MODULE 3

Fundamentals of IC Engines:

Review of Internal Combustion Engines, 2-Strokes and 4-Strokes engines, Components and working principles, Application of IC Engines in Power Generation, Agriculture, Marine and Aircraft Propulsion, Automobile.

Insight into future mobility technology:

Electric and Hybrid Vehicles, Components of Electric and Hybrid Vehicles, Drives and Transmission. Advantages and disadvantages of EVs and Hybrid vehicles.

Heat engine is a device which converts heat energy produced due to combustion of fuel taking place inside the cylinder into mechanical energy. Heat engines are classified into two categories:

1. Internal combustion engines (1.C. engines) 2. External combustion engines (E.C. engines)
In I.C. engines, combustion of fuel takes place inside the engine cylinder whereas in E.C engines, combustion takes place outside the engine cylinder.

An internal combustion engine (IC Engine) is a heat engine in which the combustion of a fuel occurs in the presence of air in a combustion chamber that is an integral part of the working fluid flow circuit.

In an internal combustion engine, the expansion of the high-temperature and high-pressure gases produced by combustion applies direct force to some component of the engine (Piston). The force is applied typically to pistons, turbine blades, rotor or a nozzle. This force moves the component over a distance, transforming chemical energy into useful work.

Classification of I.C. Engines

1. According to the type of fuel used
(i) Petrol engine (ii) Diesel engine (iii) Gas engine (iv) Bio-fuel engine.

2. According to the number of strokes per cycle
(i) Four stroke engine (ii) Two stroke engine

3. According to thermodynamic cycle
(i) Otto cycle engine (constant volume combustion) (ii) Diesel cycle (constant pressure combustion) engine (iii) Dual (or) Mixed cycle (partly constant volume and partly pressure combustion) engine

4. Method of cooling
(i) Air cooled engine (ii) Water cooled engine

5. According to method of ignition
(i) Spark ignition engine (S.I. engine) (ii) Compression ignition engine (C.1. engine)

6. According to number of cylinders
(i) Single cylinder engine (ii) Multi cylinder engine

7. According to the engine cylinder
(i) Horizontal engine (ii) Vertical engine (iii) V-engine (iv) Radial engine

Parts of I.C Engine:

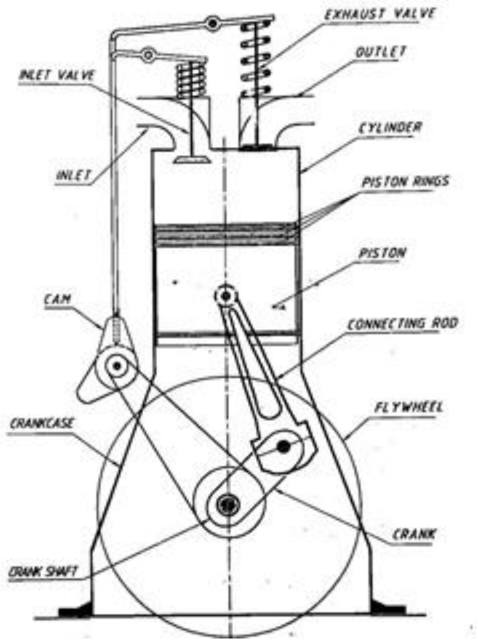


Figure: Parts of I.C Engine

1. Cylinder: It is the main body and heart of the engine in which fuel is burnt and piston reciprocates to develop the power. It is in direct contact with the products of combustion and it must be cooled to avoid damage.

2. Piston: It is a gas-tight movable cylindrical component fitted perfectly inside the cylinder. The piston is used to compress the fuel during compression stroke. It transmits the force exerted by the combustion of fuel to the connecting rod and finally to the crankshaft. Piston is usually made up of cast iron (or) aluminium alloy.

3. Cylinder head: One end of the cylinder is closed by means of a removable plate known as cylinder head. Cylinder head usually contains the inlet valve for admitting the mixture of air and fuel and exhaust valve for discharging the products of combustion.

4. Piston rings: Piston rings are metallic rings and are fitted in the circumferential grooves provided at the top end outer surface of the piston. It gives gas tight sealing between the piston and cylinder while the piston reciprocating inside the cylinder. Piston rings maintain compression pressure inside the cylinder and prevent leakage of high-pressure gases into the crank case.

5. Connecting rod: It is a kinematic link that connects the piston and the crank. It converts reciprocating motion of piston into rotary motion of crank. Its small end is connected to the piston with the help of piston pin and big end to the crank-by-crank pin. It transmits the force from piston to crank.

6. Crank and Crankshaft: The crank is a rotating element with one of its ends connected to the lower end of the connecting rod while the other is connected to the shaft called crankshaft. It rotates about the axis of the crankshaft and causes the connecting rod to oscillate. The crankshaft is supported in the main bearings and has a flywheel mounted on it to reduce the fluctuation of speed. The main function of crankshaft is to transmit the power developed by the engine to useful work (to run vehicle, boat, ship etc.)

7. Crankcase: It is the lower part of the engine serving as an enclosure for the crankshaft and also acts as an oil sump for lubricating oil.

8. Valves: Two types of valves i.e., inlet and exhaust valves located on the cylinder head (or) on the side of the cylinder.

(1) Inlet valve: It is provided on the cylinder head for regulating the charge coming into the cylinder.

(2) Exhaust valve: It is provided on the cylinder head for removing exhaust gases (products of combustion) from the cylinder.

9. Flywheel: It is a wheel mounted on the crankshaft which stores excess energy during the power stroke and releases (or) returns that energy during the other three idle strokes, thus maintaining the uniform rotation of the crankshaft.

