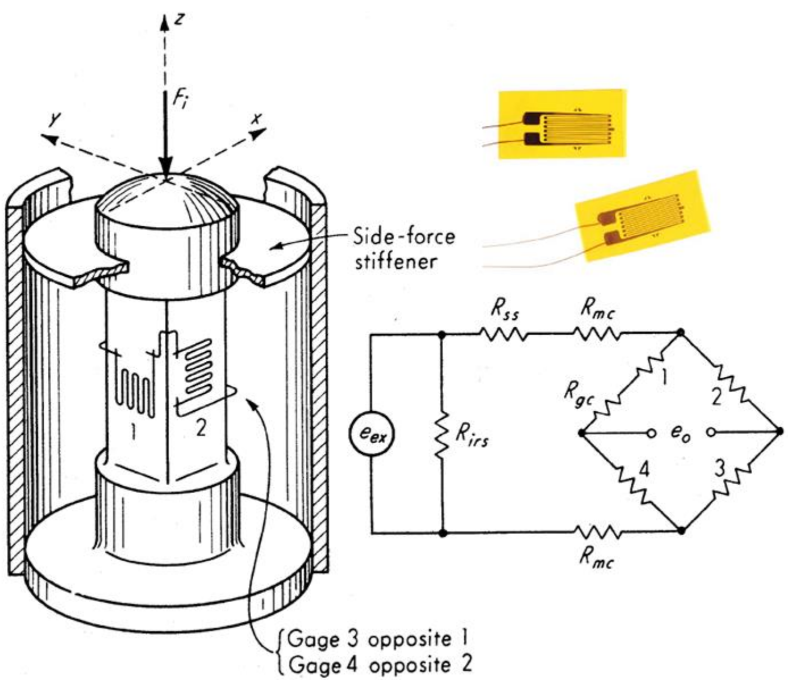
<u>Bounded Stain gage Transducers</u>

Four strain gages are employed (refer figure). They should be placed symmetric. To achieve high accuracy, additional temperature compensation resistors are used. Further, additional resistors may also be used for adjusting the input resistance and sensitivity.



1,3 direct strain and 2,4 transverse strain Deflection under full load will be in the order of 0.001 to 0.015 in

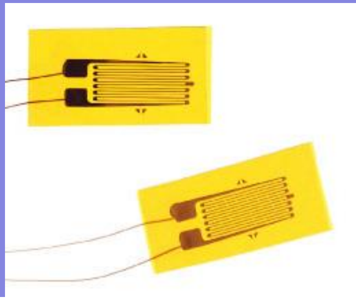
Material used SS – 4340, SS-17-4 PH, 2024-T4 aluminum alloy, etc.

When maximum output is desired, Use low modulus materials (e.g. Al) However, Low modulus usually reduces stiffness leading to excessive hysteresis, low fatigue life, etc.

Different types of load cells and their ranges

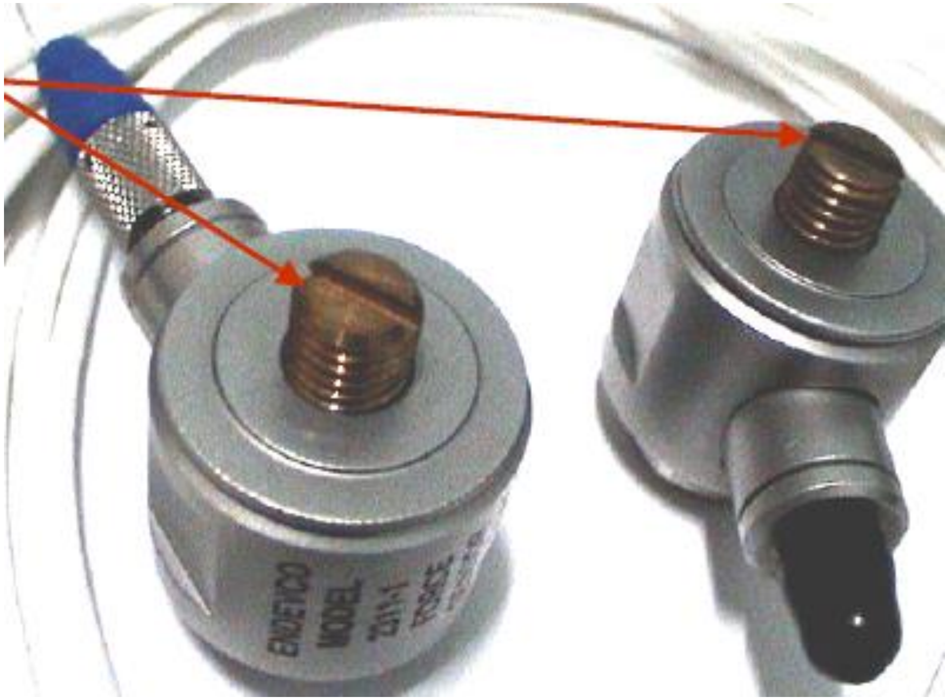
- Compression cylinder (50 kN - 50 MN)
- Compression cylinder (hollow) (10 kN - 50 MN)
- Toroidal ring (1 kN - 5 MN)
- Ring (1 kN - 1 MN)
- S-beam (bending or shear) (200 N - 50 kN)
- Double-ended shear beam (20 kN - 2 MN)
- Double-bending beam (500 N - 50 kN)
- Shear beam (1 kN - 500 kN)
- Double-bending beam (100 N - 10 kN)
- Tension cylinder (50 kN - 50 MN)

