3.0 ACTUAL ENGINE CYCLE

Reciprocating internal combustion engines operate on actual engine cycles, which are classified mainly into two groups: (i) Spark Ignition engines and (ii) Compression Ignition engines and these classifications are dependent on the mode of the ignition of the air/fuel mixture (charge) in the cylinder. The spark ignition engines operate based on the Otto cycle principle while the compression ignition engines operate basically on the Diesel cycle principle.

The sequence of operations required by a reciprocating engine to perform a mechanical work could either be two or four strokes of engine piston motion which translates to one or two crankshaft revolution respectively. The piston of a reciprocating internal combustion engine could be termed as double acting (as seen in steam engines) or single acting (as is seen in most reciprocating internal combustion engines). If the engine cycle of operation takes place in only one side of the piston, its termed single acting while it is termed double acting when the cycle takes place on both sides of the piston.

For an internal combustion engine to be efficient the following requirements are to be met:

- The mixture of fuel and air in the engine cylinder must be in the right proportion.
- Compression must take place on the mixture of air and fuel or air only before the addition of fuel (this is dependent on the engine cycle operation).
- The compressed mixture is to be ignited (which could be through the introduction of spark or auto-ignition) and the expanding combustion products used to drive the engine.
- Expulsion of the exhaust products must take place to give room for fresh charge intake.

3.1 PRINCIPLE OF OPERATION OF A FOUR STROKE ENGINE

Reciprocating internal combustion engines operating on a four stroke cycle require four strokes of the piston to complete an engine cycle of operation. The sequence of operation of in a four-stroke cycle is: induction stroke, compression stroke, power stroke and the exhaust stroke.

Induction Stroke

In a four-stroke engine, during the induction stroke, the inlet valve opens while the exhaust valve remains closed. In a spark ignition engines, a mixture of air and fuel is drawn in while in a compression ignition engine only air is drawn in during this stroke. In naturally aspirated engines, the process takes place as a result of the pressure difference between the cylinder and atmospheric pressure while in a supercharged or turbocharged engine, compressed air or a mixture of air and fuel is forced into the engine cylinder.

Compression Stroke

During this stroke in all reciprocating internal combustion engines, the intake and exhaust valves are closed and remain closed throughout this process. The fuel and air mixture in the case of a spark ignition engine and in the compression ignition engine, air alone is compressed during this process. At the top dead center (TDC), the charge occupies a volume equal to the clearance volume of the cylinder. In the case of a Spark Ignition (SI) engine, spark is timed to be initiated before TDC while in a compression ignition (CI) engine, injection of fuel is timed to start before TDC.

Power Stroke

The intake and exhaust valves remain closed during this process while the ignited charge combust and expand pushing the piston downward and useful mechanical work is developed during this process. Towards the Bottom Dead Center (BDC), the exhaust valves open and the product of combustion blow down the exhaust duct until the pressure in the cylinder has fallen to approximately the atmospheric pressure.

Exhaust Stroke

The piston changes direction towards the Top Dead Center (TDC) while the exhaust valve remains opened with the piston pushing out the remaining burned gas products through the engine cylinder swept volume. During the process, the in-cylinder pressure is slightly higher than the atmospheric pressure.

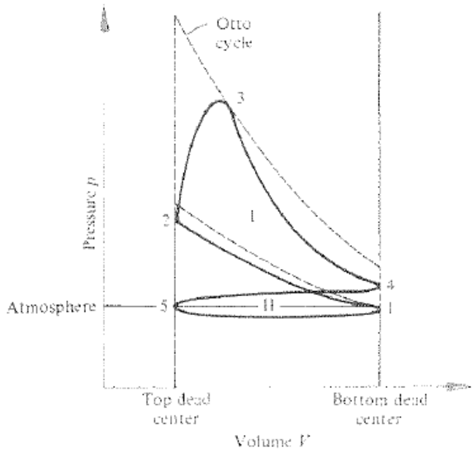

Figure 3.0: An actual four-stroke spark-ignition engine P-V diagram with the Otto cycle superimposed.