10. CAM: Cam is a rotating element used to control the opening and closing of valves. Cams are designed in such a way that to open the valve at the correct timing and to keep them open for the required duration and to close them at the correct time.

11. Spark plug / Fuel injector: In case of petrol engines, the spark plug provides the spark at the end of compression stroke to initiate the combustion process. In case of diesel engines, spark plug is replaced by fuel injector which injects diesel into the compressed air to initiate the combustion process.

I. C Engine Terminology:

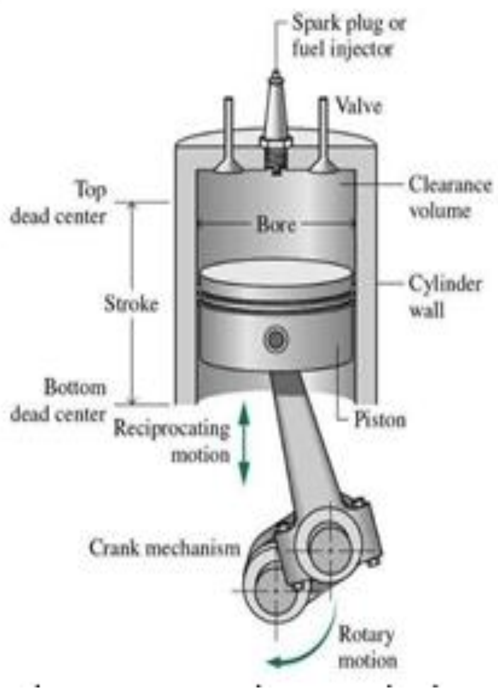


Figure: I. C Engine Terminology

1. Bore (d): Inside diameter of the engine cylinder is called bore. It is denoted by a letter ‘d’.

2. Top dead centre (TDC): The extreme position (topmost) of the piston towards cover end (or) cylinder head is known as TDC. In case of horizontal engine, this position is called inner dead centre position (IDC).

3. Bottom dead centre (BDC): The extreme position (bottom most) of the piston towards the crank end of the cylinder is called BDC. In case of horizontal engine, this position is called outer dead centre position (ODC).

4. Stroke (L): The linear distance through which the piston travel from TDC to BDC (or) vice versa is called stroke It is equal to the twice of the radius of the crank. It is designated by the latter L.

$$L=2r$$

5. Clearance volume (V): The volume contained in the cylinder above the top of piston when the piston is at TDC (or) volume of the combustion chamber when the piston is at TDC is called clearance volume. It is designated by and is pressed in cc.

6. Swept volume (K) (OR) Stroke volume: The volume swept by the working piston during one stroke. ie., when moving from TDC to BDC is called swept volume. It is designated by V

$$Vs = A \times L = \pi \times d^2 \times L /4$$

7. Volume of the cylinder (V): It is sum of the clearance volume and swept volume. It is designated by V.

$$V = Vc + Vs$$

8. Compression Ratio: It is the ratio of the total volume of the cylinder to the clearance volume.

$$C.R. = V/V_c$$

9. Piston speed: As the piston moves inside the cylinder, its speed changes continuously. The average speed of the piston is called piston speed. Mean (or) average piston speed = 2LN/ 60 where L length of the stroke, N= rotational speed of the crank.

Four Stroke Petrol Engine:

It works on the constant volume cycle (or) otto cycle. The main components of the engine are cylinder, piston, connecting rod, crankshaft, inlet and exhaust valves, valve opening mechanism and ignition system. The spark plug fitted at the top of the cover end initiates the ignition of the petrol. The charge used in a 4-s petrol engine is a mixture of air and fuel (petrol) and is supplied by carburettor in suitable proportions. Petrol engines are also called spark ignition engines since the charge is ignited by the spark generated by the spark plug fitted at the top of the cover end.

