Internal Combustion Engine Testing

Why an engine needs a test?

To find out performance before mass production and fitting it into a vehicle.

To improve the design and configuration, to integrate new materials and technology

Historically, the test basically was to find out the power and fuel consumption, also to test effectiveness of cooling, vibration and noise, lubrication, controllability, etc.

Modern regulations force engines to reduce harmful emission and comply stringent regulations, therefore, test is getting more and more sophisticated.

Testing of I.C.Engines

1.2. Important Performance Parameters of I.C.Engines:- The important performance parameters of I.C. engines are as follows:

(i) Friction Power,

(ii) Indicated Power,

(iii) Brake Power,

(iv) Specific Fuel Consumption,

(v) Air – Fuel ratio

(vi) Thermal Efficiency

(vii) Mechanical Efficiency,

(viii) Volumetric Efficiency,

(ix) Exhaust gas emissions,

(x) Noise

Basic Instrumentation for Engine Test

- Power/torque measurement - dynamometers
- Engine speed measurement
- Air flow rate measurement
- Fuel flow rate measurement

Types of dynamometers:

1)Absorption dynamometer:

- Prony brake dynamometer
- Rope brake dynamometer
- Hydraulic dynamometer

2) Transmission dynamometer:

- Belt transmission dynamometer
- Epicyclic dynamometer
- Torsion dynamometer

Dynamometers

Types

- Water dynamometer
- DC dynamometer
- AC dynamometer
- Eddy current dynamometer

A dynamometer must be capable to allowing the engine to develop torque at different engine speeds

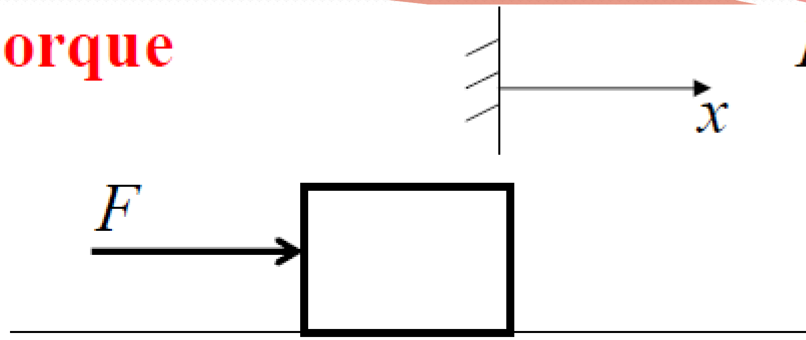
Functions

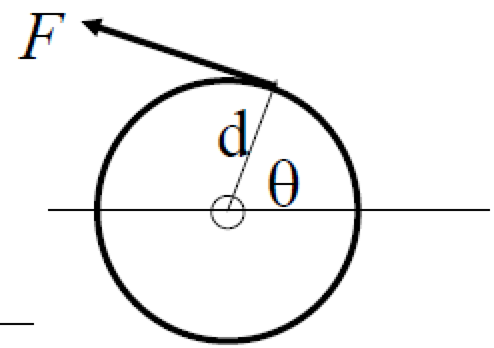
- Resist the rotation of the engine shaft - load control
- Control engine speed
- Load measurement, normally engine torque
- Start, motoring and stop engine

DYNAMOMETERS

- **Dynamometers** are used to **measure brake torque and power** over the engine operating ranges of speed and load.
- They do this by using various methods to absorb the energy output of the engine, all of which eventually **ends up as heat**.
- Some dynamometers absorb energy in a mechanical friction brake (prony brake).
- These are the simplest dynamometers but are not as flexible and accurate as others at higher energy levels.
- **Fluid or hydraulic dynamometers** absorb engine energy in water or oil **pumped through orifices** or dissipated with viscous losses in a rotor-stator combination.
- Large amounts of energy can be absorbed in this manner, making this an attractive type of dynamometer for the largest of engines.

Power and Torque

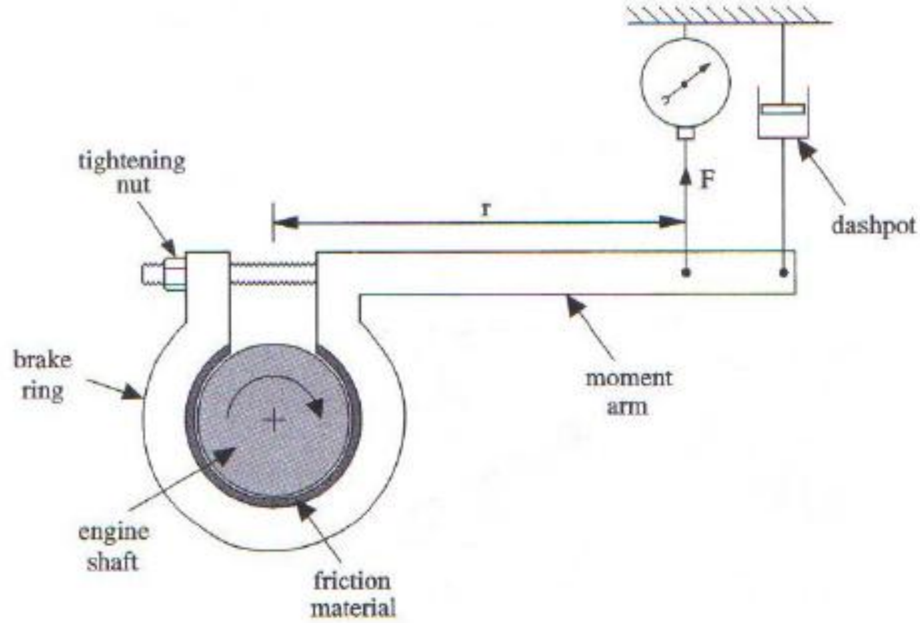




	Force (N)	Work (J)	Power (W)
Translational:	$F = m\dfrac{d^2x}{dt^2}$	$W = Fx$	$P = \dfrac{dW}{dt} = F\dfrac{dx}{dt}$
Rotational:	$T = J\dfrac{d^2\theta}{dt^2}$	$W = T\theta$	$P = \dfrac{dW}{dt} = T\dfrac{d\theta}{dt}$

- **Engine Torque**
  - The fundamental output of the engine
  - Usually expressed in Nm or BMEP
  - Torque is measured by a dynamometer or an ‘in-line’ device
  - BMEP is the accepted figure used to compare the performance of engines of differing capacities.

Torque measurement

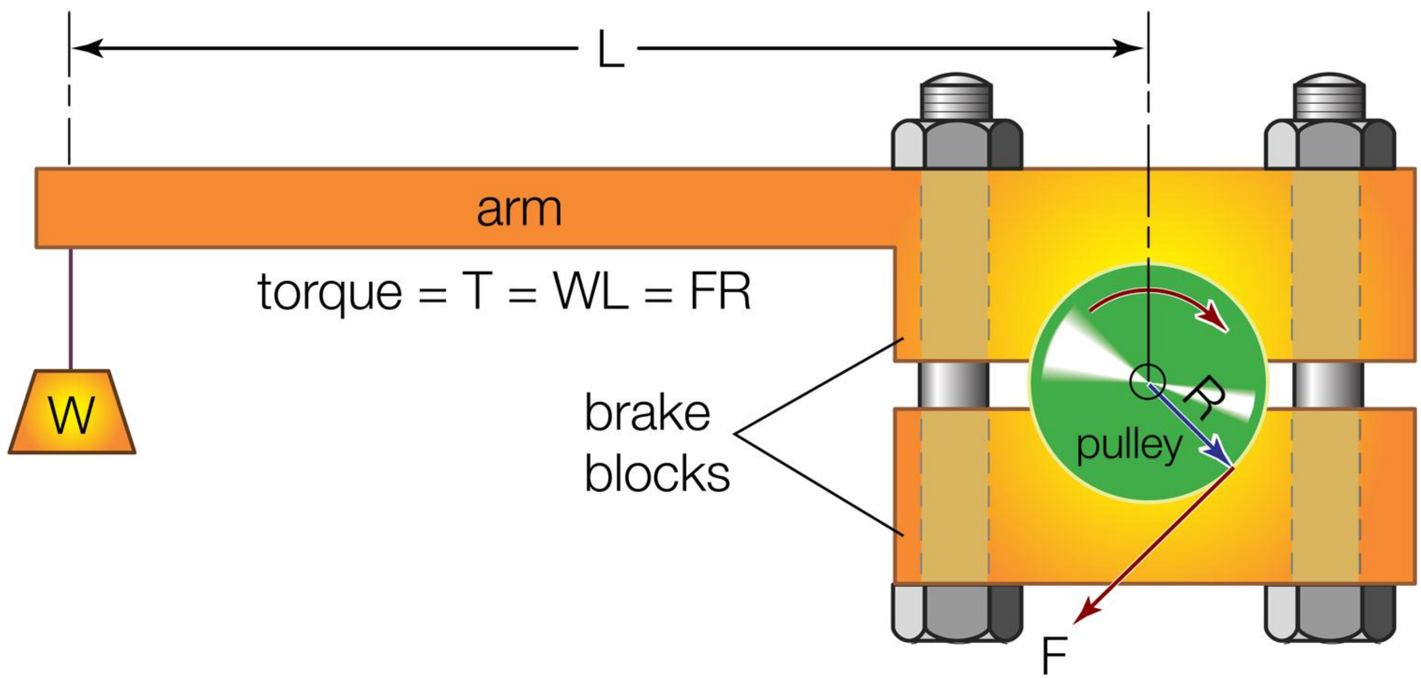


torque = restraining force × radius of moment arm
(T) (F) (r)

power = torque × angular speed
(P) (T) (ω)

angular speed = 2 π × engine speed
(ω) (N – rev/s)

Prony Brake Dynamometer



Prony Brake.

