Lecture on:
IC Engine Performance Test
1. Power and Mechanical efficiency:

- Power developed at the output shaft is known as brake power (b.p.),
  \[ b.p. = 2\pi NT \]
  where, \( T \) is Torque in Nm and \( N \) is rotational speed in revolutions per second
  \[ T = WR \]
  \[ W = 9.81 \times \text{net mass (in kg)} \text{ applied} \]
  \[ R = \text{radius in m} \]

- Power developed in the combustion chamber is known as \textit{indicated power (i.p.)}. It forms the basis for evaluation of combustion efficiency or heat release in the cylinder.

- Power utilised in overcoming friction is known as \textit{friction power (f.p.)}.
  \[ f.p. = i.p. - b.p. \]

- \textit{Mechanical Efficiency} = \( \frac{b.p.}{i.p.} = \frac{b.p.}{(b.p. + f.p.)} \)
2. **Mean effective pressure and Torque:**

- Hypothetical pressure acted upon the piston throughout the power stroke.

\[ P_m = \frac{\text{net area of indicator diagram}}{\text{length of indicator diagram} \times \text{spring constant}} \]

- **Indicated power per cylinder**, i.p. = \( P_{im} \text{ALN}/n \)

\( n = \) number of revolutions required to complete one engine cycle (\( n = 1 \) for two-stroke engine, 2 for four-stroke engine)

- For hit and miss governing, i.p./cylinder = \( P_{im}.A.L. \times \text{number of working strokes per second} \)

- **Brake power per cylinder**, b.p. = \( 2\pi NT = P_{bm} \text{ALN}/n \)

Then, \( T = \frac{P_{bm}AL}{n} \times \frac{1}{2\pi} \)

- For same mep, larger engine produces more torque
- Higher mep, higher will be the power developed by the engine for a given displacement
- Mep is basis of comparison of relative performance of different engines
- Horsepower of an engine is dependent on its size and speed
3. **Specific output:**

- It describes the efficiency of an engine in terms of the brake horsepower.

- Specific output = \( \frac{b.p.}{AL} = \text{constant} \times \text{bmep} \times \text{rpm} \)

- For same piston displacement and bmep an engine running at higher speed will give more output.

- Increasing speed increase mechanical stresses

- Increasing bmep requires better heat release and more load on engine cylinder
4. Volumetric efficiency:

\[ \eta_v = \frac{\text{Mass of charge actually inducted}}{\text{Mass of charge inducted in swept volume at NTP}} \]

- Power output is proportional to the amount of air inducted

- \( \eta_v \) of supercharged engine has more than unity due to forced induction

- \( \eta_v \) can be improved by compressing the induction charge (forced induction) or by aggressive cam phasing in naturally aspirated engines. In the case of forced induction volumetric efficiency can exceed 100%.

- Modern technique for four-stroke engines, variable valve timing, attempts to changes in volumetric efficiency with changes in speed of the engine: at higher speeds the engine needs the valves open for a greater percentage of the cycle time to move the charge in and out of the engine.
5. Fuel-air ratio (F/A):

- Ratio of mass of fuel to mass of air in mixture affects the combustion phenomenon, determines the flame propagation velocity, the heat release, maximum temperature and completeness of combustion, unwanted pollutants formation produced in the reaction.
- **stoichiometric** mixture- Enough air is provided to completely burn all of the fuel
- **Rich** mixtures: lower than stoichiometric; little air present to burn the given quantity of fuel; are less efficient, but may produce more power and burn cooler
- **Lean** mixtures: higher than stoichiometric; more air than required to burn fuel; are more efficient but may cause higher temperatures, which can lead to the formation of nitrogen oxides. Some engines are designed with features to allow lean-burn.
- AFR (air-fuel ratio) = 1/FAR
- Relative fuel-air ratio = actual fuel-air ratio/ stoichiometric fuel-air ratio
- Air-fuel equivalence ratio (λ): ratio of actual AFR to stoichiometry for a given mixture. \( \lambda = 1.0 \) is at stoichiometry, rich mixtures \( \lambda < 1.0 \), and lean mixtures \( \lambda > 1.0 \)
- For pure octane or gasoline fuel the stoichiometric mixture is approximately 15:1, or \( \lambda \) of 1.00 exactly.
Specific fuel consumption is the indication of efficiency with which the engine develops power from fuel.

\[ sf c = \frac{\text{fuel consumed}}{\text{horse power developed}} \]

Unit: g/kW.h

Basis of comparison of different sizes of engine as per efficient utilization of fuel. The engine which consumes least amount of fuel can produce high power.