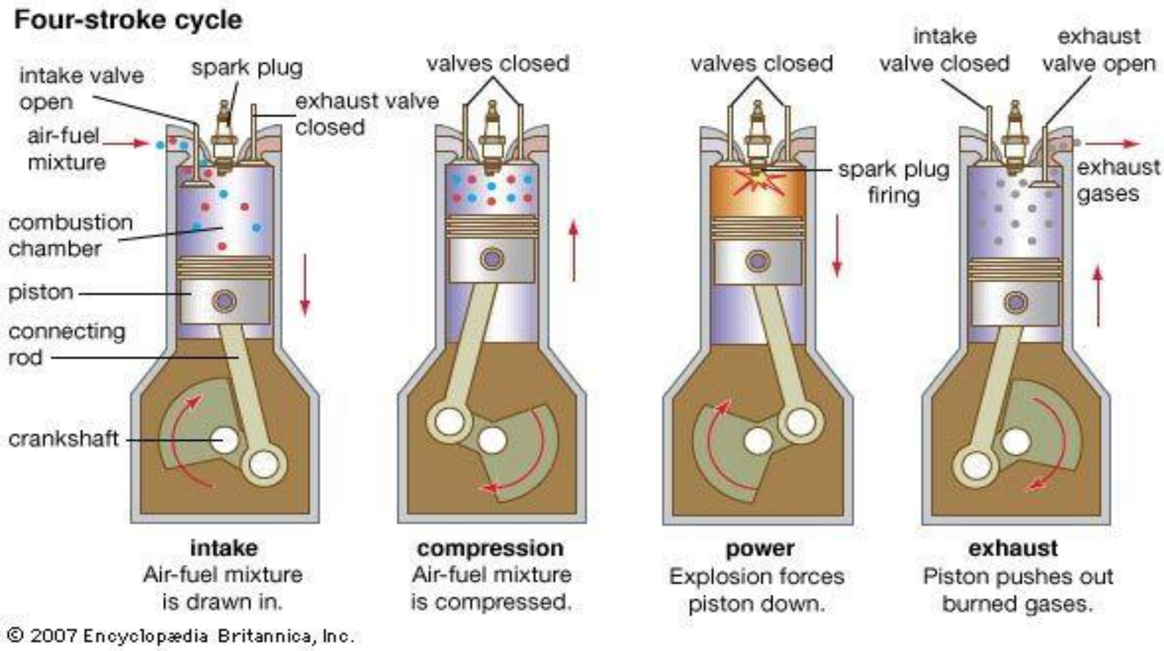


Figure: Working of 4-stroke petrol Engine

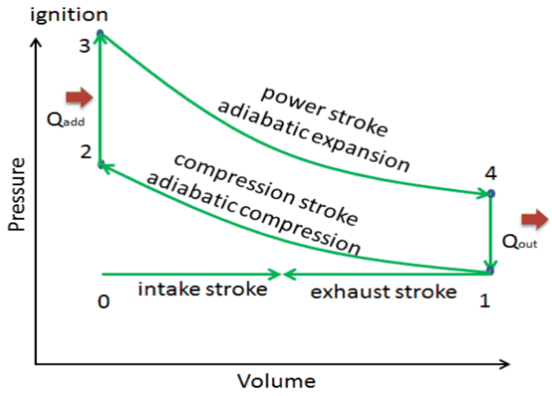


Figure: Otto Cycle

Working

The working of four stroke petrol engine is based on the four strokes. Figure shows the schematic representation of four stroke petrol engine,

1. Suction stroke: The suction stroke starts when the piston is at TDC and about to move downwards. At this time, inlet valve is open and the exhaust valve is closed. In this situation, piston moves from TDC to BDC in downward direction. Pressure in the cylinder slightly less than the atmospheric pressure. As the piston moves downwards, suction is created in the cylinder and fresh charge of air-fuel mixture enters the cylinder through inlet valve. When the piston reaches BDC, the suction stroke ends and the inlet valve closes.

2. Compression stroke: During this stroke, the piston moves from BDC to TDC in upward direction, both inlet and exhaust valves are kept closed and compresses the charge of air-fuel mixture. The compression ratio varies from 6-10 for petrol engine. At the end of compression stroke, spark is produced by the spark plug fitted at the top of the cylinder head and combustion takes place.

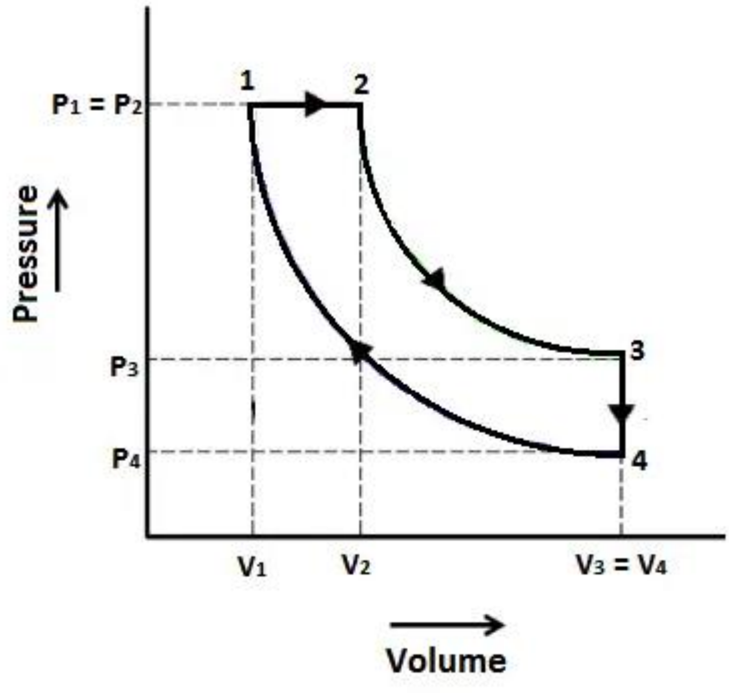
3. Power stroke: During this stroke, both valves are kept closed. The high pressure burnt gases (products of combustion) expands and forces the piston in downward direction. In this situation, piston is pushed from TDC to BDC and rotates the crankshaft at high speed. Since the work is done during this stroke, it is known as power stroke. Crankshaft inturns drives the machine connected to it. Both temperature and pressure decrease during expansion.

4. Exhaust stroke: During exhaust stroke, the exhaust valve is open and inlet. valve is closed. The piston moves from BDC to TDC pushing the burnt gases to atmosphere through open exhaust valve. The exhaust valve closes after the piston reaches TDC so as to allow the fresh charge to enter the cylinder and the cycle repeats. Excess energy developed in power stroke is stored in the flywheel which helps for the operation of 3 idle strokes.

Each cylinder of a four-stroke engine completes the above four operations in two engine revolutions, one revolution of the crankshaft occurs during the suction and compression strokes and the second revolution occurs during the power and exhaust strokes. There is only one power stroke for one completed cycle.

Four Stroke Diesel Engine:

Diesel engine works on the diesel cycle (constant pressure combustion cycle). In this type of engine fuel injector is used for injection of fuels. They are also called as compression ignition engines (C.I engines). The compression ratio is 14-20 for C.I engines. Due to the use of high compression ratio, the temperature a compression stroke is significantly high to self-ignite the fuel which is injected into the chamber.