The BP of the engine is given by

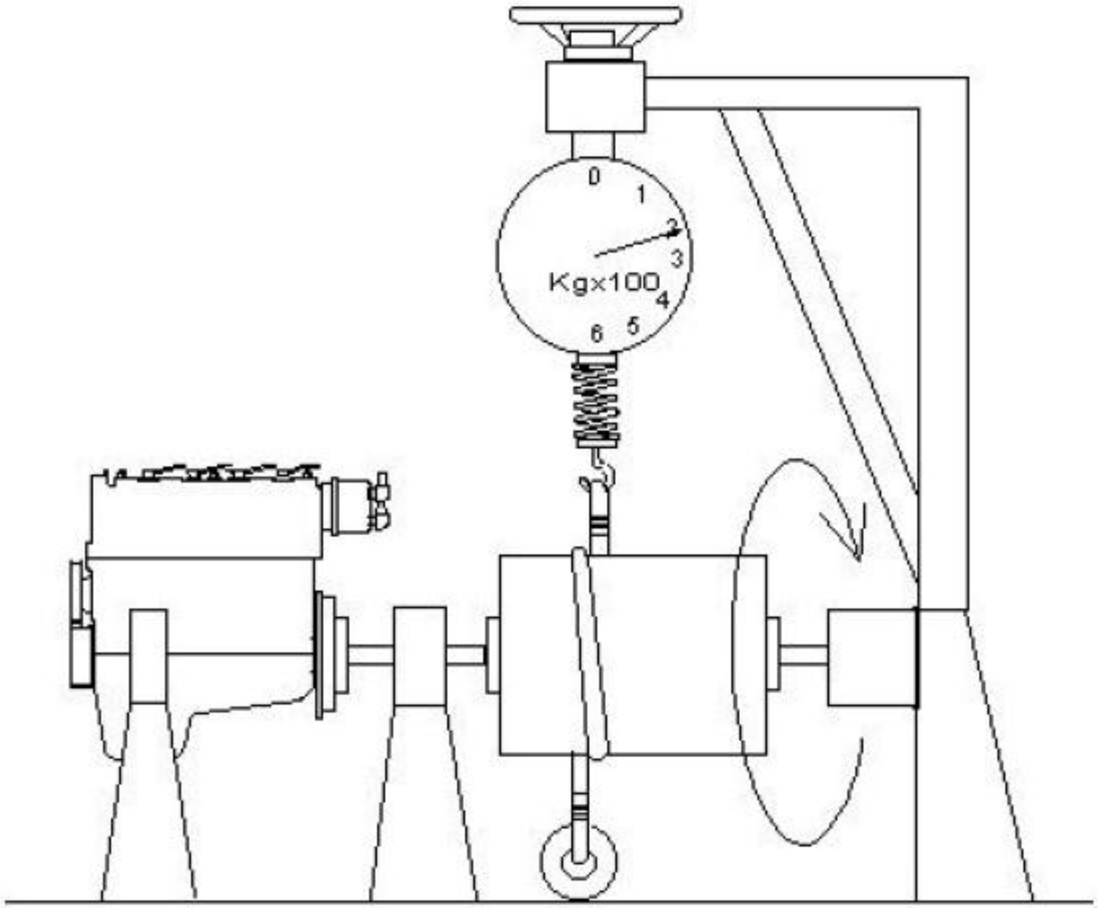
B.P (brake power) = $2*\pi*N*T/60$ watts $=2*\pi*N*T/60*1000$ Kw ….. (9)

Where T = $(W.L)$ (N-m)

Where W = Weight on load carrier, (N)

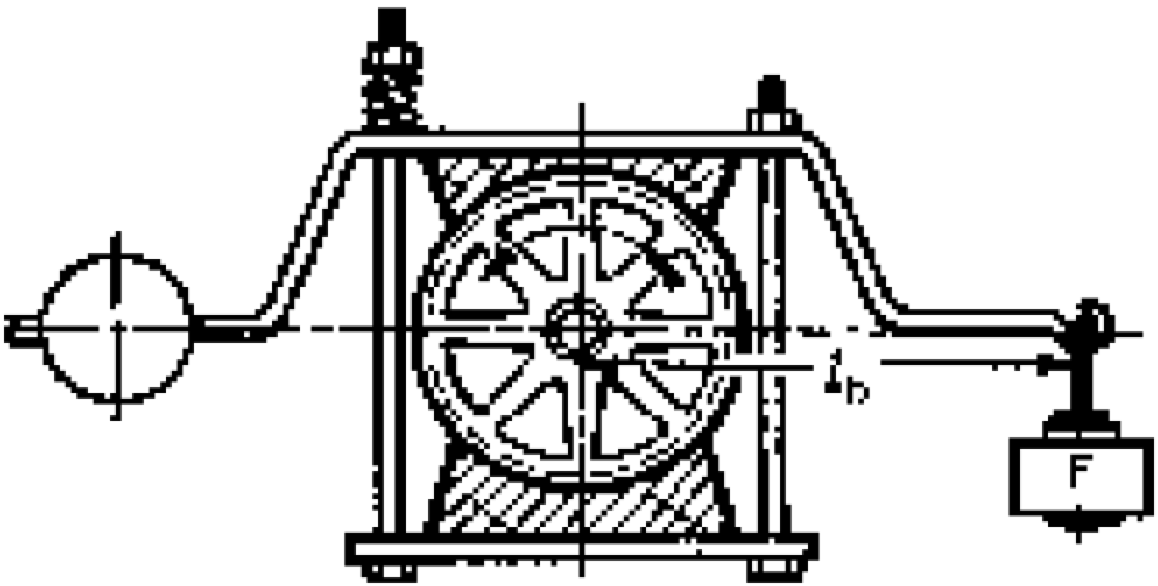
And L = Distance from the centre of shaft to the point of load-meter in meters.

Primitive: Rope break dynamometer

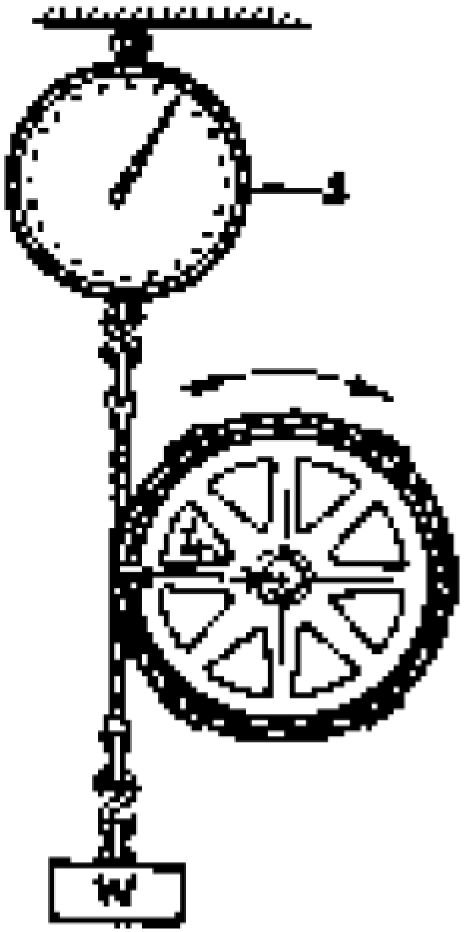


Friction Brake

Early systems were very primitive, a person was required to pour water on the blocks to prevent them from burning!

