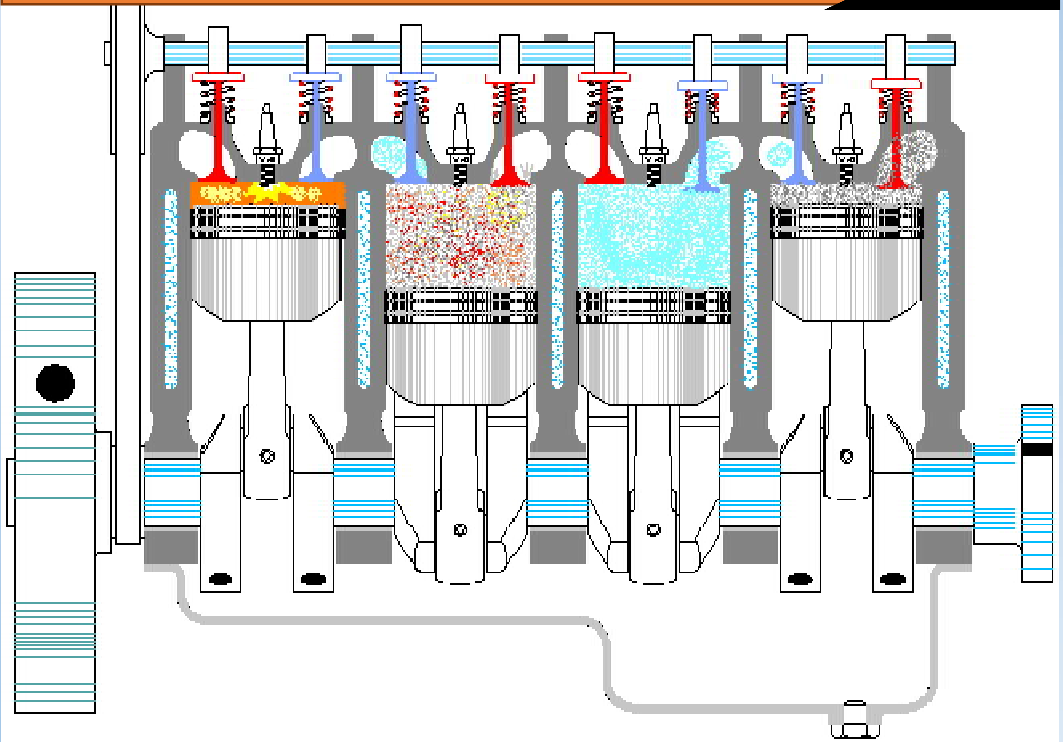
INTERNAL COMBUSTION ENGINES

THEORY AND CALCULATIONS



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Internal Combustion Engines: Theory and Calculations

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Internal Combustion Engines: Theory and Calculations

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FOREWARD

The book, **Internal Combustion Engines: Theory and Calculations** discussed both theory and calculations on internal combustion engines with simplified approach to assist students and teachers of Automobile Technology. The book consists of six chapters with ten exercises each.

Chapter one contains explanation on the classification, advantages and disadvantages of internal combustion engines. Chapter two deals with the details of the components of internal combustion engines and their functions. Chapter three explains two and four stroke cycle engines (petrol and diesel), differences between two and four stroke cycle engines, and differences between spark and compression ignition engines.

Chapter four centered on description and calculations on engine terminologies such as Top Dead Centre, Bottom Dead Centre, Bore, Piston Clearance, Piston Area, Swept Volume, Clearance Volume, Cylinder Volume and Compression Ratio. Chapter five contains definition, types and calculation on Engine Torque, Power and Efficiencies. Chapter six explains Engine Testing Parameters such as Speed, Power, Air Consumption, Fuel Consumption and Engine Volumetric Efficiency, as well as Instruments and their functions.

The book is recommended for both teachers and students as it will serve as a solid basis for understanding the theory and calculations of internal combustion engines.

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PREFACE

Textbook plays an important role in teaching and learning especially in Automobile Technology Education. It represents a useful resource for both teachers and learners. The scarcity of Automobile Technology textbooks to satisfy the educational needs and demands of Nigerian students posed a serious threat to the teaching and learning.

Professional teaching experiences attributed the shortage of textbooks on Automobile Technology to the shortage of Nigerian authors to address the challenge. This, combined with the need to encourage local authorship among teachers in the field of Automobile Technology spurred the development of **Internal Combustion Engines: Theory and Calculations.**

The book contains six chapters that covers Internal Combustion Engines, Components of Internal Combustion Engines, Two and Four Stroke Cycle Engines, Engine Terminologies, Engine Torque, Power and Efficiencies and Engine Testing. Each chapter is accompanied by a series of multiple items questions as exercise to measure students' understanding of the contents discussed in the book.

It is believed that, the contents of this book will be of significant assistance to both teachers and students of Automobile Technology in understanding the theory and calculations on internal combustion engines.

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CHAPTER ONE

INTERNAL COMBUSTION ENGINES

1.1 Introduction

Internal combustion engine is the type of engine in which the burning of fuel takes place inside the engine cylinder. It is a heat engine that converts chemical energy in a fuel into mechanical energy that move the vehicle which is usually made available on a rotating output shaft.

The chemical energy of the fuel is first converted to heat energy by means of burning of fuel mixture inside the engine. When the fuel burns inside the engine cylinder, it generates a high temperature and pressure. This high-pressure force is exerted on the piston (in the case of reciprocating engine) thereby, transmitting the pressure to the crankshaft through connecting rod which causes the wheels of vehicle to rotate. In these engines we can use only gases and high volatile fuel like petrol and diesel. These engines are generally used in automobile industries. A typical internal combustion engine is shown in Figure 1.1.

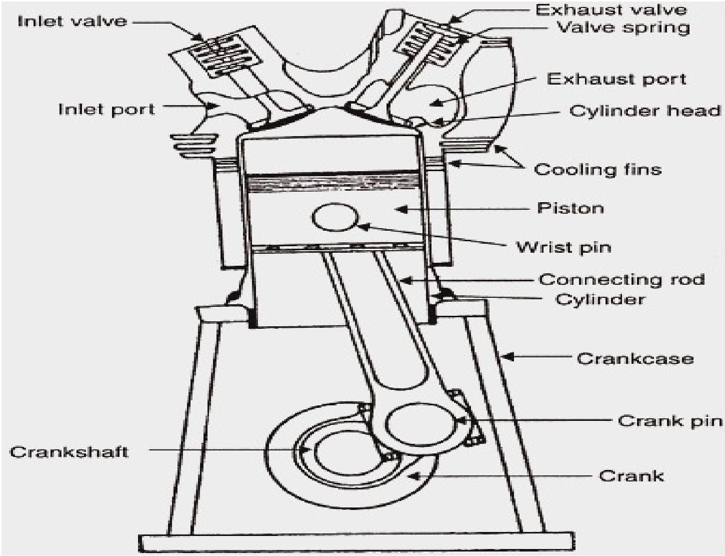

Figure 1.1: Internal Combustion Engine
Source: Denise (2020)

1.2 Classification of Internal Combustion Engines

Internal Combustion Engines may be classified according to the following parameters: number of stroke, design of engine, fuel used, method of ignition, number of cylinder, arrangement of cylinder, air intake process and cooling process.

1.2.1 According to Number of Stroke: Automobile engine could be classified as two stroke or four stroke cycles.

- **Two Stroke Engine**: In a two stroke engine the piston moves one time up and down inside the cylinder and complete one crankshaft revolution during single time of fuel injection. This type of engine has high torque compare to four stroke engine. These are generally used in motorcycles.

- **Four Stroke Engine:** In a four stroke engine, the piston moves two times up and down inside the cylinder and complete two crankshaft revolutions during single time of fuel burn. This type of engines has high average developed power compare to two stroke engine. These are generally used in light and heavy commercial vehicles.

1.2.2 According to Engine Design: Automobile engine could be reciprocating (piston) or rotary (wankel) engine.

- **Reciprocating Engine (Piston):** In reciprocating engines, power is generated by reciprocation (upward and downward movement) of the piston as a result of fuel combustion. The piston starts reciprocating motion (to and fro or up and down motion). This reciprocating motion is converted into rotary motion by the use of crank shaft. As the crank shaft starts to rotate, power that is used to drive the wheels of the vehicle is generated. This type of engine is generally used in all automobiles.

- **Rotary Engine (Wankel):** This engine is developed by Wankel in 1957. In rotary engine there is a rotor which is free to rotate. The pressure force generated by burning of fuel is exerted on this rotor. As the rotor rotates, it starts to rotate the wheels of vehicle. This engine is not commonly used in automobiles in present days.

1.2.3 According to Fuel Used: Automobile engine could be diesel, petrol or gas engines.

- **Diesel Engine:** Diesel engines are the type of automobile engine that uses diesel as fuel and are commonly refer to Compression Ignition Engine (CIE). These engines are mostly used in heavy duty vehicles and in some cases, buses, cars and tricycles.
- **Petrol Engine:** Petrol engines are the type of automobile engine that uses petrol as fuel and are commonly refer to Spark Ignition Engine (SIE). These engines are mostly used in bikes, light cars, tricycles and in some cases, in trucks.
- **Gas Engine:** Gas engines are the type of automobile engine that uses Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG) as fuel. These engines are mostly used in some light vehicles and tricycles.

1.2.4 According to Method of Ignition: Automobile engines could be compression ignition or spark ignition engine.

- **Compression Ignition Engine (CIE):** This type of engine uses diesel as fuel and have no extra equipment to ignite the fuel. Burning of fuel occurs due to temperature rise during compression of air.
- **Spark Ignition Engine (SIE):** Thistype of engine uses

petrol as fuel and ignition of fuel occurs by the means of spark generated inside the cylinder by extra equipment (Spark Plug).

1.2.5 According to Number of Cylinder: Automobile engines could be single or multi-cylinder.

- **Single Cylinder Engine:** This type of engines has only one cylinder and one piston connected to the crank shaft.
- **Multi-Cylinder Engine:** This type of engines has more than one cylinder and piston connected to the crank shaft

1.2.6 According to Arrangement of Cylinder: Automobile engines could be in-line, V-type, horizontal opposed cylinder, W-type, opposite piston or radial engines.

- **In-line Engine:** This type of engine has cylinders positioned in a straight line one behind the other along the length of the crankshaft.
- **V-type Engine:** This type of engine has two banks of cylinder inclined to each other at an angle forming V-shape and with one crankshaft.
- **Opposed Cylinder Engine:** This type of engine has two cylinders banks opposite to each other on a single crankshaft at 180^0 angle between the cylinder banks.

- **W-type Engine** This type of engine is similar to V-type engine except this has three banks of cylinders on the same crankshaft known as W-type engine.
- **Opposite Piston Engine:** This type of engine consists of two pistons in each cylinder with the combustion chamber in the center between the pistons.
- **Radial Engine:** This type of engine has pistons positioned in circular plane around the central crankshaft.

1.2.7 According to Air Intake Process: Air intake process in automobile engines could be naturally aspirated, supercharged and turbocharged engine.

- **Naturally Aspirated Engine:** In this types of engine, intake of air into the engine cylinder occur by the means of atmospheric pressure.
- **Supercharged Engine**: In this type of engine, the pressure of air intake into the engine cylinder is increased by the compressor which is driven by the engine crankshaft.
- **Turbocharged Engine**: In this type of engine, the pressure of air intake is increase by use of a turbine compressor driven by the exhaust gases from the engine cylinder.

1.2.8 According to Cooling Methods: Automobile engines could be Air or water cooled.

- **Air Cooled Engine:** This type of engine uses Air as medium for cooling. Large quantity of Air circulates naturally around the engine components to carry away heat. In some instances, fan or blowers are used to direct Air to the engine components.
- **Water Cooled Engine:** This type of engine uses water as medium for cooling. In liquid cooled engine, water jackets are provided around the cylinder and on the cylinder head of the engine to allow circulation of water to carry away heat from the engine.

1.3 Advantages of Internal Combustion Engines

The following are the advantages of internal combustion engines:

1. Size of engine is reduced compared to external combustion engines
2. Power to weight ratio is high
3. Very suitable for small power requirement applications
4. Usually more portable than their counterpart external combustion engines
5. Safer to operate
6. Starting time is very less
7. High efficiency than external combustion engine
8. No chances of leakage of the working fluids

9. Requires less maintenance
10. Lubricant consumption is less as compared to external combustion engines
11. In case of reciprocating internal combustion overall working temperature is low because peak temperature is reached for only small period of time (only at detonation of fuel).

1.4 Disadvantages of Internal Combustion Engines

The following are the disadvantages of internal combustion engines:

1. Variety of fuels that can be used is limited to very fine quality gaseous and liquid fuel
2. Fuel used is very costly like gasoline or diesel
3. Engine emissions are generally high compared to external combustion engine
4. Not suitable of large scale power generation
5. In case of reciprocating internal combustion noise is generated due to detonation of fuel.