P-v diagram of a Diesel Cycle

Working

The schematic representation of sequence of operations for 4-s diesel engine is shown in figure

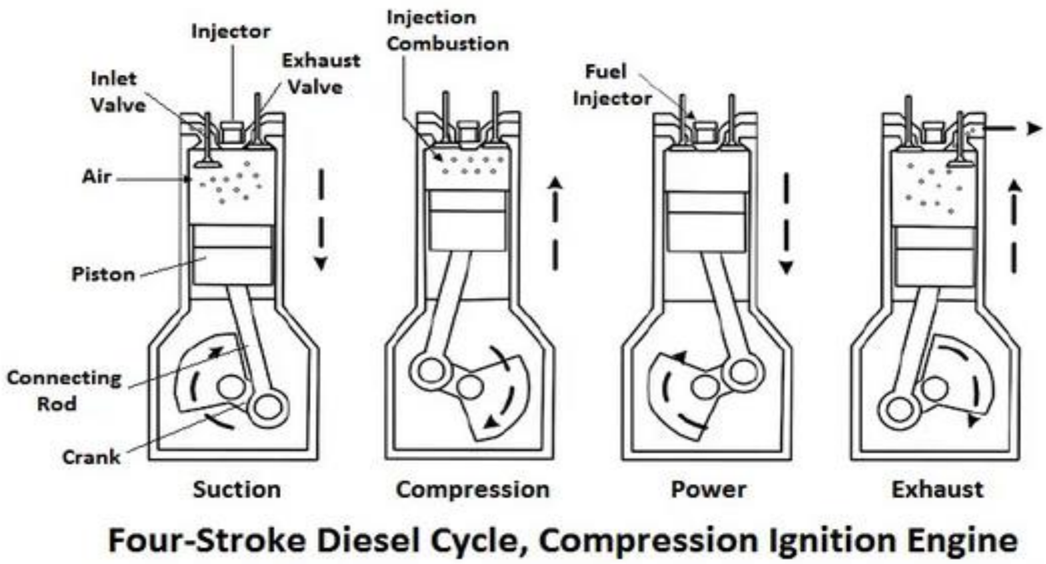


Figure: Working of Four Stroke Diesel Engine

1. Suction stroke: Suction stroke starts when the piston is at TDC and about to move downwards. At this time, inlet valve is open and exhaust valve is closed. In this situation, piston moves from TDC to BDC in downward direction. As the piston moves downward, suction is created (or) negative pressure is created in the cylinder and the fresh air is sucked into the cylinder through inlet valve. The pressure inside the cylinder will be slightly less than the atmospheric pressure. When the piston reaches BDC, suction stroke ends and inlet valve closes.

2. Compression stroke: During this stroke, piston moves from BDC to TDC and both the valves are kept closed. As the piston moves upward, the air gets compressed to high pressure and temperature. Just at the end of compression stroke, the fuel is being injected in the form of spray into the compressed air by a fuel injector and combustion of fuel takes place. The temperature of the compressed air is sufficient to auto ignite the fuel without the need of spark. Combustion of fuel takes place at constant pressure. The products of combustion (burnt gases) are formed.

3. Working stroke: In expansion stroke both the valves remain closed. Expansion of products of combustion takes place and the piston moves in the downward direction to BDC. The work is done during this stroke.

4. Exhaust stroke: During this stroke, exhaust valve opens and inlet valve remains closed. The piston moves from BDC to TDC. The piston while moving from BDC to TDC drives the burnt gases into atmosphere through the open exhaust valve so as to make room for the fresh charge (only air) to enter the cylinder. The exhaust valve closes after the piston reaches the TDC. This completes the cycle.

TWO-STROKE ENGINE:

In a two-stroke engine, piston moves up and down, total two times, completing a cycle. In other words, the cycle of operation is completed in two strokes of the piston (or) one revolution of the crankshaft. The two-stroke engine cycle was invented by a British engineer

Sir Dugald Clark (1878). Two stroke engines are used in scooters, motor cycles etc. Instead of valve and valve mechanism, two stroke engine consists of 3 ports, namely, exhaust port, transfer port and inlet port. These ports are opened and closed by the movement of the piston itself.

Two-Stroke (2-s) Petrol Engine

Description:

2-s petrol engine works on the theoretical otto cycle. The cycle consists of two-strokes (i) upward Stroke (ii) downward stroke, completed in one revolution of the crankshaft. the charge used is a mixture of air and fuel (petrol). The charge is ignited by a spark produced by a spark plug provided at the top of the cylinder head. The function of 3 ports:

- **Inlet port:** Through which petrol and air mixture admits into the crankcase Exhaust port: Through which waste gases are expelled out of the cylinder
- **Exhaust port:** Through which waste gases are expelled out of the cylinder.
- **Transfer port:** Through which petrol and air mixture is transferred from crankcase in the cylinder, which is mounted diagrammatically opposite to the exhaust port but slightly a lower level.

Working

In 2-Stroke engine cycle, all four operations ie., suction, compression, expansion and exhaust are performed in two strokes of the piston. Its schematic representation is shown in figure.