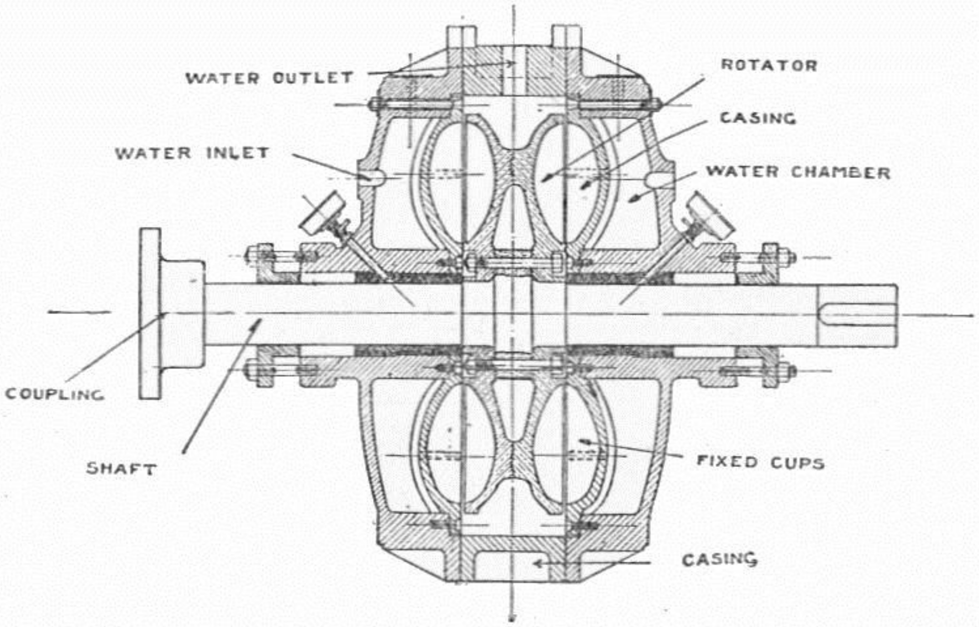


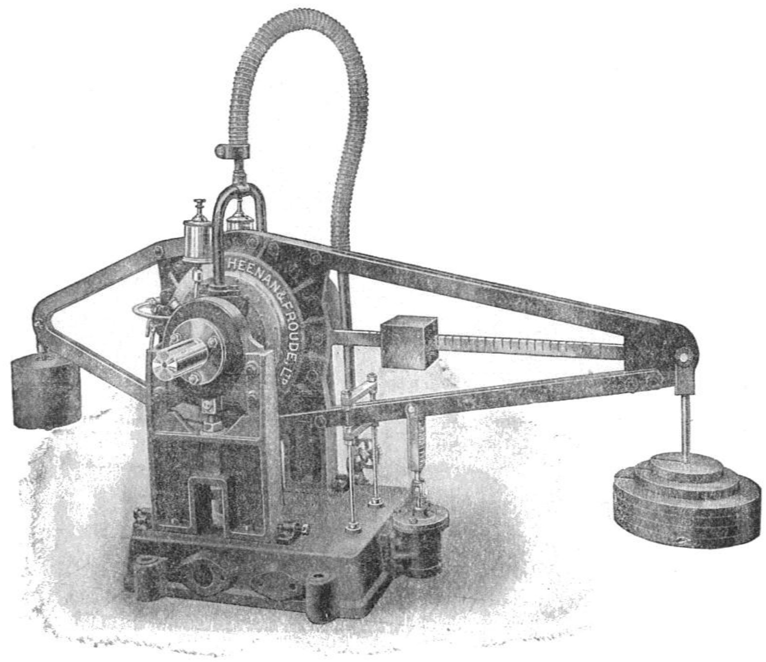
Friction Brake



The advent of accurate spring balances in the mid 1800's gave rise to a more universal and advanced dynamometer.

Hydraulic Dynamometer





Hydraulic Dynamometer.

The BP of an engine coupled to the dynamometer is given by

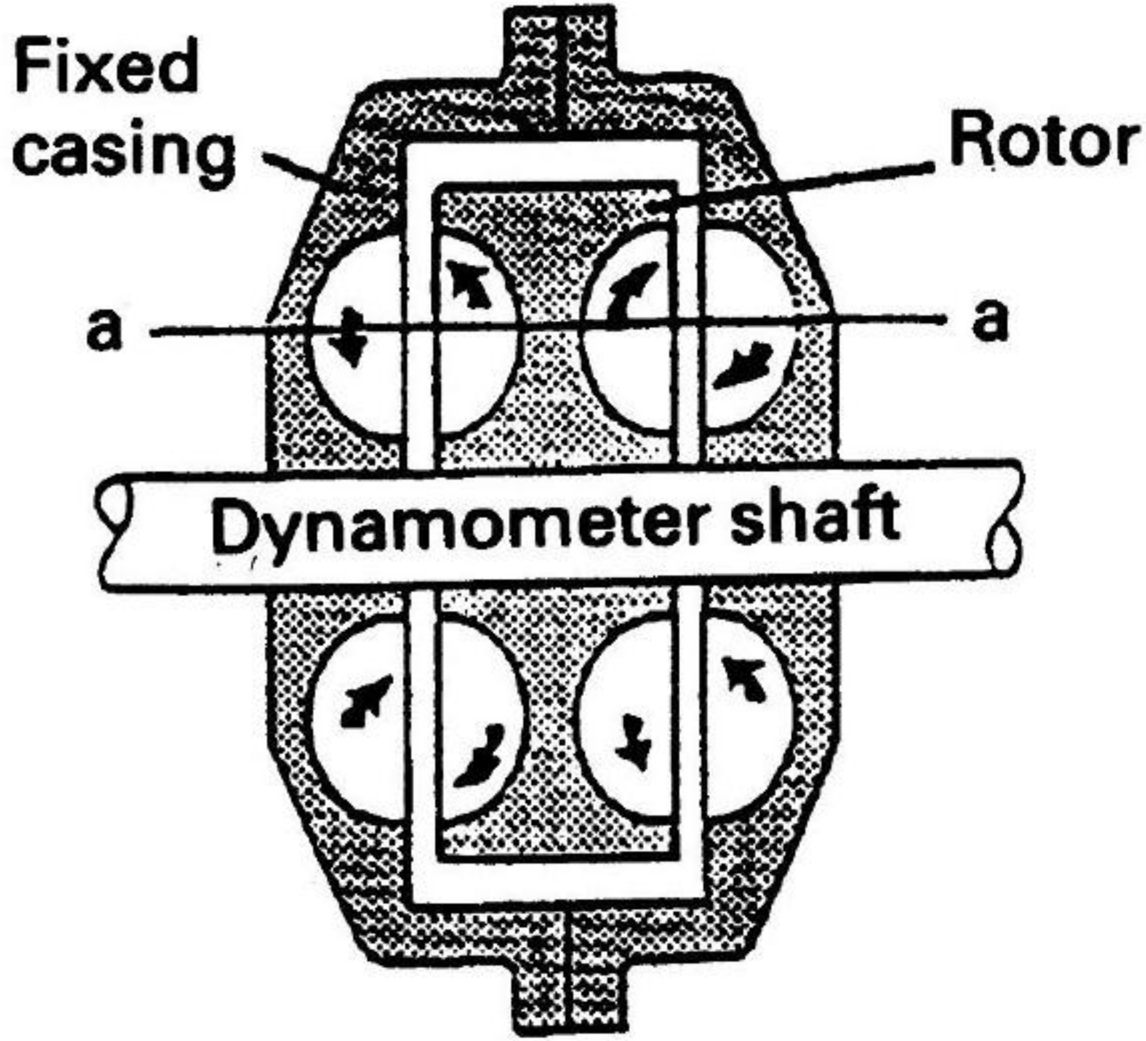
B.P (brake power) = $2*\pi*N*W*R/60*1000 = WN(2*\pi*R/60*1000)$ Kw

