# ENGINE TESTING TECHNIQUES

This introduction gives general information on engine testing with brief description of apparatus and formulae involved in determining parameters.

The testing of high-speed engines usually falls into one of the following categories:

1. Pure analytical research into the special phenomena or characteristics f engines. Engine tests are conducted on both single-cylinder and multi-cylinder types under selected operating conditions. Performance is determined by instrumentation and is usually assessed by graphical interpretation.
2. Research and development testing of new engine from the drawing board stage to prove the design and develop it until ultimately suitable for production.
3. Routine proof and acceptance tests (including quality) to ensure that production engines are satisfactory.

## PERFORMANCE VARIABLES

- ### BRAKE POWER [kW]

This is the measured output of the engine. This power from the engine drive shaft is measured by a *Dynamometer* (also known as *Brake*). The engine is connected to a brake or dynamometer, which can be loaded in such a way that the torque exerted by the engine can be measured. The dynamometer may be of the absorption or the transmission type. The absorption type is more usual and can be classified as:

**A)** Friction type, [These are used for smaller powered, lower-speed engines],
**B)** Hydraulic type,
**C)** Electrical type, or,
**D)** Air-Fan type.

The most common of all of them is the absorption type in which the all the energy output of the engine is absorbed and converted to heat. This conversion can be achieved by an electric generator and resistance bank or by straightforward transmitted to a load, and registered by torque reaction only, with negligible loss. Following is the description of the simplest absorption types i.e. the friction dynamometer.

**Electric Swinging Field Dynamometer**

In this type, an electric generator converts the mechanical energy to electrical energy. Early brakes used this principle to give direct measurement of electrical power, but heat losses in the generator windings made the accuracy of the results questionable. However, torque reaction can be measured by freely mounting the motor casing to allow angular movement, restraining such movement by the application of force provided by spring balance and torque arm. This made the torque measurement very accurate. With separately controlled dynamometer field, the degree of power absorption can be varied. The machine can also be used as motor to drive the engine, with ignition (or fuel) switch off, enabling friction losses to be measured (motoring test).

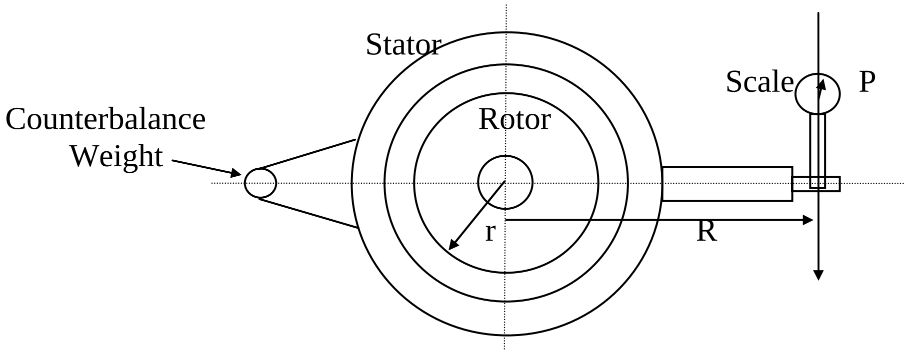


Figure (1) : Schematic Diagram on the Electric Swing Type Dynamometer.

As shown in the figure, a rotor driven by the engine under test is electrically, hydraulically or magnetically coupled to the stator.

For every revolution of the shaft, the rotor periphery moves though a distance = $2 * \pi * r$ against a coupling force "F".
Hence, work done per revolution is = $2 * \pi * r * F$
Now, the external moment or torque is = P * R (p = scale reading, R = scale arm)
This moment balances the turning moment of the coupling force = F * r
When the system is balanced, F * r = P * R
OR, we can re-write the work done per revolution equation as follows:

Work Done per revolution = $2 * \pi * P * R$
Work done per second = $2 * \pi * R * P * (N/60)$ (where N = rpm)
OR, we can write P*R = torque "T"

**Brake Power = 2*π*T*(N/60)**

- ## SPECIFIC FUEL CONSUMPTION (kg/kW-hr)

This factor represents a useful index of the fuel consumed per unit power produced (either brake of indicated). To measure the amount of fuel fed to the engine, a simple method is to measure the volume flow in a timed interval and to convert the volume o mass after measuring the specific gravity of the fuel.

