MARMARA UNIVERSITY

FACULTY OF ENGINEERING

STRUCTURAL DESIGN OF A 3-CYLINDER SMALL SIZE DIESEL ENGINE

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GRADUATION PROJECT REPORT

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STRUCTURAL DESIGN OF A 3-CYCLINDER SMALL SIZE DIESEL ENGINE

by

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ABSTRACT

The most reason of this investigate proposition is to plan a 3-cylinder motor. The content of this proposition, which is able alter the viewpoint of 3-cylinder motors, is what the diesel engine is, its history, focal points, whether it utilize will increment within the future and the components influencing it, data around plan, fuel and fuel frameworks, who will be utilized, and a few motor illustrations. Whereas planning the proposition substance, articles composed around 3-cylinder motors, master suppositions and information from factual companies were utilized. The conclusions of the master conclusions and the information of the factual companies were carefully analyzed and translated independently. As a consequence of the studies, it was discovered that 3-cylinder engines are more cost-effective than 4-cylinder engines, and that diesel engines can have a large market volume for at least twenty to thirty years. As a result, in comparison to other motors on the market, we have a propensity to develop our own style.

ABBREVIATIONS

NOX	Nitrogen Oxide
SUV	Sport Utility Vehicle
PM	Particulate Matter
ADAC	Allgemeiner Deutscher Automobil-Club RDE Redundant Data Elimination
TDI	Turbocharge Direct Injection
VAG	Volkswagen AG
SPI	Single Point Injection
MPI	MultiPort Injection
GDI	Gasoline Direct Injection
PFI	Port Fuel Injection
SFI	Sequential Fuel Injection
ECU	Engine Control Unit
MAF	Measure Air Flow
MAP	Mass Air Pressure
PPS	Pre Pilot Spray
PS	PFERDE STARKE
RS	Ralli Sport
GT	Grand Tourers
ST	Sport Technologies
MDB	Mobile Deformable Barrier
CR	Certificate of Registration
MTREC	Multi Throttle Responsive Engine Control
PGM-CARB	Programmed Carburetor
PGM-FI	Programmed Fuel Injection
VTG	Variable Turbo Geometry

1. INTRODUCTION

An engine is a component that converts a form of energy into mechanical energy. One of the most common forms is the internal combustion engine (ICE). The internal combustion engine is a heat engine which converts the chemical energy of a given fuel into mechanical energy. The combustion process with an oxidizer, which is mostly air, takes place in the combustion chamber which is inside the engine. Therefore, the name of the internal combustion engine comes from combustion occurring within the engine. The first internal combustion engines appeared in automobiles around 1880's. Rudolf Diesel had improved his compression ignition engine by 1892 and it is basically today's modern diesel engine. This report mainly focuses on diesel, straight three- cylinder engines, the improvements that have been made on three-cylinder engines since they were introduced and the reasons why they are on the rise in the past 10 years.

Figure 1.1- Diesel engine, *any internal-combustion engine in which air is compressed to a sufficiently high temperature to ignite diesel fuel injected into the cylinder, where combustion and expansion actuate a piston.*

2. LITERATURE REVIEW

2.1 SI AND CI ENGINES

Engine is a machine that converts some form of energy into mechanical work. Internal combustion engines can be divided according to several characteristics. Depending on the creating of mixture and the ignition (the thermodynamic process), engines are divided into: Otto (spark ignition) and Diesel (compression ignition) engines.

2.1.1 SI Engine

The four-stroke petrol engine performs the working cycle in four steps. During that time, the crankshaft makes two turns.

The first cycle is the, the suction valve starts to open before the piston gets to TDC and closes after the piston has passed the BDC position. A 0.7-0.9 bar pressure is generated in the cylinder, which, by means of an open valve, draws the fresh working mixture which is mixed in the cylinder with the combustion products remaining from the previous process.

During compression the clip moves to TDC and compresses the gases in the cylinder. The pressure rises from 11 to 18 bar and temperature from 400 to 600 0C. The piston begins to reduce the cylinder chamber space. Both cylinder valves are closed and compression of fuel and air is carried out.

Combustion begins before TDC and lasts until BDC. Compression ratio values range from 6 to 11. During expansion the compressed fuel and air mixture is ignited by electric high voltage spark plugs just before the piston came back to the TDC position. The combustion gas pressure at the beginning of the expansion stroke is 40-60 bar and the temperature 2000-2500 C.

Due to the high combustion pressure, the piston moves from TDC to BDC, where useful mechanical work is obtained. By increasing the volume of the cylinder and the expansion of the combustion gases, the pressure and combustion gas temperature drop so that at the end, the combustion gas pressure is 3-5 bar, and the temperature is 700-1000 C.

During the exhaustion the piston moves from BDC to TDC and then pushes out the cylinder gases through the open exhaust valve. Combustion gases are under pressure of 1.05 to 1.20 bar

Depending on the cylinder charge, the pressure in front of and behind the exhaust can be above critical and a good part of the gas comes out due to pressure difference. High pressures and temperatures in the engine cylinder represent an important precondition for achieving a high degree of efficiency.

2.1.2 CI Engine

Four-stroke diesel engine has the same cycle.

The first phase (intake) starts by opening the suction valve. Whereby due to volume increase above the piston, pressure is generated in the cylinder so that the actual cylinder pressure during the suction time is 0.7 – 0.85 bar.

In case of turbocharger engines is up to 2 bar. The second stroke (compression) begins by closing the suction valve and ends at TDC. The capacity of the injected working medium is reduced 14 to 24 times in the compression chamber.

The air pressure at the end of the compression is 30 – 60 bar and its temperature is 600 – 9000C. After compression of the air expansion begins, and the fuel is injected into the cylinder with pressure of 90 – 2000 bar, depending on the injection device. The fuel is scattered, heated, mixed with air and ignited.

During combustion the temperature rises to 2000 – 25000 °C and the pressure to 60 – 120 bar. In this tact the maximum mechanical and thermal stresses of the piston mechanism occur. During extension the clip is switched from BDC to TDC, thus draining the cylinder through the exhaust valve. The pressure at which the exhaust gases pass is 1.05 to 1.20 bar. The temperatures of the gases are 500 – 6000 °C.

S.no	Parameter	SI Engine	CI Engine
1.	**Definition**	It is an engine in which the spark is used to burn the fuel.	It is an engine in which heat of compressed air is used to burn the fuel.
2.	**Fuel used**	Petrol is used as fuel.	Diesel is used as fuel.
3.	**Operating cycle**	It operates on Otto cycle.	It operates on Diesel cycle.
4.	**Compression ratio**	Low compression ratio.	High compression ratio.
5.	**Thermal efficiency**	High thermal efficiency.	Less thermal efficiency.
6.	**Method of ignition**	Spark plug is used to produce spark for the ignition.	Heat of compressed air is used for the ignition.
7.	**Engine Speed**	High speed engines.	Low speed engines.
8.	**Pressure generated**	Low pressure is generated after combustion.	High pressure is generated after combustion.
9.	**Constant parameter during cycle**	Constant volume cycle.	Constant pressure cycle.
10.	**Intake**	Air + fuel.	Only air.
	Weight of engine	Si engine has less weight.	CI engine are heavier.
12.	**Noise production**	It produces less noise.	It produces more noise.
13.	**Production of hydrocarbon**	Less Hydrocarbon is produced.	More hydrocarbon is produced.
14.	**Starting**	The starting of SI engine is easy.	The starting of CI engine is difficult.
15.	**Maintenance cost**	Low	High
16.	**Vibration problem**	Less	Very High
17.	**Cost of engine**	Less cost	High cost
18.	**Volume to power ratio**	Less	High
19.	**Fuel supply**	Carburetor	Injector
20.	**application**	It is used in light commercial vehicles like motorcycle, cars etc.	It is used in heavy duty vehicles likes bus, trucks, ships etc.

Figure 2.1 *Comparison table of the SI and CI engines*

3. WHY 3-CYLINDER ENGINE?

During the second half of eighties and nineties, three-cylinder engines ruled Indian roads. But by the beginning of new millennium cars with four-cylinder engines captured back the Indian market. As a result of some investigations, Indian automobile manufacturers these days are increasingly focusing again on making cars with 3-cylinder engines. Anymore, manufacturers of automobiles tend to produce of 3-cylinder engine due to tightening emission and fuel regulations and additionally, 3-cylinder engines supply more power with the turbo.

We can array main reasons of this increasing like below,

- Less Raw Material Usage: This is perhaps the most sought after plus point of a 3-cylinder engine. The Having one cylinder less, the total material required to manufacture a 3-cylinder engine is lesser. This has a two-fold advantage to the manufacturers.
- Optimized for Fuel Efficiency: This is the most sought after plus point from the perspective of a consumer. A 3-cylinder engine is much more fuel efficient compared to a 4-cylinder engine of the same size. This is because of two primary factors, reduced frictional losses and lighter weight. Since there is one cylinder less, the frictional losses caused by metal surfaces coming in contact within the engine block is lesser.
- In general, a 3-cylinder engine is cheaper to maintain and run. With one cylinder less, the total parts functioning in the engine are lesser. This means there are a lesser number of parts being used in the engine. So, the automatically incurs lesser wear and tear compared to a 4-cylinder engine.

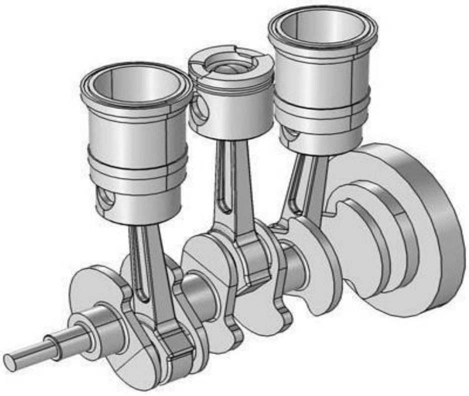


Figure 3.1. *CAD model of a three-cylinder reciprocating engine. Image showsthree sets of pistons, cylinders, and connecting rods, one crankshaft, and twobearings. The piston and cylinder are connected using a prismatic joint, while hinge joints connect pistons with connecting-rods, connecting-rodswith the crankshaft, and the crankshaft with bearings.*

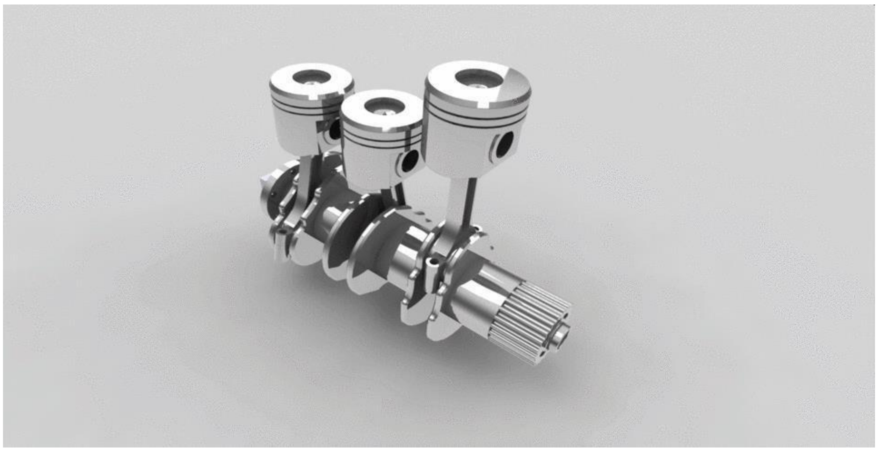


Figure 3.2. Piston crank and connecting rodmechanism

4. DIESEL ENGINE

Diesel engine**,** any internal-combustion engine in which air is compressed to a sufficiently high temperature to ignite diesel fuel injected into the cylinder, where combustion and expansion actuate a piston. It converts the energy stored in the fuel into mechanical energy, which can be used to power freight trucks, large tractors, locomotives, and marine vessels. A limited number of automobiles also are diesel-powered, as are some electric-power generator sets.

The diesel engine gains its energy by burning fuel injected or sprayed into the compressed, hot air charge within the cylinder. The air must be heated to a temperature greater than the temperature at which the injected fuel can ignite. Fuel sprayed into air that has a temperature higher than the "auto-ignition" temperature of the fuel spontaneously reacts with the oxygen in the air and burns.

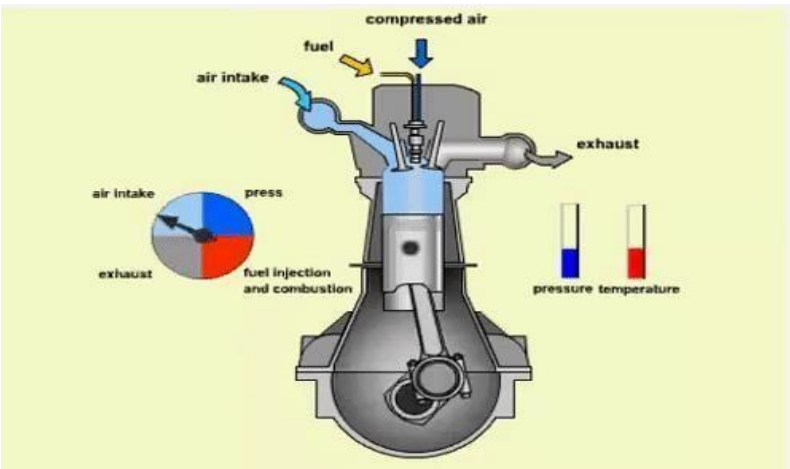


Figure 4.1. Diesel Engine working animation

4.1 THE HISTORY OF DIESEL ENGINES

The invention of the diesel engine goes way back – all the way to the 1890s. Since their introduction, they have remained one of the most common engines used in power generation applications. They have been useful in a variety of industries and functionalities.

In the 1870s, steam was the main supplier of power for factories and trains. Steam-powered cars were even being produced alongside those using internal combustion engines.

Diesel was a student learning about thermodynamics at the time, and he got the idea for creating an engine that would be highly efficient and convert the heat it generated into power. He got to work developing what would become the diesel engine. He set up his first shop in 1885 to start the development of this new engine and to put his theories into practice. One of his hypotheses was that higher amounts of compression would lead to higher efficiency and power. Diesel received patents for his designs during the 1890s. The first diesel engine prototype was built in 1893, though the first engine test was unsuccessful, so it was back to the drawing board.

In 1897, Diesel produced successful results after many improvements and tests. In February of that year, he was able to show an efficiency of 26.2% with the engine. Compared with the steam engine popular at the time, the engine Diesel had developed was more efficient by 16.2%.

