UNIT V

INTERNAL COMBUSTION ENGINE PERFORMANCE AND AUXILIARY SYSTEMS **IGNITION SYSTEM**

Pollutants emission from diesel engines

Nowadays, pollution from automobiles becomes the main concern for our lovely environment. Pollutants emitted from diesel engines and petrol engines are dangerous for our environment and our precious health. Both the petrol engines and diesel engines emit pollutants in their working conditions. But the Concentration of pollutants from diesel engines and petrol engines are different. Here we are going to see the emission of different pollutants from diesel engines

Pollutants emission from diesel engines:

1. Hydrocarbons (HC)
2. Carbon Monoxide (CO)
3. Oxides of Nitrogen (NO2)
4. Smoke and Particulate Matter
5. Aldehydes
6. Other emissions

1. Hydrocarbons:

Hydrocarbons are the significant contributors in the diesel engines emission. Black smoke from diesel engine exhaust caused by the presence of carbon particles also known as soot in the flue gases. Soot is hazardous for the health of living animals.

2. Carbon Monoxide:

Carbon Monoxide is a presence in an exhaust of both diesel engines and gasoline/petrol engines. But the concentration of Carbon Monoxide in the diesel engines is less as compared to petrol engines. If the petrol/gasoline engine produces 5% of Carbon Monoxide, then diesel engines will produce only 2% of it.

3.Oxides of Nitrogen:

When atmospheric O2 and N2 combine inside the combustion chamber at very high temperature, it produces Oxides of Nitrogen. Diesel engines produce very high Oxides of Nitrogen during the acceleration period because temperature reaches the highest due to complete combustion of the fuel in the chamber.

4. Smoke and Particulate Matter:

Color of exhaust smoke may be white smoke or black smoke. The presence of smoke at the exhaust contains visible products produced due to poor combustion of fuel and air. If white smoke observed in a diesel engine at cold starting and no load or low load running of the engine, it indicates piston rings of diesel engines are worn out and it needs a replacement. Black smoke in the diesel engine is caused due to incomplete combustion of fuel. The amount of black smoke is directly proportional to the load on the engine.

The ignition system is provided with SI engine, which is used to produce an electric spark at the end of the compression stroke to ignite the air fuel mixture. In the design of an ignition system, the following factors should be taken into account

- Engine design
- Engine speed
- Inlet manifold pressure
- Mixture composition

Requirement of an ignition system:

A smooth and reliable functioning of an ignition system is essential for reliable working of an engine. The requirements of such an ignition system are:

- ⊕ It should provide a good spark between the electrode of the plugs at the correct timing
- ⊕ It should function efficiently over the entire range of engine speed
- ⊕ It should be light, effective and reliable in service
- ⊕ It should be compact and easy to maintain
- ⊕ It should be cheap and convenient to handle
- ⊕ The interference of the high voltage source should not affect the functioning of radio and television receiver inside the automobile

Battery ignition system:

The essential components of the battery ignition system are

Battery: This provides the energy for ignition. The battery used may be lead acid battery or a alkaline battery. The battery is charged by the dynamo provided in the engine. The battery must be mechanically strong to withstand the strains to which it is constantly subjected to. It converts the chemical energy into electrical energy due to the electrochemical reaction taking place inside the battery

Ignition switch: Battery is connected to the primary winding of the ignition coil through an ignition switch and ballast resistor. With the help of the ignition switch the ignition system can be turned on or off.

Ballast resistor: A ballast resistor is provided in series with primary winding to regulate the primary current. The objective of this is to prevent injury to the spark coil by overheating if the engine should by operated for a long time at low speed. The coil is made of iron wire.

Ignition coil: The ignition coil consists of a magnetic core of soft iron sheet and two insulated conduction coils called primary and secondary windings. The secondary coil consists about 21000 turns of 38-40 gauge enamelled copper wire sufficiently insulated to withstand the high voltage. It is wound close to the core with one end connected to secondary terminal and other end is grounded to the metal case. The primary winding located outside the secondary coil generally formed 200-300 turns of 20 gauge copper wire. More heat is generated in primary than the secondary and with the primary coil wound over the secondary coil, it is easier to dissipate the heat. The entire unit is enclosed in a metal container and forms a neat and compact unit.

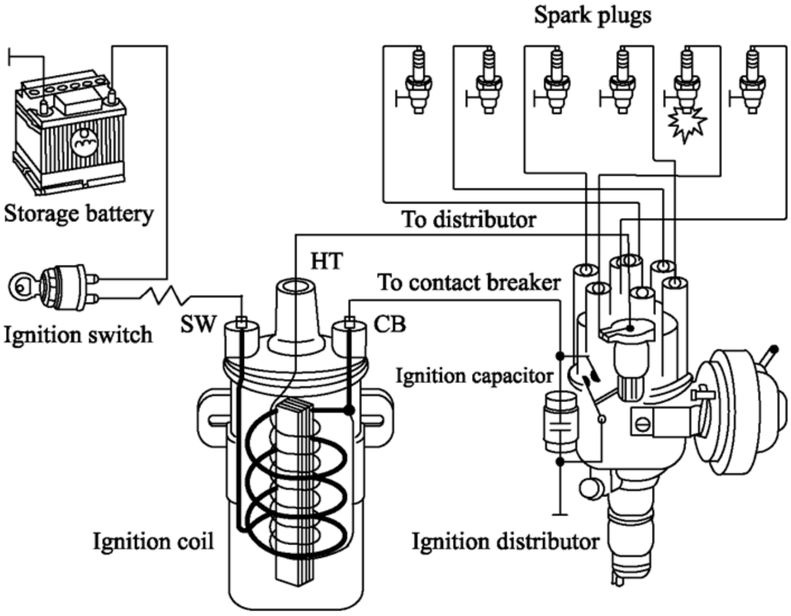


Figure: Battery Ignition system for a six cylinder engine

Contact breaker: This is a mechanical device for making and breaking the primary circuit of the ignition coil. The metal used for contact surfaces usually tungsten and diameter of contact surfaces is about 3 mm

Capacitor: The principle of construction of a ignition capacitor is the same as that of electrical capacitor. Two strips of aluminum foil and several layers of special capacitor paper, are rolled up in a solid roll. Then the roll is inserted into a metal shell for protection against moisture and damage.

Distributor: The function of the distributor is to distribute the ignition current to the individual spark plugs in correct sequence and at the correct instant of time. There two types of distributors. Brush type and gap type

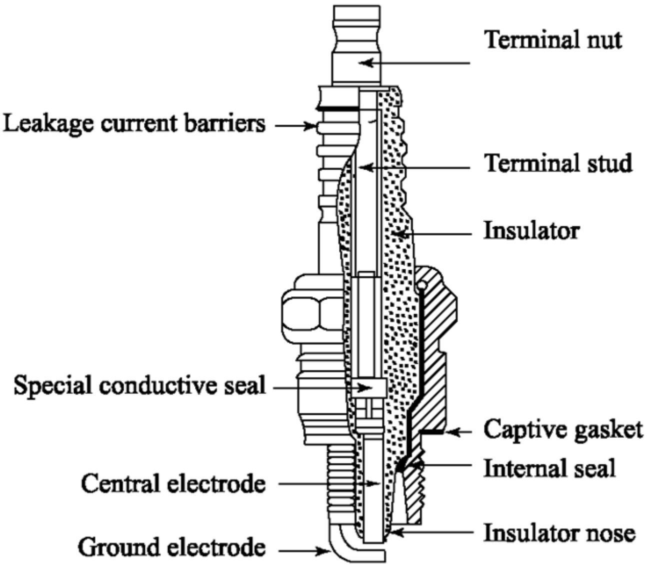


Figure: Spark Plug

Spark plug: The spark plug provides the two electrodes with a proper gap across which the high potential discharges to generate a spark and ignite the combustible mixture with in the combustion chamber. The spark plug consists of a steel shell, an insulator and two electrodes. The central electrode to which the high tension supply from the ignition coil is connected, is well insulated with porcelain or other ceramic material. The other electrode is welded to steel shell of the plug. The electrodes are usually made of high nickel alloy to withstand the severe erosion and corrosion to which they are subjected in use. The spark plugs are usually classified as hot plugs or cold plugs depending upon the relative operating temperature range of the tip of the high tension electrode