$$B.P = \frac{WN}{K} \quad \text{.....(10)}$$

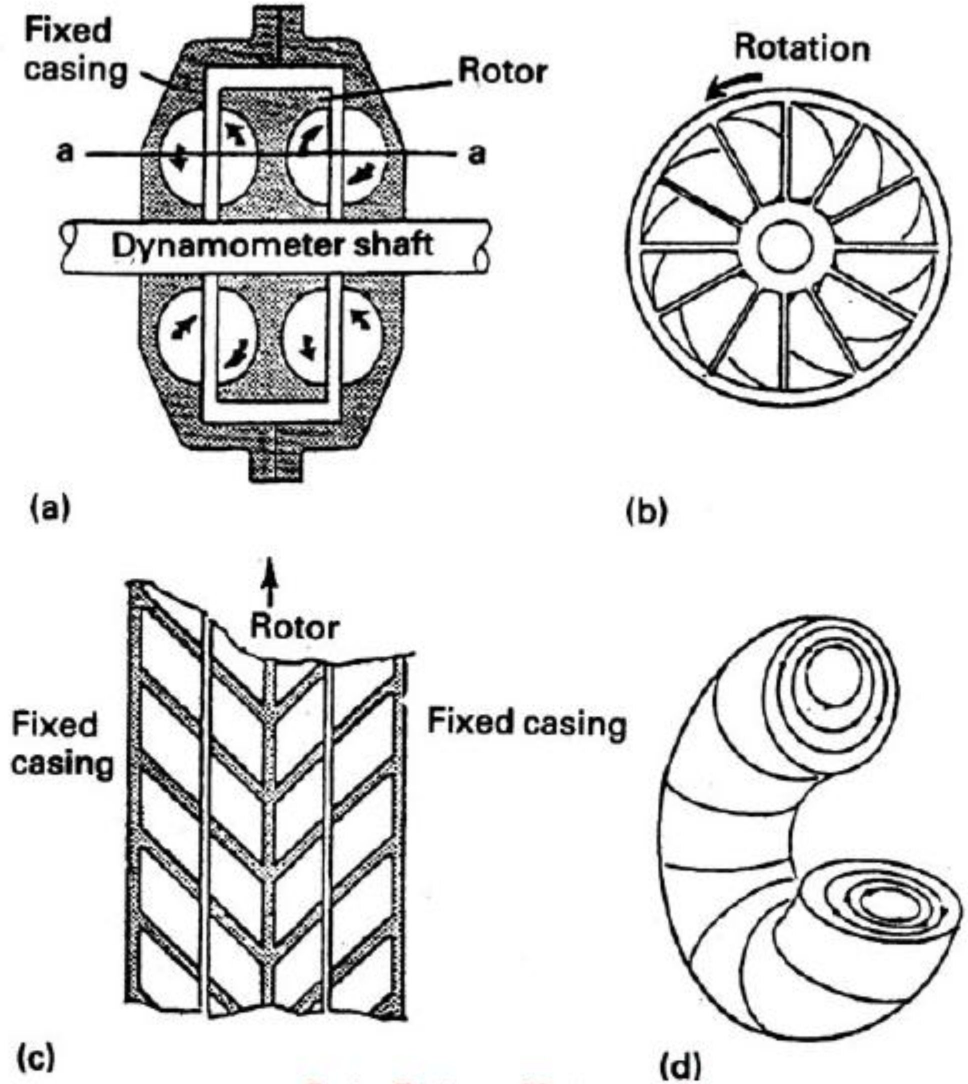
Where	W	=	Weight measured on the dynamometer, N
	K	=	Dynamometer constant (60*1000/2*pi*R)
and	N	=	RPM of the engine.

The arm length 'R' is selected in such a way that K is a whole number. These dynamometers are directly coupled with the engine shaft.

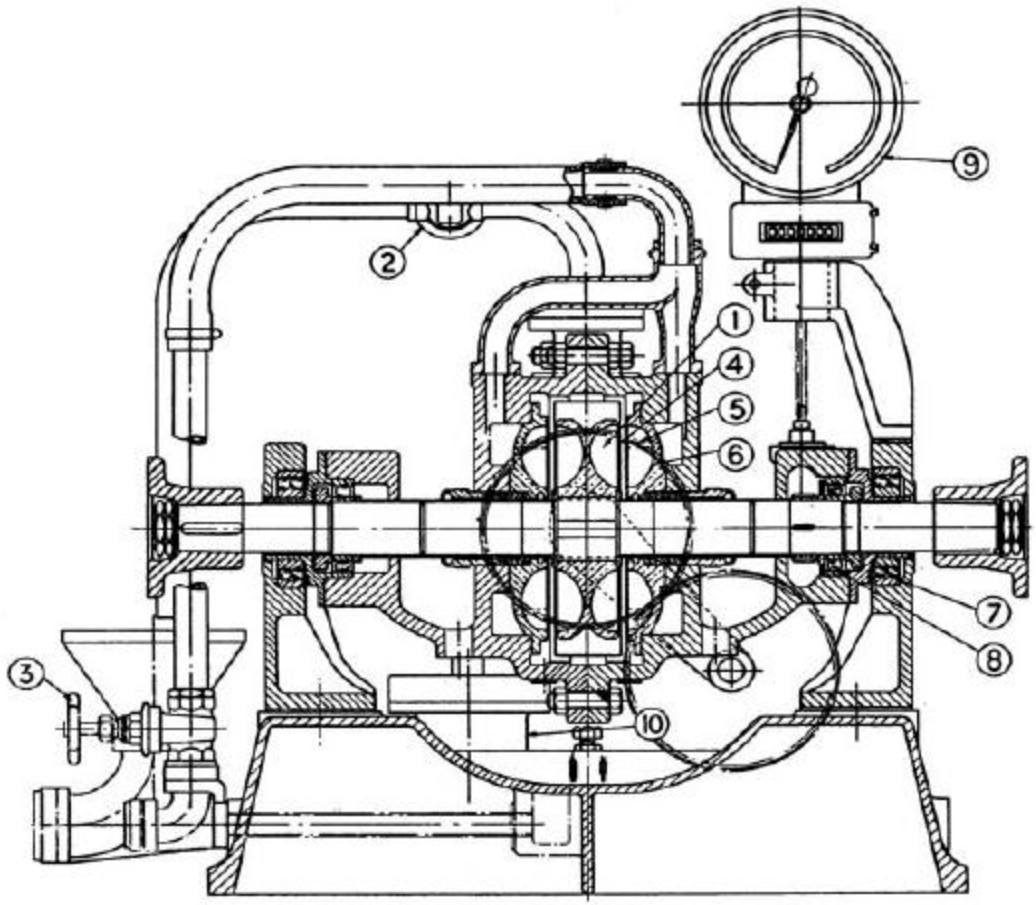
Parts of the basic hydraulic dynamometer