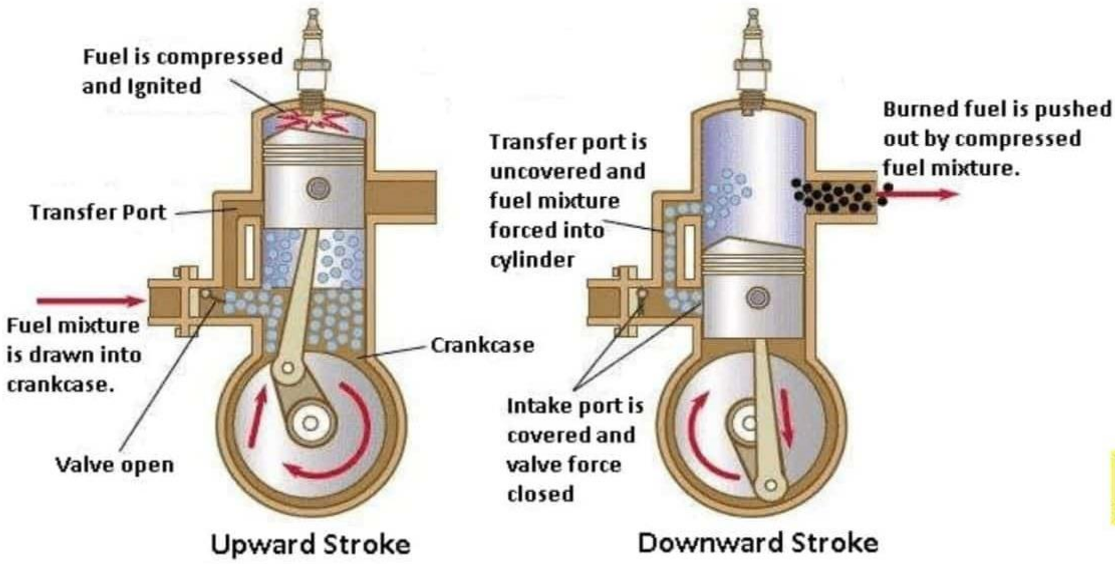


Figure: Two Stroke Petrol Engine

(1) First stroke (Downward stroke)

At the beginning of the first stroke, the piston is at the TDC. In this piston, the inter part is kept opened and other two ports are closed. The mixture of air and fuel is drawn is the crank case due to the vacuum produced by the upward movement of the piston. Also, the air and fuel mixture above the piston is compressed. The compression ratio for petrol engine varies from 7-10. The compressed charge above the piston is ignited by an electric spark generated by a spark plug. The combustion of fuel will release high pressure hot gases. These high-pressure hot gases expanded and push the piston in downward direction from TDC to BDC. This operation is called power stroke (or) expansion stroke. During downward motion, the inlet port is closed and mixture will get compressed inside the crankcase. Further downward movement of the piston uncovers first the exhaust port and then the transfer port. The burnt gases are sent to the atmosphere through exhaust port after having work on the piston and the compressed change in the crank case will enter to the space in the cylinder above the piston through transfer port. Because of the special shape of the piston crown (deflection inclined at 45°), the mixture is deflected up and is prevented from going out directly through exhaust port. Also, deflected mixture helps in pushing the exhaust gases out. Thus, during the downward stroke of the piston, we get the operation of power, exhaust and suction (intake).

(ii) Second stroke (Upward stroke)

During this stroke, piston moves from BDC to TDC. When piston moves upwards, it covers the transfer port as shown in figure and supply of charge is cut off. Further movement of piston covers the exhaust port completely as shown in figure. After closing the exhaust port, the air-fuel mixture above the piston gets compressed and the cycle is repeated. When the piston is pushed up by the flywheel, the following sequence of operations take place.

1. Closing of transfer port
2. Closing of exhaust port
3. Opening of inlet port

Application of IC Engines in Power Generation:

A generating station in which diesel engine is used as the prime mover for the generation of electrical energy is known as diesel power station.

In a diesel power station, diesel engine is used as the prime mover. The diesel burns inside the engine and the products of this combustion act as the working fluid to produce mechanical energy. The diesel engine drives alternator which converts mechanical energy into electrical energy. As the generation cost is considerable due to high price of diesel, therefore, such power stations are only used to produce small power.

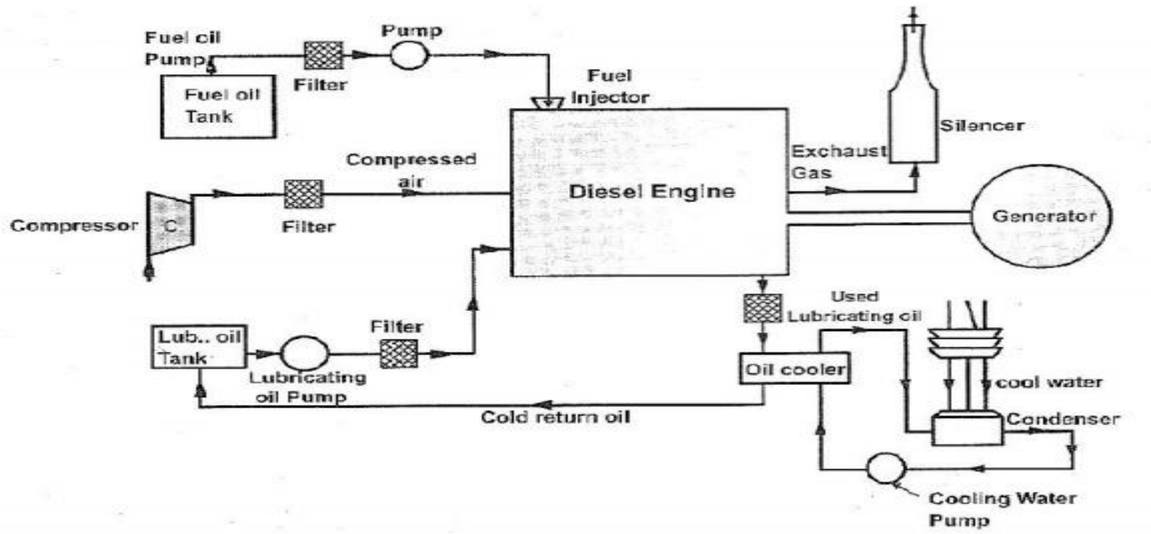


Figure: Layout of Diesel Engine Power plant

Application of IC Engines in Agriculture:

Agricultural mechanization uses basically Diesel internal combustion engines, which require energy stored in liquid form, as most agricultural operations are carried out in motion, for tractors, harvesters, and self-propelled sprinklers, among others. Currently, much of this fuel is mineral, which is from finite and non-renewable source.