3.2 PRINCIPLE OF OPERATION OF A TWO STROKE ENGINE

Engines that operate on two-stroke cycles have their valves partly or fully replaced by ports which are opened and closed by the piston movements. The two stroke cycle carries out the same operation as the four-stroke cycle but completes the operation in two strokes or one revolution of crankshaft. The number of working strokes per second in a two stroke cycle engine is equal to the number of crankshaft revolution per second.

The two stroke operation can be described by the following:

(i) Compression and induction stroke

(ii) Power and exhaust stroke

Compression and Induction Stroke

The piston at BDC allows the inflow of pre-compressed charge into the cylinder. As the piston moves up it closes the intake and the exhaust ports and the compression of the charge takes place. Close to the Top dead Center (TDC), the charge is ignited and the charge combusts. While the piston moves up to the TDC, fresh charges are drawn into the crankcase of the engine to be pre-compressed.

Power and Exhaust Stroke

Close to TDC, the charge is ignited and the high pressure generated by the combusted charge force the piston downward which leads to the generation of useful work. Close to the end of the power stroke, the exhaust port opens and the burned gases are expelled to the atmosphere. When the piston moves to BDC, the inlet port is also opened the fresh charge moves in and helps in pushing out the burned gases.

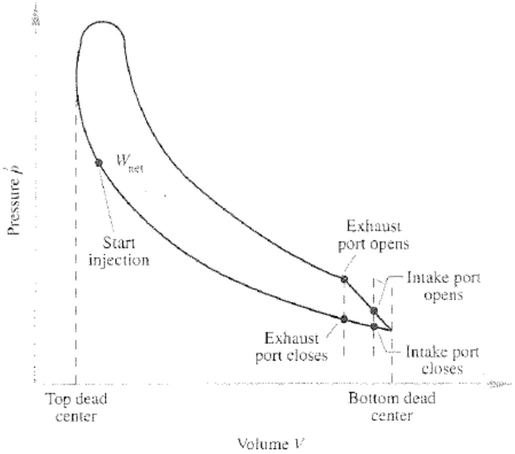

Figure 3.1: A P-V diagram for the two-stroke Diesel cycle (naturally aspirated)

3.3 ENGINE PERFORMANCE

The performance of an engine is determined by a lot of factors. The factors considered include: (i) indicated power (ip) (ii) brake power (bp) (iii) friction power (fp) (iv) indicated and brake mean effective pressures (mep) (v) mechanical and thermal efficiencies (vi) fuel consumption (specific fuel consumption) (vii) volumetric efficiency. The performance of an engine can be determined if the characteristics or parameters of the engine can be evaluated. The engine parameters may be obtained by the measurement of the engines quantities and the results plotted graphically in the form of performance curve.

3.3.1 Indicated Power

Indicated power can be defined as the rate of work done by the combusting charge on the piston as evaluated from the indicator diagram obtained from the engine. If the cross-sectional area of a piston is given as A and the expanding combusting charge in the engine cylinder exerts a pressure P on the piston's cross sectional area A, the total force exerted on the piston is given as: Force F = P.A (N).

Assuming the pressure exerted on the piston remains constant and the piston is forced through a distance L which is equal to 1 meter.

The work done W = FL = PAL.

If the piston makes n working strokes per second, then the work done per second is given as:

Power Developed = PLAn (W)

In real engine operation, the engine cylinder pressure is not constant throughout the cycle. The mean effective pressure of the engine cylinder is calculated and used as P. The power calculated from the in-cylinder engine pressure is called the indicated power.

Indicated Power (ip) = PLAn (W) or PLAn $*10^{-3}$ (KW).

The number of firing strokes per second in an engine is expressed as n while N represents the engine speed per second.