Parts of the basic hydraulic dynamometer



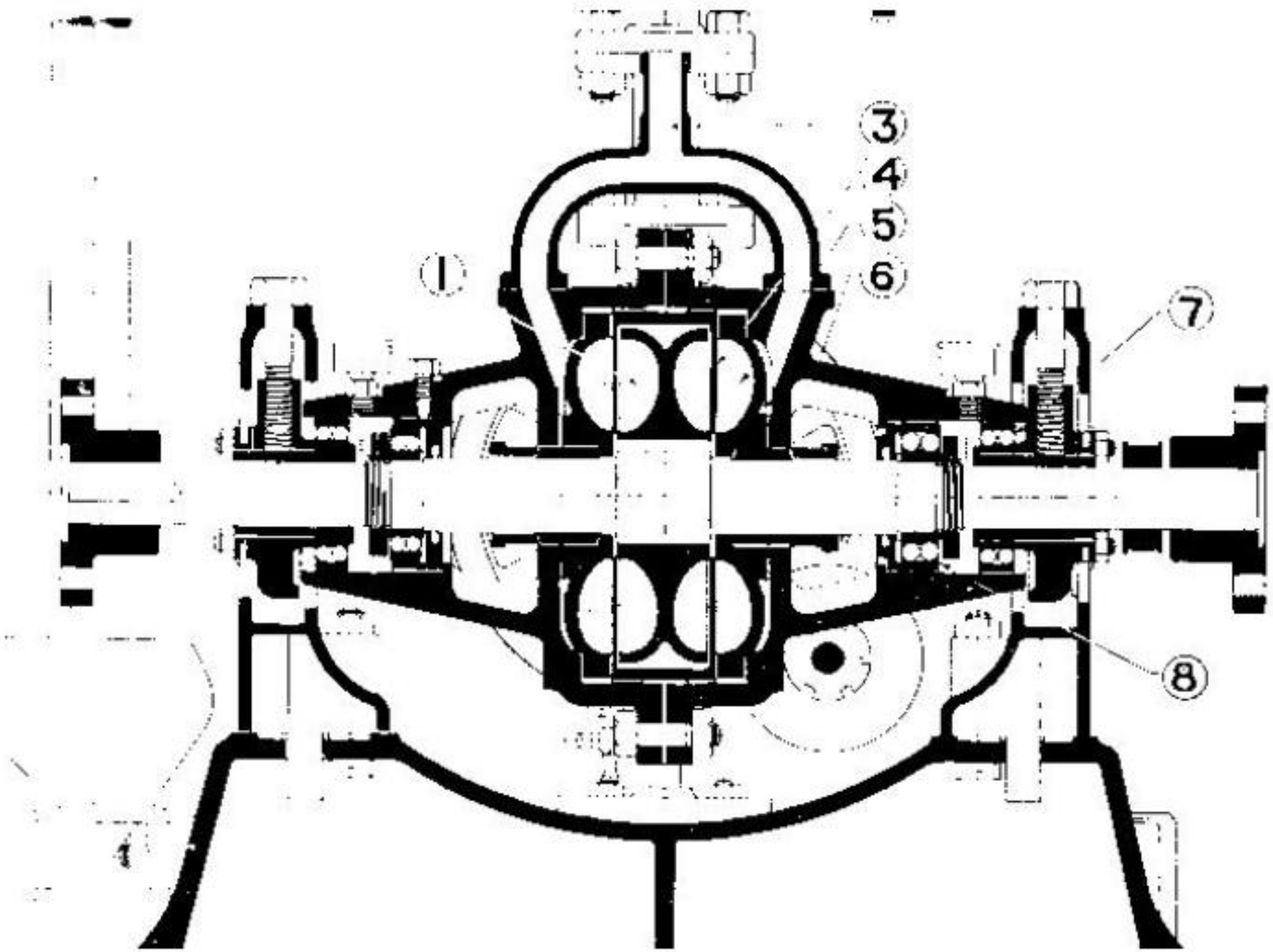
Froude Dynamometer



Typical cross-section through casing of Froude dynamometer, type DPX

(1) Rotor
(2) Water outlet valve
(3) Water inlet valve
(4) Sluice plates for load control
(6) Casing liners
(7) Casing trunnion bearing
(8) Shaft bearing
(9) Tachometer

Cross section of an early Froude dynamometer



Eddy Current Dynamometers

- **Eddy current dynamometers** use a disk, driven by the engine being tested, rotating in a magnetic field of controlled strength.
- The rotating disk acts as an electrical conductor cutting the lines of magnetic flux and producing **eddy currents** in the **disk.**
- With no external circuit, the energy from the induced currents is absorbed in the disk.

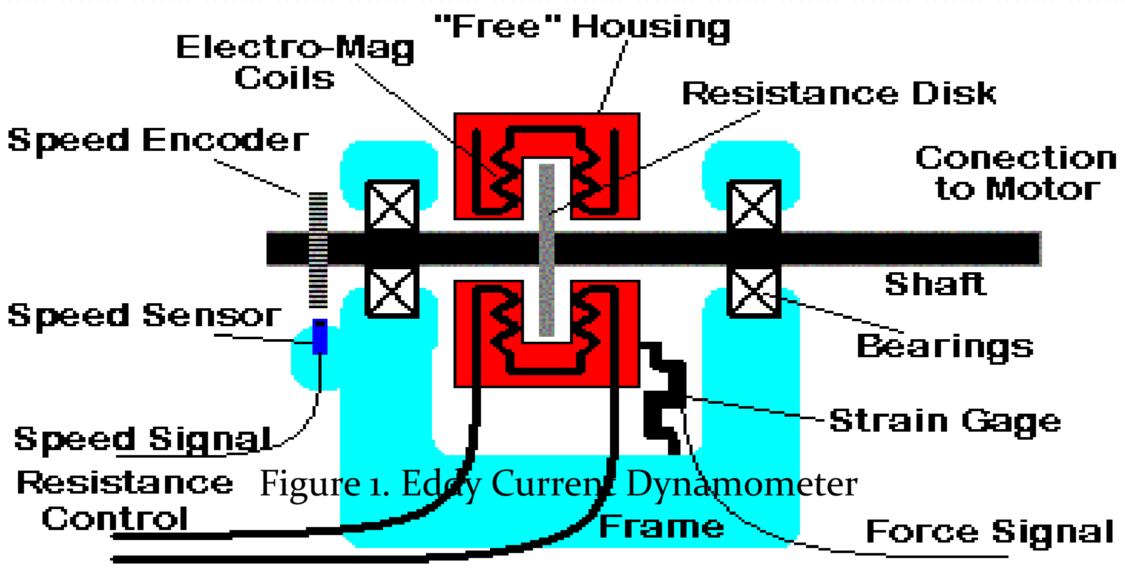


Figure 1. Eddy Current Dynamometer

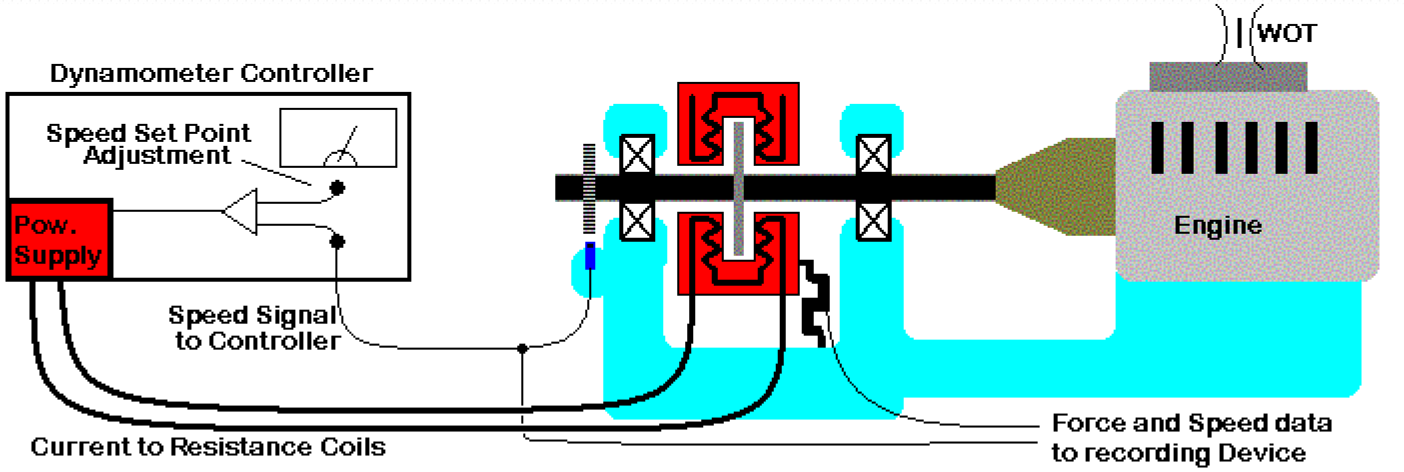
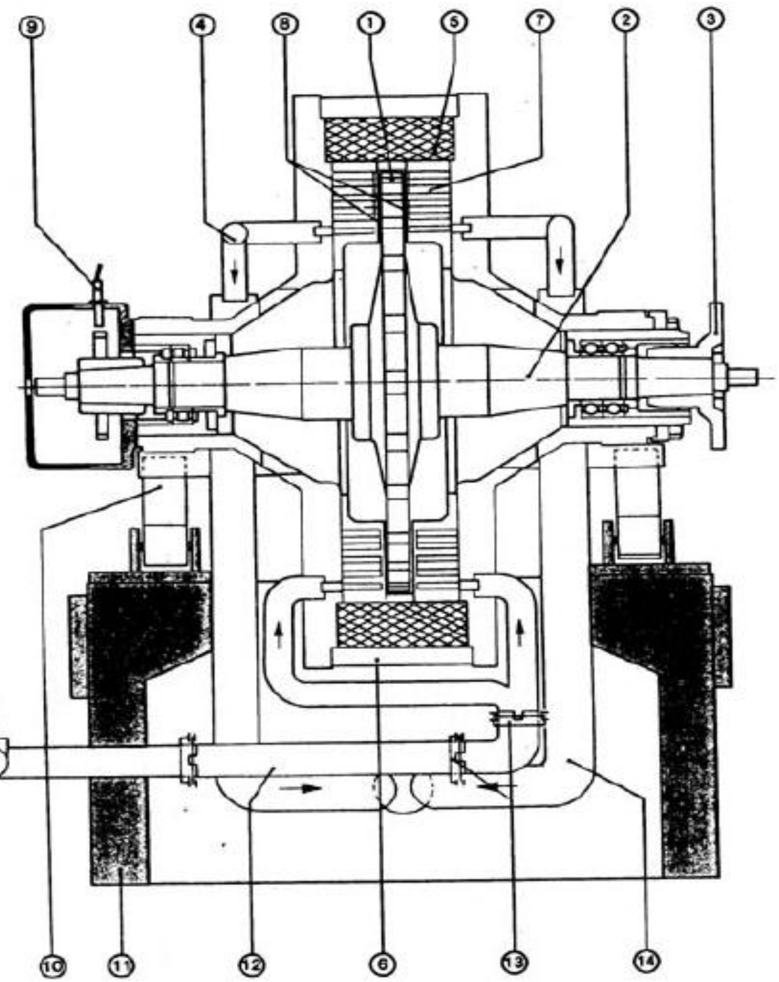


Figure 2. Schematic of a Speed Controlled test of engine at WOT

Eddy current



Eddy current dynamometer. 1 Rotor, 2 rotor shaft, 3 coupling flange, 4 water outlet with thermostat, 5 excitation coil, 6 dynamometer housing, 7 cooling chamber, 8 air gap, 9 speed pick-up, 10 flexure support, 11 base, 12 water inlet, 13 joint, 14 water outlet pipe.