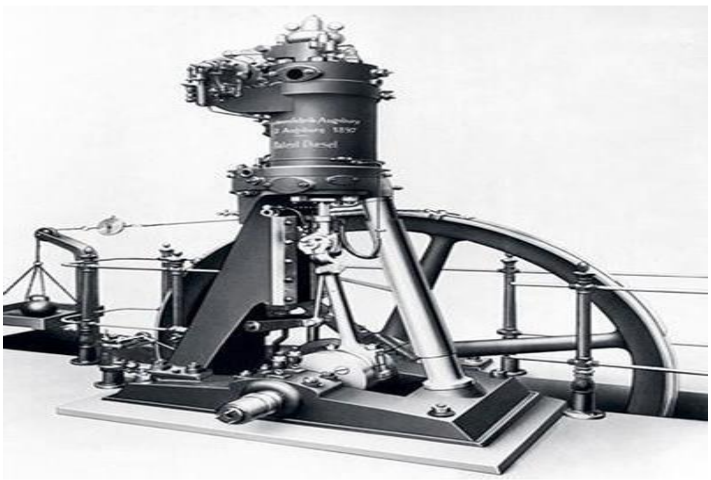


Figure 4.2 *Diesel's third test engine used in the successful 1897 acceptance test*

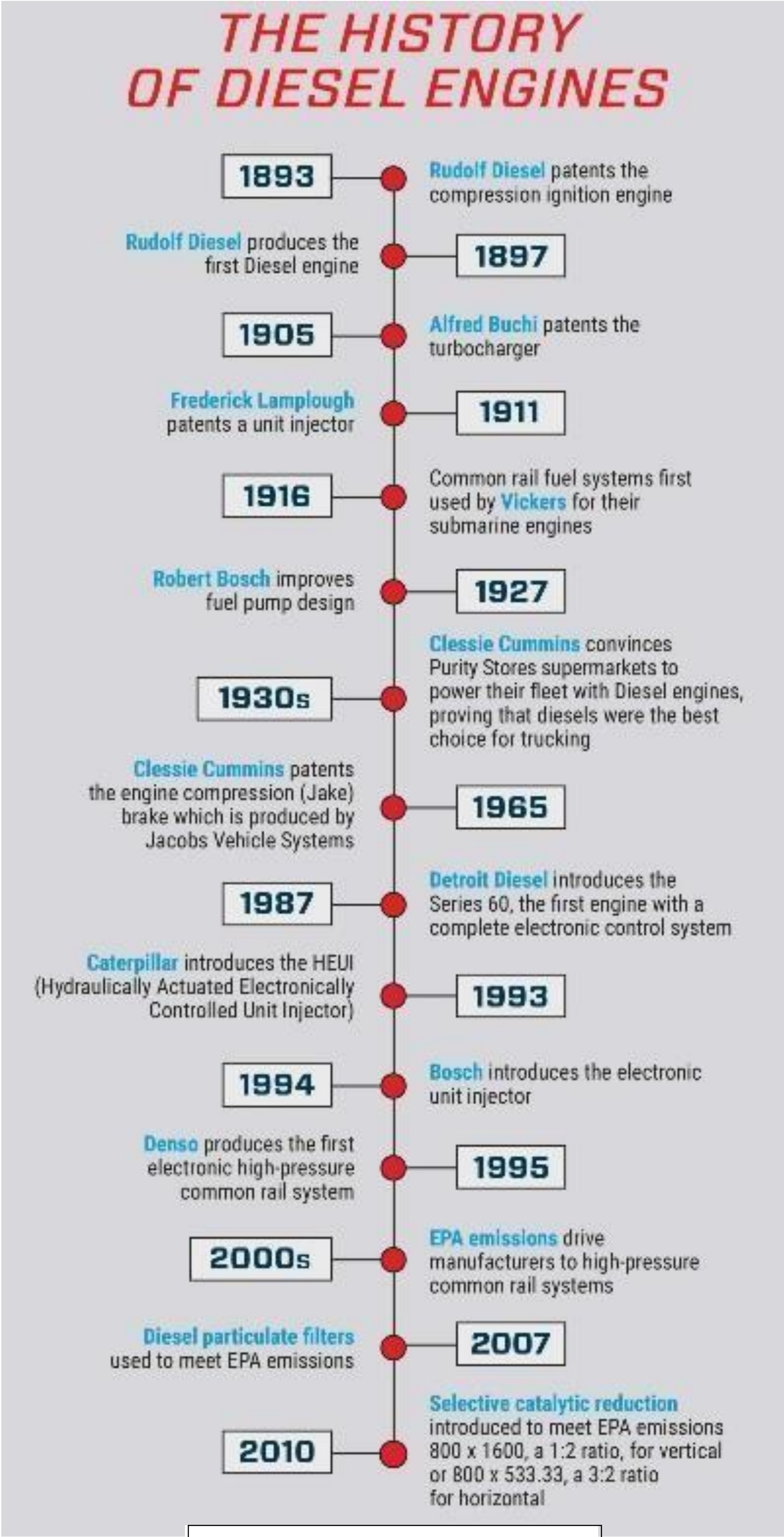


Figure 4.3. The History of Diesel Engine

4.2 THE DEVELOPMENT OF DIESEL ENGINES

4.2.1 The Diesel Engine Through the Years

The engine Diesel created was revolutionary at the time and continued to be developed. The engine itself was much more efficient at the time than steam-powered varieties, but diesel engines of today are quite different.

In 1925, Swiss engineer and inventor Alfred Büchi was able to combine his turbocharging technology with a diesel engine and increase efficiency by more than 40%. The majority of modern diesel engines utilize Büchi's principles and are turbocharged.

Fuel-injection pumps were improved upon and introduced in 1927 by German inventor and industrialist Robert Bosch, helping to increase the fuel economy and efficiency of the engines. The first passenger vehicle with a diesel engine was launched by Mercedes-Benz in 1936.

By the 1960s, diesel engines were the top source of power for the commercial trucking industry. The United States enacted the Clean Air Act in 1963 to help reduce and control pollution, and through the years the diesel engine saw updates and evolutions to help meet these guidelines.

Since the mid-2000s, diesels have become equipped with various new parts to help reduce emissions and make them more environmentally friendly. Cummins released next-generation diesels in 2017 that have redesigned emission controls and benefits to fuel economy.

Diesel engines have been used in commercial trucking and in the general car market, but they're also used as stand-alone generators for use in a range of industries. They continue to become more advanced in the realm of emissions control, with focuses on cost and efficiency as well.

5. WILL DIESEL VEHICLES BE USED IN THE FUTURE?

Diesel technology continues to evolve to meet the demands of today and tomorrow for efficient, clean, and reliable power across wide sectors of the global economy. An energy transition is underway.

Fueled by new efforts to reduce greenhouse gas (GHG) emissions, the development of emerging technologies such as batteries and fuel cells will play an increasing role in the future in the transportation and possibly other sectors of the economy. Some of these emerging technologies may replace diesel in some applications, while diesel will continue to be the dominant technology for the foreseeable future in others.

From government sources to international consulting firms, authorities agree that internal combustion engines - both gasoline and diesel - will continue to be important for many decades into the future to ensure continued progress on meeting society's greatest challenges - achieving cleaner air and reducing GHG emissions - as other emerging technologies are yet to reach commercial availability at scale and with still unknown impacts from the global pandemic.

Diesel technology continues to evolve to meet the demands of today and tomorrow for efficient, clean, and reliable power across wide sectors of the global economy. Four key strategies will define the future of diesel: reducing emissions even closer to zero, improving energy efficiency, increasing use of low carbon renewable biofuels and hybridization.

- Emissions Closer to Zero
- Increasing Energy Efficiency
- Expanded Use of Renewable Fuels
- Hybridization Where it Makes Sense

Emissions Closer to Zero

Diesel remains the dominant technology in long-haul trucking, powering 97 percent of Class 8 big-rig trucks in the United States. Cleaner diesel fuel, advanced engines and effective emissions control make up the new generation of advanced technology diesel and work together to achieve near zero emissions for fine particles and smog forming compounds like oxides of nitrogen (NOx).

Diesel’s proven energy efficiency and ability to use renewable fuels position it as a key technology to achieve cleaner air, lower GHG emissions and eliminate black carbon (a short-lived climate pollutant), which are necessary to buy important atmospheric time as longer-term strategies to deliver zero-emissions solutions become available. This new generation of diesel technology is here now, ready, and available today to deliver significant climate and clean air benefits.

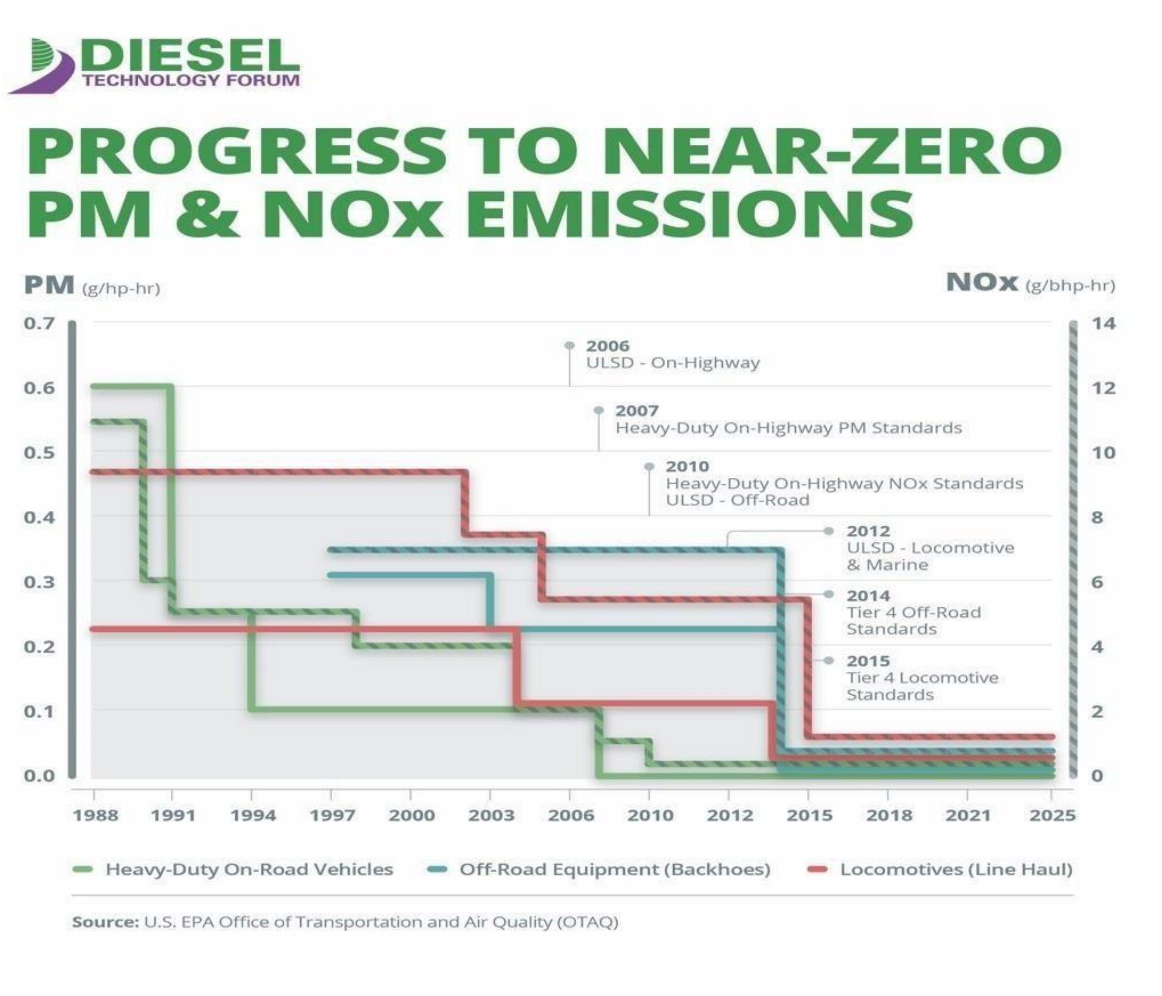


Figure 5.1. Progress to near zero PM & NOx Emissions

Increasing Energy Efficiency

Today, diesel is the technology of choice for commercial vehicles and the goods movement sector. The U.S. EPA and National Highway Traffic Safety Administration (NHTSA) estimate that the Commercial Vehicle Fuel Economy and Greenhouse Gas Reduction Standards Phase 1 rules saved 270 million tons of CO_2 and 530 million barrels of oil between 2014 and 2018, and that the Phase 2 rules will save another 1 billion tons of CO_2 and nearly 2 billion barrels of oil between 2021 and 2027. Research commissioned by the Diesel Technology Forum confirms that the majority of these significant societal benefits will be delivered by more efficient new technology diesel trucks.

Much like technologies developed to meet the model year 2010 emissions standard for commercial vehicles, off-road engine and equipment manufacturers have coupled fourth generation near-zero emissions control technology ("Tier 4") with substantial fuel savings strategies including advanced engine designs, more efficient hydraulic systems, telematics, boosts in work productivity from connectivity and hybridization. Taken together, today's generation of construction equipment delivers both fuel savings and fewer GHG emissions along with clean air benefits to many communities.

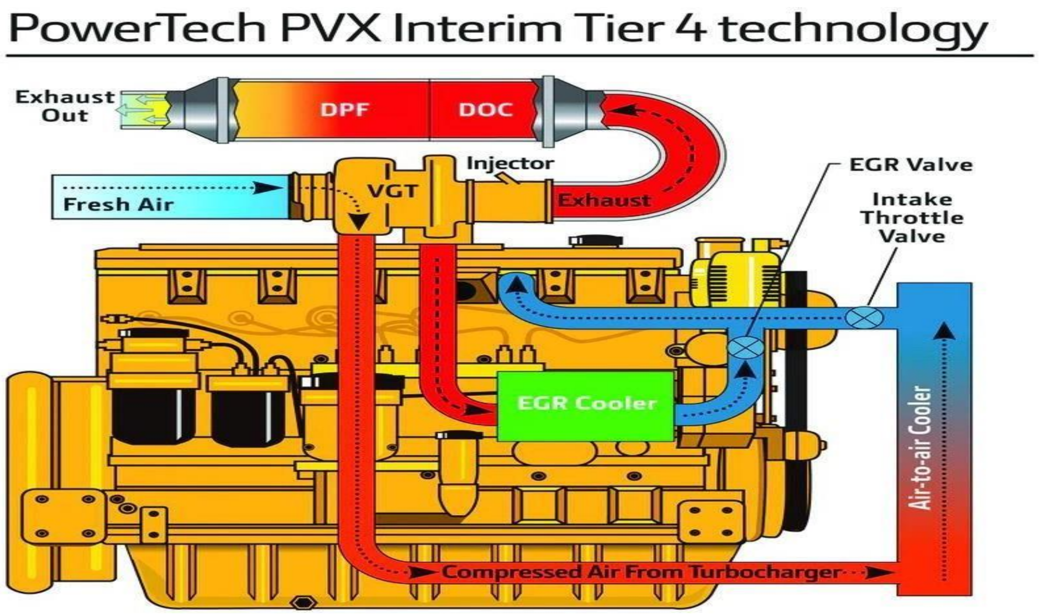


Figure 5.2 Tier 4 Technology

Expanded Use of Renewable Fuels

Advanced diesel engines and biodiesel and renewable diesel are key strategies in the effort to meet the climate challenge. High-quality biofuels are available, affordable, proven and, because they are suitable for both new and existing vehicles, they deliver substantial near-term reductions in GHG and other emissions across wide sectors of the economy that rely substantially on diesel engines today and will well into the future.

Most heavy-duty diesel engines, like those in commercial vehicles, are capable of operating on blends of biodiesel up to 20 percent (B20). Some diesel engines in fleet applications are approved to operate on higher blend levels. Renewable diesel fuel is produced to meet the same engineering standard as petroleum diesel fuel and can be used as a 100 percent replacement fuel to petroleum.

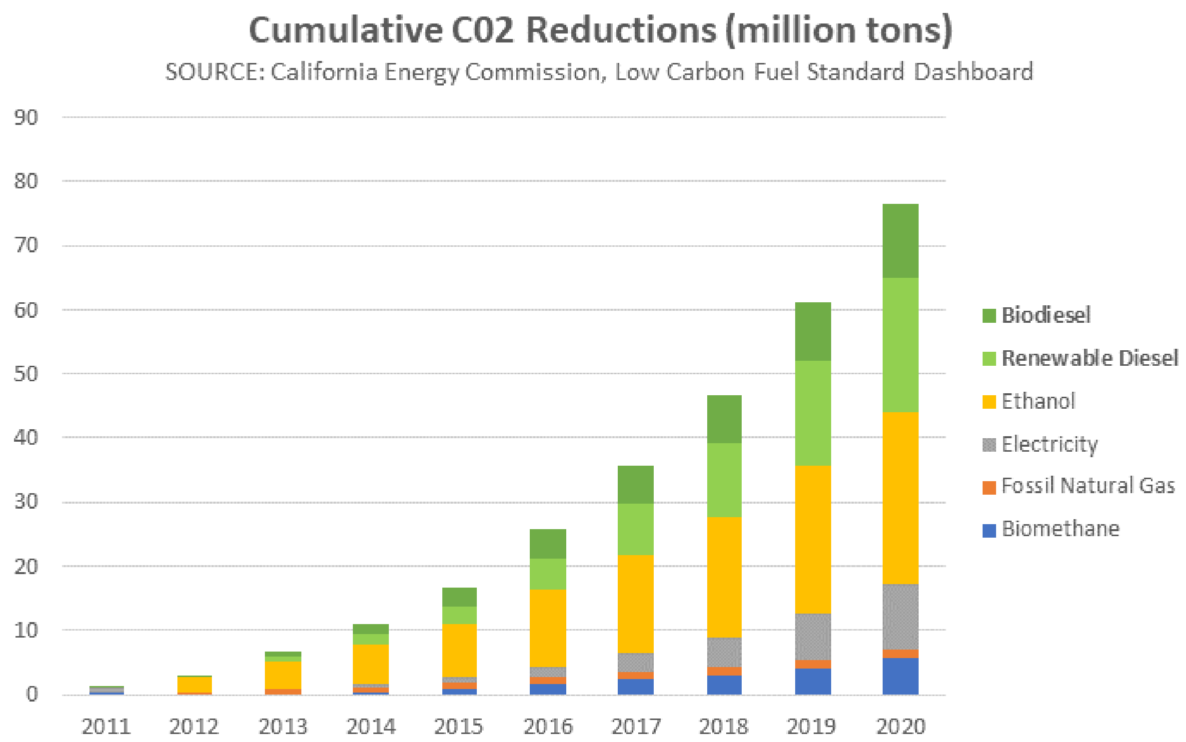


Figure 5.3 Cumulative CO2 Reductions

Hybridization Where it Makes Sense

Hybridization is technology that captures wasted energy, storing and applying it to useful work and will be a greater player in the future in selected applications. The elements of hybrid systems - electric motors, controllers and energy storage systems - work in close integration with the internal combustion engine and conventional transmissions to use energy from both sources to propel the vehicle or machine or operate accessories with overall less energy consumed than an engine alone.

