

King Abdulaziz University
Mechanical Engineering Department

MEP 365

Mechanical Measurement

Angular speed, Force, Torque and Mechanical power measurements

Dec. 2017

Force, Torque, angular speed and mechanical power measurements

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- 3-Measurement of force
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Introduction

Among the variables to be measured in the field of mechanical engineering are:

- Rotational speed of a rotating machines (RPM)
- Forces on mechanical and non mechanical elements to study the system strength and possibility of failures
- Power generated from engines, such as internal combustion engines and gas turbine engines
-

1-Rotational speed measurements

Rotational
speed

Example: speedometer in Automobile

Four ways to measure ω or N (RPM) will be discussed:

1-Angualr speed sensor used in controlling steam turbine output power

2-Stroboscope (or Tachometer)

3-Electromaganitic pickup

4-Remote optical sensing

1-Rotational speed measurements

Rotational
speed

1-Angualr speed sensor used in controlling steam turbine output power

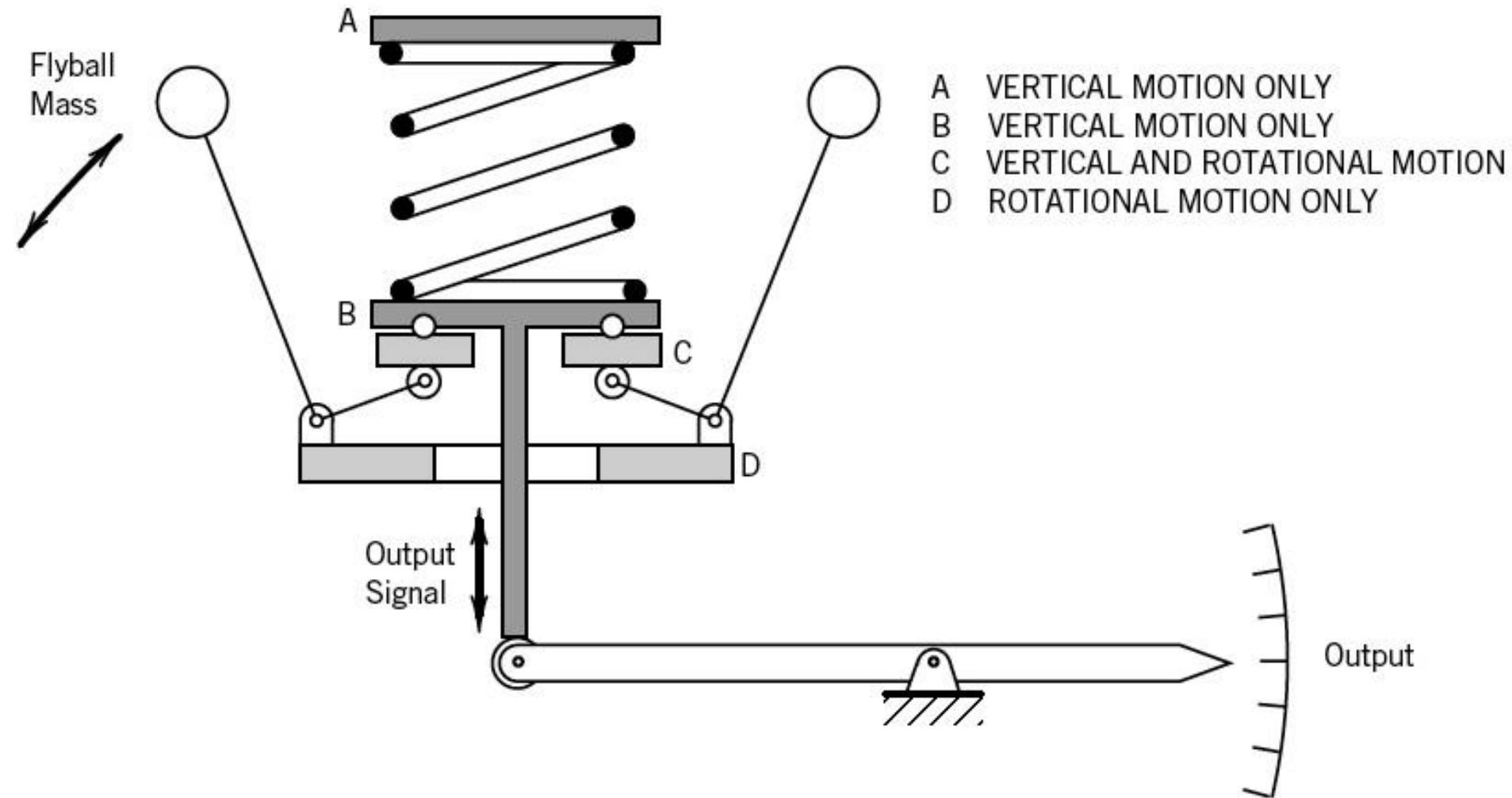


Figure 12.13 Mechanical angular velocity sensor.

Rotational speed

As the angular speed increases, the flyballs move horizontally forcing C to go up which compresses the spring and moves the pointer on the scale

Flyball Mass

A

B

C

D

Output Signal

Output

A VERTICAL MOTION ONLY
B VERTICAL MOTION ONLY
C VERTICAL AND ROTATIONAL MOTION
D ROTATIONAL MOTION ONLY

Figure 12.13 Mechanical angular velocity sensor.

Centrifugal acceleration of flyball

1-Rotational speed measurements

2-Stroboscope

Rotational
speed

High intensity light at precise frequency

Time mark on the rotating shaft

Start with high flashing rate of the stroboscope

when the mark seems stationary for the observer, the rotational speed is the flashing frequency

To make sure about the speed, double the flashing rate of the stroboscope the mark will appear as stationary



Figure 12.14 Stroboscope.
(Courtesy of Mill Devices Co.,
a division of A. B. Carter Inc.)

1-Rotational speed measurements

Rotational
speed

2-Stroboscope



1-Rotational speed measurements

**Rotational
speed**

2-Stroboscope



Commercial stroboscope

1-Rotational speed measurements

Rotational speed

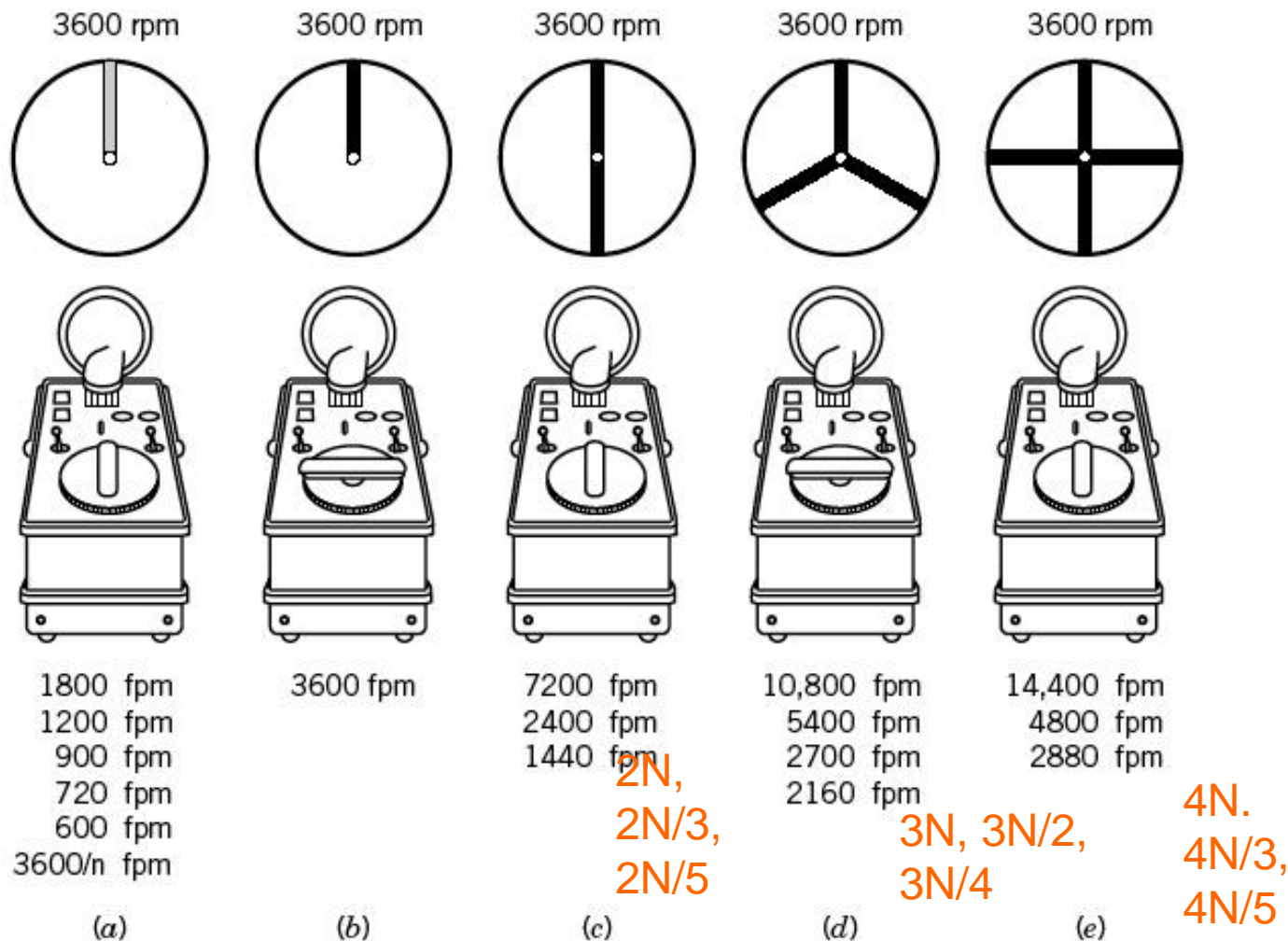


Figure 12.15 Images resulting from harmonic and subharmonic flashing rates (fpm) for stroboscopic angular speed measurement. (Courtesy of Mill Devices Co., a division of A. B. Carter Inc.)