Example of an eddy current dynamometer

Electric Dynamometer

- One of the best types of dynamometers is the electric dynamometer, which absorbs energy with electrical output from a connected generator.
- In addition to having an accurate way of measuring the energy absorbed, the load is easily varied by changing the amount of resistance in the circuit connected to the generator output.
- Many electric dynamometers can also be operated in reverse, with the generator used as a motor to drive (or motor) an unfired engine.
- This allows the engine to be tested for mechanical friction losses and air pumping losses, quantities that are hard to measure on a running fired engine.

Classification of Transmission Dynamometers

- The following types of transmission dynamometers are as follows:

1. **Epicycle-train** dynamometer
2. **Belt transmission** dynamometer
3. **Torsion** dynamometer

Epicycle-train Dynamometer

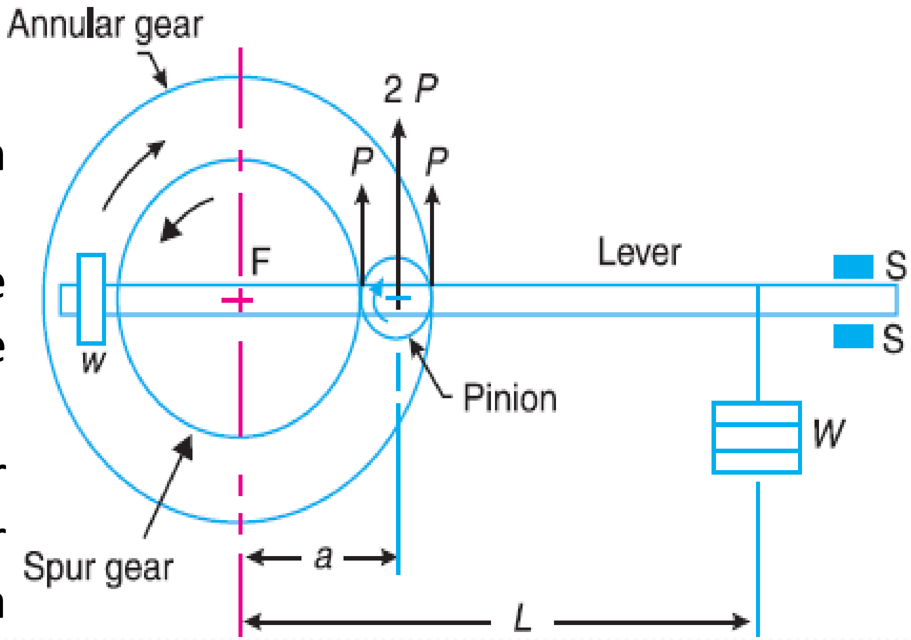
•it consists of a simple epicycle train of gears, i.e. a spur gear. The spur gear is keyed to the engine shaft and rotates in anticlockwise direction.

•The annular gear is also keyed to the driving shaft and rotates in clockwise direction.

•The pinion or the intermediate gear meshes with both the spur and annular gears. The pinion revolves freely on a lever.

• A weight w is placed at the smaller end of the lever in order to keep it in position.

• The tangential effort P exerted by the spur gear on the pinion and the tangential reaction of the annular gear on the pinion are equal.



For equilibrium of the lever, taking moments about the fulcrum F, $2P \times a = W.L$ or $P = W.L/2a$

R = Pitch circle radius of the spur gear in metres, and

N = Speed of the engine shaft in r.p.m.

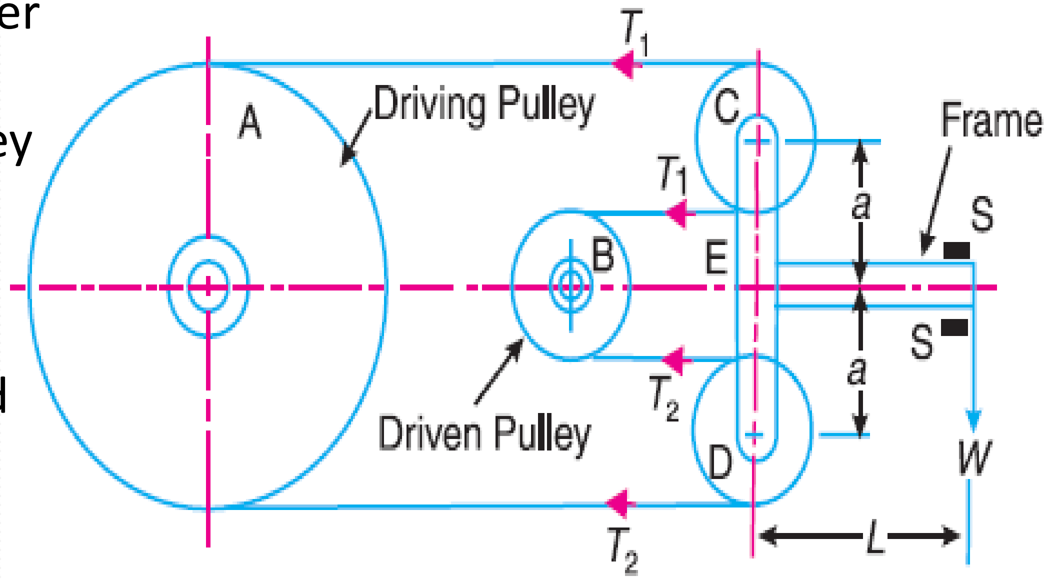
$\therefore$ Torque transmitted, $T = P.R$

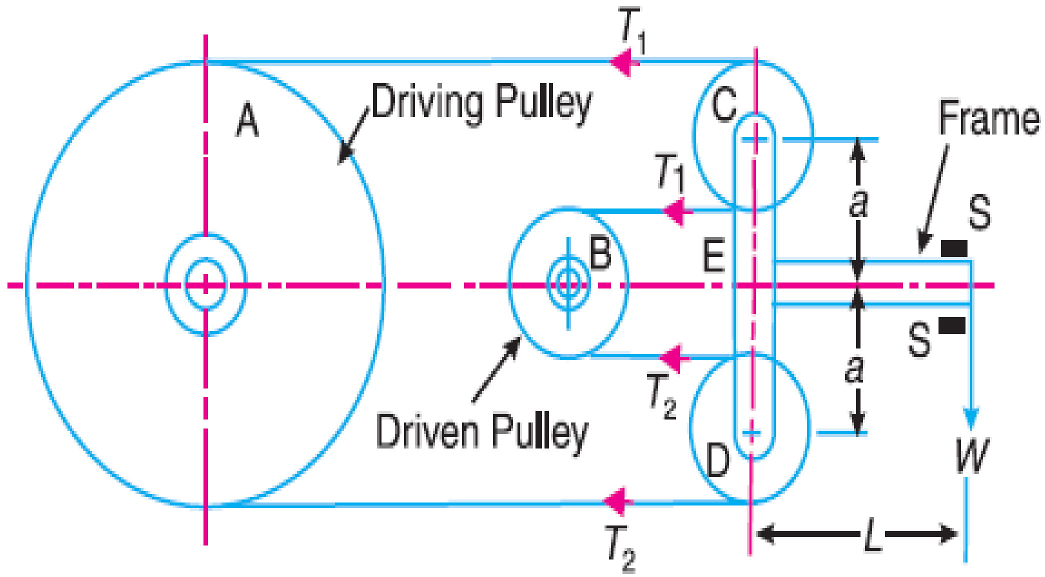
And power transmitted,

$$= \frac{T \times 2\pi N}{60} = \frac{P.R \times 2\pi N}{60} \text{ watts}$$

Belt Transmission Dynamometer

- When the belt is transmitting power from one pulley to another, the tangential effort on the driven pulley is equal to the difference between the tensions in the tight and slack sides of the belt.
- A belt dynamometer is introduced to measure directly the difference between the tensions of the belt, while it is running.