There are essentially three types of hybrid systems, parallel, series and mild.

- **Parallel systems** are ICE and electric motors working together to deliver power directly to the vehicle drivetrain and are the most common variant.
- **Full hybrid systems** can propel a vehicle or machine for some period of time on stored energy alone before switching to the ICE.
- **A series hybrid** system uses the ICE to generate electricity to power electric motors. These so-called "mild hybrid" technologies are increasingly common and used to provide energy to enable engine start/stop features for vehicles, but cannot propel the vehicle.

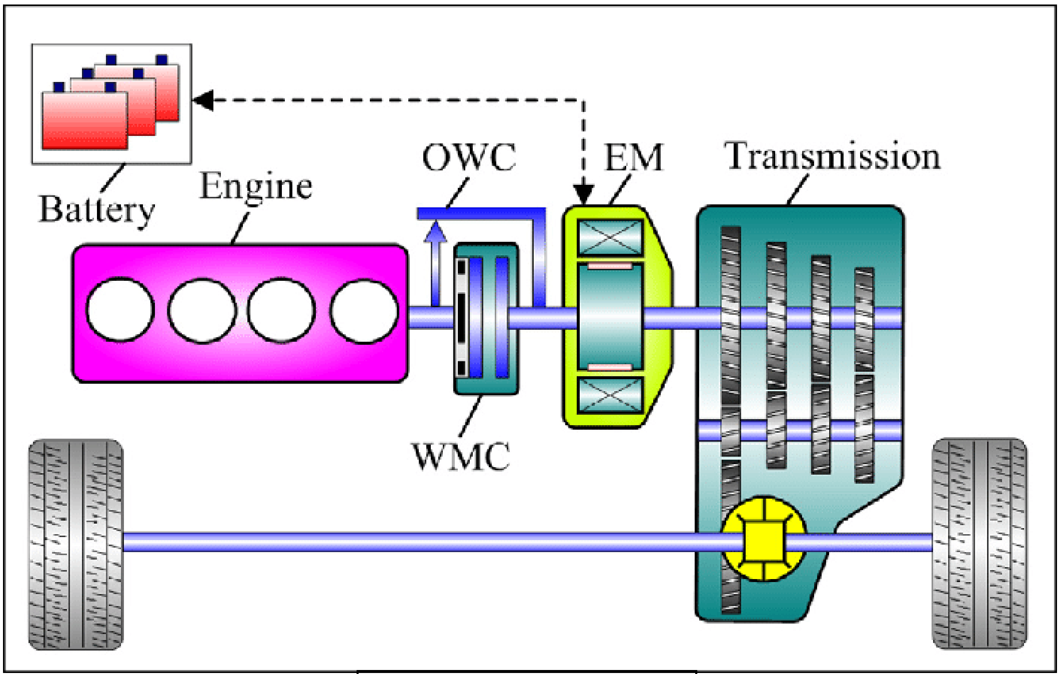


Figure 5.4 *Hybrid System*

6. INCREASED AFTERMARKET OPPORTUNIES FOR PASSENGER DIESEL

The news for the aftermarket is even more promising. The drop in new diesel car sales is sudden, but it won't take effect immediately. This indicates that the opportunity for after-sales services for diesel vehicles will continue to grow. How Does? In fact, it's all about how change happens. Things progressed faster than anyone could have predicted. Therefore, it is not necessary to go back in history to see record numbers. Not so many years ago, diesel powered vehicles made up more than half of the market.

The service life for diesel vehicles is over 13 years, and the average age of the cars sold in the market is currently around 6.7. Therefore, these vehicles have a longer service life in front of them. Considering that the diesel vehicle park in the market is at a relatively new level and diesel vehicle sales are still at a significant level, it is not foreseen that the diesel vehicle park will break away from the aftersales market in the short term. According to the data, by 2024 there will still be more than 113 million diesel passenger cars on European roads.

Today, there are more than 14 million diesel vehicles under the age of 3 on European roads. These younger vehicles will need more repairs as they age. This will create significant opportunities for service providers. For example, since most current common-rail injector systems inject multiple times and inject fuel at much higher pressures, they are subject to much faster wear. This leads to much more complex and costly repairs.

But it's not just diesel fuel injection components that benefit the aftermarket. Diesel vehicle drivers, on average, drive more kilometers than petrol vehicle drivers. This means additional opportunities in terms of wear and tear repairs.

As a result, all these developments bring opportunities for new after-sales services in the long run. Considering that diesel still has an important place in the market and that these vehicles will require medium and heavy maintenance, diesel vehicles still have a serious business volume potential in the next 20 years and beyond. Therefore, although the general opinion is negatively interpreted for diesel, this situation is far from being true with the indicators we have stated. Diesel still has huge business volume.

7. WHAT IS THE DESIGN OF 3-CYLINDER ENGINES?

7.1 DESIGN

A crankshaft angle of 120 degrees is typically used by straight-three engines,[8] since this results in an evenly spaced firing interval. Another benefit of this configuration is perfect primary balance and secondary balance; however, an end-to-end rocking couple is induced because there is no symmetry in the piston velocities about the middle piston. A balance shaft is sometimes used to reduce the vibrations caused by the rocking couple.

Other crankshaft angles have been used occasionally. The 1976-1981 Laverda Jota motorcycle used a 180-degree crankshaft, where the outer pistons rise and fall together, and inner cylinder is offset from them by 180 degrees. This results in three power strokes evenly spaced at 180 degrees each, and then no power strokes during the final 180 degrees of crankshaft rotation. The 2020 Triumph Tiger 900 motorcycle uses a "T-Plane" crankshaft where the crankshaft throws are at 90 intervals, such that the throws for cylinders 1 and 3 are separated by 180 degrees (therefore the three throws together forming a "T" shape when viewed from the end).

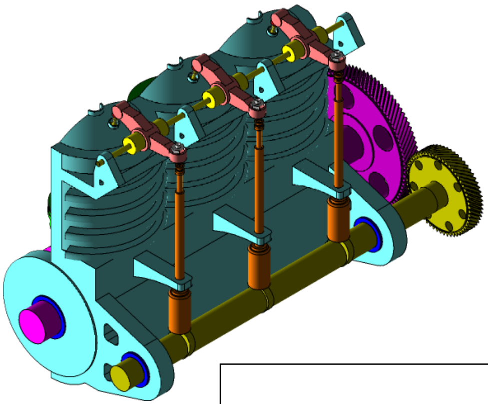


Figure 7.1. CAD of 3- cylinder

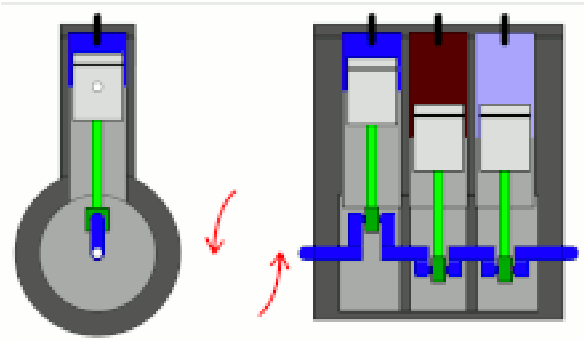


*Figure 7.2 A **straight-three engine** (also called an **inline-triple** or **inline-three**) is a three-cylinder piston engine where cylinders are arranged in a line along a common crankshaft.*

