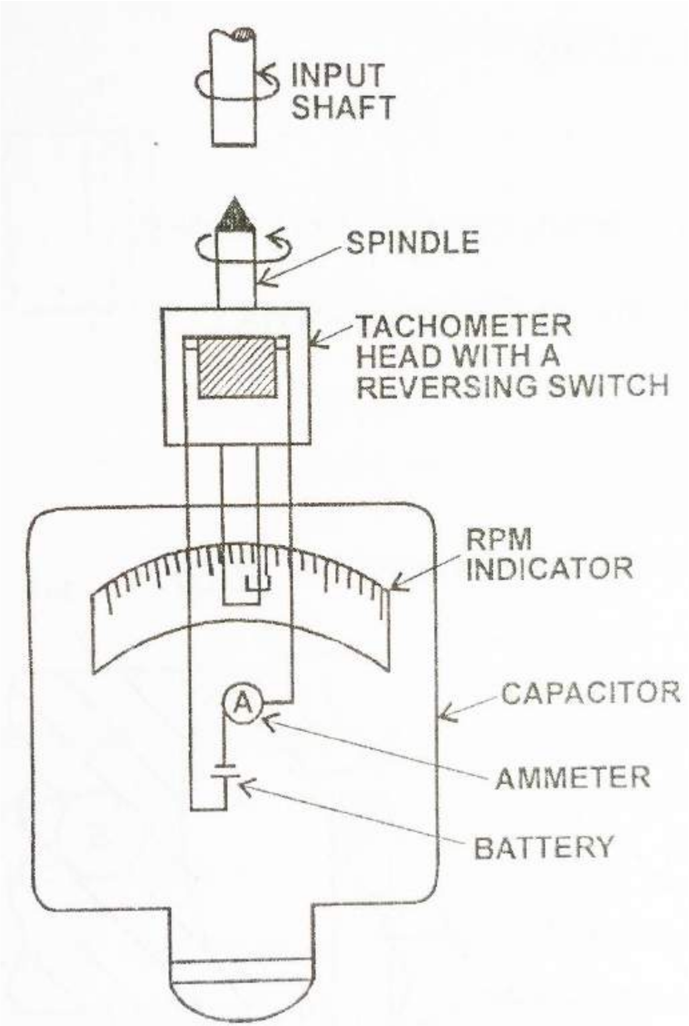
ELECTRICAL TACHOMETERS

(a) DRAG CUP TACHOMETER (EDDY CURRENT TACHOMETER)



ELECTRICAL TACHOMETERS

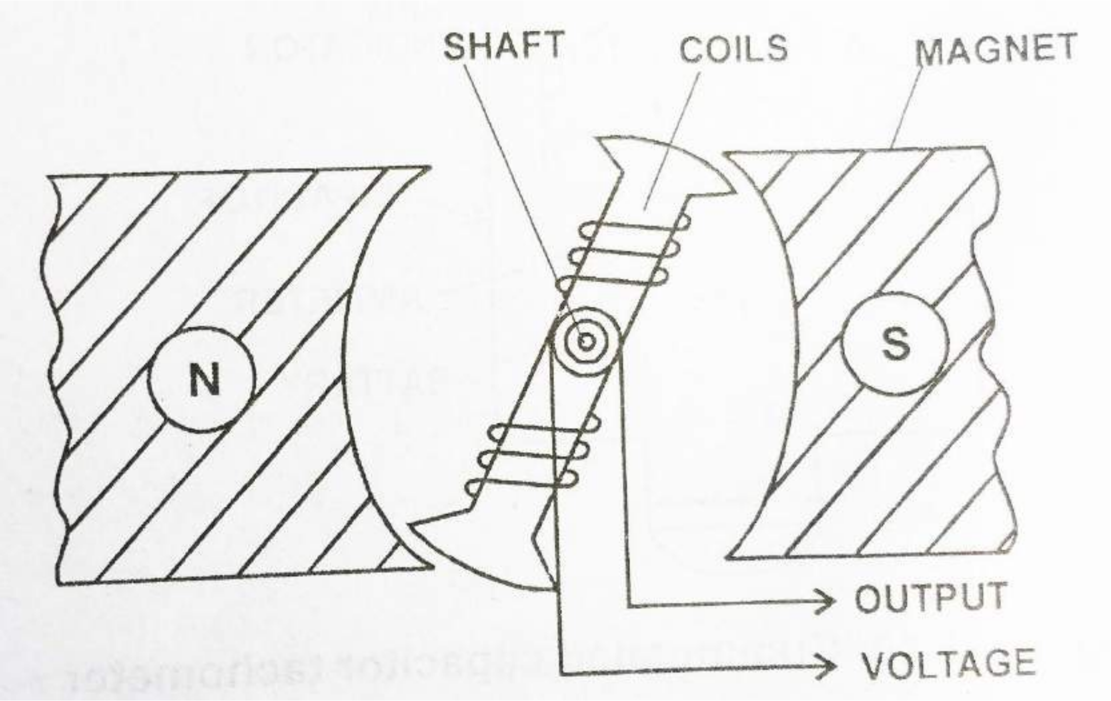
(b) COMMUTATED CAPACITOR TACHOMETER



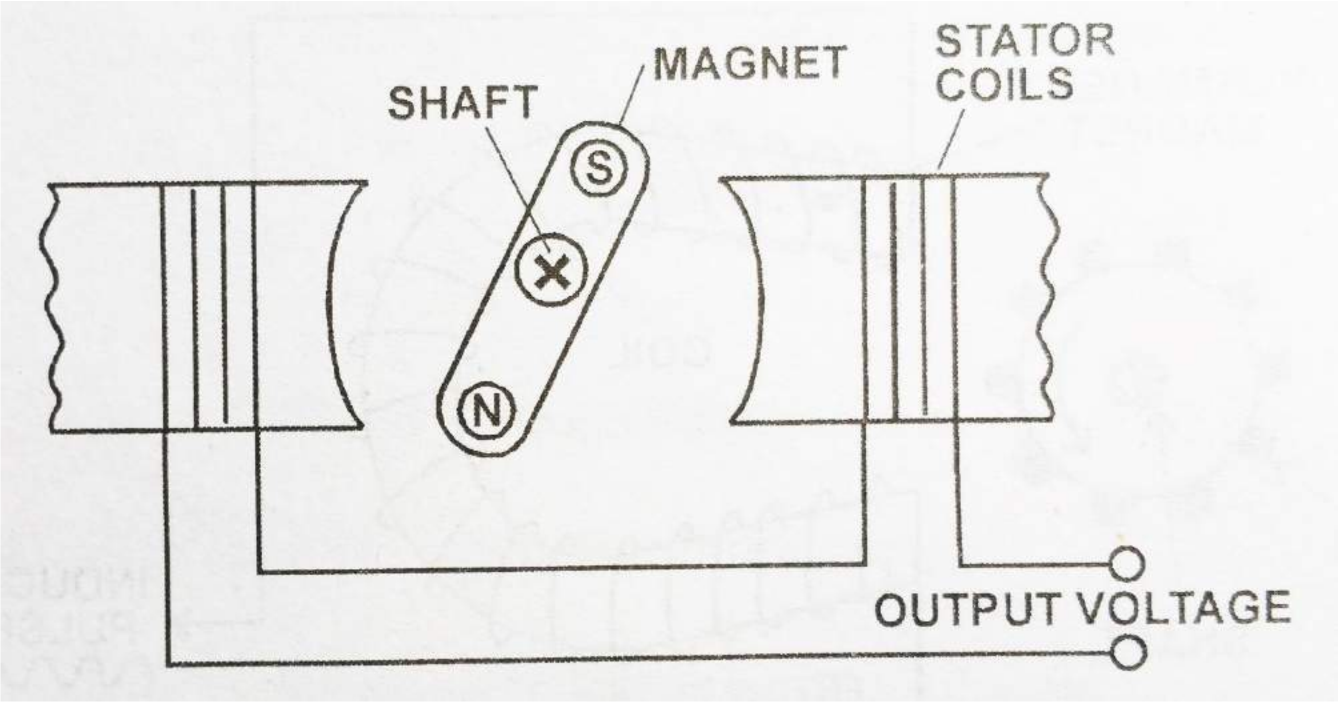
ELECTRICAL TACHOMETERS

(c) TACHOGENERATORS

DC - TACHOGENERATOR

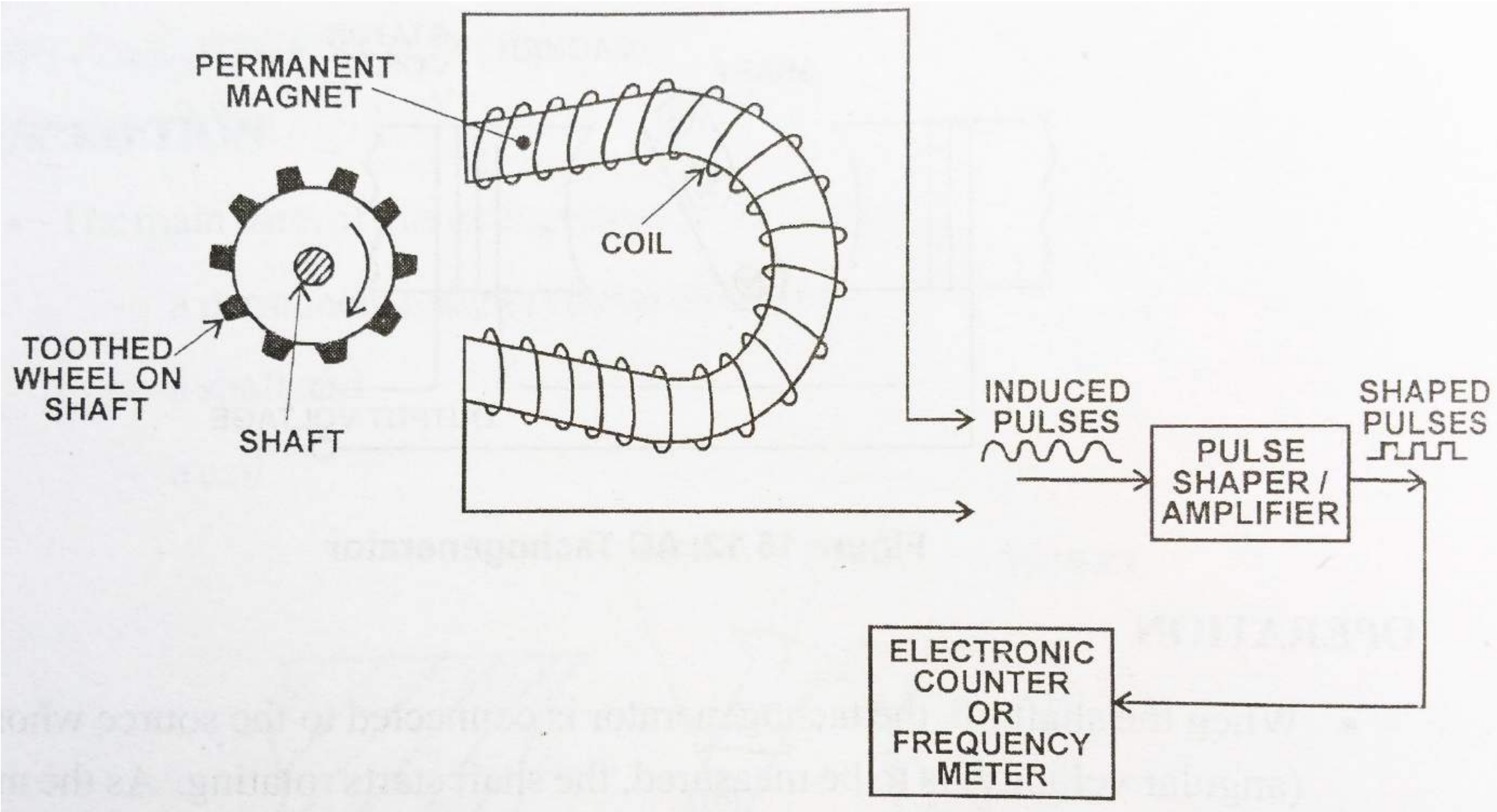


AC - TACHOGENERATOR



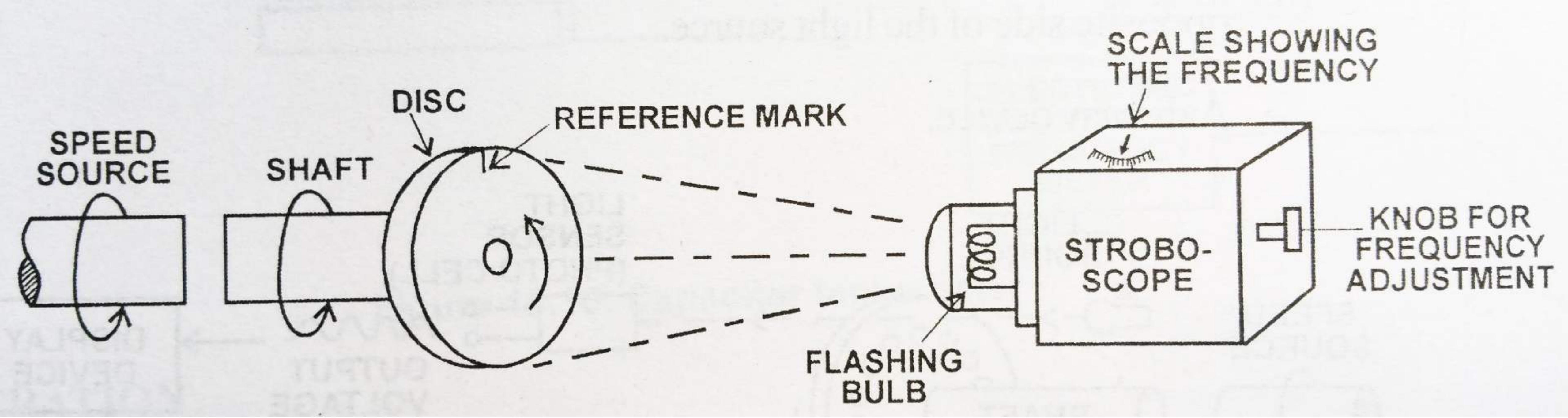
CONTACTLESS ELECTRICAL TACHOMETERS

(a) INDUCTIVE PICKUP TACHOMETER



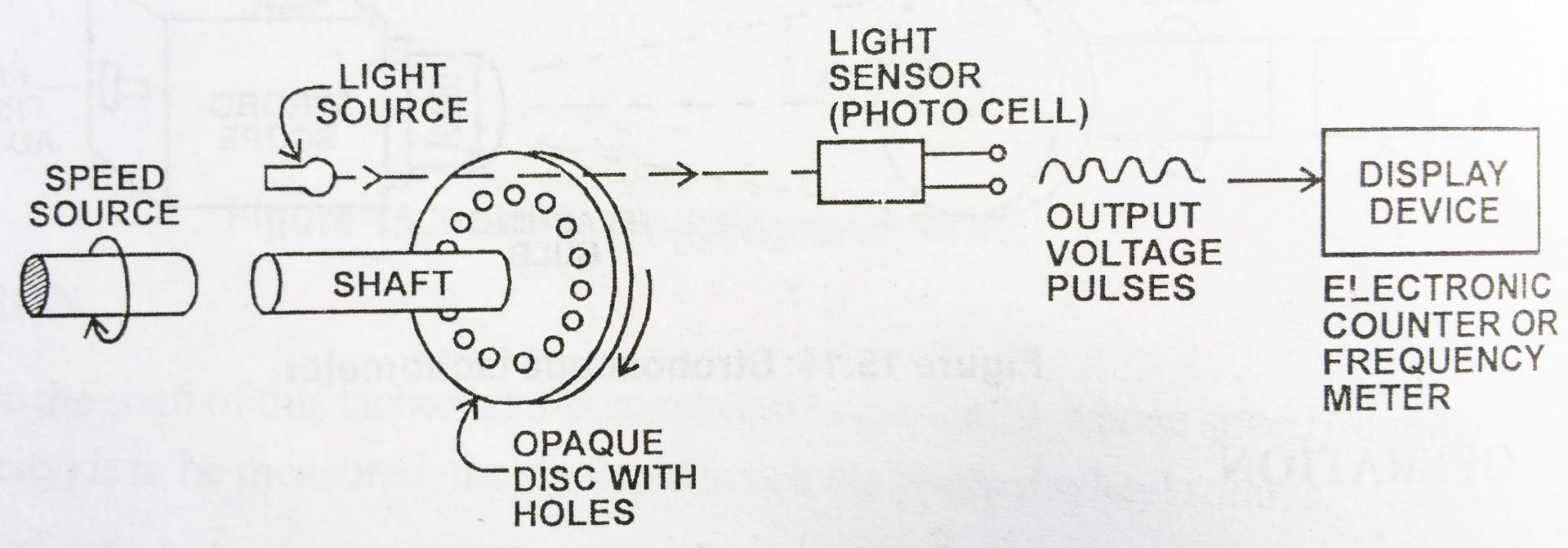
CONTACTLESS ELECTRICAL TACHOMETERS

(b) STROBOSCOPE TACHOMETER



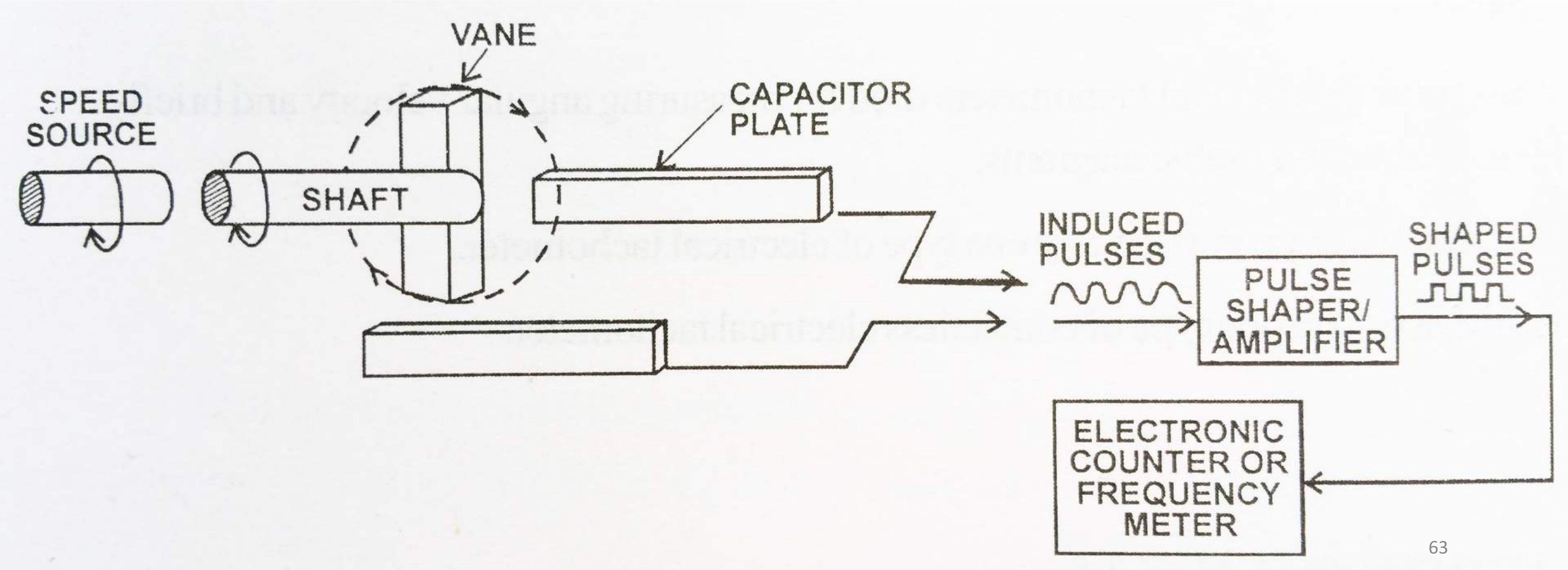
CONTACTLESS ELECTRICAL TACHOMETERS

(c) PHOTO ELECTRIC TACHOMETER



CONTACTLESS ELECTRICAL TACHOMETERS

(d) CAPACITOR TACHOMETER



MEASUREMENT OF ACCELERATION AND VIBRATION

INTRODUCTION

Def:

- If the dynamic displacement – time variation is continuous and repetitive in nature, it is termed as vibration.
- Repeated cyclic oscillations of a system is termed as vibration.
- When a machine is subjected to acceleration alternatively in two directions, vibration occurs.

Vibration is to be measured and controlled for avoiding:

- Wear and tear of machine parts
- Inaccuracy of the equipment
- Noise, etc.