1.5 Exercise 1.0:

Q1. The type of engine where combustion of fuel mixture takes place inside the engine cylinder is called……..?

a. External combustion engine
b. Heat engine
c. Internal combustion engine
d. Turbine engine

Q2. Automobile engines used the following as fuel except:

a. Charcoal
b. Diesel
c. Gas
d. Petrol

Q3. Air intake process in automobile engines could be the following except…….:

a. Electronically
b. Naturally aspirated
c. Supercharged
d. Turbocharged

Q4. Automobile engine could be classified as:

a. One or two stroke cycles
b. Three or four stroke cycles
c. Two stroke or four stroke cycles
d. Two or three stroke cycles

Q5. Automobile engine could be cooled using:

a. Air or Diesel
b. Air or freeze
c. Air or water
d. Water or Petrol

Q6. Automobile engine design could be:

a. Circular or reciprocating engine
b. Circular or rotary engine
c. Reciprocating or rotary engine
d. Rotary or straight engine

Q7. Automobile engine that uses Petrol as fuel is known as:

a. Combination of both compression and spark ignition
b. Compression ignition engine
c. Spark ignition engine
d. All of the above

Q8. Automobile engine that uses Diesel as fuel is known as:

a. Combination of both compression and spark ignition engine
b. Compression ignition engine
c. Spark ignition engine
d. All of the above

Q9. The following are automobile engine cylinder arrangement except:

a. Horizontal opposed cylinder arrangement
b. In-line cylinder arrangement
c. V-cylinder arrangement
d. Z-cylinder arrangement

Q10. The following are the advantages of internal combustion engines except:

a. Safer to operate
b. Starting time is very less
c. High efficiency
d. Requires frequent maintenance

CHAPTER TWO

COMPONENTS OF INTERNAL COMBUSTION ENGINES AND THEIR FUNCTIONS

2.1 Introduction

Basically, a typical internal combustion engine consists of the following components:

1. Cylinder block
2. Cylinder
3. Cylinder liners
4. Cylinder head
5. Gasket
6. Crankcase
7. Oil sump
8. Manifold
9. Piston
10. Piston ring
11. Gudgeon pin/Piston ring
12. Connecting rod
13. Crankshaft
14. Engine Bearing

15. Valve
16. Camshaft
17. Flywheel

2.2 Cylinder Block

Description: The cylinder block is the main component of the engine. It is a solid casting that contains a number of cylinders, depending on the type and specification of the engine, the crankcase, the cylinders, the coolant passages, the lubricating passages, and in the case of flathead engines, the valves seats, the ports, and the guides. It constitutes the basic and supporting portion of the engine power unit. Cylinder block is shown in Figure 2.1.

Function(s): The function of cylinder block is to provide space in which the piston can operate to draw in the fuel mixture or air (whether it is spark ignition or compression ignition), compress it, allow it to expand and thus generate power.

Material(s): The cylinder block is usually made of high-grade cast iron. In some cases, to give it greater strength and wear resistance with less weight, chromium, nickel and molybdenum are added to the cast iron. Another material used for cylinder blocks, although not extensively, is aluminum. Aluminum is used whenever weight is a consideration.

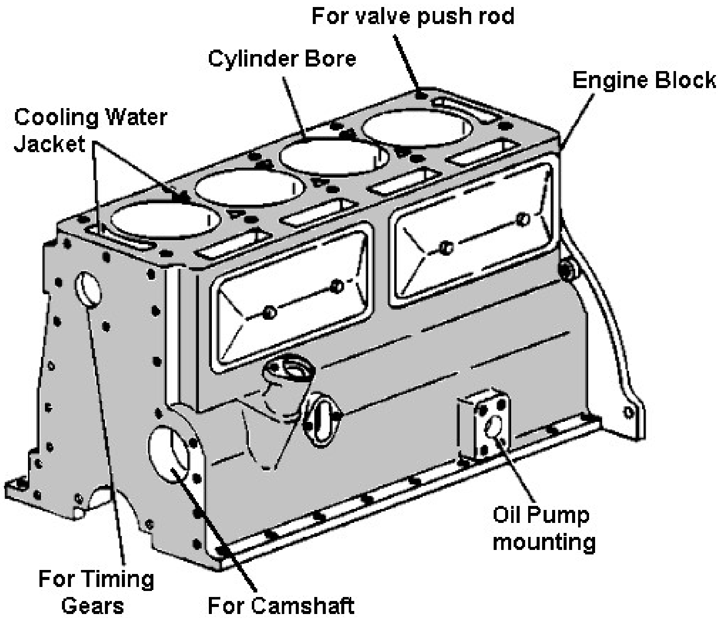

Figure 2.1: Engine Cylinder Block
Source: Themet (2020)

2.3 Cylinders

Description: Cylinders are the cylindrical part of the engine that houses the cylinder liners as well as the pistons. It is the portion of the cylinder block where the piston reciprocates, fuel burn and turned into power. Generally, engine with more cylinders produce more power than engine with fewer cylinders and engine with fewer cylinders have better fuel economy than engines with more cylinders.

Function(s): The function of cylinder is to provide space where the conversion of thermal energy to mechanical work takes place. Cylinders must be able to withstand high pressure and temperature, dissipate heat and resist wear and tear.

Material(s): Material selection is an import consideration. Ordinary cast iron is used in light duty engines but in heavy duty engines alloy steels are used.

2.4 Cylinder Liners

The cylinder liners are replaceable cylindrical component designed to protect the engine cylinder from wearing away due to the reciprocating of the piston. The inner surface of the cylinder liner is properly heat-treated in order to obtain a hard surface to reduce wear. Cylinder liners, are metal pipe shaped inserts that fit into the cylinder block.

Function(s): Cylinder liners act as cylinder walls for the piston to slide up and down on.

They are also installed in the engine cylinder block to repair badly damaged cylinder walls in cast iron blocks. There are basically two types of cylinder liners which includes the following:

1. Dry cylinder liner and
2. Wet cylinder liner.

2.4.1 Dry Cylinder Liner: A dry cylinder liner is the type of liner which does not have any direct contact with the engine cooling water. A dry cylinder liner is shown in Figure 2.2a.

2.4.2 Wet Cylinder Liner: A wet cylinder liner is the type of liner which have its outer surface in direct contact with the engine cooling water**.** A wet cylinder liner is shown in Figure 2.2b.

Material(s): The cylinder liners are made from good quality close grained cast iron (*i.e.* pearlitic cast iron), nickel cast iron, nickel chromium cast iron. In some cases, nickel chromium cast steel with molybdenum may be used. Cast iron sleeves are commonly used in aluminum cylinder blocks.

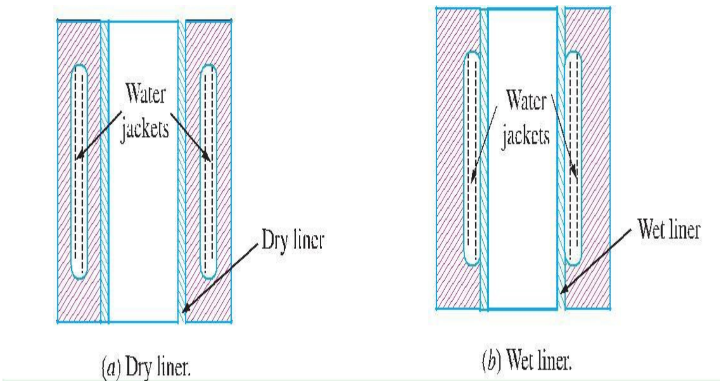

Figure 2.2: Dry andWet Cylinder Liners

2.5 Cylinder Head

Description: The cylinder head is attached to the cylinder block by means of studs fixed to the block. There are two holes or ports at the cylinder head, one for intake of fuel and other for exhaust. Both the intake and exhaust ports are closed by the two valves known as inlet and exhaust valve. The inlet valve, exhaust valve, spark plug, injector etc. are bolted on the cylinder head. It also contains a combustion chamber above each cylinder and incorporates passages for the flow of cooling water as shown in Figure 2.3.

Function(s): The main function of cylinder head is to seal the cylinder block and not to permit entry and exit of gases on cover head valve engine.

Material(s): Cylinder head is usually made from cast iron or aluminum. It is made by casting or forging and usually in one piece.

Figure 2.3: Cylinder Head
Source: Yamaha Motors (2019)

2.6 Gasket

Gaskets are mechanical seals which fills the space between two or more mating faces to prevent leakage from or into the joint objects. Gaskets are used to provide a tight fitting joint between two surfaces.

2.6.1 Requirements of a Gasket

The requirements/properties of the gasket are as follows:

Conformity: Gaskets should conform to the mating surfaces which may have roughness or warpage.

Resistance: Gasket should have resistance to high pressures, extreme temperature, vibrations and to chemicals such as fuel, products of combustion, coolant and engine oil.

Impermeability: The gasket must be impermeable to the fluid.

Provision of openings: The gasket must have openings for any studs, bolts and other contents such as coolant, lubricants air, exhaust etc.

Function(s):

There are several gaskets in automobile engines performing different functions related to their type that include: cylinder head, oil sump, oil pump and manifold gaskets.

2.6.2 Cylinder head gasket

The cylinder head gasket seals the joint between the cylinder head and the cylinder crankcase as shown in Figure 2.4.

2.6.3 Oil sump gasket

The oil sump gasket seals the joint between oil sump and the crankcase.

2.6.4 Oil pump gasket

The oil pump gasket seals the joint between oil pump and the cylinder block.

2.6.5 Manifold gasket

The manifold gasket seals the joint between manifolds (inlet and exhaust) and the cylinder block.

Material(s): The various materials used for gaskets are: Asbestos, Copper, Steel, and synthetic rubber.

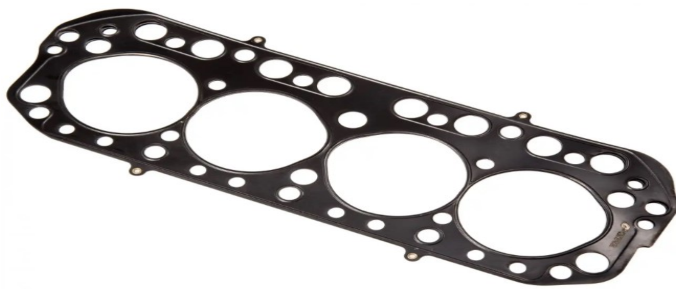

Figure 2.4: Cylinder Head Gasket
Source: Med Engineering (2020)

2.7 Crankcase

Description: The crankcase is a rigid construction shaped like a box having no bottom that forms part of the cylinder block below the cylinders. The crankcase also has mounting brackets to support the entire engine on the vehicle frame. These brackets are either an integral part of the crankcase or are bolted to it in such a way that they support the engine at three or four points. These points are cushioned by rubber mounts that insulate the frame and body of the vehicle from engine vibration. This prevents damage to engine supports and the transmission. Crankcase can be casted integrally with the block or separately and attached to the block with bolts. A typical separate crankcase is shown in Figure 2.5.

Function(s): The function of the crankcase is to:

1. Provide support for the main journals and bearing of the crankshaft
2. Maintaining the alignment of their axes of rotation under various engine loads
3. Provides the mounting surface for the cylinders, the oil pump and oil sump, forms passages for lubricating oil
4. It also supports and encloses the crankshaft.

Material(s): The crankcase is made of grey cast iron and in some cases, it is made of aluminum since it needs the ability to dissipate large amounts of heat.

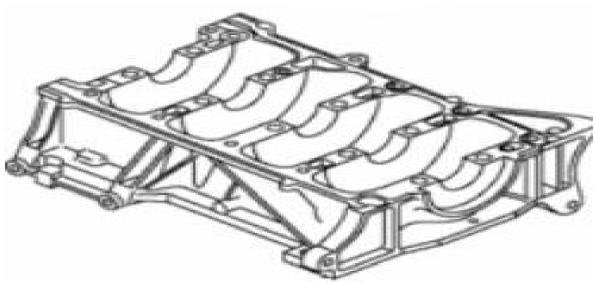

Figure 2.5: Separate Crankcase
Source: Media Engine (2019)

2.8 Oil Sump

Description: Oil sump is the bottom half of the crankcase attached through set screws and with a gasket to make the joint leak proof. The oil sump serves as a reservoir for the storage, cooling and ventilation of engine lubricating oil. The oil pump in the lubricating system draws oil from the oil sump and sends it to all working parts in the engine. Oil sump have a drain plug at the bottom to drain out the dirty oil at the time of oil replacement.

Function(s): The various functions of the oil sump are as follows:

1. Store the engine oil for the lubrication system.
2. Collect the returning engine oil for lubricating other engine parts.
3. Serve as container for impurities or foreign particles.
4. Serves as a medium for cooling the engine oil used for lubricating.

Material(s): Generally, oil sump is made of pressed steel sheet or aluminum alloy casting.

2.9 Manifolds

Description: Manifolds are separate sets of pipes attached to the cylinder head which carry the air-fuel mixture and the exhaust gases. Manifold consist of flanges to connect the engine with the silencer and carburetor. The manifold consists of passages designed with smooth walls and a minimum of bends that collect fuel to reduce the condensing of the mixture. There are two types of manifold in automobile engine that include:

1. Inlet manifold and
2. Exhaust manifold

2.9.1 Inlet Manifold

Inlet manifold on petrol engine carries air-fuel mixture from the carburetor and distributes it to the cylinders and carries only air into the cylinders on diesel engine. Inlet manifold is shown in figure 2.6.

Functions(s): Inlet manifold is designed to perform the following functions:

1. Deliver the air (in the case of diesel engine) and air-fuel mixture (in the case of petrol engine) to the cylinders in equal quantities and proportions
2. Aid in the vaporization of the air-fuel mixture
3. Help to keep the vaporized air-fuel mixture from condensing before it reaches the combustion chamber.