Operation of a battery ignition system:

When the ignition switch is closed, the primary winding of the coil is connected to the positive terminal post of the storage battery. If the primary is closed through the breaker contacts, a current flows, the so called primary current. This current, flowing through the primary coil, which is wound on a soft iron core, produces a magnetic field in the core. A cam driven by the engine shaft is arranged to open the breaker points whenever an ignition discharge is required. When the breaker points open, the current which had been flowing through the points now flows into the condenser, which is connected across the points. As the condenser becomes charged, the primary current falls and the magnetic field collapses. The collapse of the field induces a voltage in the primary winding, which charges the condenser to a voltage much higher than battery voltage. The condenser then discharges into the battery, reversing the direction of both the primary current and the magnetic field. The rapid collapse and reversal of the magnetic field in the core induce a very high voltage in the secondary winding of the ignition coil. The secondary winding consists of a large number of turns of very fine wire wound on the same core with the primary. The high secondary voltage is led to the proper spark plug by means of a rotating switch called the distributor. This ignition system is used in cars and commercial vehicles.

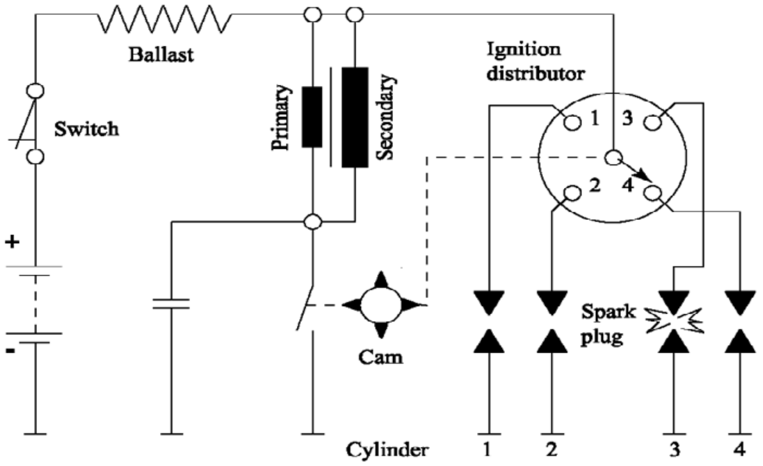


Figure: Working of Battery Ignition System

Magneto Ignition System

Magneto is a special type of ignition system with its own electric generator to provide the necessary energy for the system. It is mounted on the engine and replaces all the components of the coil ignition system except the spark plug. A magneto when rotated by the engine is capable of producing a very high voltage and does not need a battery as a source of external energy. Magneto may be rotating armature type or rotating magnet type. The working principle of the magneto ignition system is exactly the same as that of the coil ignition system. With the help of a cam, the primary circuit flux is changed and a high voltage is produced in the secondary circuit.

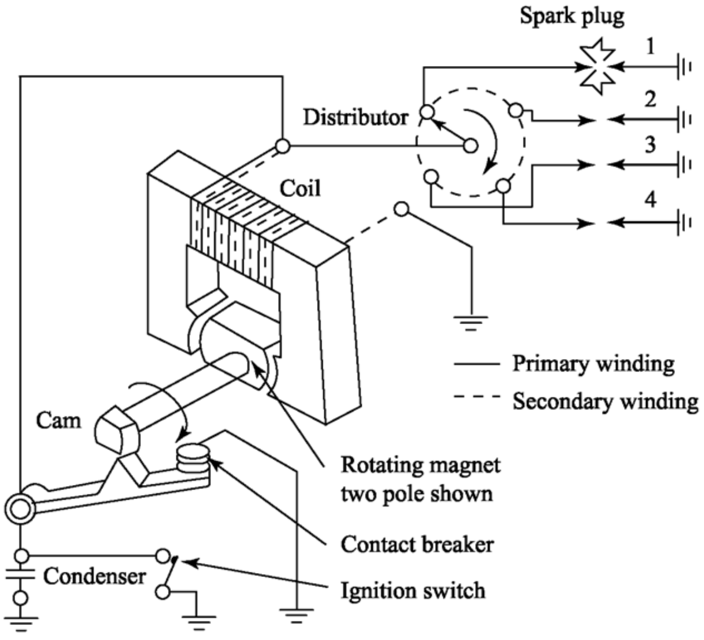


Figure: Magneto Ignition System

Comparison of battery ignition system and magneto ignition system

Battery ignition system	Magneto ignition system
Battery is necessary. Difficult to start the engine when battery is discharged	No battery is needed and therefore there is no problem of battery discharge
Maintenance problem are more due to battery	Maintenance problem are less since there is no battery
Current for the primary circuit is obtained from the battery	The required electric current is generated by the magneto
A good spark is available at the spark plug even at low speed	During starting, quality of spark is poor due to low speed
Efficiency of the system decreases with the reduction in spark intensity as engine speed rises	Efficiency of the system improves as the engine speed rises due to high intensity spark
Occupies more space	Occupies less space
Commonly employed in cars and light commercial vehicles	Mainly used in racing cars and two wheelers

FUEL SUPPLY SYSTEM FOR CI ENGINE

The fuel injection system is the most vital component in the working of CI engines. The engine performance is greatly dependent on the effectiveness of the fuel injection system. The injection system has to perform the important duty of initiating and controlling the combustion process. The schematic diagram of the fuel injection system of CI engine is shown in figure.

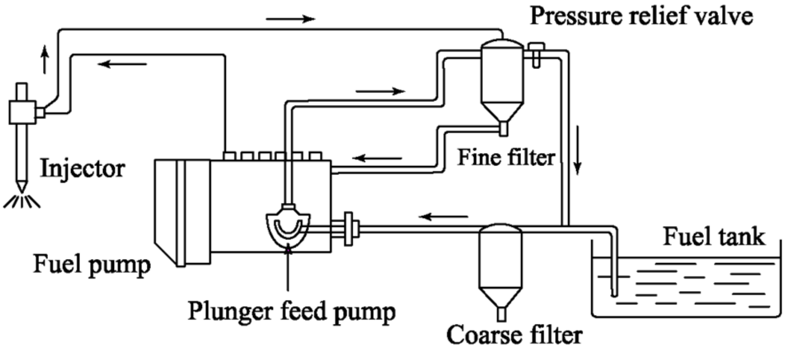


Figure: Fuel supply system for CI engine

The fuel from the tank is taken by the plunger feed pump through the coarse filter and flow to the fine filter then to the fuel pump. The coarse and fine filters remove all kinds of impurities from the fuel. The fuel pump raises the pressure of the fuel to the injection pressure approximately 200 bar and supplies the fuel to the fuel injector which injects the fuel in fine droplets. These droplets vaporize due to the heat transfer from the compressed air and form a fuel-air mixture. The temperature of the fuel reaches a value higher than its self-ignition temperature and the combustion process is initiated spontaneously. A pressure relief valve is also provided for the safety of the system. For proper running and better performance of the engine, the fuel injection system must meet the following requirements.

- Accurate metering of fuel injected per cycle
- Timing the injection of fuel correctly in the cycle
- Proper control of rate of injection so that desired heat release pattern is achieved during combustion
- Proper atomization of fuel into very fine droplets
- Proper spray pattern to ensure rapid mixing of fuel and air
- Uniform distribution of fuel throughout the combustion chamber
- To supply equal quantity of injection in the case of multi cylinder engine

The fuel injection used in the CI engine is classified into two types: (i) air injection systems and (ii) solid injection systems. They are briefly explained below.