<u>Commercially available load cells</u>



Piezoelectric load cells

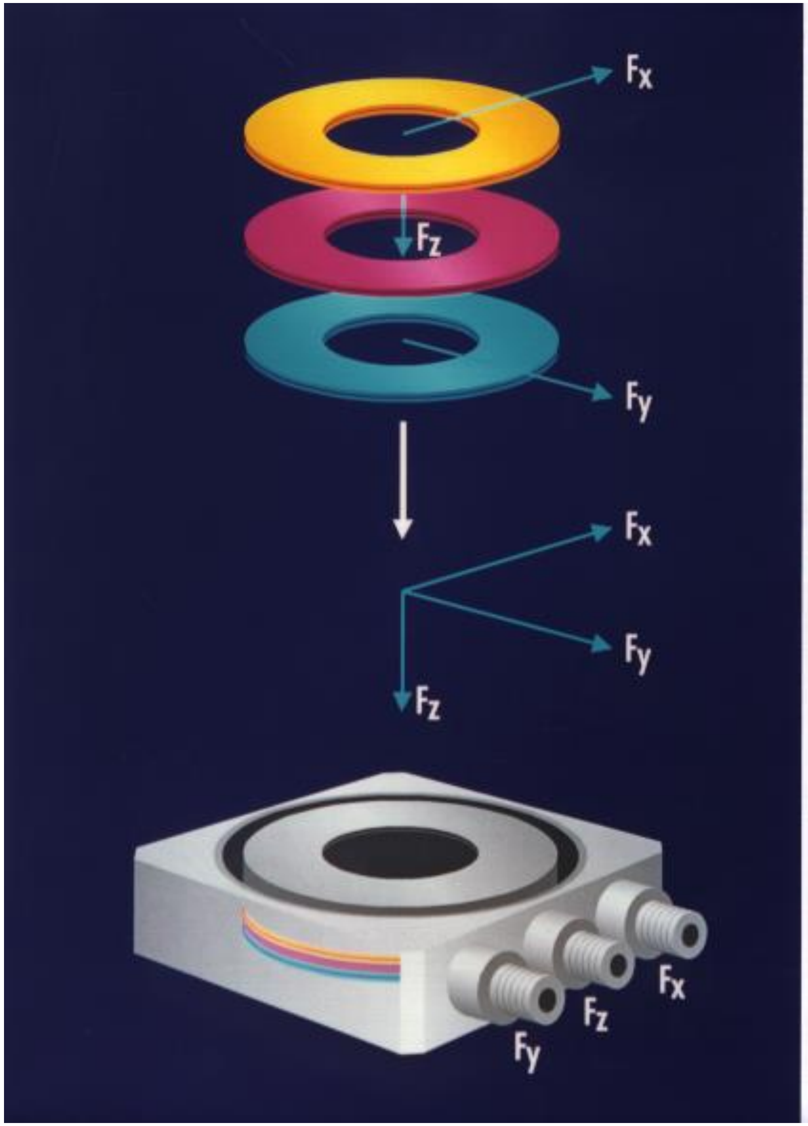
Mounting Screws

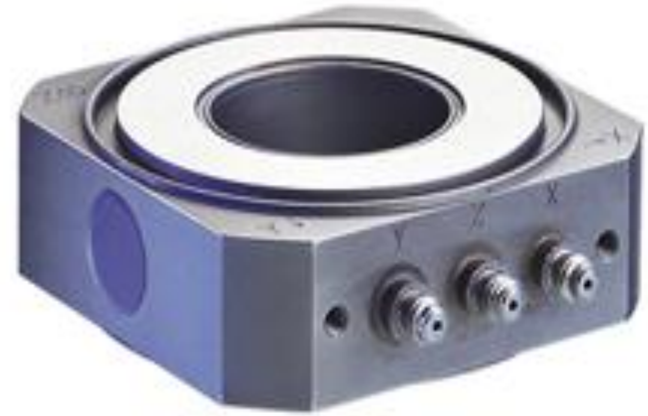


Mainly used for dynamic force measurement.

Cell with large time constant may be used for short term static force.

3-Component Force Sensor

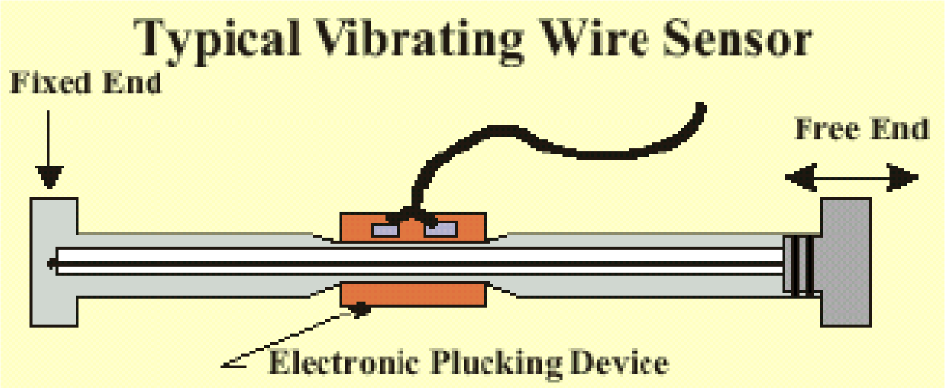




Vibrating Wire Transducers

- First natural frequency ω of a string of length L and mass per unit length m, which is tensioned by the force F to be measured

$$\omega = \frac{1}{2L}\sqrt{\frac{F}{m}}$$

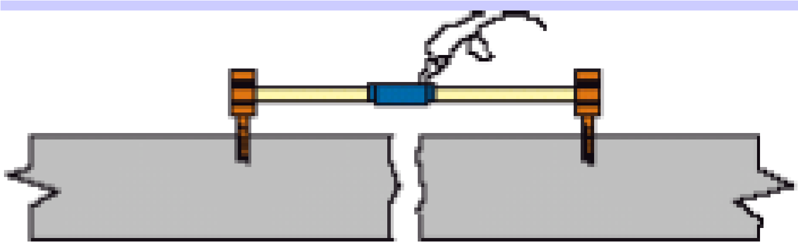


Frequency is measured and then it is related to the applied force. **Frequency is measured by conventional digital counters.**