Material(s): The intake manifold can be made of cast iron, aluminum or plastic.

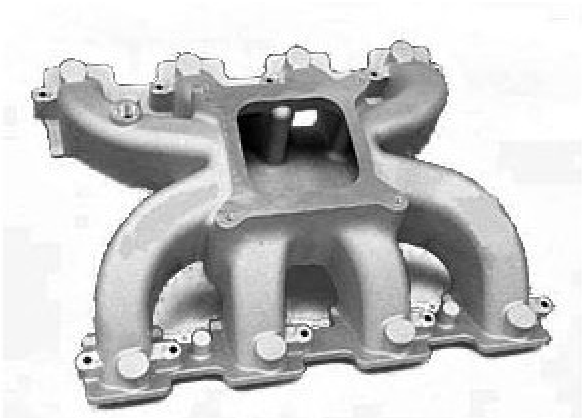

Figure 2.6: Inlet Manifold
Source: Scott (2020)

2.9.2 Exhaust Manifold

The exhaust manifold connects all of the engine cylinders to the rest of the exhaust system. Exhaust manifold is shown in figure 2.7.

Function(s): Exhaust manifolds convey the burnt gases from the engine cylinder to the atmosphere via other exhaust system components.

Material(s): Exhaust manifolds are generally made of cast iron so as to withstand the high temperature of the exhaust gases.

Figure 2.7: Exhaust Manifold
Source: Scott (2020)

2.10 Piston

Pitons are most important engine parts compared to other. The piston is a cylindrical plug that moves up and down in the cylinder. Pistons are forged with cooling space inside to allow engine oil to carry away heat generated. The piston is closed at one end and open on the other end to permit direct attachment of the connecting rod and its free action. It is connected to the connecting rod by a gudgeon pin. A typical piston is shown in figure 2.8.

2.10.1 Piston Parts

Piston comprises of the following parts:

1. **The piston head:** Piston head is the top of the piston and is exposed to the heat and pressure of combustion. This area must be thick enough to withstand these forces. It must

also be shaped to match and work with the shape of the combustion chamber for complete combustion.

2. **The piston skirt:** Piston skirt is the side of the piston below the last ring. Piston skirt consist of space for gudgeon pin which transmit power to the connecting rod. It also helps in transferring the side thrust produced by the connecting rod. Piston skirts are also provided to prevent the piston from tipping and jamming in the cylinder. Piston skirt could be slipper or straight.

i. **The slipper skirt:** Provides clearance between the piston and the crankshaft counterweights that allow the piston to slide farther down in the cylinder without hitting the crankshaft. Slipper skirt is produced when portions of the piston skirt below the piston ends are removed.

ii. **The straight skirt**: Is flat across the bottom, a style no longer common in automotive engines.

3. **The Piston ring grooves:** Piston ring grooves are slots machined in the piston to accommodate the piston rings. The upper two groves accommodate the compression rings while the lower piston groove accommodate the oil ring.

4. **The Piston oil hole**: Piston oil hole in the bottom ring groove allow the oil to pass through the piston and onto the cylinder wall.

5. **The piston ring lands**: Piston ring lands are the areas between and above the ring grooves. They separate and support the piston rings as they slide on the cylinder.

6. **The piston boss**: Piston boss is a reinforced area around the piston pin hole. It must be strong enough to support the piston pin under severe loads.

7. **The piston pin hole**: Piston pin hole is machined through the pin boss for the piston pin. It is slightly larger than the piston pin.

2.10.2 Qualities of a Piston

The following are the qualities of a piston**:**

1. Rigidly to withstand high pressure and temperature
2. Light in weight, to reduce the reciprocating mass to perform at higher engine speed.
3. Good heat conductivity.
4. Less noise while operating.

Function(s): Some of the important function of the piston are as follows:

1. It helps to convert heat energy obtained by the combustion of fuel into useful mechanical power.
2. It transfers this power to the crankshaft through connecting rod.

3. It forms a seal so that high-pressure combustion gases do not escape to the crankcase.
4. It serves as a support for the small end of the connecting rod.
5. It sucks the charge and push out the exhaust gases.

Material(s): Cast iron and Aluminum alloy are the chief materials used for the construction of piston. Cast iron is chosen due to its high compressive strength and Aluminum alloy are preferred mainly due to it lightness.

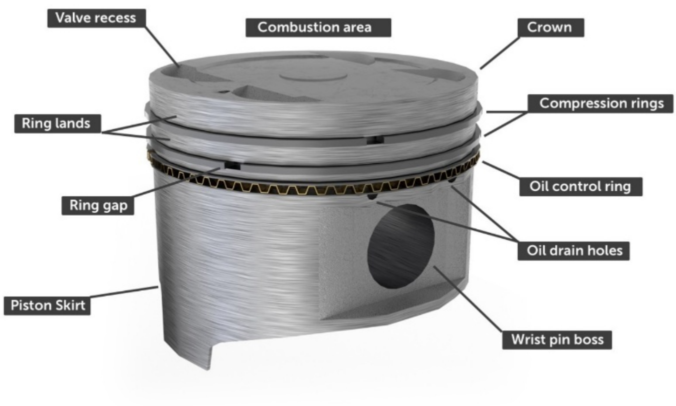

Figure 2.8: Piston
Source: Hassan (2017)

2.11 Piston Rings

Description: The piston rings are fitted in grooves which have been cut in the piston. They are split at one end so they can expand or slipped over the end of piston.

Materials: Piston rings are made of cast iron of fine grain and high elastic material which is not affected by the working heat. Sometimes it is made from alloy spring steel.

Function(s): Generally, piston rings perform the following functions:

1. Forms a gas tight combustion chamber for all positions of piston.
2. Reduces contact area between cylinder wall and piston wall preventing friction losses and excessive wear.
3. Controls the cylinder lubrication.
4. Transmits the heat away from the piston to the cylinder walls.

2.11.1 Types of Piston Ring

Basically, there are of two types of piston rings that include, compression and oil scrapping ring.

- **Compression Ring:** Compression rings are usually plain, single piece and are always placed in the grooves of the piston nearest to the piston head. They prevent leakage of gases from the cylinder and helps increasing compression pressure inside the cylinder.
- **Oil Scrapping Ring:** Oil scrapping rings are grooved or slotted and are located either in lowest groove above the piston pin or in a groove above the piston skirt.

They control the distribution of lubrication oil in the cylinder and the piston

2.12 Gudgeon/Piston Pin

Description: The gudgeon pin also called the wrist pin is generally hollow and tubular in form. It fits through the hole in the piston and the connecting rod small end.

Function(s): Gudgeon pin perform the basic function of connecting the piston to the small end of the connecting rod.

Material: Low carbon case hardened steel is used for the construction of gudgeon pin**.** This steel comprises of 0.15% Carbon, 0.30% Silicon, 0.50% Manganese and 99.05% Iron.

2.13 Connecting Rod

Description: Connecting rod consists of two ends; one is known as big end and other as small end as shown in Figure 2.9. The big end is connected to the crankshaft and the small end is connected to the piston by use of gudgeon pin.

Function: Connecting rod connects the piston to crankshaft and transmits the motion and thrust of piston to crankshaft. It converts the reciprocating motion of the piston into rotary motion of crankshaft.

Materials: The connecting rods are made of nickel, chrome, and chrome vanadium steels. For small engines the material may be aluminum.

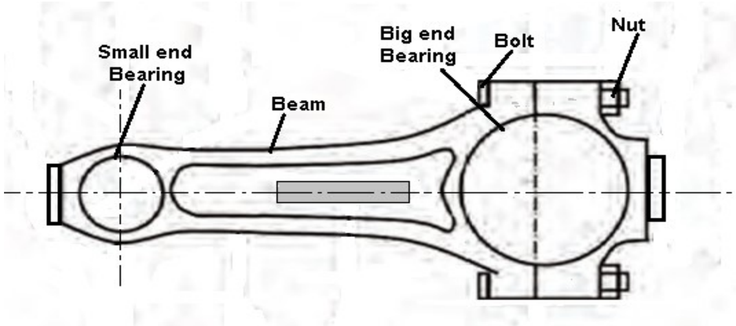

Figure 2.9: Connecting Rod
Source: Saif (2018)

2.14 Crankshaft

Description: Crankshaft is an integral part of an internal combustion engines located in the bottom of the engine. It is connected to the big end bearing of the connecting rod and have flywheel attached to it at one end. Crankshafts consists of crank web, oil passage, flywheel mounting flange, main journal, crank pin, counter weight and keyway. Crankshaft can range in size from just a few centimeters long (for small engines) to up to 15 or even 16 meters long (mostly for use in marine diesel engines). A crankshaft is shown in figure 2.10.

Function(s): Crankshaft converts the reciprocating motion of the piston into rotary motion. It also transmits power through the flywheel, clutch, transmission and differential to drive the vehicle.

Material: Crankshaft is usually made by steel forging, but some makers use special types of cast-iron such as spheroidal graphitic or nickel alloy castings which are cheaper to produce and have good service life.

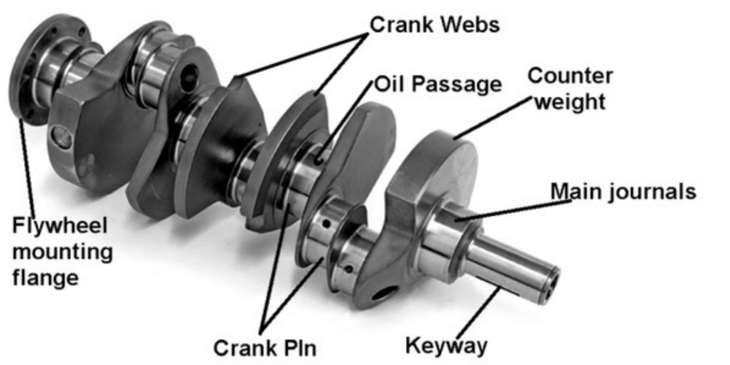

Figure 2.10: Crankshaft
Source: Iran (2016)

2.15 Engine Bearing

Description: Everywhere there is rotary action in the engine, bearings are needed. Bearings are used to support the moving parts. The crankshaft is supported by bearing. The connecting rod big end is attached to the crank pin on the crank of the crankshaft by a bearing.

Function(s): The main function of bearings is to reduce friction between these moving parts. In an IC engine, sliding and rolling types of bearing used. The sliding type bearing which are sometime called bush is use to attach the connecting rod to the piston and crankshaft. They are split in order to permit their assembly into the engine.

Materials: The typical bearing half is made of steel or bronze back to which a lining of relatively soft bearing material is applied.

2.16 Valves

Description: Valves are integral part of an internal combustion engine located either onthe cylinder head or on the cylinder block of the engine. The valves are fitted in the port at the cylinder head by the use of strong spring to keep them closed. The number of valves in an engine depends on the number of cylinders. Valve actuating mechanism includes the engine camshaft, the camshaft followers (tappets), the pushrods, and the rocker arms. Two valves are used for each cylinder known as inlet and exhaustvalves respectively. The inlet valve is always larger than the exhaust valve to allow adequate fuel into the engine cylinder. A valve is shown in figure 2.11.

Function(s): The function of inlet valve is to allow the mixture of air and petrol or air only to enter into the engine cylinder. The function of exhaust valve is to allow the exhaust or burnt gases to escape from the engine cylinder.

Materials: Generally, valves are made from carbon steel alloys, stainless steels, high strength nickel-chromium stainless alloy and titanium.

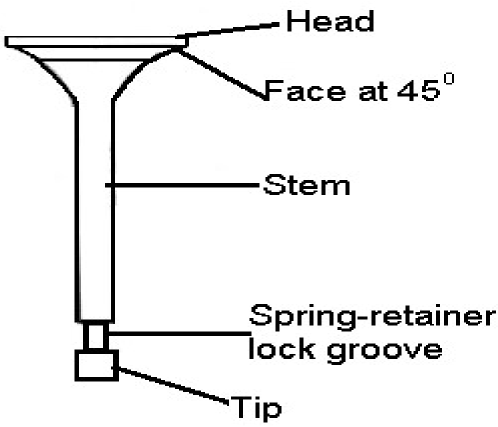

Figure 2.11: A Valve
Source: Edwards (2019)

2.17 Camshaft

Description: The camshaft itself is forged from one piece of steel, on which the lobes are ground. On single-camshaft engines there are twice as many lobes as there are cylinders, plus a lobe for fuel pump actuation and a drive gear for the distributor. The camshaft is driven by the crankshaft, usually through a set of gears or a chain or belt. The camshaft always rotates at half of crank revolution per minute (rpm), taking two full rotations of the crankshaft to complete one rotation of the cam, to complete a four-stroke cycle. For proper engine output inlet valve should open at the end of exhaust stroke and closed at the end of intake stroke. So to regulate its timing, a cam is use which is oval in shape and it exerts a pressure on the valve to open and release to close. A camshaft is shown in figure

2.12.

Function(s): The camshaft performs the following functions:

1. Drives the distributor to electrically synchronize spark ignition.
2. Operates the lifters (also called tappets or cam followers) that in turn operate the rest of the valve train.
3. Control the opening and closing of valves at proper timing.

Materials: Camshafts are made from cast iron or steel and can be mostly found in the head of an engine, nestled above the cylinders.

Figure 2.12: A Camshaft
Source: Summit (2018)

2.18 Flywheel

Description: Flywheel is a round metallic disc with ring gear at it outer edge. It is mounted at the rear of the crankshaft near the rear main bearing.

