Safety Hazards
Internal Combustion Engine Laboratory Room 120

HAZARD: Rotating Equipment

Be aware of pinch points and possible entanglement

Personal Protective Equipment: Safety Goggles; Standing Shields, Sturdy Shoes
No: Loose clothing; Neck Ties/Scarves; Jewelry (remove); Long Hair (tie back)

HAZARD: Projectiles / Ejected Parts

Articles in motion may dislodge and become airborne

Personal Protective Equipment: Safety Goggles; Standing Shields

HAZARD: Heating – Burn

Be aware of hot surfaces

Personal Protective Equipment: Safety Goggles**;** High Temperature Gloves

HAZARD: Chemical - Burn / Fume / Explosion

Use Adequate Ventilation and / or Rated Fume Hood

Personal Protective Equipment: Safety Goggles**;** Chemically Rated Gloves;

HAZARD: Electrical - Burn / Shock

Care with electrical connections, particularly with grounding and not using frayed electrical cords, can reduce hazard. Use GFCI receptacles near water.

HAZARD: High Pressure Air / Gas Cylinders / Vacuum

Inspect system integrity before operating any pressure / vacuum equipment. Gas cylinders must be secured at all times.

Personal Protective Equipment: Safety Goggles

HAZARD: Water / Slip Hazard

Clean any spills immediately.

HAZARD: Noise

Personal Protective Equipment: Ear Plugs

ME 406 - Experiment 1

INTERNAL COMBUSTION ENGINE TEST

I. OBJECTIVE

To determine the performance characteristics of a spark ignition internal combustion engine mounted on a dynamometer test stand.

II. BACKGROUND

The spark ignition IC engine is probably the most widely encountered prime mover currently in existence, being the preferred power plant in most automobiles, small trucks, and portable power supplies. As such, its behavior is of particular importance to mechanical engineers.

Although capable of being constructed as either a two-stroke or a four-stroke engine, it is the latter, which will be studied here. This requires two complete revolutions of the engine to accomplish one cycle or sequence of events in the thermodynamic sense. The four strokes can be described in the following way:

a) Intake stroke: Air is induced to flow into the cylinder by the partial vacuum created by the movement of the piston toward its maximum volume position. This flow occurs through an opened inlet valve while liquid fuel (in this case gasoline) is atomized and introduced into the air stream. At the end of the intake stroke the intake valve is closed resulting in the heterogeneous mixture consisting of fresh air, atomized and partially vaporized fuel and residual products of combustion from the previous cycle being confined in the cylinder.

b) Compression stroke: The above mixture is compressed by the movement of the piston toward the minimum volume position. This results in an increase in pressure, temperature and density of the fuel. Just prior to the completion of this stroke the fuel-air combination is ignited by the introduction of a spark, resulting in a controlled combustion process which changes some of the chemical energy into internal energy of the products of combustion. This brings about a further increase in pressure and temperature. Note that for any one cylinder these two strokes combined require one complete revolution of the engine.

c) Power stroke: The high-pressure action on the face of the piston forces it to move towards its maximum volume position while doing work on whatever device the engine is attached. This expansion of the gases is accompanied by a lowering of the pressure and temperature while the combustion process continues in the direction of the chemical reaction, i.e. toward completion. Just prior to the end of the power stroke the exhaust valve is opened and residual high pressure expels some of the spent gases outward into the exhaust system.

d) **Exhaust stroke:** The exhaust valve remains open and more spent gas is pushed from the cylinder as the piston is moved towards its minimum volume position. At the end of this stroke the exhaust valve is closed, the inlet valve opened and the sequence of events is repeated on the next cycle. Note that the combination of power and exhaust strokes require a second revolution of the engine and that all four strokes require two revolutions.

With this description of the thermodynamic and mechanical sequence of events occurring in the engine, the engineer would certainly be concerned with certain performance parameters since they are, at least partially, under the control of the designer.

At what rate is fresh air passing through the engine?
At what rate is fuel being introduced to the engine?
What external torque is available from the engine?
What useful power is produced?
What portion of the chemical energy of the fuel is being converted into useful work?
How do the above parameters change as the throttle position and RPM of the engine are changed?

Answers to these and other questions are to be provided by analyzing the test results and generating "*characteristic curves*", curves that characterize engine performance. These curves show the evolution of torque and power developed by the engine as a function of speed.