Figure: Tractors and Harvesters

Application of IC Engines in Marine:

Modern marine power plants have been designed to improve the overall ship's efficiency. During the previous years, diesel oil has been extensively used on-board ships. Due to the high price of light diesel oil and the environmental problems resulting from the use of heavy fuel oil, it has become necessary to search for an alternative to traditional fuels. As a result, natural gas fuel has been used on-board some types of ships, especially short-voyage cruise ships.

The use of hydrogen fuel on-board ships, particularly in modern power plants may contribute to overcoming the above problems. Compared to the diesel engine, the hydrogen fuelled engine is found to be lower in thermal efficiency and fuel consumption, however, some adjustments are needed.

Application of IC Engine in Aircraft Propulsion:

Airplanes used internal combustion engines to turn propellers to generate thrust. Today, most general aviation or private airplanes are still powered by propellers and internal combustion engines, much like automobile engine.

The basic mechanical design of the Wright engine is remarkably similar to modern, four-stroke, four-cylinder automobile engines. On the power stroke the piston turns a crank which converts the linear motion of the piston into circular motion. The turning crankshaft is then used to turn the aircraft propeller. Many different types of IC engines are used depending upon the application and size of the aircraft. Some of the IC Engines used in Aircraft propulsions are: horizontal opposed engines, radial Engines, V-type engines.

Comparisons/Difference

Sl. No	4-Stroke Engine	2-Stroke Engine
1	Four Stokes, two revolutions of crankshaft, one power stoke in two revolutions of crank Shaft	Two strokes, one revolution of crank shaft, one power stoke in each revolution of crank shaft
2	Heavier Fly wheel	Lighter Flywheel
3	Weight of engine per hp is high	Weight of engine per hp is comparatively low
4	There are inlet and exhaust valves in the engine	There are inlet and exhaust ports instead of valve
5	Thermal efficiency is high	Thermal efficiency is comparatively low
6	Lesser cooling and lubrication, Lower rate of wear and tear	Greater cooling and lubrication, Higher rate of wear and tear
7	Initial cost of engine is more	Initial cost is less
8	Used where efficiency is important (Buses, trucks, tractors, aero planes etc.)	Used where Low cost. Compactness and light weight are important (mopeds, scooters,

Sl No	SI Engines (Petrol engine)	CI Engines (Diesel engine)
1	Ignition of the fuel by spark plug	Ignition of the fuel by spraying fuel to compressed air at high temperature
2	Works on theoretical Otto cycle	Works on theoretical Diesel cycle
3	A mixture of air and petrol is drawn during suction stroke	Only air is drawn during suction stroke
4	Combustion is at constant volume	Combustion is at constant pressure
5	Low compression ratio ranging from 7:1 to 12:1	High compression ratio ranging from 16:1 to 22:1
6	Fuel cost is high	Fuel cost is low
7	Power output will be less	Power output will be more

Insight into future mobility technology

Electric vehicles

An electric vehicle, also called an electric drive vehicle, uses one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery, solar panels or a generator to convert fuel to electricity. In the 21st century, EVs saw a resurgence due to technological developments and an increased focus on renewable energy.

Configurations of Electric Vehicles

Previously, the EV was mainly converted from the existing ICEV by replacing the internal combustion engine and fuel tank with an electric motor drive and battery pack while retaining all the other components, as shown in Figure 4.1. Drawbacks such as its heavy weight, lower flexibility, and performance degradation have caused the use of this type of EV to fade out.

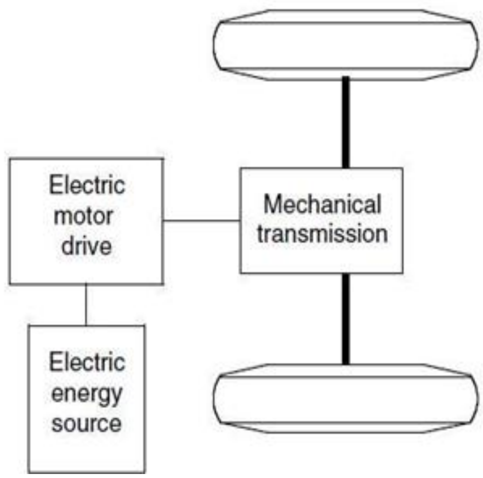


Figure: Primary electric vehicle power train

The modern EV is built based on original body and frame designs. This satisfies the structure requirements unique to EVs and makes use of the greater flexibility of electric propulsion. A modern electric drive train is conceptually illustrated in Figure below.
The drive train consists of three major subsystems: electric motor propulsion, energy source, and auxiliary.