Function(s): Flywheel perform the following functions:

1. Stores energy from the power strokes and smoothly delivers it to the drive train of the vehicle between the engine and the transmission.
2. Ensures fewer fluctuations in speed and smoother engine operation.
3. Serves as mating surface for the clutch assembly on vehicle equipped with manual transmission.
4. Supports the front of the torque converter on vehicles equipped with automatic transmission
5. Engages the drive gear on the starter motor for cranking the engine.

Materials: The flywheels are generally made of cast iron and forged steel or forged aluminum. Flywheel of large and low speed engines are usually made of cast iron while small and high-speed engines usually use the forged steel or forged aluminum flywheel.

2.19 Exercise 2.0:

Q1. …………act as cylinder walls for the piston to slide up and down on

a. Cylinder
b. Cylinder block
c. Cylinder head
d. Cylinder liner

Q2. Mechanical seals which fills the space between two or more mating faces are called……..?

a. Crankshaft
b. Cylinder
c. Gasket
d. Sump

Q3. The sets of pipes attached to the cylinder head which carry the air-fuel mixture and the exhaust gases are called………?

a. Crankcase
b. Cylinder block
c. Manifolds
d. Oil gallery

Q4. Piston comprises of the following parts except………..

a. Casing
b. Groove
c. Head
d. Skirt

Q5. ……….. converts the reciprocating motion of the piston into rotary motion

a. Connecting rod
b. Crankshaft
c. Gudgeon pin

d. Piston

Q6. The engine component that provide space in which the piston operates is………?

a. Cylinder
b. Cylinder block
c. Cylinder head
d. Cylinder liner

Q7. ……… is the cylindrical part of the engine that houses the cylinder liners as well as the pistons

a. Cylinder
b. Cylinder block
c. Cylinder head
d. Cylinder liner

Q8. ……….. provides support for the main journals and bearing of the crankshaft

a. Connecting rod
b. Crankcase
c. Cylinder head
d. Gudgeon pin

Q9. The component fitted into piston grooves is……..

a. Piston head
b. Piston skirt
c. Piston rings
d. Piston

Q10. ………… connects the piston to the small end of the connecting rod

a. Connecting rod
b. Crankshaft
c. Gudgeon pin
d. Piston hole

CHAPTER THREE

TWO AND FOUR STROKE ENGINES

3.1 Introduction

A two stroke engine is a type of internal combustion engine which completes a power cycle with two strokes (i.e. up and down movements) of the piston during only one revolution of the crankshaft. In a two-stroke engine, the end of the power stroke and the beginning of the compression stroke happen simultaneously.

3.2 Two Stroke Engine Cycles of Operation

The cycles of operations of two stroke engine consists of intake, crankcase compression, transfer/exhaust, compression and power.

Intake: The fuel/air mixture is first drawn into the crankcase by the vacuum that is created during the upward stroke of the piston.

Crankcase Compression: During the downward stroke, the poppet valve is forced closed by the increased crankcase pressure. The fuel mixture is then compressed in the crankcase during the remainder of the stroke.

Transfer/Exhaust: Toward the end of the stroke, the piston exposes the intake port, allowing the compressed fuel/air mixture in the crankcase to escape around the piston into the main cylinder. This expels the exhaust gasses out the exhaust port, usually located on the opposite side of the cylinder. Unfortunately, some of the fresh fuel mixture is usually expelled as well.

Compression: The piston then rises, driven by flywheel momentum, and compresses the fuel mixture. (At the same time, another intake stroke is happening beneath the piston).

Power: At the top of the stroke, the spark plug ignites the fuel mixture. The burning fuel expands, driving the piston downward, to complete the cycle. (At the same time, another crankcase compression stroke is happening beneath the piston).

3.3 Petrol Engine Two Stroke Cycle

The principle of two stroke cycle of petrol engine is shown in Figure 3.1.

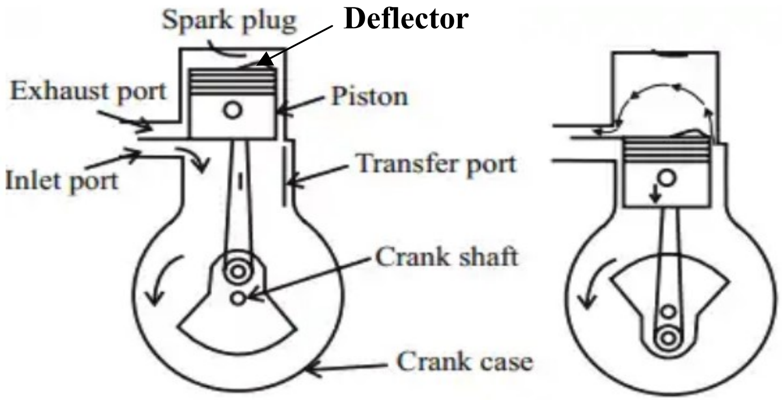

Figure 3.1: Diagram of Petrol Engine Two Stroke Cycle of Operation
Source: Vikash (2019)

Upward Stroke

During the upward stroke, the piston moves from BDC to TDC, compressing the air and petrol mixture in the cylinder. Due to upward movement of the piston, a partial vacuum is created in the crankcase, and a new charge (mixture of air and petrol) is drawn into the crankcase through the uncovered inlet port. The exhaust port and transfer port are covered when the piston is at the TDC position. The compressed charge is ignited in the combustion chamber by a spark provided by the spark plug.

Downward Stroke

As soon as the charge is ignited, the hot gases forces the piston to move downwards, rotating the crankshaft, thus doing the useful work. During this stroke, the inlet port is covered by the piston and the new charge is compressed in the crankcase. Further downward movement of the piston uncovers the exhaust port and then the transfer port. The burnt gases escape through the exhaust port. As soon as the transfer port opens, the compressed charge from the crankcase flows into the cylinder. The charge is deflected upwards by the hump provided on the head of the piston and pushes out most of the exhaust gases. The incoming air and petrol mixture helps the removal of burnt gases from the engine cylinder.

3.4 Diesel Engine Two Stroke Cycle

The principle of diesel engine two stroke cycle is shown in Figure 3.2.

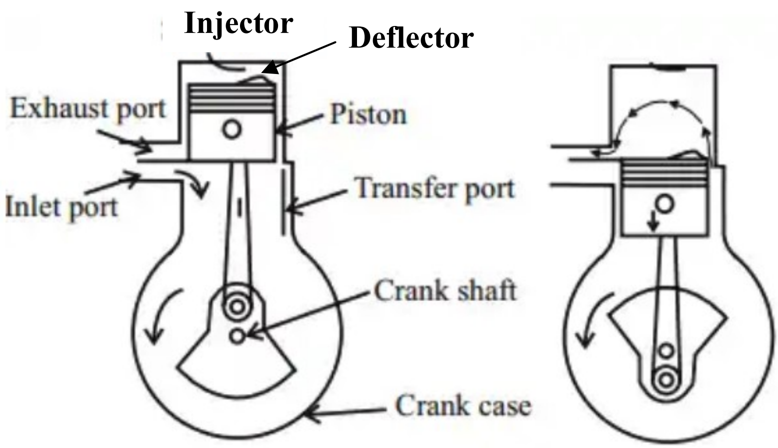

Figure 3.2: Diagram of Diesel Engine Two Stroke Cycle of Operation

Source: Vikash (2019)

Upward Stroke

During the upward stroke, the piston moves from Bottom Dead Centre (BDC) to Top Dead Centre (TDC) compressing only Air in the cylinder. Due to upward movement of the piston, a partial vacuum is created in the crankcase, and fresh Air is drawn into the crankcase through the uncovered inlet port. The exhaust port and transfer port are covered when the piston is at the TDC position. The highly compressed air is ignited in the combustion chamber by the spray of diesel fuel from the injector.

Downward Stroke

As soon as the charge is ignited, the combustion of fuel forces the piston to move downwards, rotating the crankshaft, thus doing the useful work. During this stroke, the inlet port is covered by the piston and the fresh Air is compressed in the crankcase. Further downward movement of the piston uncovers the exhaust port and then the transfer port. The burnt gases escape through the exhaust port. As soon as the transfer port opens, the compressed Air from the crankcase flows into the cylinder. The charge is deflected upwards by the hump provided on the head of the piston and pushes out most of the exhaust gases. The incoming Air helps the removal of burnt gases from the engine cylinder.

3.5 Four Stroke Engine

A four-stroke cycle engine is an internal combustion engine that utilizes four distinct piston strokes (intake, compression, power, and exhaust) to complete one operating cycle. The piston makes two stroke (upward and downward movement of the piston in the engine cylinder) to complete one operating cycle. An operating cycle requires two revolutions (720°) of the crankshaft. The four-stroke cycle engine is the most common type of small engine. The four stroke engine are of two types and these are: Diesel and Petrol four stroke engines.

3.6 Petrol Engine Four-Stroke Cycle

The petrol engine four-stroke cycle include: intake, compression, power and exhaust strokes as shown in Figure 3.3.

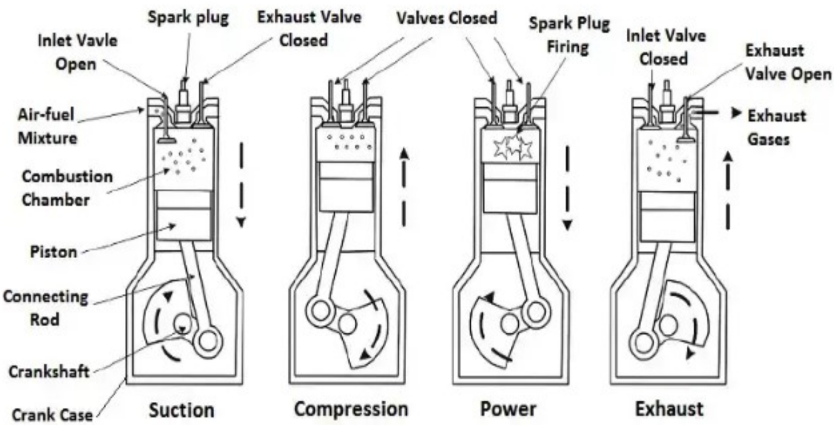

Figure 3.3: Petrol Engine Four-Stroke Cycle

Source: Saif (2019)

Intake/Suction Stroke: During the intake stroke, inlet valve opens while exhaust valve remains closed with the piston at the TDC moving to the BDC. This movement of the piston create an increasing volume in the combustion chamber, which in turn creates a vacuum. The resulting pressure difference between the vacuum created inside the engine cylinder and the atmospheric pressure causes proportionate mixture of Air and Petrol to be pushed into the cylinder.

Compression Stroke: During the compression stroke, both valves remain closed with the piston at the BDC moving to the TDC. The movement of piston from BDC to TDC causes compression of Air and Petrol mixture in the engine cylinder. The compression of Air and Petrol mixture raises both the pressure and temperature in the cylinder ready for the introduction of spark to initiate combustion.

Power Stroke. During the power stroke, both valves remain closed with the piston at the TDC. The spark plug introduces spark of suitable intensity into the engine cylinder containing highly compressed mixture of Air and Petrol. The introduction of spark into the engine cylinder causes the combustion of the highly compressed Air and Petrol mixture. The combustion of Air and Petrol mixture causes the forceful movement of the piston to the BDC. This movement of the piston is responsible for rotating the crankshaft and moving the vehicle as well.

Exhaust Stroke. During the exhaust stroke, exhaust valve opens while the inlet valve remains closed with the piston at the BDC moving to the TDC. The pressure and temperature in the engine cylinder are still high relative to the surroundings at this point. The pressure difference is created through the exhaust system which is open to atmospheric pressure. This pressure difference causes much of the hot exhaust gas to be pushed out of the cylinder and through the exhaust system.

3.7 Diesel Engine Four-Stroke Cycle

In diesel engines four-stroke cycle, there are four strokes completing two revolutions of the crankshaft. These are respectively, the intake, compression, power and exhaust strokes as shown in Figure 3.4.

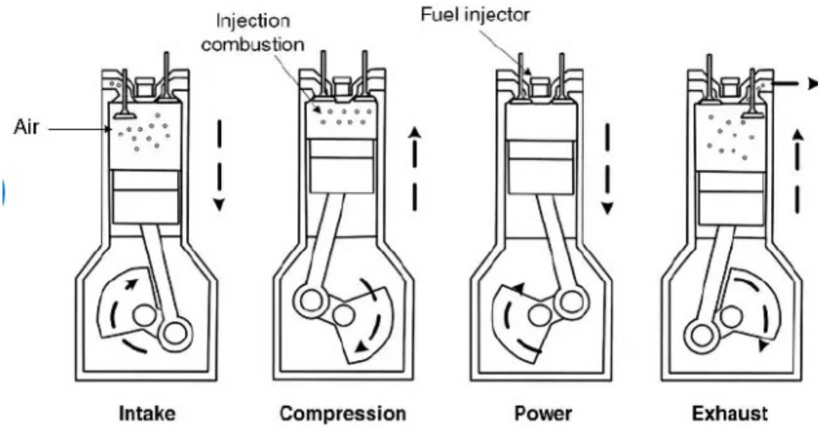

Figure 3.4: Diesel Engine Four-Stroke Cycle
Source: Saif (2019)

Intake Stroke: During this stroke, inlet valve opens while exhaust valve remains closed with the piston at the TDC moving to the BDC. This movement of the piston create an increasing volume in the combustion chamber, which in turn creates a vacuum. The resulting pressure difference between the vacuum created inside the engine cylinder and the atmospheric pressure causes only air to be pushed into the cylinder. As the air passes through the intake system, fuel is added to it in the desired amount by means of fuel injectors.

