Internal Combustion Engines

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Features of

Learning Objectives

After going through this chapter, the students will be able to:
- explain the working of various air standard cycles.
- define air standard thermal efficiency and mean effective pressure.
- understand the significance and processes involved in different air standard cycles.
- analyse the factors affecting thermal efficiency and mean effective pressure of different air standard cycles.
- highlight the suitability of each air standard cycle vis-à-vis the actual engines.

Learning Objectives

Each chapter of the book begins with 'Learning Objectives', which lists the major topics discussed in the chapter.

Figures and Images

The concepts are made easier to understand with the aid of numerous well-illustrated figures and actual images.

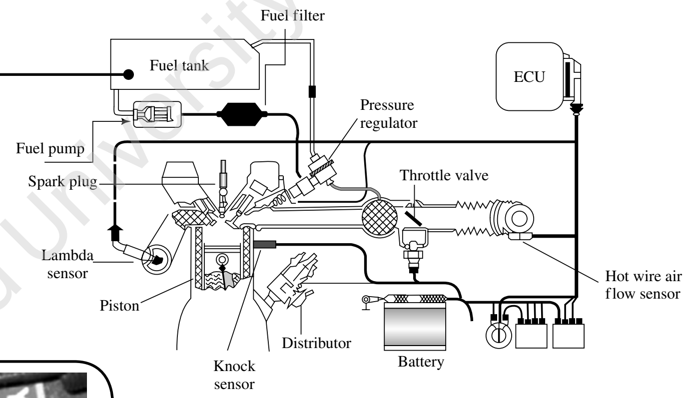

Fig. 7.34 Schematic of MPFI system

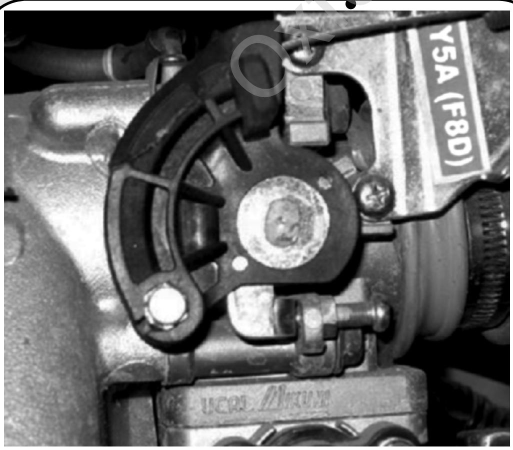

Fig. 7.41 Throttle position sensor

the Book

Example 16.42 A six-cylinder four-stroke petrol engine (bore = 90 mm; stroke = 110 mm) running at a speed of 3700 rpm develops a torque of 140 Nm. The clearance per cylinder is 70 cc. If the fuel consumption is 21 kg/h, calculate the brake thermal efficiency and relative efficiency. Calorific value of fuel is 42000 kJ/kg.

Solution: Swept volume $V_s = \frac{\pi}{4} \times D^2 \times L = \frac{\pi}{4} \times 9^2 \times 11 = 699.4$ cc

Compression ratio, $r = \frac{V_s + V_c}{V_c} = \frac{699.4 + 90}{90} = 8.77$

Solved Examples

Discussion on each topic is reinforced with solved numerical examples to enable application of concepts learned.

Review Questions

1. What are the requirements of an ignition system?
2. Discuss the various stages of ignition process.
3. With a neat sketch explain the working of a battery ignition system.
4. What are the drawbacks of the battery ignition system? How can it be mitigated by a magneto ignition system?
5. What is the need for advancing/retarding the ignition timing?
6. Discuss the vacuum advance mechanism with a neat sketch.
11. Discuss the working of (i) magnetic pulse generator (ii) Hall effect sensor (iii) optical photo-diode sensor.
12. Explain the working of an electronic ignition system with distributor and mechanical spark advance.
13. What is the advantage of having a distributor-less ignition system?
14. What is the function of crank and cam sensor in distributorless ignition system?
15. What is meant by waste spark ignition system?
16. Distinguish between dual spark ignition and

Multiple Choice Questions and Review Questions

Each chapter supports a wealth of multiple choice questions and review questions to help students during exam preparation.

Multiple Choice Questions

1. Expansion of the unit of power, PS is
   (a) Pferde Starke (b) power stroke
   (c) power (d) none of these
2. Prony brake dynamometer is used to measure
   (a) speed (b) torque
   (c) power (d) none of these

(a) at maximum volumetric efficiency of engine
(b) at minimum speed of engine
(c) at maximum speed of engine
(d) at maximum power of engine

9. High-speed engines are generally

Practice Problems

29. An air standard cycle consists of the following processes; isentropic compression from 15°C, 1.01 bar through a compression ratio of 5; heat addition at constant volume of 2600 kJ/kg; isentropic expansion to the initial volume; heat rejection at constant volume. Sketch the cycle on *p-V* and *T–s* diagrams, and calculate its ideal efficiency, mean effective pressure, and peak pressure.
(**Ans.** 51.16%, 19.44 bar, P_3 = 88.6 bar)
30. The cycle in Problem 29 is modified so that the heat is added (a) at constant pressure, (b) half at constant volume and half at constant pressure. The compression ratio is increased so as to allow the same peak pressure as before. Sketch the two cycles on *P-V* and *T-s* diagrams, and calculate their ideal efficiencies and mean effective pressures.
(**Ans.** (a) 61.98%, 15.49 bar; (b) 55.65%, 8.472 bar)
31. In a Carnot cycle, 1 kg of air is compressed isentropically from 1.0 bar to 4.0 bar, the temperature being 10°C. The maximum temperature reached in the cycle is 400°C. Find the efficiency and mean effective pressure of the cycle. (**Ans.** 57.97%, 2.59 bar)

Practice Problems

The book includes a good number of numerical problems for practice.

Preface

Internal combustion engines are the driving force of fuel-operated vehicles. They represent the class of machines in which the chemical energy of the fuel is converted to mechanical energy in a single component. Besides being a component of automobiles, IC engines also find application in numerous industries, including stationary power generation.

Internal combustion engines is a topic of interest for engineers especially mechanical and automobile, and is a field where a lot of development in technologies is taking place day by day. Some of the latest technologies being employed in internal combustion engines include variable valve timing technology, electronic fuel injection system, programmed electronic ignition systems, exhaust gas treatment technologies, and nano fuel additives. Today in the market, there is a dearth of books that include the latest advances in the field. The objective of this book is to fill that void.

About the Book

A course on Internal Combustion Engines is part of the curriculum of the undergraduate programme in mechanical engineering and related branches of most of the universities globally. This book *Internal Combustion Engines* focuses on the fundamental aspects of IC engines, while emphasizing on the latest technologies. It will help students to understand the working of various types of IC engines, their components, and performance analysis which help them in conducting further research to propose solutions to challenges in the industry.

This book is designed for the undergraduate students of mechanical engineering and equivalent branches, and will also serve as a valuable reference for postgraduate students in the relevant discipline. A review of the latest technologies covered in this book will be of much benefit to Ph.D scholars, pursuing research in the areas of combustion, fuels, and exhaust emission control technologies. It will also be useful for engineers working in various automotive firms and as a ready-reference for candidates preparing for competitive examinations like GATE, as well as recruitment interviews.

Key Features

- Discusses thermodynamic analysis of combustion and heat release in IC engines
- Includes nanoparticle fuel and oil additives for emission reduction and performance improvement
- Describes flame visualization techniques for combustion analysis
- Includes electronic fuel injection systems such as MPFI, GDI, CRDI, and air-assisted fuel injection system
- Presents emission norms and extensive description of emission control strategies for satisfying the present and future emission norms
- Rich pedagogy comprising
  - 120 solved examples
  - 115 practice problems
  - 270 multiple choice questions

- 273 review questions
- Chapter-end summary

Organization of the Book

The book consists of 17 chapters. A chapter-wise scheme of the book is presented here.

Chapter 1 of the book starts with the history of internal combustion engines, followed by a description of engine nomenclature and components. This is followed by a description of four-stroke and two-stroke engines and their comparison. The chapter also includes a note on future engines.

Chapter 2, which discusses the analysis of air standard cycles, starts with an introduction to thermodynamics followed by the analysis of various ideal cycles such as Carnot cycle, Otto cycle, Diesel cycle, Dual combustion cycle, and their comparisons. Stirling and Miller cycles are also covered in this chapter.

Chapter 3 discusses the analysis of fuel–air cycle and the influence of factors such as variable specific heat and dissociation. The chapter supports a number of solved problems as well as practice problems with answers to enable practical application of concepts learned in the chapter.

Chapter 4 discusses the analysis of actual cycles and factors such as heat losses, time losses, combustion losses, factors affecting volumetric efficiency, and so on.

Chapter 5 discusses the various types of fuels, their properties, and measurement methods. Different types of alternative fuels and various types of fuel additives are also covered in this chapter.