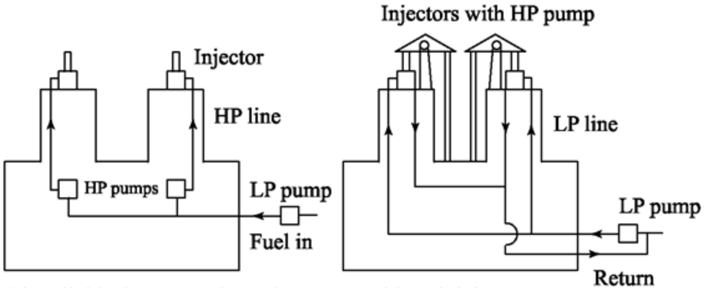
Air Injection System

In this system, the fuel is forced into the cylinder by means of compressed air. This system is little used nowadays, because it requires a bulky multistage air compressor. This causes an increase in engine weight and reduces the brake power output further. One advantage of this type is good mixing of fuel with the air. Another advantage is the ability to utilize fuels of high viscosity.

Solid Injection System

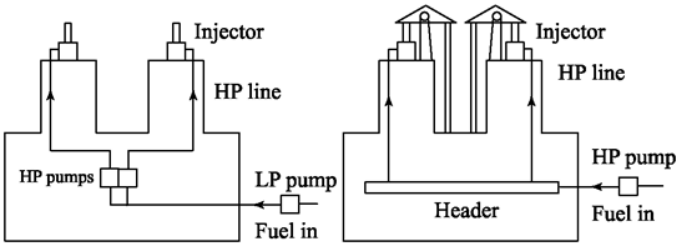
In this system the fuel is directly injected into the combustion chamber without the aid of compressed air. This system is further classified into four types

(a) Individual pump and nozzle system
(b) Unit injector system
(c) Common rail system
(d) Distributor system



(a) Individual pump and nozzle with separated pumps

(c) Unit injector system



(b) Individual pump and nozzle with pumps in cluster

(d) Common rail system

Figure: Solid injection systems

(a) Individual pump and nozzle system: (Refer figure a&b) In this system, each cylinder is provided with one pump and one injector. In this arrangement a separate metering and compression pump is provided for each cylinder. The pump may be placed close to the cylinder (figure a) or they may be arranged in a cluster (figure b). The plunger of high pressure pump is actuated by a cam and produces the fuel pressure necessary to open the injector valve at the correct time. The amount of fuel injected depends on the effective stroke of the plunger.

(b) Unit injector system: (Refer figure c) In this system the pump and injector nozzle are combined in one housing. Each cylinder is provided with one of these unit injectors. Fuel is brought up to the injector by a low pressure pump, at correct time a rocker arm actuates the plunger and thus injects the fuel into the cylinder. The amount of fuel injected is regulated by the effective stroke of the plunger.

(c) Common rail system: (Refer figure d) In the common rail system a HP pump supplies fuel under high pressure to a fuel header. From the header the fuel supplied to the individual cylinders through pipes. The amount of fuel entering the cylinder is regulated by varying the length of the push rod stroke.

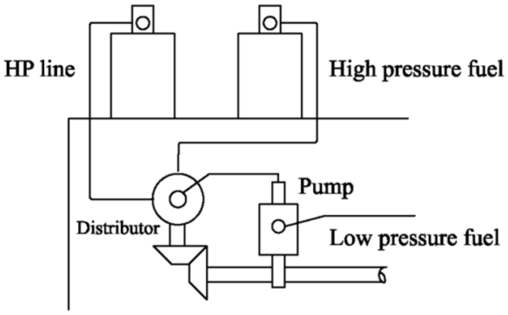


Figure: Distributor system

(**d) Distributor system**: (Refer figure) In this system the pump which pressurizes the fuel also meters and times it. The fuel pump after metering the required amount of fuel supplies it to a rotating distributor at the correct time for supply to each cylinder.

Fuel Injection Pump

The main objective of the fuel injection pump is to deliver accurately metered quantity of fuel under high pressure at the correct instant to the injector fitted on each cylinder. Injection pumps are generally of two types

Jerk type pump: Figure shows the Jerk type fuel injection pump.

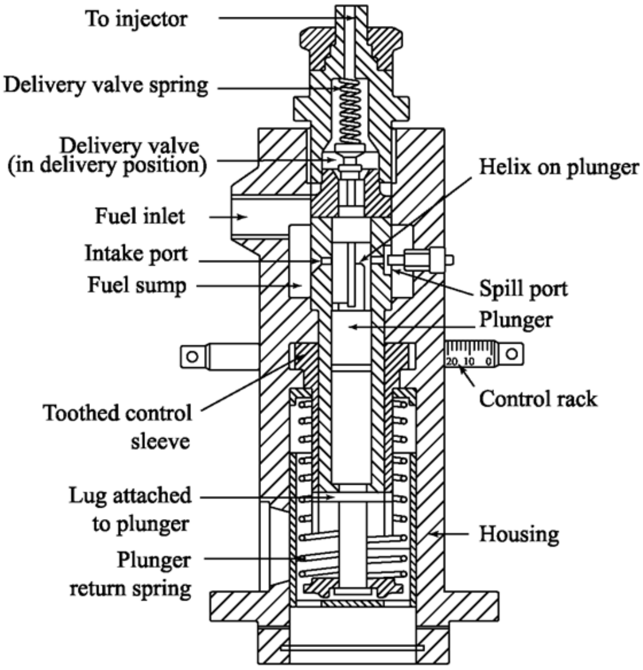


Figure: Jerk type fuel injection pump

In the Jerk type pump, the fuel is pressurized by the plunger movement. The reciprocating movement is given to the plunger by means of the cam and the rotating movement is given by the rack mechanism. When the plunger is in the bottom most position, through the intake port the fuel is admitted into the cylinder of the pump and during the upward movement of the plunger the fuel is pressurized and delivered to the injector though the opening at the top of the pump against the delivery valve spring pressure. When the control rack rotates the plunger, the high pressure fuel in the top of the cylinder is exposed to spill port through the helix on the plunger so that the pressure of the fuel decreases and injection is stopped. It is important to remember here that though the axial distance traversed by the plunger is same for every stroke, the rotation of the plunger by the rack determining the length of the effective stroke and thus the quantity of the fuel injected.

Distributor type pump: Figure shows the distributor type fuel injection pump. This pump has only a single pumping element and the fuel is distributed to each cylinder by means of a rotor. There is a central longitudinal passage in the rotor and also two sets of radial holes (each equal to the number of engine cylinders) located at different heights. One set is connected to pump inlet via central passage whereas the second set is connected to delivery lines leading to injectors of the various cylinders. The fuel is drawn into the central rotor passage from the inlet port when the pump plunger moves away from each other. Wherever, the radial delivery passage in the rotor coincides with the delivery port for any cylinder the fuel is delivered to each cylinder in turn. The main advantage of this type is small size and light in weight.