The instrument used for measuring vibration or acceleration is called as **vibrometer** or **accelerometer.**

What to measure in vibrating systems?

- The peak values of displacement, velocity and acceleration, which are related to each other, and if one of them is known then other two can be determined easily.

SEISMIC ACCELEROMETERS

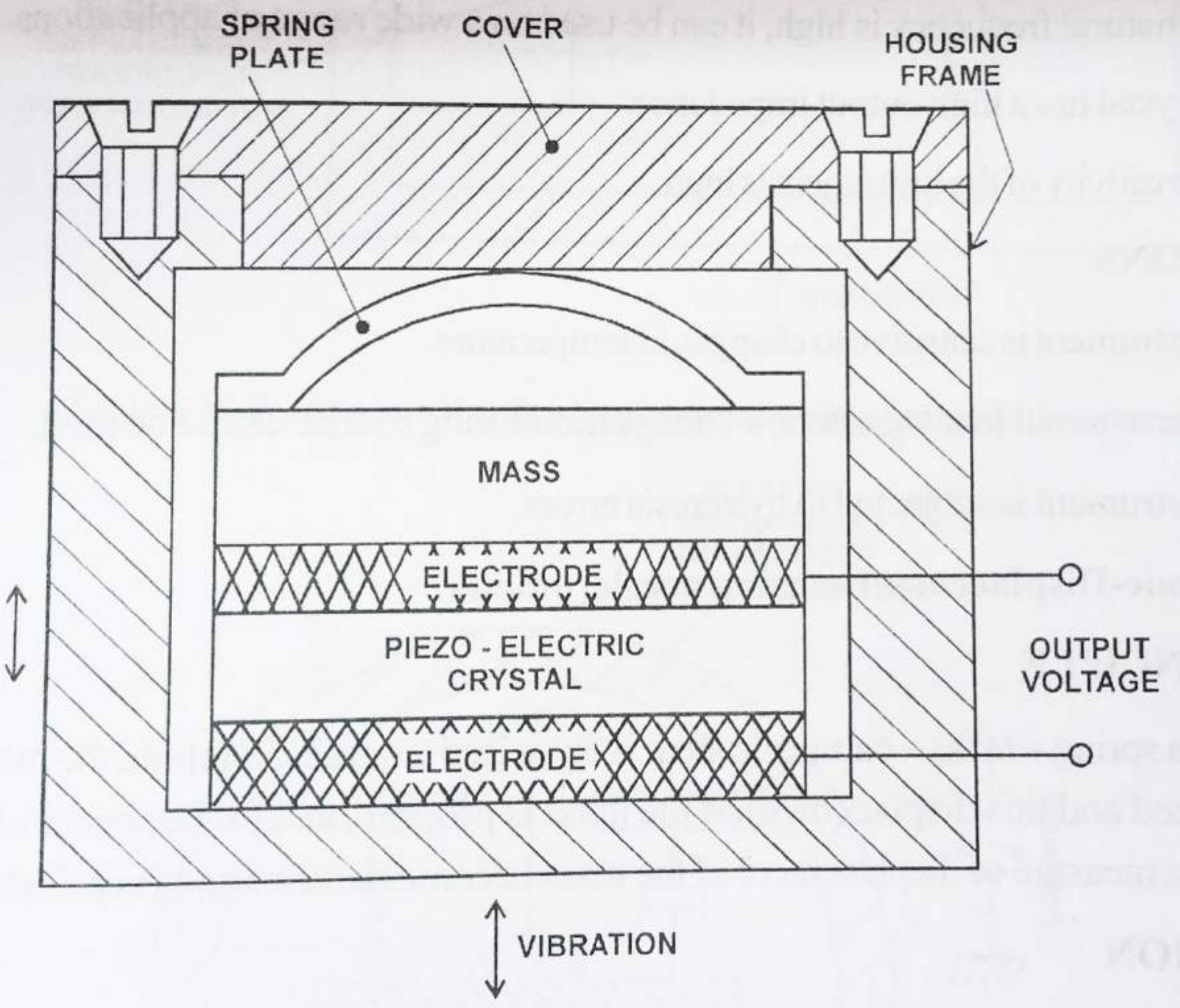


Figure 16.1: Piezo-electric accelerometer

SEISMIC ACCELEROMETERS

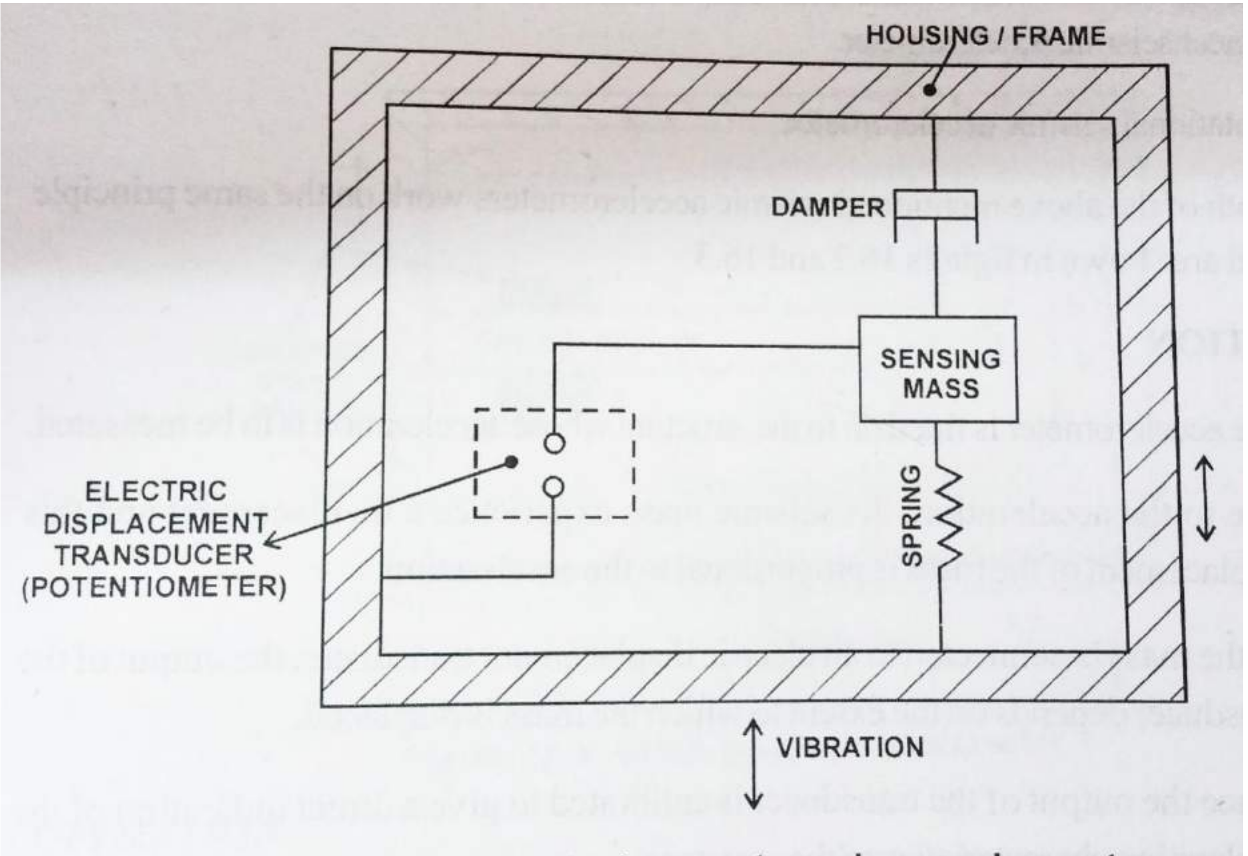


Figure 16.2: Linear seismic displacement sensing accelerometer

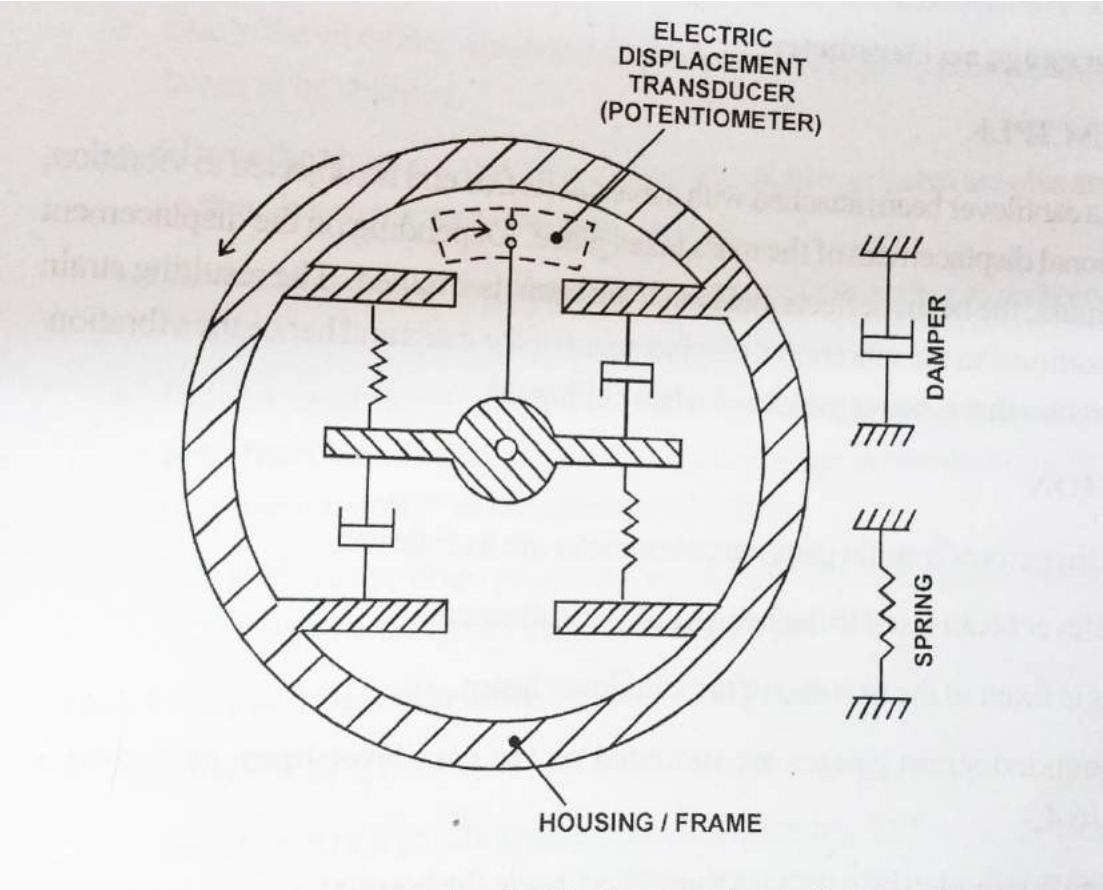


Figure 16.3: Rotational seismic displacement sensing accelerometer

SEISMIC ACCELEROMETERS

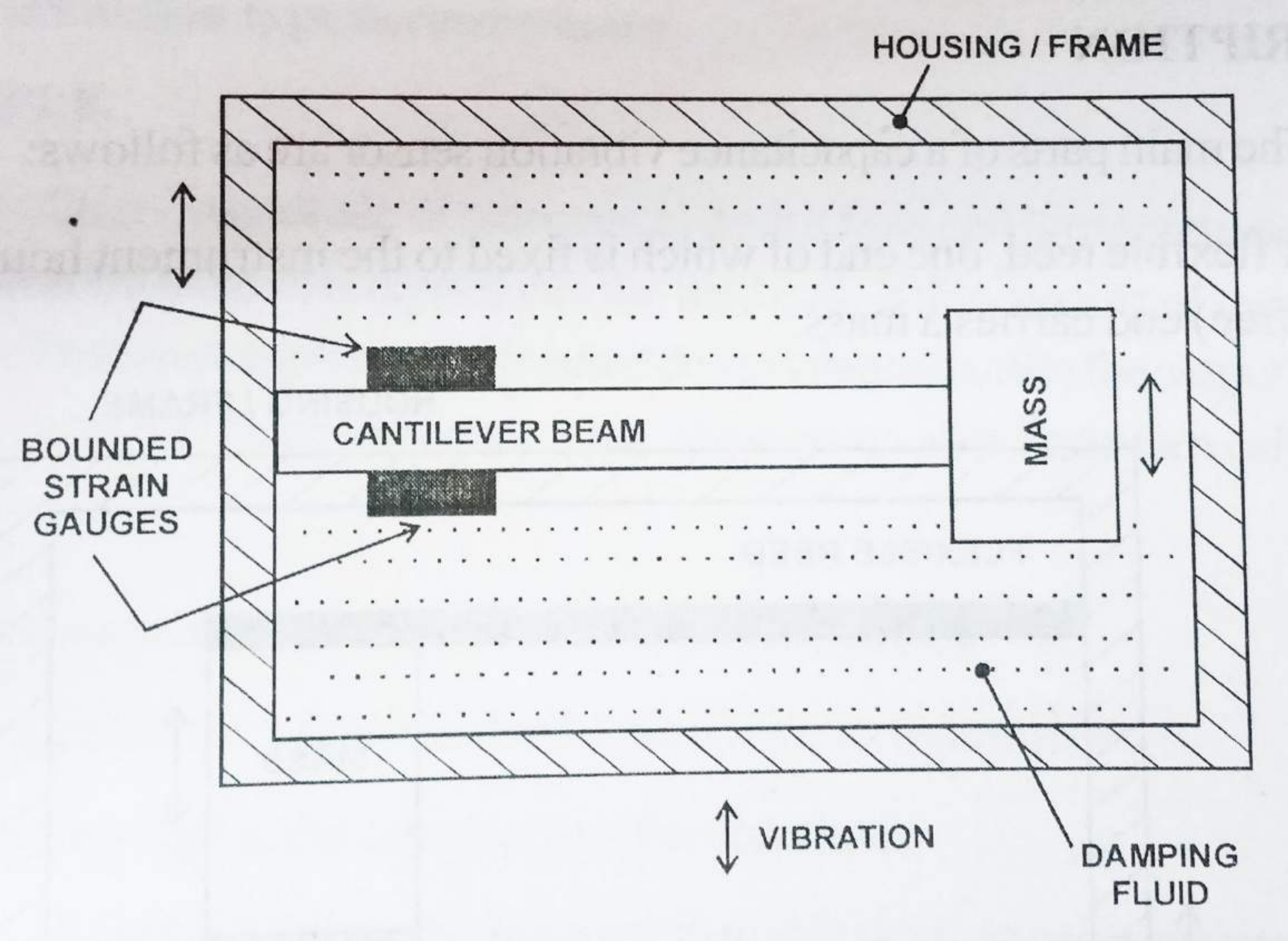


Figure 16.4: Strain gauge accelerometer

SEISMIC ACCELEROMETERS

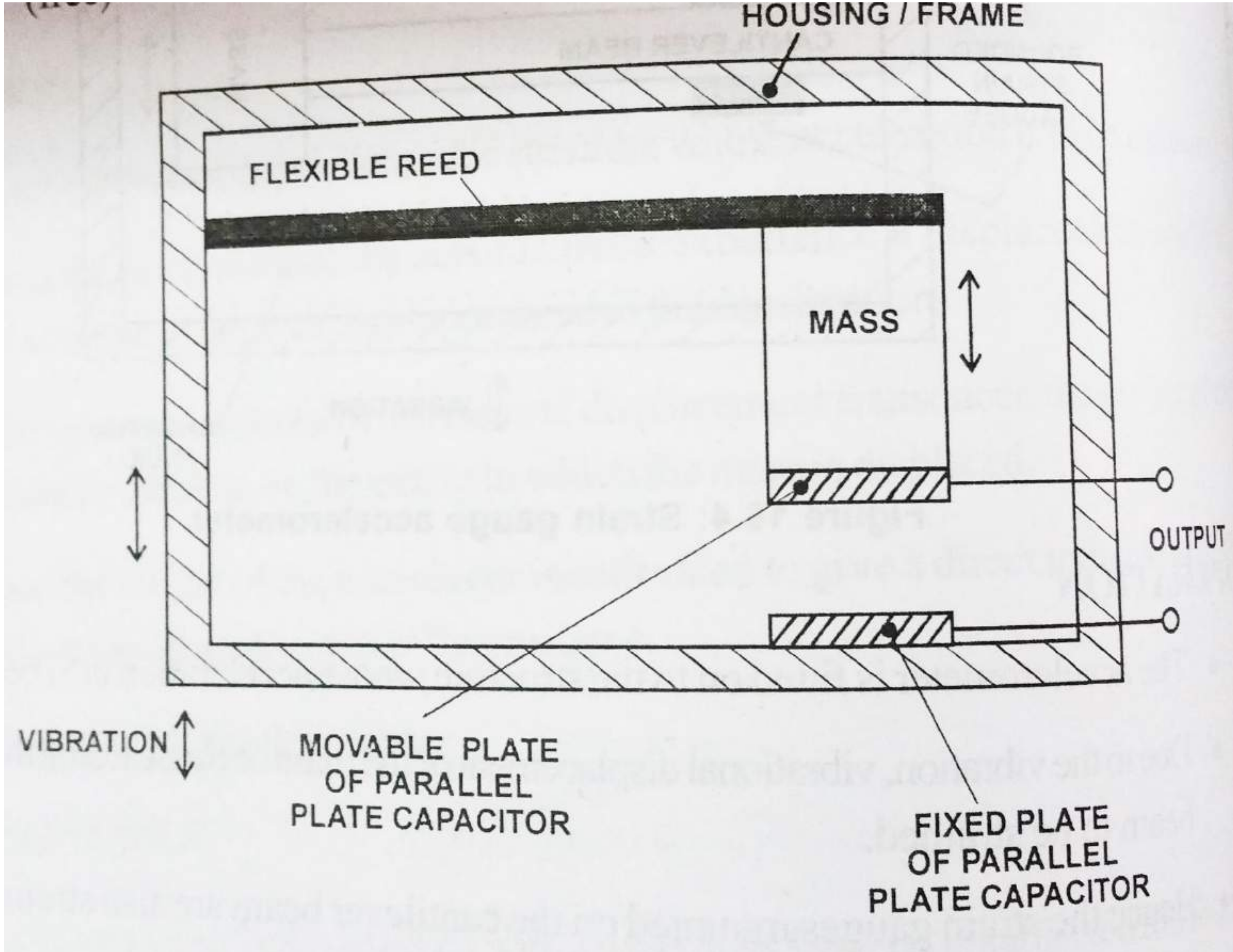


Figure 16.5: Capacitance accelerometer

SEISMIC ACCELEROMETERS

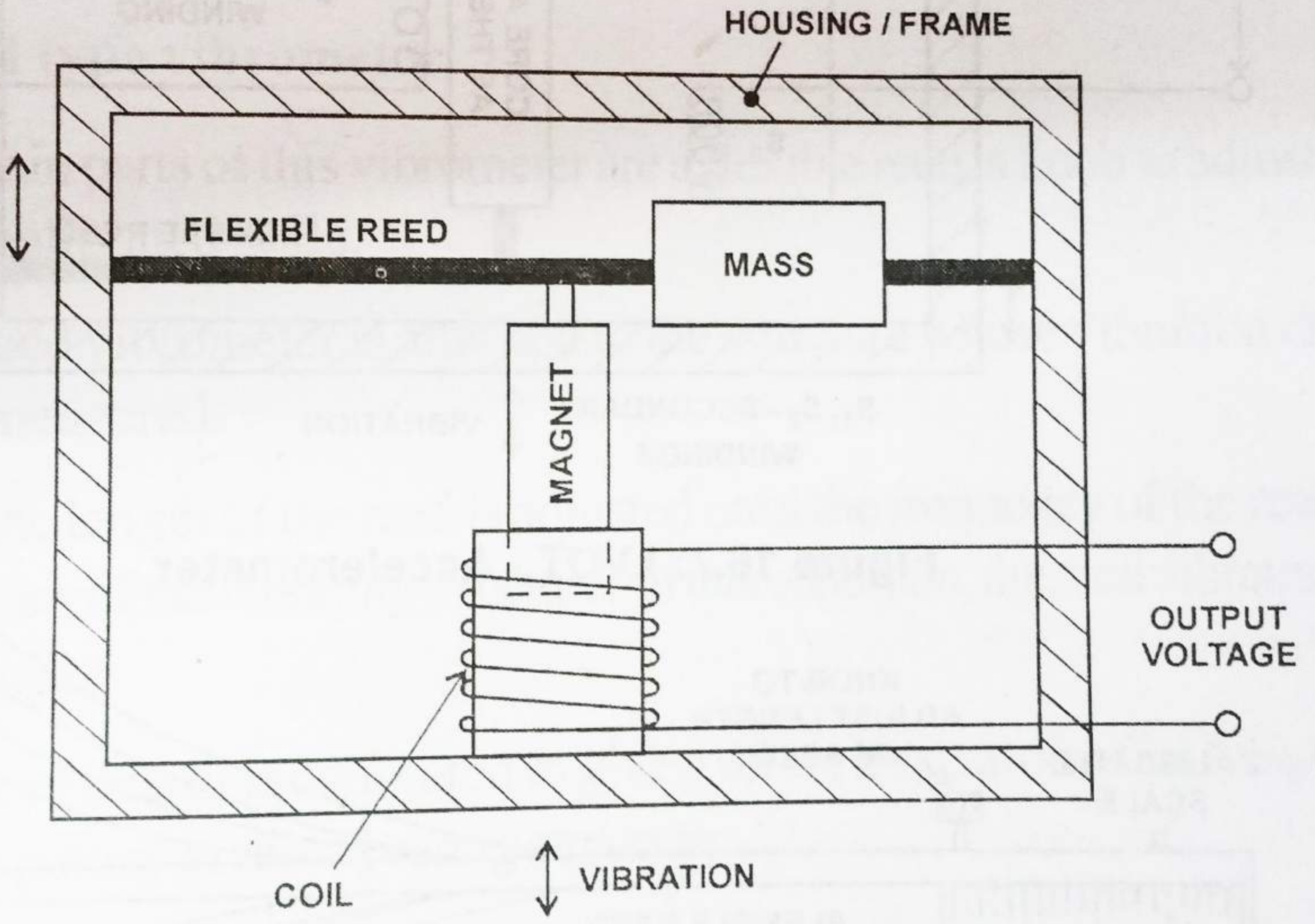


Figure 16.6: Variable induction accelerometer