Chapter 6, which discusses combustion in SI and CI engines, starts with the basics of combustion, combustion stoichiometry, chemical equilibrium, and goes on to provide a detailed explanation of combustion in SI and CI engines. The abnormal combustion in SI engines and the effect of different parameters on combustion are covered in detail in this chapter. The discussion of different stages of combustion in CI engines, followed by knocking and the parameters affecting knocking are included here. Theoretical aspects of combustion and the measurement techniques for flame temperature distribution are the strengths of this chapter, which will be beneficial for research scholars. A comparison of combustion in SI and CI engines is also detailed.

Chapter 7 mainly discusses the fuel systems in SI engines, which include carburettor and electronic fuel injection systems. The chapter also covers in detail the latest technologies in electronic fuel injections system such as throttle body fuel injection (TBI) multi-point fuel injection (MPFI), gasoline direct injection (GDI), and air-assisted fuel injection system (orbital combustion process).

Chapter 8 covers the different types of fuel systems employed in CI engines, which include conventional unit injector system and common rail direct injection system (CRDI). A description of different types of fuel injectors is also included in this chapter. The different types of sensors being used in electronic fuel injection system are discussed in detail with the help of illustrations in chapters 7 and 8.

Chapter 9 on ignition systems discusses the conventional ignition systems and mechanical ignition advance systems. In addition to these, various types of ignitions systems which include the latest electronic ignition systems, corona discharge ignition system, capacitor discharge ignition systems, and distributor-less ignition system are covered in detail in this chapter.

Chapter 10 discusses engine friction and various types of lubrication systems being used in a wide variety of automobiles including wet sump and dry sump lubrication systems in four-stroke engines and mist lubrication system used in two-stroke engines.

Chapter 11 discusses lubricating oils, their properties, and measurement methods. Various types of additives, including solid lubricants such as WS_2, MoS_2 nanoparticle for friction reduction are also discussed.

Chapter 12 elucidates the different types of cooling systems in engines such as air cooling and liquid cooling systems. The chapter also includes a discussion on the desirable properties of coolants.

Chapter 13 discusses in detail the two-stroke engines. Different types of scavenging schemes and their comparison are provided in this chapter. The chapter also includes a detailed description of air-assisted fuel injection system for two-stroke petrol engines.

Chapter 14 discusses superchargers and turbochargers. The advantages of superchargers and turbochargers are explained with the help of ideal cycles.

Chapter 15 analyses the causes of air pollution and the impact of harmful emissions on human health, with special emphasis on emission norms. Different types of emission control strategies being adopted to satisfy the existing and future emissions norms are dealt with in detail in this chapter. The chapter also includes a note on nanoparticle catalysts as fuel-borne additive for emission reduction.

Chapter 16 discusses testing and performance analysis of CI and SI engines. The chapter covers various standard methods adopted for the measurement of torque, speed, and frictional horse power for both SI and CI engines. It also explains the principle and methodology of emission measurement techniques.

Chapter 17 discusses the engine gas exchange systems, which include intake and exhaust systems in engines. It also includes the valve timing diagram and various valve technologies being adopted for better power and mileage.

Online Resources

To aid the faculty and students using this book, the following resources are available at www.india.oup.com/orcs/9780199479481

For Faculty

- Solutions manual
- Chapter-wise lecture PPTs
- Additional reading material on gas turbines

For Students

- Colour photographs of engines presented in the book
- Additional reading material on gas turbines

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Suggestions and feedback are welcome can be sent to us at sajith@nitc.ac.in and/or shijo@nitc.ac.in.

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Shijo Thomas

Brief Contents

Detailed Contents

Chapter 1

Introduction

Learning Objectives

After going through this chapter, the students will be able to:
- develop an overall idea on various types of engines and their classification.
- explain the different components of an internal combustion engine.
- develop an understanding on the working of four- and two-stroke engines.

1.1 Heat Engines—An Introduction

In today's civilized world, energy plays a major role in running the entire system on this planet. The demand rate of energy is increasing day-by-day and new sources of energy are being explored. The conversion of energy from one form to another is a necessity and the efficiency of this conversion really matters. Heat engine is a device which derives heat energy from the combustion of fuels or any other source and converts this energy to mechanical work. A heat engine operates by taking heat from a source, converting some of that heat into work, and dumping the rest into a sink. In the modern society, different types of heat engines are being used which include, hot air engines, petrol engines, diesel engines, gas turbines, etc. for various applications. Heat engines can be broadly classified as,

(a) External combustion engines
(b) Internal combustion engines

In external combustion engines, combustion of fuel occurs outside the cylinder whereas in internal combustion engines combustion occurs within the cylinder. Steam engine is a popular external combustion engine in which heat of combustion is employed to generate steam which produce useful work in the engine. Other types of external combustion engines include hot air engines, steam turbines, and closed cycle gas turbine, which are generally used in locomotives, ships, generators, etc. The external combustion engines like steam engines are complicated and bulky with lower efficiency as compared to the internal combustion engines. Hence, external combustion engines are generally less suitable for automobiles. In the case of internal combustion engines the combustion of fuel and air occurs within the engine cylinder and is directly converted to mechanical work. Hence, the efficiency of internal combustion engines is more than that of external combustion engines. Petrol engines, diesel engines, Wankel engines, and open cycle gas turbine are common examples of internal combustion engines. Internal combustion engines are commonly used in automobiles, trucks, and buses.

Several types of internal combustion engines were developed and tested during the second half of the 19th century. Christian Huygens, developed the first internal combustion engine which employed the gunpowder as fuel, in 1680. Even though many attempts were made utilizing coal gas as power source, during the period 1820–1860, the first practical engine was invented by J.J.E. Lenoir in 1860. Later in 1867 Otto Langen free piston engine was developed. Otto Langen engine basically consists of a piston, which moves vertically outwards during explosion and expansion strokes. All the engines developed until 1860, involved the combustion of the charge at atmospheric pressure. It was in 1876 that Nikolaus Otto, a German engineer demonstrated a practical engine working on a four-stroke cycle. Internal combustion engines started being used in automobiles in 1880s. Most of the spark ignition engines operated today are similar to Nikolaus Otto's gas engine and hence the series of processes that model the thermodynamic cycle in today's four-stroke spark ignition engine is called Otto cycle. In 1881, Dugald Clerk, a Scottish engineer patented a two-stroke engine, having one working stroke per revolution as opposed to the four-stroke engine having one working stroke in two revolutions. In 1892, Rudolf Diesel, a German engineer proposed the compression ignition engine or today's diesel engine, in which the air is compressed to sufficiently high temperature to ignite the fuel which is injected towards the end of compression stroke. By 1920s multi-cylinder diesel engines were used in automobiles and trucks. Felix Wankel invented the basic design of the rotary engine, which was successfully tested in 1957. The rotary engine basically has a three-lobe rotor which is driven eccentrically in a casing to obtain the rotary motion directly.

Stirling engine was invented by Robert Striling in 1816, and was later developed in 1965. Stirling engine is basically an external combustion engine, operating on cyclic compression and expansion of air or any other gas. In Stirling engine the working fluid is kept at different temperature levels, which results in the net conversion of heat energy to mechanical work. Extensive research is being done all over the world in the quest of internal combustion engines with lower specific fuel consumption and low emissions. As the emission norms are becoming stringent for controlling the emissions from automobiles, it is mandatory to adopt new technologies to meet the prevailing and future emission norms. With the advent of advanced electronics, petrol and diesel engines with electronic fuel injection systems are becoming popular due to their inherent advantage of precise control of mixing of air and fuel, thus leading to low specific fuel consumption and better emissions.

This chapter discusses the classification of the internal combustion engines based on various parameters. A brief description of different components of an internal combustion engine and its functions are given here. The basic working of the four-stroke diesel and petrol engines, and two-stroke diesel and petrol engines is also discussed here.

1.2 Classification of Engines

Different types of internal combustion engines are being used in automobiles depending upon their applications. Today's internal combustion engines can be classified in several ways. The most general way of classification of IC engines is shown in Fig. 1.1.