For IC engines, it is of two types:

Indicated Specific Fuel Consumption (ISFC)

ISFC = Fuel consumption per unit time / Indicated horse power

Brake Specific Fuel Consumption (BSFC)

BSFC = Fuel consumption per unit time / Brake Horse Power: measure of the efficiency of any prime mover that burns fuel and produces rotational, or shaft power.
7. Thermal Efficiency ($\eta_{th}$) and Heat Balance:

- Ratio of engine power output to input power i.e. chemical energy in the form of fuel supply. Based on power output, it may be divided into brake thermal efficiency ($\eta_{bth}$) or indicated thermal efficiency ($\eta_{ith}$).

  \[
  \text{Brake thermal efficiency} = \frac{\text{b. p.}}{m_f \times C. V.}
  \]

  \[
  \text{Indicated thermal efficiency} = \frac{\text{i. p.}}{m_f \times C. V.}
  \]

- Heat balance: In IC engine, total input energy is not fully converted to useful work, energy goes out in various ways. The heat balance gives the detail of amount of energy wasted in percentage from various parts. The components of heat balance are brake output, coolant losses, heat going to exhaust, radiation and other losses.
8. Exhaust smoke and other emissions:

Exhaust emissions such as smoke, oxides of nitrogen, unburned hydrocarbons, carbon monoxides etc. are necessary to consider as a performance parameters and components of air pollutions.

9. Specific weight:

It gives the engine bulkiness i.e. weight of the engine in kg for each brake power developed. In aircraft engines, specific weight plays important role.
Basic measurements to be undertaken to evaluate the performance of an engine are as follows:

- Speed
- Fuel consumption
- Air consumption
- Brake horse-power
- Friction horse power
- Indicated horse power and
- Heat balance sheet or performance of SI and CI engine
- Smoke density
- Exhaust gas analysis
1. Measurements of speed:

- Measurements of IC engine speed is done to count the number of revolutions in a given time-Tachometer.

- Different types of Tachometers available in the market are:
  (a) On the basis of method of display: Analog and Digital
  (b) On the basis of data acquisition: Contact and non-contact
  (c) On the basis of measurement technique: Time based and frequency based

  The time measurement device calculates speed by measuring the time interval between the incoming pulses; whereas, the frequency measurement device calculates speed by measuring the frequency of the incoming pulses. Time measuring tachometers are ideal for low speed measurements and frequency measuring tachometers are ideal for high speed measurements.
  (d) On the basis of working principle: Mechanical tachometers, electrical tachometers and contactless electrical tachometers
**Analog Tachometer:**

- Comprised of a needle and dial-type of interface. They do not have provision for storage of readings and cannot compute details such as average and deviation.

**Digital Tachometer:**

- Comprised of LCD or LED readout and a memory for storage.
- They provide numerical readings instead of using dials and needles.
- Digital tachometers are often used in airplanes, laser instruments, medicine, etc. In medicine, this instrument is placed in a vein or artery to accurately estimate the blood flow rate.
- Types of digital tachometer:
  - **Contact type** and
  - **Non-contact type**
**Contact type digital tachometer:**

Contact type tachometers are fixed to the machine or electric motor and an optical encoder or magnetic sensor will be attached to it so that it can measure the RPM.

**Non-Contact type digital tachometer:**

- Non-contact type is ideal for applications that are mobile, and uses a laser or optical disk.
- A laser or an optical disk is attached to the rotating shaft, and it can be read by an IR beam or laser, which is directed by the tachometer.
- It can measure from 1 to 99,999 rpm; the measurement angle is less than 120 degrees, and has a five-digit LCD display.
- These are efficient, durable, accurate, and compact, and also visible from long distance.
**Mechanical Tachometers:** It employs only mechanical parts and mechanical movements for the measurement of speed.

- Hand speed tachometer or hand held tachometer,
- revolution counter,
- Tachoscope,
- Centrifugal force tachometer, and
- Resonance (vibrating reed) tachometer.
(i) **Hand speed tachometer or hand held tachometer:**

- It consists of a worm gear attached to spindle which meshes with a spur gear that in turn moves a pointer on calibrated dial to indicate revolutions.
- Generally, two dials are placed in position. In one dial each division represents one revolution of the spindle while on the other on division represents the one revolution of the former.
- A stop watch is attached to the revolution. For measuring the speed, the tachometer is manually pressed at the contact point at the rotating shaft whose speed is to be measured.
- The hand speed tachometers can be used to speed of 20,000 to 30,000 rpm with an accuracy of 1%.
(ii) **Revolution counter:**

- Measures an average rotational speed over a short interval of time rather than instantaneous rotational speed.
- Worm gear coaxially attached to the driving shaft which provides the speed source. A spur gear is connected with its rotating axis perpendicular to the axis of worm gear. The pointer indicates number of revolutions.
- These tachometers can measure up to a speed of 30000 rpm with an accuracy of 1%.