1-Rotational speed measurements

Rotational
speed

2-Stroboscope

Stroboscope can be utilized for measuring speed higher than the maximum flashing rate

For synchronization N times

$$\omega = \frac{\omega_1 \omega_N (N - 1)}{\omega_1 - \omega_N}$$

where

ω_1 is the largest synchronous speed

ω_N is the lowest Nth synchronous speed

N is the number of synchronous speeds

1-Rotational speed measurements

Rotational speed

Example on calculating the rotation speed for speeds higher than the stroboscope limit

Find the rotation speed of a motor if it was observed using a stroboscope the synchronous speed is 30,000, 24000, and 20,000 RPM

$$\omega = \frac{\omega_1 \omega_N (N - 1)}{\omega_1 - \omega_N}$$

$\omega_1=30,000$ RPM the highest achieved by the stroboscope

$\omega_2=24,000$ RPM the net synchronous speed, then

$$\omega = \frac{30,000 * 24,000(2 - 1)}{30,000 - 24,000} = 120,000$$

or

$$\omega = \frac{30,000 * 20,000(3 - 1)}{30,000 - 20,000} = 120,000$$

or

$$\omega = \frac{24,000 * 20,000(1)}{24,000 - 20,000} = 120,000$$

1-Rotational speed measurements

3-Electromagnetic pickup

Rotational
speed

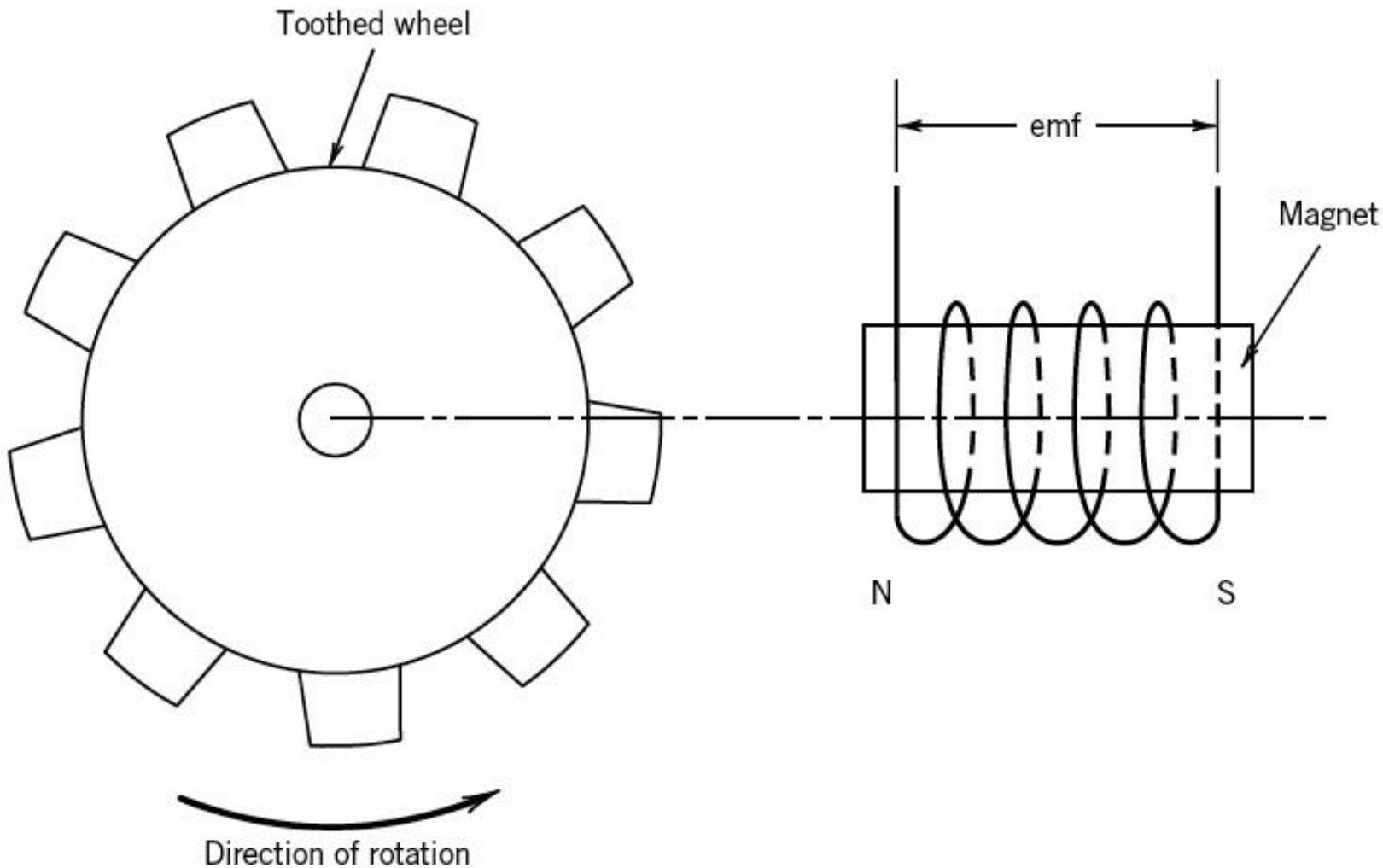


Figure 12.16 Angular velocity measurement employing a toothed wheel and magnetic pickup.

1-Rotational speed measurements

Rotational
speed

3-Electromagnetic pickup

As the toothed wheel rotates an emf is generated in the coil.

From either the amplitude or the frequency of the emf generated one can find the rotational speed

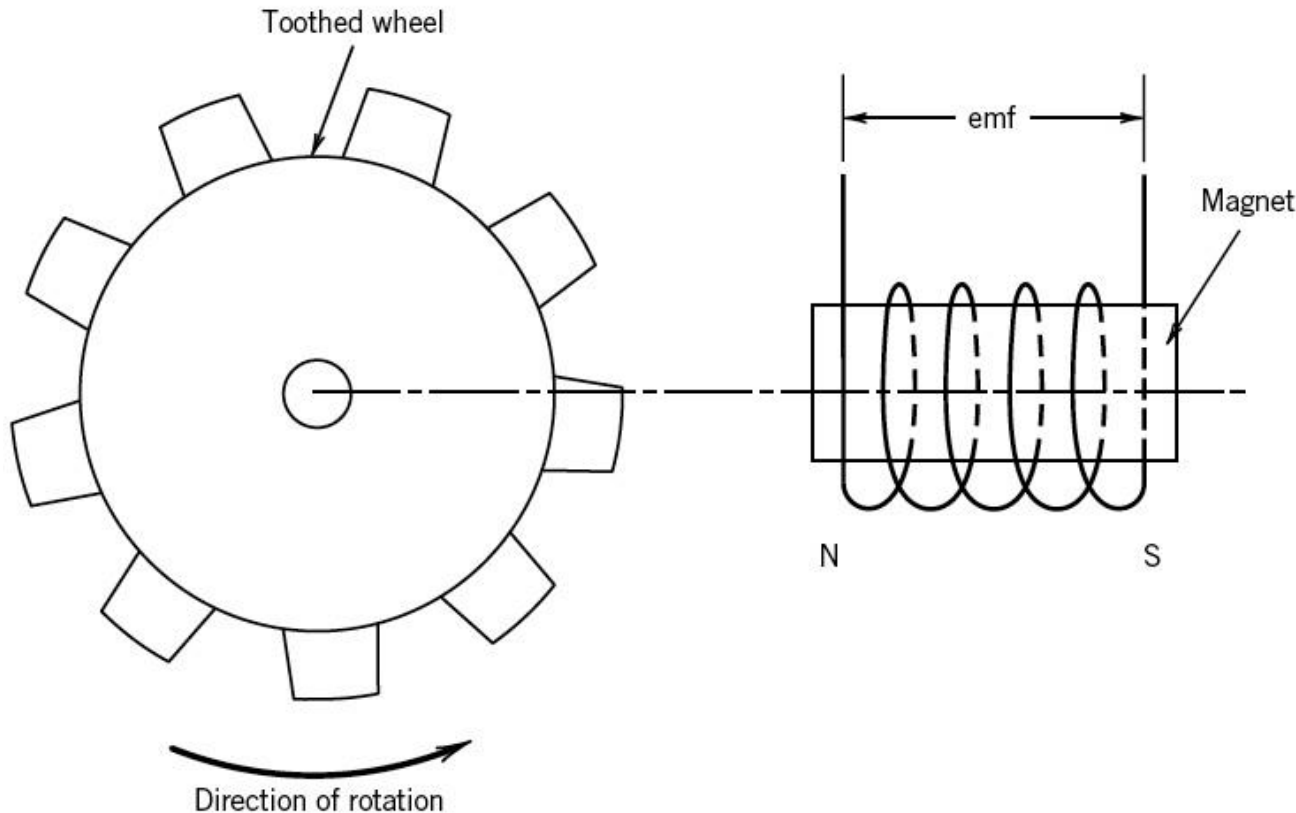


Figure 12.16 Angular velocity measurement employing a toothed wheel and magnetic pickup.

1-Rotational speed measurements

Rotational
speed

3-Electromagnetic pickup

$$E = C_B N_t \omega \sin(N_t \omega t)$$

E output voltage

N_t number of teeth

ω rotational speed

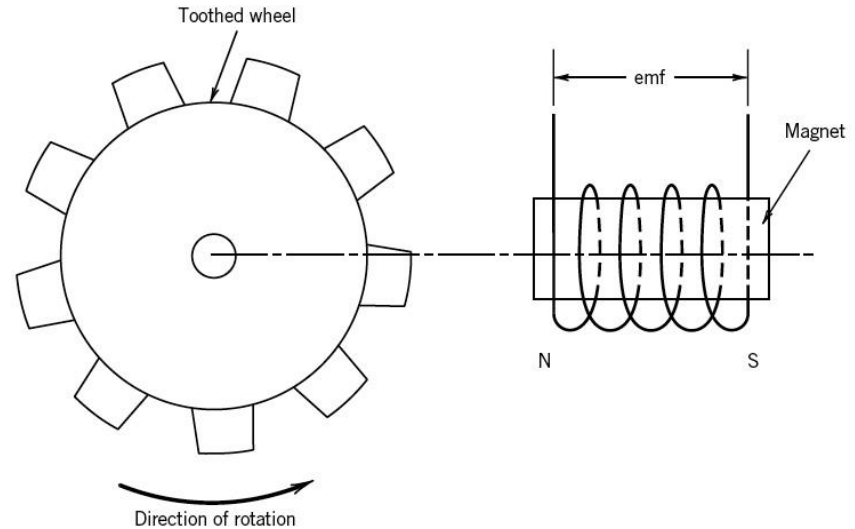


Figure 12.16 Angular velocity measurement employing a toothed wheel and magnetic pickup.