Fuel Calculations :

Fuel consumption measured in liter per hour but quoted in kilograms per hour,

**i.e. (Liter/hour) * Specific Gravity of fuel = (Kilograms/hour)**

$$m_f = \frac{\text{Volume}}{\text{Time}} * \text{Specific Gravity of Fuel}$$

$$m_f = \frac{v}{t} * \gamma \quad \text{(kg / sec)}$$

where: sp. gr. for petrol = 0.741 (kg/L)
sp. gr. for diesel = 0.84 (kg/L)

From the definition of the specific fuel consumption, we can write:

$$\text{B.S.F.C (Kg/unit of Brake Power - hour)} = \frac{\text{fuel consumption in (kg / h)}}{\text{brake power (kw)}} \quad \text{(kg/kW.h)}$$

- ## Volumetric Efficiency

This parameter (sometimes called Breathing Efficiency) determines or compares the actual volume of air taken into the engine with the ideal volume. It is invaluable in testing the suitability of the inlet duct design. The volumes compared should both be calculated for environmental conditions, but it is simpler to compare masses of air. The amount of air-fuel mixture taken into the cylinder on the intake stroke is a measure of the engine's volumetric efficiency. If the mixture were drawn into the cylinder very slowly, a full measure could get in. But the mixture must pass very rapidly through a series of restricting openings and bends in the carburetor and intake manifold. In addition, the mixture is heated (from engine heat); it therefore expands. The two conditions; rapid movement and heating, reduce the amount of mixture that can get into the cylinder. A full charge of air-mixture cannot enter, because the time is too short and the air because the air becomes heated.

*Volumetric efficiency* is the ratio between the amount of air-fuel mixture that actually enters the cylinder and the amount that could enter under ideal conditions.

$$\eta_V = \frac{\text{Mass of air induced}}{\text{Mass of free air occupying volume equal to swept volume of engine}} \times 100\%$$

$$\eta_{Vol} = \frac{\dot{m}_a}{\rho_a \frac{N}{n} V_d} \times 100\%$$

where;

$$\dot{m}_a = \rho_a . V_a . A . Cd$$

$$V_a = \sqrt{2 \Delta h g \frac{\rho_w}{\rho_a}}$$

$$\rho_a = \frac{P}{R.T}$$

Cd = coefficient of discharge ; = 0.625
d = orifice diameter ; 48 mm
P = atmospheric pressure (bar)
T = room temperature (K)
R = gas constant
$V_d$ = Swept volume ($m^3$)
Va = Air velocity (m/s)
$\rho_w$ = water density ($Kg/m^3$)
$\rho_a$ = air density ($Kg/m^3$)
h = manometer height (m)
Swept volume for Petrol engine = 598 $cm^3$
Swept volume for Diesel engine = 1500 cm3

# APPARATUS

Here, a description of the apparatus is presented to serve for all the experiments assigned under this laboratory.

## ✓ GENERAL ARRANGEMENT

This unit is a completely self - contained test bed incorporating a swinging field DC dynamometer. The dynamometer, which is capable of absorbing 22 kW (30 hp), is supplied in standard form for absorbing power only. Service includes oil/water heat exchanger for the main cooling system and a water/oil heat exchanger for the oil cooling system.

## ✓ BASE PLATE

The main base plate is welded up from substantial channel sections to form a rectangular frame of great rigidity and stability. Bolting down is not necessary as the engines are flexibly mounted in the frame. Instrumentation is mounted where possible on a separate overhead frame that is free standing and structurally isolated from the main chassis. This avoids harmful vibration that could cause damage to instruments and errors of observation.

The base plate carries the following items:

- **(a)** The engine and dynamometer.
- **(b)** The water / water heat exchanger and header tank.
- **(c)** The water /oil heat exchanger.
- **(d)** Engine starting and battery charging panel.

## ✓ ENGINE

The bed is supplied with a 4-cylinder, 4-stroke, water-cooled diesel engine of 1500 $cm^3$ swept volume.

## ✓ CONTROL UNIT

The field control unit is enclosed in a steel cabinet located on a platform in the overhead frame. The unit is for use with 220/240 V single-phase 50/60 HZ supplies.

The AC input from the mains is transformed and rectified for the field circuit of the dynamometer. Voltage control is by variable transformers. Overload protection is essential in a test bed. A circuit of accessible at the rear provides this.

The instruments incorporated in the control unit are as follows:

A. Armature voltmeter.
B. Armature ammeter
C. Field voltage control. This control knob regulates the field strength when absorbing power.
D. Turn clockwise to increase field strength.
E. Tachometer. This is the read-out of the electronic tachometer described later.