8. CAD MODELS AND TECHNICAL DRAWINGS OF THE ENGINE

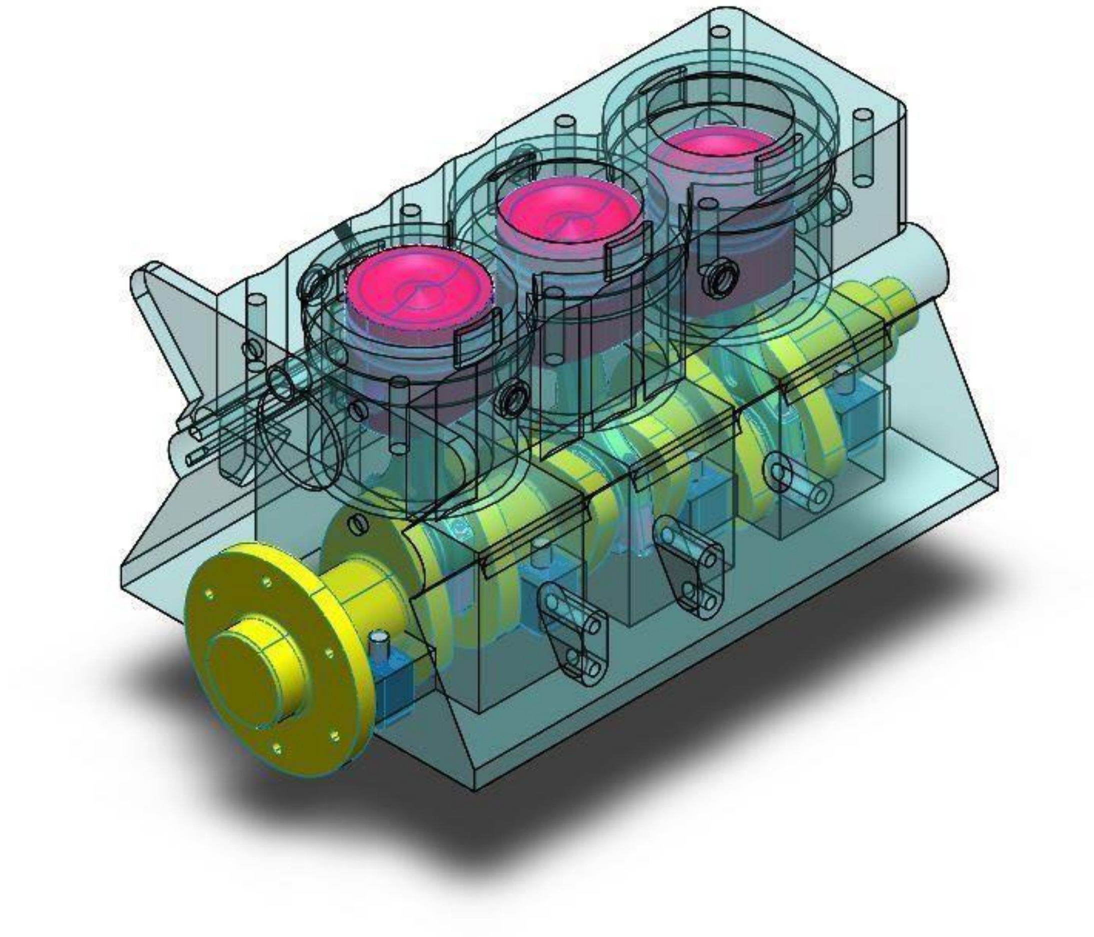


Figure 8.1 *motor block assembly*

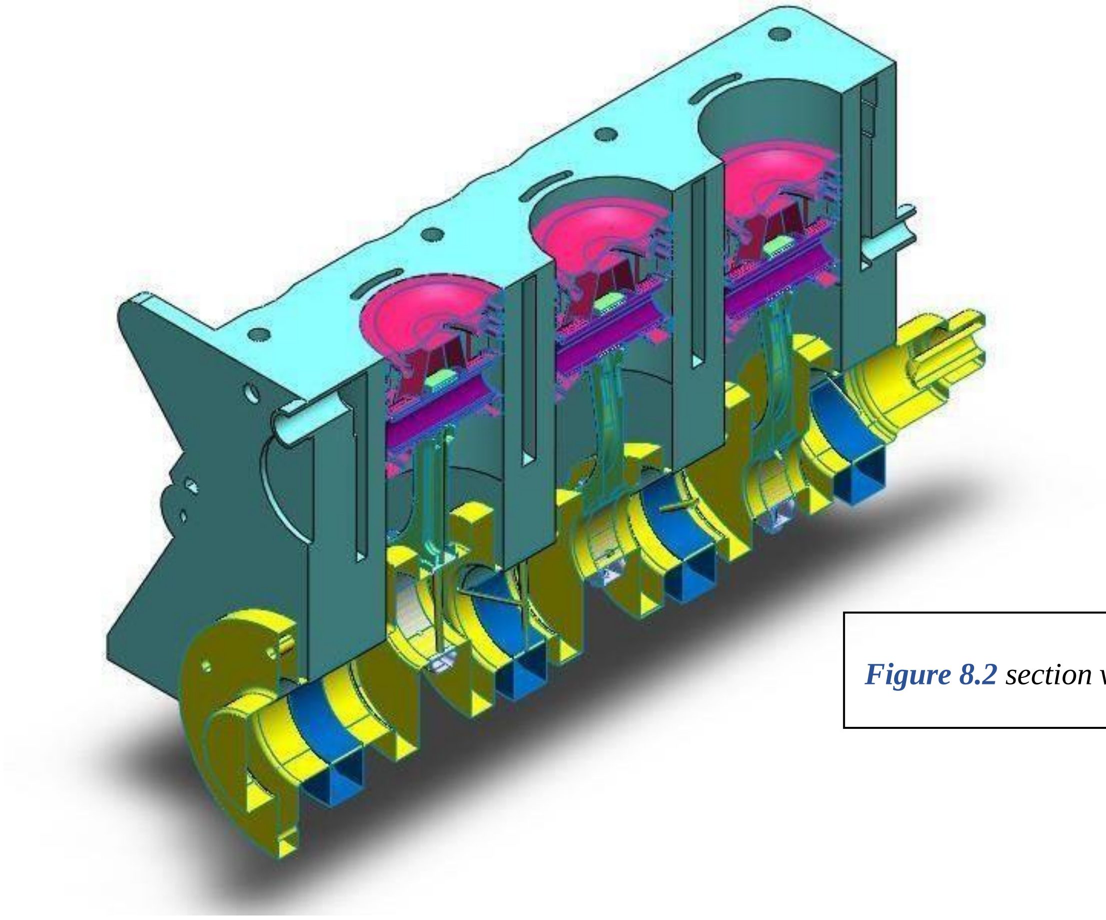


Figure 8.2 section view of the motor

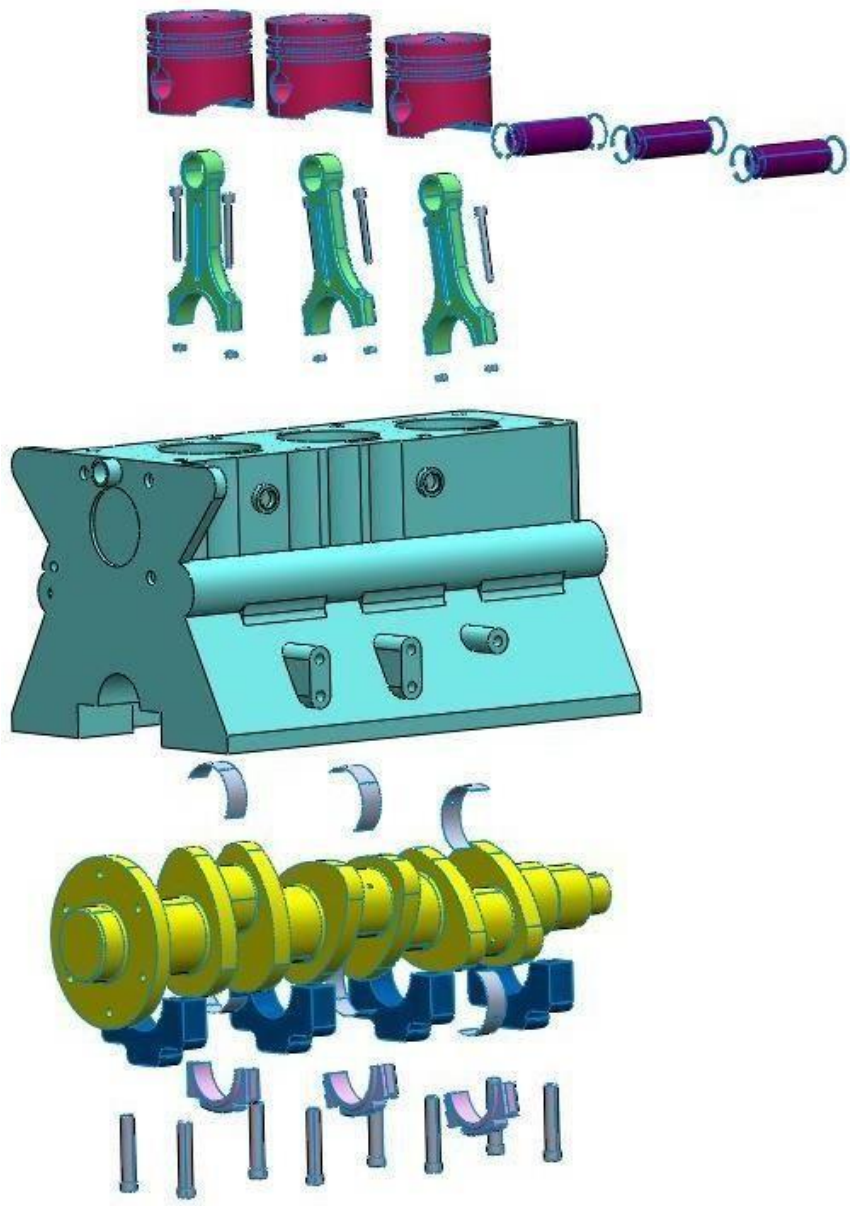


Figure 8.3 exploded view of the block assembly

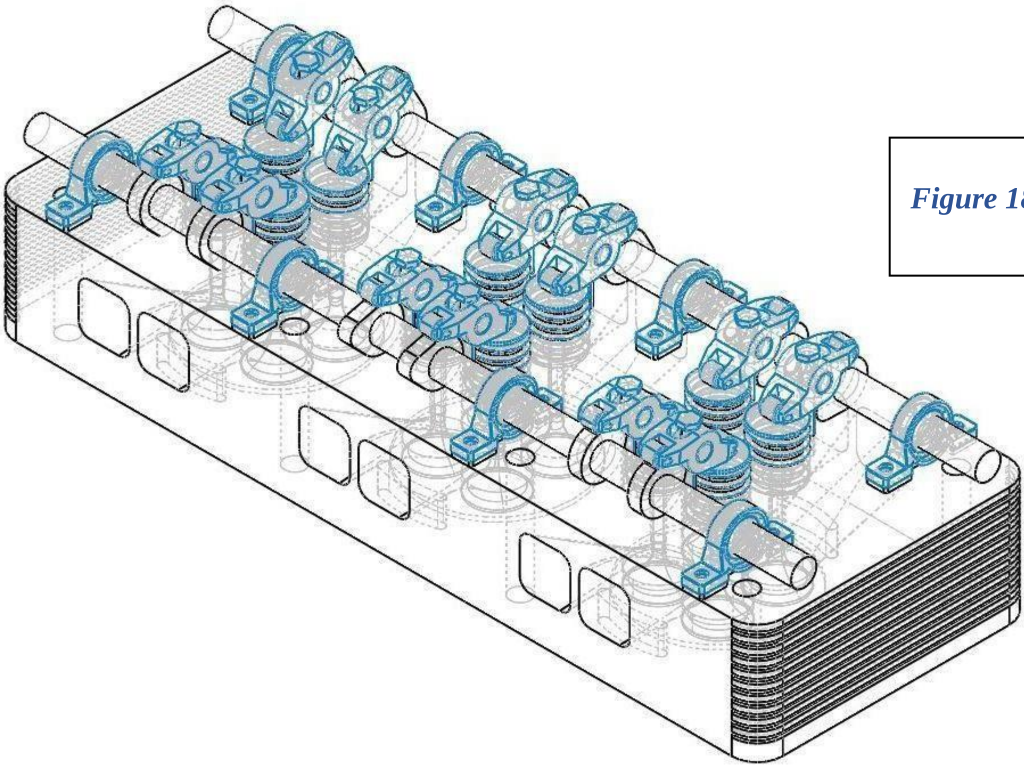


Figure 18 top view of the cylinder head

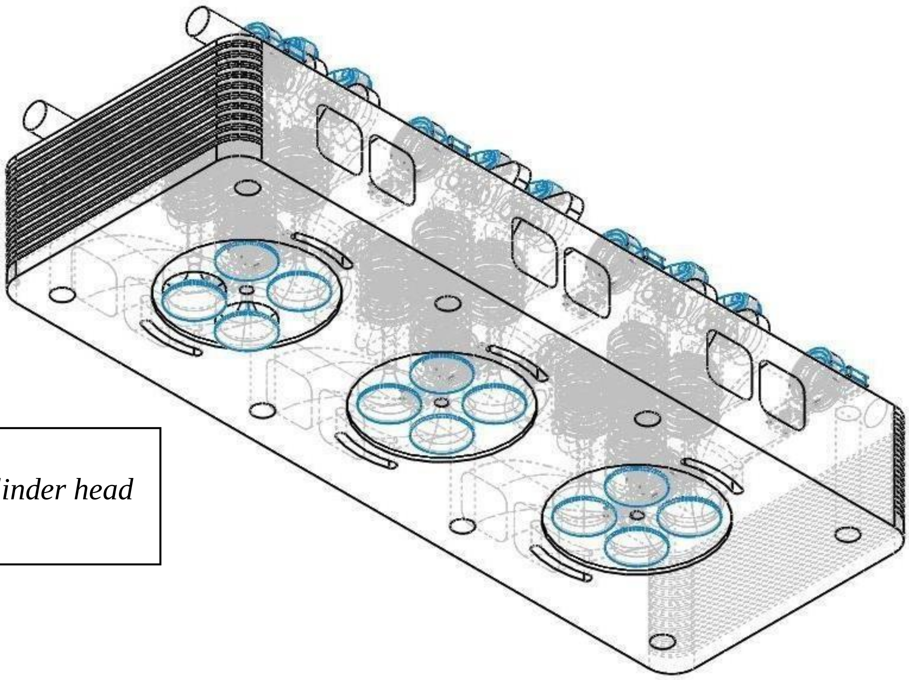


Figure 8.4 bottom view of the cylinder head

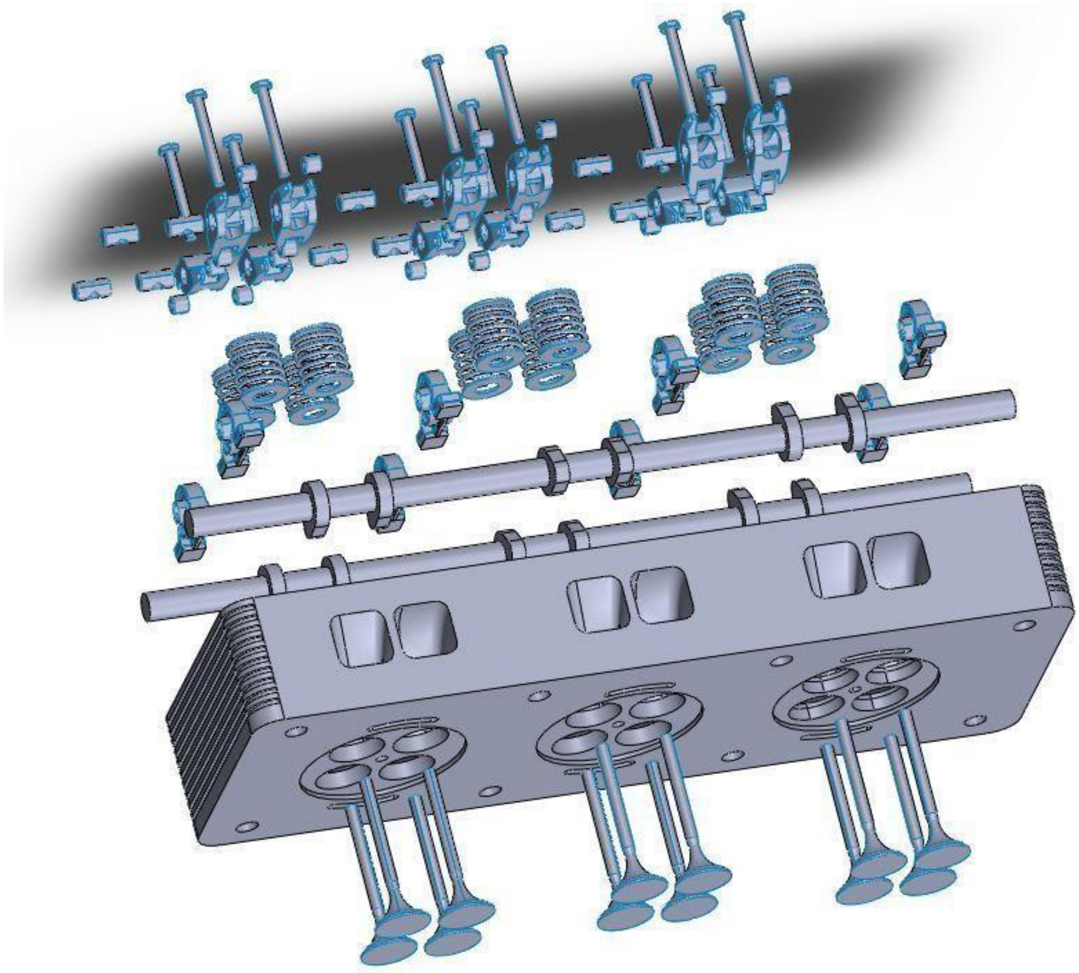


Figure 8.5 exploded view of the cylinder head

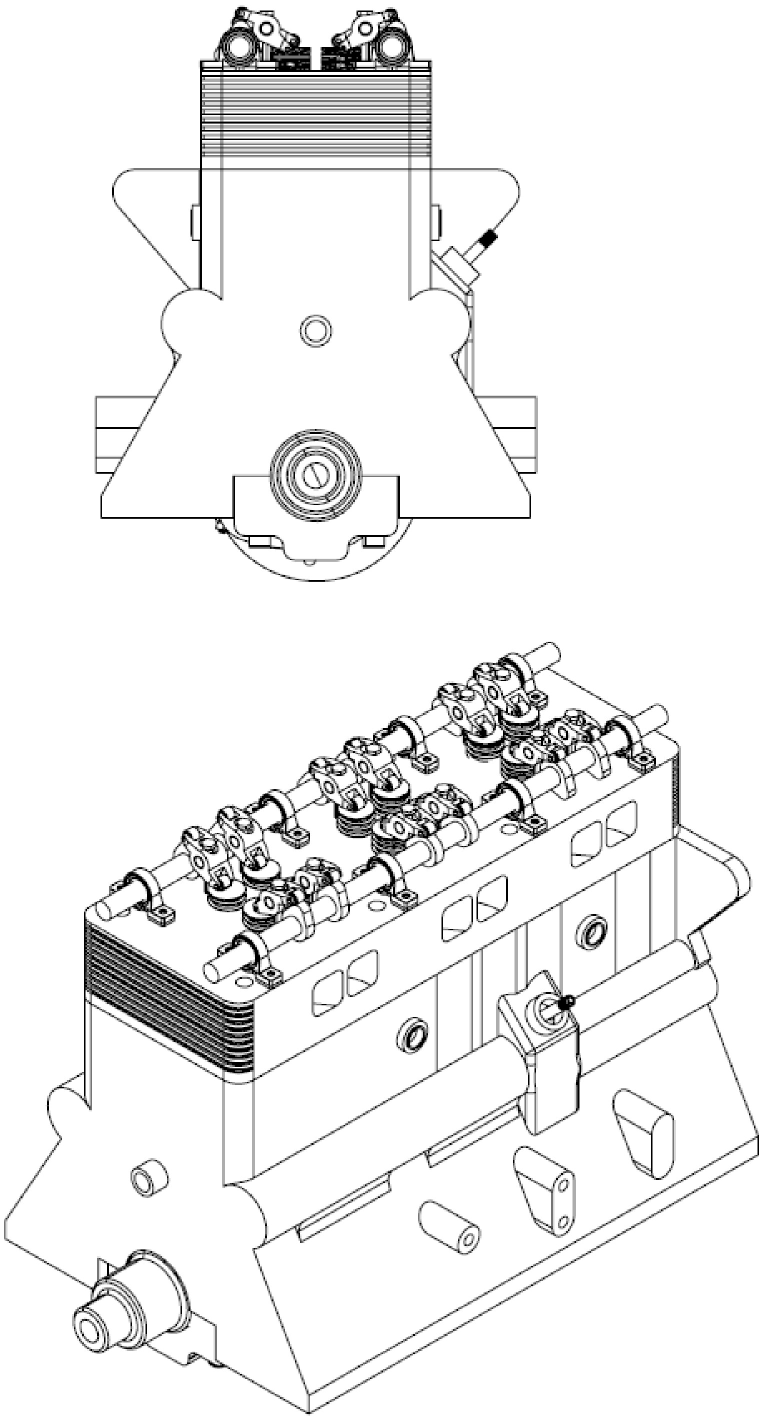


Figure 8.6 side and angular view of the full-assembly

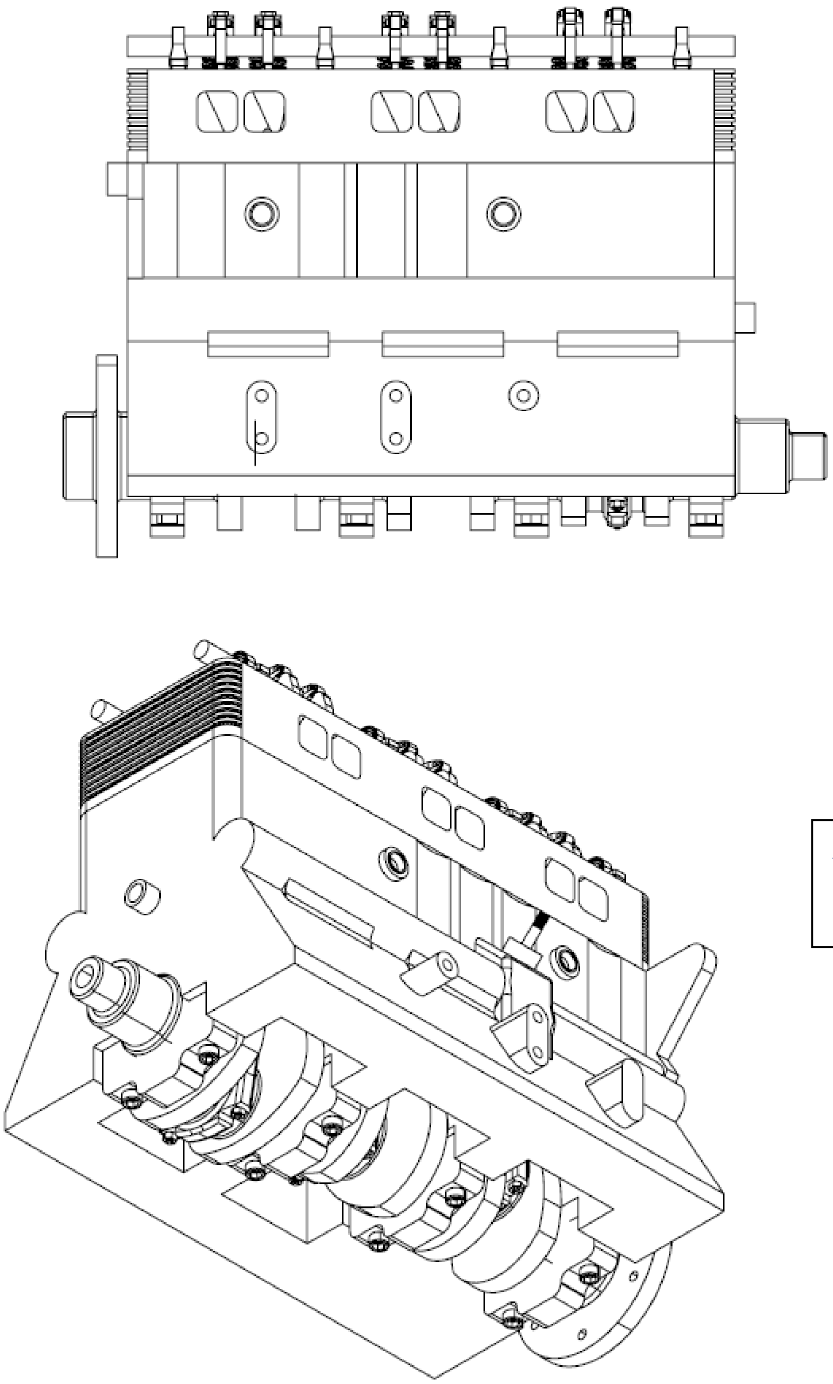


Figure 8.7 side and angular view of the full-assembly