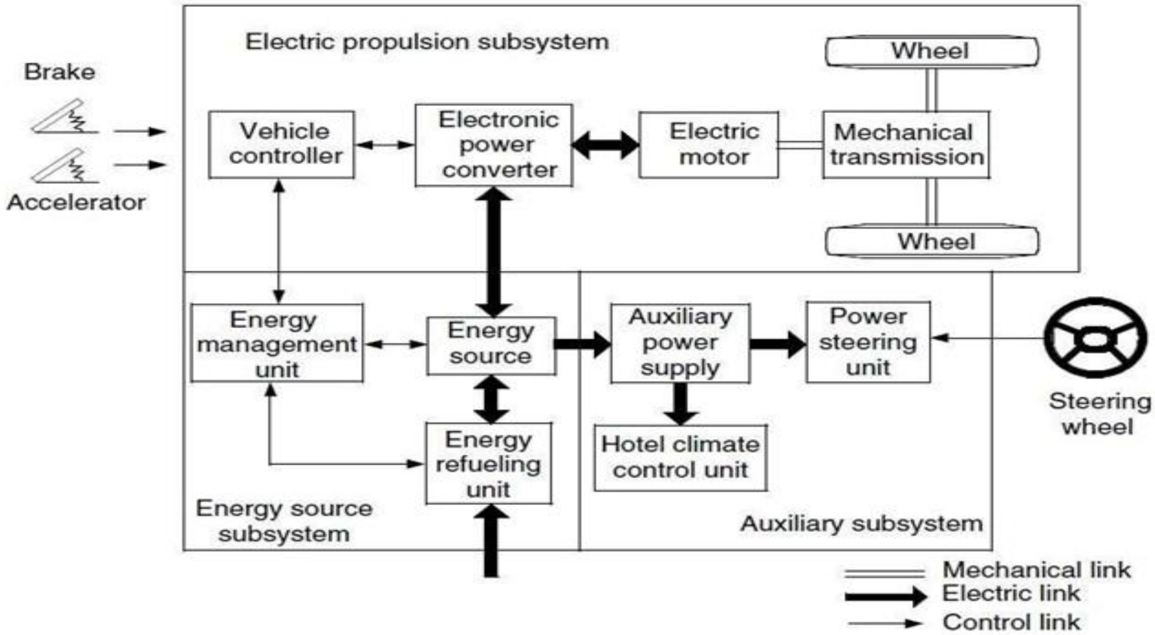


Figure: Conceptual illustration of general EV configuration

The electric propulsion subsystem is comprised of a vehicle controller, power electronic converter, electric motor, mechanical transmission, and driving wheels. The energy source subsystem involves the energy source, the energy management unit, and the energy refueling unit. The auxiliary subsystem consists of the power steering unit, the hotel climate control unit, and the auxiliary supply unit.

Based on the control inputs from the accelerator and brake pedals, the vehicle controller provides proper control signals to the electronic power converter, which functions to regulate the power flow between the electric motor and energy source. The backward power flow is due to the regenerative braking of the EV and this regenerated energy can be restored to the energy source, provided the energy source is receptive. The auxiliary power supply provides the necessary power at different voltage levels for all the EV auxiliaries, especially the hotel climate control and power steering units.

Parts of Electric Vehicle:

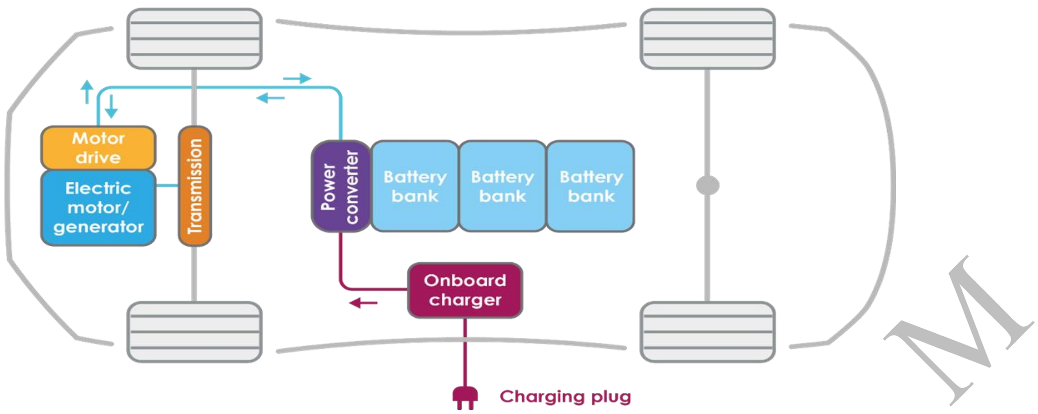
Electric Engine/Motor - Provides power to rotate the wheels. It can be DC/AC type, however, AC motors are more common.

Inverter/Power Converter - Converts the electric current in the form of Direct Current (DC) into Alternating Current (AC)

Drivetrain/Transmission - EVs have a single-speed transmission which sends power from the motor to the wheels.

Batteries- Store the electricity required to run an EV. The higher the kW of the battery, the higher the range.

Charging - Plug into an outlet or EV charging point to charge your battery.



Basic Components of Electric Vehicle

Working Principle of Electric Vehicle

When pedal of the car is pressed, then: Power is converted from the DC battery to AC for the electric motor. Controller takes and regulates electrical energy from batteries and inverters .The accelerator pedal sends a signal to the controller which adjusts the vehicle's speed by changing the frequency of the AC power from the inverter to the motor. Electric motor converts electrical energy into mechanical energy (rotation). The motor connects and turns the wheels through a cog. Rotation of the motor rotor rotates the transmission so the wheels turn and then the car moves. When the brakes are pressed or the electric car is decelerating, the motor becomes an alternator and produces power, which is sent back to the battery.