SEISMIC ACCELEROMETERS

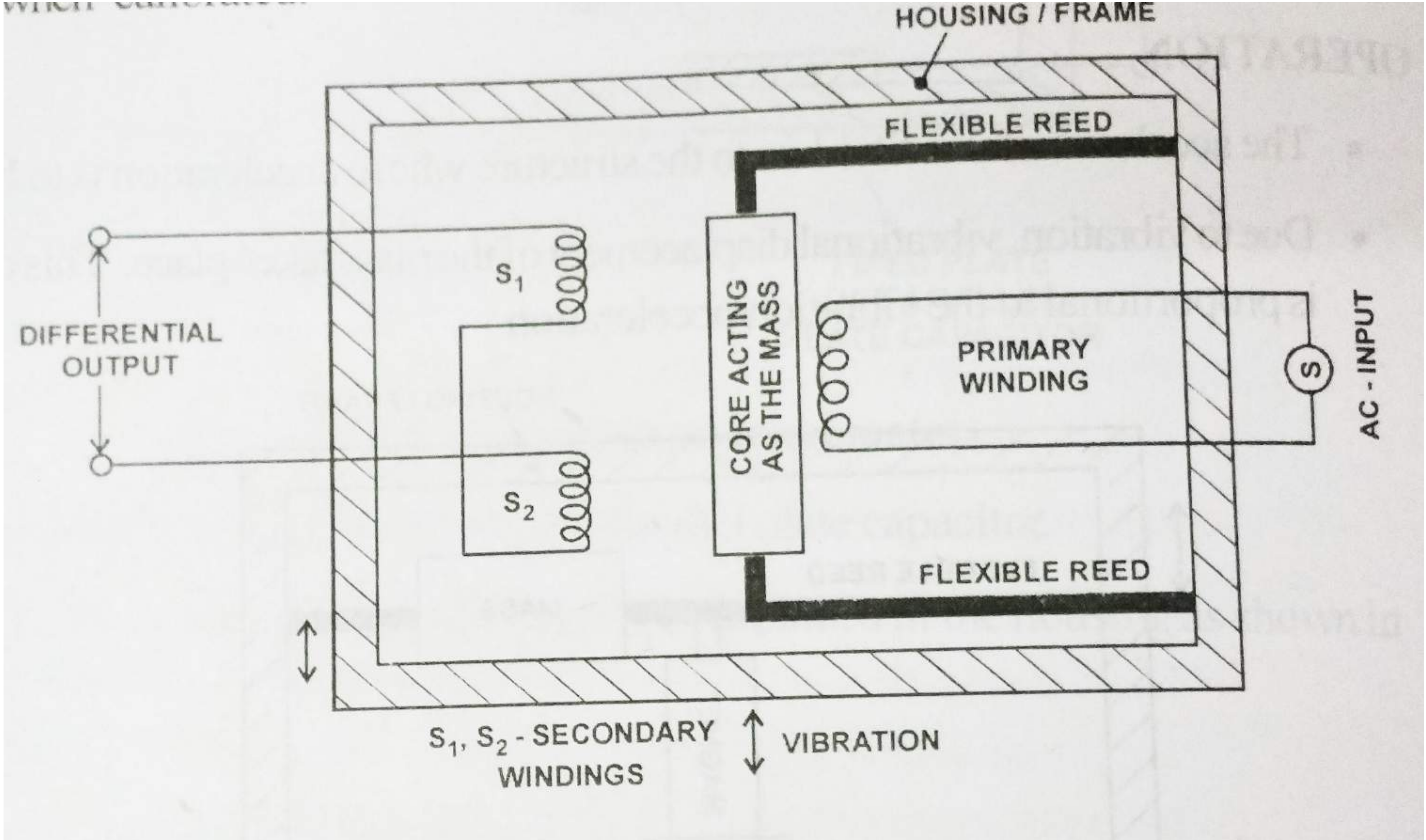


Figure 16.7: LVDT - Accelerometer

SEISMIC ACCELEROMETERS

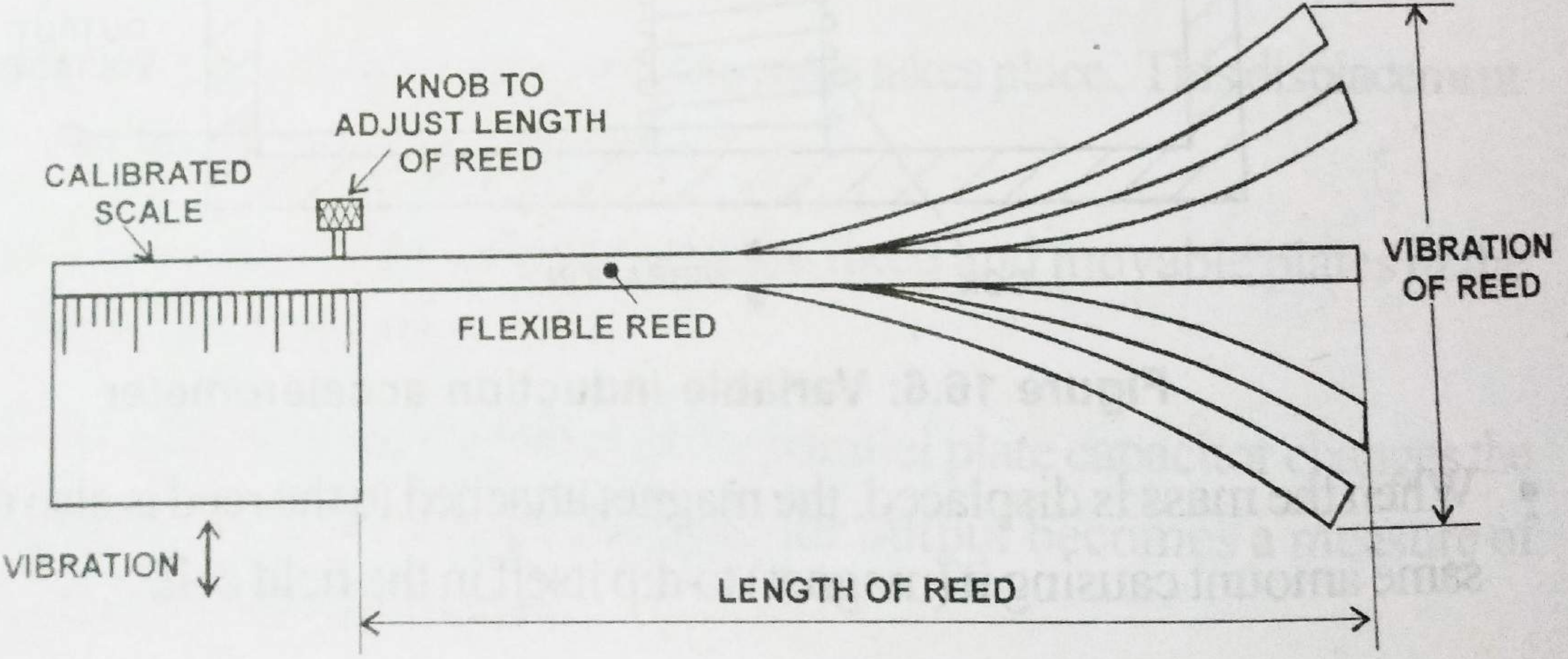


Figure 16.8: Reed type vibrometer

SEISMIC ACCELEROMETERS

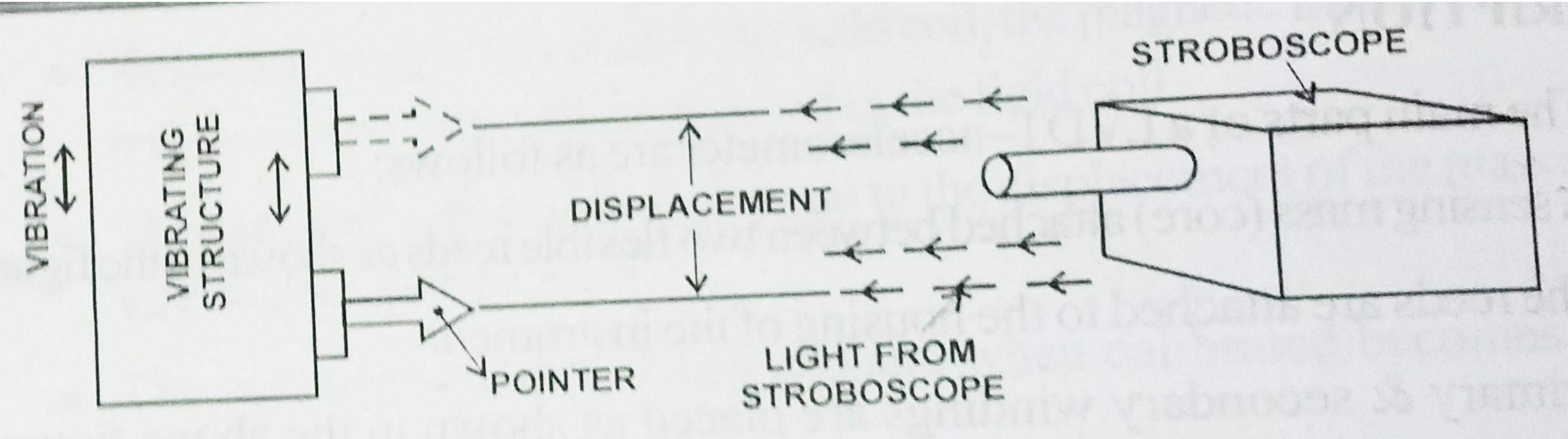


Figure 16.9: Vibration measurement using Stroboscope

UNIT-IV

MEASUREMENT OF STRAIN

Strain gauges are the devices used to measure the dimensional change of components under test.

Important Terms:

- Strain=Change in length/Original length (dimensionless)
- Strain gauge: Measurement transducer used to measure strain.
- Positive strain: strain gauge subjected to tension – positive strain (resistance of the gauge increases)
- Negative strain: strain gauge subjected to compression – negative strain (resistance of the gauge decreases)
- Poisson's ratio=lateral strain/longitudinal strain=(dD/D)/(dL/L)
- Gauge factor: fractional change in resistance due to a unit change in length