## ✓ DYNAMOMETER

The dynamometer is a 400 V (nominal) DC machine, compound wound and separately excited carried on Turin mountings, and used for absorbing power only. The maximum permissible speed is 3000 rev/min. but the belt reduction drive permits the engine speed to reach 5000 rev/min. The belt drive obviates the need for a flexible coupling to accommodate shaft misalignment; it has negligible friction and hysteresis losses.

The dynamometer casing is restrained by a combination of spring balance and masses. The spring balance is anchored to the overhead frame and the torque of the dynamometer. A constant torque of 80 Newton meters may be maintained from 1500 rev/min. to 3000 rev/min. Two stops restrict the movement of the dynamometer, but when in use the torque arm should "float" between the stops. On the dynamometer casing is a "load control" switch for adjusting the field strength in conjunction with the "field voltage" control on the power unit. With the switch in the "half "position the field control will handle all loads up to 2000 rev/min. (engine speed) and in the " full " position all loads above 2000 rev/min. N. B The field control should be turned to zero before operating the switch.

## ✓ FUEL SYSTEM

The fuel tank is mounted at the top of the overhead frame and has capacity for 30 liters (7 Imp . gal). Fuel measurements by simple gravity pipette type gauge, with two bulbs calibrated for 50 $cm^3$ and 100 $cm^3$ respectively The system may be easily be drained for safety when not in use.

## ✓ COOLANT FLOW METER

A drowned orifice plate is inserted in the water circuit between the engine and the header tank. The pressure differential across the orifice is indicated by a mercury manometer (U-tube), calibrated in mm mounted on the instrument chassis of the test bed. Connections to the manometer are by rubber or plastic tubing.The rate of flow is given by the formula $Q = K\sqrt{h}$ where the value of k, the meter constant is given on the manometer panel.

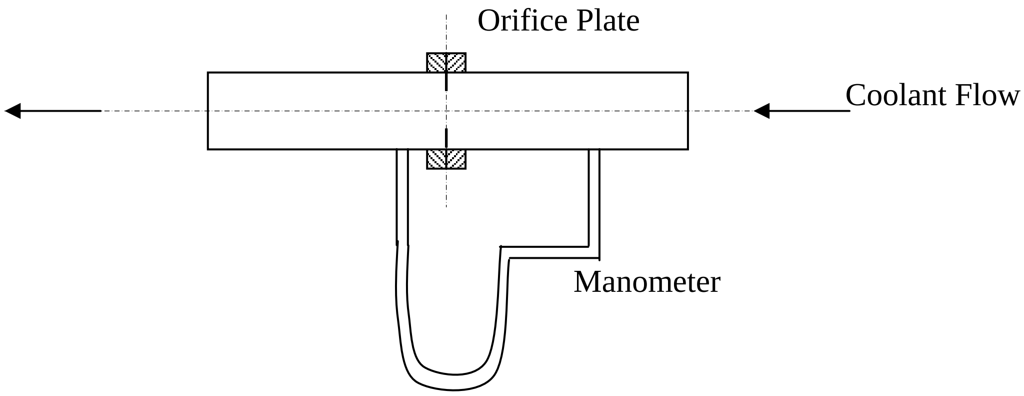


Figure (2) : Orifice Meter Setup.

## ✓ INLET AIR ORIFICE FLOW METER

For general purpose engine testing the inlet air for combustion may be measured by a simple orifice-type flow meter. The pressure differential across the orifice ' h' is displayed on a mercury manometer (U-tube). The flow rate is given by the equation $\mathbf{Q = K \sqrt{h}}$ where k is the meter constant indicated on the manometer panel. This relationship is true for steady conditions but due to the pulsating nature of the airflow to a reciprocating engine, root mean square errors will occur. Also, when an engine is operated over a wide speed range, a large pressure drop may develop at the orifice resulting in breathing and cerebration difficulties. (This is a consequence of the relationship between Q and h).

The correct choice of orifice size and meter capacity, and the provision of resilience may minimize these problems in the system. The orifice air meter uses a cylindrical reservoir or damping chamber to minimize the effect of pulsation's and produce a steadier flow through the orifice inserted in one of its end walls. The other end wall of the chamber consists of a resilient synthetic rubber diaphragm secured at its edges between rings of marine plywood sealed to the cylinder.

Movement of this diaphragm compensates for fluctuations in flow to the engine. The air outlet to the engine is via a branch from the underside of the curved surface. The capacity of the reservoir is matched to the requirements of the engine whose supply it meters. It cannot therefore be used indiscriminately on engines of all types. The air supplied with a sensitive inclined manometer calibrated in mm of water gauge, which measures the depression inside the chamber, near to the orifice. This effectively the pressure differential across the orifice if the engine is naturally aspirated.