Rotational speed can be found from either the amplitude or the frequency measurements

1-Rotational speed measurements

Rotational
speed

4-Remote Optical sensing

Laser or light is emitted from a source, reflected on the rotating object and picked by a sensor. The frequency of the received reflected light is a measure of RPM



ACT-3 Engine RPM Detector
specify 115 or 230 Vac or 12 Vdc power



2-Measurement of force

Force

Weight is a force due to mass and gravitational acceleration

$$W = mg$$

Newton's 2nd law

$$\sum \vec{F} = m\vec{a}$$

Stresses pressure and strains are related to force

2-Measurement of force

Force

1-Using analytical balance

2-Using Stain gauges with Elastic Element

3-Load cell (Strain gage based)

4-Using Piezoelectric crystal elements

2-Measurement of force

Force

Analytical balance

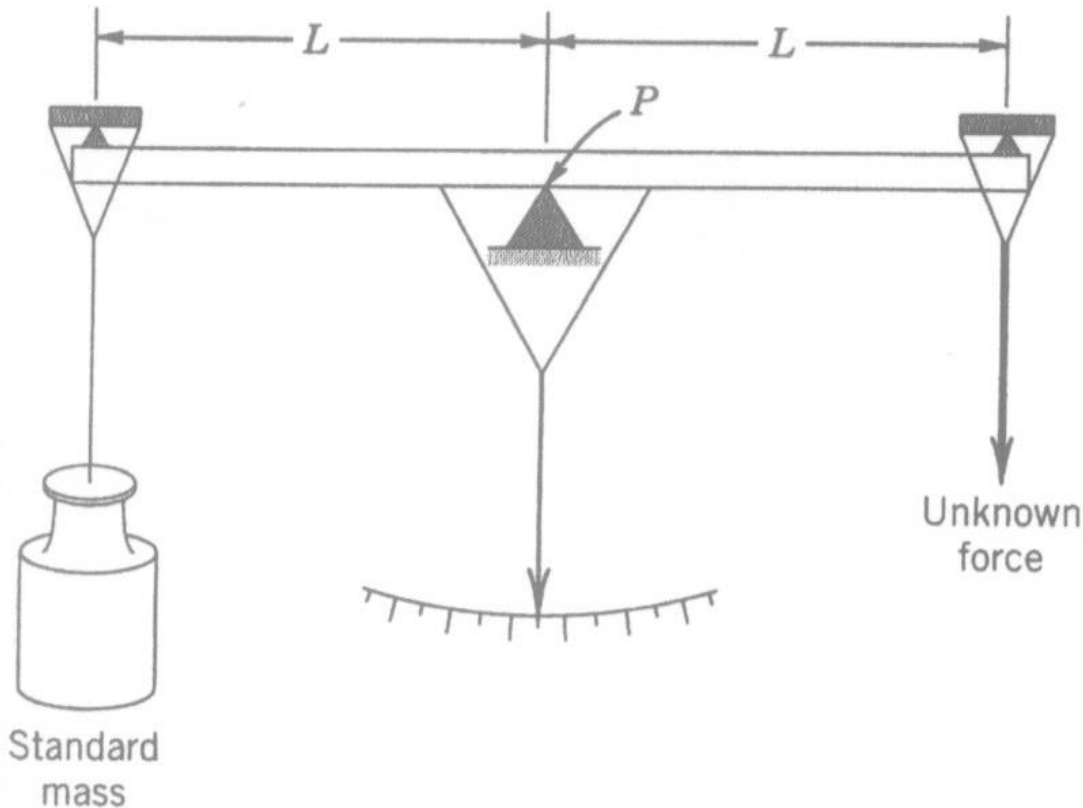


Figure 12.13 Construction of an analytical balance.

2-Measurement of force

Force

Analytical balance

Weight is a force

$$W = mg$$

Sensitivity of the balance depends on L , vertical distance between P and gravity center of the arm.

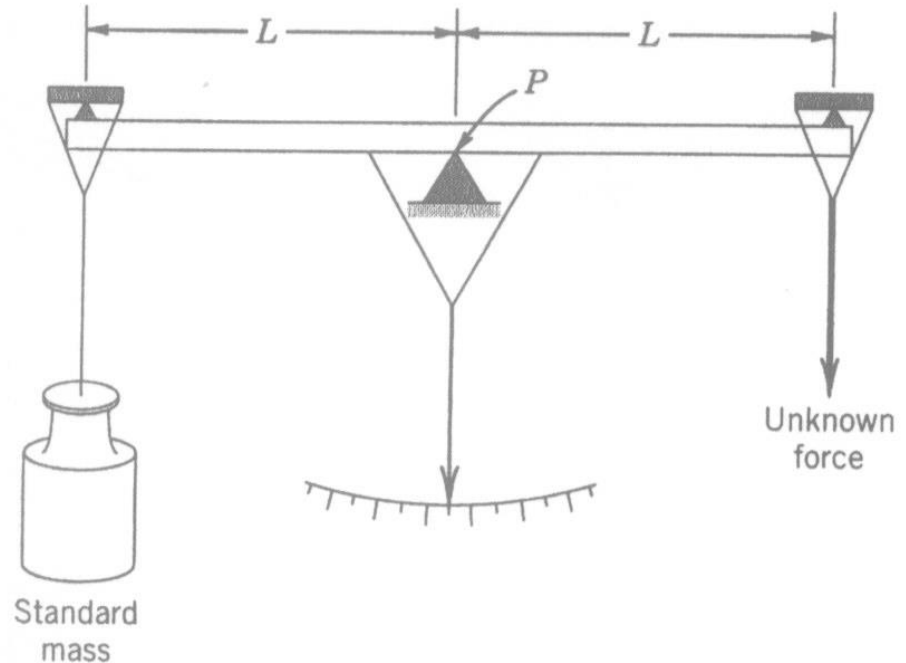


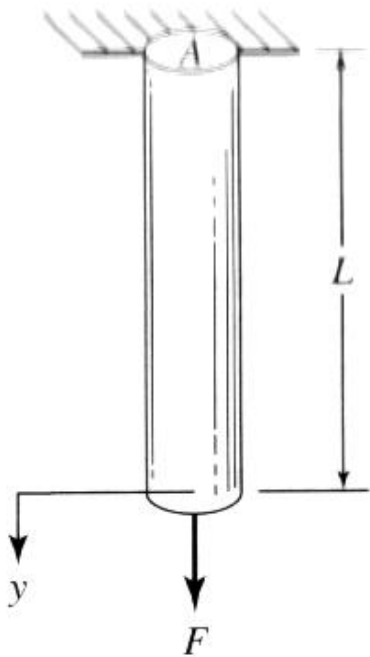
Figure 12.13 Construction of an analytical balance.

standard mass can be in kg, g or less

2-Measurement of force

Force

Elastic element for force measurement



$$F = ky$$

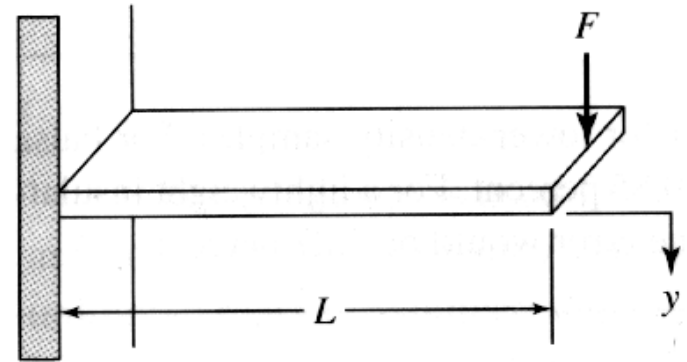
$$F = \frac{AE}{L} y$$

A =Cross sectional area

L =length

E = Young's Modulus

Simple elastic element.



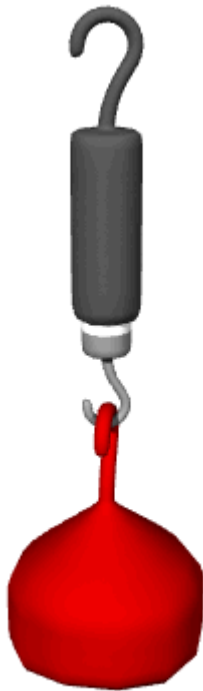
Cantilever elastic element.