Compression Stroke: During this stroke, both valve remain closed with the piston at the BDC moving to the TDC. The movement of piston from BDC to TDC causes compression of air in the engine cylinder. The compression of air raises both the pressure and temperature in the cylinder. As the air is progressively compressed in the cylinder, its temperature increases, until when near the end of the compression stroke, it becomes sufficiently high (650-80O^{o}C) to instantly ignite any fuel that is injected into the cylinder. The compression ratio usually varies from 14:1 to 22:1 and the pressure at the end of the compression stroke ranges from 30 to 45 kg/cm^2.

Power Stroke. During this stroke, both valve remain closed with the piston at the TDC. Fuel mixture is introduced into the engine cylinder. The introduction of fuel into the engine cylinder containing highly compressed air causes combustion. The hot products of combustion consisting chiefly of carbon dioxide, together with the nitrogen left from the compressed air expand, thus forcing the piston to the BDC which produces the work output of the engine cycle. During power stroke, the pressure falls from its maximum combustion value (47-55kg/cm^2), which is usually higher than the greater value of the compression pressure (45 kg/cm^2), to about 3.5-5 kg/cm2 near the end of the stroke.

Exhaust Stroke. During this stroke, exhaust valve opens while the inlet valve remains closed with the piston at the BDC moving to the TDC. The pressure and temperature in the engine cylinder are still high relative to the surroundings at this point. The pressure difference is created through the exhaust system which is open to atmospheric pressure. This pressure difference causes much of the hot exhaust gas to be pushed out of the cylinder and through the exhaust system.

3.8 Differences Between Two Stroke and Four Stroke Engines

Table 3.1: Differences between Two Stroke and Four Stroke Engines

S/N	Two Stroke Engine	Four Stroke Engine
1	One revolution of crankshaft complete a power stroke	Two revolutions of crankshaft complete a power stroke
2	It can generate high torque	It generates less torque
3	Charges are partially burnt in the engine cylinder	Charges are fully burnt in the engine cylinder in ideal condition.

4	Less thermal efficiency.	High thermal efficiency
5	High power to weight ratio	Lower power to weight ratio
6	Uses ports (inlet and exhaust)	It used valves (inlet and exhaust)
7	Easy lubrication due to lubrication oil mix with the fuel	Comparatively complicated lubrication
8	More lubricating oil is required because some oil burns with fuel.	Comparatively less lubricating oil is required
9	Require lighter flywheel compare to other engines because it generates more balanced force due to one revolution for one power stroke	Requires heavy flywheel because it generates unbalance force due to two revolutions for one power stroke
10	Creates much mechanical noise	Creates less mechanical noise
11	Less efficient	More efficient
12	Generate more smoke	Generate less smoke
13	Comparatively cheaper in construction	More expensive in construction
14	Easy to manufacture	difficult to manufacture
15	Generally lighter in weight	Heavier in weight
16	Mostly used in motorcycles	Mostly used in cars, truck, and other automobiles
17	Liable to more wear and	Less wear and tear

	tear due to poor lubrication	

3.9 Difference Between Spark Ignition Engine and Compression Ignition Engine

Table 3.2: Difference between Spark Ignition Engine and Compression Ignition Engine

S/N	**Spark Ignition Engine**	**Compression Ignition Engine**
1	Spark is used to burn the fuel-air mixture	Heat of compressed air is used to burn the diesel fuel
2	Petrol is used as fuel	Diesel is used as fuel
3	It operates on Otto cycle	It operates on Diesel cycle
4	High speed engines	Low speed engines
5	Low pressure is generated	High pressure is generated

	after combustion	after combustion
6	Low compression ratio	High compression ratio
7	High thermal efficiency	Less thermal efficiency
8	Spark plug is used to produce spark for the ignition	Heat of compressed air is used for the ignition
9	Constant volume during cycle	Constant pressure during cycle
10	Air and fuel gets into the engine cylinder	Only Air gets into the engine cylinder
11	Lighter in weight	Heavier in weight
12	Produces less mechanical noise	Produces high mechanical noise
13	Less Hydrocarbon is produced	More hydrocarbon is produced
14	Easy starting	Difficult starting
15	Low maintenance cost	High maintenance cost
16	Less prone to vibration problem	Highly prone to vibration problem
17	Less volume to power ratio	High volume to power ratio
18	Less initial cost	High initial cost
19	Uses carburetor to supply fuel	Uses injector to supply fuel
20	Used in light commercial vehicles and motorcycle	Used in heavy duty vehicles likes bus, trucks and ships

3.10 Exercise 3.0:

Q1. The type of internal combustion engine which completes a power cycle with two strokes is called…………..?

a. Four stroke engine
b. One stroke engine
c. Three stroke engine
d. Two stroke engine

Q2. The type of internal combustion engine that utilizes four distinct piston strokes is called………..?

a. Four stroke engine
b. One stroke engine
c. Three stroke engine
d. Two stroke engine

Q3. …………gets into the engine cylinder during induction stroke in a diesel engine

a. Air and diesel
b. Only air
c. Only diesel
d. All of the above

Q4. …………introduces spark into the engine cylinder during power stroke in a petrol engine

a. Injector
b. Spark plug
c. Valve
d. All of the above

Q5. ………….gets compressed in the engine cylinder during compression stroke in a diesel engine

a. Air and diesel
b. Only air
c. Only diesel
d. All of the above

Q6. One revolution of crankshaft complete a power stroke in………..?

a. Four stroke engine
b. One stroke engine
c. Three stroke engine
d. Two stroke engine

Q7. Two revolutions of crankshaft complete a power stroke in………..?

a. Four stroke engine
b. One stroke engine
c. Three stroke engine
d. Two stroke engine

Q8. ………… uses inlet and exhaust ports

a. Four stroke engine
b. One stroke engine
c. Three stroke engine
d. Two stroke engine

Q9. ……… uses inlet and exhaust valves

a. Four stroke engine
b. One stroke engine
c. Three stroke engine
d. Two stroke engine

Q10. Four stroke engine possesses the following advantages except………?

a. Comparatively cheaper in construction
b. Creates less mechanical noise
c. Generate less smoke
d. More efficient

CHAPTER FOUR

ENGINE TERMINOLOGIES

4.1 Introduction

Engine terminologies associated to the internal combustion engines. These terms include: Top Dead Center, Bottom Dead Center, bore, piston clearance, piston area, swept volume, clearance volume, cylinder volume and compression ratio among others. Some of these terminologies are indicated in figure 4.1.

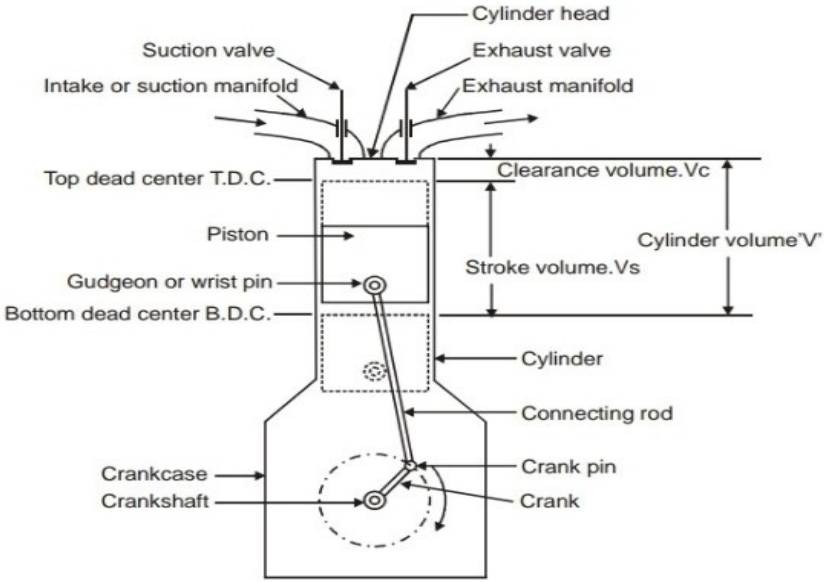

Figure 4.1: Engine Terminologies

4.1.1 Top Dead Center: TheTop Dead Center (TDC)is the highest position the piston reaches in the engine cylinder.

4.1.2 Bottom Dead Centre: The Bottom Dead Centre (BDC) is the lowest position the piston reaches in the engine cylinder.

4.1.3 Bore: The bore is the nominal inner diameter of the working engine cylinder.

4.1.4 Piston Clearance: Piston clearance is the amount of space between the sides of the piston and the cylinder wall. It allows a lubricating film of oil to form between the piston and the cylinder and also allows for expansion when the piston heats up.

4.1.5 Piston Area (A): The area of a piston is the total size of the surface equal to engine cylinder diameter (bore). The SI unit is cm^2. Mathematically, it is express as:

$$\textbf{Area} = \pi/4 \times D^2$$

Where:

$\pi = 3.143$

D = Engine cylinder diameter

Example: calculate the area of an engine cylinder with radius of 4cm.

Solution:

$$\text{Area} = \pi/4 \times D^2$$

$$= 3.143/4 \times (4 \times 2)^2$$

$$= (.786) \times (64)$$

$$= 50.3 \text{ cm}^2$$

4.1.6 Swept Volume: This is the volume that the piston displaces during its movement from BDC to TDC. Mathematically, it is express as:

$$\textbf{Swept Volume} = (\pi/4)\, D^2LN$$

Where:

$\pi = 3.143$

D = Cylinder bore in cm

L = Stroke length in cm

N = Number of cylinder

4.1.7 Clearance Volume: Is the volume left above the TDC. This is the space left when the piston reaches its' highest limit of travel in the engine cylinder. It tells how much cylinder volume is compressed. Mathematically, it is express as:**Clearance Volume =** Cylinder Volume - Swept Volume.

4.1.8 Cylinder Volume: Is **t**he sum of swept volume and clearance volume. Mathematically, it is express as: **Cylinder Volume =** Clearance Volume + Swept Volume.

4.1.9 Compression Ratio: The ratio of maximum volume to minimum volume of cylinder is known as the compression ratio. In other words, compression ratio is the numerical value of the cylinder volume divided by the numerical value of clearance volume. It is 8 to 12 for spark ignition engine and 12 to 24 for compression ignition engine. Mathematically, it is express as: **Compression Ratio =** Total Cylinder Volume/ Clearance Volume.

Example: A four-cylinder engine with a 10 cm bore diameter and 8 cm stroke length, is said to have a total cylinder volume of 3147 $cm^{3.}$ Determine the piston swept volume, clearance volume and compression ratio. Take π = 3.143

Solution:

Swept Volume = $(\pi/4)\ D^2LN$

$= (\pi/4) \times 10^2 \times 8 \times 4$

$= (.786) \times 100 \times 8 \times 4$

Answer = 2515.2 cm3

Clearance Volume = Cylinder Volume - Swept Volume

= 3147 -2512.2

Answer = 634.8 cm

Cylinder Volume = Swept Volume + Clearance Volume

= 2512.2 + 634.8

Answer = 3147

Compression Ratio = Total Cylinder Volume/ Clearance Volume

= 3147/634.8

Answer = 4.9575

4.1.10 Exercise 4.0:

Q1. The highest position the piston reaches in the engine cylinder is called………?

a. Bottom Dead Centre
b. Highest Dead Centre
c. Lowest Dead Centre
d. Top Dead Centre

Q2. The lowest position the piston reaches in the engine cylinder is called………?

a. Bottom Dead Centre
b. Highest Dead Centre
c. Lowest Dead Centre
d. Top Dead Centre

Q3. ……… is the nominal inner diameter of the working engine cylinder

a. Bore
b. Clearance volume
c. Piston clearance
d. Swept volume

Q4. ………… is the amount of space between the sides of the piston and the cylinder wall

a. Bore
b. Clearance volume
c. Piston clearance
d. Swept volume

Q5. ……….is the total size of the surface equal to engine cylinder diameter

a. Clearance volume
b. Piston area
c. Piston clearance
d. Swept volume

Q6. ………… is the volume that the piston displaces during its movement from BDC to TDC

a. Clearance volume
b. Piston area

c. Piston clearance
d. Swept volume

Q7. The space left when the piston reaches its' highest limit of travel in the engine cylinder is ……..?

a. Clearance volume
b. Piston area
c. Piston clearance
d. Swept volume

Q8. The ratio of maximum volume to minimum volume of cylinder is known as……..?

a. Compression ratio
b. Cylinder volume
c. Piston volume
d. Swept volume

Q9. $(\pi/4)\ D^2LN$ is the formula for………..?

a. Compression ratio
b. Cylinder volume
c. Piston volume
d. Swept volume

Q10. Calculate the area of an engine cylinder with radius of 3cm

a. $50.3\ cm^2$
b. $55.6\ cm^2$
c. $63.7\ cm^2$

d. 67.4 cm^2

CHAPTER FIVE

ENGINE TORQUE, POWER AND EFFICIENCY

5.1 Engine Torque

Torque (T) is an important measure of engine performance. It is the force applied on some point to cause a turning effect. In an engine, the piston applies a torque to the crankshaft through the connecting rod and crankshaft when it is moving down on the power stroke. The amount of torque depends on the pressure exerted by the piston and the length of the crankshaft. The greater the pressure on the piston, the greater the torque. Torque should not be confused with power. Torque is the twisting effort that the engine applies through the crankshaft, whereas power is the rate at which the engine does work. The unit of torque is kg/m. Mathematically, it is express as: Torque (T) = F x r

Where:

F = Force
r = distance of force from the centre of shaft

Example: A of pressure 50 kg exerted on the piston with .5m diameter. Calculate the torque produced by the crankshaft.