1.2.1 Applications

Both diesel and petrol engines are used for various applications, depending upon the suitability and the requirement. On the basis of application, IC engines can be broadly classified into the following:

(a) Automotive: (i) Motor bikes (ii) Car/jeeps/Auto rickshaw (ii) Truck/Bus (iii) Off-highway
(b) Light aircraft
(c) Locomotive (generally four-stroke diesel engines)
(d) Marine: (i) Outboard (ii) In board (iii) Ship (generally two-stroke diesel engines)

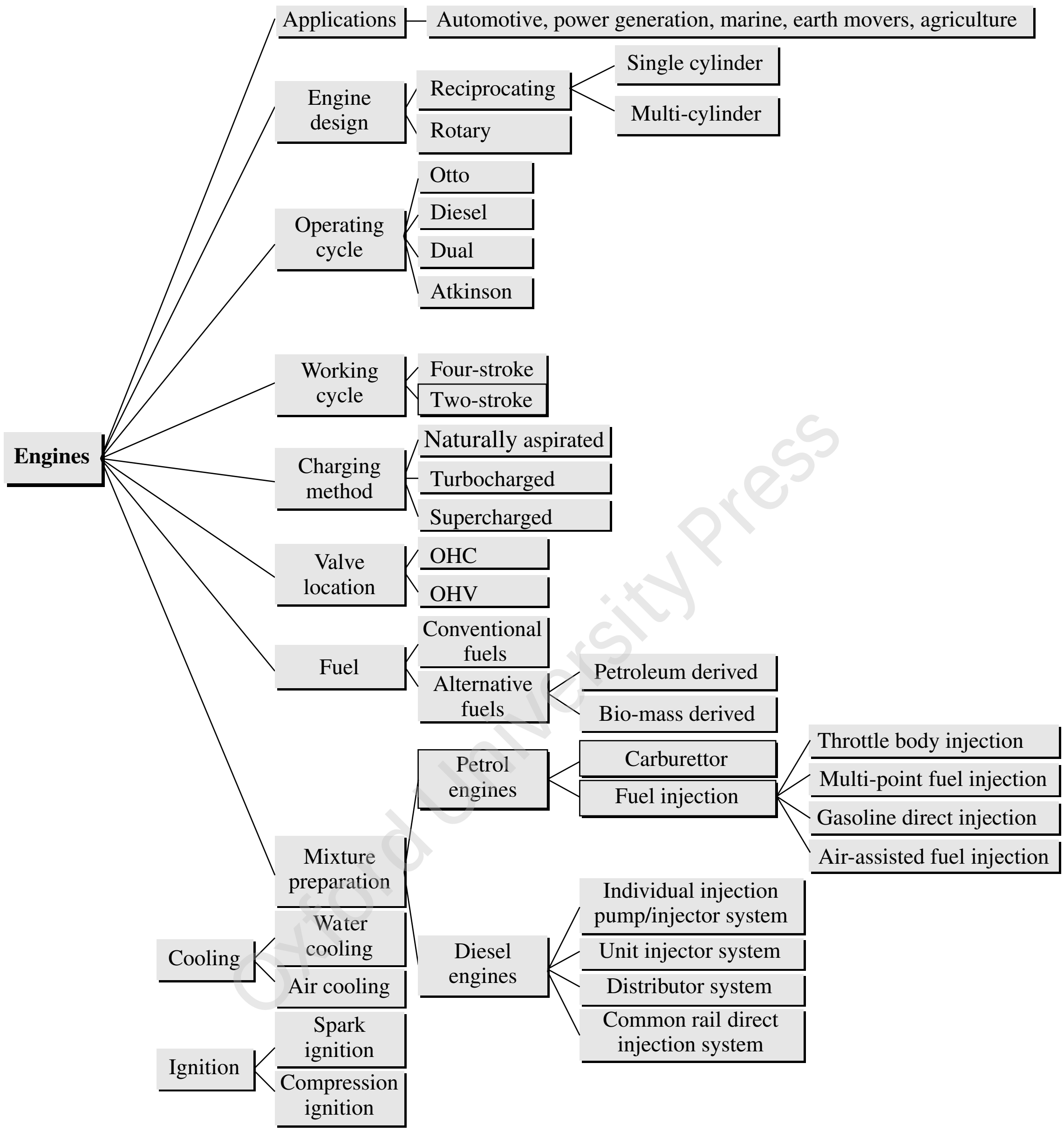

Fig. 1.1 Classification of IC engines

(e) Power generation: (i) Portable generators (household purpose) (ii) Stationary generators (power plants—generally four-stroke diesel engines)

(f) Agricultural: (i) Pumpsets (ii) Tractors (generally four-stroke diesel engines)

(g) Earthmoving vehicles: (i) Dumpers (ii) Tippers (iii) Mining equipment (generally four-stroke diesel engines)

(h) Home use: (i) Lawnmowers (ii) Snow blowers (iii) Tools

1.2.2 Basic Engine Design

Internal combustion engines are classified based on the design as (i) reciprocating type and (ii) rotary type.

Reciprocating Type

The reciprocating type engine basically consists of a piston which reciprocates inside the cylinder and the reciprocating motion of the piston is converted to rotary motion by means of the connecting rod and crank mechanism (as shown in Fig. 1.2). The number of cylinders in the reciprocating engine mainly depends upon the power and mileage requirements, and are further classified into (i) single cylinder engines and (ii) multi-cylinder engines.

Most of the bikes of low/medium power are provided with single cylinder engines. The number of power strokes per revolution depends on the number of cylinders. Even though the power of the engine increases with the number of cylinders, the mileage decreases correspondingly. Depending upon the arrangement of cylinders, multi-cylinder engines can be classified as (i) inline (ii) V (iii) radial (iv) opposed cylinder, and (v) opposed piston. Figure 1.2 shows the different types of engines based on the orientation of cylinders. In inline-type engines, all the cylinders of the engine are in a straight line and are popularly used in cars, jeeps, etc. In V-type engines, the cylinders are arranged in two separate banks at an angle connected to the same crankshaft. V-type of engines can have more number of cylinders with a shorter bonnet length, giving better road visibility and are used in buses, trucks, etc. V-engines are well balanced, smooth, and quiet in operation. A boxer engine is a 'V' engine with 180° angle between the cylinder banks. As the number of cylinders increases, even though the mileage of the engine decreases, the brake power output of the engine increases resulting in quick acceleration, and more uniform flow of power leading to a comfortable ride.

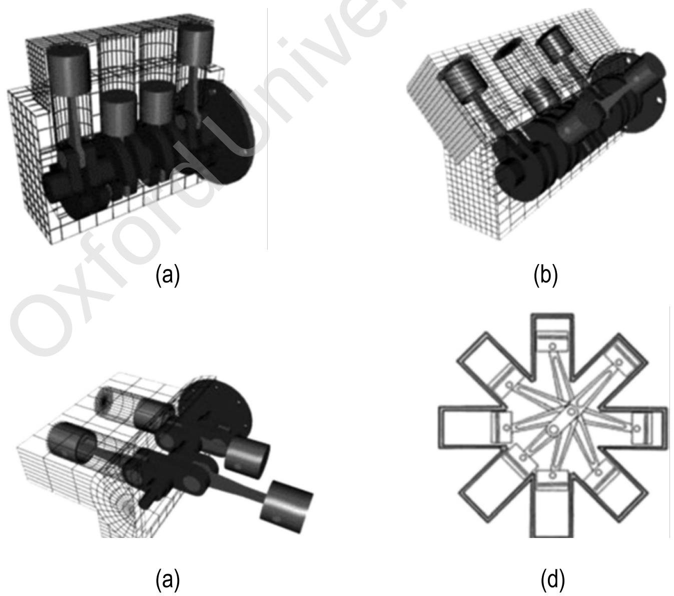

Fig. 1.2 Engines based on the orientation of cylinders (a) Inline type, (b) V type, (c) Horizontally opposed/Boxer type, (d) Radial type

Rotary Type

In a rotary engine the rotary motion is directly obtained, as opposed to the reciprocating engine where the reciprocating motion is converted to rotary motion. Depending upon the number of rotors, rotary engines are classified into those with (a) single rotor or (b) multi-rotors.

1.2.3 Operating Cycle

IC engines can be classified on the basis of operating cycle, that is, depending upon the method of heat addition and rejection, as:

- Otto cycle—combustion at constant volume (for conventional SI engine)
- Diesel cycle—combustion at constant pressure (for CI engine)
- Dual—combustion at constant volume and pressure (for actual diesel engine)
- Atkinson (for complete expansion SI engine)
- Miller (for early or late inlet valve closing-type SI engine)

1.2.4 Number of Working Strokes

Depending upon the number of strokes in a cycle, IC engines can be generally classified as follows:

(a) Four-stroke cycle
(b) Two-stroke cycle: two-stroke engines
  (i) Crankcase scavenged
  (ii) Externally scavenged

In two-stroke engines one power stroke is obtained per revolution of the engine as opposed to four-stroke engines, where there is one power stroke in two revolutions. Four-stroke engines are generally used where mileage is the prime consideration and two-stroke engines are used where power-to-weight ratio is the major factor. The two-stroke petrol engines of small/medium size are used in motor cycles, mopeds, autorickshaws, etc. However, emissions from two-stroke petrol engines are higher as compared to the four-stroke petrol engines. Large two-stroke diesel engines are normally used for marine propulsion. Depending upon the scavenging method two-stroke engines can be classified as crankcase scavenging or externally scavenging type.

1.2.5 Charging Method

According to the method of charging, engines are classified as follows.

(a) *Naturally aspirated type*: Admission of air or air–fuel mixture at atmospheric pressure.
(b) *Supercharged/Turbocharged type*: Admission of air or air–fuel mixture under pressure.