$$F = \frac{3EL}{L^3} y$$

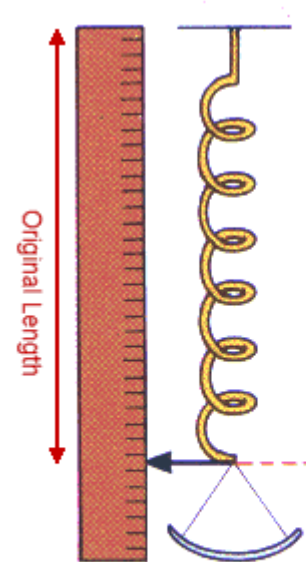
2-Measurement of force

Force

Elastic element for measuring the force



$$F = ky$$

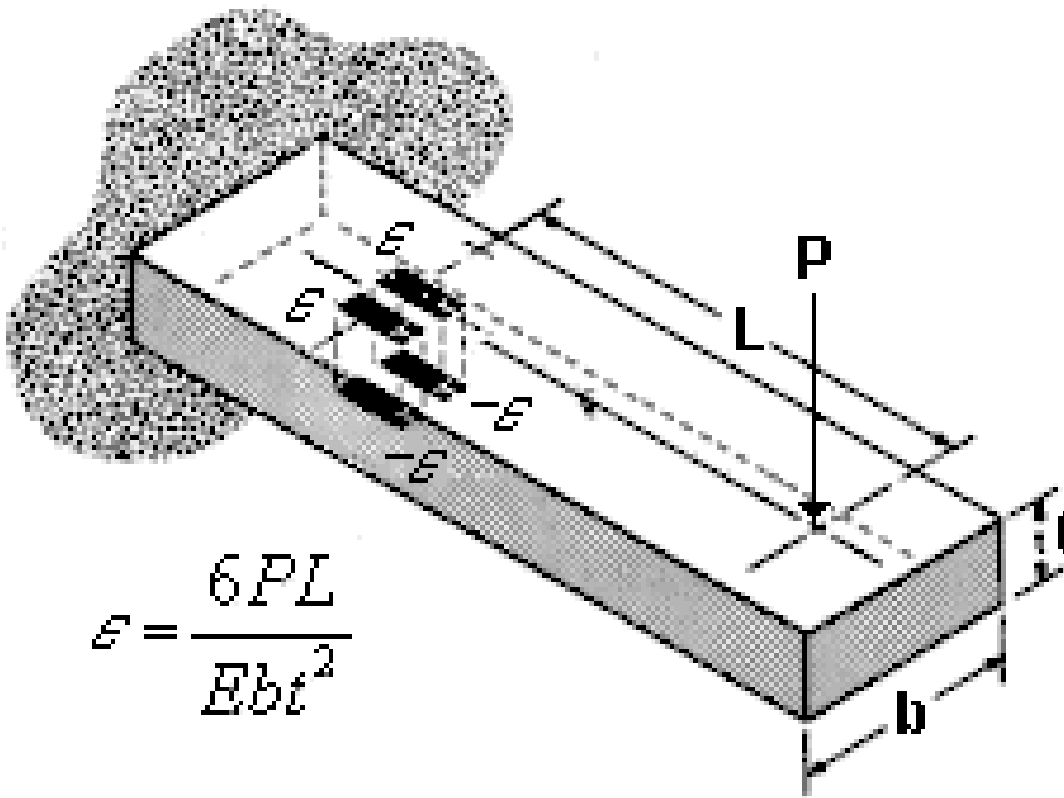


2-Measurement of force

Force

Elastic element for measuring the force

Bending of cantilever beam



$$\sigma = \frac{Mc}{I} \quad c = \frac{t}{2}$$

M=bending moment

$$I = \frac{bt^3}{12} \quad \text{Area moment of inertia}$$

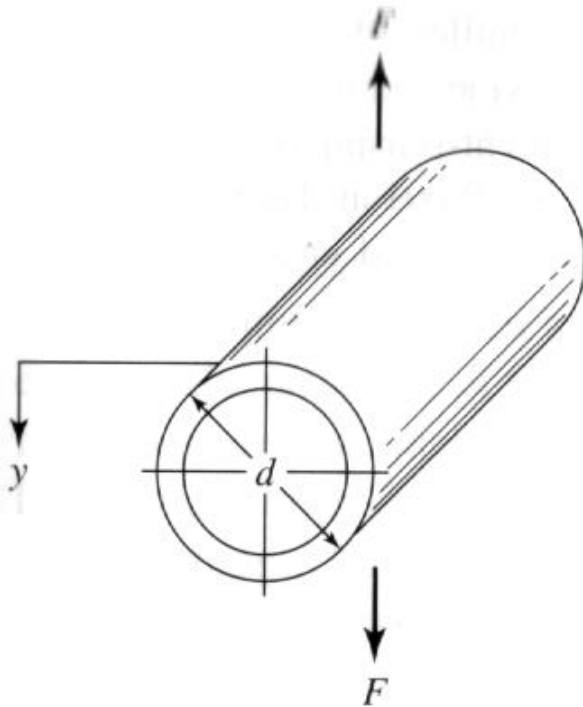
$$\sigma = \frac{PL \frac{t}{2}}{\frac{bt^3}{12}} = \frac{6PL}{bt^2} = \epsilon E$$

By measuring the strain one can find the force P

2-Measurement of force

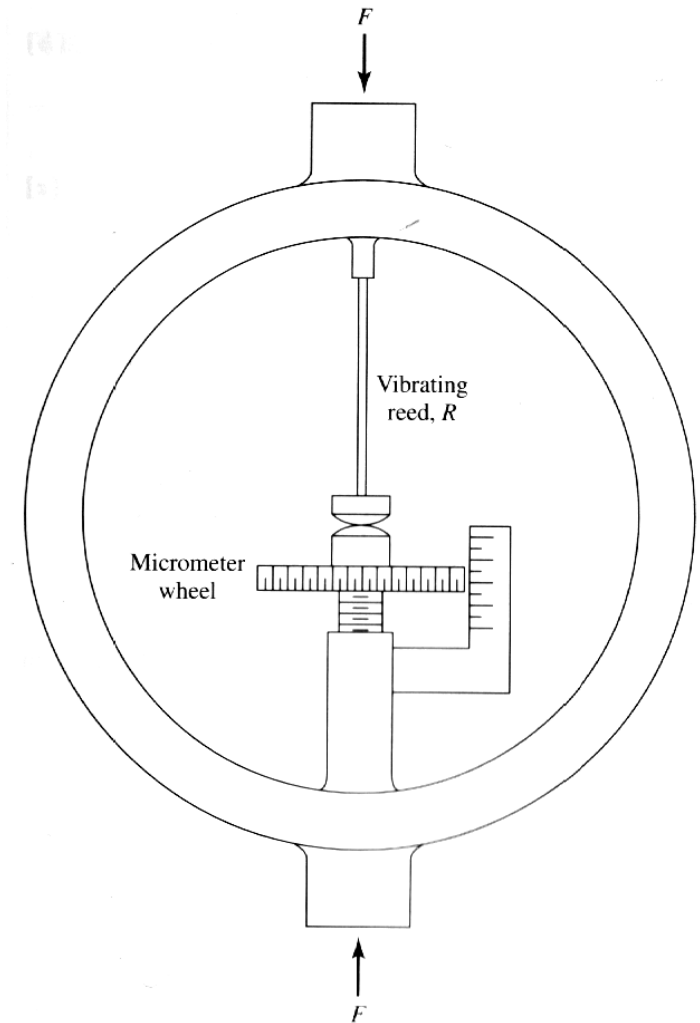
Force

Thin walled cylinder and proving ring



Thin-ring elastic element.

$$F = \frac{16}{\pi/2 - 4/\pi} \frac{EI}{d^3} y$$

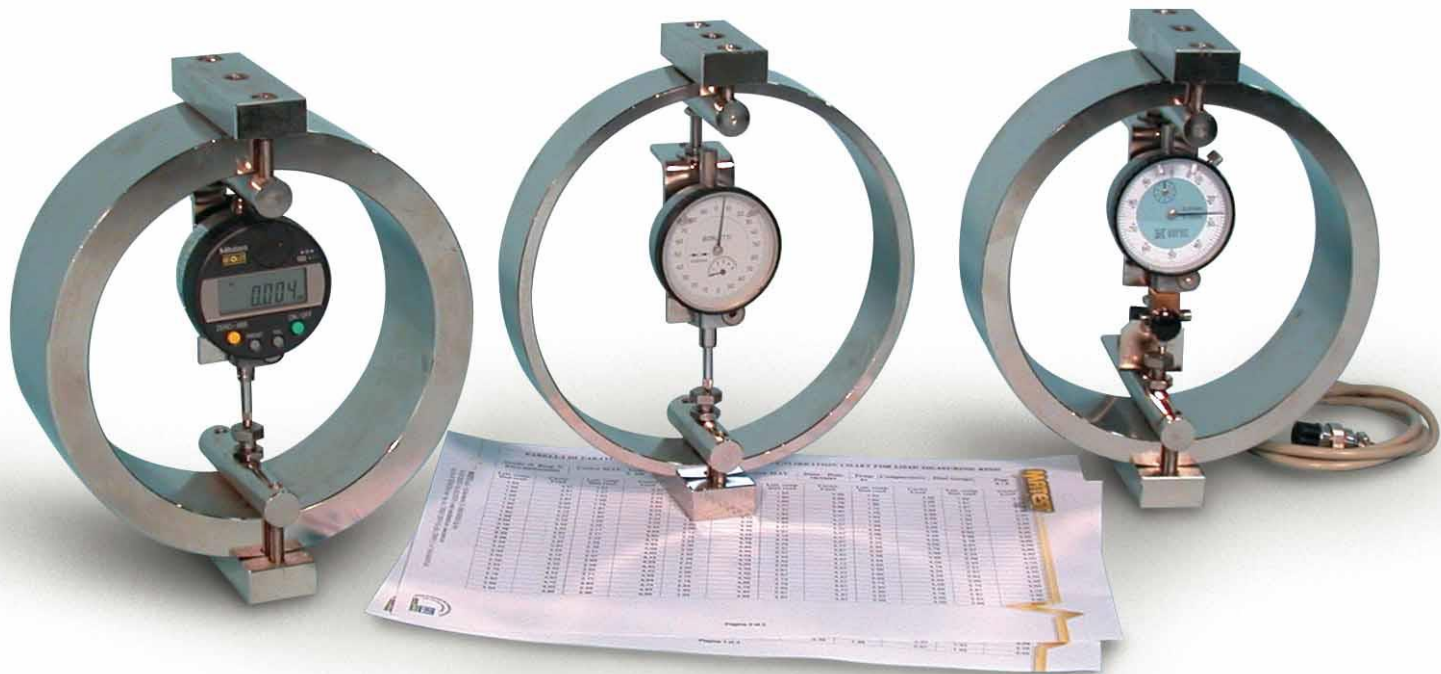


Proving ring.