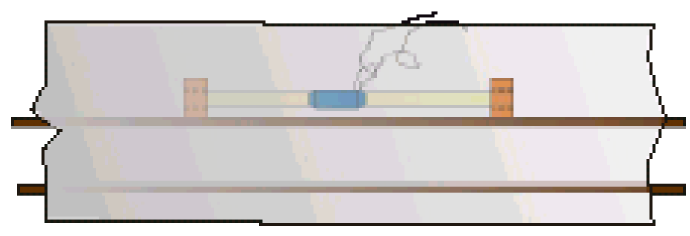
- Wires are thin electrically conducting metals placed in the fields of permanent magnets.
- Temperature sensitivity (tension of the wire changes with temperature)
- Non – Linear relation

Vibrating Wire Transducer Applications

1. Embedded in concrete to measure reinforcing steel stress
2. Underwater crack movement
3. Joint movement between two structural members
4. Minute rotational movement of structural members



VW Strain gauge positioned across a crack to measure crack movement



VW Strain gauge welded to reinforcing steel and embedded in concrete to measu reinforcing steel stress

Plastic Deformation Method

- Records the Plastic deformation of the sample which is being subjected to an applied force.
- The deformation for a particular size, shape and material properties may be calibrated by testing of similar elements.

Magneto Elastic Force Transducer

- When a ferromagnetic material is subjected to mechanical force, the magnetic properties of the material are altered and the change is proportional to the applied force.
- The magneto-elastic load cell can be used in rough and electrically disturbed environments such as in rolling mills.
- Ranges are 2 KN – 5 MN.

Resolving forces and moments

- **To test aircraft and rocket engine**

  Major objects is to resolve three components of forces and moments resulting from the engine thrust.

- **Wind tunnel balance**

  For measuring forces on wind tunnel model

- **Lathe and other machines**

  For resolving cutting forces in lathe tool machines

Torque measurement

Torque measurement is the basis of the power measurement / power required to derive a particular machine etc.

Methods

- **Absorption type (Prony Brake) Dissipate mechanical energy as torque. Mainly used for power measurement.**
- **Driving type (Dynamo meters). Measure both power and energy requirement.**
- **Transmission type (Torque sensors). They are simply placed at an appropriate location within a machine, for the purpose of sensing the torque. They neither add to nor subtract energy from the machine.**

- Torque, or moment, may be measured by measuring the angular deformation of a bar or a hollow cylinder.
- The moment is given by

$$M = \frac{\pi G(r_0^4 - r_i^4)}{2L}\phi$$

M = Moment , N-m

G = Shear modulus of elasticity M/m2

r_i & r_0 = inside and outside radius of cylinder, m

L = Length of the cylinder, m

Φ = angular deflection, rad

$$G = \frac{E}{2(1+\mu)}$$

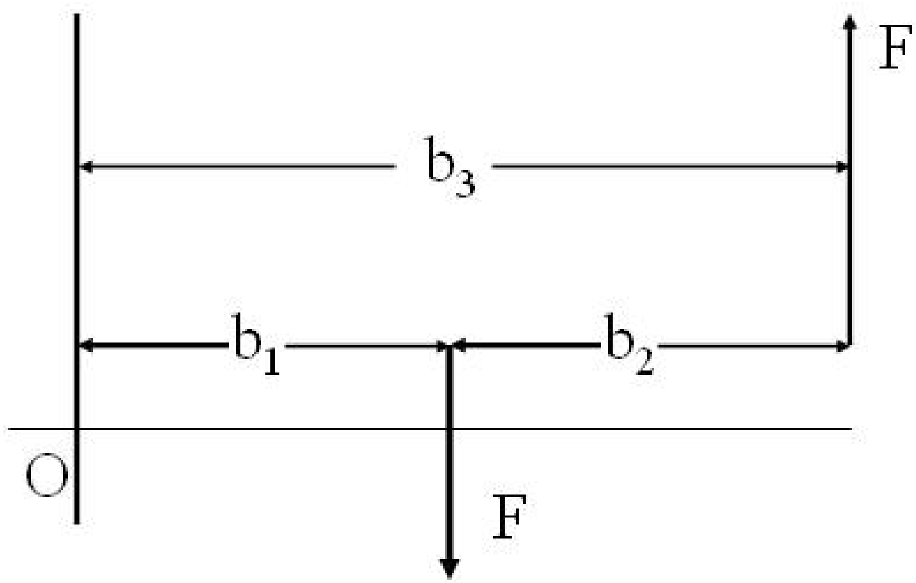
A force sometimes may exert a turning effort on a body. Such a turning effect is called torque or couple.