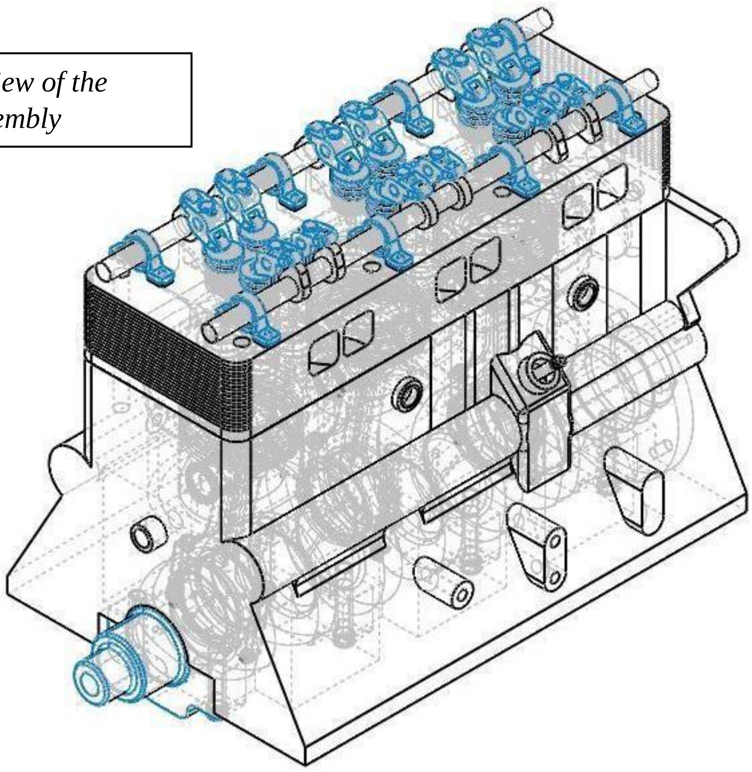


Figure 8.8 *angular view of the full- assembly*

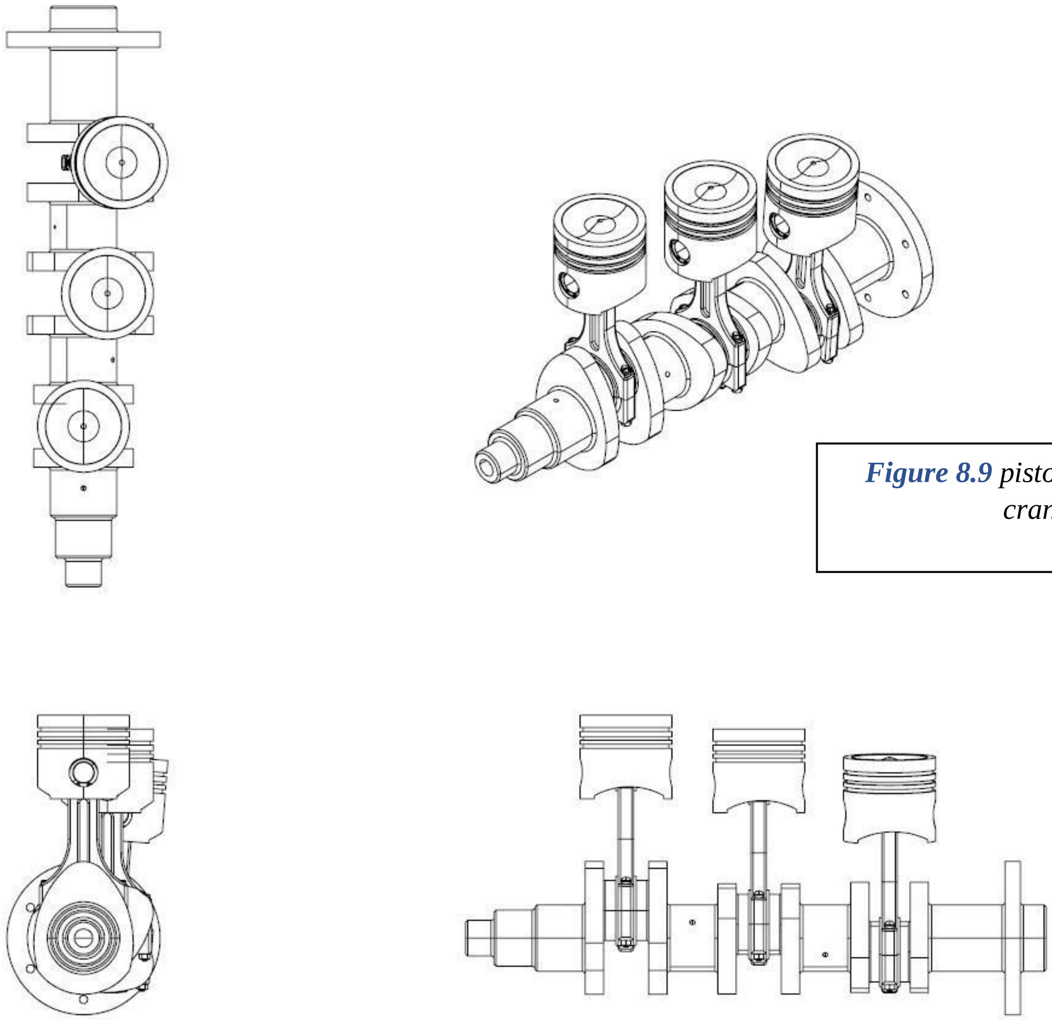


Figure 8.9 *piston-rod-crankshaft assembly*

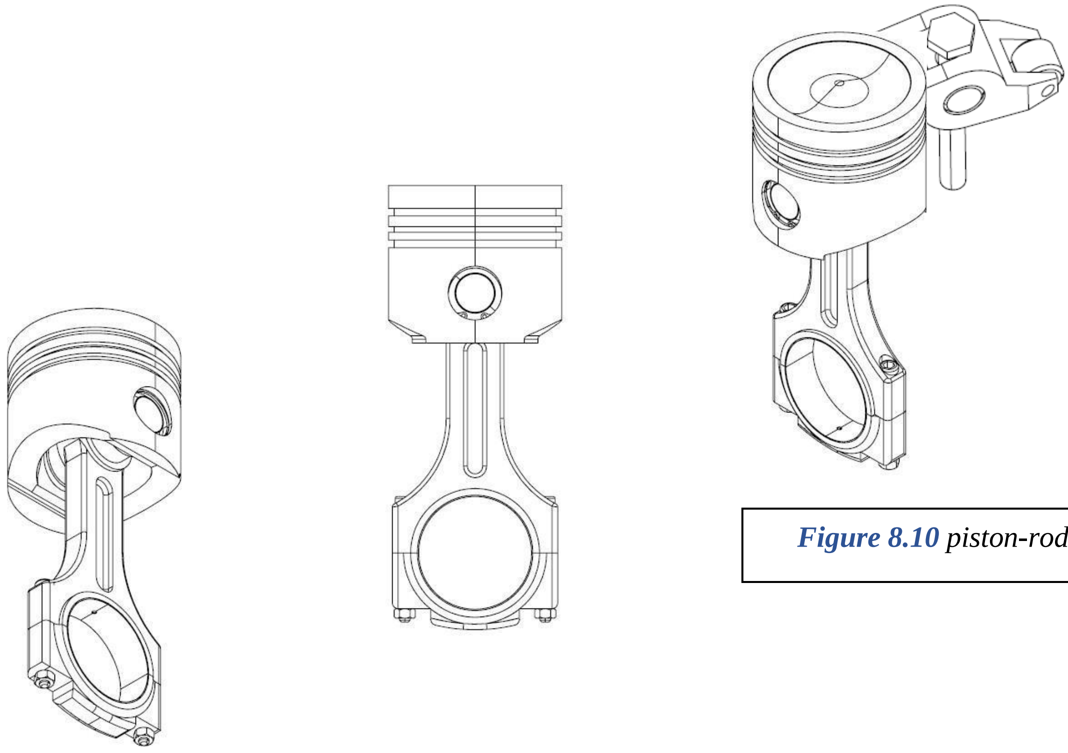


Figure 8.10 *piston-rod assembly*

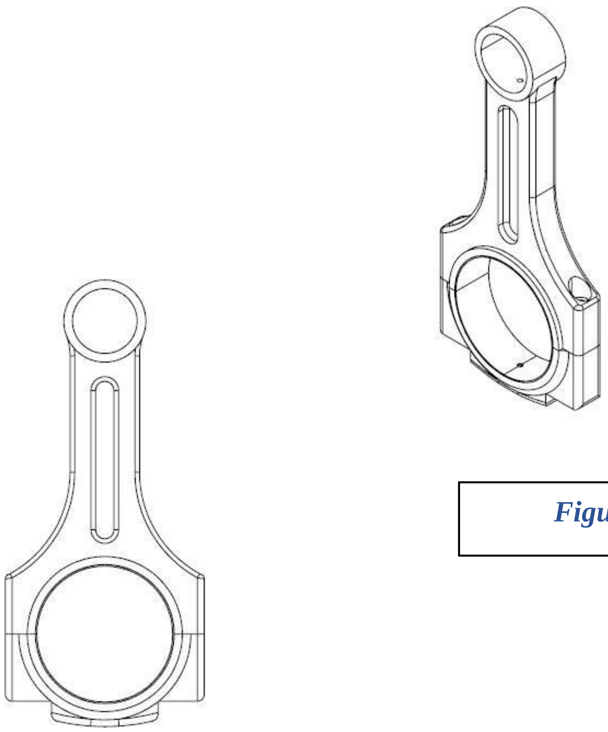


Figure 8.11 *rod assembly*

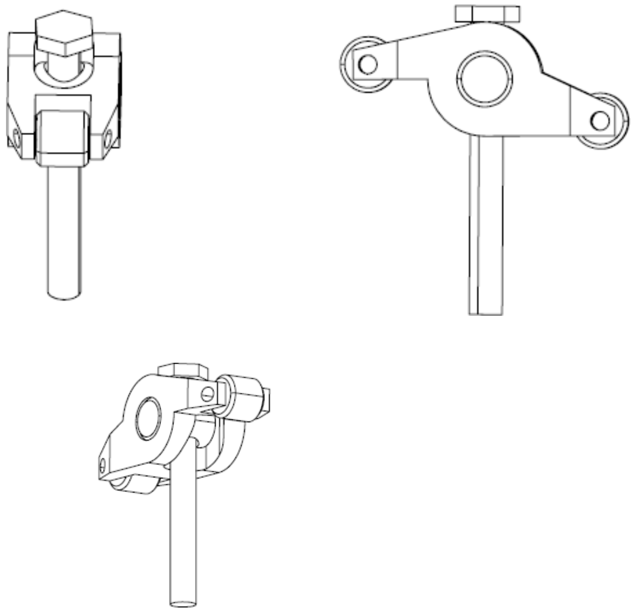
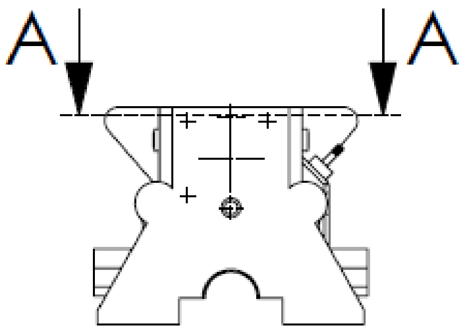
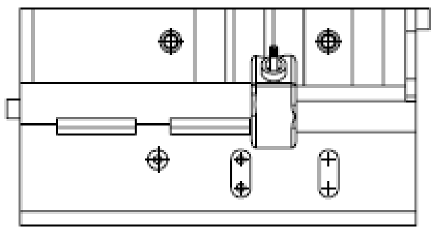
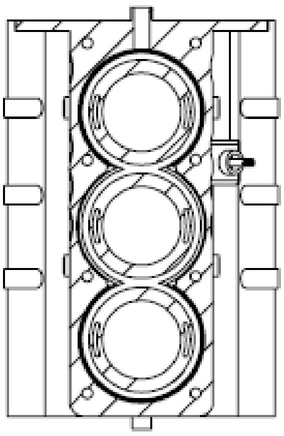


Figure 8.12 rocker sub- assembly







SECTION A-A

Figure 8.13 technical drawing of the block. Section view shows cooling canals from the top view.

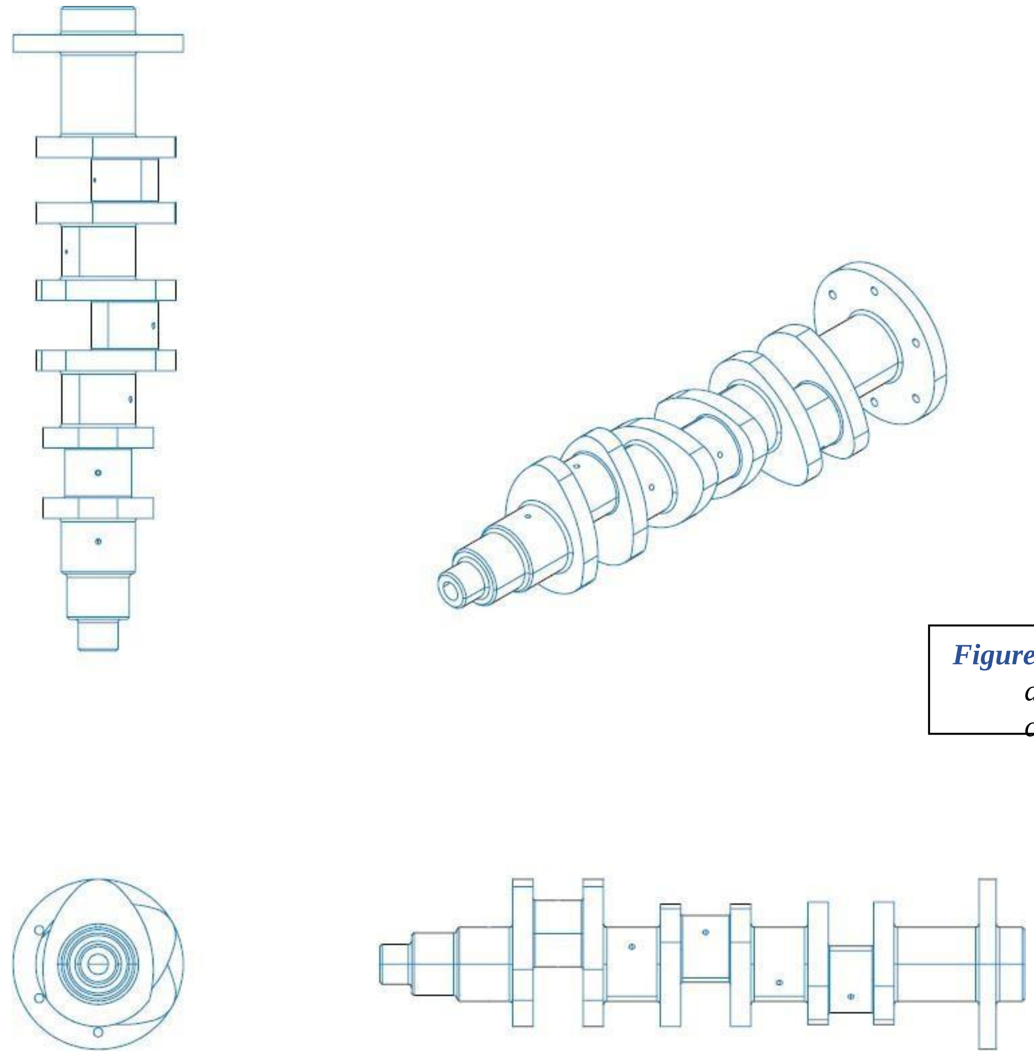
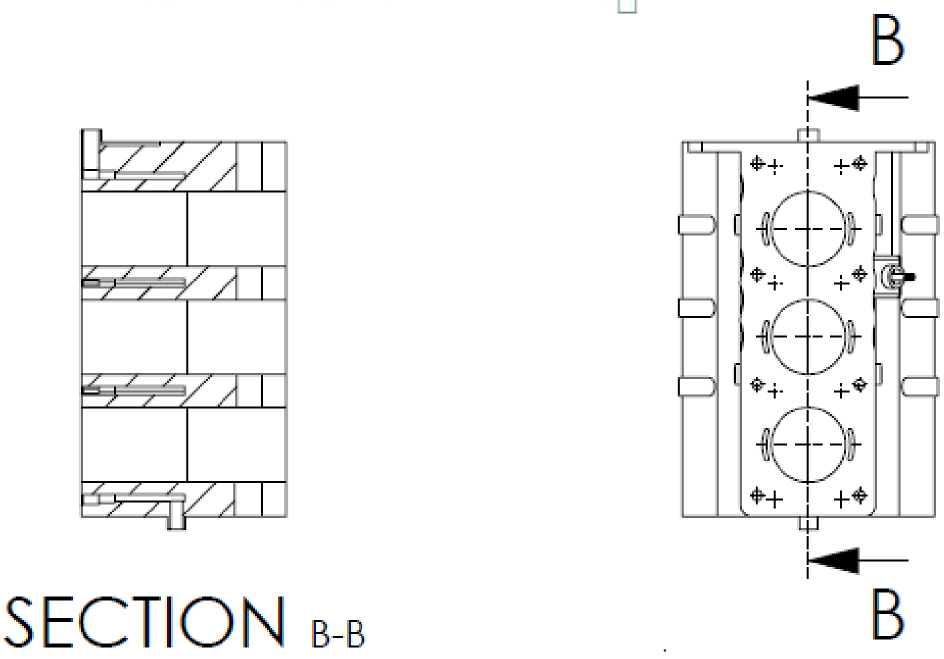