$$F=(dR/R)/(dL/L)$$

STRAIN GAUGES

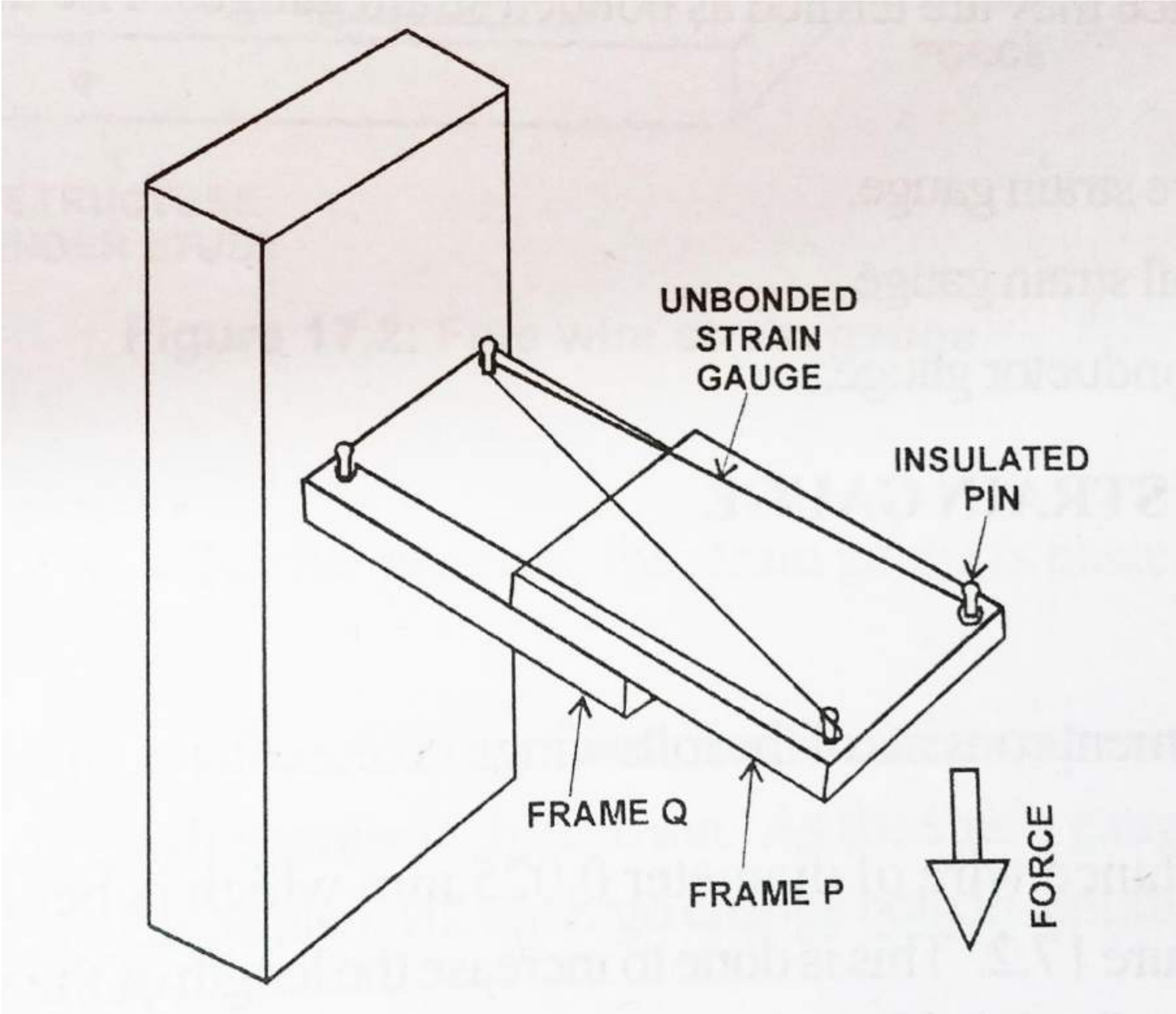


Figure 17.1: Unbonded strain gauge

STRAIN GAUGES

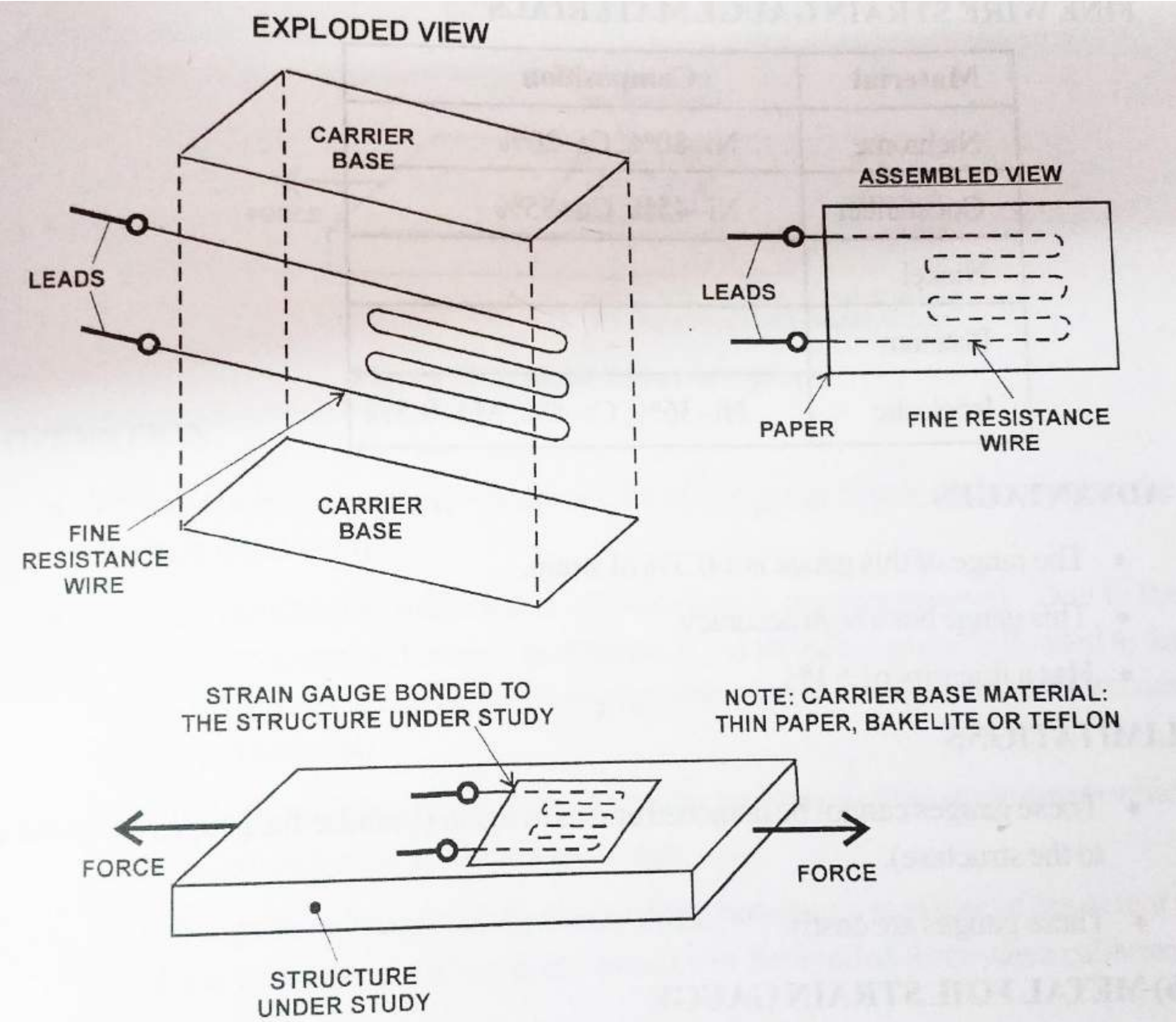


Figure 17.2: Fine wire strain gauge

STRAIN GAUGES

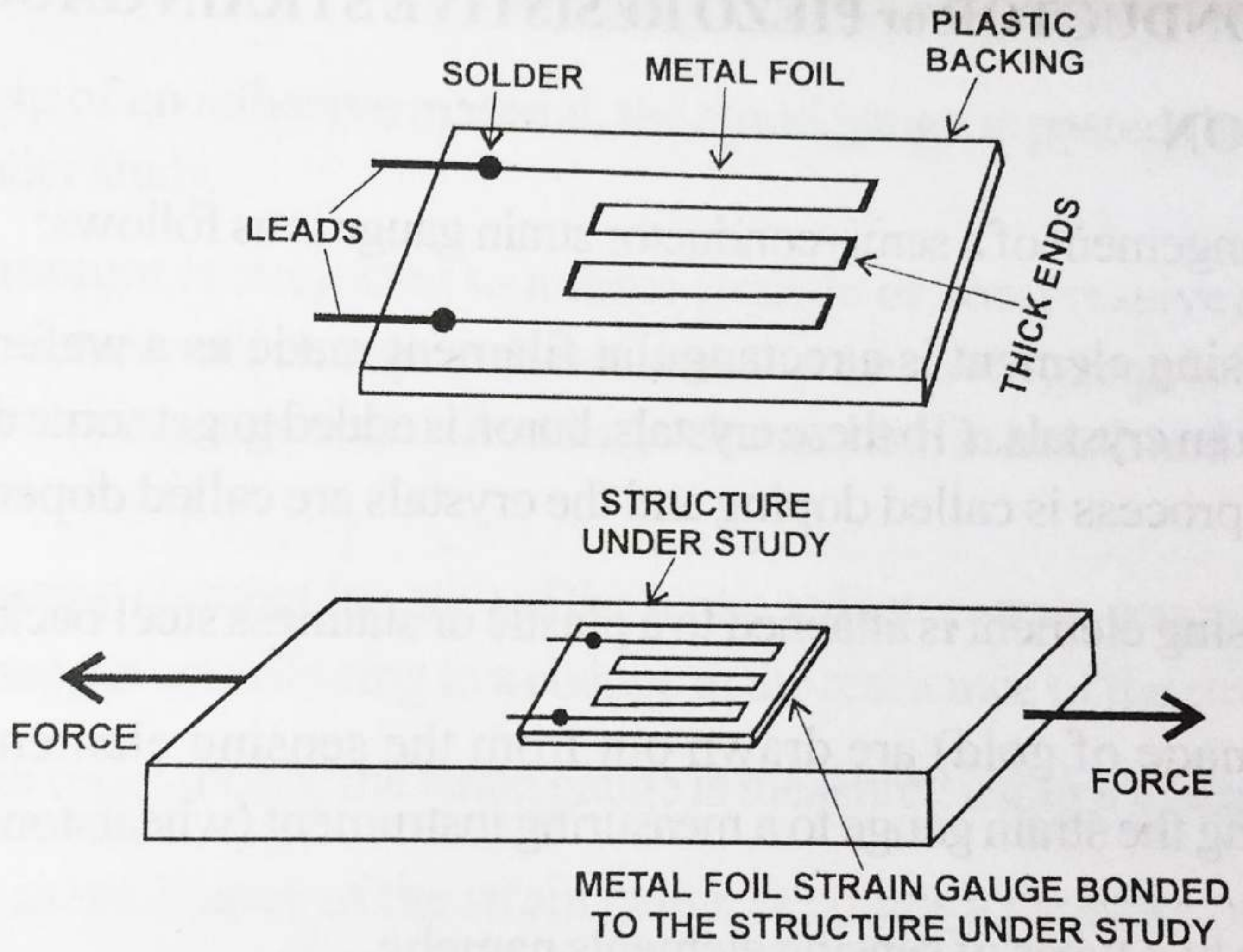


Figure 17.3: Metal foil strain gauge

STRAIN GAUGES

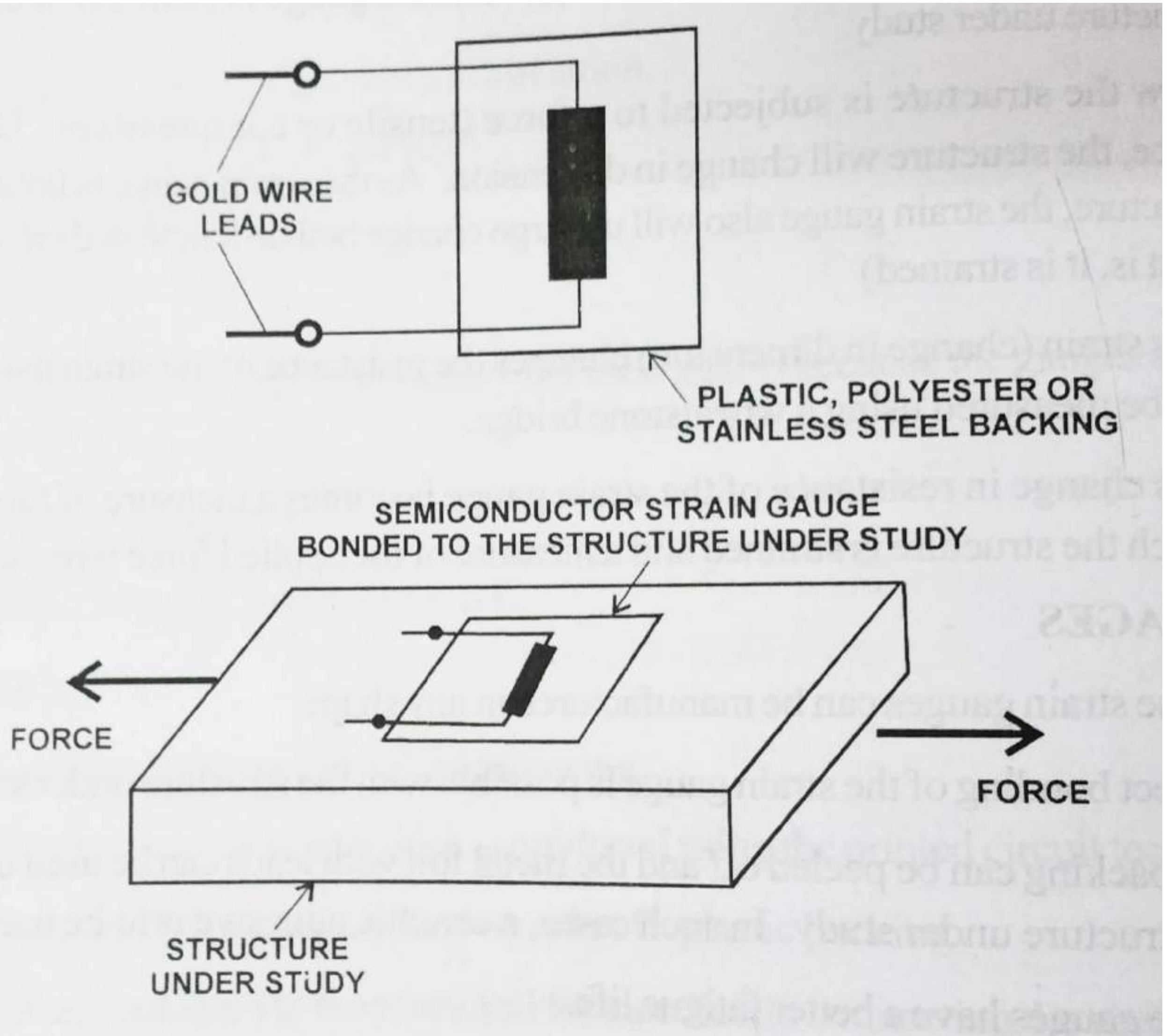


Figure 17.4: Semiconductor strain gauge

STRAIN GAUGES

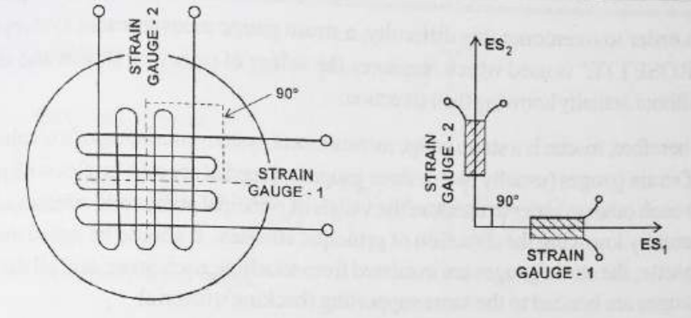


Figure 17.9: Two element rosettes

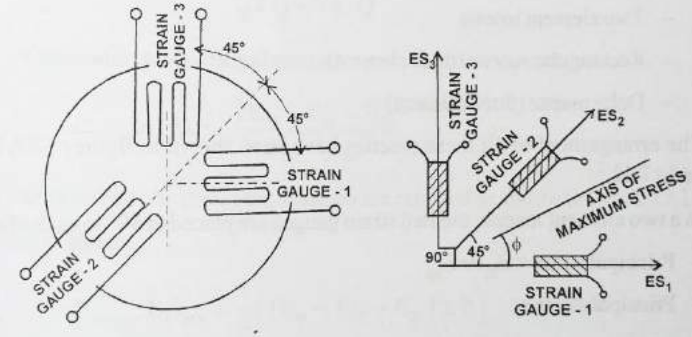


Figure 17.10: Rectangular rosettes

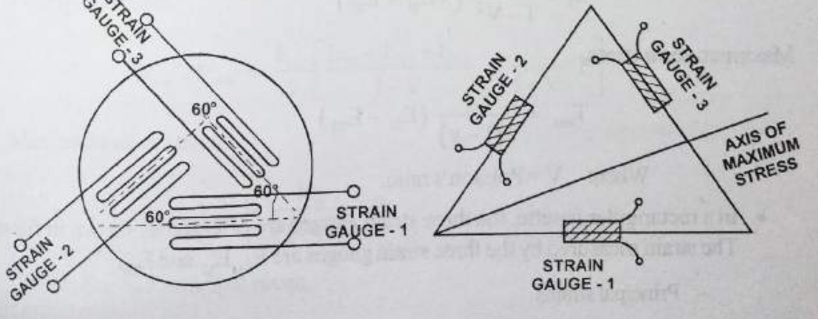


Figure 17.11: Delta rosettes

MEASUREMENT
OF
HUMIDITY

SLING PSYCHROMETER

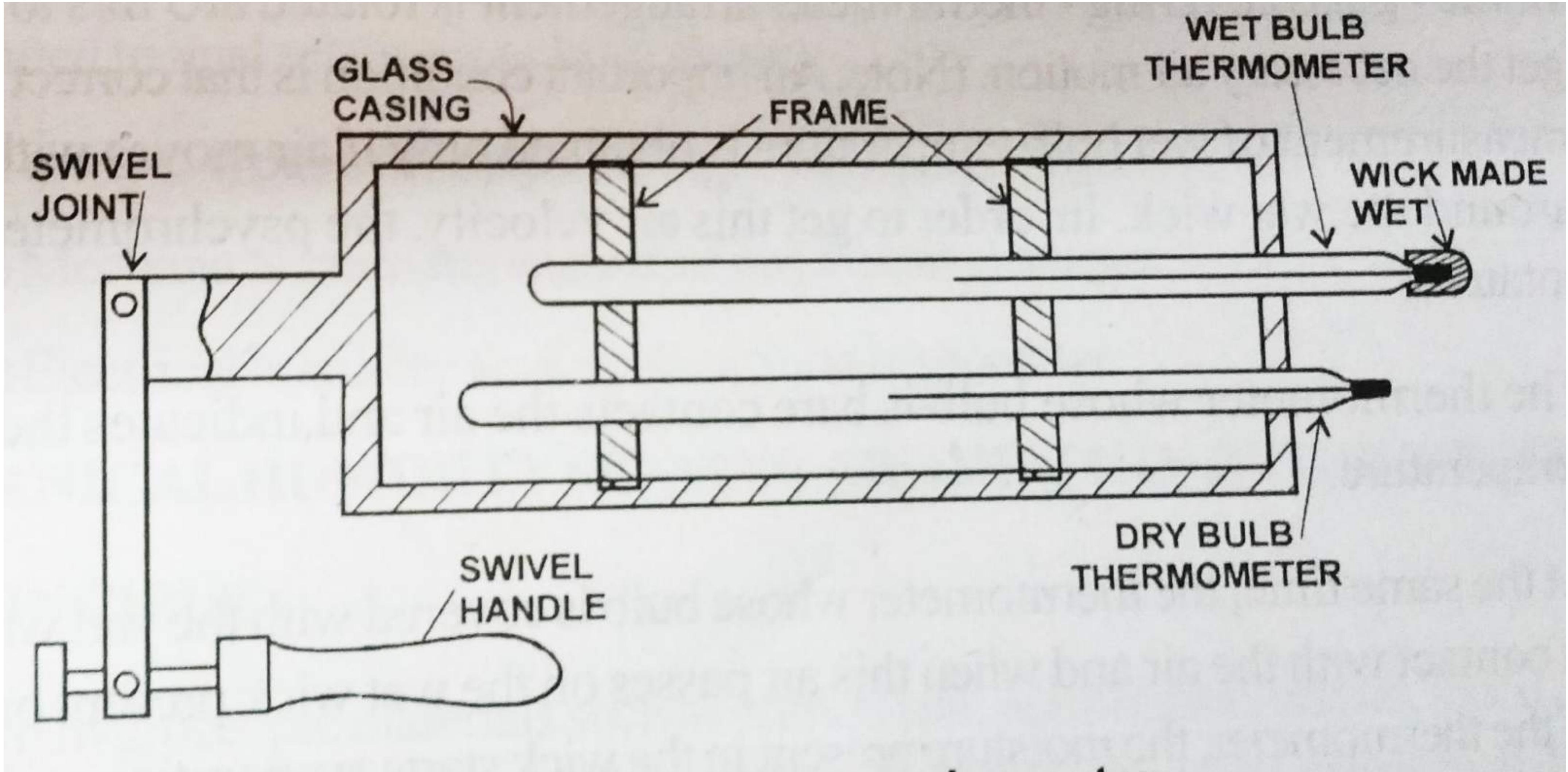


Figure 19.1: Sling psychrometer

HAIR HYGROMETER

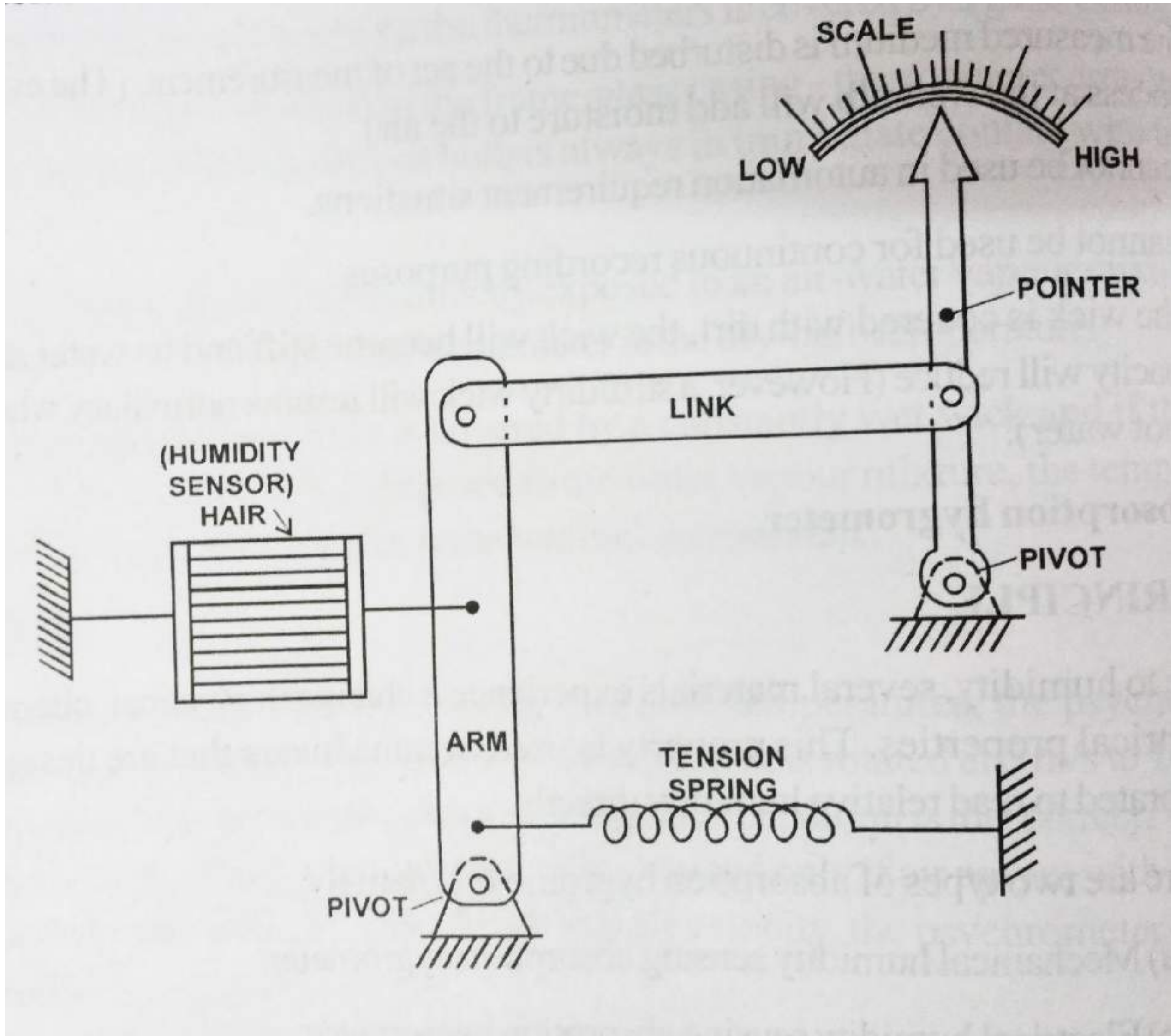


Figure 19.2: Hair hygrometer

ELECTRICAL ABSORPTION HYGROMETER

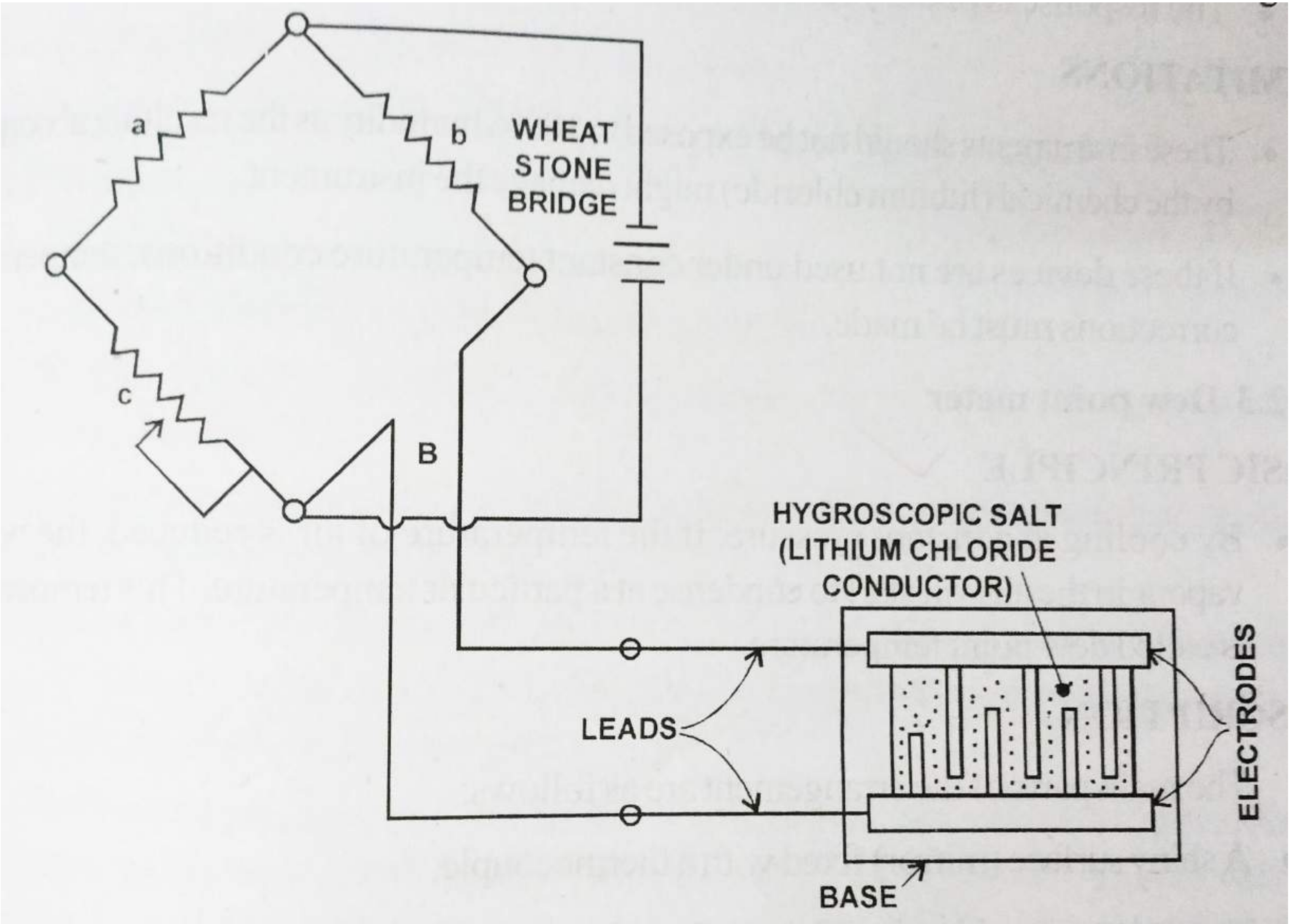