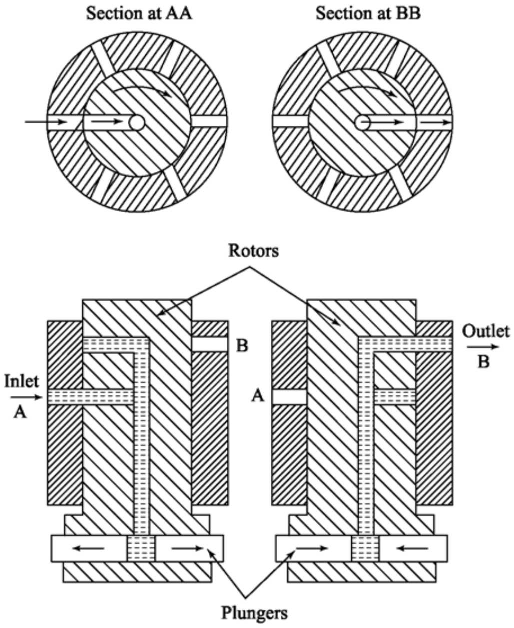
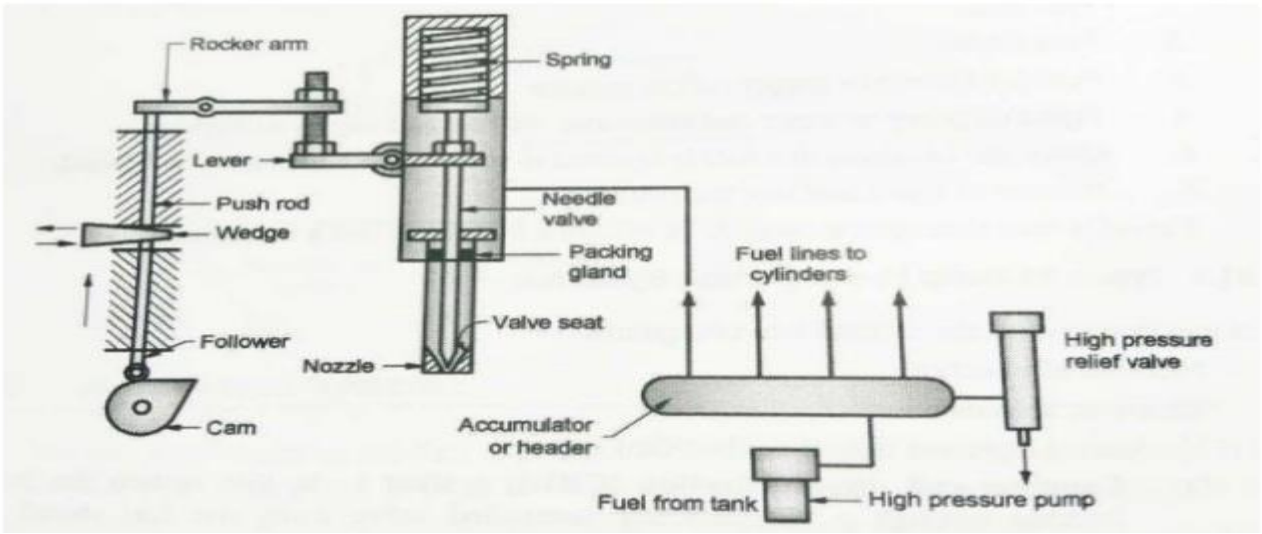


Figure: Distributor type fuel injection pump

Common Rail Direct Injection or CRDI System:

There are two different types of injection systems in the diesel engines or compression ignition (C I Engines). One is the Air Injection System and another one is Airless or Solid Injection System. In this post, we are going to learn about the Common Rail Direct Injection System CRDI System which comes under a solid injection system.



Working of CRDI System or Common Rail Direct Injection:

1. As you can see in the diagram of the CRDI system, the high-pressure pump is used to supply fuel to the accumulator or the header from the fuel tank. In case pressure in the accumulator increases beyond the limit, the high-pressure relief valve which is connected to the accumulator helps to reduce the pressure.

2. Now, this fuel from the accumulator supplied to engine cylinders using fuel lines with the help of solid injectors.
3. Another spring-loaded high-pressure relief valve used to maintain the constant pressure in the system for smooth operations. It also returns the extra fuel of the accumulator to the fuel tank.
4. In the diagram, you can see the needle valve. It is used to control the opening and closing of the nozzle while it sprays the fuel into the cylinders. The upward and downward motion of the nozzle is measured by the cam.
5. Cam is connected to the spring with the help of a rocker arm and lever. During the dwell period of the cam, spring with the help of the needle valve prevents the injection of the fuel into the cylinder.
6. The packing gland ensures the level of the fuel above the valve seat for better injection of the fuel into the cylinders.
7. The wedge plays the main role in this system. It controls the amount of fuel to be injected into the cylinder in accordance with the power required for the engine. The wedge is operated by a governor or it can be operated manually as per requirement.

Advantages of CRDI System:

- CRDI system can control the flow of fuel in accordance with the load and speed of the engine.
- This system requires only one fuel pump for multiple cylinders.
- CRDI system is beneficial for the environment as it reduces noise, smoke and particulate matter.
- It gives high power output at low rpm.
- The main advantage of the CRDI system is fuel economy.

Disadvantages of CRDI System:

- This system is complex than MPFI system and needs good engineering work.
- The CRDI system cannot suit ordinary engines.

3.10.4 Fuel Injector

Quick and complete combustion is ensured by a well-designed fuel injector. By atomizing the fuel into very fine droplets, it increases the surface area of the fuel droplets resulting in better mixing and subsequent combustion. Atomization is done by forcing the fuel through a small orifice under high pressure. The injector assembly consists of a needle valve, a compression spring, a nozzle and an injector body as shown in figure 3.24. When the fuel is supplied by the injection pump it exerts sufficient force against the spring to lift the nozzle valve and the fuel is sprayed into the combustion chamber in a finely atomized particles. After fuel from the delivery pump gets exhausted the spring pressure pushes the nozzle valve back on its seat. For proper lubrication between nozzle valve and its guide a small quantity of fuel is allowed to leak through the clearance between them and then drained back to fuel tank through leak off connection. The spring tension and hence the valve opening pressure is controlled by adjusting the screw provided at the top.

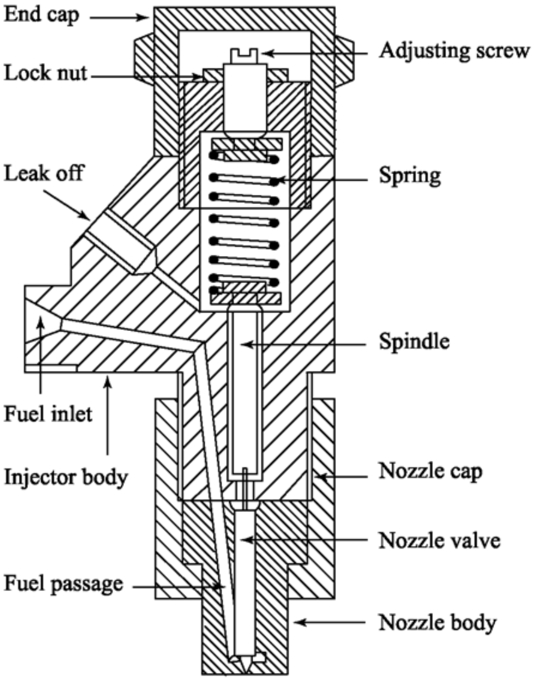


Figure: Fuel Injector

Fuel Injection Nozzle

Nozzle is that part of an injector through which the liquid fuel is sprayed into the combustion chamber. The nozzle should fulfil the following functions:

- **Atomization:** This is very important function since it is the first phase in obtaining proper mixing of the fuel and air in the combustion.
- **Distribution of fuel:** Distribution of fuel to the required areas with the combustion chamber. Factors affecting this are injection pressure, density of air and physical properties of fuel.
- **Prevention of impingement on walls:** Prevention of the fuel from impinging directly on the walls of combustion chamber or piston. This is necessary because fuel striking the walls decomposes and produces carbon deposits. This causes smoky exhaust as well as increase in fuel consumption.
- **Mixing:** Mixing the fuel and air in case of no turbulent type of combustion chamber should be taken care of by the nozzle

Various types of nozzles used in CI engine are shown in figure 3.25 and briefly explained below.

(**a) The pintle nozzle**: The stem of the nozzle valve is extended to form a pin or pintle which protrudes through the mouth of the nozzle. The size and shape of the pintle can be varied according to the requirement. It provides a spray operating at low injection pressures of 8 to 10 MPa. The spray cone angle is generally 60^0 Advantage of this nozzle is that it avoids weak injection and dribbling. It prevents the carbon deposition on the nozzle hole.

(b) Single hole nozzle: At the centre of the nozzle body, there is a single hole which is closed by the nozzle valve. The size of the hole is usually of the order of 0.2 mm. Injection pressure is of order of 8 to 10 MPa and spray cone angle is about 15^o Major disadvantage with such nozzle is that they tend to dribble. Besides their spray angle is too narrow to facilitate good mixing unless higher velocities are used.

(c) Multi hole nozzle: It consists if a number of holes bored in the tip of the nozzle. The number of holes varies from 4 to 18 and the size from 35 to 200 µm. The hole angle may be form 20^o upwards. These nozzles operate at high injection pressures of the order of 18 MPa. Their advantage lies in the ability to distribute the fuel properly even with power air motion available in open combustion chamber.