![Revolution counter diagram](image-url)
(iii) Tachoscope:

This tachometer is a contact type tachometer and has the basic working principle of revolution counter and timer. The two components are integrally mounted and start simultaneously when contact pint is pressed against rotating shaft. Sometimes, it is difficult to start both timer and counter simultaneously.

It can be used to measure speeds up to 5000 rpm.

Fig: Tachoscope
(iv) Centrifugal force tachometer:

- The principle of operation of centrifugal tachometer is that the centrifugal force is proportional to the speed of rotation.
- This centrifugal force compresses the spring and a grooved collar or sleeve attached to its free end slides on the spindle and its position can be calibrated with the spindle speed.
- These types of instrument can be used up to 40000 rpm. They are also used in the speed governors to break circuit for speed control.
- These tachometers have a distinct advantage over revolution counter in that they indicate whether or not the speed remains substantially constant.
(v) **Resonance (vibrating reed) tachometer:**

- The measurement of speed can be achieved on basis of frequency of vibrations created by machine body.
- Mostly, multi reed or Frahm tachometers measure speeds by contact, this type of tachometer is the solution to many speeds measuring problems, especially checking speeds of totally enclosed rotating equipment.
- Ruggedly constructed, permanent accuracy, simple to use. Applicable to measure the speed range of 600-10000 rpm with an accuracy of ±0.5% of rated speed.
Electrical Tachometer:

- Electrical tachometers provide the advantages of electrical transducers
- Electrical signal generated in proportion to the rotational speed of the shaft
- These tachometers are lightweight and accurate under all conditions.
- Depending upon the type of transducer, electrical tachometers have been constructed in the variety of designs which are as follows:

  **Commutated capacitor tachometer**

  **Eddy current or drag cup tachometer**

  **Tachometer generator**
(i) **Commutated capacitor tachometer:**

- Based on alternately charging and discharging capacitor controlled by speed of rotating member.
- The head of tachometer containing a reversible switch, operated by a spindle which reverses two times with one revolution. Indicating unit, voltage source, capacitor, a millimetre and a calibrated circuit.
- When the switch is closed in one direction, the capacitor gets charged from DC supply and the current starts flowing through ammeter. When the spindle operates the reversing switch to close it in opposite direction, capacitor discharges through the ammeter with the current flow direction remaining the same.
- The indication is proportional to the rate of reversal of contacts which in turn are proportional to the speed of the shaft and reflected on the scale accordingly.
(ii) **Eddy current or drag cup tachometer:**

- The rotating shaft rotates a permanent magnet and this induces eddy currents in a disc. The eddy current produces a torque that rotates the disc against the torque of a spring.

- The disc turns in the direction of rotating magnetic field until the torque developed equals that of spring. A pointer attached to the disc indicated the rotational speed on a calibrated scale. The deflection is proportional to the emf, induced and hence proportional to speed of shaft.

- Magnets rotates inside soft iron casing. It is widely used in automobile speedometers and the current produced is proportional to angular speed of shaft.

Fig: Working Principle of Eddy current tachometer
(iii) **Tachometer generator**
Works on the principle that the e.m.f. generated depends upon the magnetic field and the speed. The tachometer generator may be AC or DC type of tachometer depending upon the taking out means of e.m.f. generated.

**DC tachometer generator:** Permanent magnet, armature, commutator, brushes, variable resistor, and the moving coil voltmeter are the main parts of the DC tachometer generator. The machine whose speed is to be measured is coupled with the shaft of the DC tachometer generator. The DC tachometer works on the principle that when the closed conductor moves in the magnetic field, EMF induces in the conductor. The magnitude of the induces emf depends on the flux link with the conductor and the speed of the shaft. The armature of the DC generator revolves between the constant field of the permanent magnet. The rotation induces the emf in the coil. They are widely used in applications for feedback and display purposes. DC tachometers are also excellent rate generators for velocity damping in low speed position servo applications.

![DC tachometer generator diagram](image)
AC tachometer generator:

- The AC tachometer has stationary armature and rotating magnetic field. Thus, the commutator and brushes are absent in AC tachometer generator.