Figure 19.3: Electrical humidity sensing absorption hygrometer

DEW POINT METER

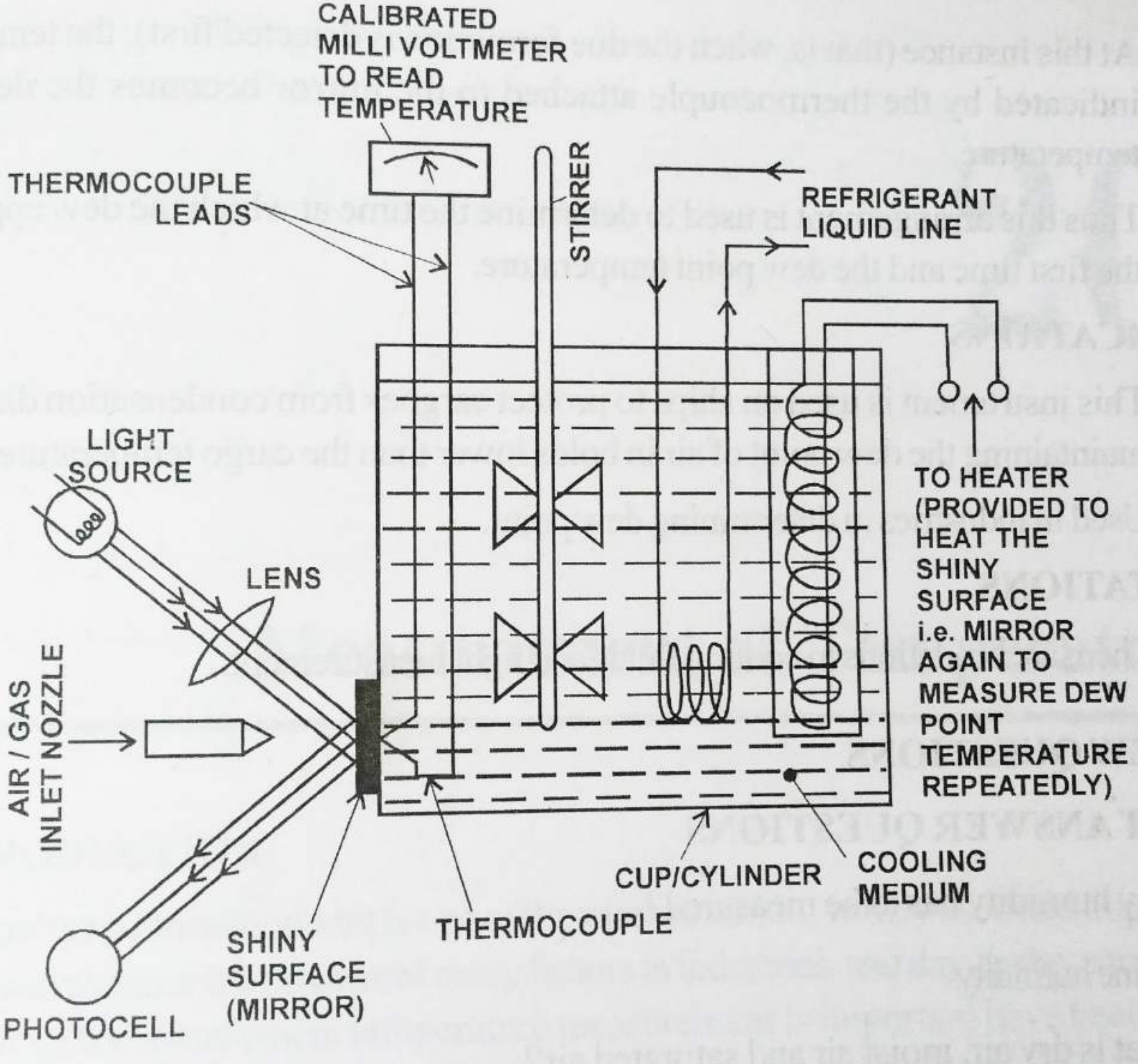


Figure 19.4: Dew point meter

MEASUREMENT OF FORCE

EQUAL & UNEQUAL ARM BALANCE

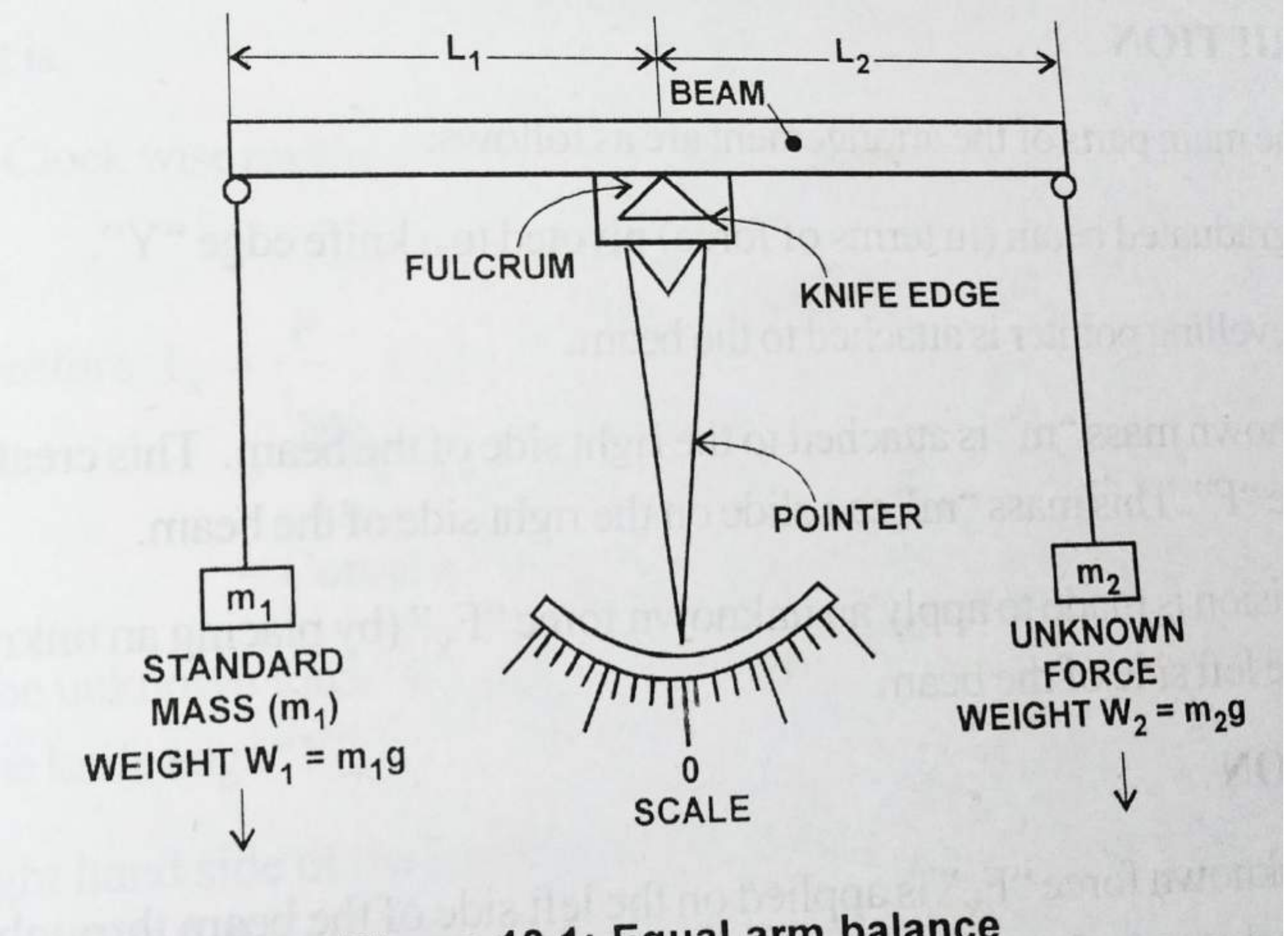


Figure 10.1: Equal arm balance

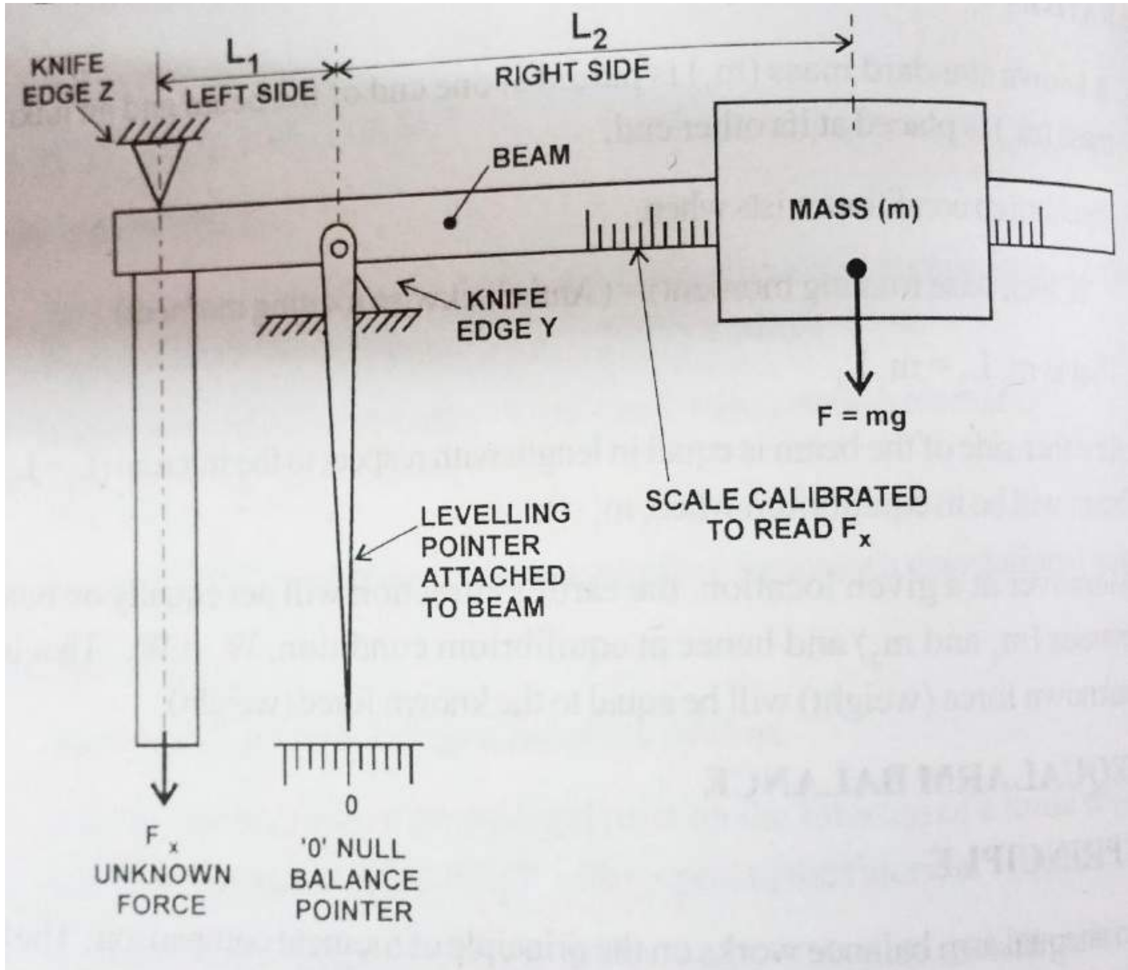


Figure 10.2: Unequal arm balance

PENDULUM SCALE

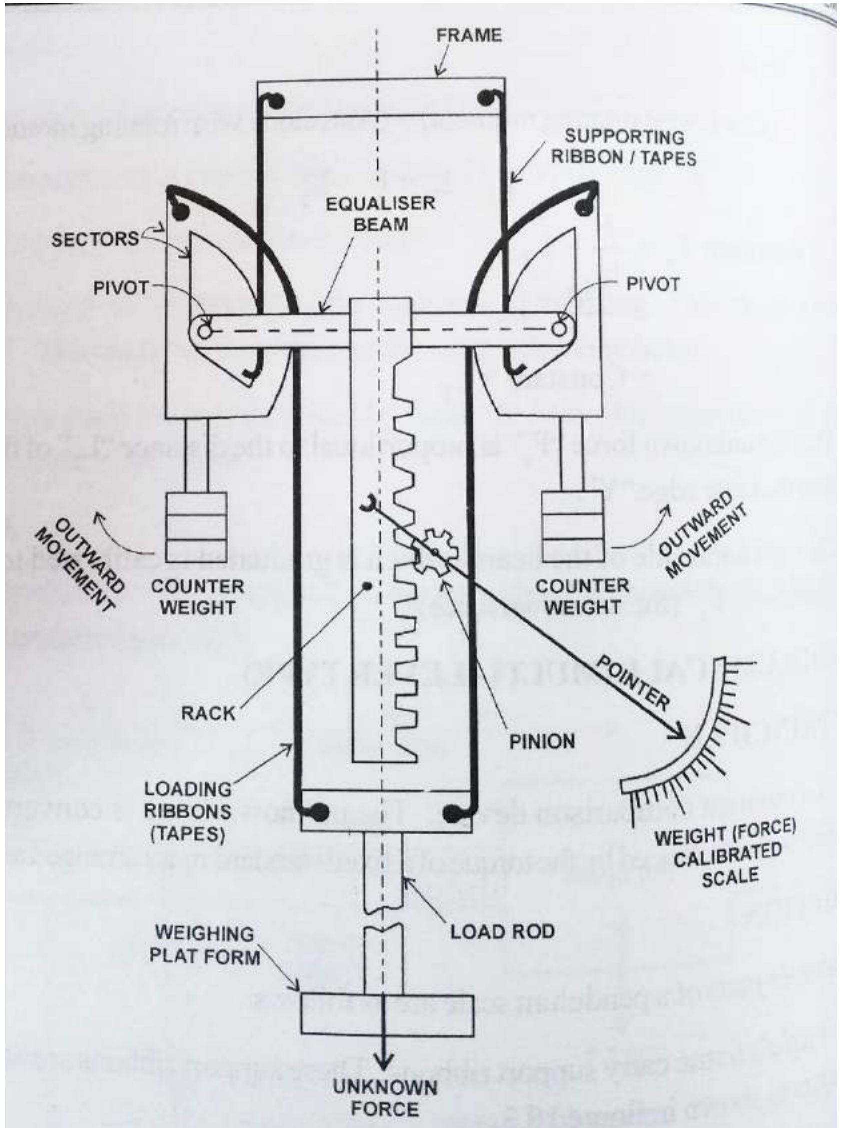


Figure 10.3: Pendulum scale

PROVING RING

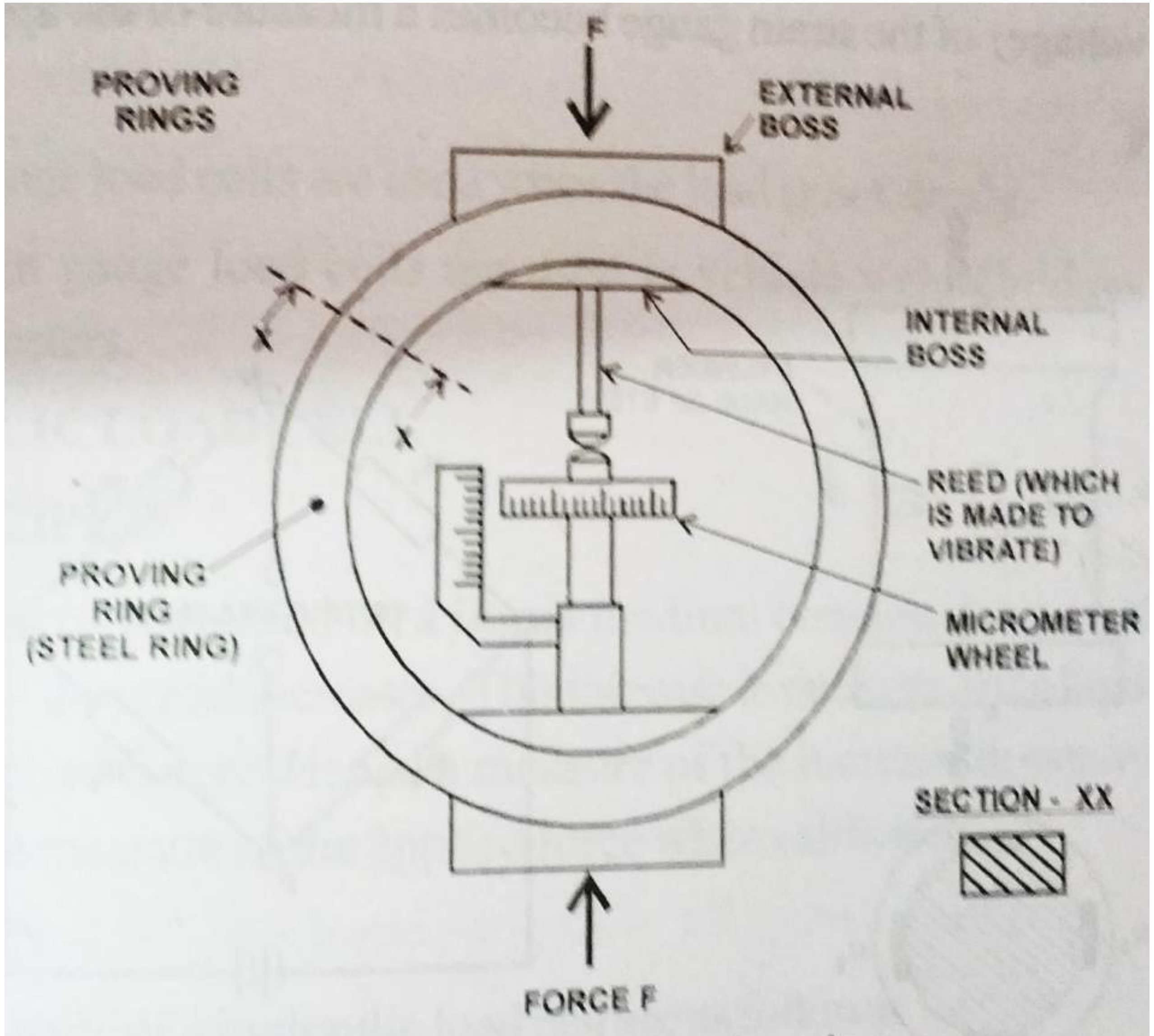


Figure 10.4: Proving ring

STRAIN GAUGE LOADING CELL

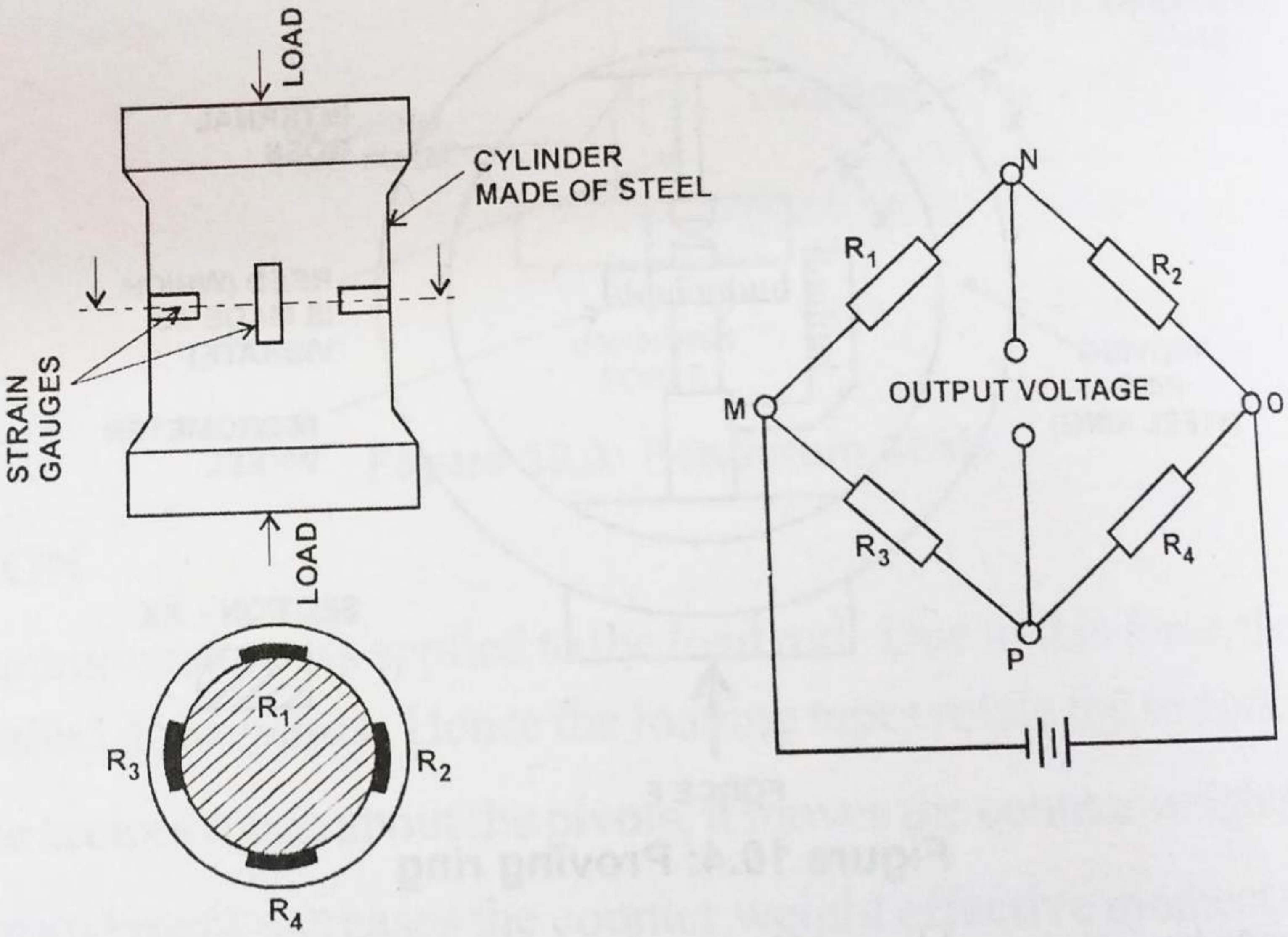


Figure 10.5: Strain gauge load cell

HYDRAULIC LOAD CELL

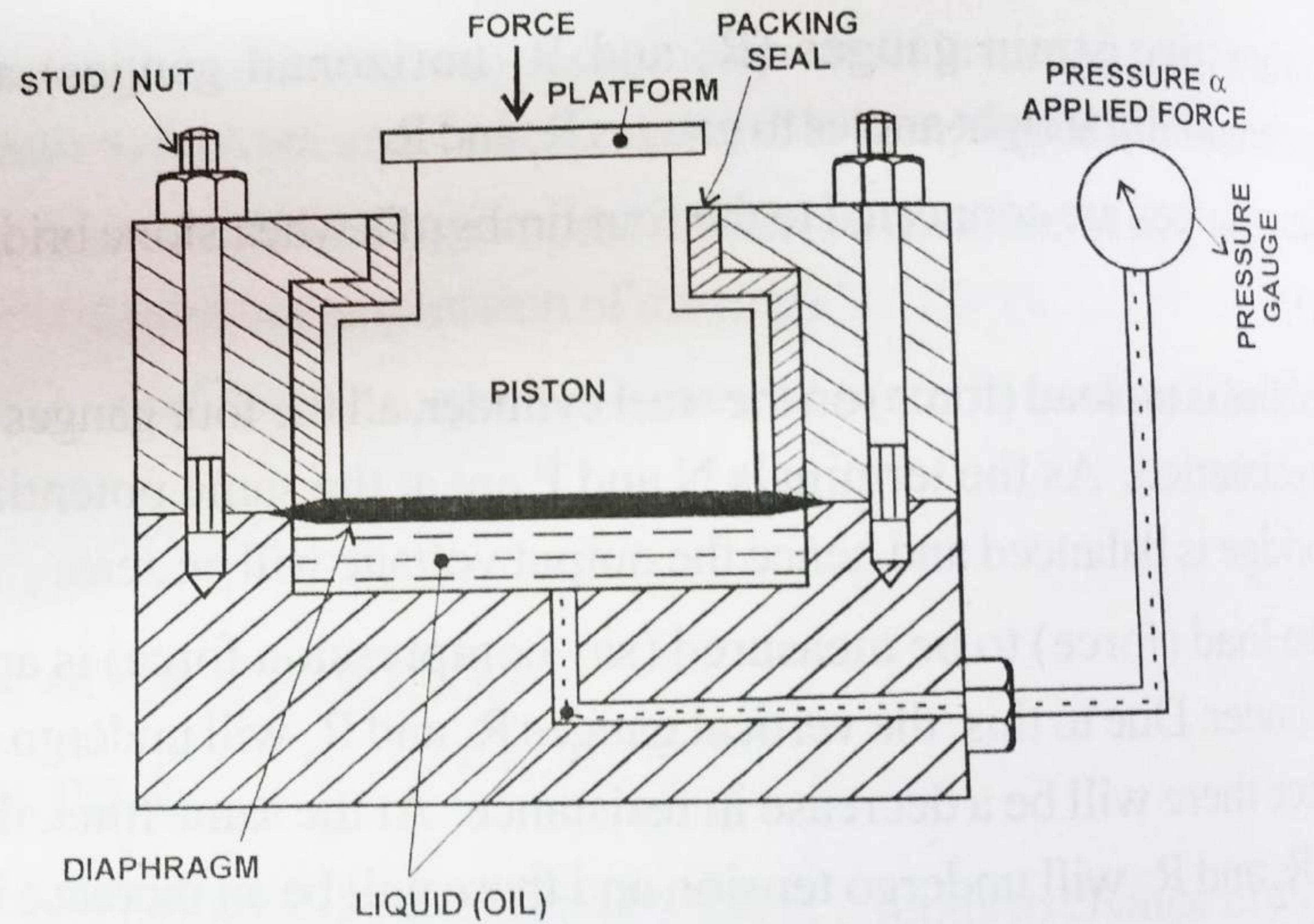


Figure 10.6: Hydraulic load cell

PNEUMATIC LOAD CELL

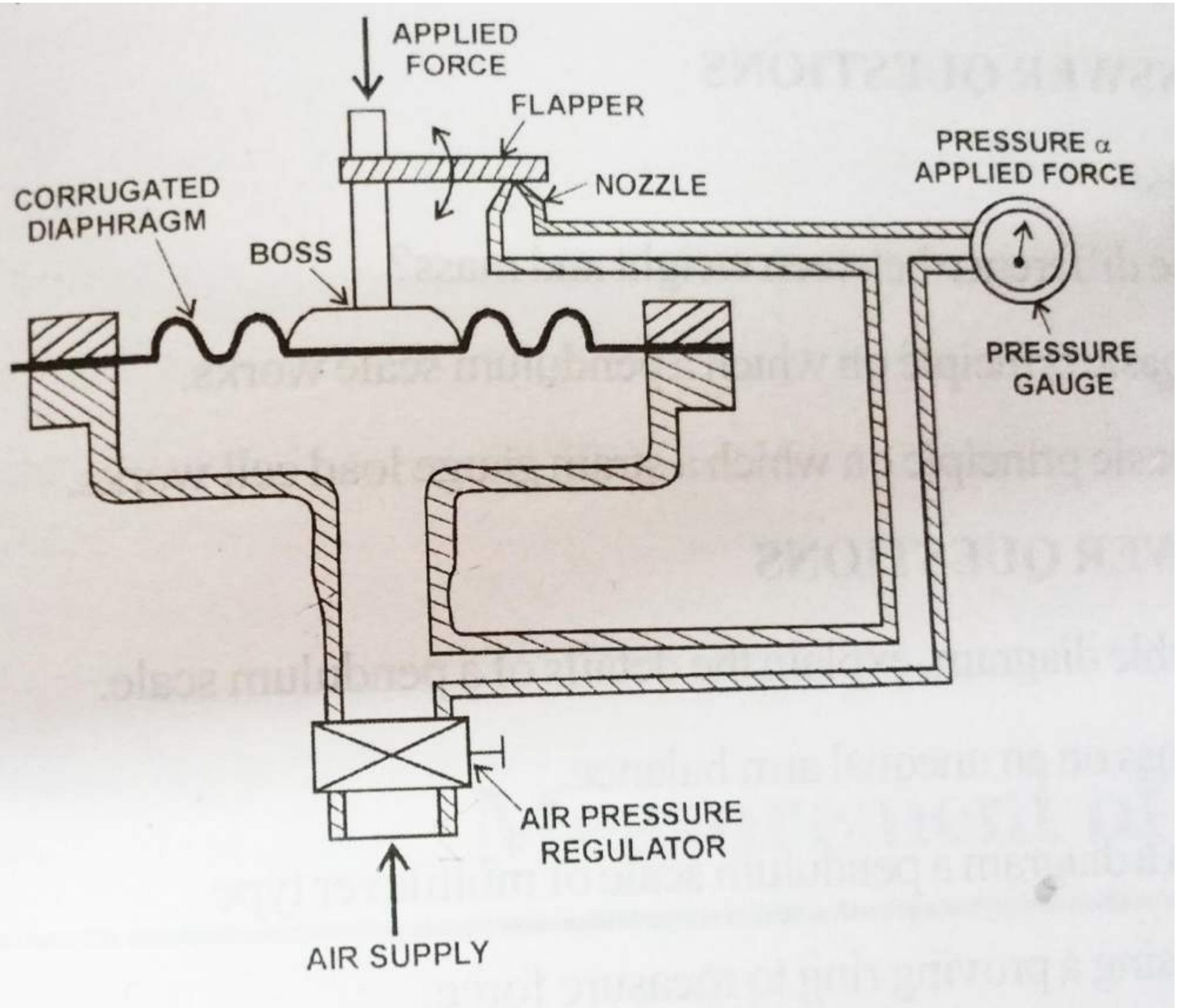


Figure 10.7: Pneumatic load cell

MEASUREMENT OF TORQUE

MECHANICAL TORSION METER

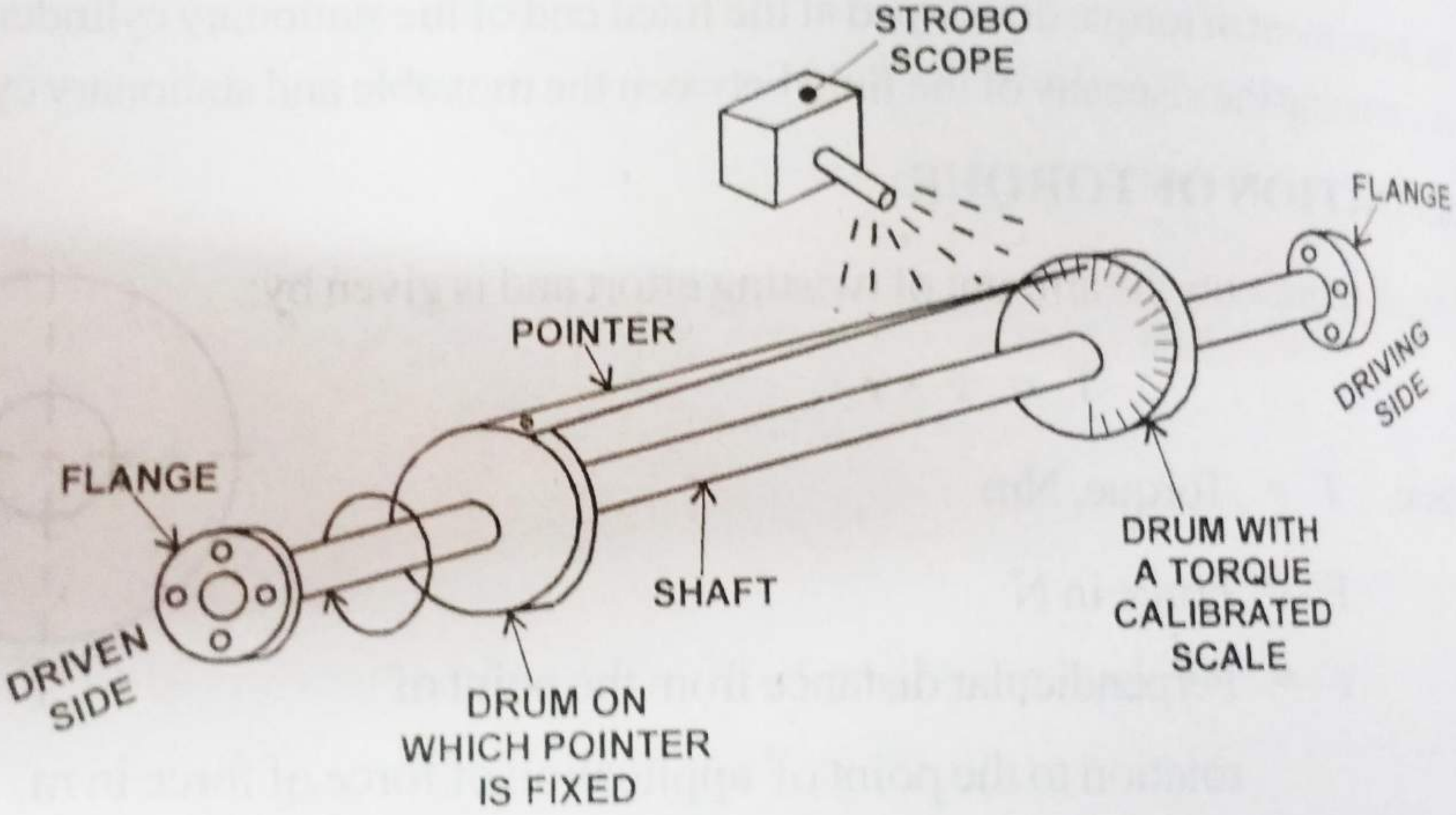


Figure 11.1: Mechanical Torsion Meter