The torque or the couple = $F \times b_1 - F \times b_3 = Fb_2$

The torque T may also be computed by measuring the force F at a known radius 'r' by T=Fr.

Torque measurement is used for the determination of power.

The power $P = 2\pi NT$



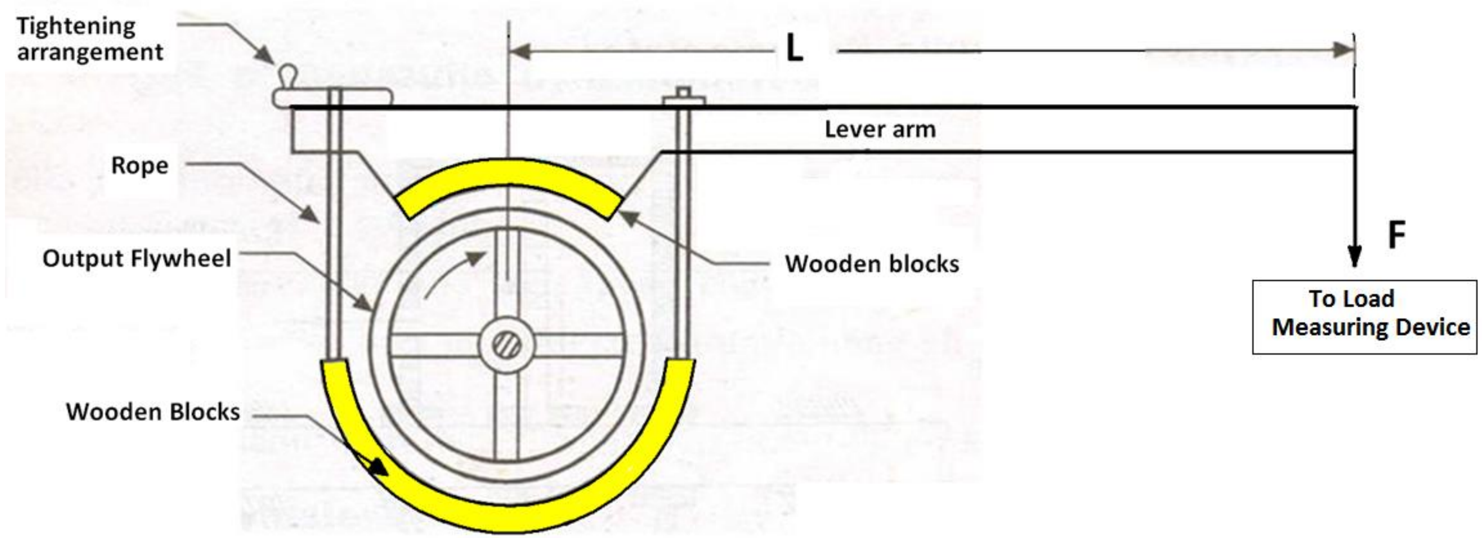
- **Torque is a measurement of twisting force.**
- **A 1 foot wrench with 1 pound of force pushing on the end of the wrench is said to produce 1 foot-pounds of torque.**
- **There does not need to be motion to create torque, unlike horsepower.**
- **Torque is a SCALAR measurement, which means it has magnitude only.**
- **Electric motors can produce torque at zero rpm.**
- **Engines can’t because they won’t run at low rpm.**

Shaft Power Measurements

Dry friction (Prony brake)

- The absorbing element is brake assembly.
- Power absorbed is carried away by cooling water circulated
- Prony brake friction torque is manually adjusted

Prony brake



Prony Brake

- A flywheel is attached to the rotating shaft.
- Two wooden blocks are mounted diametrically opposite on a flywheel.
- One block carries a lever arm, and an arrangement is provided to tighten the rope which is connected to the arm.
- Lever arm rests on a scale. As the engine runs, the rope is tightened so that the RPM is steady. The force and the RPM are noted.
- Torque , T = F. L

- Prony brake was made of wood and leather.
- Wood block mechanism attached to ouput shaft of engine.
- Lever arm rests on a scale
- As engine is run, thumb screws are tightened until rpm is steady.
- Force on scale is read and rpm is recorded.
- Very primitive.

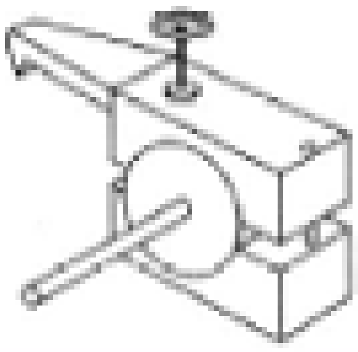
Power measurement

$$P = \frac{2\pi N T}{60}$$

P = Power, watts
N = Speed of the shaft, rpm
T = Measured torque, N.m

Torque and speed are measured separately and power is calculated

Prony Brake at IITG



Force Transducer

Adjustable Pulley

Fluid friction (Air and water brakes, Hydraulic dynamometer)

- **Water and air brakes utilize the churning action of paddle wheel or vanes rotating inside a fluid-filled casing**
- **The absorbing element is the housing.**
- **Energy absorption at any given speed is controlled by water flow rate. They are larger in size.**
- **Greater the water flow through the dynamometer, greater the braking action or load**