- A belt transmission dynamometer, is called a Froude or Throneycroft transmission dynamometer.
- It consists of a pulley A (called driving pulley) which is rigidly fixed tothe shaft of an engine whose power is required to be measured.
- There is another pulley B (called driven pulley) mounted on another shaft to which the power from pulley A is transmitted. The pulleys
- A and B are connected by means of a continuous belt passing round the two loose pulleys C and D which are mounted on a T-shaped frame.
- The frame is pivoted at E and its movement is controlled by two stops S,S. Since the tension in the tight side of the belt (T1) is greater than the tension in the slack side of the belt (T2),so the total force acting on the pulley C (i.e. 2T1) is greater than the total force acting on the pulley D (i.e. 2T2). It is thus obvious that the frame causes movement about E in the anticlockwise direction. In order to balance it, a weight W is applied at a distance L from E on the frame as shown in Figure.

- Now taking moments about the pivot *E, neglecting friction,*

$$2T_1 \times a = 2T_2 \times a + W.L \quad o \quad T_1 - T_2 = \frac{W.L}{2a}$$

D = diameter of the pulley A in metres

N = Speed of the engine shaft in r.p.m.

∴ Work done in one revolution = $(T_1 - T_2)\,\pi\, D$ N-m

and workdone per minute = $(T_1 - T_2)\,\pi\, DN$ N-m

∴ Brake power of the engine,

$$\text{B.P.} = \frac{(T_1 - T_2)\,\pi\, DN}{60} \text{ watts}$$

Torsion Dynamometer

- A torsion dynamometer is used for measuring large powers particularly the power transmitted along the propeller shaft of a turbine or motor vessel.
- A little consideration will show that when the power is being transmitted, then the driving end of the shaft twists through a small angle relative to the driven end of the shaft. The amount of twist depends upon many factors such as
  - torque acting on the shaft (*T*)
  - *length of the shaft (l)*
  - *diameter of the shaft (D)*
  - *modulus of rigidity (C) of the* material of the shaft.

- We know that the torsion equation is,

$$\frac{T}{J} = \frac{C.\theta}{l}$$

where θ = Angle of twist in radians, and

J = Polar moment of inertia of the shaft.

- For a solid shaft of diameter D, the polar moment of inertia

$$J = \frac{\pi}{32} \times D^4$$

- for a hollow shaft of external diameter *D and internal diameter d, the polar moment of inertia,*

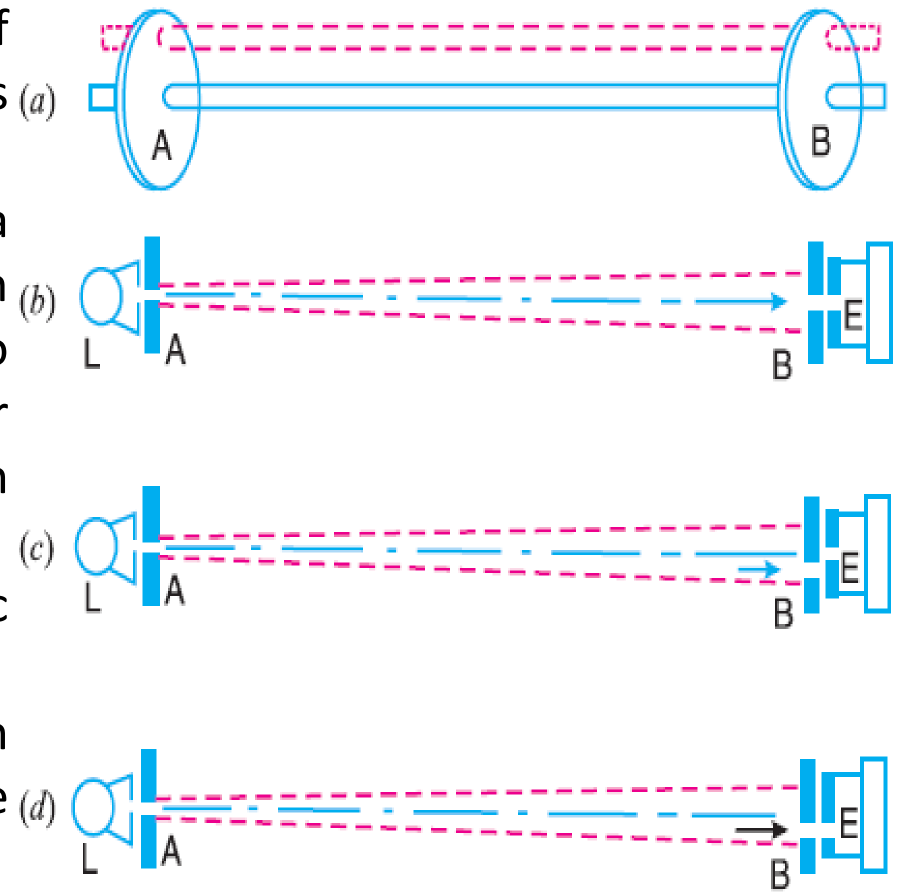
$$J = \frac{\pi}{32}(D^4 - d^4)$$

- From the above torsion equation $T = \frac{C.J}{l} \times \theta = k.\theta$
- the power transmitted,

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

Bevis-Gibson Flash Light Torsion Dynamometer

- It depends upon the fact that the light travels in a straight line through air of uniform density and the velocity of light is infinite.
- It consists of two discs A and B fixed on a shaft at a convenient distance apart Each disc has a small radial slot and these two slots are in the same line when no power is transmitted and there is no torque on the shaft.
- A bright electric lamp L, behind the disc A, is fixed on the bearing of the shaft.
- At every revolution of the shaft, a flash of light is projected through the slot in the disc A
- An eye piece E is fitted behind the disc B on the shaft bearing and is capable of slight circumferential adjustment.



- When the shaft does not transmit any torque (i.e. at rest), a flash of light may be seen after every revolution of the shaft, as the positions of the slit do not change relative to one another as shown in Figure (b)
- when the torque is transmitted, the shaft twists and the slot in the disc B changes its position, though the slots in L, A and E are still in line.
- Due to this, the light does not reach to the eye piece as shown in Figure (c). If the eye piece is now moved round by an amount equal to the lag of disc B, then the slot in the eye piece will be opposite to the slot in disc B as shown in Figure (d) and hence the eye piece receives flash of light.
- The eye piece is moved by operating a micrometer spindle and by means of scale and vernier , the angle of twist may be measured upto1/100th of a degree.

1.3. Measurement of Performance Parameters in a Laboratory

1.3.1. Measurement of Friction Power:

Friction power includes the frictional losses and the pumping losses.

Following methods are used in the laboratory to measure friction power:

(i) Willan's line method;

(ii) From the measurement of indicated power and brake power;

(iii) Motoring test;

(iv) Retardation test;

(v) Morse Test.

1.3.1.1. Willan's Line Method:- This method is also known as fuel rate extrapolation method. In this method a graph of fuel consumption (vertical axis) versus brake power

Willan' s Line

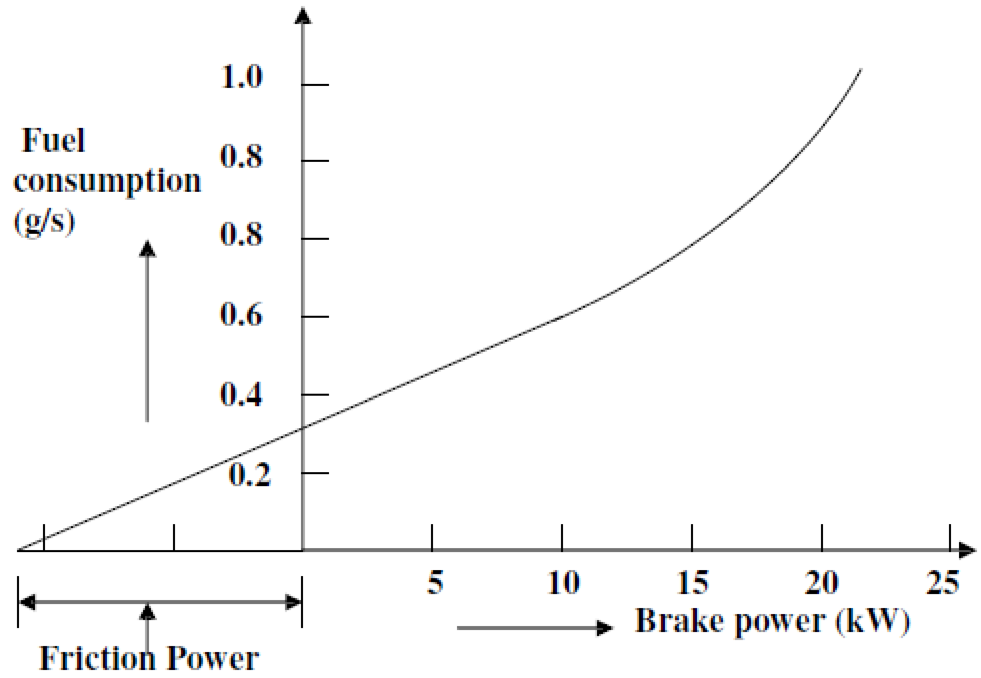


Figure.1 Willan's line method

1.3.1.2.From the Measurement of Indicated Power and Brake Power.