OPTICAL TORSION METER

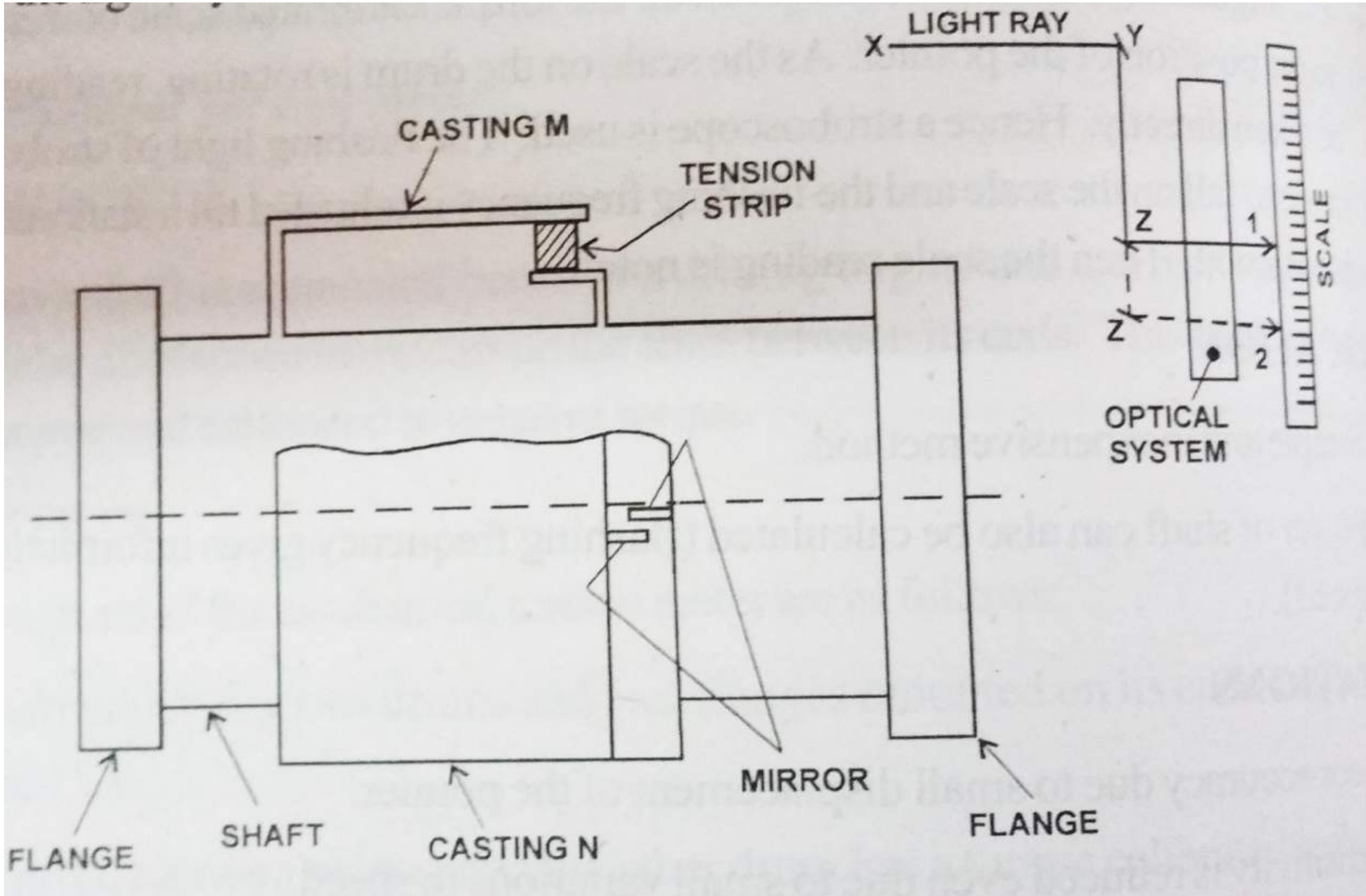


Figure 11.2: Optical Torsion Meter

ELECTRICAL TORSION METER

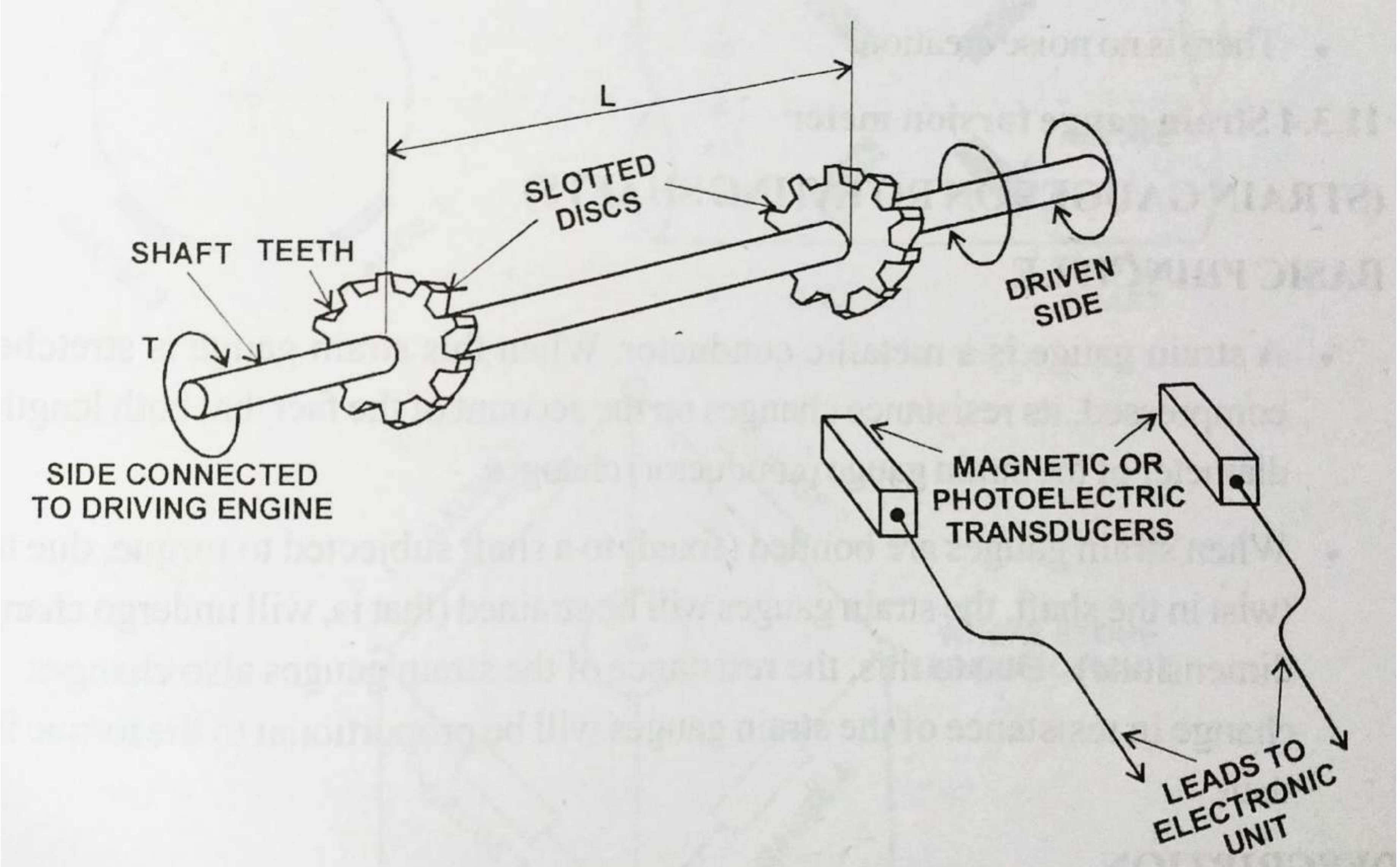


Figure 11.3: Electrical torsion meter

STRAIN GAUGE TORSION METER

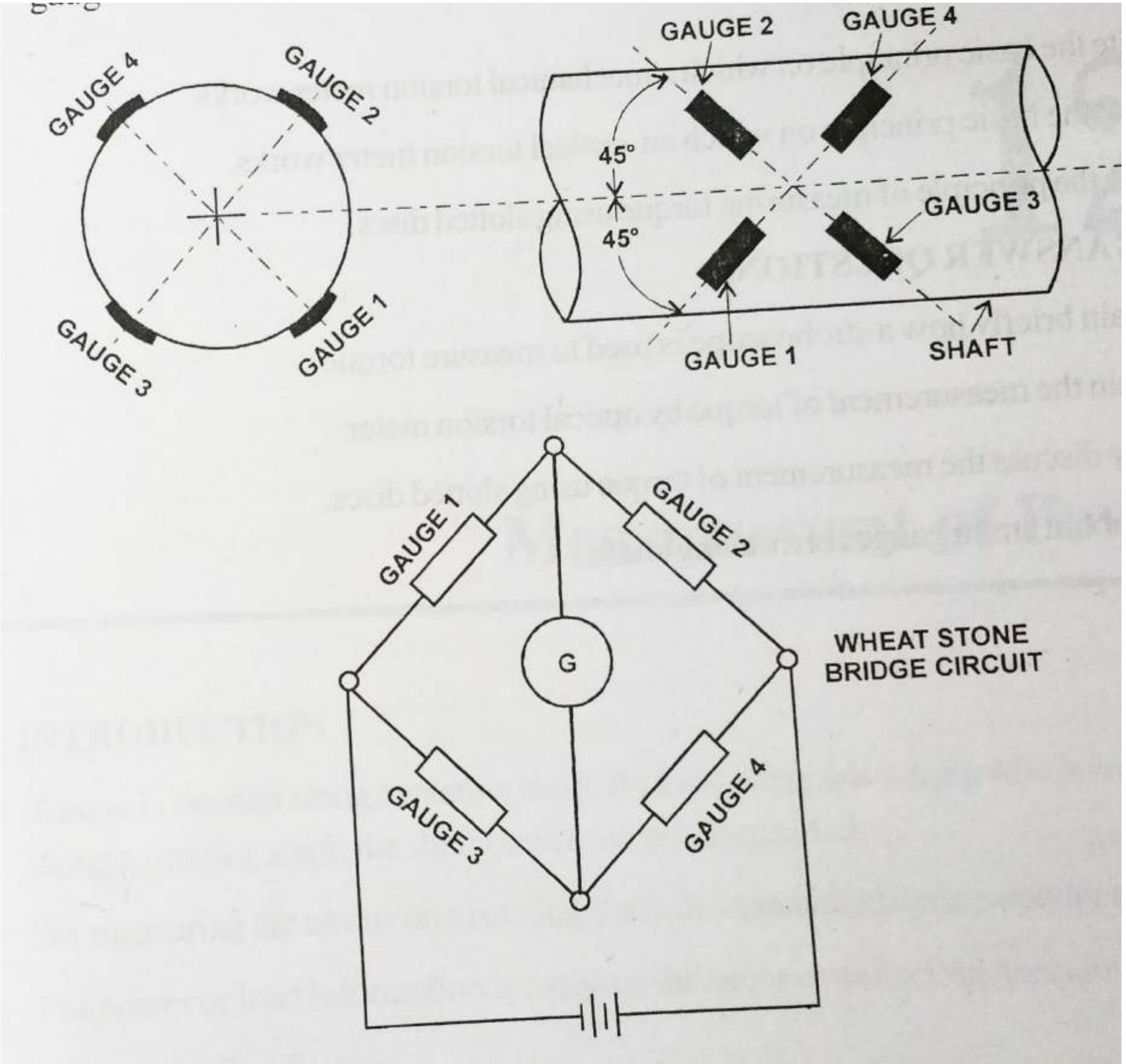


Figure 11.4: Strain gauge torsion meter

MEASUREMENT OF POWER

PRONY BRAKE

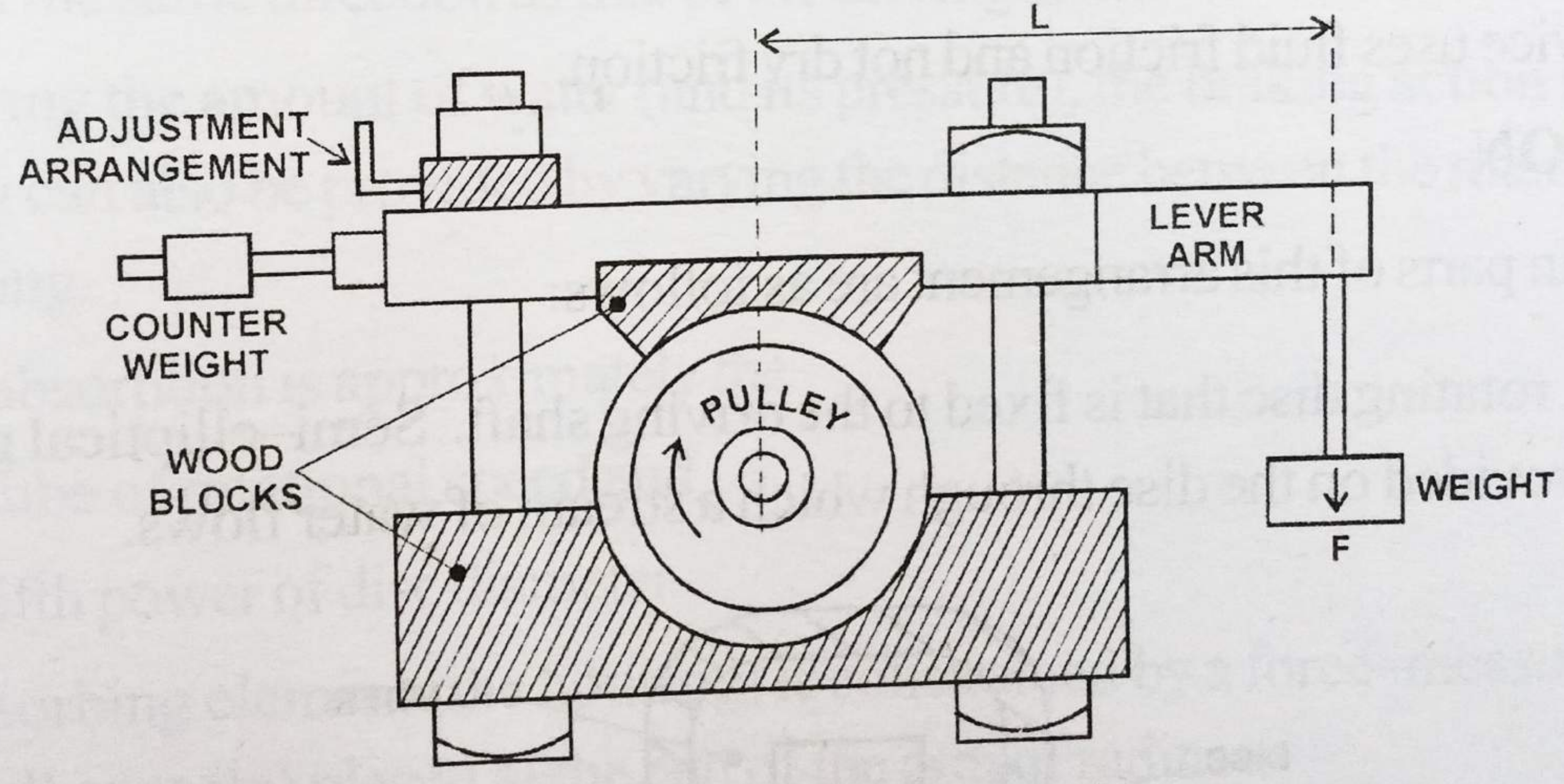


Figure 12.1: Prony brake

WATER BRAKE

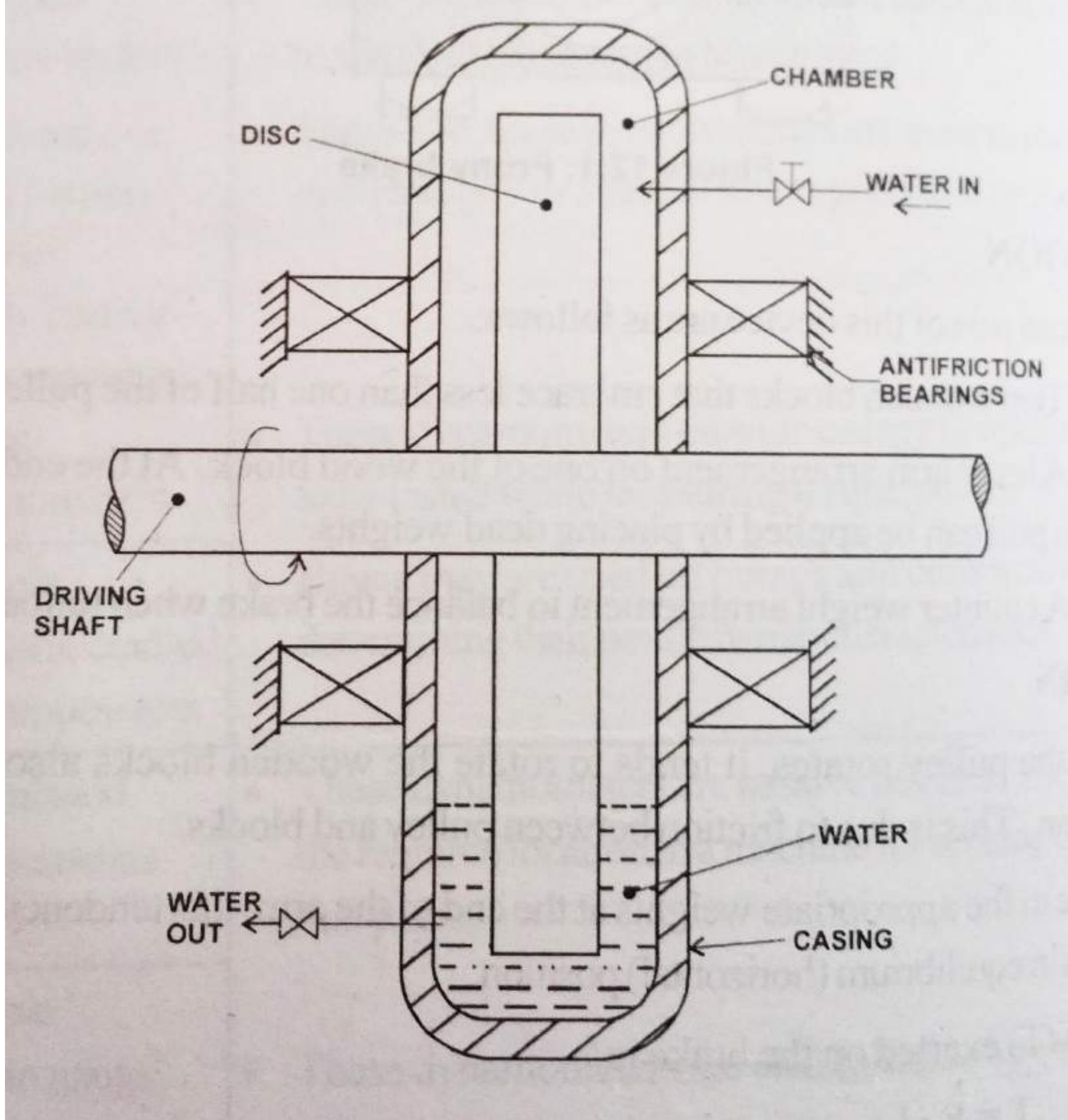


Figure 12.2: Water brake

EDDYCURRENT DYNAMOMETER

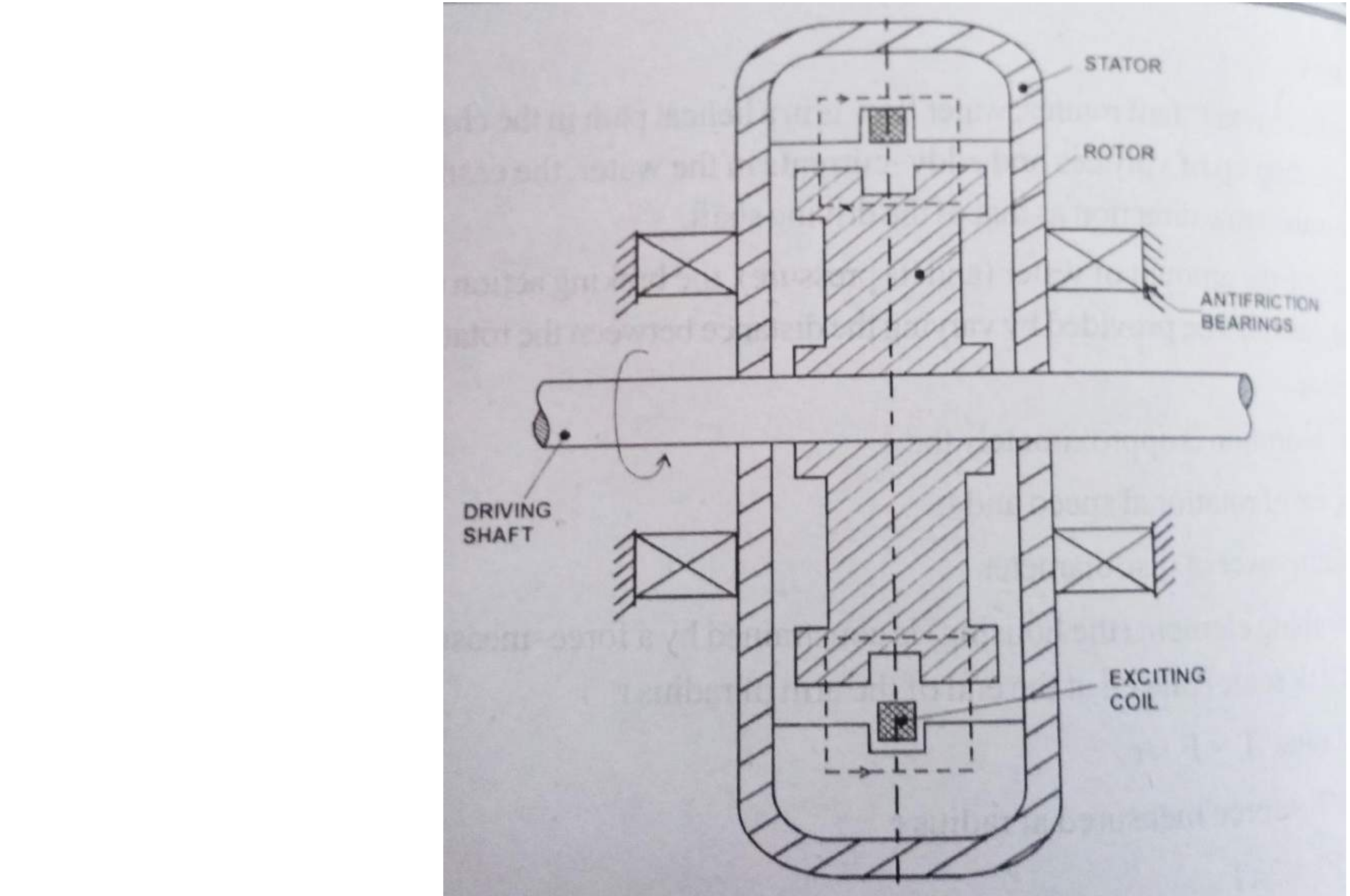


Figure 12.3: Eddy current dynamometer

DC CRADLED DYNAMOMETER

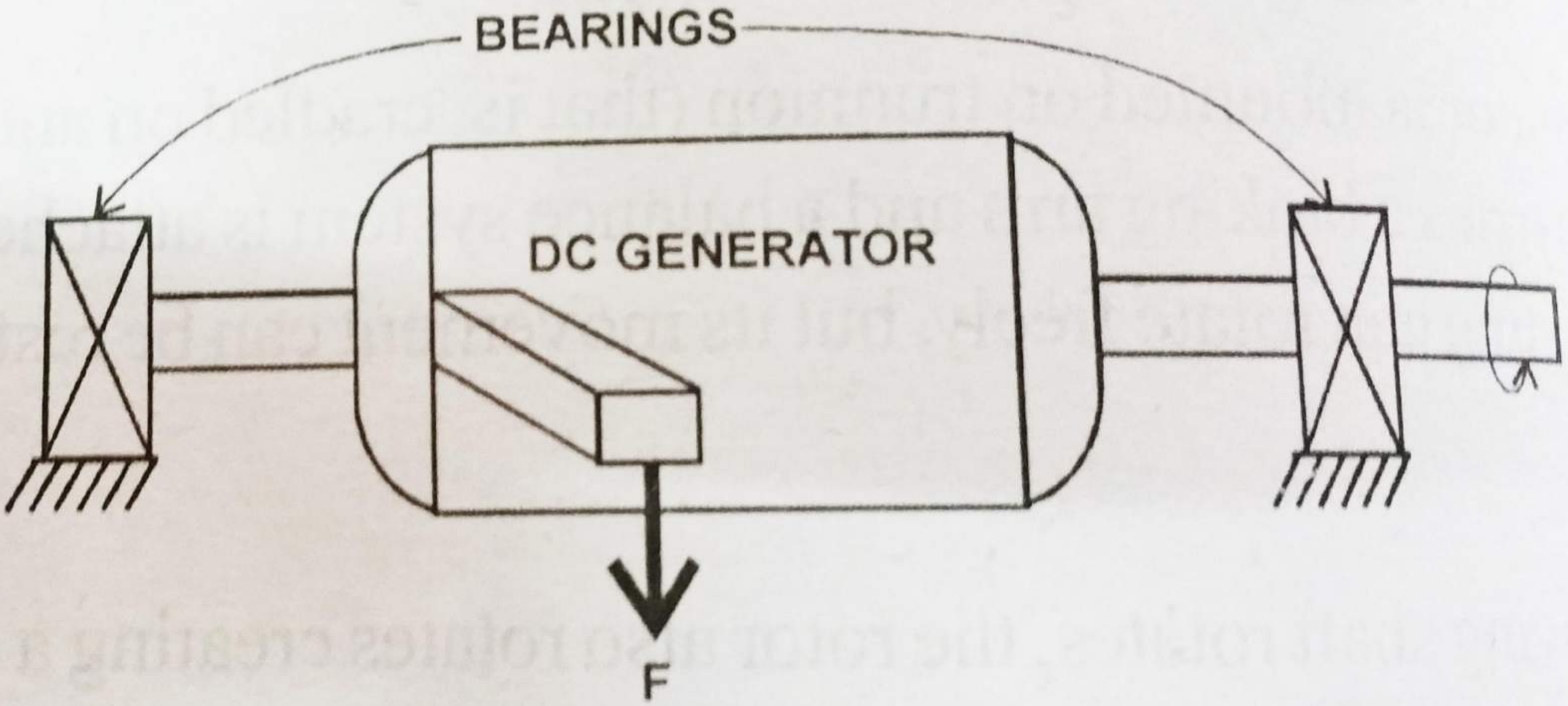


Figure 12.4: DC cradled dynamometer

FLASH LIGHT TORSION DYNAMOMETER

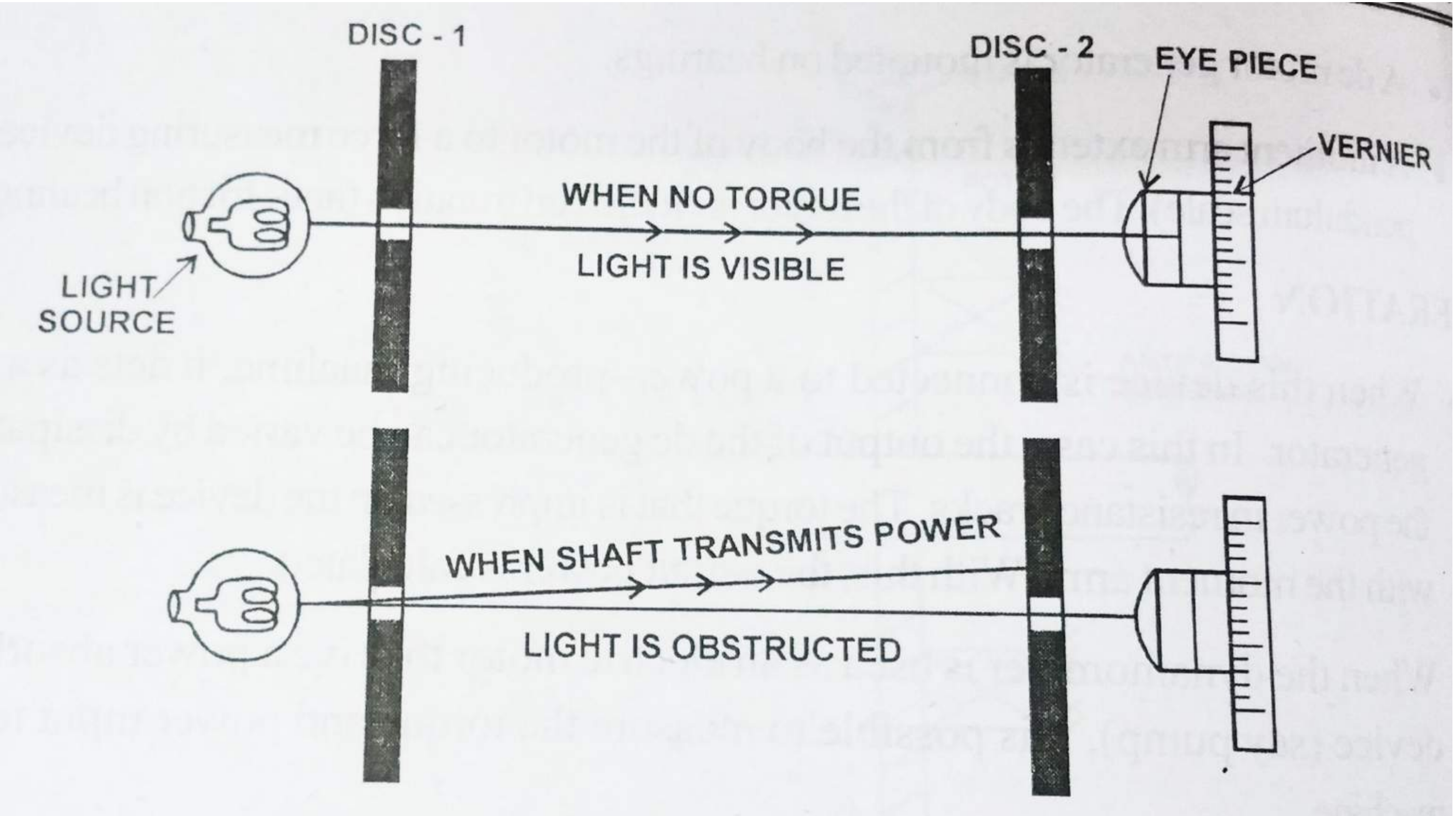


Figure 12.5: Flash light torsion dynamometer

UNIT-V

ELEMENTS OF CONTROL SYSTEMS

ELEMENTS OF CONTROL SYSTEMS

28.2 REQUIREMENTS OF A CONTROL SYSTEM