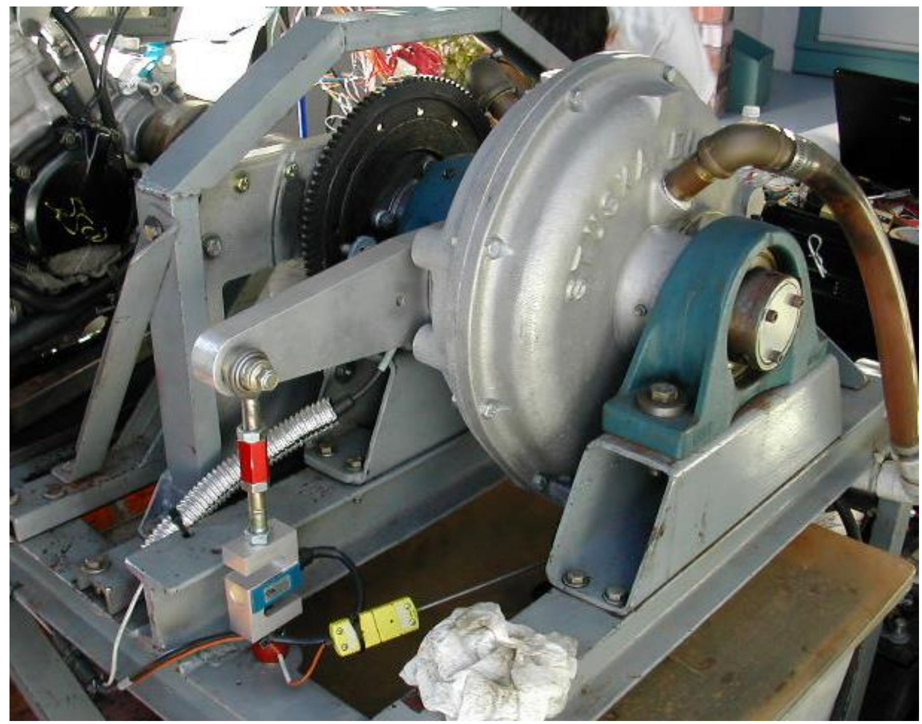
Water Brake Dynamometer

Works on the principle of viscous coupling.

The output shaft of the engine is coupled to a fan that spins inside housing housing.

While the engine is running, the housing is filled with a controlled amount of water.

The more water that is allowed into the housing, the more load the engine will feel.



Water Brake Dynamometer

- As the fan spins, the water is whipped around.
- Water will push the housing with equal and opposite force that the fan is pushing on the water. Shear forces in the water acts tangential to the housing radius.
- A load cell is oriented perpendicular to the arm extending from the housing at a measured distance from the center of the housing.
- The torque output of the engine is just the force measured at the load cell multiplied by the distance to where the extended arm and load cell connect.

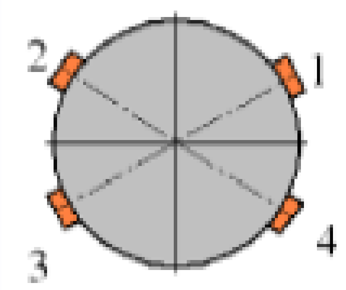
$$P = \frac{2\pi N T}{60}$$

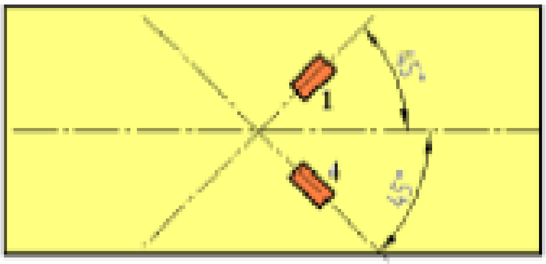
Torsion bar Dynamometer

- **Two discs attached to the shaft at two different locations**
- **Angular moment /displacement is measured using optical gage.**
- **Using $T/J = G\theta/L$; the un know Torque T is measured.**
- **Typical operating ranges : up to 5000 N.m ;**
- **Accuracy of the system is $\pm$ 2.5% (F.S)**

Strain gauge torque sensors

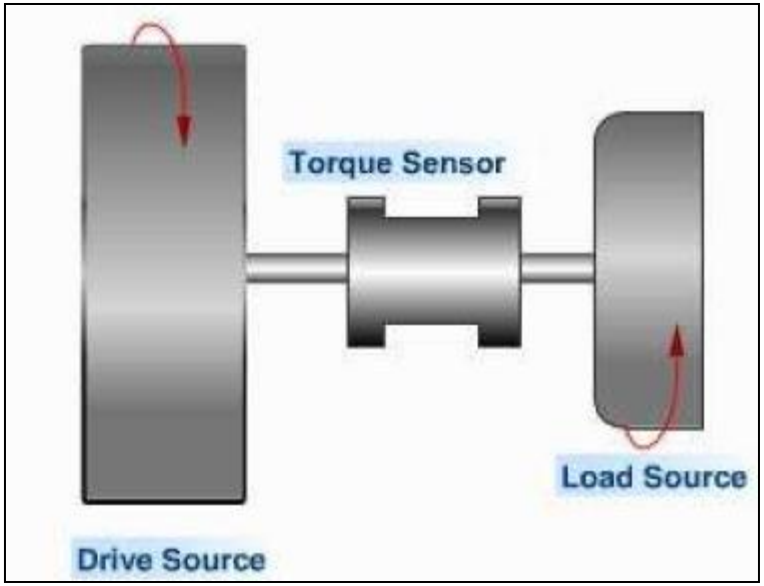
- Gauges precisely fixed at 45° with the shaft axis
- Set of two, diametrically opposite to each other
- Types
  - Hollow cruciform
  - Solid
  - Square shaft