- The rotating magnetic field induces the EMF in the stationary coil of the stator. The amplitude and frequency of the induced emf are equivalent to the speed of the shaft.

- The tachometers are designed primarily for use on shaft ends to measure speeds of up to 100,000 rpm and extremely low torque burdens of less than 1 ounce-inch.

Fig: AC tachometer generator
**Contactless electrical tachometers:** There are three types of contactless electrical tachometers such as:

1. Magnetic pickup
2. Photoelectric tachometer
3. Stroboscope
(i) **Magnetic pickup:**

- Magnetic pickup is most common type of transducers for measuring the angular speed of a rotating member (gear, shaft, pulley, etc.).

- It is essentially a coil wound around a permanently magnetized probe. When discrete ferromagnetic objects—such as gear teeth, turbine rotor blades, slotted discs, or shafts with keyways—are passed through the probe's magnetic field, the flux density is modulated. This induces AC voltages will be directly proportional to the rotational speed of the shaft.

- Ideally, the air gap should be as small as possible—typically 0.005 inch. The standard solid gear comes with various dimensions and with 48, 60, 72, 96, or 120 teeth.

- A magnetic pickup may also be used as a timing or synchronization device—as, for example, in ignition timing of gasoline engines, angular positioning of rotating parts, or stroboscopic triggering of mechanical motion.

![Magnetic pickup](image)
(ii) Photoelectric tachometer:

- The photoelectric tachometer utilizes a rotating shaft to intercept a beam of light falling on a photo conductive cell. The shaft has an intermittent reflecting (white) and non-reflecting (black) surfaces. When a beam of light hits the reflecting surface on the rotating shaft, light pulses are obtained and the reflected light is focused on to the photoelectric cell. The frequency of light pulses is proportional to the shaft speed.

- Photoelectric tachometer is a digital instrument. It however requires replacing the light source periodically.
(iii) **Stroboscopes:**

- Stroboscope is an instrument that provides *intermittent* illumination of a rotating or vibrating object in order to study the motion of the object or to determine its rotary speed or *vibration* frequency.

![Stroboscopes Diagram](image)

- Stroboscopes, commonly referred to as strobes, use a flash lamp—generally xenon or LED-driven by an oscillator to inspect or measure the rotational speed.

- The primary use for a stroboscope was to stop motion for diagnostic inspection purposes.
2. **Fuel consumption measurement:**

Fuel consumption is measured in two ways:
(a) The fuel consumption of an engine is measured by determining the volume flow in a given time interval and multiplying it by the specific gravity of the fuel which should be measured occasionally to get an accurate value.
(b) Another method is to measure the time required for consumption of a given mass of fuel.

Two basic types of fuel measurement methods are:
- Volumetric type
- Gravimetric type

(i) **Volumetric type flow meters are of types:**
   - Burette method,
   - Automatic Burette flow meter
   - Turbine flow meter.
• **Burette method:**
Simplest method to measure volumetric fuel flow to an engine which has glass burette having bulbs of known volume and having a mark on each side of bulb. Time taken to fuel consumption is measure with the help of stop watch and volume flow rate is calculated by dividing the volume by time.

Fig: Burette method
Automatic Burette flow meter

In this type, fuel level against the mark on the burette photocells are used. It has following sections:

1. Equalization chamber
2. Measuring volume
3. Magnetic valve
4. Upper measuring level
5. Lower measuring level
6. Light source
7. Photocell
8. Air tube
9. Spring
10. Equalization pipe
• **Turbine Fuel Flow Meters**

A rotating turbine is the main feature of a turbine fuel flow meter. A turbine rotates on an axis and the flow rate is recorded as the fluid passes over it. The fluid’s velocity will be proportional to the rotation speed once it becomes constant. In the case of a digital turbine fuel flow meter one of the blades of the turbine would have a magnet or sensor on it that passes a pulse to the computer on each rotation.
**Gravimetric Fuel Flow Measurement**

The efficiency of an engine is related to the kilograms of fuel which are consumed and not the number of litres. The method of measuring volume flow and then correcting it for specific gravity variations is quite inconvenient and inherently limited in accuracy. Instead if the weight of the fuel consumed is directly measured a great improvement in accuracy and cost can be obtained. There are three types of gravimetric type systems which are commercially available include Actual weighing of fuel consumed, Four Orifice Flow meter, etc.
3. Measurement of air consumption:

In IC engines, the satisfactory measurement of air consumption is quite difficult because the flow is pulsating, due to the cyclic nature of the engine and because the air a compressible fluid.