Figure 8.15 *technical drawing of the crankshaft.*

Figure 8.14 *technical drawing of the block. Section view shows cooling canals from the side view.*



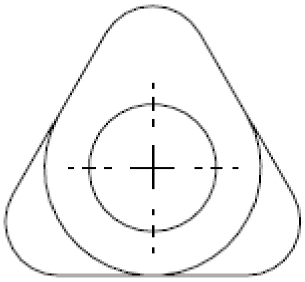


Figure 8.16 *technical drawing of the camshat from the top view.*

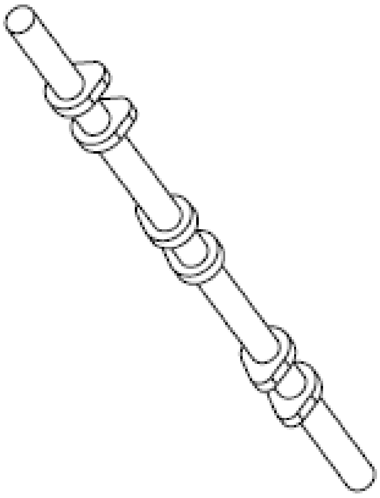


Figure 8.17 *technical drawing of the camshat from the angular*

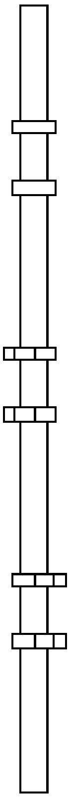


Figure 8.18 *technical drawing of the camshat from the side view.*

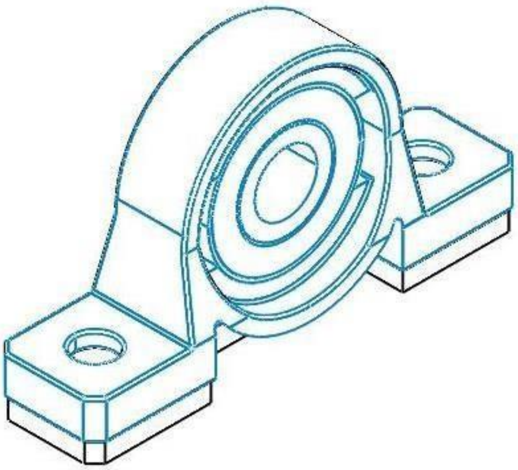


Figure 8.19 *technical drawing of the ballbearing*

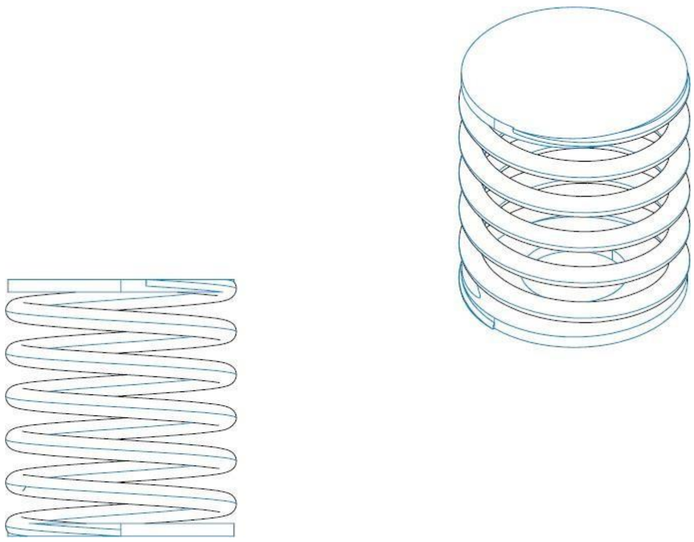


Figure 8.20 *technical drawing of the spring*

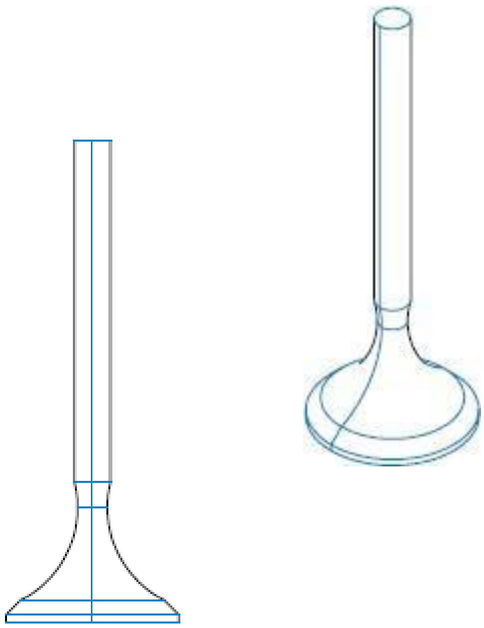


Figure 8.21 *technical drawing of the valve*

9. VIBRATION OF 3-CYLINDER ENGINE

In most 3-cylinder engines the occurrence of vibration is higher at slower speeds due largely to the fewer number of power strokes (number of times the cylinders are fired). To contain the rotational forces that literally shake the 3-cylinder engine, multiple measures are adopted.

Three-cylinders typically have more vibration than an equivalent four-cylinder engine (or higher) of the same displacement. This isn’t to say they are worse—they’re just different, and the vibrations can be quelled to almost negligible levels with good old-fashioned engineering creativity.

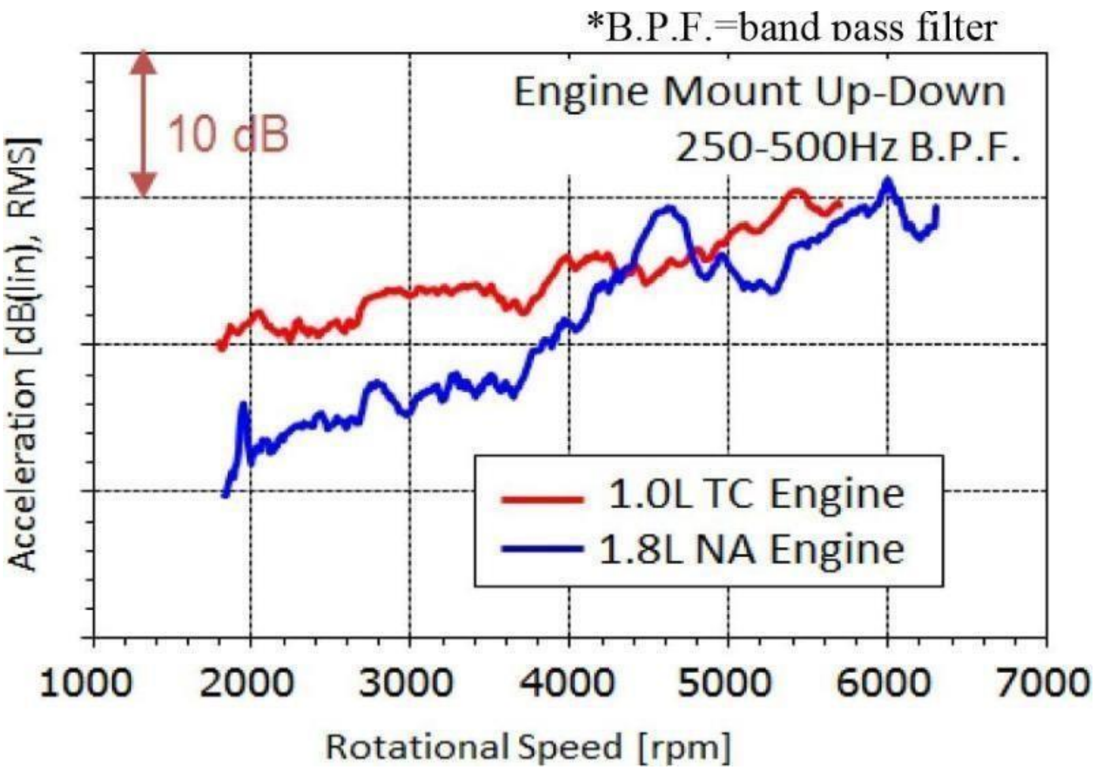


Figure 9.1. 3-cylinder (red) vibrates more than 4-cylinder (blue). The gap closes at higher RPM.

However, it's still hard for a 3-cylinder to beat the naturally cancelled out forces of an even-numbered-cylinder engine. Look at the graph above and you will see that the three-cylinder still vibrates more.

9.1 Vibration During Process of Engine Startup

Schematic of the powerplant mounting system in the whole vehicle as below,

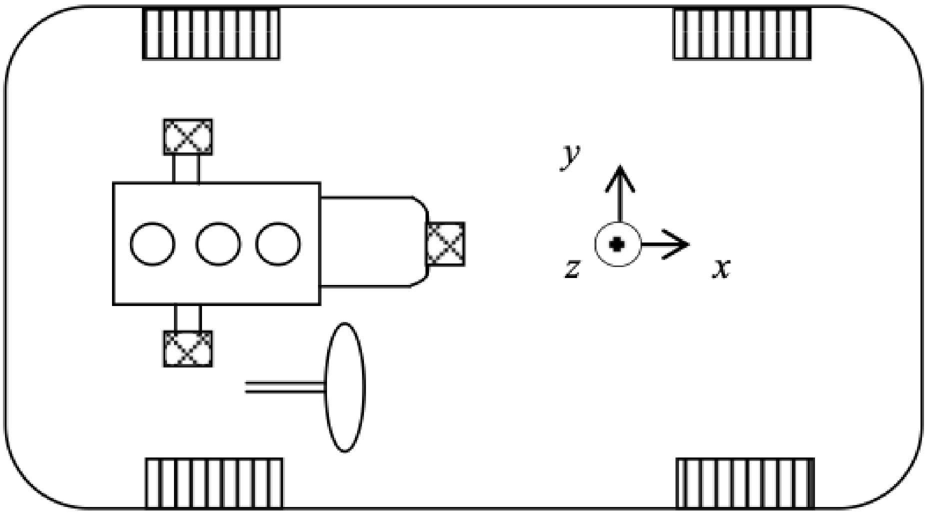


Figure 9.2. powerplant mounting system in the vehicle

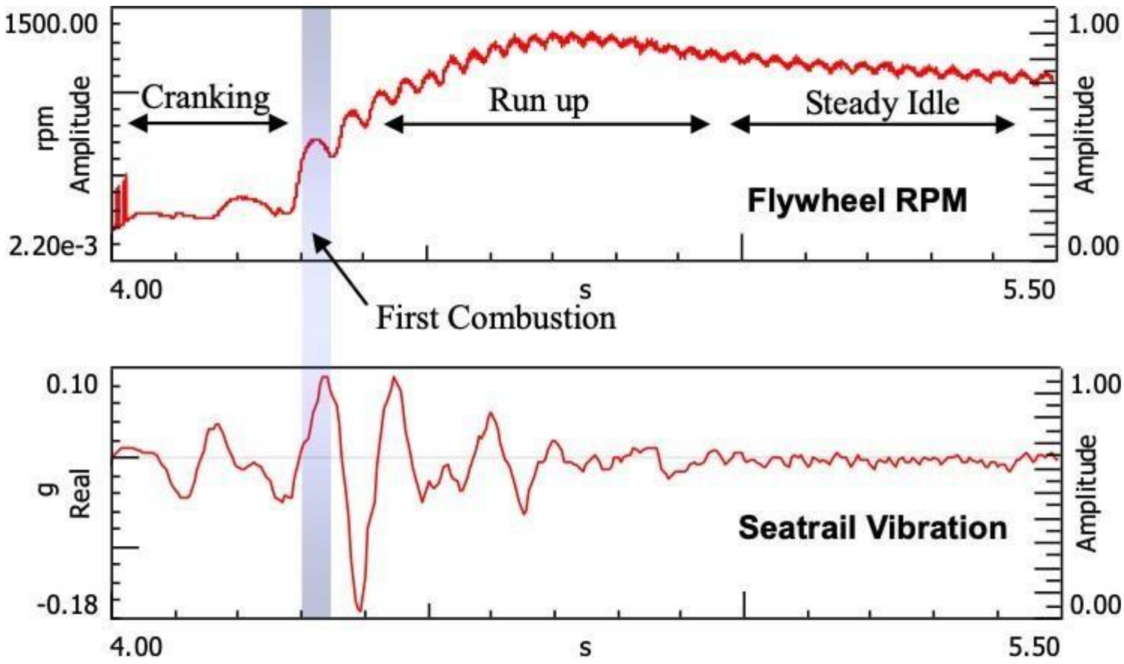


Figure 9.3. Process of engine startup

During the startup processing, the powerplant transits from initial static state to idle vibration. At the moment of the engine ignition, the engine excitation forces itself to rotate around its crankshaft, which causes the powerplant to rotate and do translate movement. After the engine speed becomes stable, the powerplant just rotates around the torque roll axis [4]. The rotation and movement will cause the vehicle interior vibration. Hence, the engine excitation in key on condition should be studied before the startup vibration analysis.

9.2 INFLUENCE FACTORS STUDY OF THE STARTUP VIBRATION

The interior vibration during the startup processing can be studied from two aspects: sources and transfer paths. Factors affecting the startup vibration may include the followings: engine cylinder pressure, mode distribution of the mounting system, nonlinear mount stiffness design and the starter motor cranking speed, etc.

9.3 Engine Cylinder Pressure

The engine cylinder pressure is related to the gas combustion, which is bound up with the engine electric fuel injection management system. Changing the ignition advance angle, injection volume and the intake air quantity, the engine cylinder pressure may be extensively changed. Usually, ignition advance angle and fuel injection quantity will change with the changing of engine air intake.

Changing the intake air in the maximum 20% regulation range, the gas pressure changes about 15%, as shown in figure 8. The model in this paper doesn't include the crank and connecting rod mechanism, the pressure change inside cylinder can be realized by tuning the excitation amplitude directly. The simulation results of the startup transient vibration for tuning the engine excitations are shown in Figure 9. Different cylinder pressure has a little influence on the startup vibration. To validate the results, changing the intake air quantity, the vibration is tested during the startup processing, as shown in fig.10-11. The vibrations for the three cases correspond to different ignition time. There is almost no difference between maximal and minimal vibrations in Z direction, but there exists a little change in Y direction. According to subjective evaluation, people feel no difference. Thus, the cylinder pressure has no influence on the startup vibration.