Stability, accuracy and speed of response are the three requirements of a control system.

(a) **STABILITY:** A system is said to be stable if the output of the system after fluctuations, variation or oscillations, if any, settles at a reasonable value for any change in input or change in disturbance.

(b) **ACCURACY:** A system is said to be 100 percent accurate if the error (difference between input and output) is zero. An accurate system is costly. There is no point in going in for a 100 percent accurate system when that much of accuracy is not really required.

EXAMPLE: When a variation of say 0.2 degree centigrade cannot be sensed by a human being , there is no need to have a home heating system of temperature variation equal to zero.

(c) **SPEED OF RESPONSE:** This refers to the time taken by the system to respond to the given input and give that as the output. Theoretically the speed of response should be infinity, that is, the system should have an instantaneous response. This requirement is of prime concern with follow-up systems.

Any ideal system is perfectly stable, 100 percent accurate and has instantaneous speed of response. Unfortunately, the requirements are incompatible. Hence there should be a compromise between these requirements.

ELEMENTS OF CONTROL SYSTEMS

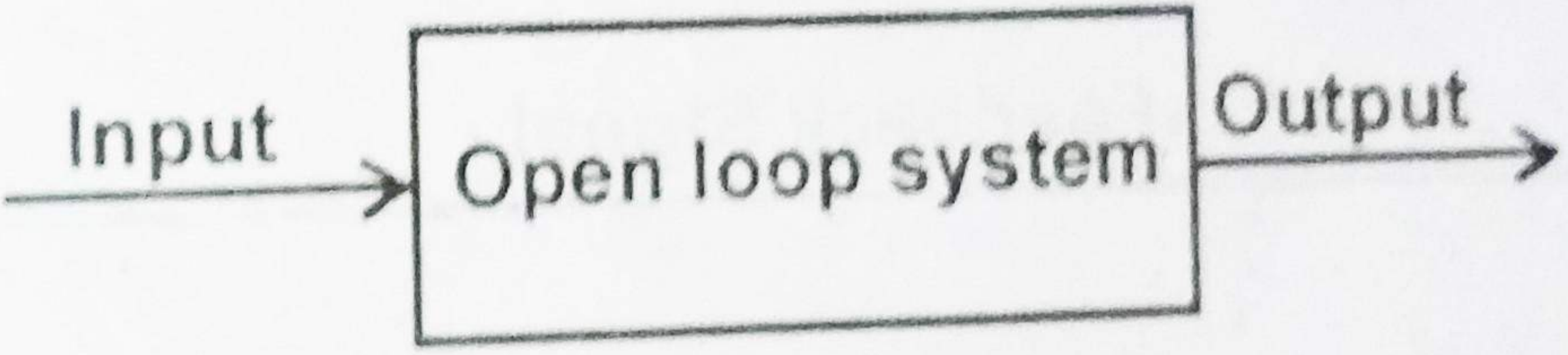


Figure 28.1: Open loop system

ELEMENTS OF CONTROL SYSTEMS

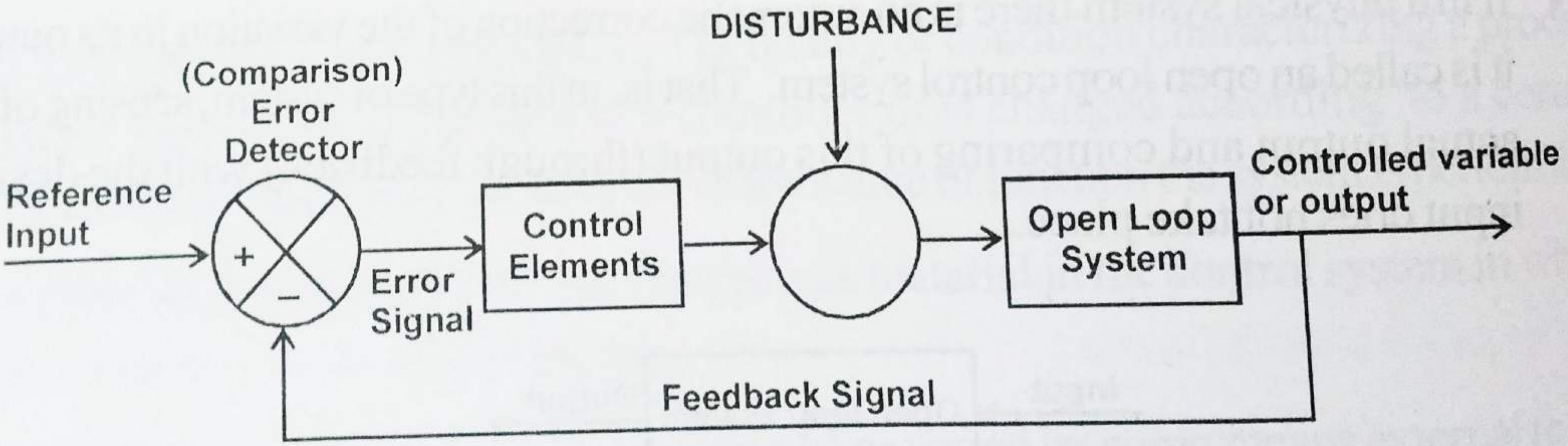


Figure 28.2: Closed loop system

ELEMENTS OF CONTROL SYSTEMS

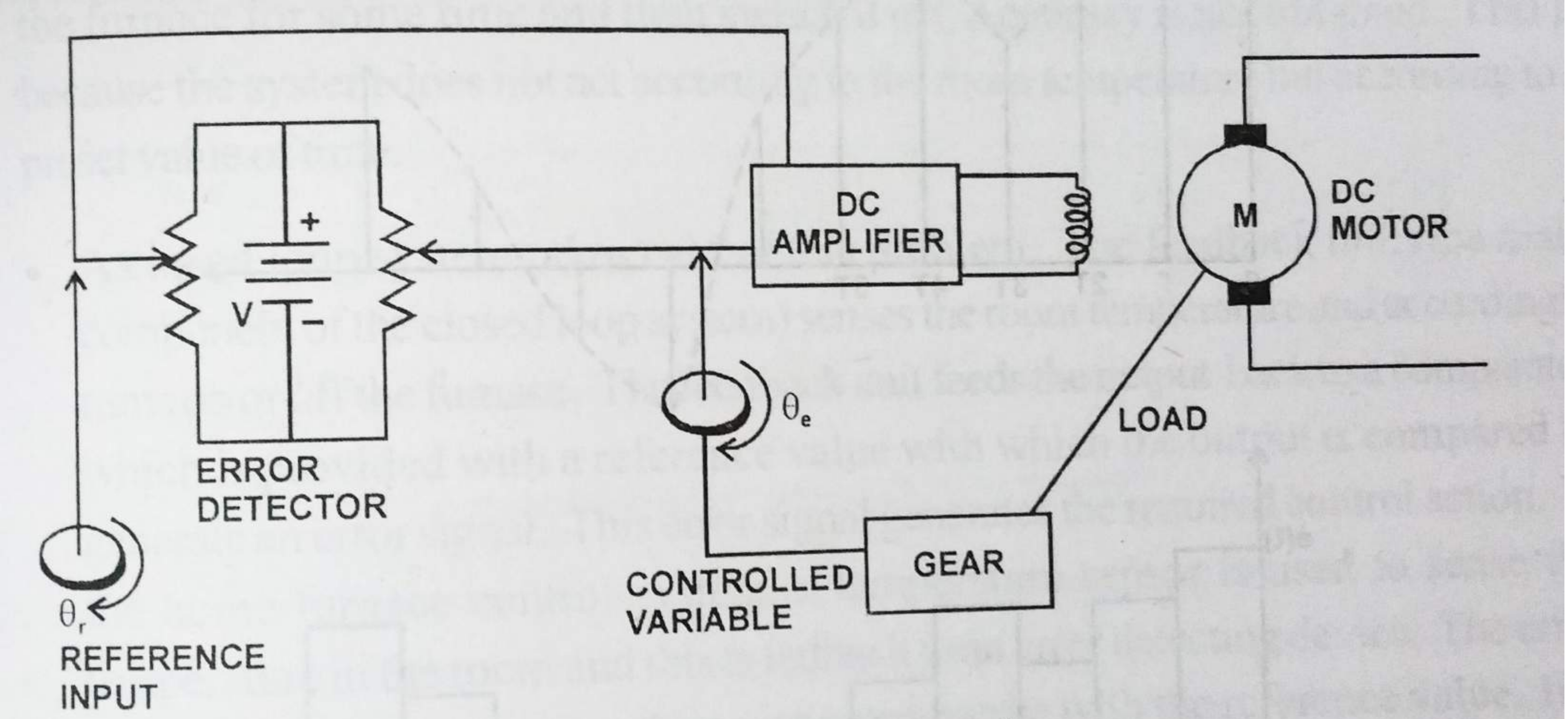


Figure 28.3: DC Servo system

ELEMENTS OF CONTROL SYSTEMS

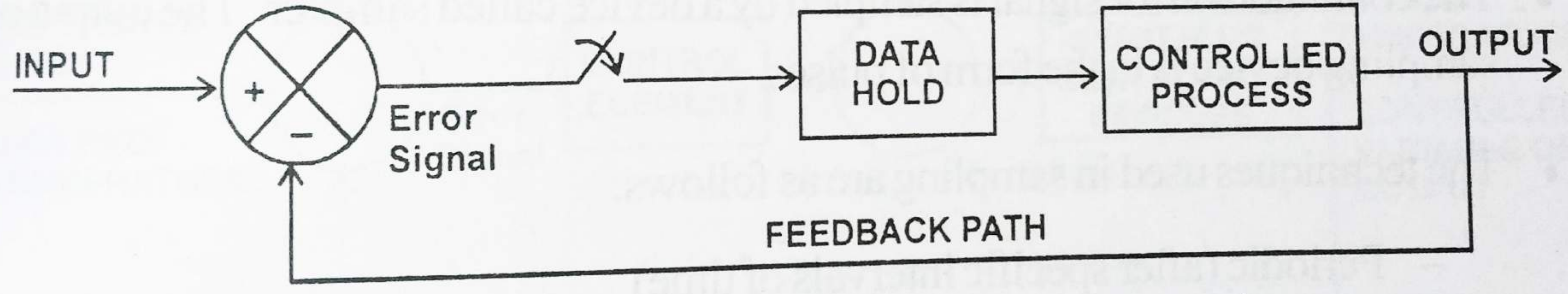


Figure 28.4: Sampled data control system

ELEMENTS OF CONTROL SYSTEMS

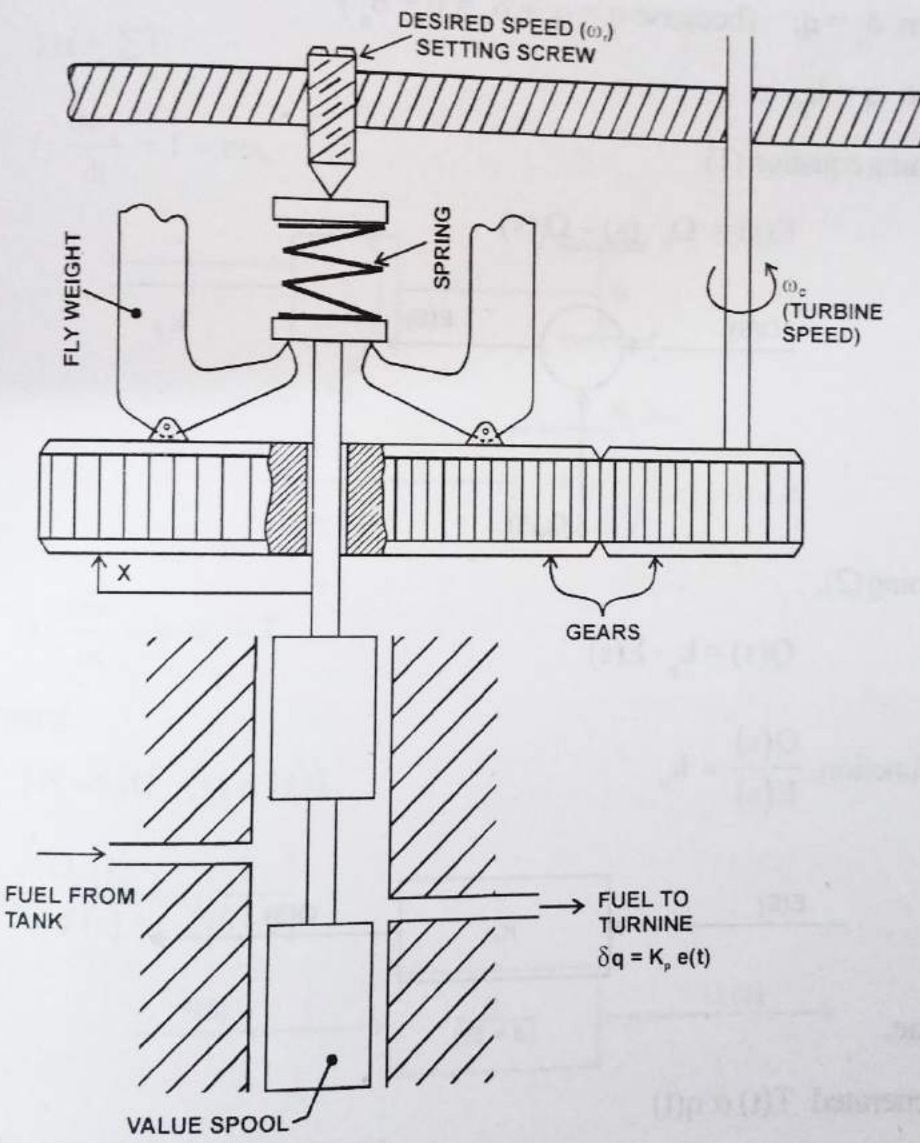


Figure 28.15: Proportional controller

ELEMENTS OF CONTROL SYSTEMS

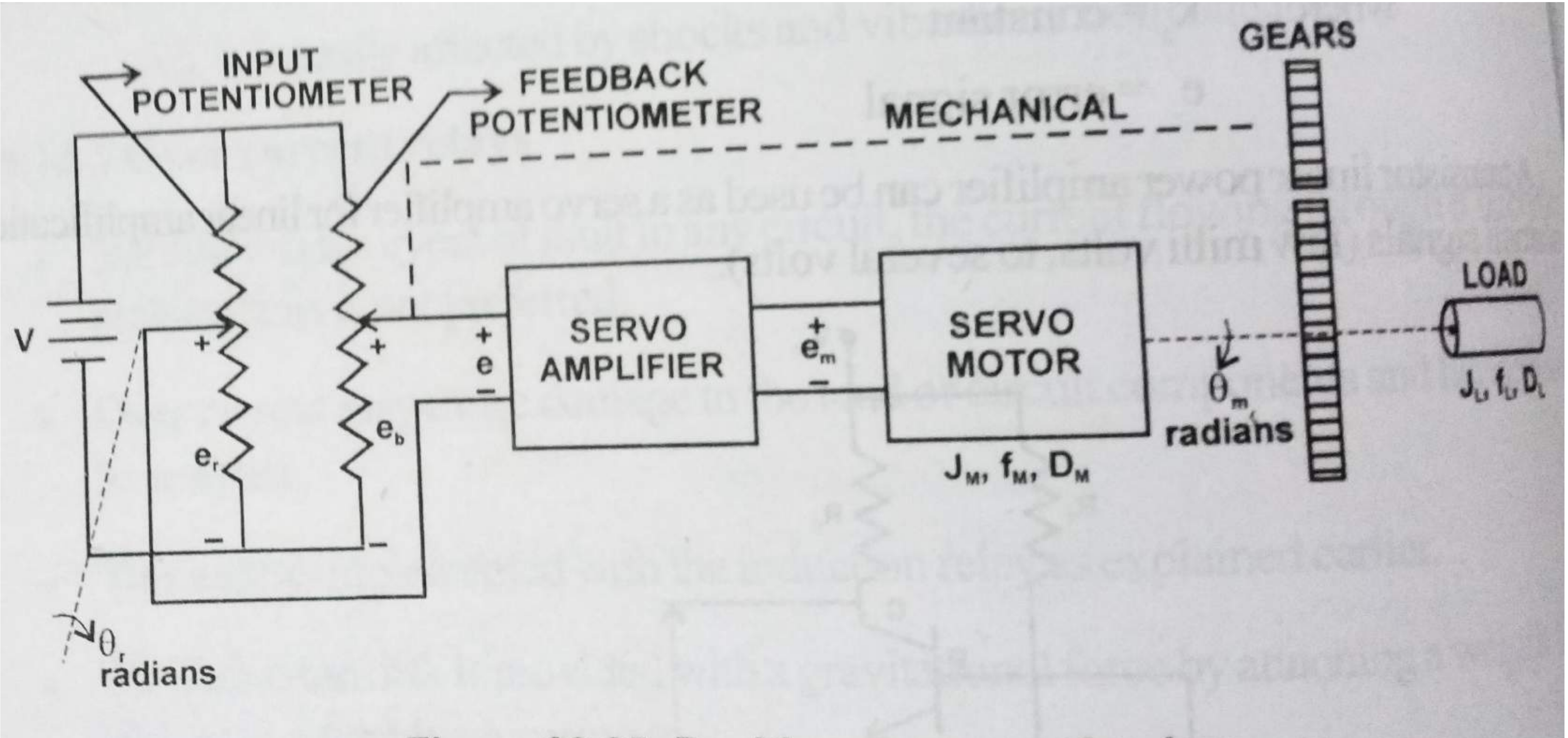


Figure 28.25: Position servo mechanism