For a two-stroke engine n = N

For a four-stroke engine n = N/2

For a double acting engine n = 2N

QUESTION 1

Calculate the indicated power of a diesel engine running at 4200rpm; given that the mean effective pressure is 540KN/m^2 and the engine bore and stroke are 70mm and 105 mm respectively. The engine works on a four-stroke cycle and has 6 cylinders.

Solution

n = N/(60 X 2) = 4200/(120) = 35 rps

The indicated power per cylinder (ip) = $\frac{540 \times 1000 \times 0.105 \times \pi \times 0.07^2 \times 35}{1000 \times 4}$ = 7.637 KW

For the six cylinders, the indicated power developed = 6 X 7.637 = 45.82 KW.

3.3.2 Brake Power

The power available at the piston is the indicated power and it is measured by the indicator diagram. The useful power finally generated by the engine (available to the crankshaft) is lower than the indicated power because of the power used to overcome friction at the bearings and sliding parts.

The power output of the engine available to the engine crankshaft is known as the brake power or shaftpower. It is called brake power because it is measured by a brake at the crankshaft.

The difference between the indicated power and brake power is known as the friction power of the engine.

Friction Power fp = ip – bp

3.3.3 Mechanical Efficiency

The mechanical efficiency of an engine is defined as the ratio of the power available to the crankshaft to the power available at the piston i.e. the ratio of engine brake power to the indicated power.

Mechanical Efficiency $\eta_{th} = \frac{bp}{ip}$

QUESTION 2

A compression ignition engine has a bore of 0.1m, stroke of 0.12m and an indicated mean effective pressure of 500KN/m^2. Calculate the indicated power at the crank-speed of 3600 rpm. If the mechanical efficiency of this load and speed is 84%, compute the brake power output and the power lost from friction. The engine operates on a two-stroke cycle

Solution

Area of piston A = $\frac{\pi d^2}{4} = \frac{\pi (0.1)^2}{4}$ = 0.00785m^2

The indicated power (ip) = $\frac{500000 \times 0.12 \times 0.00785 \times 3600}{1000 \times 60}$ = 28.2 KW

The brake power (bp) = ip X η_{th} = 28.2 (0.84) = 23.7 KW

Friction power (fp) = 28.2 – 23.7 = 4.5 KW

3.4 BRAKE POWER MEASUREMENT

Brake power can be defined as the power output available to the crankshaft which could be measured by a rope brake. Work is done when resisting force F is overcome through a certain distance S, the amount of work being measured is a product of F and S. Power is defined as the rate of doing work.

Consider a rotating wheel of radius r in which a brake force F is applied at its rim, the product F.r is referred to as the resisting torque, T. Assuming the wheel rotates at a speed of N, rev/s against the braking force, then:

Work done per second = Force of Resistance x Distance overcome by force

$= F \times 2\pi r \times N$

The work done per second $= 2\pi N \times Fr$

$= 2\pi NT$

Thus, brake power $P_b = 2\pi NT = T\omega$ (Watts)

Where;

$T = Fr$ and $\omega = 2\pi N$

A rope is wound once round the rim of the drum fixed to the engine’s crankshaft. At one end of the rope a dead load is attached and at the other end a spring balance scale is attached. The direction of the crankshaft rotation is such that it is set against the dead weight. The engine is run at off load condition and gradually the load is added and increased until a steady load is attained when the engine runs at a steady speed.