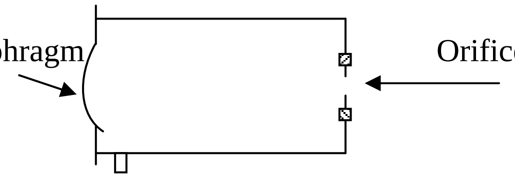


Figure (3) : Inlet Air Orifice Flow Meter.

## POWER & TORQUE

**OBJECTIVE**

To measure the general performance of the engine at fixed load setting.

**PURPOSE**

Simple test to measure or calculate the variation of brake power, torque, fuel consumption, specific fuel consumption and efficiencies engine speed, while maintaining a constant load. Further, the engine torque and power will be compared with the electrical system for the purpose of calibration.

**PROCEDURE**

**1.** Start engine.
**2.** Introduce brake load and open the throttle to its widest setting.
**3.** Increase the brake load to reduce the speed to the lowest possible value consistent with stability of operation.
**4.** Where possible adjust ignition timing and mixture strength controls (if appropriate) to optimum settings.
**5.** Observe the readings listed below :
**(a)** Engine speed.
**(b)** Brake loads (Newton).
**(c)** Fuel consumption timing (sec)
**(d)** Manometer reading $\Delta p =$ mm
**(e)** Dynamometer Voltage and Current
**6.** Increase the speed is even steps by reducing the load and record observations after each step. Taking cares to ensure that steady conditions have been reached.
**7.** Repeat the test procedure for a medium and a low setting of the throttle to observe the displacement of the peak power and peak torque values.
**8.** Stop the engine.

**CALCULATIONS**

**1.** To determine the torque use: **T (N-m) = F (N) . r (m)** with r (arm radius) = 0.4 m
**2.** To determine the brake power use: **BP = 2π (T.N / 60000)** (kW)
**3.** To calculate the rate of fuel consumption use:

$$\mathbf{M_f = (Volume/Time) * Specific\ Gravity\ of\ the\ Fuel}$$

$$\mathbf{M_f = (V/t)*\gamma \quad (Kg/Sec)}$$

Where the specific gravity of the fuel = 0.741 Kg/Liter for petrol and = 0.84 Kg/L for diesel fuels.

**4.** To dtermine the specific fuel consumption use:

**BSFC = (Fuel Consumption in Kg/h)/(Brake Power (kW)**

**5.** To determine the brake thermal efficiency use:

**Brake Thermal Efficiency = (Brake Power *100%)/(Fuel Equivalent of Power)**

where;

**Fuel equivalent of power = mass flow rate of fuel * Calorific Value**

$CV_f$ = 42000 kJ/Kg for petrol and 39000 kJ/Kg for diesel.

**6.** To determine the combustion air flow rate use:

$$\mathbf{M_a}\ (Kg/Sec) = \boldsymbol{\rho_a}\ (Kg/m^3) * \mathbf{V_a}\ (m/sec) * \mathbf{A}\ (m) * \mathbf{C_d}$$

Where; $\rho_a$ = density of air at 20 C. = 1.2 $Kg/m^3$

$\rho_w$ = density of water

A = Cross-Sectional area of the orifice

$V_a$ = Velocity of the air = $\sqrt{2 * \Delta h * g * (\rho_w / \rho_a)}$

**Table (1) : Data Recording and result presentation**

| **Engine Speed (rps)** | **Brake Load (N)** | **Manometer Reading ΔP mm of Water** | **Time needed for fuel consumption (Kg/s)** | **Armature Current (A)** | **Armature Voltage (V)** |
|---|---|---|---|---|---|
| 10 | | | | | |
| 20 | | | | | |
| 30 | | | | | |
| 40 | | | | | |
| 50 | | | | | |
| 60 | | | | | |

**RESULTS AND DISCUSSION**

After making necessary calculations for the Brake Power, Brakle Torque, Mass flow rate of fuel, Mass flow rate of air, Brake Thermal Efficiency and volumetric efficiency, plot the following:

1) All the above parameters (on Y-Axis) versus Engine Speed (on X-axis).
2) Compare the relative position of maximum power and maximum torque. Also compare the positions of maximum brake thermal efficiency and minimum fuel consumption.
3) The brake power (mechanical) versus brake power (electrical).
4) Make calibration for the engine brake power as you have studied in Engineering Measurement course.