2-Measurement of force

Force

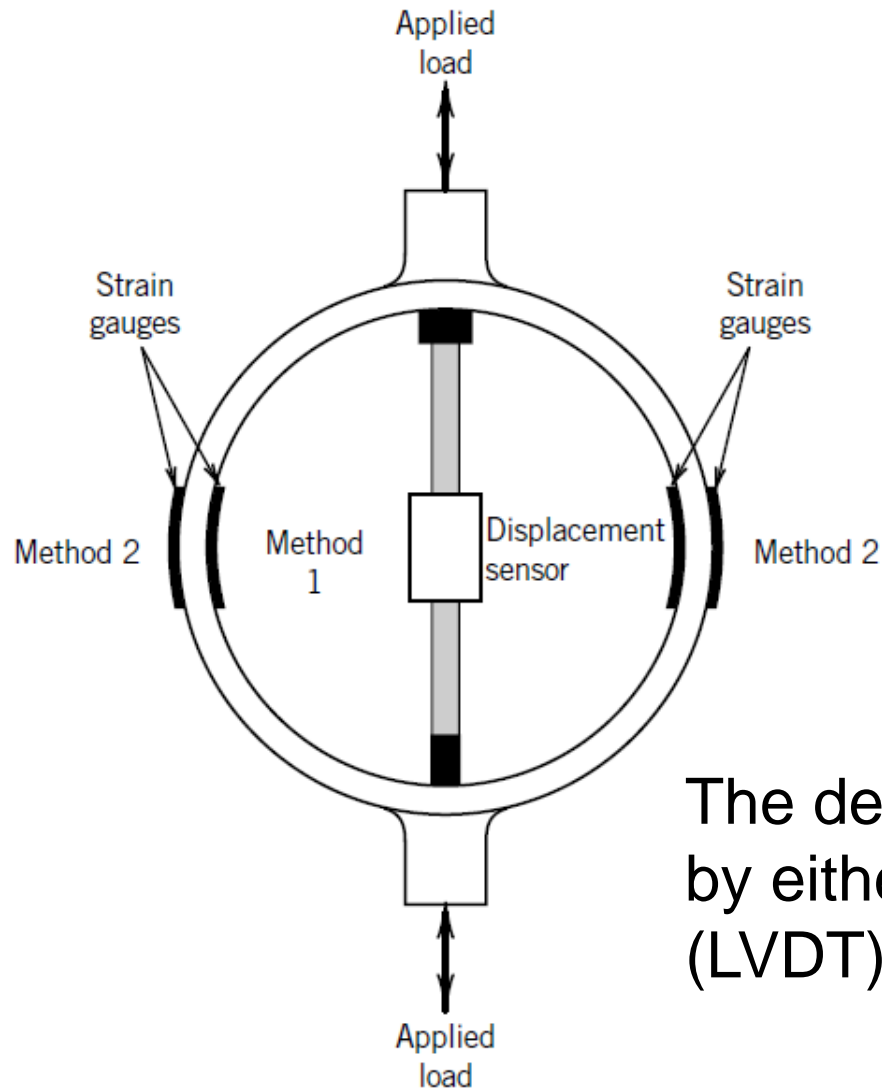
Force measurement using Proving ring



2-Measurement of force

Force

Proving ring



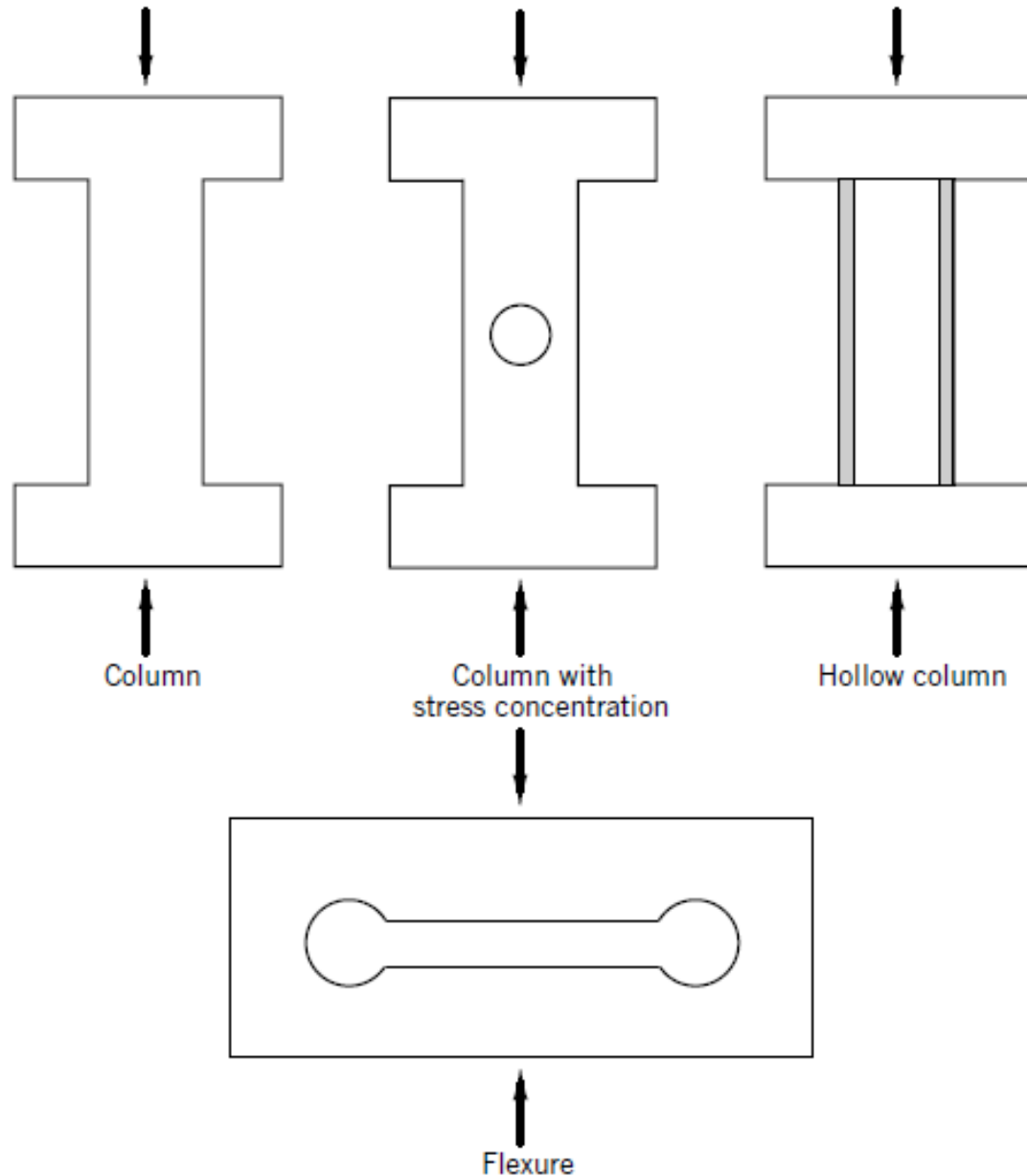
$$\delta y = \left(\frac{\pi}{2} - \frac{4}{\pi} \right) \frac{F_n D^3}{16EI}$$

The deflection can be measured by either a displacement sensor (LVDT) or by strain gauges

2-Measurement of force

Force

Load Cells



2-Measurement of force

Force

Load Cells

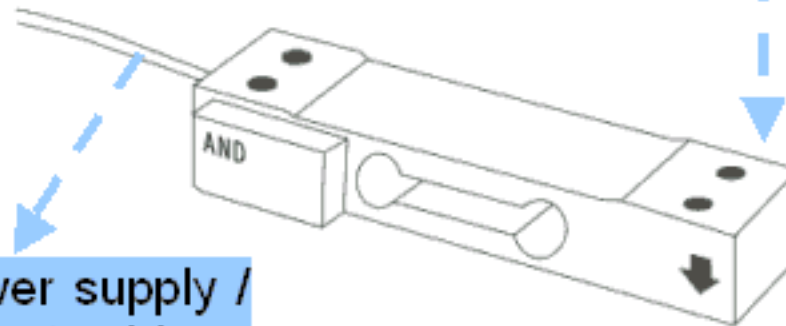
On detecting force, a load cell converts the force into electrical signals and then outputs the electrical signals.

Force is applied here



Power supply /
Output cable

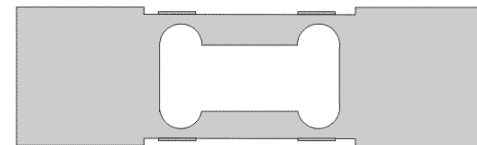
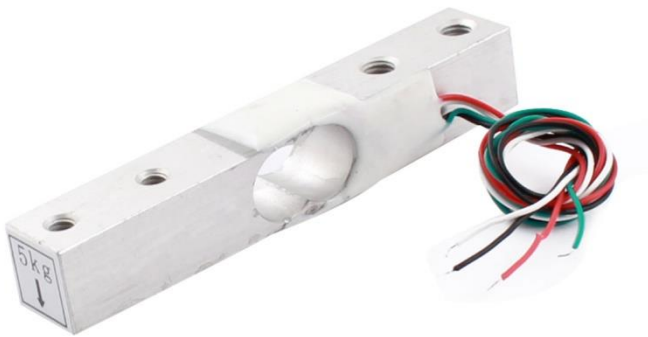
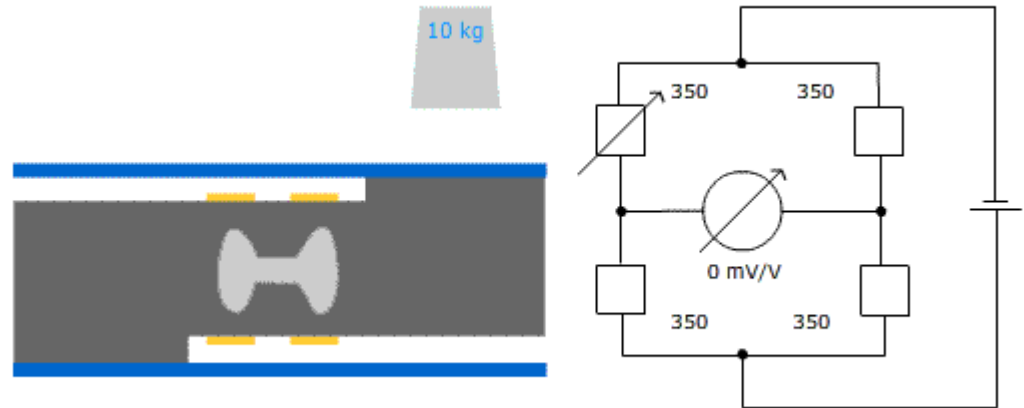
[A&D load cell LCB03]



2-Measurement of force

Force

Load Cells



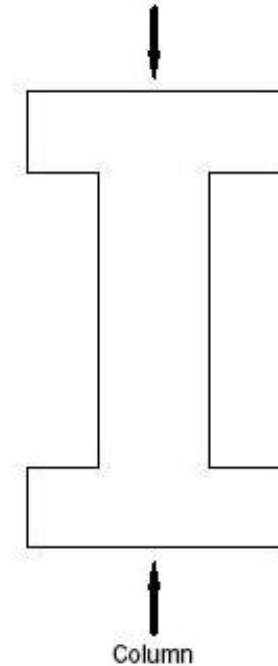
2-Measurement of force

Force

Load Cells

A load cell is a transducer that generates voltage as a result of an applied force.