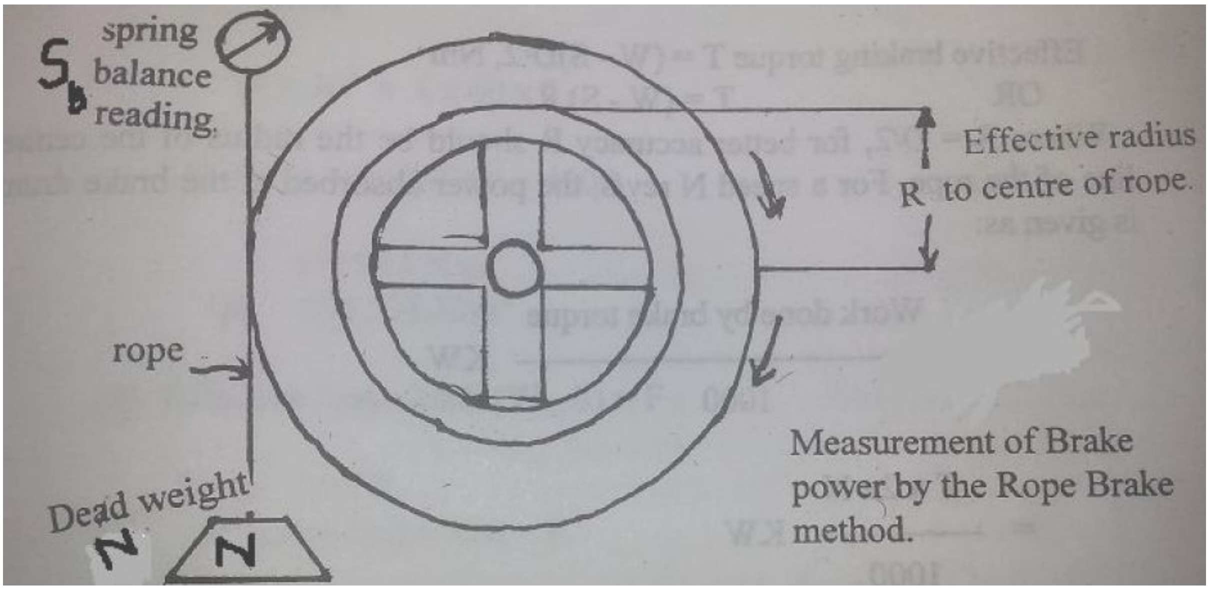

Figure 3.2: Brake power measurement

Readings are taken at this load.

N = dead load on the rope brake, N

S_b = the reading of the spring balance, N

D = the diameter of the brake wheel, N

The load is considered to act along the centreline of the rope, thus resisting torque due to the dead load= **N**D/2.

The torque as a result of the spring balance load S_b, which reduces the resisting torque because it acts in the same direction of the rotating wheel is expressed as : S_b (D/2) Nm

The effective braking torque, T $= (N-S_b)D/2$ Nm

$= (N-S_b)R$ Nm

For an engine with a speed of N rev/s, the power absorbed by the brake drum is given as:

$$BP = \frac{\omega T}{1000} KW$$

$$BP = \frac{2\pi NT}{1000} KW$$

QUESTION 3

A four cylinder, single acting internal combustion engine, working on a four stroke cycle develops an indicated power of 56KW at 4000rev/min. The cylinder diameter is 76 mm and the stroke 93 mm. Find the mean effective pressure in each cylinder. If the mechanical efficiency is 80% what effective brake load would be required if the effective brake drum diameter is 610 mm.

Solution

Indicated power IP $= P_i Lan$

P_i = IP/Lan

The indicated power for one cylinder IP = 56/4 = 14KW

$$P_i = \frac{14000 \cdot 60 \cdot 2}{\pi \cdot (0.038)^2 \cdot 0.093 \cdot 4000} = 9.9955 \text{ bar}$$

Recall,

Brake Power (BP) = 2Πnt and also,

$$BP = \eta_{mech} IP$$

η_{mech} = 80%

BP = 0.8 x 56 KW

BP = 44.8KW

The Engine Torque T = $\frac{BP}{2\pi N} = \frac{44.8 * 60}{2\pi * 4000}$

T = 106.952N-m

T = F.r= F.D/2

F = T/r = 106.952/0.305 = 350.66N.

The Effective Brake Load F = 350.6N