Electric and Hybrid Vehicles

A hybrid vehicle combines any two power (energy) sources. Possible combinations include diesel/electric, gasoline/fly wheel, and fuel cell (FC)/battery. Typically, one energy source is storage, and the other is conversion of a fuel to energy. The combination of two power sources may support two separate propulsion systems. Thus, to be a True hybrid, the vehicle must have at least two modes of propulsion.

For example, a truck that uses a diesel to drive a generator, which in turn drives several electrical motors for all-wheel drive, is not a hybrid. But if the truck has electrical energy storage to provide a second mode, which is electrical assists, then it is a hybrid Vehicle.

These two power sources may be paired in series, meaning that the gas engine charges the batteries of an electric motor that powers the car, or in parallel, with both mechanisms driving the car directly.

Hybrid electric vehicle (HEV)

Consistent with the definition of hybrid above, the hybrid electric vehicle combines a gasoline engine with an electric motor. An alternate arrangement is a diesel engine and an electric motor.

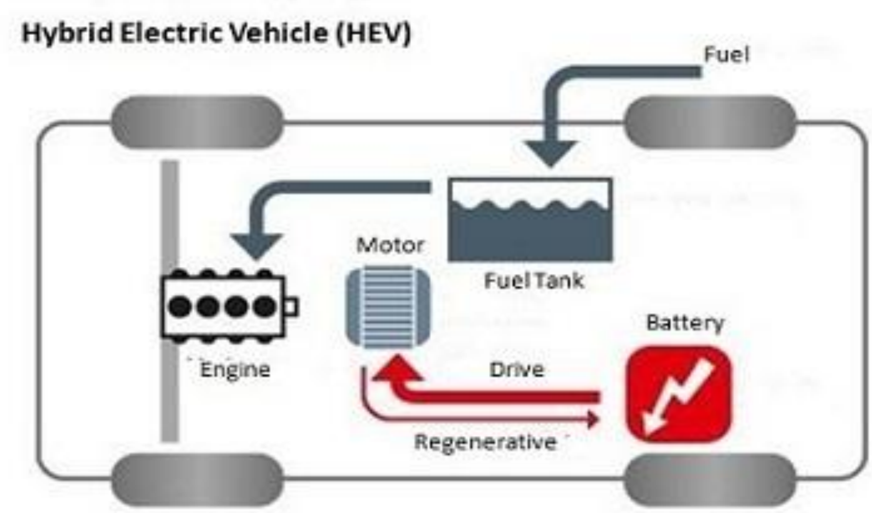


Figure: Components of a hybrid Vehicle that combines a pure gasoline with a pure EV.

As shown in Figure, a HEV is formed by merging components from a pure electrical vehicle and a pure gasoline vehicle. The Electric Vehicle (EV) has an M/G which allows regenerative braking for an EV; the M/G installed in the HEV enables regenerative braking. For the HEV, the M/G is tucked directly behind the engine. The transmission appears next in line. This arrangement has two torque producers; the M/G in motor mode, M-mode, and the gasoline engine. The battery and M/G are connected electrically.

HEVs are a combination of electrical and mechanical components. Three main sources of electricity for hybrids are batteries, FCs, and capacitors. Each device has a low cell voltage, and, hence, requires many cells in series to obtain the voltage demanded by an HEV.

- The FC provides high energy but low power.
- The battery supplies both modest power and energy.
- The capacitor supplies very large power but low energy.

Advantages EVs and Hybrid vehicles:

1. Environmentally Friendly
2. Convenience of Charging
3. Cost-effective
4. Low Maintenance
5. Noiseless operation
6. Battery life and Cost
7. Ease of Driving
8. Regenerative braking System
9. In case of hybrid vehicles, the vehicle is provided with duel powered drives.

Disadvantages of Electric and Hybrid vehicles:

1. Expensive compare to gasoline vehicles
2. Battery replacement cost is very high
3. Battery replacement and recycling
4. Charging point convenience
5. Longer Charging time

Comparisons

	Hybrid Cars	**Electric Cars**
Power/Fuel Source	Electricity and Fossil Fuel (Petrol and Diesel)	Electricity Through Battery Pack (DC)
Engine	Internal Combustion Engine (ICE) and Electric Motor(s)	Electric Motor(s)
Fuel Efficiency	Combination of ICE and Battery Range	Depends on Battery Range
Emission Levels	Higher Compared to Electric Cars	Lower Compared to ICE and Hybrid Cars
Price Range	Similar to Conventional ICE Cars	High
Charging	Not Needed	Needed

IC Engine (ICE) Vehicles	Electric Vehicles (EV)
• Powertrain: IC engine	• Powertrain: Motor (+ Engine)
• High specific energy of fuel	• Low specific energy of battery
• Power density: High	• Power density: Low
• Emits greenhouse gases	• No tailpipe emissions
• Travels > 300 miles / fill	• Travels < 100 miles / charge
• Short refilling time (< 5 min.)	• Long charging time (0.5-8 hr.)
• Fuel tank takes less space	• Battery takes large space
• Fuel weight is very less	• Batteries are very heavy
• Higher maintenance costs	• Lesser maintenance costs
• Braking energy not recovered	• Can recover braking energy
• Running cost: high	• Running cost: low
• Engine efficiency: ~ 30%	• Motor efficiency: ~ 80%
• Needs complex gear system	• Needs only one gear
• Noisy operation	• Quiet operation
• Ample refilling infrastructure	• Lacks charging infrastructure
• Need to pick up some speed to deliver maximum torque	• Produce maximum torque instantly after starting of motor
• Uses only hydrocarbons	• Uses electricity from many resources