In supercharged/turbocharged engines the intake air is pressurized by means of a compressor, before admitting into the engine cylinder. In supercharger the power to run the compressor is directly obtained from the engine. In turbocharger, the compressor input power is obtained from the enthalpy of the exhaust stream, by means of a turbine in the exhaust pipe of the engine, which in turn spins the compressor. Even though turbocharger utilizes the waste energy in the exhaust for pressurizing the air, it creates some amount of back pressure in the exhaust system.

1.2.6 Valve Location

Depending upon the position of camshaft there are two types of configurations—(i) overhead valve (OHV) and (ii) overhead cam (OHC).

In *overhead valve system*, the camshaft is placed near to the crankshaft and the motion is transmitted to the valves in the cylinder head through push rods. In overhead cam system the camshaft is placed within the cylinder head above the combustion chamber and drives the valves/lifters directly without the use of push rods. Depending upon the number of camshafts, the overhead cam system can be single overhead camshaft (SOHC) or double overhead camshaft (DOHC). Depending upon the location of the valves in the cylinder head, engines can be classified as those with (i) T-head, (ii) L-head, (iii) F-head, and (iv) I-head.

1.2.7 Fuel

The heat energy is released in an internal combustion engine by burning the fuel in the engine cylinder. Internal combustion engines are operated on different types of fuels such as gaseous, liquid, and even solid fuels. Fuels can be broadly classified as,

1. Conventional
   (a) Crude oil derived: (i) petrol (ii) diesel
   (b) Other sources: (i) coal (ii) wood (includes bio-mass) (iii) tar sands (iv) shale
2. Alternate fuels
   (a) Petroleum derived (i) CNG (ii) LPG
   (b) Bio-mass derived (i) ethanol (ii) vegetable oils (iii) producer gas (iv) biogas (iv) hydrogen

1.2.8 Mixture Preparation

The engines can be classified on the basis of the process of preparation of the air–fuel mixture as,

(a) Carburetion—Carburettor is used in conventional petrol engines to prepare and supply air–fuel mixture into the cylinder, which is becoming obsolete as it fails to satisfy the emissions norms.
(b) Fuel injection—The fuel injection system can be either mechanical type or electronic type. Electronic fuel injection systems are commonly used in both diesel and petrol engines. The electronic fuel injection system used in petrol engines are classified based on the point of fuel injections as
   (i) Throttle body fuel injection (TBI—fuel injection in throttle body)
   (ii) Multi-point fuel injection (MPFI—fuel injection in inlet manifold)
   (iii) Gasoline direct injection system (GDI—fuel injection directly into cylinder)
   (iv) Air-assisted fuel injection system (air–fuel mixture injection directly into cylinder)

   The fuel injection systems used in diesel engines are
   (i) Individual pump and injector system
   (ii) Unit injector system
   (iii) Distributor system
   (iv) Common rail direct injection system (CRDI)

1.2.9 Ignition

Based on the type of ignition of the air–fuel mixture, engines can be classified into the following two types:

Spark ignition engines These require an external source of energy (spark plug) for the initiation of spark leading to the combustion process. The types of ignition systems used in SI engines are (i) battery ignition system, (ii) magneto ignition system, (iii) transistorized coil ignition system, and (iv) capacitive discharge ignition system.

Compression ignition system These do not require any external means to initiate the combustion as the air–fuel mixture is ignited by only autoignition. Compression ignition systems can have heterogeneous charge (as in conventional engines) or homogenous charge (as in homogenous charge compression ignition engines (HCCI)).

1.2.10 Cooling

Cooling is very essential for proper functioning of the engine. Basically there are two types of cooling, namely (i) air cooling (ii) liquid cooling.

An air cooling system uses fins attached to the engine parts for the dissipation of heat, while in a liquid cooling system, the coolant circulating through the water jackets removes the heat from the engine parts and finally rejects to the atmosphere through the radiator.

1.3 Engine Components

The engine is the heart of an automobile. Figure 1.3 shows a typical SI engine. Various components of an internal combustion engine are discussed here.

Cylinder Block

The engine cylinder block is the basic frame of an engine. Cylinder block is the housing of various engine components such as cylinder, water jackets, water pump, timing gear, ignition distributor (in the case of petrol engines), valves, and fuel pump. The cylinders of air-cooled engines have closely spaced fins surrounding the barrel to enhance the dissipation area. In water-cooled engines, the cylinders are surrounded by jackets through which the coolant circulates and these jackets are cast integrally with the cylinder block. Normally the cylinder block and crankcase are often cast as a single piece. The cylinder block is extremely strong so as to withstand high pressure and temperature.

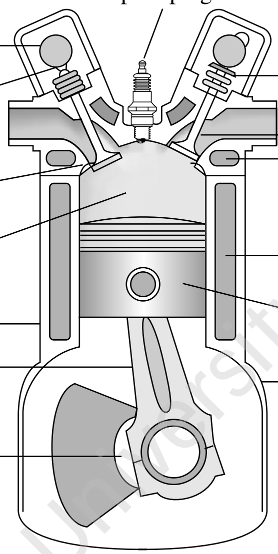

Fig. 1.3 Spark ignition engine

Cylinder Head

Cylinder head is a separate casting bolted to the top of the cylinder block. It contains the combustion chambers, spark plug, valves, and water jackets. A gasket is used between the cylinder block and cylinder head to avoid leakage. Depending upon the arrangement of valves, the cylinder head can be I-head, T-head, or F-head.

Crankcase

Crankcase is the base of the engine which supports the crankshaft and camshaft. The top half of the crankcase is an integral part of the cylinder block and the bottom half of the crankcase is the oil pan (pressed steel or aluminium). 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 so that they support the engine at three or four points. The material of crankcase is normally ferrous alloy or semi-steel.

Piston

Piston is basically a partly hollow cylindrical part closed at one end, fitted to each of the engine's cylinders and attached to the crankshaft by a connecting rod. Each piston reciprocates in its cylinder, transmitting the work obtained from the expansion of gas in the cylinder to the crankshaft via the piston and connecting rod.

Piston is made of either heavy iron or lighter aluminium alloy. It is equipped with piston rings to provide a good sealing between the piston and cylinder and at the same time sufficient clearance to reduce friction. The space enclosed between the upper part of the cylinder and the top of the piston during the combustion process is called the combustion chamber.

Connecting rod

The connecting rod transmits the piston load to the crankshaft causing the latter to turn, while converting the reciprocating motion of the piston to the rotary motion of the crankshaft. The small end of the connecting rod is connected to the piston by means of a gudgeon pin and the big end is connected to the crank pin. Figure 1.4 shows the piston and connecting rod.

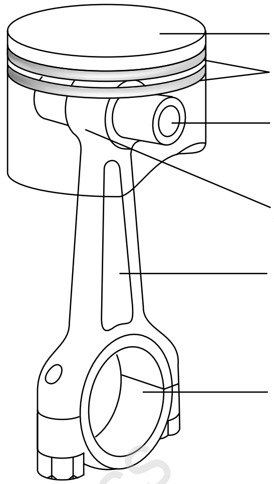

Fig. 1.4 Piston and connecting rod

Crankshaft

The connecting rod and crank arm of the crankshaft translate the reciprocating motion of the piston to rotational motion of crankshaft. The crankshaft is made from steel forging and is supported on bearings attached to the crankcase. The shape of crankshaft, that is, the mutual orientation of the cranks depends on the number of cylinders, arrangement of cylinders, and firing order of the engine. Figure 1.5 shows the crankshaft with flywheel attached to it. Crankshaft has passages drilled for the flow of oil to the connecting rod bearings.

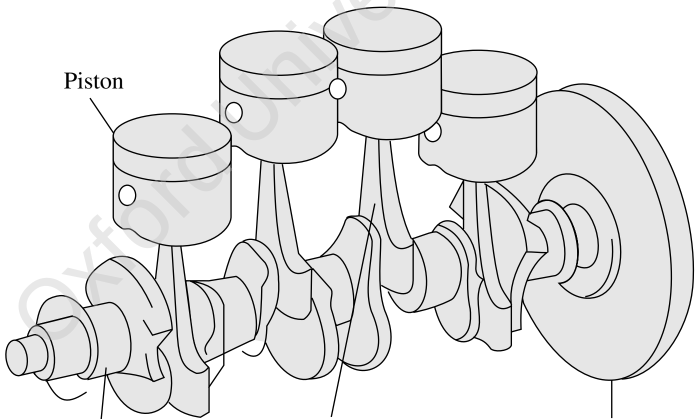

Fig. 1.5 Crankshaft and flywheel

Flywheel

Flywheel is basically an energy reservoir to store rotational energy for smoothening out the firing impulses. It is a heavy metal wheel attached to the back of the crankshaft. Flywheel provides inertia to keep the crankshaft turning smoothly during the periods when no power is obtained. It also forms a base for the starter ring gear and for the clutch assembly in manual transmission.