The **operation** of an engine is determined by two parameters, speed of rotation and position of the throttle. Engine **performance** can best be determined through the variation of these parameters.

Mechanical characteristics: Characteristic curves obtained as a function of engine speed, by keeping the throttle position a constant and varying the load. The characteristic diagrams obtained in this manner must include an indication of the position of the throttle. The diagrams of greatest interest are the ones obtained at ***full intake*** conditions by measuring, for each speed of rotation, the torque that can be obtained. Mechanical characteristics makes it possible to determine whether or not a given engine is suitable for use on a given automobile, by comparing the evolution of torque with that of the resistant torque applied by the wheels to the engine through the driveshaft.

III. EQUIPMENT

The engine to be tested is a four cylinder, spark ignition, water cooled Fiat automobile engine coupled to a hydraulic dynamometer.

Engine specs:

Engine – 4 cylinder in-line
Displacement – 1,108 cm^3 (67.61 in^3)
Compression ratio – 9.6

Bore – 65.2 mm
Stroke – 67.41 mm
Torque – 88 Nm @ 2,750 rpm
Power – 40 kW @ 5,500 rpm
Maximum speed – 6,000 rpm

Dynamometer: The measurement of torque and power is achieved by means of a reaction type hydraulic dynamometer brake. This device is able to absorb the mechanical power generated by the engine by simulating the behavior of the automobile for which the engine is intended (e.g., simulating the resistant torque applied by the wheel to the engine through the driveshaft.) The dynamometer brake consists of a rotor integral with the crankshaft and a stator frame, mounted on bearings which let it free to oscillate about its axis. Torque is transmitted from the rotor to the stator via a fluid (water), which is interposed between the rotor and the stator. Since torque produced by the engine is transmitted in full to the stator frame of the brake, it can be determined on the basis of the torque that has to be applied in order to keep the stator stationary. The latter is measured by means of a loading cell, which measures the force necessary to prevent the stator frame from rotating.

On the basis of the torque value determined by means of the load cell and the measure of rotation speed, we can determine the power developed by the engine.

Data acquisition system: Electronic transducers fitted to the engine test bench aid in the acquisition of torque, speed of rotation, air and fuel consumption values.

Torque transducer: The torque produced by the engine is measured by measuring the reaction torque on a stator frame of the dynamometer brake by means of a loading cell located at a distance b (m) from the rotation axis. Hence a load F (in kg) on the cell corresponds to a torque T (in Nm) expressed by the relationship

$$T = F \times b \times 9.81 \text{ Nm}$$

Fuel flow transducer: Fuel consumption is measured by means of a geared volumetric flow-meter fitted to the fuel feed line.

Air flow-rate transducer: The air taken in by the engine is determined by a calibrated diaphragm, which measures the change in pressure inside the intake conduit, from which the volume flow-rate is calculated.

Angular speed transducer: The engine speed is measured by means of a magnetic transducer and a voltage frequency converter.

IV. PROCEDURE

Mechanical characteristics curves:

1. In the introductory computer screen, select the testing mode "*Torque and power Vs. Speed.*"
2. Start the test by selecting <*New*> function in the <*File*> menu, and enter values in the fields displayed.
3. Work gradually on the accelerator till full intake condition is reached.
4. By means of the brake adjustment unit, increase breaking torque until speed of rotation decreases to minimum advisable value of 1,500 rpm.
5. Wait a few seconds for operating conditions to stabilize and acquire data by pressing the <*Test*> button and store acquired data in the work file by pressing the <*Input*>button.
6. Work on the brake adjustment unit, reducing the breaking torque until the speed increases by 500 rpm and repeat the data acquisition process.
7. Repeat Step 6 until the maximum possible rotation speed is reached (within limits of safety).
8. Examine acquired and calculated data by selecting the <*Browse*> function in the <*File*> menu or by pressing the data button inside the data acquisition window.

Note: The procedure described above is performed at full intake condition. Repeat the above steps for two other throttle settings, medium and low.