Basically a strain gauge of defined shape and orientation to measure the force in a given direction



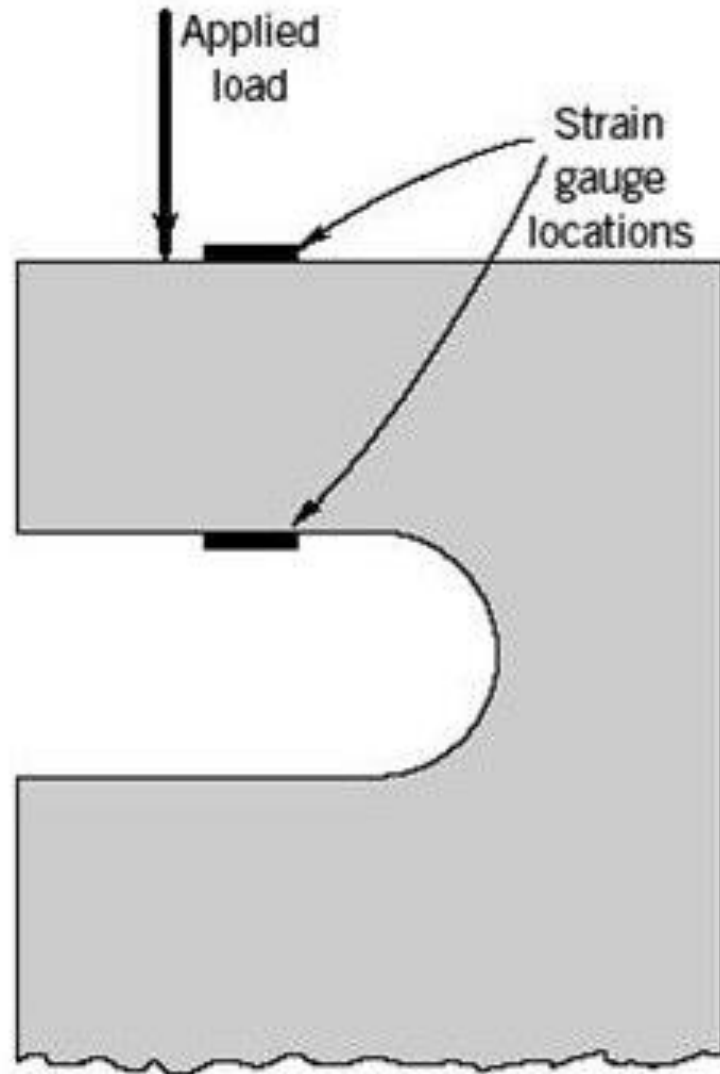
2-Measurement of force

Force

Load cell

Can be used for study of forces, moment on bodies

Sometimes installed permanently on structure to monitor forces and strain



Bending beam load cell

2-Measurement of force

Force

Load Cells



Figure 12.20 Typical load cells. (Courtesy of Transducer Techniques, Inc.)

2-Measurement of force

Force

Load Cells



2-Measurement of force

Force

Load Cells



2-Measurement of force

Force

Load Cells



Torque measurements

Torque

Very much needed in order to find the power, especially for internal combustion engines

Relation between power, torque and rotational speed

$$P = T\omega$$

One way to measure the torque on a shaft is through measuring the maximum shear τ_{\max}

$$\tau_{\max} = TR_o / J$$

where

T is torque

R_o radius of the shaft

J is polar moment of inertia $= \pi R_o^4 / 2$ (for cylinder)

Torque measurements

Torque

$$\tau_{\max} = TR_o / J$$

Measuring the maximum torsional shear on a rod using strain gauge

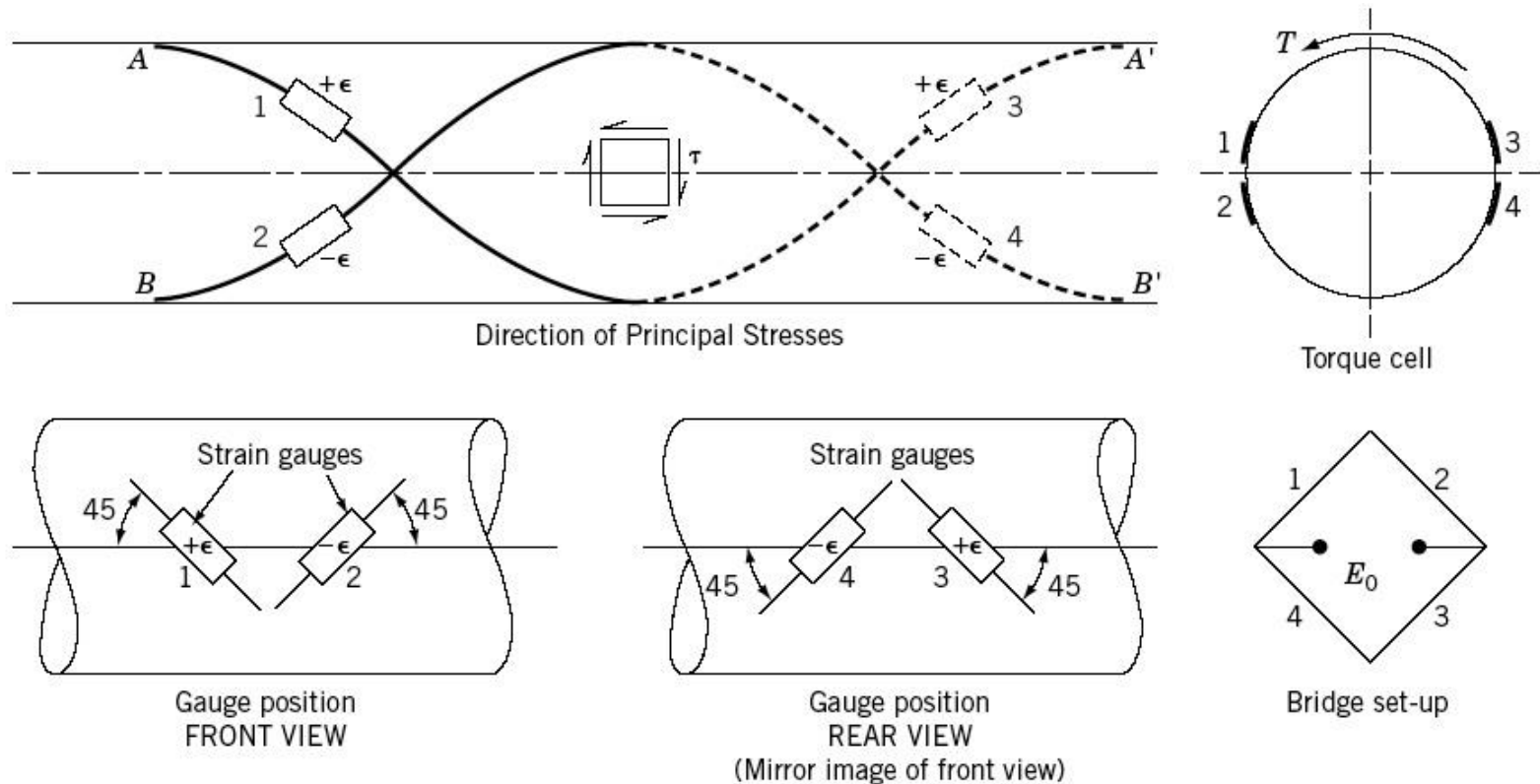


Figure 12.23 Direction of principal stresses for a shaft in pure torsion and corresponding shaft instrumented for torque measurement.