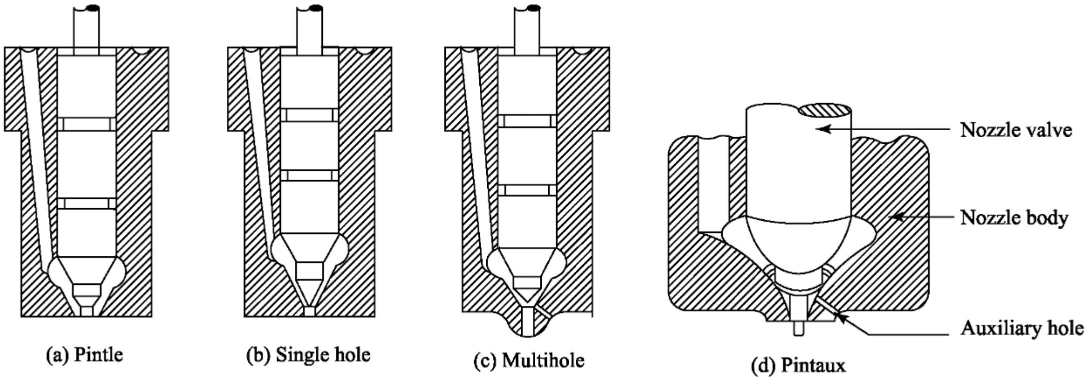

(a) Pintle (b) Single hole (c) Multihole (d) Pintaux

Figure: Types of nozzles

(e) **Pintaux nozzle**: It is a type of pintle nozzle which has an auxiliary hole drilled in the nozzle body. It injects a small amount of fuel through this additional hole in the upstream direction slightly before the main injection. The needle valve does not lift fully at low speeds and most of the fuel in injected through the auxiliary hole. Main advantage of this nozzle is better cold starting performance.

(f) **Indicated Power:** The power is produced inside the engine cylinder is called indicated power. The indicated power is calculated from the indicator diagram.

(g) The indicated power is calculated by: IP = $P_{im} \times A \times L \times n \times k$ kW

(h) Where P_{im} = Indicated mean effective pressure

(i)
$$P_{im} = \frac{\text{Area of the indicator diagram}}{\text{Length of indicator diagram}} \times \text{Spring constant (N/m}^2\text{/m)}$$

A = Area of the cylinder (m2),
L = Stroke length (m)
n = Number of explosions per second (n = N for two stroke engine, n=N/2 for four stroke engine), N= Speed of the engine in rps,

k = Number of cylinders

Brake power: The power available at engine crank shaft for external work is called brake power. The brake power is determined by Prony brake dynamometer, Rope brake dynamometer and Hydraulic dynamometer.

(j) **Prony brake dynamometer:** BP = 2×π×N×T kW
Where T = Torque = W×R,
W = Load applied (kN),

R = Radius of brake drum (m)

(k) **Rope brake dynamometer:** BP = π×D×N×(W – S) kW
Where D = Diameter of brake drum (m),

W = Weight applied at the end of the rope (kN), S = Spring scale reading (kN)

(l) **Hydraulic dynamometer:** BP = WN / 2000 kW

Where W = brake load (kN)

(m) **Friction power:** Friction power is the difference between indicated power and brake power of an engine.

FP = IP – BP

(n) The friction power is the measure of internal losses in the engine. The friction power is determined by Willan's line method, Morse test, Motoring test and Retardation test.

(o)

(p) **Brake specific fuel consumption (BSFC)** is the amount of fuel consumed per kW of brake power developed.

$$BSFC = \frac{FC}{BP} \qquad \text{kg/kW s}$$

(q) **Mechanical Efficiency** $\eta_{mech} = \frac{\text{Brake Power}}{\text{Indicated Power}}$

(r) **Brake thermal efficiency**: $\eta_{br.the} = \frac{BP}{FC \times CV}$

(s) **Indicated thermal efficiency** $\eta_{in.the} = \frac{IP}{FC \times CV}$

(t) **Relative efficiency** $\eta_r = \frac{\text{Brake thermal efficiency}}{\text{Air standard effificney}}$ *or* $\frac{\text{Indicated thermal efficiency}}{\text{Air standard effificney}}$

(u) **Volumetric efficiency** $\eta_v = \frac{m_{act}}{m_{th}}$

Quantity of Fuel Injected

The quantity of fuel injected per cycle is given by

$$Q = \left(\frac{\pi}{4} d^2 n\right) \times V_f \times \left(\frac{\theta}{360} \times \frac{60}{N}\right) \times \left(\frac{N_i}{60}\right)$$

Where n = number of holes in nozzle,

d = diameter of orifice,

V_f = velocity of fuel,

θ = duration of fuel injection in crank angle,

N = speed of the engine, and N_i = number of injection per min (N/2 for four stroke engine and N for two stroke engine)

A four stroke, four cylinder gasoline engine has a bore of 60 mm and a stroke of 100 mm. On test it develops a torque of 66.5 N m, when running at 3000 rpm. If the clearance volume in each cylinder is 60 cc, the relative efficiency with respect to brake thermal efficiency is 0.5 and the calorific value of the fuel is 42 MJ/kg, determine the fuel consumption in kg/h and the brake mean effective pressure.

Given: D=60cm,

L=100cm, T=66.5Nm, N=3000rpm, CV=42000 kJ/kg, VC = 60CC, ηRbt = 0.5

Solution:

Brake Power: BP = 2πNT 60 BP = 2×π×3000×66.5 60 BP = 20891.59 W

BP = **20. 89**kW

Brake Mean Effective Pressure BP = PBMEPLAnk

20.89 = PBMEP × 0.1 × π×0.062 4 × 3000 2×60 × 4 **P**

BMEP = 738.83 **kN*m*2**

Fuel Consumption: ηBT = *BP* ṁ f×CV ṁ f = 20.89×3600 0.25×42000

ṁf = **7. 16*kghr***

Brake Thermal Efficiency: ηRbt = ηbt ideal ηbt = ηRbt × ideal ηbt = 0.5 × 0.5 **ηbt** = **0. 25** Ideal

Efficiency: ηIdeal = 1 − 1 *rcγ*−1 ηIdeal = 1 − 1 5.7421.4−1 **ηIdeal** = **0. 5**

Where, r*C* = *V*1 *V*2 = *VS*+*VCVC* r*C* = **2.83×10−3+60×10−660×10−6r*C*** = **5. 742***VS* = *πD* 2 4 × *L*

VS = π×0.062 4 × 0.1 ***VS*** = **2. 83** × **10−3*m***

Calculate the diameter and length of the stroke of a diesel engine working on four stroke constant pressure cycle from the following data. IP=18.75 kW rotation per minute=220 CR=14 fuel cut-off ratio=1/20th of stroke, index of expansion=1.3, index of compression=1.35, L/D=1.5. Assume the pressure and temperature of the air at inlet are 1 bar and 40˚C respectively.

IP=18.75kW, N=220rpm, CR=14, L/D=1.5 , P1 = 1*bar*, T1 = 40℃

Cutoff Ratio: *V*3 − *V*2 = 0.05 (*V*1 − *V*2) → 0.05 = *ρ*−1 rc−1 ***ρ*** = **1. 65**

Mean Effective Pressure:

Pm = P1rc γ [γ(ρ−1)−rc 1−γ (ρ γ−1)] (γ−1)(rc−1)

Pm = 1×141.3 [1.3(1.65−1)−14 1−1.3 (1.651.3−1)] (1.3−1)(14−1)

Pm = **3. 4ba**

Indicated Power: IP = PIMEPLAnk

18.75 = 3.4 × 102 × 1.5D × $\pi \times D$ 2 4 × 220 2×60 × 1 D = 0.294m

Length of Stroke: L

D = 1.5 L = 1.5 × 0.294

L = 0. 589

During an experiment on four stroke single cylinder engine the indicator diagram obtained has average height of 1 cm while indicator constant is 25 kN/m2per mm. The engine run at 300 rem and the swept volume is 1.5 × 104 cm3The effective brake load upon dynamometer is 60 kg while the effective brake drum radius is 50 cm. The fuel consumption is 0.12 kg/min and the calorific value of fuel oil is 42 MJ/kg. The engine is cooled by circulating water around it at the rate of 6kg/min. The cooling water enters at 35o C and leaves at 70oC. Exhaust gases leaving have energy of30 kJ/s with them. Take specific heat of water as 4.18 kJ/kg K. Determine indicated power output, brake power output and mechanical efficiency. Also draw the overall energy balance in kJ/s.