Solution:

F = 50
r = .25 (.5/2)
T = 50 x .25
= 12.5 kg/m

5.2 Engine Power

Power is the rate at which work is done. The rate at which the engine can do work is measured in horse power (HP). Engine horsepower is the maximum power that an engine can put out. It can be expressed in kilowatts or horsepower.

5.2.1 Factors Affecting the Power Output of an Engine:

The output of an engine depends on several factors among which include: displacement, compression ratio, gas flow and engine speed.

1. **Displacement:** Engine power output increases with engine displacement (other factors constant). A given displacement can be obtained with fewer cylinders of greater individual displacement or with greater number of cylinders of smaller displacement.
2. **Compression Ratio (CR)**: Reduction in cylinder volume increases the CR and high CR results to greater the power output. Engine design considerations and fuel characteristics limit the maximum compression that can be obtained.
3. **Gas flow**: Restricted gas flow limits engine performance as well as the power output. The intake manifold should be shaped and arranged in such a way that it does not retard the flow.
4. **Engine Speed:** Since one power stroke is produced per cycle, engine power output tends to increase with engine speed.

5.2.2 Types of Engine Power

There are several categories of horsepower, the most common includes indicated, brake and frictional horse power:

5.2.2.1 Indicated Horse Power (IHP): It is the power generated in the engine cylinder and received by the piston. It is the power developed in a cylinder without accounting frictional losses. The amount of power that can be measured on the flywheel is always less than the powergenerated in the engine on account of expansion of the combusted fuel. Mathematically, it is express as:

IHP = pLAN

Where:

p = Mean effective pressure in kg/cm2
L = Stroke length in m
A = Area of cylinder in cm2
N= Shaft speed (for a four stroke engine N = rpm/2 and for a two-stroke engine N = rpm).

Example:
Test on a four-cylinder engine produce the following results:
Mean effective pressure (p)= 500 kPa
Stroke (L) = 80 mm
Cylinder diameter (D) = 80 mm
Shaft speed = 2000 rpm
Calculate the Indicated Horse Power of the engine. Take π = 3.143

Solution:

IHP = PLAN

$= 500 \times (80/1000) \times (3.143/4 \times (80/1000)^2) \times (2000/60)/2$
$= 500 \times 0.08 \times 0.00503 \times 16.67$

= 3.35 kw per cylinder

IHP for four cylinders **=** 3.35 x 4 = **13.4 kw**

Note:

Stroke (L) = 80/1000

Area (A) = 3.143/4 x $(80/1000)^2$

Shaft speed = (2000/60)/2

5.2.2.2 Brake Horse Power (BHP): It is the power delivered by the engine at the end of the crankshaft. It is measured by a dynamometer. Mathematically, it is express as:

$$\textbf{BHP} = 2\,\pi NT$$

Where:

T = Torque in kg.m

N = Shaft speed, rev/s

Example: Test on a four-cylinder engine produce the following results:

Shaft speed (N) = 2000 rev/min

Shaft distance (r) = .3 m

Force on the shaft (F) = 180 N

Calculate the Brake Horse Power of the engine. Take π = 3.143

Solution:

BHP = 2πNT

= 2 x 3.143 x (2000/60) x (180 x .3)

= 6.286 x 33.3 x 54

= **11303.5 w**

= **11. 30kw**

Note: Shaft speed (N) = 2000/60 = 3.3 rev/sec and Torque (T) = 180 X .3 kg/m

5.2.2.3 Friction Horse Power (FHP): It is the power required to run the engine at a given speed without producing any useful work. It represents the friction and pumping losses of an engine. Mathematically, it is express as:

FHP = mfC x CV

Where:

mf = fuel consumption, kg/s
CV = calorific value, kJ/kg

Example

Test on a four-cylinder engine produce the following results:

Fuel consumption (mf), 2 g/s
Calorific value (CV), 20 J/kg
Calculate the Friction Horse Power of the engine

Solution:

FHP = mf x CV
= (2/1000) x (20 x 1000)
= 0.002 x 200000
= **40 kw**

5.3 Engine Efficiency

Engine efficiency is the relationship between the total energy contained in the fuel and the amount of energy used to perform useful work. Engine thermal efficiency could be seen as the dimensionless performance measure of a device that uses thermal energy such as internal combustion engine.

5.3.1 Types of Engine Efficiency

Basically, there are three types of engine thermal efficiency that include: indicated, brake and mechanical thermal efficiencies.

5.3.1.1 Indicated Thermal Efficiency (ηith): Indicated thermal efficiency is the ratio of energy in the indicated power to the frictional power. It tells how much Mathematically, indicated thermal efficiency is given by:

ηith = Indicated Power/ Frictional Power x 100

5.3.1.2 Brake Thermal Efficiency (ηbth): A measure of overall efficiency of the engine is given by the brake thermal efficiency. Brake thermal efficiency is the ratio of energy in the brake power to the frictional power. Mathematically, brake thermal efficiency is given by:

ηbth = Brake Power / Frictional Power x 100

5.3.1.3 Mechanical Thermal Efficiency (ηmth): Mechanical thermal efficiency is the ratio of brake horse power (delivered power) to the indicated horse power (power provided to the piston). Mathematically, mechanical thermal efficiency is given by:

ηmth = Brake Power / Indicated Power x 100

Example:

Test on a four-cylinder engine produce the following results:

Mean effective pressure (p)= 500 kPa
Stroke (L) = 80 mm
Cylinder diameter (D) = 80 mm
Shaft speed = 2000 rpm
Shaft speed (N) = 2000 rev/min
Shaft distance (r) = .3 m
Force on the shaft (F) = 180 N
Fuel consumption (mf), 2 g/s
Calorific value (CV), 20 J/kg

Calculate the indicated, brake and mechanical thermal efficiencies of the engine. Take π = 3.143

Solution:

IHP = PLAN

$= 500 \times (80/1000) \times (3.143/4 \times (80/1000)^2) \times (2000/60)/2$

$= 500 \times 0.08 \times 0.00503 \times 16.67$

= 3.35 kw per cylinder

IHP for four cylinders **=** 3.35 x 4 = **13.4 kw**

BHP $= 2\pi NT$

$= 2 \times 3.143 \times (2000/60) \times (180 \times .3)$

$= 6.286 \times 33.3 \times 54$

= **11303.5 w**

= **11. 30kw**

FHP = mf x CV

= (2/1000) x (20 x 1000)

= 0.002 x 20000

= **40 kw**

ηith = Indicated Power/ Frictional Power x 100

= 13.4/40 x 100

= 33.5%

ηbth = Brake Power / Frictional Power x 100

= 11.30/40 x 100

= 28.25%

ηmth = Brake Power / Indicated Power x 100

= 11.30/12.4

= 84%

5.4 Exercise 5.0:

Q1. The force applied on some point to cause a turning effect is called…….?

a. Area
b. Force
c. Momentum
d. Torque

Q2. A of pressure 40 kg exerted on the piston with .4m diameter. Calculate the torque produced by the crankshaft

a. 8kg/m
b. 10 kg/m
c. 16 kg/m

d. 20 kg/m

Q3. The rate at which the engine can do work is measured in ………?

a. Horse power
b. Kilogram
c. kilowatt
d. Watt

Q4. The output of an engine depends on the following factors except………

a. Compression ratio
b. Displacement
c. Gas flow
d. Temperature

Q5. The power generated in the engine cylinder and received by the piston is called…..?

a. Brake Horse Power
b. Engine power
c. Friction Horse Power
d. Indicated Horse Power

Q6. Test on a four-cylinder engine produce the following results:

- Mean effective pressure (p)= 400 kPa
- Stroke (L) = 60 mm
- Cylinder diameter (D) = 70 mm

- Shaft speed = 1800 rpm

Calculate the Indicated Horse Power of the engine. Take π = 3.143

a. 5.616 kw
b. 56.16 kw
c. 561.6 kw
d. 5616 kw

Q7. The power delivered by the engine at the end of the crankshaft is called…..?

a. Brake Horse Power
b. Engine power
c. Friction Horse Power
d. Indicated Horse Power

Q8. Test on a four-cylinder engine produce the following results:

- Shaft speed (N) = 2200 rev/min
- Shaft distance (r) = .4 m
- Force on the shaft (F) = 200 N

Calculate the Brake Horse Power of the engine. Take π = 3.143

a. 1.847 kw
b. 18.47 kw
c. 184.7 kw
d. 1847 kw

Q9. The power required to run the engine at a given speed without producing any useful work is called…….?

a. Brake Horse Power
b. Engine power

c. Friction Horse Power
d. Indicated Horse Power

Q10. Test on a four-cylinder engine produce the following results:

- Fuel consumption (mf), 2.5 g/s
- Calorific value (CV), 25 J/kg

Calculate the Friction Horse Power of the engine

a. 6.25 kw
b. 62.5 kw
c. 625.1 kw
d. 6251 kw

CHAPTER SIX

INTERNAL COMBUSTION ENGINE TESTING

6.1 Introduction

The testing of Internal Combustion (IC) Engines is the process of assessing the performance and operation of the engine in the efficient manner. There are various parameters which can be measured for testing of IC Engines. The testing of the engine is necessary for understanding the efficient operation of the engine and the engine components. The operation of the new engine depends upon the surface finish, tolerance and lubrication and cooling system. The engine performance can be improved by adjustment of the various parameters and proper settings of all components of the engine.

The engine condition can deteriorate as the engine operates for length of the service and some components wear out. The condition of these components due to wear and tear can be assessed during testing and such components can be replaced by new components. The testing of the engine provides improvement in the performance of the engine by increasing the efficiency and fuel economy of the engine. The continuous testing of engine can maintain fuel efficient operation of the engine and help in diagnosis of the failures of parts or components. During the testing of IC Engines, there are various instrument used for measurement of engine parameters. The various parameters measured during the test are:

1. Speed
2. Power
3. Air consumption

4. Fuel consumption
5. Volumetric Efficiency of Engine

6.2 Speed Testing

Engine speed should be held as constant as far as possible by means of applied dynamometer load at wide open throttle, or by throttle adjustment at part load. The speed of the engine can be measured at the crankshaft of the engine in revolution per minute (RPM). The instruments used for measurement of engine speed are:

a. Tachometer
b. Stroboscope
c. Sensor

6.2.1 Tachometer: These are electro-mechanical devices in which output voltage is measured, which are proportional to the velocity of the shaft. It is a transducer which converts velocity of the shaft into an electronic signal. The tachometers are of two types that include:

i. Contact type
ii. Non-contact type.

6.2.1.1 Contact Type Tachometers: The contact type tachometers are used to measure the speed of shaft by making contact. The probe of tachometer is attached to the shaft and the speed is measured by making contact.

6.2.1.2 Non-Contact Type Tachometers: The non-contact type tachometers are used for measurement of speed. The speed of the rotating shaft is sensed by a sensor placed on the rotating shaft and the light emitted by tachometer.

6.2.2 Stroboscope: The device measures the speed by variable frequency flashing brilliant light. The variable frequency oscillator controls the frequency of flashing light. A spot is placed on the rotating object and light of variable frequency is adjusted on the moving object to show the spot to be stationary. The frequency of light which shows spot stationary of rotating object measures the speed of object.

6.2.3 Sensor: The sensors are used to measure the speed by digital measurement and non-contact type system. The sensors use electro-mechanical techniques and pickups to measure the speed. These are two types of sensor that include:

i. Photo-electric
ii. Magnetic

6.2.3.1 Photo-Electric Pick-Up Sensor: It consists of light sensor emitting rays on an opaque disc having holes arranged systematically along the periphery, which is mounted on the shaft. When the device rotates light rays passes through the holes of the disc and light sensor produces a pulse which is given to a digital counter. Figure 6.1 shows the diagram of photo-electric pick-up sensor.

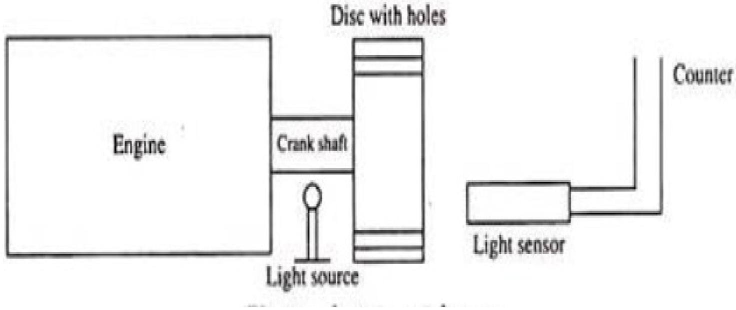

Figure 6.1: Photo-Electric Pick-Up Sensor

6.2.3.2 Magnetic Pickup Sensor: It consists of permanent magnet on which a coil is wound. A toothed metallic wheel is fitted to measure the speed of the device. The toothed wheel is made to pass the air gap of a permanent magnet. Every time when tooth passes the air gap, it changes reluctance and flux of the coil which creates Electro-Motive Force (EMF) in the coil. Figure 6.2 shows the magnetic pickups sensor.