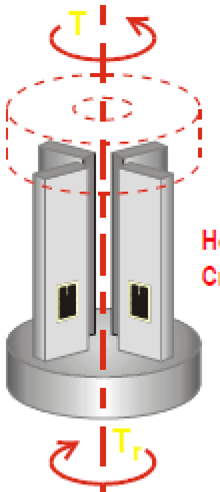




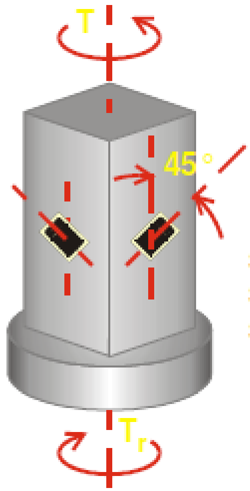
- Gauges on square, rather than round, cross section has advantages (Possible to fix the gage without any lateral moment)
- Temperature compensation should be provided

The torque sensor measures the twist or windup between a rotating drive source and load source such as an engine crank shaft.

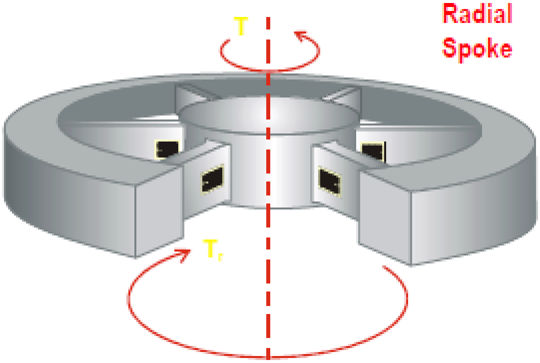




Hollow Cruciform

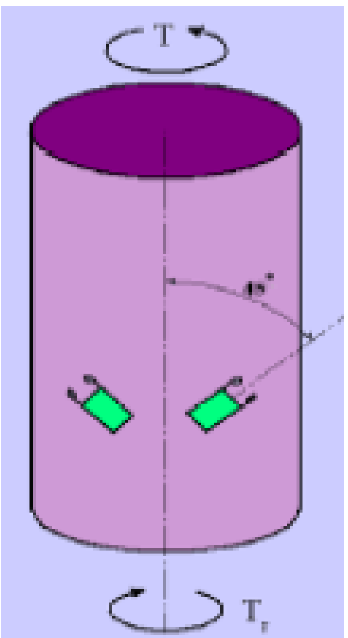


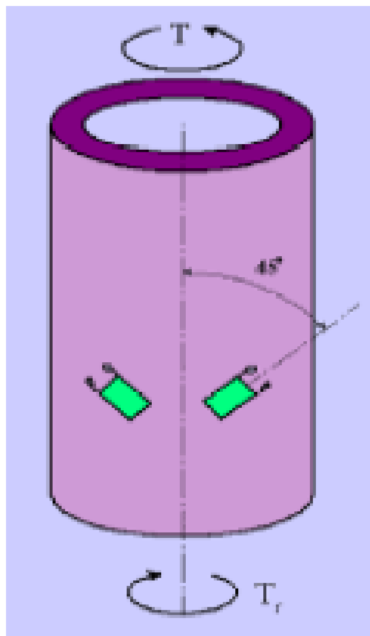
Solid Square Shaft

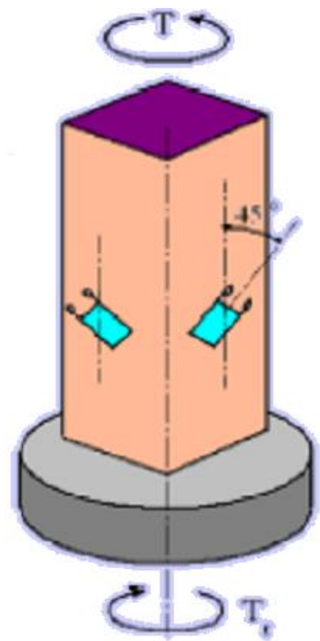


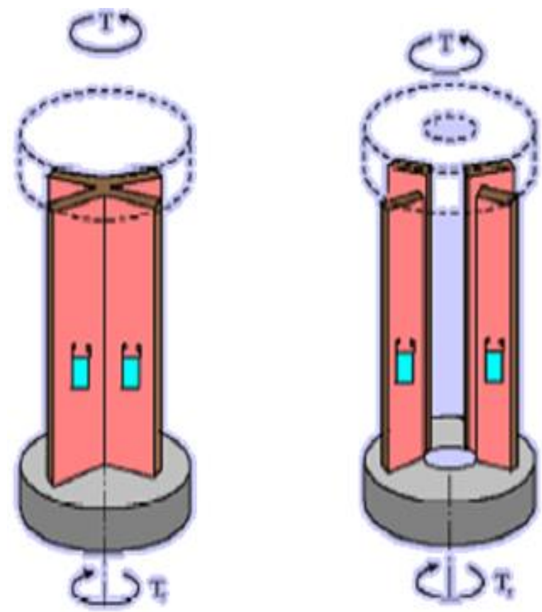
Radial Spoke

Hollow Tubular









Solid shaft **Hollow shaft** **Square shaft** **Hollow cruciform**

Commercial strain gage torque sensors

- Ranges are from 0.001 N.m to 80,000 N.m
- Speeds 350 rpm to 24,000 rpm
- Accuracy $\pm$ 1%

Strain measured by the strain gage

$$\varepsilon = \frac{T}{\pi G R^3} \qquad G = \frac{E}{2(1+\mu)}$$

G- Shear modulus ; E- young's modulus and μ poison's ratio

Electric Dynamometers

Eddy current dynamometer:

- Absorption type. Used to measure the power generated by IC engine or generator.
- Works based on electro magnetic principle. When a conductor moves though a magnetic flux, voltage is generated, which causes current to flow.
- Load is controlled by adjusting the field current.