Indicator Diagram Height =1cm,

Indicator Constant = 25 kN/mmper mm,

N=300rpm,

VS = 1.5 ×104cm3

PIMEP = Ind. diagram height × Indicator Constant

PIMEP = 10mm × 25 kNmm×m2

PIMEP = 250 Kn

Heat Loss due to Brake power:

P =2πNT60

BP = 4.62 kJs× 60 BP = 277. 2kJmin

Unaccounted Loss:

Qua = QS − Qw+Qg + QBP Qua = 5040 − 877.8 + 1800 + 277.2 qua = 2085 kJmin

%Qw =Qw/QS

%Qw =877.8/5040

%Qw = 17. 42

%Qg =Qg/QS

%Qg =1800/5040

%Qg = 35. 71

%QBP =QBP/QS

%QBP =277.2/5040

%QBP = 5. 5

%Qun =Qun/QS

%Qun =2085/5040

%Qun = 41. 37

MECHANICAL SUPERCHARGING

Superchargers are the main category of forced induction systems. Superchargers are compressors that are driven by mechanical means. Typically, they are driven by the crankshaft of an engine with the help of belts and pulleys. They are coupled directly to the engine and this does not allow for any delay to exist between the engine and the compressor. Superchargers are classified into two categories such as positive displacement pumps (Eg. Lysholm, Roots, Eaton, Scroll, Vane) and rotodynamic pumps (Eg. Centrifugal).

Positive Displacement Type

Mechanical supercharging is probably the oldest way of boosting the IC engine [Ainsdale, 1980]. Positive displacement supercharger is simpler in construction. They are easy to install and doesn't require complicated controls in most cases. It draws power through mechanical connection to the crankshaft, and its revolution (rotational speed) is directly proportional to the speed of the engine. The engine-compressor matching is relatively easy, and the boost pressure is almost constant over the entire range of engine operating speeds. Therefore, the torque curve is flat, and the turbo-lag problem is completely overcome. In effect, a supercharged engine behaves as a naturally aspirated engine with a larger displacement volume. It is this linearity that makes designing and predicting its boosting characteristics relatively easier than turbo charging. However, a supercharged engine consumes more fuel than a turbocharged engine with comparable power since the supercharger draws power directly from the engine crankshaft.

A supercharger has two rotors, a male and a female, forming a set of chambers between themselves and the housing. The chamber's volume is changing during the rotation and thus compresses the air internally. Since the power needed to drive the supercharger is taken directly from the crankshaft, most development work has been invested to increase the efficiency and to minimize the parasitic losses when the supercharger is not needed (i.e. part load of the engine).

The most common types of the supercharger in the market today are the Lysholm compressor and the Roots blower. Figure 2.1 & 2.2 shows the cut-away view of the Lysholm screw and roots type supercharger [Heinz, 1995]. Both are displacement pumps and from a first glance they look very similar. They differ on one big point; the Lysholm screw has internal compression while the Roots do not have internal combustion. The Lysholm Compressor works with internal compression.

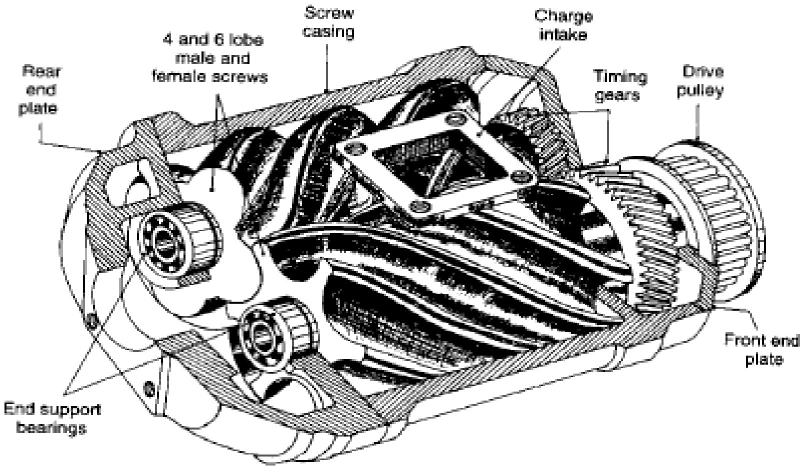


Figure 2.1 Cut-way view of the Lysholm screw supercharger [Heinz, 1995].

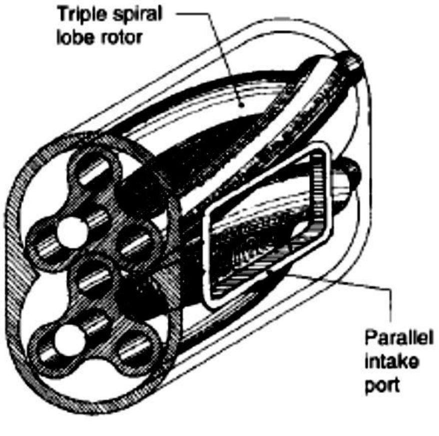


Figure 2.2 Cut- way view of the roots type supercharger [Heinz, 1995].

The Roots on the other hand works without internal compression, the compression takes place as the air is discharged from the blower outlet instead of inside the supercharger. This means that the compression takes place at isochoric conditions (i.e. constant volume). This process is known to be more power consuming and heat producing than the adiabatic process.

Centrifugal Compressor as a Supercharger

The centrifugal compressor has an isentropic efficiency that can match, and sometimes exceed, the efficiency of a Lysholm screw compressor. It is a dynamic machine where the rotor increases the internal energy of the air, both through increased density and increased velocity. The velocity is then carefully diffused to recover the kinetic energy as static pressure. Consequently, the centrifugal compressor has internal compression. Figure 2.3 shows the cut-away view of the centrifugal supercharger.

Unfortunately, the flow vs. speed characteristics of the centrifugal compressor is very non-linear. A fixed gear ratio between the compressor and the crankshaft results in a very peaky boost pressure delivery. Despite this, it has been used in cars, during the 1930s and 1950s. The speed of the centrifugal compressor is above 100000rpm and it is up to 10 times higher than roots and about 3 to 5 times the speed of a screw compressor. The need for a gearbox caused trouble for the designer. High speeds can lead to both sound problems if gears are used and the torque needed for acceleration can be rather high even if the moment of inertia is not particularly high.

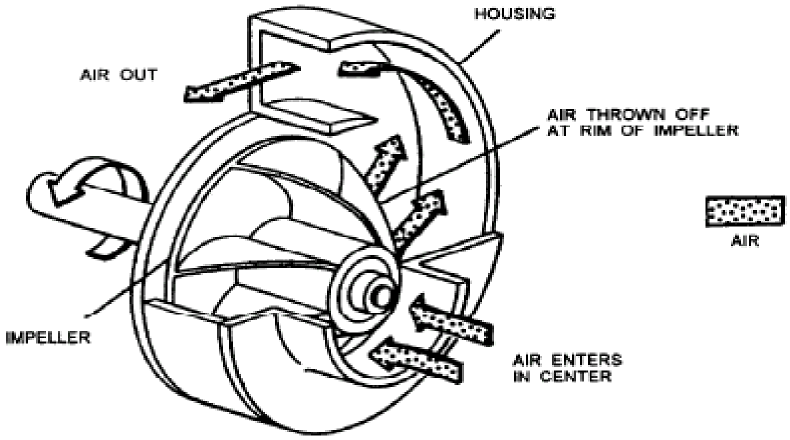


Figure 2.3 Cut view of centrifugal supercharger

Parasitic Losses

The largest problem of using a mechanical supercharger on a downsized engine is not the top-end performance, but the parasitic losses on part load. Miyagi et al., (1996) showed that for a Lysholm compressor only 20-30% of the parasitic losses come from mechanical losses and the rest from losses in the airflow, i.e. unnecessary pumping. Therefore, it is most important to try to minimize the airflow losses.