1.4 Engine Nomenclature

The terms/nomenclature associated with an internal combustion engine are explained here for the better understanding of the working principle of engines (Fig. 1.6).

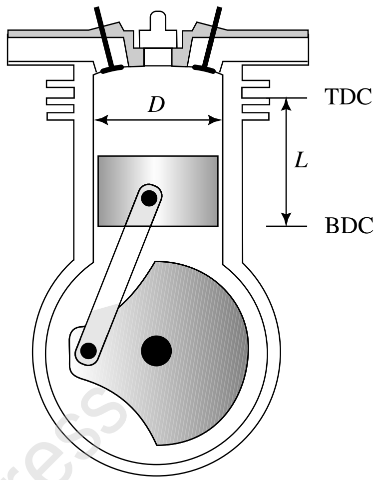

Fig. 1.6 Engine nomenclature

Top dead centre In a reciprocating engine the piston moves in a to-and-fro motion in the cylinder. As the piston moves in the upward direction in the cylinder, the point at which the piston comes to rest or changes its direction is known as top dead centre (TDC), situated at top end of the cylinder.

Bottom dead centre As the piston moves in the downward direction, the point at which the piston comes to rest or change its direction is known as bottom dead centre (BDC) and is situated at the bottom side of the cylinder.

Stroke Stroke is the distance between the top dead centre and bottom dead centre. It is the maximum distance travelled by the piston in a single direction and is designated by the letter L.

Bore The inner diameter of the cylinder is known as bore of the cylinder and is designated by the letter D.

Stroke-to-bore ratio It is the ratio of the length of stroke to the inner diameter of the cylinder. It is generally equal to one for small engines and less than one for large engines. Engines are classified based on L/D ratio as follows:

(a) Under square piston, if $D < L$
(b) Square piston, if $D = L$
(c) Over square piston, if $D > L$

Petrol engines are normally designed with over square pistons ($D > L$), whereas diesel engines have under square pistons ($D < L$). In diesel engines with under square pistons, longer stroke increases engine friction as the piston travels a greater distance per stroke, which limits the maximum speed. Hence, diesel engines are most often tuned to develop peak torque at relatively low speeds.

Piston area (A) It is the area of a circle of diameter equal to cylinder bore.

Cylinder volume (V) It is the volume of cylinder when the piston is at BDC. Generally, it is expressed in centimeter cube (cc) or in litres (L) for example, 100 cc engine in motor bikes, 2.5 litre engine in SUVs, etc.

Clearance volume (V_c) It is the volume of cylinder when the piston is at TDC.

Swept or displacement volume (V_s) It is the volume swept through by the piston in moving between TDC and BDC. Swept volume is the difference between the total volume and clearance volume,

$$V_s = V - V_c \tag{1.1}$$

Swept volume is calculated as the product of piston area and stroke.

$$V_s = A \times L = \frac{\pi}{4} D^2 \times L. \tag{1.2}$$

Compression ratio The ratio of maximum volume to minimum volume of the cylinder is known as the compression ratio. Compression ratio is in the range of 8–12 for spark ignition engines and 12–24 for compression ignition engines.

$$\text{Compression ratio} = \frac{\text{Cylinder volume}}{\text{Clearance volume}} = \frac{V}{V_c} = \frac{V_s + V_c}{V_c} \tag{1.3}$$

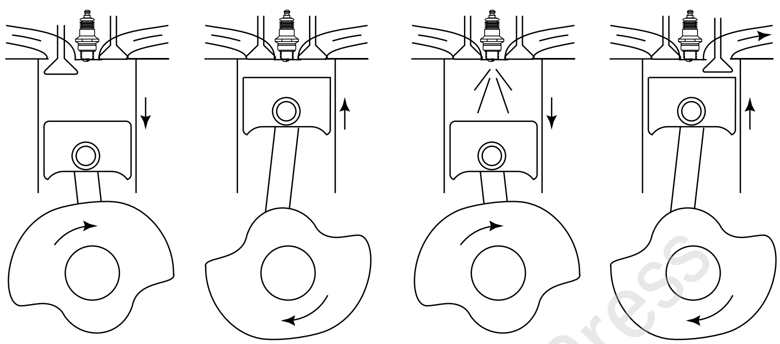

Fig. 1.7 Four-stroke spark ignition (SI) engine cycle (a) Intake, (b) Compression, (c) Power, (d) Exhaust

1.5 Four-stroke SI Engines

In a four-stroke cycle engine, the cycle of operation is completed in four strokes of the piston or two revolutions of the crankshaft. A stroke refers to the full travel of the piston along the cylinder, in one direction. Figure 1.7 shows various strokes of a four-stroke spark ignition (SI) engine cycle and Fig 1.8 shows the actual indicator diagram of a four-stroke SI engine. Figure 1.9 shows the actual valve timing of a four-stroke petrol engine, which gives a clear idea about the actual position of the piston during the opening and closing of inlet and exhaust valves. The four strokes of a conventional petrol engine are discussed here.

Intake stroke Intake stroke of the piston begins at TDC and ends at BDC. The inlet valve remains open and the exhaust valve remains closed during this stroke. The volumetric efficiency and hence the power of the engine mainly depends on the amount of air or air–fuel mixture sucked during the suction stroke. Hence, the inlet valve is normally opened slightly ahead of TDC (IVO 20° in Fig. 1.9) so as to ensure that inlet valve is fully opened and fresh charge starts to flow into the cylinder as soon as possible after the TDC. As the piston descends, moving away from the cylinder head (Fig. 1.7(a)), a depression of pressure is created within the cylinder which inducts fresh charge of air and atomized fuel into the cylinder. An engine which sucks fresh charge by means of a depression in the cylinder is called 'normally aspirated'. In the case of carburetted engine, air–fuel mixture preparation takes place in the carburettor, whereas in multi-point fuel injection (MPFI) engines, during the suction stroke air enters into the cylinder and fuel is injected into the air in the manifold, behind the inlet valve thus mixing the air and fuel. As the piston moves towards the BDC during the suction stroke, the fresh charge enters the cylinder. However, due to inertia the fresh charge continues to flow into the cylinder for some time even when the piston starts moving to the TDC in the compression stroke. In order to take the advantage of this *Ram effect* the inlet valve is closed slightly after the TDC (IVC 35° in Fig. 1.9) so as to induct maximum amount of air.

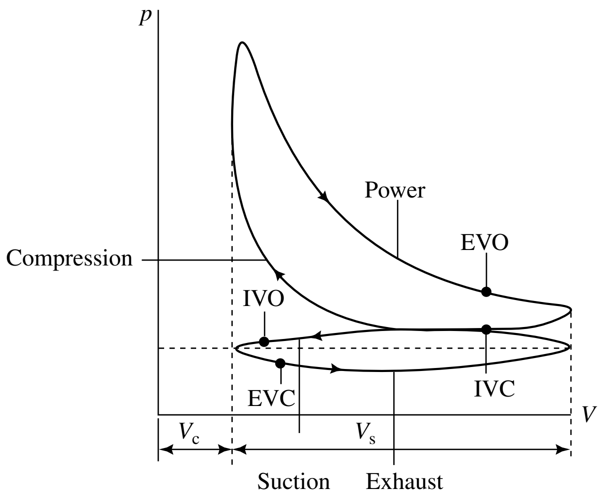

Fig. 1.8 Actual indicator diagram of a four-stroke petrol engine

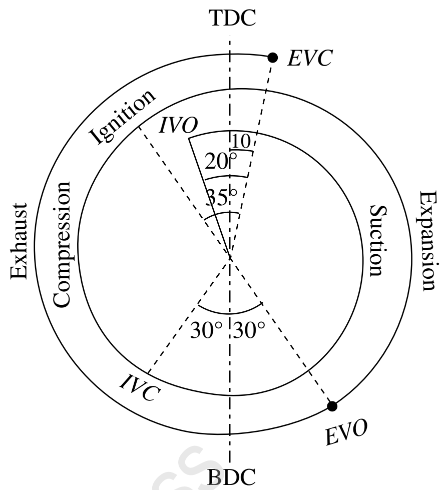

Fig. 1.9 Actual valve timing diagram

Compression stroke Compression stroke begins at BDC and ends at TDC. Both the intake and exhaust valves remain closed during this stroke. The air–fuel mixture which occupies the entire cylinder volume is progressively compressed into clearance volume and the pressure and temperature of the air–fuel mixture rise.

Power stroke During power stroke both inlet and exhaust valves are closed. Towards the end of the compression stroke, the mixture is ignited by means of an electric spark between the electrodes of the spark plug located in the combustion chamber wall. By the time the piston reaches the TDC, the charge mixture begins to burn, generates heat, and rapidly raises the pressure in the cylinder until the gas pressure exceeds the resisting load. The burning gases in the cylinder expand and change the piston's direction of motion and push it to its outermost position (BDC).