1.3.1.3.Morse Test:- This method can be used only for multi – cylinder IC engines.

Total indicated power
when all the cylinders are working $= ip_1 + ip_2 + ip_3 + \ldots\ldots\ldots\ldots + ip_k = \sum_{j=1}^{k} ip_j$

We can write $\sum_{j=1}^{k} ip_j = B_t + F_t$ ……………………………………..(1)

If the first cylinder is cut – off, then it will not produce any power, but it will have frictional losses. Then

we can write $\sum_{j=2}^{k} ip_j = B_1 - F_t$……………………………………..(2)

where B_1 = total brake power when cylinder 1 is cut - off and

F_t = Total frictional power.

where B_1 = total brake power when cylinder 1 is cut - off and

F_t = Total frictional power.

Subtracting Eq. (2) from Eq. (1) we have the indicated power of the cut off cylinder. Thus

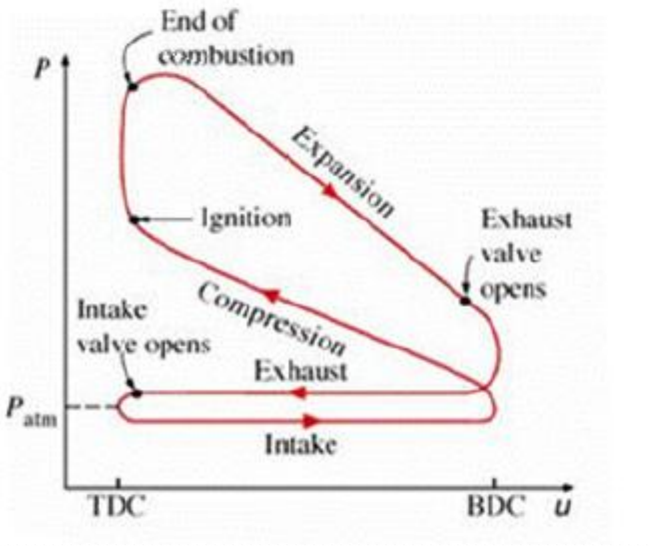
$$ip_1 = B_t - B_1 \text{ ....(3).}$$

Similarly we can find the indicated power of all the cylinders, viz., ip_2, ip_3, ...ip_k. Then the total indicated power is calculated as

$$(ip)_{total} = \sum_{j=1}^{k} ip_j \text{ ....(4)}$$

The frictional power of the engine is therefore given by

$$F_t = (ip)_{total} - B_t \text{ ....(5)}$$



The areas, the positive loop and negative loop, are measured with the help of a planimeter and let these be A_p and A_n cm^2 respectively, the net positive area is $(A_p - A_n)$. Let the actual length of the diagram as measured be L cm, then the average height of the net posiive area is given by

$$h=(A_p-A_n)/L \quad \text{in centimetre}$$

The height multiplied by spring-strength (or spring number) gives the indicated mean effective pressure of the cycle.

$$Imep=(A_p-A_n)*S/L \qquad .....(6)$$

Where S is spring scale and it is defined as a force per unit area required to compress the spring through a height of one centimeter (N/m^2/cm).

net indicated mean effective pressure is given by

$$P_m = A_p * S_p / L - A_n * S_n / L \quad .....(7)$$

Where S_p = Spring strength used for taking *p-v* diagram of positive loop, (N/m^2 per cm)

S_n = Spring strength used for taking *p-v* diagram of negative loop, (N/m^2 per cm)

A_p = Area in Cm2 of positive loop taken with spring of strength S_p

A_n = Area in Cm2 of positive loop taken with spring of strength S_n

Sometimes spring strength is also noted as spring constant.

The IP developed by the engine is given by

$$IP = P_m LAn/L \quad .....(8)$$

Where '*n*' is the number of working strokes per second.

Testing of Internal Combustion Engines

There are a wide variety of engine tests, starting from simple fuel and air-flow measurements to taking of complicated injector needle lift diagram, swirl patterns and photographs of the combustion process, etc..
Here only certain basic tests and measurement will be considered.

1-Measurement of speed:

A wide variety of speed measuring devices are available they range from a mechanical tachometer to digital and triggered electrical tachometers.
The best method of measurement is to count the number of revolution in a given time; this could be done either mechanically or electrically.

2-Fuel consumption measurement:

The fuel consumption of an engine is measured by determining the volume flow in a given time interval, or to measure the time required for the consumption of a given
volume (or mass) of fuel.

3-Air consumption measurement:

The measurement of the air flow in the engine intake is not an easy task, because of the cyclic nature of the engine which causes a pulsating air flow:

a) Air box method:

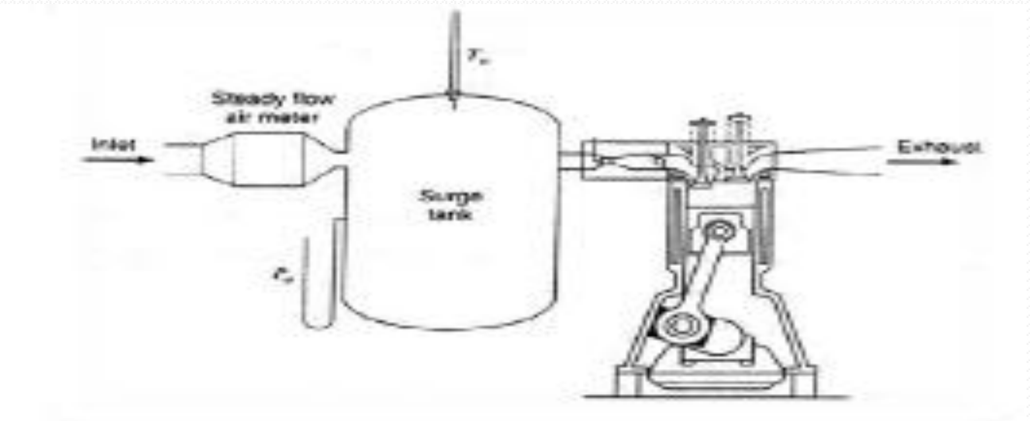


Figure (6-2): Testing equipment for measured of air consumption

b) Positive – Displacement meters:

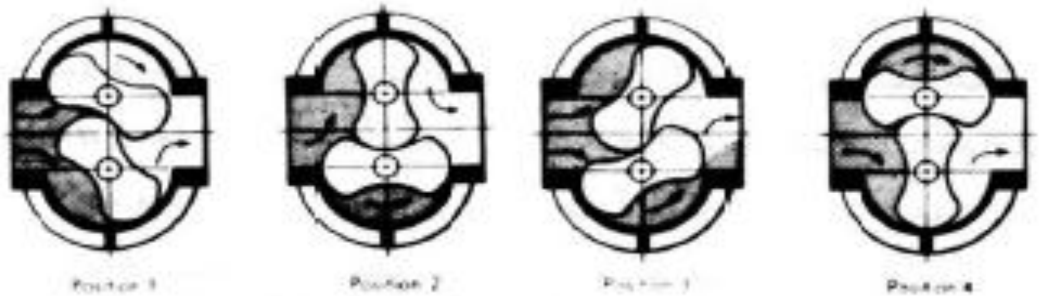


Figure (6-3):Rotary positive displacement meter

c) Viscous – flow air meter:

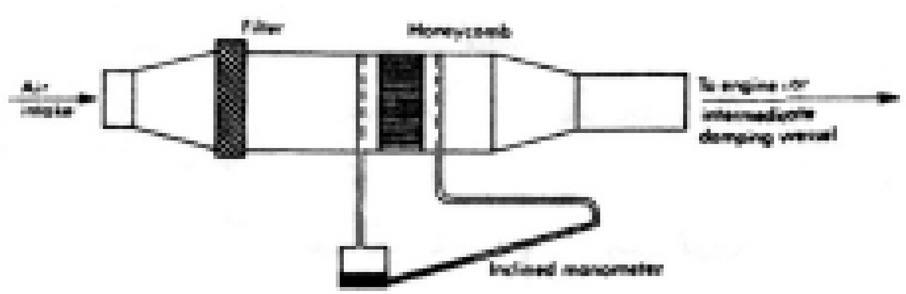


Figure (6-4): Viscous- flow air meter