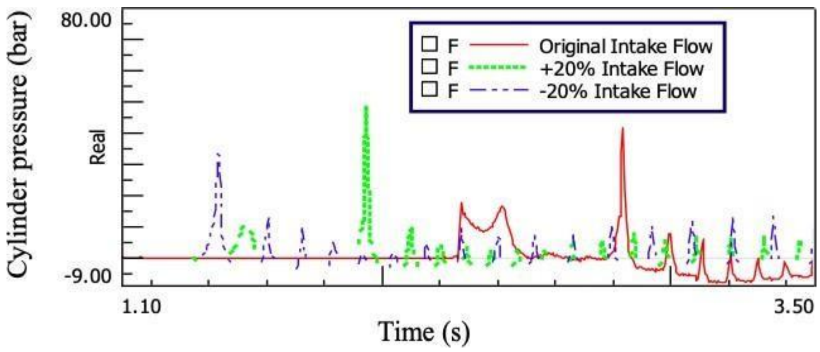


Figure 9.4 *Cylinder pressure curve for different air intake.*

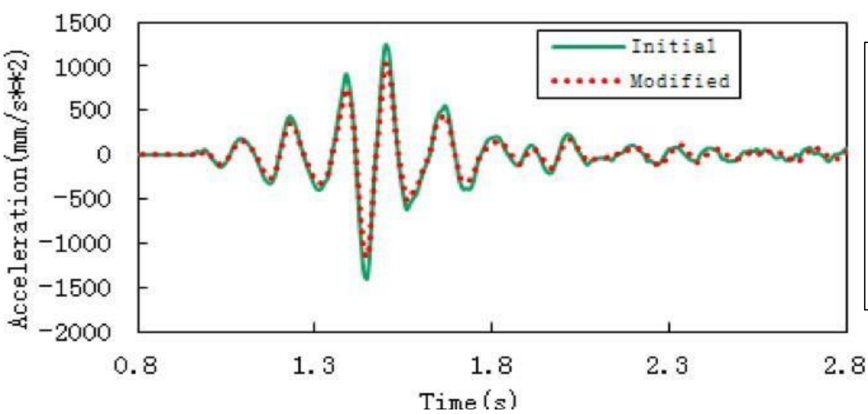


Figure 9.5 *Comparison of the interior vibration of startup processing*

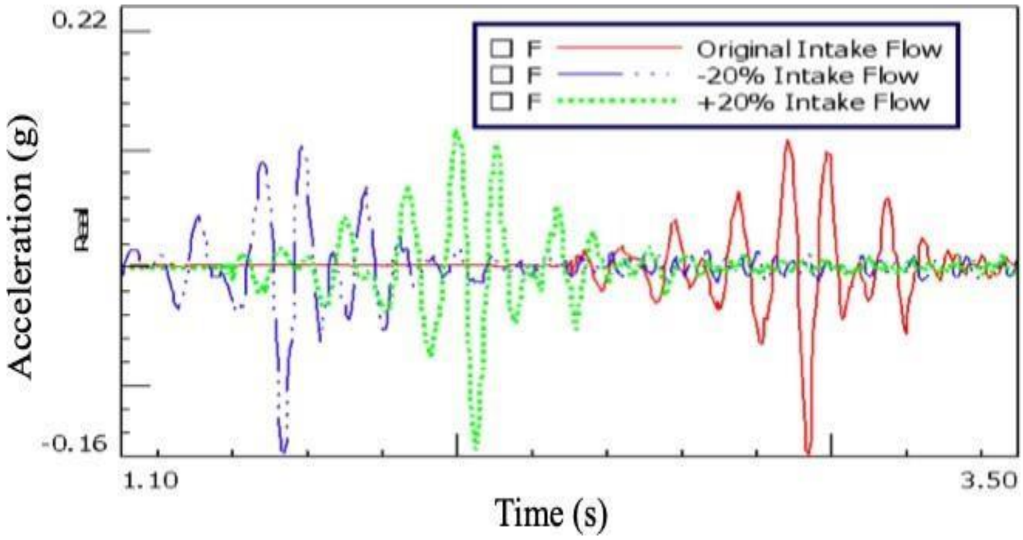


Figure 9.6 Vibration of the seatrail in Y direction

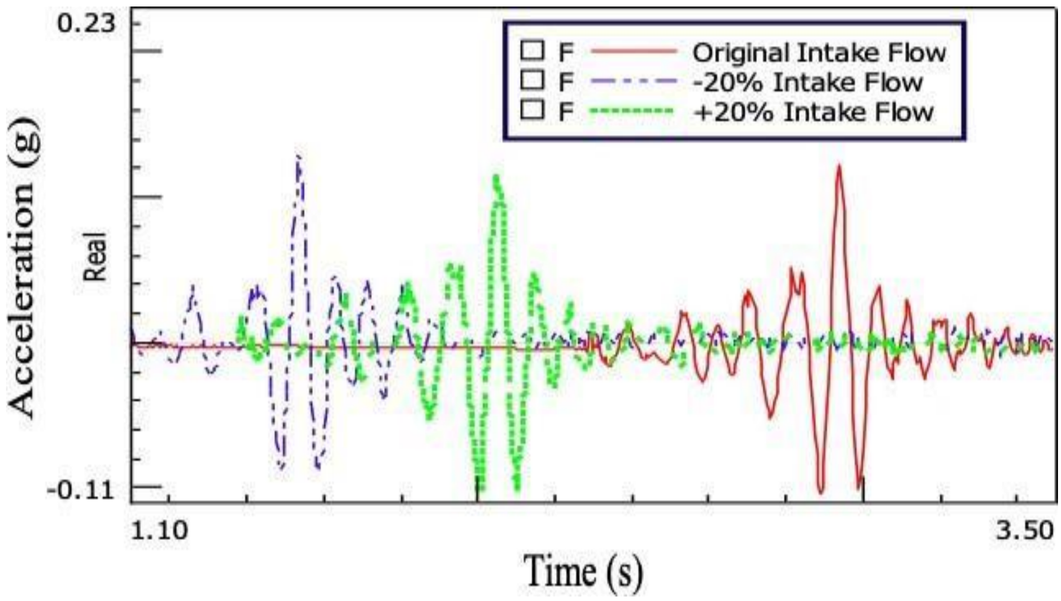


Figure 9.7 Vibration of the seatrail in Z direction.

10 FUEL INJECTION SYSTEMS IN ICE

In a fuel injection system, the fuel is injected either directly into the cylinders or just ahead of the intake valve. A fuel injection system usually incorporates these basic components: engine-driven fuel pump, fuel/air control unit, fuel manifold (fuel distributor), discharge nozzles, auxiliary fuel pump, and fuel pressure/flow indicators.

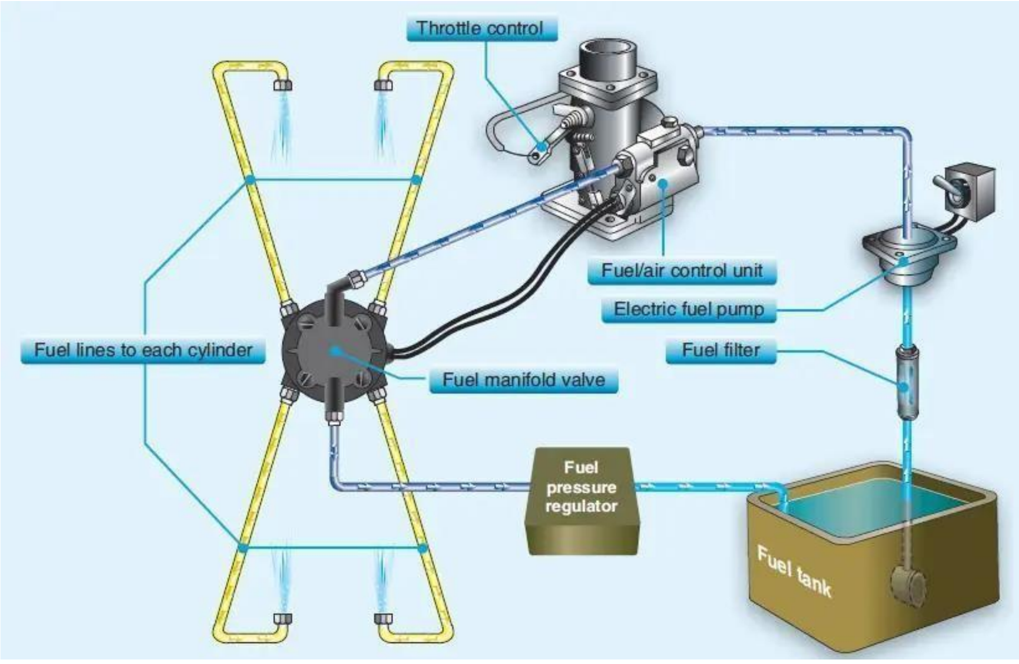


Figure 10.1 fuel injection system

The engine-driven fuel pump provides fuel under pressure from the fuel tank to the fuel/air control unit. This control unit, which essentially replaces the carburetor, meters the fuel and sends it to the fuel manifold valve at a rate controlled by the throttle. After reaching the fuel manifold valve, the fuel is distributed to the individual fuel discharge nozzles. The discharge nozzles, which are in each cylinder head, inject the fuel/air mixture at the precise time for each cylinder directly into each cylinder intake port.

Some of the advantages of fuel injection are

- Better fuel flow.
- Faster throttle response.
- Precise control of mixture.
- Better fuel distribution.
- Easier cold weather starts.

Disadvantages include

- Difficulty in starting a hot engine.
- Vapor locks during ground operations on hot days.
- Problems associated with restarting an engine that quits because of fuel starvation.

10.1 FUEL CONSUMPTION

In terms of fuel consumption, engines with first-generation gasoline direct injection were claimed to achieve a reduction in fuel consumption of roughly 40% when running at idle as opposed to conventional engines with port fuel injection. A reduction in fuel consumption of roughly 15% was achieved with lean stratified charge operation at part-load operating points. As the lean stratified charge range was limited to low engine speeds and loads, it was not possible to turn this potential into perceptible fuel savings for customers.

It only became possible to operate these engines through the New European Driving Cycle (NEDC) predominantly with lean stratified-charge operation (i.e. with low fuel consumption) following the transition to second-generation gasoline direct injection with spray-guided systems. Once the engine has warmed up, it is only necessary to interrupt the lean stratified-charge operation during the regeneration phases of the nitrogen oxide storage catalyst.

The increased efficiency and optimised performance of spray-guided combustion systems mean that the corresponding fuel consumption is around 4–6% less than for wall-guided systems. In termsof fuel consumption, customers have benefited from more extensive use of the stratified charge operation with second-generation gasoline direct injection.

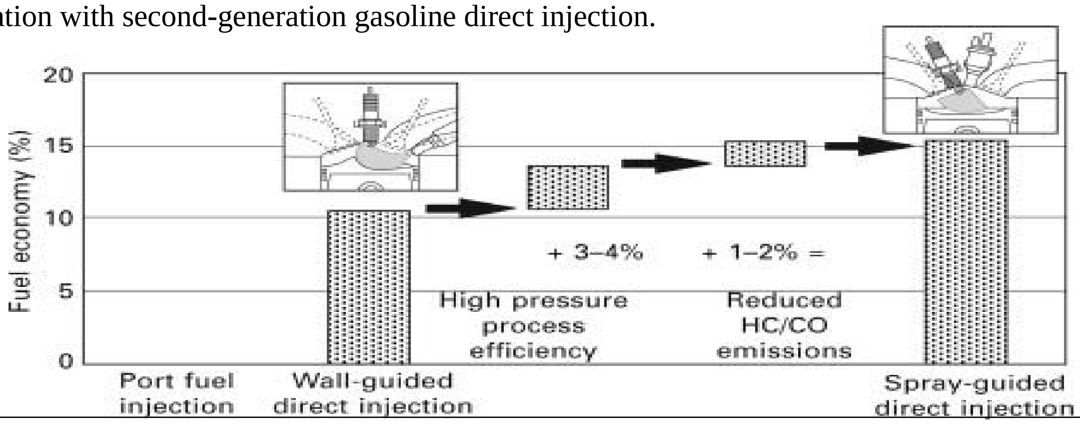


***Figure 10.2** Fuel economy of first- and second-generation direct injection compared to port fuel injection engines (Wirth et al., 2003).*

10.2 FUEL SYSTEM OF 3-CYLINDER ENGINES

The main function of the fuel system is to take fuel from the storage tank and deliver it to the engine combustion chamber, where it mixes with air, vaporizes, burns, and generates mechanical power. The fuel system consists of an injector, pump, filter, fuel tank, and carburetor. The proper working of all these parts is very important to achieve the desired performance of the vehicle. A fuel storage tank uses to store the fuel, which can be either gas, diesel, or petrol. When the engine needs fuel, a fuel pump takes fuel from the fuel tank, passes through the fuel lines, and transfers it into the carburetor or injectors. The carburetor/injector takes air from the environment and makes an air-fuel mixture. As the air-fuel mixture is made, the fuel is delivered to the combustion chamber, where the combustion process takes place. Fuel injection system is the part of the vehicle that is responsible for the proper supply of fuel to the engine. A fuel system works in the following way:

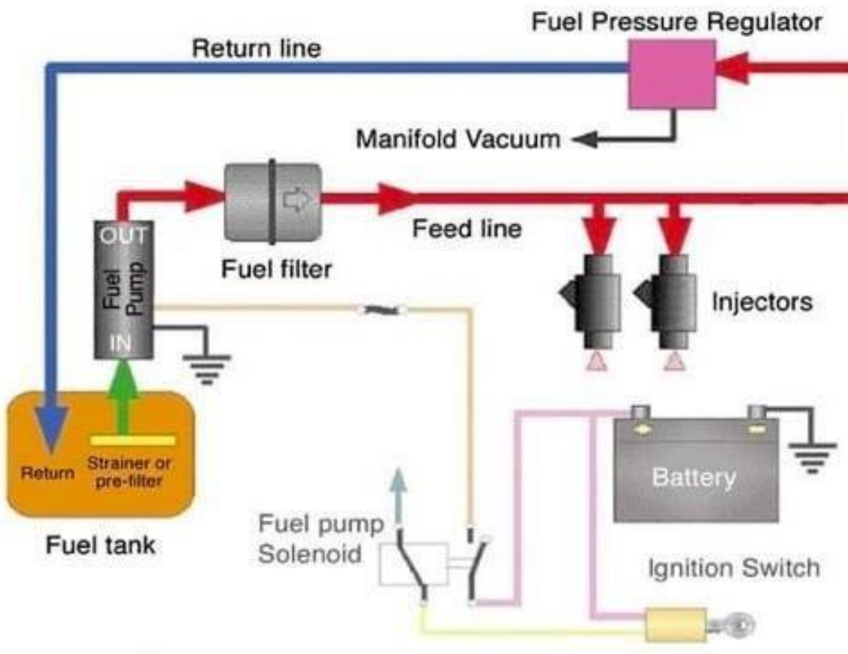


Figure 10.3 *Working of EFI (electronic fuel injection*

- First of all, a fuel pump takes fuel from the fuel tank and passes this fuel through a fuel filter.This filter removes debris from the fuel. It prevents the fuel injector, fuel lines, and carburetor from clogging.
- As the fuel is filtered, the fuel is sent into the fuel injector through the fuel lines. The plastic material or durable metal is used for the construction of fuel lines. These lines are located under the car floor and appear to be in vulnerable places. They install in an area that can't damage from engine exhaust, weather, road conditions, or other components.
- The working of the fuel injector varies according to the design of the engine. In the case of a diesel engine, the fuel injector directly injects fuel into the combustion chamber. However, in the case of a SI engine, the injector firstly injects fuel into the carburetor, which firstly makes an air-fuel mixture and then sends this mixture to the combustion chamber.
- A pressure regulator is used to control the pressure of the fuel injector fuel.
- As the fuel enters the carburetor, the carburetor takes air from the environment, mixes the air with fuel, and makes an air-fuel mixture. As the air-fuel mixture is made according to the engine requirements, it delivers to the combustion chamber.
- The combustion chamber compresses the air-fuel mixture, ignites the mixture, and generates mechanical power.

10.3 TYPES OF FUEL SYSTEM

The fuel system has the following major types:

1. **Single-Point**
2. **Multi-Point System**
3. **SPFI system**
4. **Direct Injection system**

10.3.1 Single Point or Throttle- Body Injection

The single-point injection system is one of the most famous types of the fuel injection system. It is also known as the throttle body injection system.

In this system, the carburetor replaces with up to two fuel injectors in a throttle body. For the starter, the throttle body works as the starting point for the car's engine ventilation system, much like the starting point for the intake manifold.

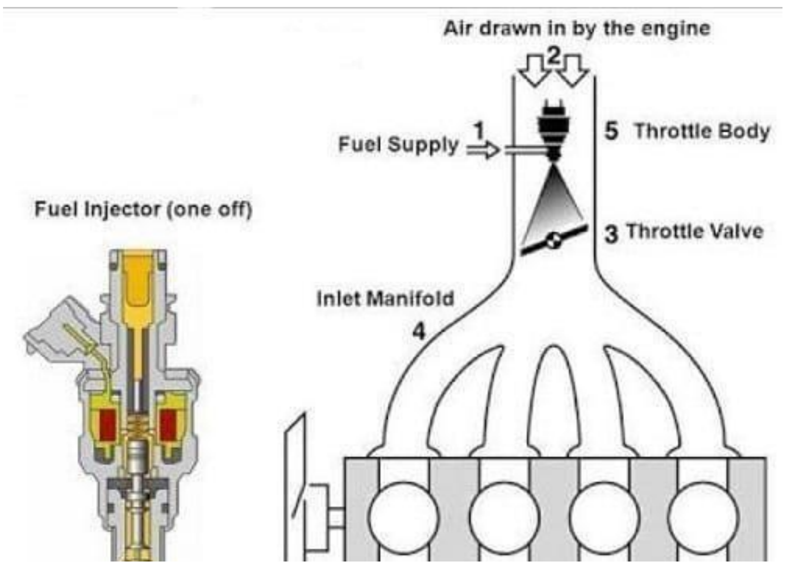


Figure 10.4. *Singlepoi S.I.*

Before the advent of the multi-point injection system, throttle body injection systems were a good alternative to simple carburetors. These are not as precise as multi-point injection systems, but they deliver excellent efficiency compared to carburetors.