Clutch

The most obvious way of limiting the parasitic losses is to have a clutch to engage and disengage the compressor. Using a clutch has the advantage of reducing both losses in the air and the mechanical losses, assuming that the clutch is positioned on the crankshaft end of the belt. Since the compressor has a non-negligible inertia and that it rotates with high speed, it is necessary to apply large amounts of torque in order to accelerate the compressor to working speeds within reasonable time. These torque impulses will result in comfort problems if the work has to be taken from the crankshaft.

TURBOCHARGER

Turbochargers are commonly used in engines because they extract some of the energy from the exhaust gases that would have otherwise been lost [Corky Bell, 1997]. Turbochargers consist of a turbine (the component that is being spun by the passing exhaust gases) and the compressor (the component increasing the intake pressure) which is coupled to the turbine by a rotor. Figure 2.4 shows schematic layout of turbocharging system in a diesel engine.

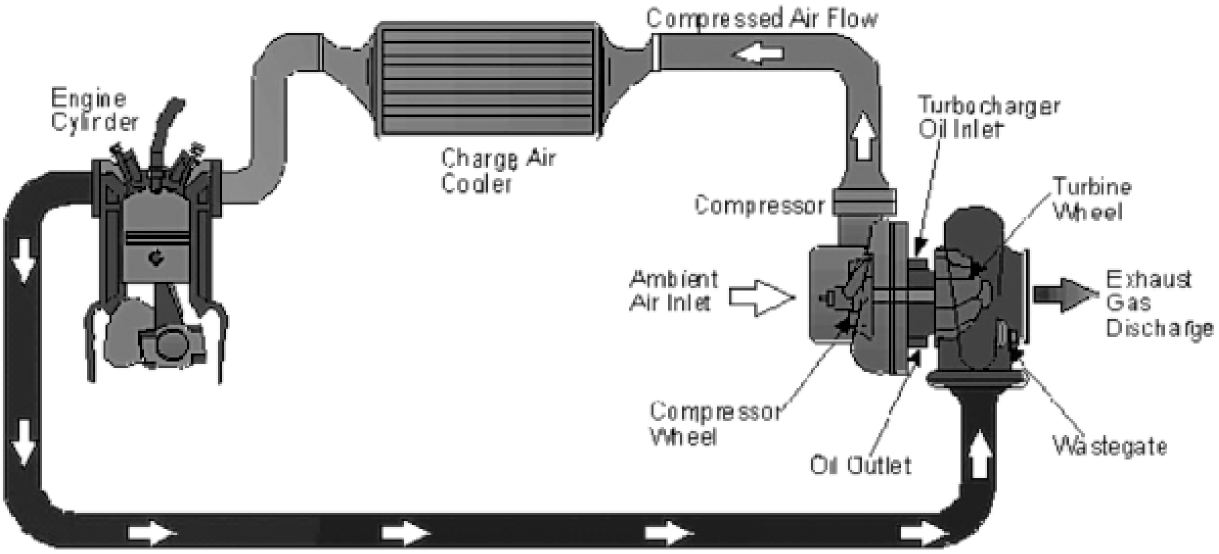


Figure 2.4 Typical schematic layout of turbocharger system of an IC engine

One of the advantages of turbochargers is that they are able to recuperate some of the energy of the exhaust gases. This makes turbochargers suitable for use in engines where efficiency is important, as well as for diesel engines that are otherwise not able to produce a high power. Another reason why turbochargers are preferred in diesel engines is because of the lower exhaust temperature [Cengel and Boles, 2006], which doesn't damage the turbine blades (unlike gas powered engines). Typically, turbines are very delicate and require special grades of oils because of their very high rotational speeds (sometimes exceeding 150000 rpm); as long with this in gas powered engine, the higher temperature of exhaust gases tends to melt the tips of the turbine blades which dramatically decreases the efficiency of the turbine which causes a significant decrease in engine power. In road going vehicles and race cars, turbochargers are well known for the turbo lag. The turbo lag is an unwanted effect and is caused because of the high turbine spool time due to the moment of inertia of the turbine and compressor. As well, it is due to the fact that the driving force of the turbine comes from the exhaust gases which are compressible. The turbo lag is in other words a delay in the turbine response

Waste Gate Operation

Some turbochargers are equipped with a waste gate [Figure 2.5]. This device allows some of the exhaust gases to bypass the turbine rotor at higher engine speeds**.** With this arrangement, the turbocharger can be designed to be more effective at lower engine speeds. The waste gate consists of a valve, actuator, and connecting linkage. The actuator consists of a diaphragm and spring enclosed in canister housing. The valve is located in an exhaust bypass line. Under low boost conditions, the spring pushes against the diaphragm moving the linkage to close the waste gate valve. Turbo boost pressure is directed against the other side of the diaphragm. As boost pressure increases with increased engine speed, the diaphragm moves against spring pressure to open the valve and allow a portion of the exhaust gases to bypass the turbine wheel through a connecting line. As boost pressure drops, spring pressure moves the diaphragm and linkage to close the valve. The waste gate is preset at the factory and no adjustment can be made.

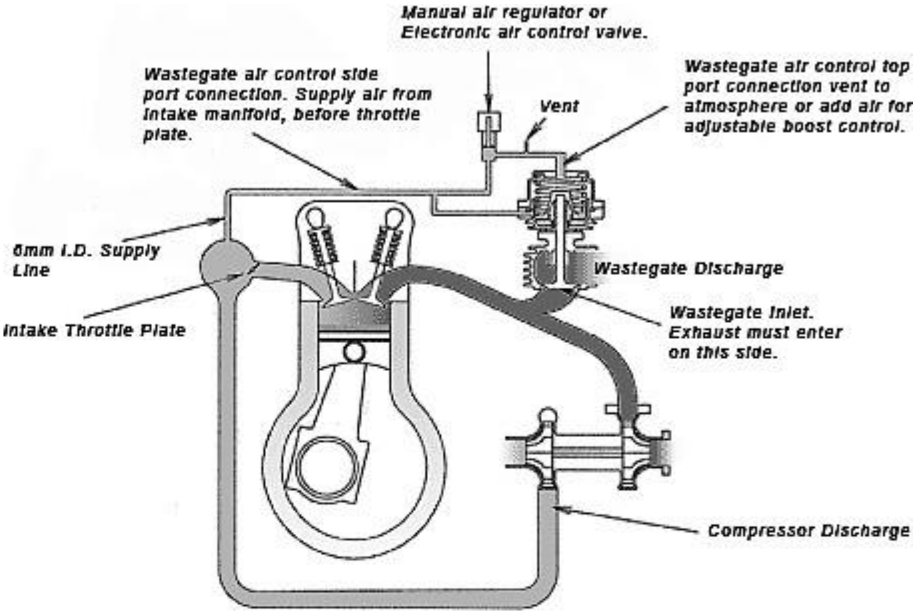


Figure 2.5 Waste gate arrangements in a turbocharged engine.

Trend of Turbo Charging Technologies

The goals that a turbocharger must satisfy are the ability to provide high-pressure turbocharging at low engine speeds, a high transient response, and high efficiency at a high pressure ratio. A fixed geometry turbine is not capable of supplying enough power to the compressor for the boost pressure required for low speed and during transient conditions. On the other hand, it offers a higher turbine inlet pressure which leads to increased fuel consumption if the turbocharger characteristics are optimized for low engine speeds. In addition, the flow range of a centrifugal compressor is a limiting factor, and if higher boost pressures are demanded, it will be even more difficult to achieve satisfactory width of the usable range since the width of the compressor map becomes narrower as the boost pressure approaches its maximum.

Different turbocharger designs such as the variable geometry turbocharger, electrically assisted turbocharger, and two-stage turbocharger have been developed as a means of achieving the above-mentioned performance improvements. Also, the Variable-Nozzle Turbocharger (VNT), which is capable of changing the flow capacity of the turbine, is already in widespread use in diesel passenger cars. The electrically assisted turbocharger improves the transient response and, because it is excellent at achieving high-pressure turbo charging at low speeds, manufacturers are putting considerable effort into its development.