Exhaust stroke At the end of the power stroke the inlet valve remains closed but the exhaust valve is open and the piston returns to TDC. As the valve opening is spread over a considerable number of crankshaft degrees, exhaust valve is opened slightly before BDC (EVO 35° in Fig. 1.9) so that the entire area is available for the flow of exhaust during the beginning of the exhaust stroke, that is, when the piston moves up from BDC. Most of the burnt gases are expelled due to the pressure energy of the gas and the piston also pushes the exhaust gases out of the cylinder through the exhaust-valve port to the atmosphere. During the exhaust stroke the exhaust gases continue to flow out of the cylinder for some more time even when the piston starts moving to the BDC in the suction stroke of the next cycle, mainly due to inertia. In order to take advantage of this inertia effect exhaust valve is closed slightly after the TDC in the suction stroke of the next cycle (EVC 35° in Fig. 1.9). Some of the residual exhaust gases remain in the cylinder, which will be used in the next cycle.

However, there exists a period where both intake and exhaust valves are open at the same time during some degrees of crankshaft rotation (20–30° crank angle) and is called *valve overlapping*. During valve overlapping, that is, towards the end of a cycle both valves remain open, which results in the back flow of exhaust gases to the inlet manifold, especially during part-load operation. This exhaust gas dilution mainly occurs as the exhaust gas pressure is higher than the intake manifold pressure. The exhaust gas dilution during idling and part-load conditions causes poor combustion resulting in low thermal efficiency and higher exhaust emissions. The overlap is mainly due to the early opening of intake valve and delayed closing of exhaust valve, which is done to improve the volumetric efficiency and hence the power of the engine. However, this results in the higher specific fuel consumption especially at idling and part-load conditions, which in fact is a problem in conventional petrol engines. The opening and closing of the intake and exhaust valve depend on the profile of the cams and is fixed for any engine. However, the actual time available depends on the engine speed and hence at lower speed (during idling and part load conditions) the time available for back flow of exhaust is maximum, which results in maximum exhaust gas dilution. This inherent problem of SI engines is being solved in today's engines that use the latest electronic control systems by means of variable valve timing technologies. The valve timing is changed either by (i) changing the cam profile using multiple cams (VTEC in Honda vehicles) or by (ii) advancing or retarding the exhaust/intake camshafts (VVTi in Toyota vehicles). Variable valve timing technologies are discussed in detail in Section 17.7 of Chapter 17.

In petrol engines with GDI system, during the suction stroke, air is inducted and pressurized fuel is directly injected into the cylinder by means of a fuel injector mounted in the cylinder, either during the end of suction stroke or during the compression stroke depending upon the load conditions. For higher output the fuel is injected towards the end of suction stroke to obtain a homogenous mixture whereas for better economy, fuel is injected during the compression stroke thus obtaining a heterogeneous mixture. The petrol engine with air-assisted fuel injection system is like GDI engines wherein air is sucked during the suction stroke. However, in air-assisted fuel injection systems instead of injecting the fuel at high pressure, a rich air–fuel mixture is injected at lower pressure either during suction or compression stroke thus achieving better atomization. MPFI, GDI, and air-assisted fuel injection systems are discussed in detail in Chapter 7.

1.6 Four-stroke CI Engines

Four-stroke CI engines are similar to four-stroke SI engines except in the initiation of the combustion process. In the petrol engines combustion is initiated by means of spark whereas in CI engines autoignition of fuel is caused by the high temperature at the end of compression stroke due to high compression ratio. In the diesel engine, during the suction stroke only air is inducted into the cylinder and fuel is injected directly into the cylinder by means of a high pressure pump. The four strokes of a conventional diesel engine shown in Fig. 1.10 are discussed here.

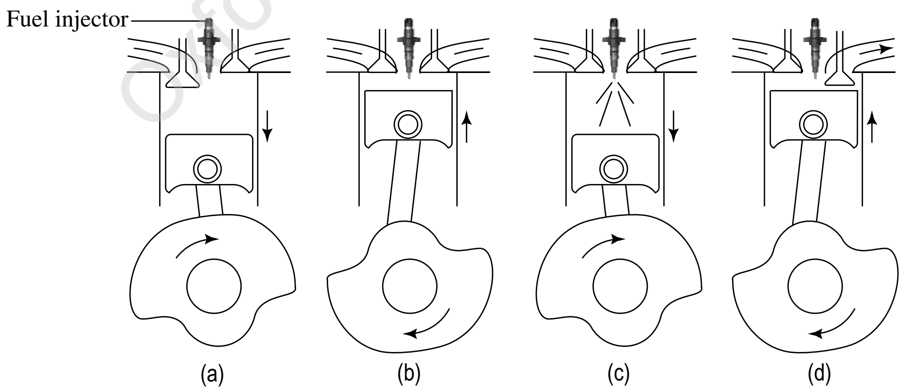

Fig. 1.10 Four-stroke compression ignition (CI) engine cycle (a) Intake, (b) Compression, (c) Power, (d) Exhaust

Suction stroke During suction stroke the piston moves from TDC to BDC and air at atmospheric pressure is drawn into the cylinder through the inlet valve. The inlet valve remains open until the piston reaches the lower end of the cylinder and closes slightly after the BDC, in order to take advantage of the inertia effect, as explained earlier.

Compression stroke During compression stroke the piston moves from BDC to TDC and both the valves remain closed. The upward movement of the piston compresses the air and raises the pressure and temperature inside the cylinder.

Power stroke Towards the end of the compression stroke when the piston is near TDC a metered quantity of diesel is injected into the cylinder by a fuel injector. The heat of compressed air ignites the diesel and generates high pressure which pushes down the piston. At the end of power stroke the piston reaches the bottom end of the cylinder. Both valves remain closed during power stroke.

Exhaust stroke When the piston reaches the BDC after the power stroke, the exhaust valve opens. Exhaust valve is opened slightly before BDC to expel maximum amount of exhaust gases. The cylinder pressure is slightly above the atmospheric pressure which allows the exhaust gases to escape through the exhaust port and the piston moves towards TDC. The inlet valve remains closed during the exhaust stroke and is opened towards the end of the exhaust stroke.

1.7 Two-stroke Petrol Engines

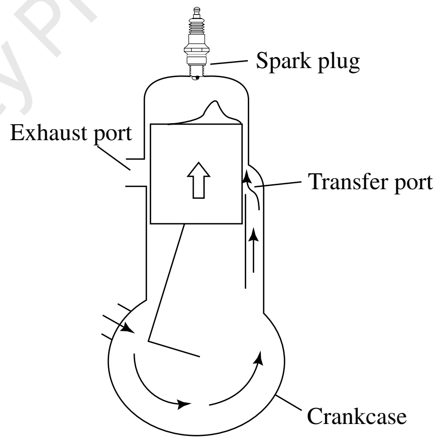

Fig. 1.11 Two-stroke petrol engine

In four-stroke engines, there exist separate strokes (exhaust and suction) for the removal of exhaust gases and filling of fresh charge. However in two-stroke engines (See Fig. 1.11) the entire cycle completes in two piston strokes, one for compressing the fresh charge and the other for power stroke. During the suction stroke, in a typical two-stroke petrol engine as shown in Fig. 1.11, the compressed air from crankcase (external blower in the case of externally scavenged engines) enters the cylinder and also removes the combustion products through the exhaust ports. As the piston moves upwards, pressure in the crankcase decreases and air/charge is sucked into the crankcase, through the spring loaded inlet valve. The upward motion of the piston results in lower pressure in the crankcase which opens the reed valve. Meanwhile the air/charge above the piston gets compressed and towards the end of compression, ignition occurs leading to combustion. The engine cylinder is filled with the combustion products and the downward motion of piston first uncovers the exhaust port, expelling the combustion products. Further motion of piston uncovers the transfer ports and the compressed air/air–fuel mixture enters the cylinder through the transfer ports. The piston has a deflector on the top to deflect the fresh air to sweep up to the top, before leaving the cylinder through the exhaust ports. This process of removal of exhaust gas from the cylinder by the fresh charge is known as scavenging. During the scavenging process a portion of fresh charge is carried along with the exhaust gases and is known as *short circuiting*. As the piston moves up the transfer port will be closed first, due to the symmetry followed by the closure of exhaust port. The actual compression of air/charge occurs only after the closure of exhaust port unlike in four-stroke engines, in which compression stroke starts as the piston moves from BDC to TDC.

1.8 Two-stroke Diesel Engines

One of the main problems associated with conventional two-stroke petrol engines is the loss of air–fuel charge during the scavenging process, resulting in lower thermal efficiency and high emissions. However, in diesel engines there is no short circuiting as only air is used for scavenging and diesel at higher pressure is directly injected into the cylinder after the closure of exhaust port. In diesel engines, the combustion initiates with auto-ignition which requires high pressure and temperature for the air in the cylinder. As high pressure cannot be obtained by crankcase scavenging, a separate blower is essential for external scavenging for the two-stroke diesel engines. The use of blowers makes the two-stroke diesel engines more bulky and hence two-stroke engines are generally not used in bikes. However for marine application, in ships two-stroke diesel engines are widely used.