V. ANALYSIS

Determination of power:

From torque value determined from the load cell, we can determine the power developed by the engine at any desired speed using the relationship.

$$P = \frac{2\,\pi\,N\,T}{60{,}000}$$

where:

P: power (kW)
T: torque (Nm)
N: rotational speed (rpm)

Determination of specific fuel consumption and thermal efficiency:

In addition to the performance capability of the engine it is also important to determine the efficiency with which thermal energy is converted into mechanical energy. To determine this efficiency, together with the engines power output, we must measure fuel flow, so as to be able to correlate the amount of fuel used up during a certain time period to the work produced. The ratio between these two quantities is referred to as *specific fuel consumption* and can be determined from the following relationship:

$$\omega = \frac{m_{fuel}}{P} = \frac{Q_f \cdot \rho_f}{P} \cdot 1{,}000$$

where:

ω : specific fuel consumption (g/kWh)

Q_f : fuel flow (liters/hour)

ρ_f : fuel density (kg/liter) [0.720 – 0.780 kg/liter]

P: power (kW)

Another quantity that is frequently used is the ***brake thermal efficiency (total efficiency)***, which is used to compare work output, not with the quantity of fuel used but with the energy that can be obtained from the fuel itself.

$$\eta_t = \left(\frac{P \cdot 3{,}600}{Q_f \cdot \rho_f \cdot HHV} \right) \times 100$$

where:

η_t : brake thermal efficiency

Q_f : fuel flow (liters/hour)

ρ_f : fuel density (kg/liter) [0.720 – 0.780 kg/l]

P: power (kW)

HHV: higher heating value of fuel (kJ/kg) [44,000 kJ/kg]

Determination of air/fuel ratio and volumetric efficiency:

The study of performance capabilities of I.C engines cannot overlook two important operating parameters: the air/fuel ratio, *A/F* and volumetric efficiency η_v .

The air/fuel ratio is defined as the ratio of the air taken in by weight and fuel used up by weight, that is:

$$A/F = \frac{m_{air}}{m_{fuel}} = \frac{Q_a \cdot \rho_a}{Q_f \cdot \rho_f}$$

where:

Q_a : flow rate of air taken in (m^3/hour)

Q_f : fuel flow (liters/hour)

ρ_f :fuel density (kg/liter) [0.720 – 0.780 kg/l]

ρ_a : density of air in the intake environment (kg/m^3) [1.205 kg/m^3 @ 760 mmHg, 20°C]

Stoichiometric air/fuel ratio – A/F_{st}

Having determined the air/fuel ratio, it would be interesting to compare it with the chemically correct or theoretical air/fuel ratio of petroleum [14.6]

Based on the A/F and A/F_{st}, we may determine the relative air/fuel ratio A/F_r, defined as follows:

$$A/F_r = \frac{A/F}{A/F_{st}}$$

The physical meaning of the relative air/fuel ratio can be summarized as follows:

$A/F_r > 1$	Lean mixture, too much air
$A/F_r = 1$	Stoichiometric mixture
$A/F_r < 1$	Rich mixture, too much fuel

Volumetric efficiency:
Volumetric efficiency is defined as the ratio of the flow of air by weight actually taken in to the reference value consisting of the flow by weight that could be taken in if the entire engine displacement were filled with air with a density corresponding to the measured density of the intake environment. Thus:

$$\eta_v = \frac{Q_a}{Q_{displacement}}$$

where:

η_v: volumetric efficiency
Q_a: flow rate of air taken in (m^3/hour)
$Q_{displacement}$: displacement volume (m^3/hour)

Hence, the volumetric efficiency expresses the efficiency with which the volume available in the cylinders (i.e. displacement) is utilized to take in fresh air at the end of each cycle.

Determination of mean effective pressure:
Since the maximum torque produced by the engine depends on the displacement volume of the engine, it is not easy to compare the performance characteristics of engines with different displacement values. This is why it is of use to introduce a new quantity that will be proportional to the torque regardless of the engine size.

We define the mean effective pressure b_{mep} as the ratio between the effective work performed and the cylinder displacement for the same period of time, i.e.:

$$b_{mep} = \frac{P}{Q_{displacement}}$$

VI. RESULTS

1. Tabulate your results for three different throttle settings.
2. For each of the quantities listed below, plot and comment on the nature of the curves by comparing the results of the <u>three</u> <u>throttle</u> <u>settings</u>:

Torque vs. engine speed.
Power vs. engine speed.
Specific fuel consumption vs. engine speed.
Brake thermal efficiency vs. engine speed.
Volumetric efficiency vs. engine speed.
b_{mep} *vs. engine speed.*

3. From the above results carry out a set of sample calculations for full throttle at the *rpm* corresponding to the peak power and compare with experimental results.