The various methods and meters used for air flow measurement include,

(a) Air box method: It is orifice method used to damping out the pressure pulsation. Air box of suitable (500 to 600 times the swept volume in single cylinder engines and less in case of multi cylinder engines) can damping out the pulsation. 

$U$ is the non-dimensional factor to provide the suitable dimensions for air box

$$U = \frac{1}{40.94 \times 10^5} \left( \frac{\eta_D C V N^2 n^2}{T d^4 p^2} \right)$$

C=air box volume, V=engine swept volume, d=orifice diameter, p=strokes of the piston per induction stroke

U should not be less than 2.5.
Let, uniform depression in air box, density constant, compressibility effect negligible

Velocity across orifice\(=c\sqrt{2gh_{air}}\)

\(h=\)differential head causing flow measured by water column and converted into equivalent air column

Thus, \(h_{water} \times 1 \times \rho_{water} = h_{air} \times 1 \times \rho_{air}\)

\[h_{air} = h_{water} \times \left(\frac{\rho_{water}}{\rho_{air}}\right)\]

\[C = \sqrt{2g \times \left(h_w \times \rho_w\right)/\rho_a}\]

Volume flow of air, \(Q = A\sqrt{(2gh_w\rho_w)/\rho_a}\)

Theoretical mass flow\(=Q \times \rho_a = A\sqrt{(2gh_w\rho_w)/\rho_a} \times \rho_a\)

\[= A\sqrt{(2gh_w\rho_w)\rho_a}\]

Actual mass flow\(= C_dA\sqrt{(2gh_w\rho_w)\rho_a}\)
b) Viscous-flow air meter:
This meter is used where viscous resistance is the principal sources of pressure loss and kinetic effects are small. It gives accurate reading under pulsating flow. The viscous element is in the form of a honeycomb passage. This gives a linear relationship between pressure difference and flow instead of a square law one. Advantage: large range of flow can be measure without pressure head being too small.

In case of linear relationship:

\[ Q = k_1 h \]
\[ Q = k_1 \times 100 \]
\[ k_1 = Q / 100 \]

If \( h = 100 \) mm of water, flow is reduced 1/10, \( h = 10 \) mm

In case of square relationship,

\[ Q = k\sqrt{h} \]
\[ Q = k\sqrt{100} \]
\[ k = Q / \sqrt{100} \]

If \( h = 100 \) mm of water, flow is reduced 1/10, \( h = 1 \) mm
Brake power measurement involves the determination of the torque and the angular speed of the engine output shaft.

✔ Dynamometer

1) **Power absorption dynamometers**: measure and absorb the power output of the engine to which they are coupled. Power absorbed is usually dissipated as heat by some means. Example of such dynamometers is prony brake, rope brake, hydraulic dynamometer, etc.

2) **Transmission dynamometer**: the power is transmitted to the load coupled to the engine after it is indicated on some type of scale. These are also called torque-meters.
(A) Prony brake dynamometer:

simplest methods of measuring brake power (output) is to attempt to stop the engine by means of a brake on the flywheel and measure the weight which an arm attached to the brake will support, as it tries to rotate with the flywheel.

\[
BP = 2\pi NT
\]

where, \( T = W \times l \)

\( W \) being the weight applied at a radius \( l \).
(B) Rope brake dynamometer:

consists of a number of turns of rope wound around the rotating drum attached to the output shaft.

\[ BP = \pi DN (W - S) \]

where, \( D \) is the brake drum diameter, \( W \) is the weight in Newton and \( S \) is the spring scale reading.

Rope brake is cheap and easily constructed but not a very accurate method because of changes in the friction coefficient of the rope with temperature.

The \( BP \) is given by

\[ BP = \pi DN (W - S) \]
(C) Hydraulic dynamometer:

Hydraulic dynamometer works on the principle of dissipating the power in fluid friction rather than in dry friction.
(D) Eddy current dynamometer:

- consists of a stator on which are fitted a number of electromagnets and a rotor disc made of copper or steel and coupled to the output shaft of the engine.
- When the rotor rotates eddy currents are produced in the stator due to magnetic flux set up by the passage of field current in the electromagnets.
The following are the main advantages of eddy current dynamometer:

- High brake power per unit weight of dynamometer.
- They offer the highest ratio of constant power speed range (up to 5 : 1).
- Level of field excitation is below 1% of total power being handled by dynamometer, thus, easy to control and programme.
- Development of eddy current is smooth hence the torque is also smooth and continuous under all conditions.
- Relatively higher torque under low speed conditions.
- It has no intricate rotating parts except shaft bearing.
- No natural limit to size-either small or large.
(E) Swinging Field d.c. Dynamometer

A swinging field d.c. dynamometer is a d.c. shunt motor so supported on trunnion bearings to measure their action torque that the outer case and field coils tend to rotate with the magnetic drag. Hence, the name swinging field. The torque is measured with an arm and weighing equipment in the usual manner. Many dynamometers are provided with suitable electric connections to run as motor also. Then the dynamometer is reversible, i.e. works as motoring as well as power absorbing device.