1.9 Four-stroke and Two-stroke Engines—A Comparison

The differences between two- and four-stroke cycle petrol engines are given below:

- In the case of four-stroke engines one cycle is completed in two revolutions of the crankshaft or four strokes of the piston. However in two-stroke engines, the entire cycle is completed in two strokes of the piston or in one revolution of the crankshaft. Hence, one power stroke is obtained in each revolution of the crankshaft.
- In a four-stroke engine one power stroke is obtained in every two revolutions of crankshaft and hence power flow is not so uniform, thus requiring heavier flywheel. However, a two-stroke engine requires lighter flywheel only.
- As one power stroke is obtained per revolution, power produced for the same size of engine is more for two-stroke engines as compared to four-stroke engines. In other words, for the same power, four-stroke engines will be more heavy and bulky as compared to two-stroke engines. Two-stroke engines have higher power-to-weight ratio compared to four-stroke engines.
- The lubrication and cooling requirement is more for two-stroke engines as compared to four-stroke engines, since one power stroke is obtained per revolution in two-stroke engines. The wear and tear of two-stroke engines will also be more than that of four-stroke engines of the same capacity.
- Four-stroke engines have valve and associated complicated valve mechanism, whereas two-stroke engines do not have valve but only ports which make the engine simple.
- The cost of four-stroke engines will be higher because of heavy weight and complication of valve mechanism, whereas two-stroke engines are cheaper due to the absence of valves.
- Four-stroke engines have higher volumetric efficiency due to greater time of induction as compared to two-stroke engines.
- Brake thermal efficiency and part-load efficiency of four-stroke engines are higher as compared to two-stroke engines. Lower efficiency of two-stroke engines is due to the short circuiting of fuel during the scavenging process.
- The emissions from conventional two-stroke petrol engines are more than that of four-stroke petrol engines due to the short circuiting phenomenon.
- Four-stroke engines are used where efficiency is of prime importance such as in cars, buses, trucks, and generators. These engines are used where cost, compact, and lightweight is the prime consideration. Two-stroke diesel engines are used in ships because of their high power-to-weight ratio.

1.10 SI and CI Engines—A Comparison

A comparison of SI and CI engines is made from various aspects as discussed below:

Basic cycle Petrol engine is based on Otto cycle (constant volume) whereas diesel cycle is based on diesel cycle (constant pressure).

Fuel The fuel used in petrol engine should have high self-ignition temperature for better anti-knocking quality, whereas for the fuel used in diesel engine lower self-ignition temperature is desirable.

Mixture preparation In a carburetted-type petrol engine the air and fuel are mixed in the carburettor whereas in MPFI engines air is inducted during the suction stroke and fuel is injected into the inlet manifold thus mixing the air and fuel. In the gasoline direct injection system air is inducted during the suction stroke and fuel is injected directly into the cylinder at high pressure. However, in diesel engines during the suction stroke, air is inducted into the cylinder and fuel is injected at very high pressure towards the end of compression stroke to obtain a heterogeneous mixture.

Compression ratio Compression ratio used in petrol engine is in the range of 8–12, the maximum limit of which is fixed by the anti-knocking quality of petrol. However, in diesel engines higher compression ratio in the range of 12–24 can be used. The upper limit of compression ratio is limited by increase in weight of the engine and percentage of unutilized air with increase in compression ratio.

Fuel economy Petrol engines can have thermal efficiencies ranging between 20 and 30%. The corresponding diesel engines generally have improved efficiencies, between 30 and 40%. Both sets of efficiency values are considerably influenced by the chosen compression ratio and design. The lower maximum efficiency of petrol engines is mainly due to lower compression ratio as compared to that of diesel engines.

Power and torque Petrol engines have maximum torque and power at higher speeds as compared to similar diesel engines which have maximum torque/power at lower speeds. In a petrol engine as the speed increases the chance of abnormal combustion (knocking) decreases, whereas in conventional diesel engines abnormal combustion is more prominent at high speeds. Hence, the petrol engines are usually designed with a shorter stroke (over square piston, $D > L$) and operates over much higher engine speed to enable more power to be developed towards the upper speed range which is necessary for high road speeds. However, conventional diesel engines are designed with longer stroke (under square piston, $D < L$). At a given engine speed for engines with under square pistons, longer stroke increases engine friction as the piston travels a greater distance per stroke, which in turn increases the stress on the crankshaft due to the higher peak piston acceleration. Hence, the diesel engines with under square piston are most often tuned to develop peak torque at relatively low speeds, which is essential for heavy commercial vehicles. However with the invention of common rail direct injection system, the tendency of knocking in diesel engines has been reduced thus achieving smooth operation.

Pollution The pollution from diesel engines is more harmful as compared to that from petrol engines. The particulate matter in the diesel exhaust is very toxic which mainly causes respiratory problems.

Cost The cost of diesel engine is normally higher than that of the petrol engine (identical) due to the heavy construction and injection equipment.

1.11 Performance Parameters

Engine performance is basically the indication of the degree of success of conversion of the chemical energy contained in the fuel to useful mechanical work. The various parameters to be considered for the performance evaluation of an engine are listed below. More details of the performance parameters are given in Chapter 16.

- Power and torque
- Mean effective pressure (MEP)
- Specific fuel consumption (sfc)
- Specific output
- Air–fuel ratio

- Air standard efficiency
- Thermal efficiency
- Relative efficiency
- Mechanical efficiency
- Volumetric efficiency

1.12 The Future Engines

The future stringent emission norms and low fuel consumption requirements demand intensified research both on engine and after-treatment technologies. Various developments that could improve the performance and efficiency of an internal combustion engine are discussed here.

The smaller engines are found to be more efficient, even though they make less power as compared to bigger ones. This is mainly attributed to the reduction in inertia and engine frictional losses associated with smaller engines. Many automotive companies now adopt smaller engines to achieve high engine power and lower fuel economy simultaneously, with the aid of three technologies, namely (i) turbochargers, (ii) direct fuel injection, and (iii) variable valve timing. Even though the use of turbochargers in petrol engine boosts the power, it leads to detonation due to higher mixture temperature and pressure. This necessitates the use of lower compression ratio thus compromising the efficiency. The direct injection of gasoline into the cylinder solves this problem by cooling the intake charge by the fuel and thereby minimizing the detonation. In addition, by means of variable valve timing the intake and exhaust valve overlap duration can be extended. Hence, the turbocharger can blow more fresh air through the cylinder for removing the hot leftover gases from the previous combustion cycle, thereby improving the volumetric efficiency of the engine and hence the torque and power. Even though the application of above-mentioned technologies to downsize the engines keeps the peak power same as big engines along with a 10–20% improvement in the efficiency, the cost of the engines increases correspondingly.

One of the problems with conventional petrol engines is the low part-load efficiency due to the high pumping losses at low loads. Variable displacement is a method to improve the efficiency of multi-cylinder engines, in which the engine displacement volume is varied by turning off the cylinder depending upon the power requirement. By cutting down the number of firing cylinders, throttle must be opened further to get the same power from the remaining cylinders, thereby reducing the pumping losses. Another approach to improve the performance of IC engines is the incorporation of variable compression ratio. A variable compression ratio (VCR) engine is an internal combustion engine which can change the length of the piston stroke to achieve greater or lesser compression of the air–fuel mixture, thereby optimizing the performance of the engine for either maximum power or maximum fuel efficiency, as needed.

Modern engines incorporate variable valve timing technologies (VTEC, VVTi, VANOS, etc.) for achieving better performance and lower specific fuel consumption. The variable valve timing technology changes the valve timing by changing the cam profile using multiple cams, even though only few cam profiles can be in operation at once. Valve timing is also changed by advancing or retarding the exhaust/intake camshafts, which in fact is complicated. Another approach for varying the lift of the valve is Fiats MultiAir technology. In Fiats MultiAir engines the lift of the valve is varied by means of a hydraulic chamber that connects the intake valves and the camshaft. The pressure in the hydraulic chamber is controlled by solenoid valves thereby varying the valve lift, depending upon the requirement. Fiat's MultiAir technology has various benefits over the conventional petrol engines such as (i) improvement in power, (ii) reduction in fuel consumption, (iii) reduction in particulates, NO_x and CO_2 emissions. A new concept for the improvement of the performance of IC engines is the Camless engine (free valve engines), which increases efficiency by digitally controlling the valves thereby regulating the intake and exhaust valves. Free valve engines have electromagnetic, hydraulic, or pneumatic actuators on top of each cylinder for controlling the valves and thus get rid of the camshaft. Free valve engines can also shut down the number of cylinders, etc. depending upon the power requirement.