Mechanical power measurements Power

Power measurement is required for internal combustion engines and steam turbine engines to calculate the engine efficiency

A dynamometer is a device that absorbs and measure power from a prime mover such as an engine

Types to be presented:

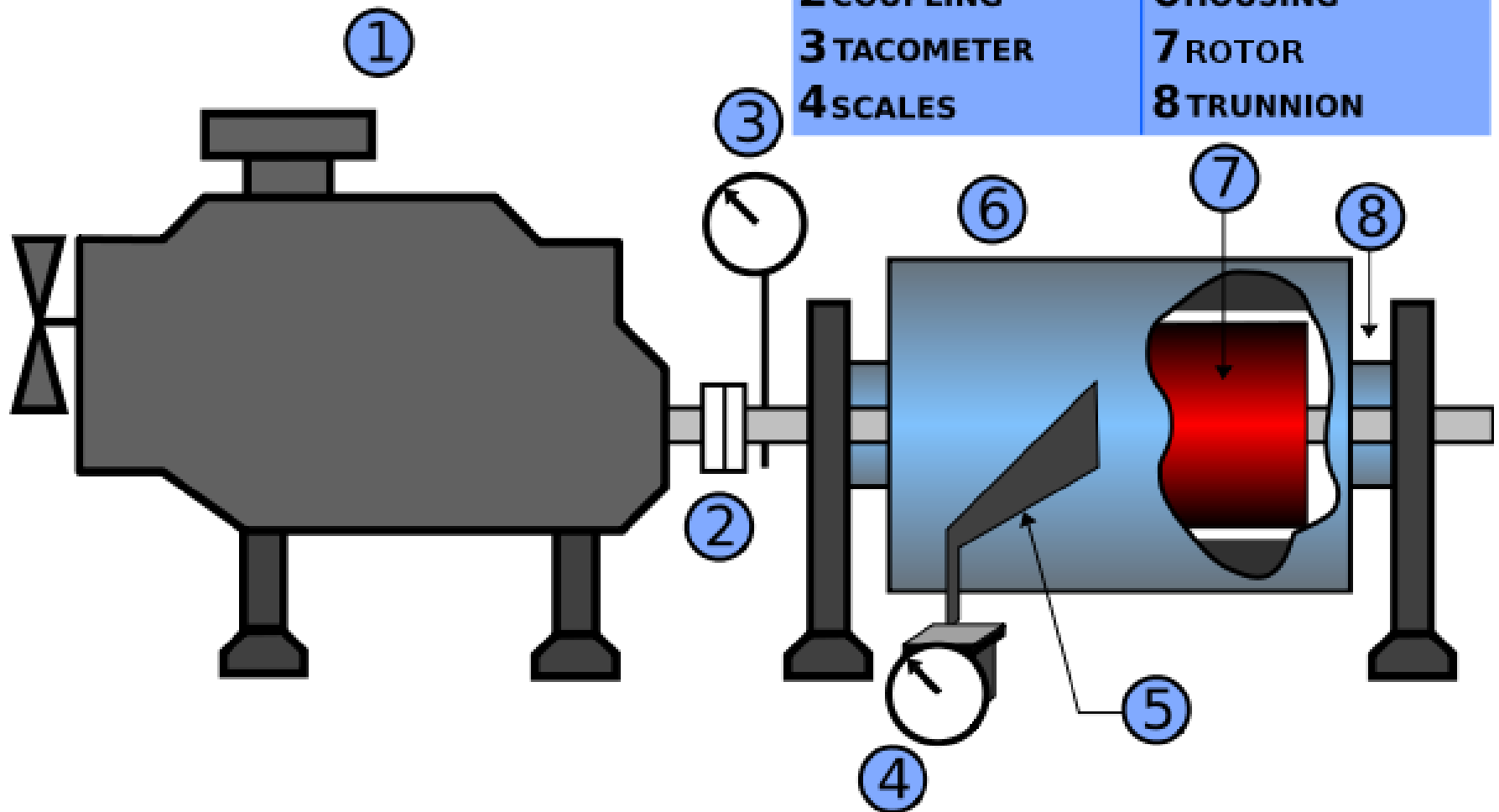
1-Prony brake dynamometer

2-Cradle dynamometer

3-Water break dynamometer

Mechanical power measurements Power

DYNAMOMETER



Mechanical power measurements Power

Prony Brake Dynamometer

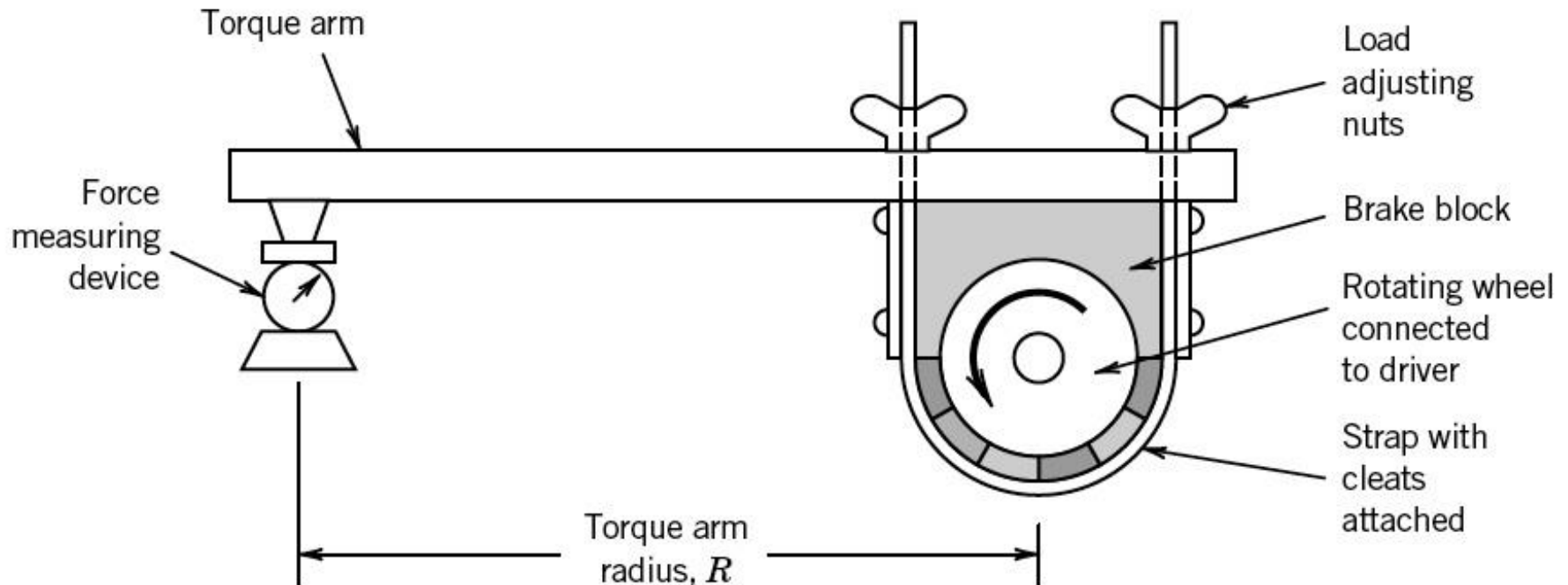
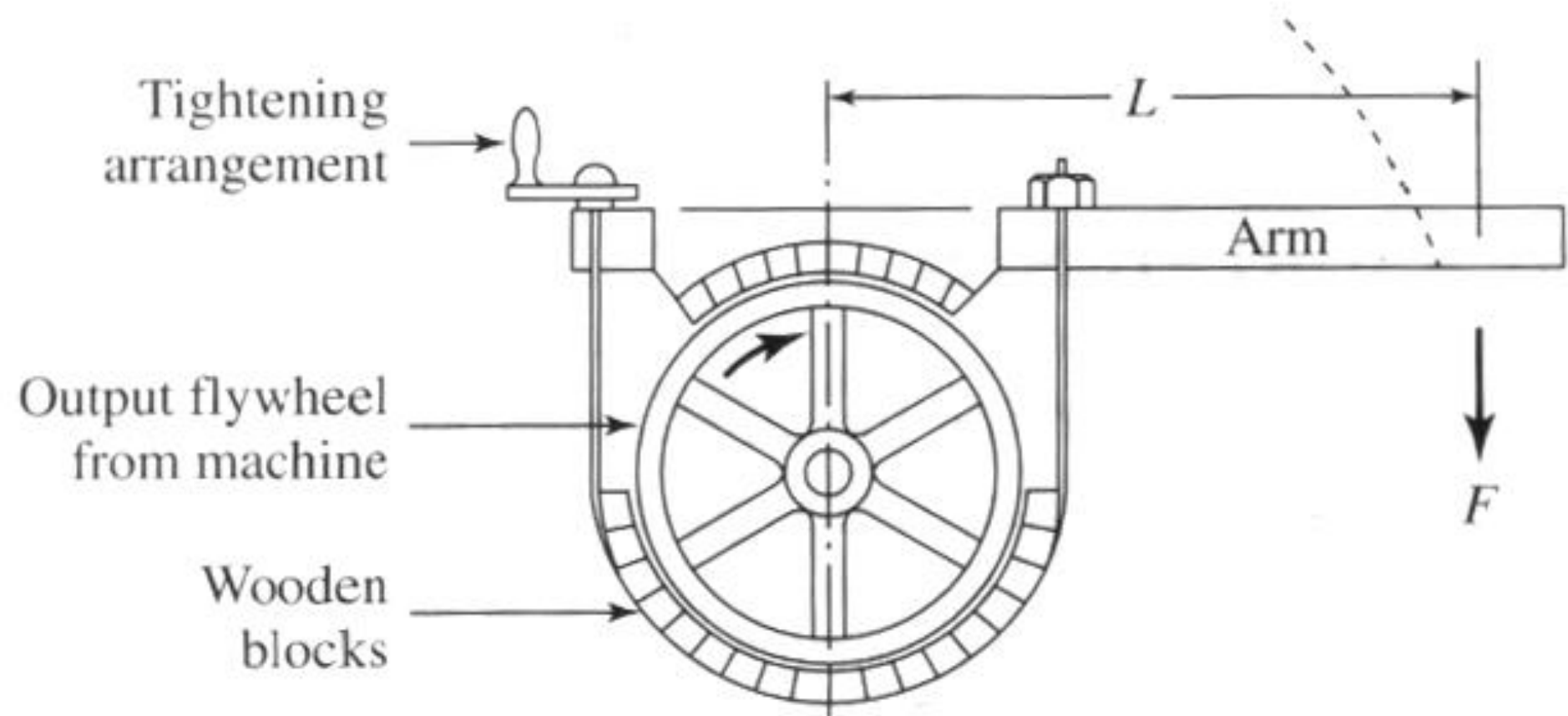


Figure 12.24 Prony brake. (Courtesy of the American Society of Mechanical Engineers, New York. Reprinted from PTC 19.7-1980 [10].)

Mechanical power measurements Power

Prony Brake Dynamometer



Schematic of a Prony brake.