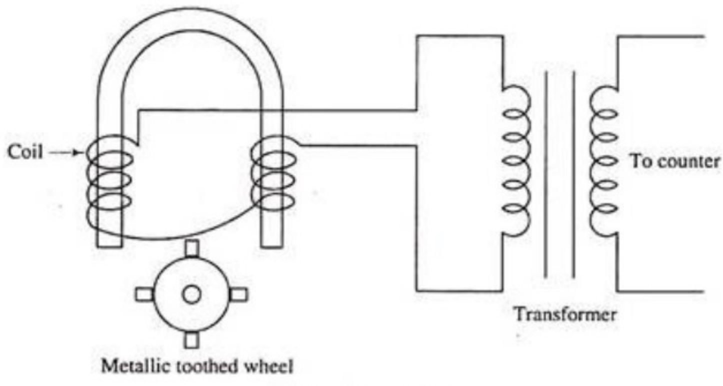

Figure 6.2: Magnetic Pickup Sensor

6.3 Measurement of Power

Measurement of engine power involves measuring indicated, brake and frictional horse powers.

6.3.1 Measurement of Indicated Horse Power

The Indicated Power (IHP) of the engine is the useful power produced by the engine after the combustion of the fuel in the engine cylinder. The heat energy produced by the combustion of the fuel is converted into useful work in the engine cylinder which is known as indicated power of the engine. The indicated power can be measured by following methods:

1. Engine indicator
2. Morse test

6.3.1.1 Engine Indicator: The indicated power of the internal combustion engine may be estimated when the following data are available:

a. Area of the positive loop of the indicator diagram
b. Area of the pumping loop or negative loop of the indicator diagram
c. Spring scale for each indicator diagram
d. Nature of the cycle (two stroke cycle or four stroke cycle)
e. Dimensions of the engine
f. Speed of the engine.

6.3.1.2 Morse Test: The Morse test is which a close estimate of the indicated power of a multi-cylinder internal combustion engine can be made. In this method, the engine under test is coupled to a suitable dynamometers and the Brake Horse Power (BHP) is determined. 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 in case of petrol engines or by disconnecting the injector in case of diesel engines. The difference in the outputs is a measure of the Indicated Horse Power (IHP) of the cut-out cylinder.

Though, this method gives reasonably accurate results and is liable to errors due to changes in mixture distribution and other conditions by cutting-out one cylinder. The test is conducted in five stages for four-cylinder engine. The stages include:

1. Test the engine with all four cylinders working
2. Test the engine with the 1^{st}cylinder not working
3. Test the engine with the 2^{nd}cylinder not working
4. Test the engine with the 3^{rd}cylinder not working
5. Test the engine with the 4^{th}cylinder not working

Let:

A = BHP for all the four cylinders working

B = BHP for one cylinder not working

Therefore, A – B = IHP of the cut-out cylinder.

IHP = (A – B1) + (A – B2) + (A – B3) + (A – B4)

= A (B1 + B2 + B3 + B4)

Frictional Horse Power = IHP - BHP

6.3.2 Measurement of Brake Horse Power

The brake power measurement involves the determination of the torque and the angular speed of the engine output shaft. The torque measuring device is called a dynamometer. Dynamometers can be broadly classified into two main types, power absorption dynamometers and transmission dynamometer.

6.3.2.1 PowerAbsorption Dynamometers

These dynamometers measure and absorb the power output of the engine to which they are coupled. The power absorbed is usually dissipated as heat by some means. Example of such dynamometers is prony brake, rope brake, hydraulic, swinging field direct current and fan dynamometer among others.

1. **Prony Brake Dynamometer:** One of the 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. It consists of wooden block mounted on a flexible rope or band the wooden block when pressed into contact with the rotating drum takes the engine torque and the power is dissipated in frictional resistance. Spring-loaded bolts are provided to tighten the wooden block and hence increase the friction.Figure 6.3 shows prony brake dynamometer.

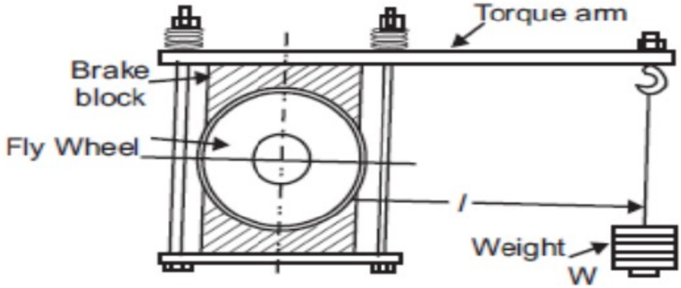

Figure 6.3: Prony Brake Dynamometer

2. Rope Brake Dynamometer: It consists of a number of turns of rope wound around the rotating drum attached to the output shaft. One side of the rope is connected to a spring balance and the other to a loading device. The power is absorbed in friction between the rope and the drum. The drum therefore requires cooling. Rope brake is cheap and easily constructed but not a very accurate method because of hanges in the friction coefficient of the rope with temperature. Figure 6.4 shows Rope brake dynamometer.

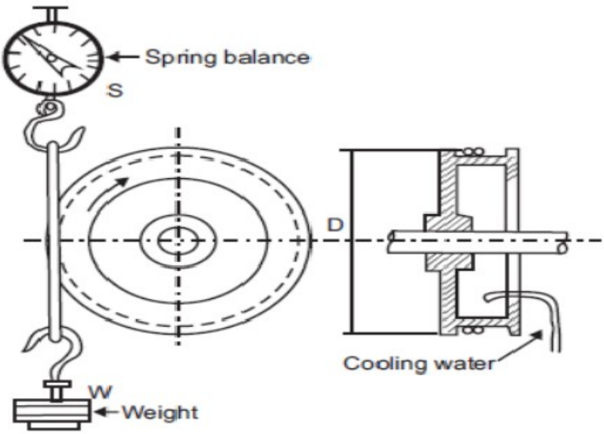

Figure 6.4: Rope Brake Dynamometer

3. **Hydraulic Dynamometer:** Hydraulic dynamometer works on the principle of dissipating the power in fluid friction rather than in dry friction. In principle, its construction is similar to that of a fluid flywheel. It consists of an inner rotating member or impeller coupled to the output shaft of the engine. This impeller rotates in a casing filled with fluid. This outer casing, due to the centrifugal force developed, tends to revolve with the impeller, but is resisted by a torque arm supporting the balance weight. The frictional forces between the impeller and the fluid are measured by the spring-balance fitted on the casing. The heat developed due to dissipation of power is carried away by a continuous supply of the working fluid, usually water. The output can be controlled by regulating the sluice gates which can be moved in and out to partially or wholly obstruct the flow of water between impeller, and the

casing. Hydraulic dynamometer is shown in figure 6.5.

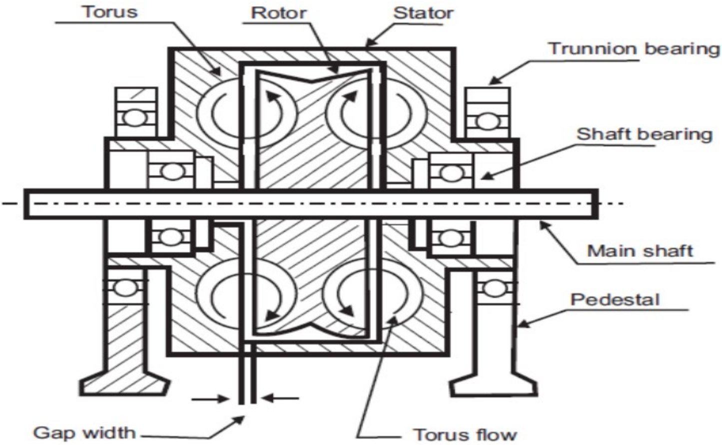

Figure 6.5: Hydraulic Dynamometer

4. Eddy Current Dynamometer: It 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. These eddy currents are dissipated in producing heat so that this type of dynamometer also requires some cooling arrangement. The torque is measured exactly as in other types of absorption dynamometers, i.e. with the help of a moment arm. The load is controlled by regulating the current in the electromagnets. Eddy current dynamometer is shown in figure 6.6.

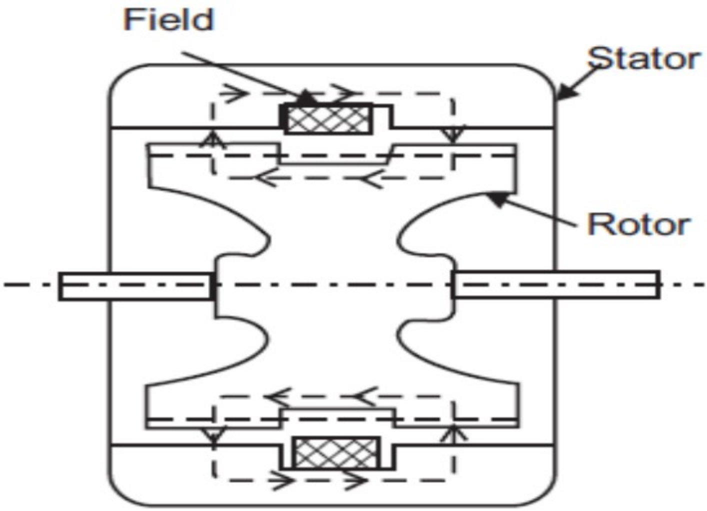

Figure 6.6: Eddy Current Dynamometer

The following are the main advantages of eddy current dynamometer:

1. High brake power per unit weight of dynamometer.
2. They offer the highest ratio of constant power speed range (up to 5:1).
3. Level of field excitation is below 1% of total power being handled by dynamometer, thus, easy to control and programme.
4. Development of eddy current is smooth hence the torque is also smooth and continuous under all conditions.
5. Relatively higher torque under low speed conditions.

6. It has no intricate rotating parts except shaft bearing.
7. No natural limit to size-either small or large.

5. Swinging Field Direct Current (DC) Dynamometer: Basically, a swinging field DC dynamometer is a DC shunt motor supported on trunnion bearings to measure their action torque that the outer case and filed coils tend to rotate with the magnetic drag. Hence, the name swinging field. The swinging field DC dynamometer is reversible, i.e. works as motoring as well as power absorbing device. When used as an absorption dynamometer, it works as a DC 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 DC voltage is needed to drive the motor. The load is controlled by changing the field current.

6. 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.

6.3.2.2 Transmission Dynamometers

In transmission dynamometers, the power is transmitted to the load coupled to the engine after it is indicated on some type of scale. 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 gauges is avoided. Transmission dynamometers are very accurate and are used where continuous transmission of load is necessary. These are used mainly in automatic units. Transmission dynamometer is shown in figure 6.7.

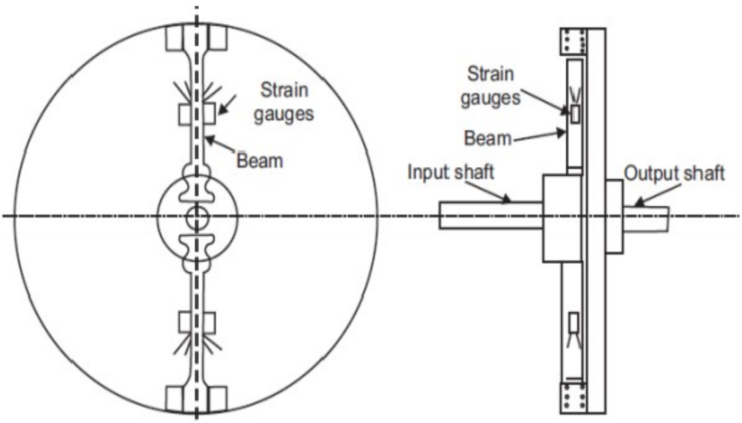

Figure 6.7: Transmission Dynamometer

6.3.3 Measurement of Friction Horse Power

The difference between indicated horse power and the brake horse power output of an engine is the friction horse power.

Almost invariably, the difference between a good engine and a bad engine is due to difference between their frictional losses. The frictional losses are ultimately 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 friction horse power of an engine is determined by the following methods:

1. Willan's line method
2. Motoring test
3. Morse test

6.3.3.1 Willan's Line Method: In this method, gross fuel consumption versus brake horse power at a constant speed is plotted and the graph is extrapolated back to zero fuel consumption. The point where this graph cuts the brake horse power 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 curve 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 accuracy obtained in this method is good compares with other methods if extrapolation is carefully done. Willian's line method is shown in Figure 6.8.