Even though diesel engines are more efficient than petrol engines, they are the main contributors to the toxic air pollutants such as particulate matter (PM) and NO_x emissions that are difficult to mitigate. PM is composed of black soot particles, usually soaked with unburned or partially burned fuel components. NO_x emissions combine with other pollutants in the atmosphere to create ground-level ozone, or smog. Diesel particulate filters are generally used to control the PM emissions. One way to reduce these two most problematic pollutants emitted by diesel engines is by adopting low-temperature combustion (LTC). Different strategies are adopted for achieving low-temperature combustion. There are engines in which some exhaust gases are re-circulated back into the cylinder where they absorb heat and lower the combustion temperatures, which reduces NO_x formation. The fuel injection is also initiated earlier in the engine cycle so as to give the fuel more time to mix with air before it burns. Hence NO_x emissions are reduced by avoiding high-temperature zones and PM emissions are controlled by avoiding fuel-rich regions. Even though low-temperature combustion minimizes NO_x and PM, other pollutants such as unburned hydrocarbons (UHCs) increase. Homogeneous charge compression ignition (HCCI) is an advanced combustion strategy to achieve low-temperature combustion, details of which are given in Chapter 8.

Even though electric powered vehicle is the ultimate solution for the control of exhaust emissions, they are expensive. Hybrid electric vehicles (HEVs), which are intended to achieve better fuel economy and performance than conventional engines are becoming popular. An HEV combines a conventional internal combustion engine (ICE) system with an electric propulsion system (hybrid vehicle drive train). Even modern HEVs convert the vehicle's kinetic energy into electric energy to charge the battery by means of regenerative brakes. In this case the electric motor which will supplement the power during starting and peak-load conditions will act as a dynamo and charge the battery during braking.

Another major area where much research is being done is on hydrogen-powered engines. The main advantage of the use of hydrogen as fuel in automobiles is their zero emissions as H_2 and O_2 combine to form water, a harmless product. Hydrogen can be used directly in IC engines or can be used in fuel cells to power the automobile. A fuel cell vehicle (FCV) is a type of electric vehicle which uses a fuel cell that generates electricity to power its on-board electric motor. A fuel cell is basically a device consisting of an anode, a cathode, and an electrolyte which converts the chemical energy of a fuel into electricity through the chemical reaction of positively charged hydrogen ions with oxygen or another oxidizing agent. Fuel cells differ from batteries in the fact that the fuel and oxidant are not contained within the fuel. A fuel cell requires a continuous source of fuel and oxygen or air to sustain the chemical reaction as opposed to a battery. Active research is going on all over the world and new materials and technology are being developed for the storage of hydrogen.

Summary

- Heat engine is a device which derives heat energy from the combustion of fuels and converts this energy to mechanical work.
- The engine is the heart of an automobile.
- The ratio of maximum volume to minimum volume of cylinder is known as the compression ratio.
- In four-stroke cycle engine, the cycle of operation is completed in two revolutions of the crankshaft, whereas in two-stroke engines, the entire cycle completes in one revolution.
- In petrol engines combustion is initiated by means of spark whereas in diesel engines autoignition of fuel is caused by the high temperature at the end of compression stroke due to high compression ratio.
- Four-stroke engines are used where efficiency is of prime importance whereas two-stroke engines are used where cost, compact, and lightweight is the prime consideration.

- Engine performance is basically the indication of the degree of success of conversion of the chemical energy contained in the fuel to useful mechanical work.
- The future stringent emission norms and low fuel consumption requirements demand intensified research both on engines and after-treatment technologies.

Multiple Choice Questions

1. Higher thermal efficiency of diesel engines is due to
   (a) higher compression ratio
   (b) type of fuel
   (b) constant pressure heat addition
   (d) none of the above
2. The compression ratio of diesel engines is in the ratio
   (a) 7–10 (b) 5–7
   (c) 12–24 (d) 10–12
3. The compression ratio of petrol engines is
   (a) 8–12 (b) 4–7
   (c) 14–20 (d) 10–12
4. Engines normally used for marine applications are
   (a) two-stroke diesel engines
   (b) two-stroke petrol engines
   (c) four-stroke diesel engines
   (d) four-stroke petrol engines
5. Which of the following engines emits maximum particulate emissions?
   (a) Two-stroke petrol engines
   (b) Four-stroke petrol engines
   (c) Four-stroke diesel engines
   (d) All of the above
6. In gasoline direct injection system (GDI), fuel is injected directly into
   (a) inlet manifold
   (b) engine cylinder
   (c) exhaust manifold
   (d) none of the above
7. In multi-point fuel injection system (MPFI), fuel is injected directly into
   (a) inlet manifold
   (b) engine cylinder
   (c) exhaust manifold
   (d) none of the above
8. In a four-stroke petrol engine, the inlet valve is opened
   (a) slightly before TDC
   (b) slightly after TDC
   (c) slightly before BDC
   (d) slightly after BDC
9. In a four-stroke petrol engine, the exhaust valve is closed
   (a) slightly before TDC
   (b) slightly after TDC
   (c) slightly before BDC
   (d) slightly after BDC
10. Wankel engine is a
   (a) rotary engine
   (b) reciprocating engine
   (d) gas turbine
   (d) none of the above
11. Petrol engines are normally designed with
   (a) over square pistons
   (b) under square pistons
   (c) square pistons
   (d) none of the above
12. Diesel engines are normally designed with
   (a) over square pistons
   (b) under square pistons
   (c) square pistons
   (d) none of the above
13. Gudgeon pin forms the link between
   (a) piston and small end of connecting rod
   (b) piston and big end of connecting rod
   (c) connecting rod and crank
   (d) none of the above
14. The type of engine which admits air or air–fuel mixture into engine cylinder at atmospheric pressure is
   (a) super charged
   (b) turbo charged

(c) naturally aspirated
(d) none of the above

15. The main advantage of two-stroke petrol engines over four-stroke petrol engines is
(a) low specific fuel consumption
(b) low emissions
(c) high efficiency
(d) high power-to-weight ratio

16. The space enclosed between the upper part of the cylinder and the top of the piston during the combustion process is called the
(a) combustion chamber
(b) swept volume
(c) cylinder volume
(d) None of the above

17. Which of the following is used to store rotational energy for smoothening out the firing impulses in a petrol engine?
(a) Flywheel (b) Crank shaft
(c) Piston (d) Connecting rod

18. The distance between the top dead centre and bottom dead centre is called
(a) bore (b) stroke
(c) clearance volume (d) none of the above

19. ____ is the process in which a portion of fresh charge is carried along with the exhaust gases during the scavenging process in a two-stroke petrol engine.
(a) Uni flow scavenging
(b) Suction stroke
(c) Short circuiting
(d) Exhaust stroke

20. In Fiat's Multiair engines the lift of the valve is varied by means of a
(a) pneumatic chamber
(b) solenoid actuator
(c) hydraulic chamber
(d) none of the above

21. The volume swept through by the piston in moving between TDC and BDC is called
(a) swept volume
(b) clearance volume
(c) cylinder volume
(d) none of the above

22. ____ is the base of the engine which supports the crankshaft and camshaft.
(a) Crankcase
(b) Crank shaft
(c) Cylinder head
(d) None of the above

23. ____ provide a good sealing between the piston and cylinder.
(a) Piston rings
(b) Liners
(c) Gaskets
(d) None of the above

24. Which of the following is commonly used for marine application?
(a) Two-stroke petrol engines
(b) Two-stroke diesel engines
(c) Four-stroke diesel engines
(d) None of the above

25. Turbochargers are used to improve
(a) power
(b) efficiency
(c) emission reduction
(d) none of the above

Review Questions

1. Compare SI and CI engines.
2. What are the advantages of two-stroke engines over four-stroke engines?
3. Explain the working of a two-stroke petrol engine.
4. Explain how engines are classified based on (i) arrangement of cylinders, (ii) charge preparation.
5. Explain why two-stroke diesel engines are not commonly used in motor bikes.
6. Draw the valve timing diagram of a typical SI engine.
7. Explain why the maximum torque and power are attained at lower speeds in conventional diesel engines as opposed to petrol engines.

8. What is meant by bore/stroke ratio? How are engines classified based on bore/stroke ratio?
9. Explain the working of a four-stroke diesel engine.
10. Define (i) swept volume, (ii) clearance volume, and (iii) compression engine.
11. Define the terms (a) TDC (b) BDC (c) stroke (d) bore.
12. Discuss how engines are classified based on (i) application (ii) valve location (iii) charging method.
13. Compare in line type and V type engines.
14. Discuss the function of the following engine components (i) connecting rod (ii) crank shaft (iii) piston.
15. Write a note on Future engines.

Answers to MCQs

1. (a)	2. (c)	3. (a)	4. (a)	5. (c)	6. (b)	7 (a)
8. (a)	9. (b)	10. (a)	11. (a)	12. (b)	13. (a)	14 (c)
15. (d)	16. (a)	17. (a)	18. (b)	19. (c)	20. (c)	21. (a)
22. (a)	23. (b)	24. (b)	25. (a)			