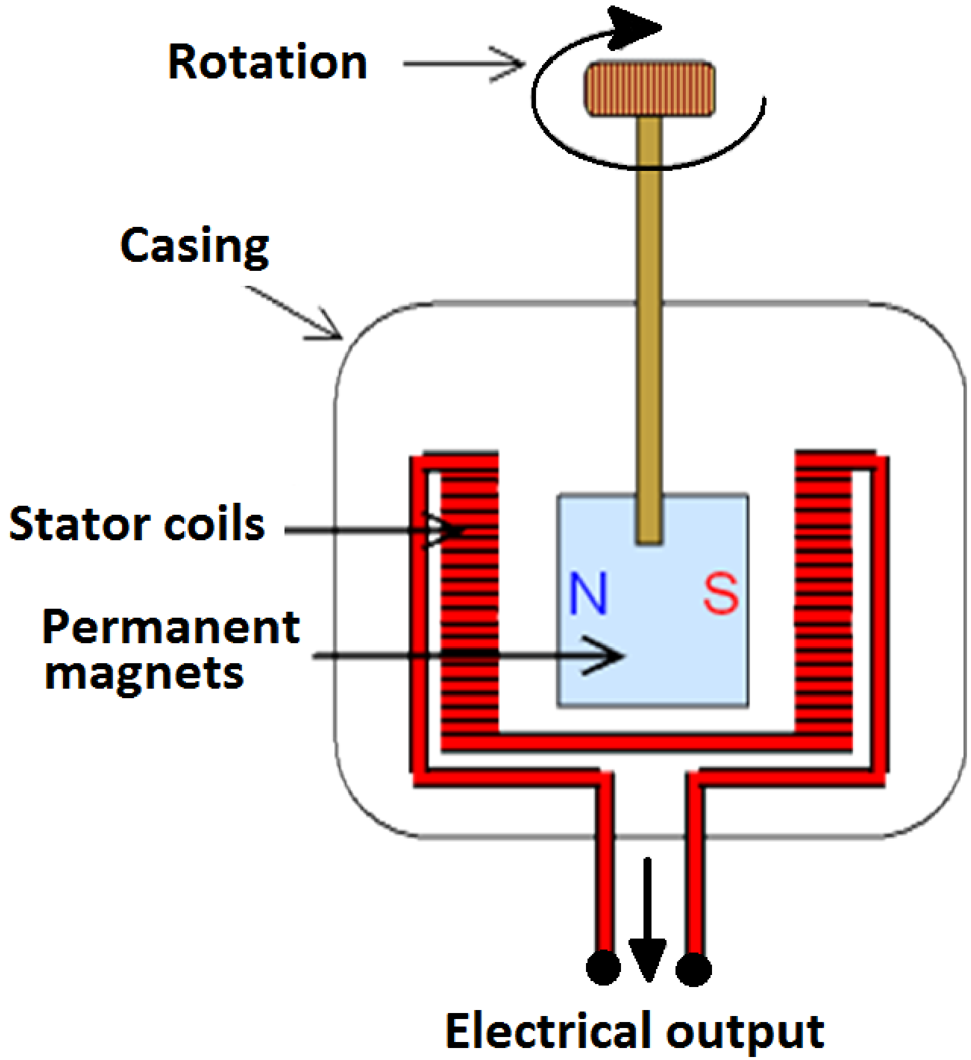
Cradled dc dynamometer:

- Both absorption and driving type. Basically it's a dc motor with suitable controls to permit operation in either mode.
- Absorption type (Generator): Mechanical energy is converted into electrical energy which is dissipated in resistance disks.
- Heat is dissipated outside the machine.
- Force measurement is done using cradle mechanism.

Eddy current dynamometer :Principle

Eddy current dynamometers operate on the principle of slip losses that occur when an electrically conductive drum is made to rotate against a stationery and non-uniform flux distribution, formed around its periphery.

The relative speed between the stationery flux and the rotating drum, causes flow of eddy currents, in the drum material, governed by the laws of electromagnetic induction. The reactive magnetic field, resulting from induced currents, is responsible for the braking torque developed by the unit.


Rotation
Casing
Stator coils
Permanent magnets
N
S
Electrical output

Eddy current dynamometer in IC engine lab IITG

Power Measurement (absorbed)