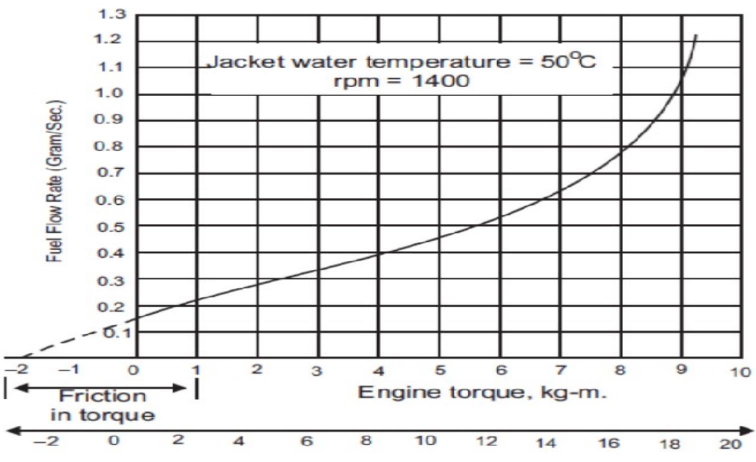

Figure 6.8: Willian's Line Method

6.3.3.2. Limitation of Willan's Line Method

1. Willan's Line Method is only used in compression ignition engine.

2. The friction power given by this method is approximate
3. Friction power changes with increase in engine speed.

6.3.3.3 Motoring Test: In the motoring test, the engine is connected to the electric motor and the engine is run at constant speed using the motor. The power required to drive the engine is given by the power consumed by the motor. The power is consumed by the motor in overcoming the friction of the engine moving parts. This is frictional power of the motor. The indicated power can be calculated by adding frictional power to the brake power.

6.4 Measurement of Air Consumption

The air consumption of an internal combustion engine may be measured for the following reasons:

1. To determine the air-fuel ratio
2. To obtain the total mass of exhaust gases
3. To obtain the combustion chamber efficiency especially in the case of petrol engines running on a rich mixture
4. To determine the volumetric efficiency.

The air taken into the cylinder of an internal combustion engine can be estimated in various ways. The following are a few methods which are commonly employed in the laboratory:

a. Gasometer
b. Orifice meter
c. Viscous air flow meter

d. Air box meter
e. Exhaust gas analysis.

6.4.1 Gasometer: The measurement of air by gasometer is exact one but the method is cumbersome.

6.4.2 Orifice Meter: The orifice method of air measurement is not reliable on pulsating flows. With single cylinder engine the method is very unsatisfactory while fairly reliable results are obtained with multi-cylinder engines running at high speed.

6.4.3 Viscous Air Flow Meter: The viscous air flow air meter is used for measurement of flow rates. The air flows through a form of honey comb so that the flow is viscous. The resistance of the element is directly proportional to the velocity of air. The pressure difference can be measured across the honey comb by use of inclined manometer.The felt pads are fitted in the manometer connections to damp out the fluctuations. A damping vessel can be fitted between the meter and engine to reduce the effect of pulsations. Figure 6.9 shows viscous air flow meter.

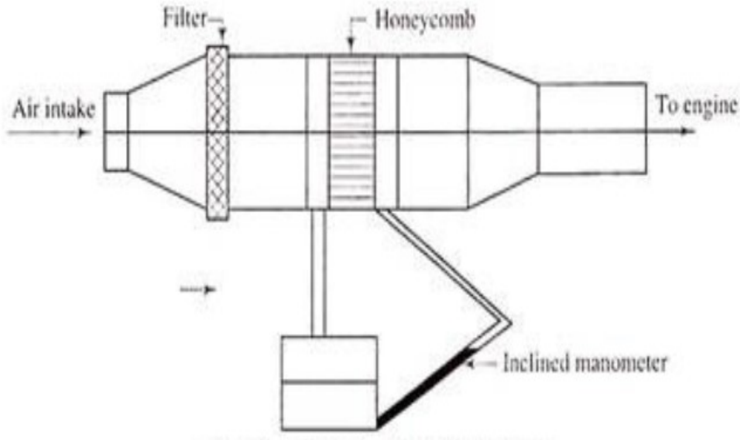

Figure 6.9: Viscous Air Flow Meter

6.4.4 Air Box Meter: The air box meter uses a very large tank fitted with sharp edge orifice. The engine suction pipe is connected to the tank and the orifice is fitted on the opposite side of the tank. The size of box is 200 times the engine cylinder volume so that the pulsating flow required by the engine can be converted to steady flow by the use of air box. The air is sucked continuously by the orifice and the air is supplied to the engine through the suction pipe intermittently. Due to continuous flow of air across the orifice, there is pressure difference on the two sides of orifice. This pressure head can be measured by use of the manometer. The water manometer is normally used for measurement of pressure head across the orifice.

6.4.5 Exhaust Gas Analysis: Exhaust gas analysis method assumes that all the carbon present in the fuel finally appears in the carbon dioxide or carbon monoxide and the flue gas analysis difference term is always nitrogen.

6.4.6 Factors Affecting Air Intake

The quantity of charge or air taken into the cylinder depends upon:

1. Temperature of charge entering the cylinder.
2. Back pressure of the gases in the engine cylinder, and
3. Resistance to the flow of fresh charge into the cylinder through the inlet valves and ports.

6.5 Measurement of Fuel Consumption

Fuel consumption shall be measured simultaneously with brake power; The fuel consumption measurement shall not be started until the engine is stabilized. A measuring interval of not less than 60 seconds shall be used when measuring speed and fuel consumption. All specific fuel consumption figures shall be based upon observed brake power.

6.6 Volumetric Efficiency of Engine

The volumetric efficiency is the ratio of the mass of actual air sucked in the engine cylinder during suction process to the theoretical mass of air which can be admitted in the cylinder. The theoretical mass of air can be calculated at the engine conditions or ambient temperature. If the volumetric efficiency is at the engine conditions, then it is the ratio of volume of charge per cycle drawn in during the suction stroke to the swept volume of piston is known as the volumetric efficiency of the engine. Both the volumes should be measured at the same temperature and pressure of the atmosphere surrounding the engine.

6.6.1 Effect of Parameters on Volumetric Efficiency: In a modern un-supercharged engine, the volumetric efficiency very rarely exceeds about 80%. Its actual value, however, depends upon a variety of factors, among the more important of which are:

1. Engine Speed: The volumetric efficiency reduces with increase in the speed of the engine, because less time is available for filling of the cylinder at higher speeds. Figure. 6.10 shows the variation of speed versus volumetric efficiency.

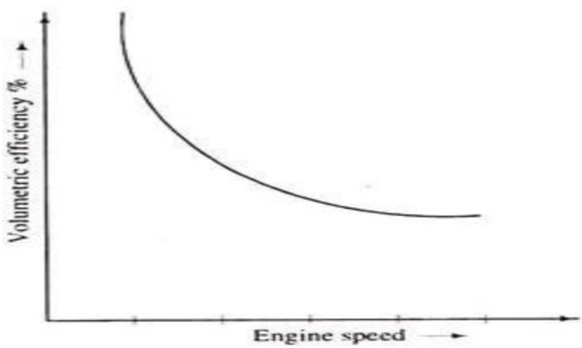

Figure 6.10: Variation of Speed Versus Volumetric Efficiency

2. Compression Ratio: The volumetric efficiency depends upon compression ratio because the clearance volume reduces with the compression ratio. The reduction in clearance volume effects the amount of exhaust gases in the clearance volume and this increase the volumetric efficiency of the engine. Figure 6.11 shows variation compression ratio with respect to volumetric efficiency.

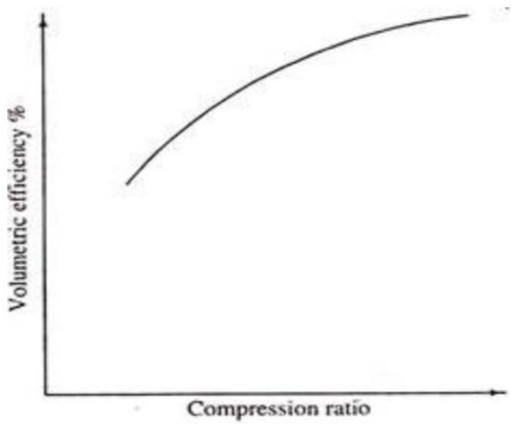

Figure 6.11: Variation of Compression Ratio with Volumetric Efficiency

3. Inlet Charge Temperature: The volumetric efficiency is effected by the inlet charge temperature. If the charge temperature is higher than the density of charge is less and mass of charge admitted in the cylinder is less. This reduces the volumetric efficiency of the engine. Figure 6.12 shows the variation of inlet charge temperature versus volumetric efficiency.

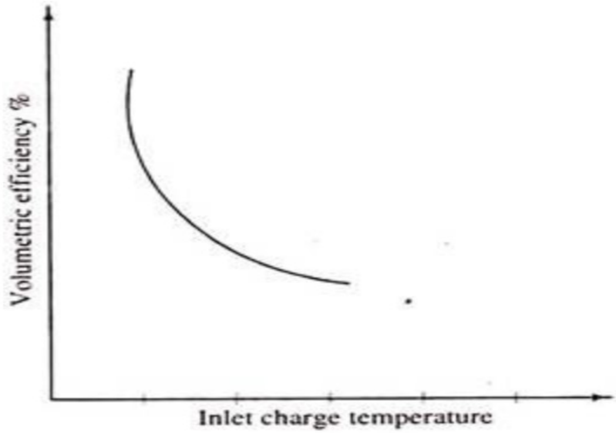

Figure 6.12: Variation of Inlet Charge Temperature Versus Volumetric Efficiency

4. **Mixture Strength:** The mixture strength slightly effects the volumetric efficiency of the engine. If the mixture is rich, then the large amount of exhaust gases is produce which reduces the volumetric efficiency. If the mixture is lean then the less amount of exhaust gases is produced, these increase the volumetric efficiency. Figure 6.13 shows the variation of volumetric efficiency versus mixture strength.

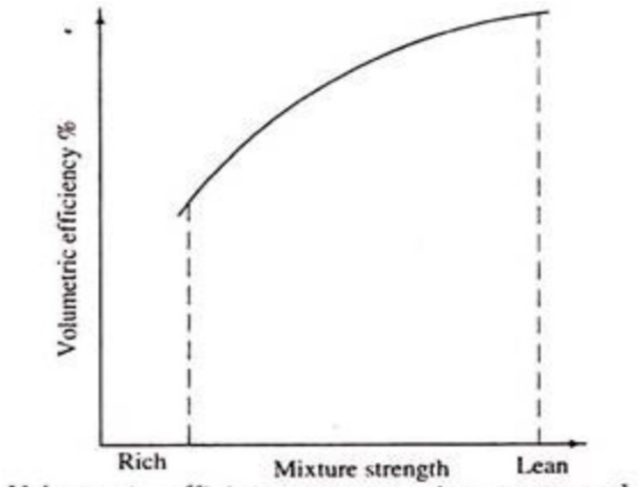

Figure 6.13: Variation of Volumetric Efficiency Versus Mixture Strength

6.7 Exercise 6.0:

Q1. The process of assessing the performance and operation of the engine called……….

a. Engine anatomy
b. Engine checking
c. Engine testing
d. Engine turning

Q2. The following are instruments used for measurement of engine speed except……….

a. Dynamometer
b. Sensor
c. Stroboscope
d. Tachometer

Q3. Measurement of engine power involves measuring the following except…………

a. Brake horse power
b. Clutch horse powers
c. Frictional horse power
d. Indicated horse power

Q4. ……….. is the test in which a close estimate of the indicated power of a multi-cylinder internal combustion engines

a. Bench test
b. Engine test
c. Morse test
d. Speed test

Q5. The torque measuring device is called …………….

a. Dynamometer
b. Sensor
c. Stroboscope
d. Tachometer

Q6. The two main types of dynamometer are………..

a. Brake and clutch dynamometers
b. Brake and power dynamometers
c. Power absorption and transmission dynamometer
d. Transmission and brake dynamometers

Q7. The following are dynamometers that measure and absorb the power output of the engine to which they are coupled except…………

a. Brake dynamometer
b. Clutch dynamometer
c. Power absorption dynamometer
d. Transmission dynamometer

Q8. Measuring friction horse power include the following tests except………….

a. Friction test
b. Motoring test
c. Morse test
d. Willan's line method

Q9. The air taken into the cylinder of an internal combustion engine can be estimated using the following methods except…………

a. Gasometer
b. Orifice meter
c. Oxygen meter
d. Viscous air flow meter

Q10. The quantity of air taken into the engine cylinder depends upon the following except…………..

a. Back pressure of the gases in the engine cylinder
b. Resistance to the flow of fresh charge into the cylinder
c. Temperature of charge entering the cylinder
d. Volume of charge in the cylinder

ANSWERS TO THE EXERCISES

Exercise 1.0:		**Exercise 2.0:**	
Question	**Answer**	**Question**	**Answer**
1	C	1	D
2	A	2	C
3	A	3	C
4	C	4	A
5	C	5	B
6	C	6	B
7	C	7	A
8	B	8	B
9	D	9	C
10	D	10	C
Exercise 3.0:		**Exercise 4.0:**	
Question	**Answer**	**Question**	**Answer**
1	D	1	D
2	A	2	A
3	B	3	A
4	B	4	C
5	B	5	B
6	D	6	D
7	A	7	A
8	D	8	A
9	A	9	D
10	A	10	C

Exercise 5.0:		Exercise 6.0:	
Question	**Answer**	**Question**	**Answer**
1	D	1	C
2	A	2	A
3	A	3	B
4	D	4	C
5	D	5	A
6	A	6	C
7	A	7	C
8	B	8	A
9	C	9	C
10	B	10	D

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About the Book

The book covers Internal Combustion Engines, Components of Internal Combustion Engines, Two and Four Stroke Cycle Engines, Engine Terminologies, Engine Torque, Power and Efficiencies and Engine Testing.The book is recommended for teachers/lecturers and students of Automobile Technology in Technical Colleges, Vocational Enterprises Institutes, Innovation Institutes, Colleges of Education, Polytechnics and Universities in Nigeria.

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