-When used as an absorption dynamometer it works as a d.c. generator and converts mechanical energy into electric energy which is dissipated in an external resistor or fed back to the mains.
-When used as a motoring device an external source of d.c. voltage is needed to drive the motor.

The load is controlled by changing the field current.

Fan Dynamometer:

It is also an absorption type of dynamometer in that when driven by the engine it absorbs the engine power. Such dynamometers are useful mainly for rough testing and running. The accuracy of the fan dynamometer is very poor. The power absorbed is determined by using previous calibration of the fan brake.
Transmission Dynamometers
Transmission dynamometers, also called torque meters, mostly consist of a set of strain-gauges fixed on the rotating shaft and the torque is measured by the angular deformation of the shaft which is indicated as strain of the strain gauge. Usually, a four arm bridge is used to reduce the effect of temperature to minimum and the gauges are arranged in pairs such that the effect of axial or transverse load on the strain gauge is avoided.

Transmission dynamometers are very accurate and are used where continuous transmission of load is necessary. These are used mainly in automatic units.
Lecture on:
Measurement of Friction power
The frictional losses are dissipated to the cooling system (and exhaust) as they appear in the form of frictional heat and this influences the cooling capacity required. Moreover, lower friction means availability of more brake power; hence brake specific fuel consumption is lower.

The \textit{bsfc} rises with an increase in speed. Thus, the level of friction decides the maximum output of the engine which can be obtained economically.

The friction force power of an engine is determined by the following methods:

- \textit{Willan's line method}.
- \textit{Morse test}.
- \textit{Motoring test}.
- \textit{Difference between ip and bp}.
(A) **Willan’s line method**

- In this method, gross fuel consumption vs. $bp$ at a constant speed is plotted and the graph is extrapolated back to zero fuel consumption.
- The point where this graph cuts the $bp$ axis is an indication of the friction power of the engine at that speed. This negative work represents the combined loss due to mechanical friction, pumping and blow by.
- The main drawback of this method is the long distance to be extrapolated from data measured between 5 and 40% load towards the zero line of fuel input.
- The directional margin of error is rather wide because of the graph which may not be a straight line many times.
- The changing slope along the curve indicates part efficiencies of increments of fuel. The pronounced change in the slope of this line near full load reflects the limiting influence of the air-fuel ratio and of the quality of combustion.
- Similarly, there is a slight curvature at light loads. This is perhaps due to difficulty in injecting accurately and consistently very small quantities of fuel per cycle.
Therefore, it is essential that great care should be taken at light loads to establish the true nature of the curve. The Willan’s line for a swirl-chamber CI engine is straighter than that for a direct injection type engine. The accuracy obtained in this method is good and compares favorably with other methods if extrapolation is carefully done.
(B) **Morse Test**

- The Morse test is applicable only to multicylinder engines.
- In this test, the engine is first run at the required speed and the output is measured.
- Then, one cylinder is cut out by short circuiting the spark plug or by disconnecting the injector as the case may be.
- Under this condition all other cylinders “motor” this cut-out cylinder.
- The output is measured by keeping the speed constant at its original value.
- The difference in the outputs is a measure of the indicated horse power of the cut-out cylinder.
- Thus, for each cylinder the \( ip \) is obtained and is added together to find the total \( ip \) of the engine.
Text Books:


Reference Books:


Website collection:

https://www.slideshare.net/abdulqadirlakdawala/speed-measurement-tachometeraqml
http://ecoursesonline.iasri.res.in/pluginfile.php/4057/mod_resource/content/1/Lesson_26.htm
https://www.youtube.com/watch?v=6-H4CBgnri4
http://www.davis.com/Category/Sticht_Vibrating_Reed_Tachometers/53058
https://www.youtube.com/watch?v=QuAA3rU9GBs
https://circuitglobe.com/electrical-tachometer.html
https://www.britannica.com/technology/tachometer#ref77812