For a turbocharged engine with the Variable Nozzle Turbine (VNT), as is widely used in diesel engines, the boost pressure can be raised by controlling the variable nozzle at low engine speeds. Figure 2.6 shows an example of a VNT that was developed for use in diesel engines. In addition, improving the turbocharger efficiency in the region where the pressure ratio is high is important to reduce the turbine inlet pressure for high-pressure turbo charging.

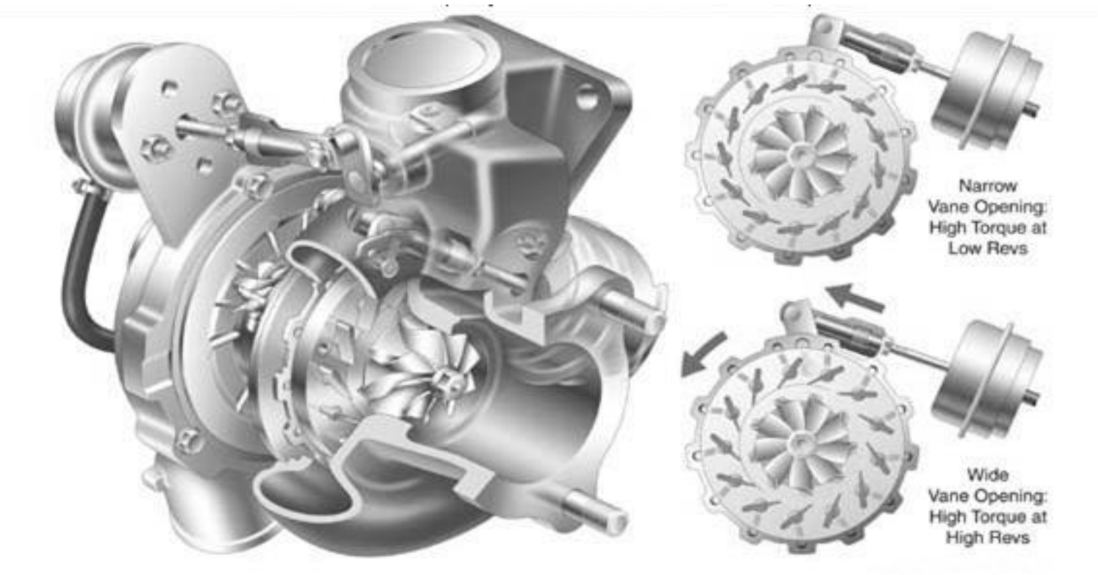


Figure 2.6 A typical example of a VNT that was developed for use in diesel engines

The VNT has rapidly gained popularity in Japan and Europe despite its higher cost because it offers the advantages of low-end torque, transient response, and lower turbine inlet pressures at high speeds, relative to conventional turbochargers. At present, the VNT is the only technology available that allows diesel engines to satisfy current emissions regulations. On the other hand, the VNT is not compatible with the high gas temperatures of gasoline engines because of its complicated structure and links. However, the amount by which the pressure can be increased at low engine speeds is limited due to the low exhaust energy, such that engine back pressure arises.

The Motor-Assist turbocharger (MAT), however, is able to raise the boost pressure at low engine speeds. So, by adding motor assistance, torque characteristics on a par with a large-displacement engine can be attained. A MAT can also recover thermal exhaust energy by acting as a dynamo at high engine speeds [Figure 2.7]. The high-speed motor has its permanent magnet installed on the shaft of the rotor while the stator is in the bearing housing. Because the motor is sensitive to heat, the cooling method is an important aspect of the development.

Moreover, the outer diameter of the permanent magnet cannot be made much bigger than already present because the combined strength of the permanent magnet and the shaft is low. To increase the power of the motor, therefore, the length of the permanent magnet has to be extended. Unfortunately, this leads to a reduction in the critical speed of the rotor shaft, vibration, and a risk of damage when operating at high speeds. Because the surge phenomenon of the compressor sometimes leads to damage to the rotor, it has been the subject of research for some time and by many different manufacturers.

Many kinds of casing treatments have been investigated to improve the surge characteristic and have been put commercialized in large-scale turbochargers. To obtain a high boost pressure over the wide operating range of a turbocharged engine, the turbocharger has to operate at a high pressure ratio and high rotational speed over a wide flow range. On the other hand, the compressor has a surge limit that is related to the flow rate and therefore cannot be operated at flow rates less than the surge limit. Otherwise, the flow becomes unstable and periodic pressure fluctuations characterized by loud noise.

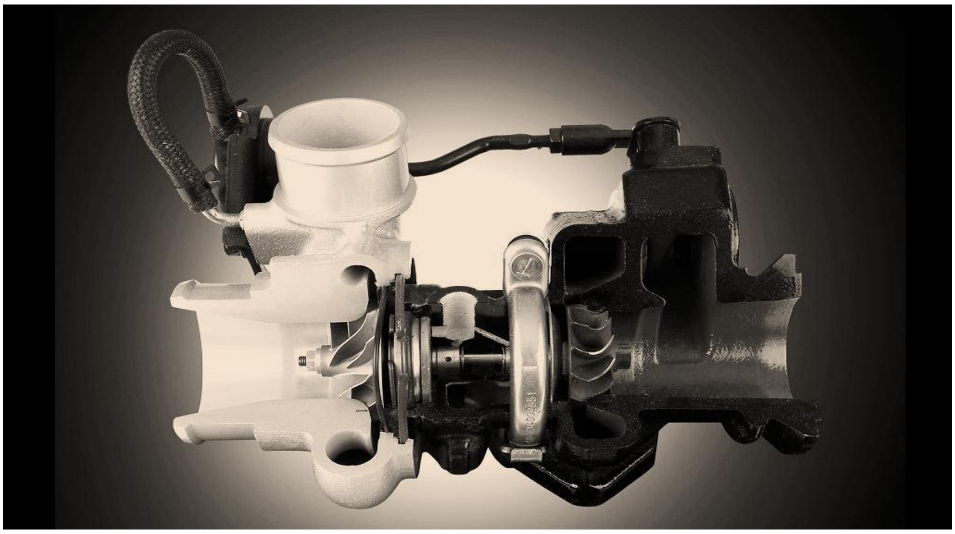


Figure Schematic layout of a MAT.

To overcome this, the rotational speed of the turbocharger has to be increased by controlling the variable nozzle vane angle or the power of the motor assistance, while shifting the surge limit of the compressor towards a lower flow rate, or eliminating it altogether, in order to increase the boost pressure at low engine speeds.

There are two ways of eliminating the surge limit. The first is the application of two-stage turbo charging whereby the small compressor of the high-pressure turbocharger is used at low engine speeds. Unfortunately, a disadvantage of two-stage turbo charging is that the system is more complex and larger than single-stage turbo charging. The second method involves bypassing the compressor discharge air to the compressor inlet so as to increase the flow rate of the compressor. This, however, causes an increase in the turbine inlet pressure due to the increase in the compressor power. As a result, the fuel consumption of the engine deteriorates. Therefore, a means of improving the surge limit of the compressor is an essential technology. There are several means of improving the surge limit of a centrifugal compressor. One effective means is to re-circulate part of the air that is compressed by the impeller to the impeller inlet by using a casing treatment on the shroud wall.

The surge flow rate can be reduced by using a compressor with a variable inlet guide vanes (VIGV) or a variable diffuser. A VIGV installed upstream from the impeller inlet can control the velocity angle of the flow at the impeller inlet, so that the flow characteristics of the compressor can be controlled. A variable diffuser installed downstream from the impeller exit can control the flow through the diffuser where the velocity is higher than at the impeller inlet. So, the changes in the flow characteristics with the diffuser vane angle are very sensitive compared with the VIGV. And, the performance of the compressor with the variable diffuser is highly dependent on the clearances between the stationary side walls and the variable diffuser vanes.