Mechanical power measurements Power

Prony Brake Dynamometer



Mechanical power measurements

Power

Cradle Dynamometer

Measuring the reaction torque (T) and the rotational speed (ω)

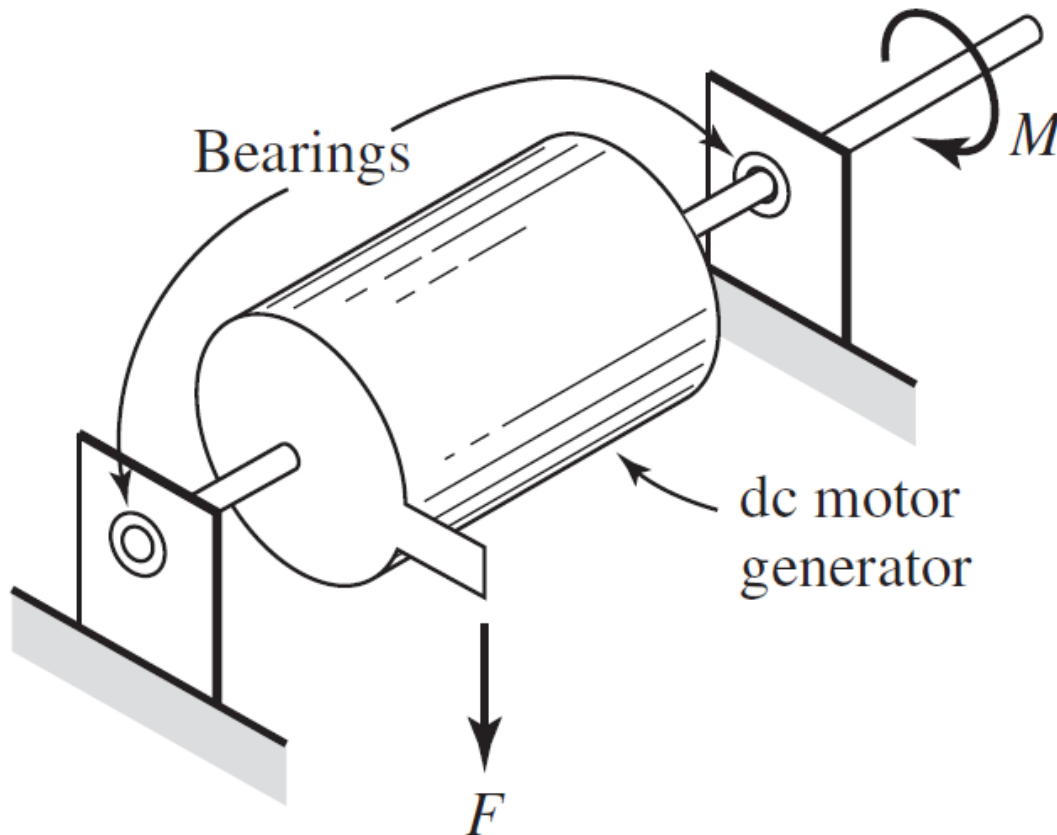
The shaft power is then

$$P = T\omega$$

T is the torque [N.m]

ω is the rotational speed in [rev/s]

Cradle Dynamometer



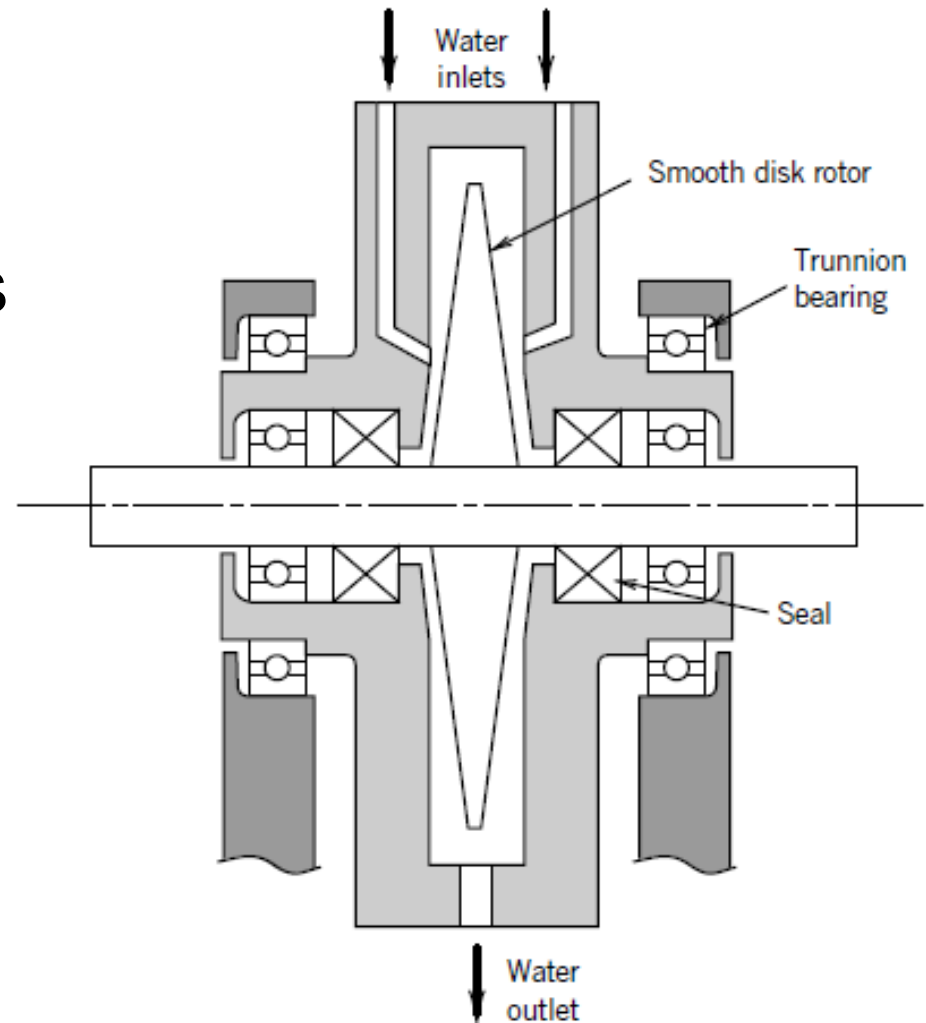
The dc motor and generator can act like a generator. The output of the generator is measured and can represent the power of the engine

Mechanical power measurements

Power

Water break dynamometer

The power of the engine is dissipated in water due to friction. The energy transferred to water is measured

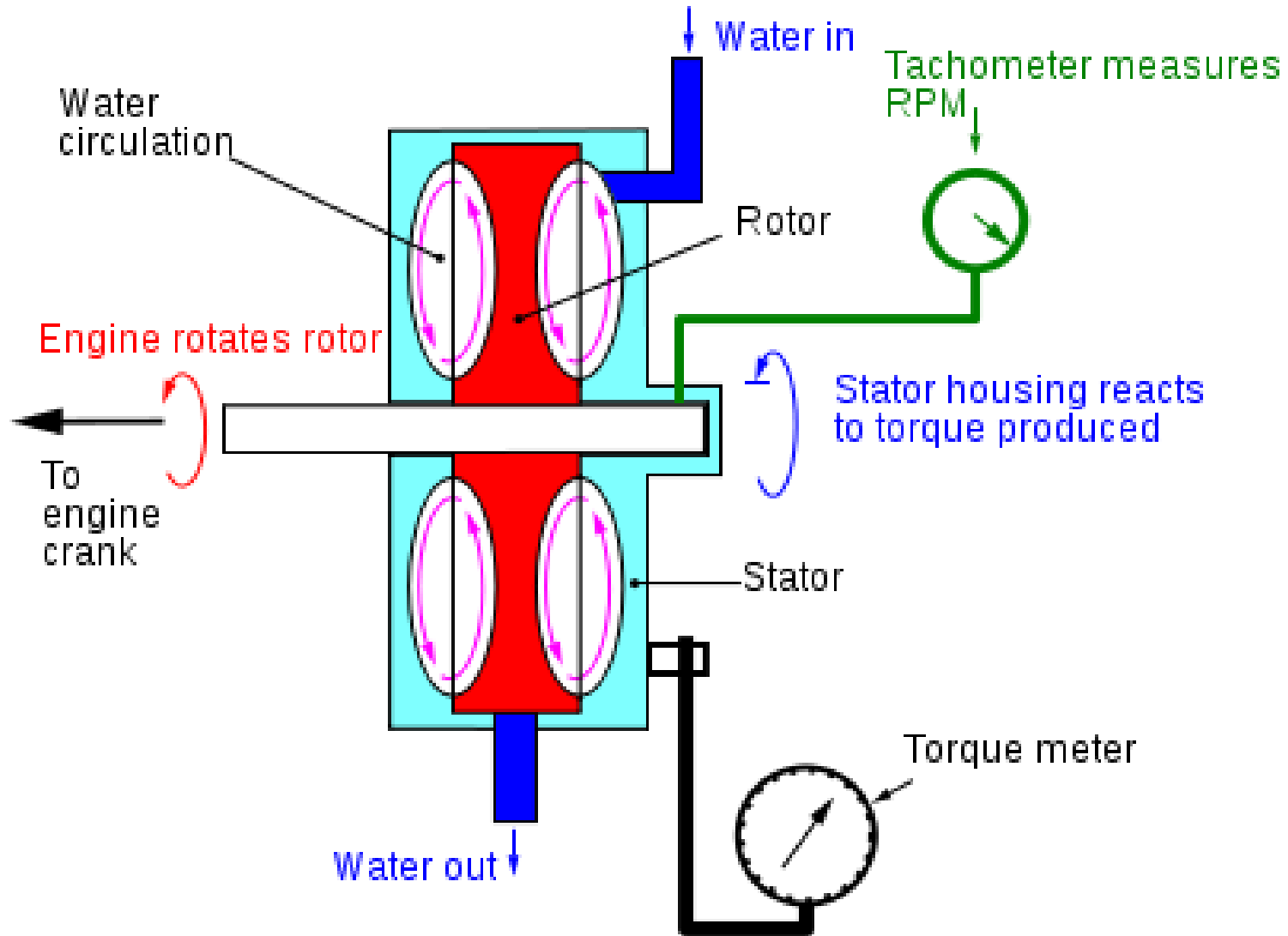


(a) Viscous shear type

Mechanical power measurements

Power

Water break dynamometer



الحمد لله