$$P = \frac{EI}{Efficiency}$$

P = Power, wattmeter output

E = output voltage, volts

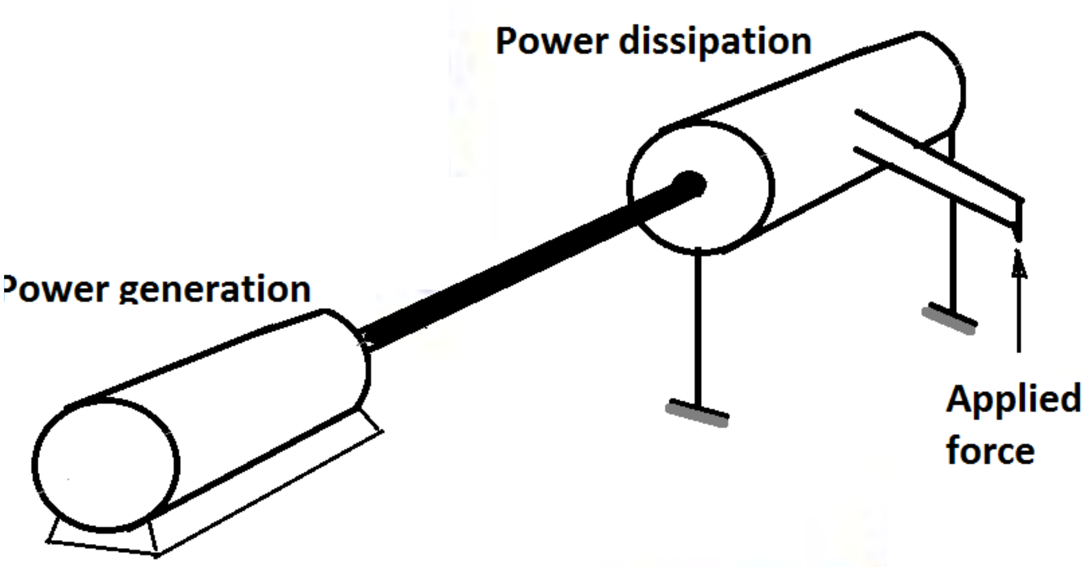
I = output current, amps

Efficiency = generator efficiency

Cradle Shaft

Cradle: Is a support in bearing and has a moment arm connected to a force measuring device.

Moment and speed give the shaft power



Trunnion Bearing

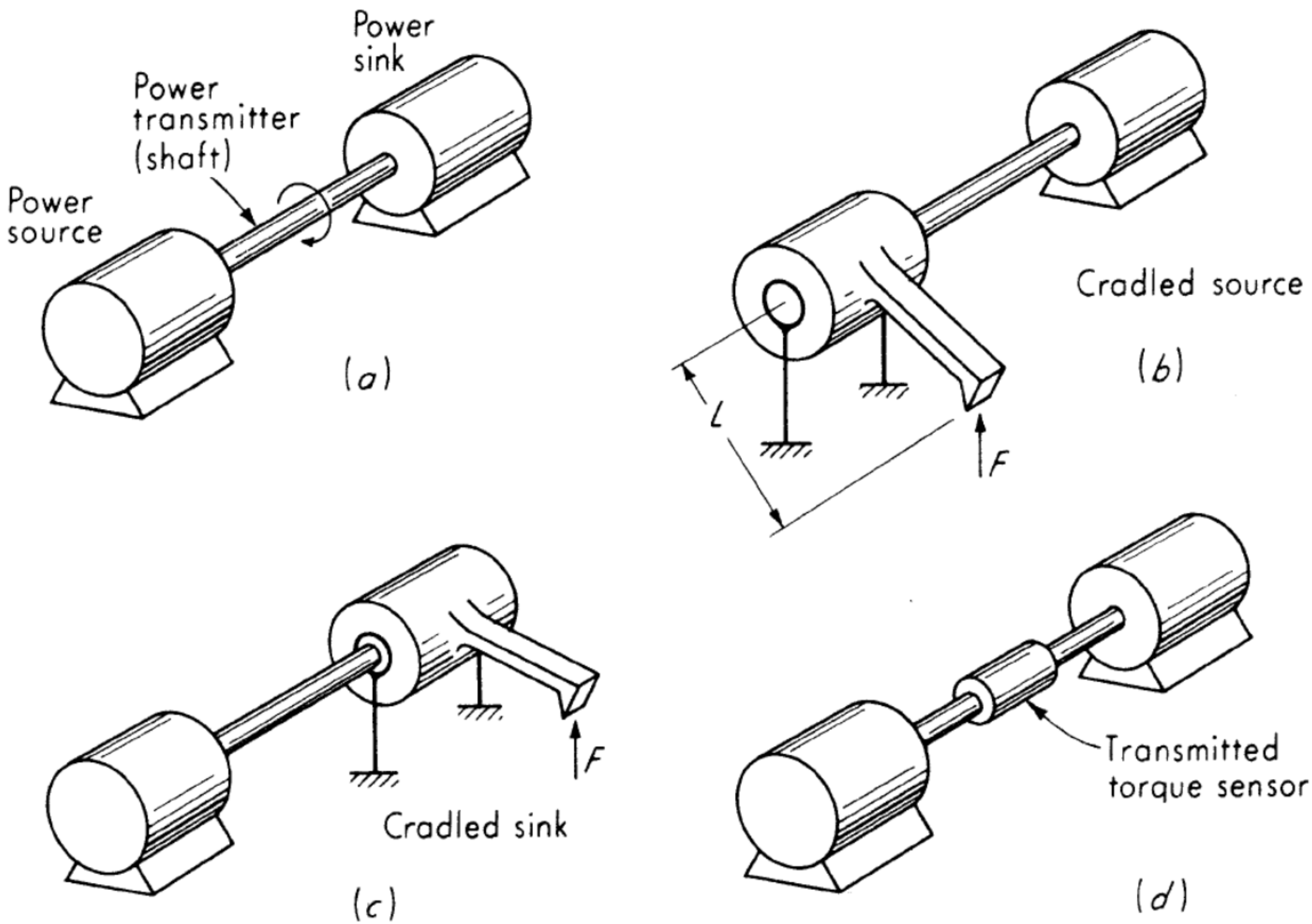


Fig. 5.13 *Torque measurement of rotating machines.*