In addition, the single-point fuel injection system requires very low maintenance and repair. It has an easy design than the multi-point injection system. It has low maintenance and repair costs. The main disadvantage of this system is that it is less efficient and less precise than the multi-point unit.

Advantages	Disadvantages
It requires low maintenance and service.	it is less efficient than a multi-point injection system.
This system delivers more excellent efficiency than the carburetor system.	It is less precise than a multi-point unit.
It has an easy design.	
It has low maintenance and repair costs.	

10.3.2 Multi Point Injection System

A multi-point fuel injection system is a most commonly used injection system. It provides a separate injector nozzle for each cylinder. This type of fuel injection system installs on outside of each air intake. Therefore, it is also known as a port injection system.

Bringing the fuel vapor close to the air intake draws the fuel vapor fully into the cylinder and improves the efficiency of the combustion process.

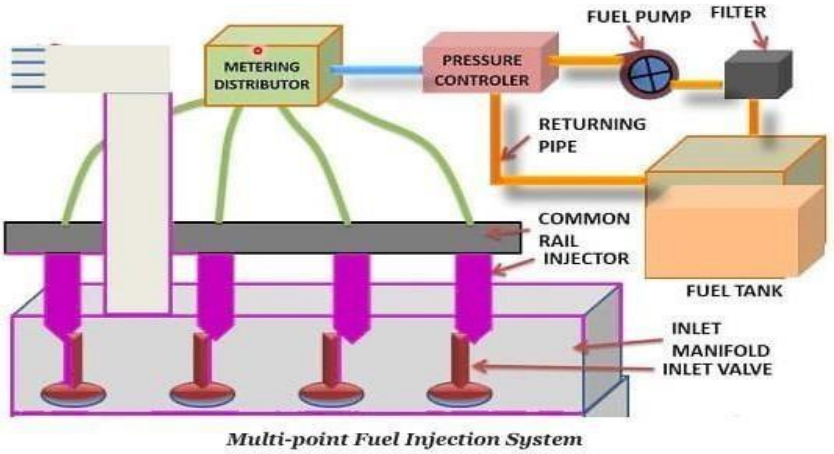


Figure 10.5. *Multi-point Fuel Injection System*

Advantages and Disadvantages of Single-Point Injection System

Advantages	Disadvantages
It is more precise and efficient than a single-point injection system.	it requires more maintenance.
It reduces the chances of fuel shortening in the intake manifold.	It has more maintenance and repair costs than the single-point fuel injection system
It controls fuel more efficiently than single-point fuel injection or carburetor.	It has a complex design.

10.3.3 Sequential Port Fuel Injection System (SPFI)

The SPFI system is also called a timed fuel injection system or sequential fuel injection system.

The main difference between a sequential injection system and a multi-point injection system is that in the case of multi-point fuel injection, all injectors inject fuel at the same time. This means when the engine is idling, fuel typically remains in an orifice for more than 148 milliseconds. It may not seem like a long time, but actually, this is enough time to reduce efficiency.

While in the case of the SPFI system, all injection nozzles don't inject fuel simultaneously, and each nozzle injects fuel according to the corresponding cylinder requirements. These nozzles inject fuel just before the opening of the inlet valve. That means the fuel doesn't have to stay long. Therefore, this system increases efficiency and reduces emissions rate.

One of the main advantages of a sequential injection system is that it is more precise than a multi-point injection system. It also increases engine efficiency.

10.3.4 Direct Injection System

This is one of the most simple and innovative type of injection system. This system injects fuel directly into the combustion chamber after opening the valves.

Direct fuel injection systems are most commonly used in diesel engines but have recently become popular in petrol engines as well.

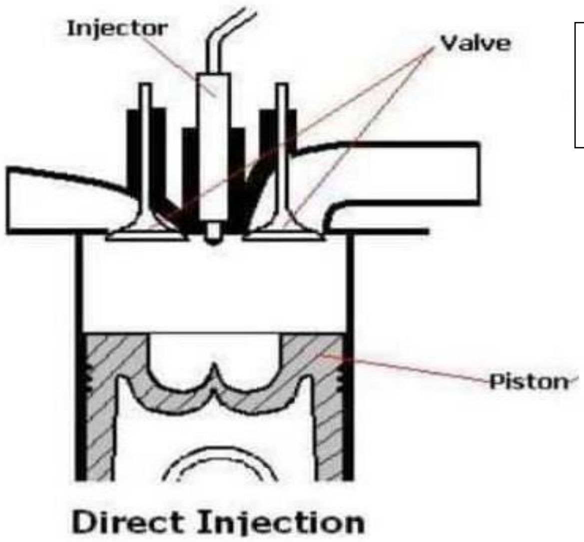


Figure 10.6. *Direct Injection System*

For example, the **Hyundai Venue's 1.0-liter turbocharged petrol engine** uses a direct-injection system sold as the "**GDI.**" In this configuration, fuel preparation and injection timing are superior than any other injection system.

10.4 COMPONENTS OF FUEL SYSTEM

The fuel system has the following major parts:

1. Fuel Tank
2. Fuel Pump
3. Fuel Injector
4. Carburetor
5. Fuel Filter
6. Fuel Lines
7. Fuel Gauge

8. Fuel Gauge Sending Unit
9. Emission Vapor Controls
10. Fuel Pressure Regulator

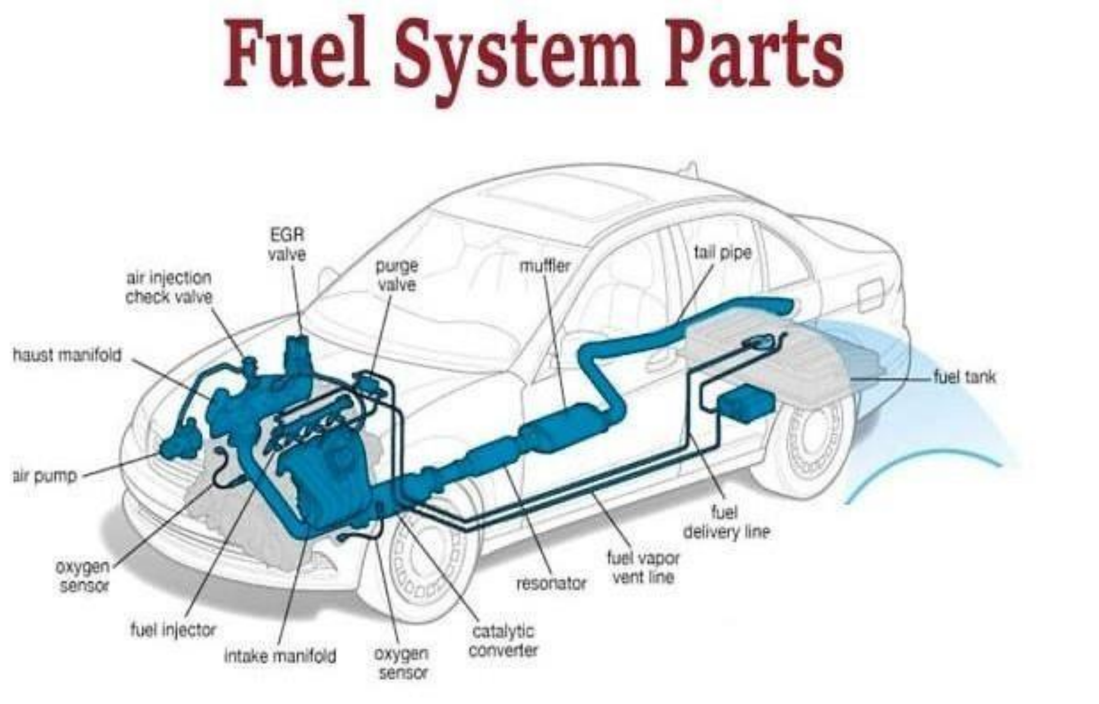


Figure 10.7. *Fuel System*

1. Fuel Tank

A fuel tank is a place where fuel (such as gas, diesel, or petrol) is stored. If the fuel tank is clogged or leaked, the fuel can't be supplied properly to the combustion chamber of the engine. The proper operation of this tank plays a big role in the proper working of the vehicle. A fuel pump uses to deliver fuel from the fuel tank to the carburetor or combustion chamber.

2. Fuel Pump

A fuel pump takes fuel by the fuel tank and delivers it to the fuel injector through fuel lines. In the case of the petrol engine, the fuel injector injects fuel into the carburetor. In contrast, in the diesel engine, the fuel injector directly injects fuel to the combustion chamber.

The fuel pump has the following major two types:

- **Mechanical fuel pump:** An engine uses to drive this pump. A chain or belt uses to connect the motor to the fuel pump.
- **Electric fuel pump:** An electric fuel injection system uses to control this pump. It has more reliability than a mechanical pump. It has very low-reliability problems.

3. Fuel Injector

A fuel injector uses to inject the fuel into the combustion chamber of each throttle body or each cylinder. Actually, a fuel injector is a nozzle with a valve that creates a spray of fuel and air droplets.

The fuel injector is powered by a fuel pump. It takes fuel by the fuel pump. The injection process of the fuel injector varies according to the nature of the engine.

In the case of a diesel engine, the fuel injector injects fuel directly into the combustion chamber. In contrast, in the petrol engine, the fuel injector firstly injects fuel into the carburetor where fuel is mixed with air, and then the carburetor transfers the air-fuel mixture to the combustion engine.

4. Carburetor

A carburetor is most commonly used in the petrol engine. The main function of this part of the fuel system is to make an air-fuel mixture.

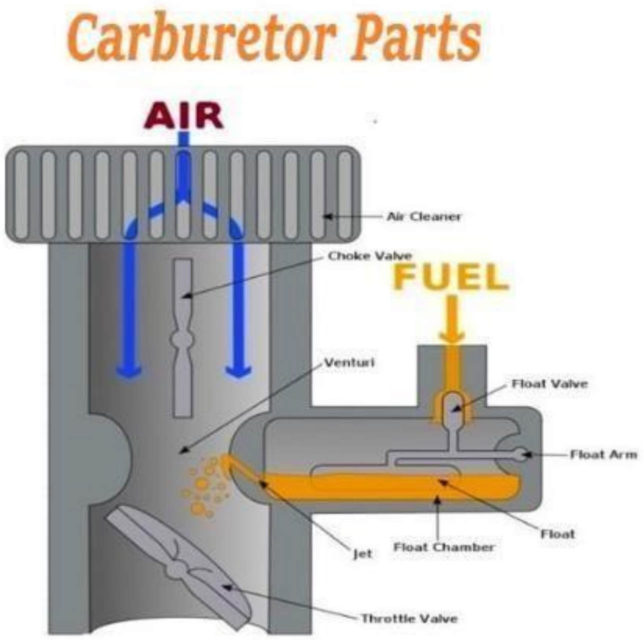


Figure 10.8. Carburetor Parts

As the fuel injector injects fuel into the carburetor, it sucks air from the environment, mixes it with the injected fuel, and makes a fuel-air mixture. After proper mixing, the carburetor transfers the fuel-air mixture to the engine combustion chamber for the combustion process.

5. Fuel Filter

The fuel filter plays a big role in the proper operation of the fuel supply system. Due to the tight tolerances of fuel injectors, they can be damaged very easily by debris, and fuel-injected vehicles also use electric fuel pumps.

The fuel filter installs in between the fuel pump and fuel tank. As the fuel tank sucks fuel from the fuel tank, the fuel firstly passes through the filters. The filters remove the fuel solid contamination and then deliver filtered fuel to the fuel pump.

6. Fuel Lines

These lines link all the different parts of the fuel system. Flexible hoses and steel lines transport the fuel from the tank to the engine.

Do not use copper or aluminum when repairing or replacing steel fuel lines. You must replace the steel lines with steel. Similarly, when you replace the flexible rubber hose, you must use the correct hose. When you are replacing, carefully disconnect all hoses from the exhaust system.

7. **Fuel Gauge**

You can see the fuel gauge on the dashboard of your car. It is connected to the fuel tank. It uses to show the driver an actual fuel quantity in the tank.

In traditional vehicles, the fuel gauge couldn't show an exact amount of fuel in the fuel tank. If this is your first time driving a classic car, take the time to understand the precision of the system. This part of the fuel system eliminates the hassle of running to a gas station when your tank runs out of gas!

8. **Fuel Gauge Sending Unit**

In the case of a fuel system, it is probably your biggest concern. The sending unit is a flawed design at best. This unit is most precise between 1/4 and 3/4 of the gas in the tank. Even if the tank limit (full or empty) is reached, the display becomes less accurate.

9. **Emissison Vapor Controls**

These controls use in combination with fuel return lines. This part of the overall system uses to prevent petrol vapors from being discharged into the ambient air. When this happens, following some bad things can happen:

- A bad odor of gasoline enters the car
- The earth-shattering roar of gasoline fumes ignites
- it's bad for the environment

10. **Fuel Pressure Regulator**

This unit of the fuel delivery system makes sure that the system properly maintains a proper amount of pressure. This unit is most commonly used in fuel-injected vehicles because fuel injectors generate more pressure than carburetors.

10.5 SYMPTOMS OF BAD FUEL SYSTEM

A bad fuel system affects the performance of the engine. A bad fuel system has the following major signs:

- Difficult Engine Starting
- Engine stalling issues
- Irregular power loss
- Engine idling issues
- Extreme Engine Smoke
- Unpleasant fuel odors
- A reduction in fuel economy

10.6 ADVANTAGES AND DISADVANTAGES OF FUEL INJECTION SYSTEM

Advantages of Fuel Injection System:

- It increases the engine and vehicle performance.
- It prevents the engine from damage.
- The fuel injection system increases the engine service life.
- It increases engine efficiency.
- It offers better fuel efficiency.

Disadvantages of Fuel Injection System:

- A fuel injection system has many parts, including a fuel tank, fuel pump, fuel lines, and fuel injector. Therefore, this system increases the weight of the vehicle.
- The parts of this system have a high cost.
- It has high repairing and maintenance costs.

10.7 FUEL SYSTEM OF DIESEL ENGINE

During engine operation, the fuel is supplied by gravity from fuel tank to the primary filter where coarse impurities are removed. From the primary filter, the fuel is drawn by fuel transfer pump and is delivered to fuel injection pump through second fuel filter. The fuel injection pump supplies fuel under high pressure to the injectors through high pressure pipes. The injectors atomize the fuel and inject it into the combustion chamber of the engine. The fuel injection pump is fed with fuel in abundance. The excess fuel is by-passed to the intake side of the fuel transfer pump through a relief valve.

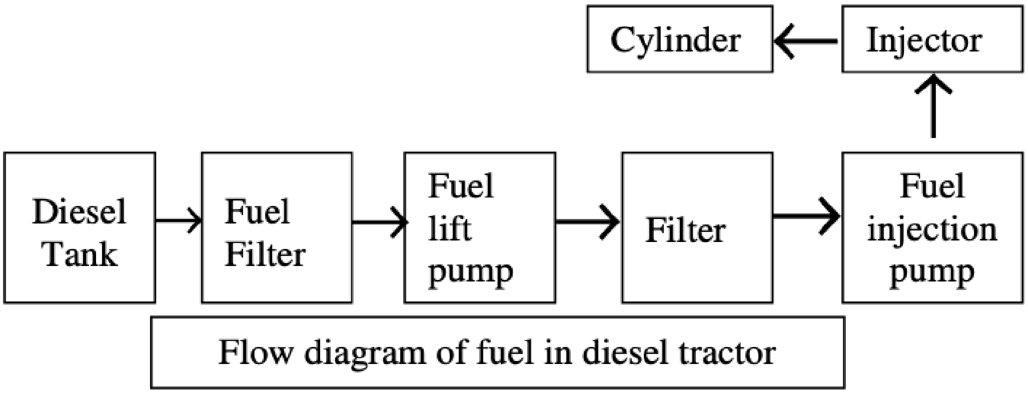


Figure 10.9. *Flow Diagram of Fuel in Diesel Tractor*

Two conditions are essential for efficient operation of fuel system: The fuel oil should be clean, free from water, suspended dirt, sand or other foreign matter, The fuel injection pump should create proper pressure, so that diesel fuel may be perfectly atomised by injectors and be injected in proper time and in proper quantity in the engine cylinder. Fuel should be filtered before filling the tank also. If these precautions are followed, ninety per cent of diesel engine troubles are eliminated.

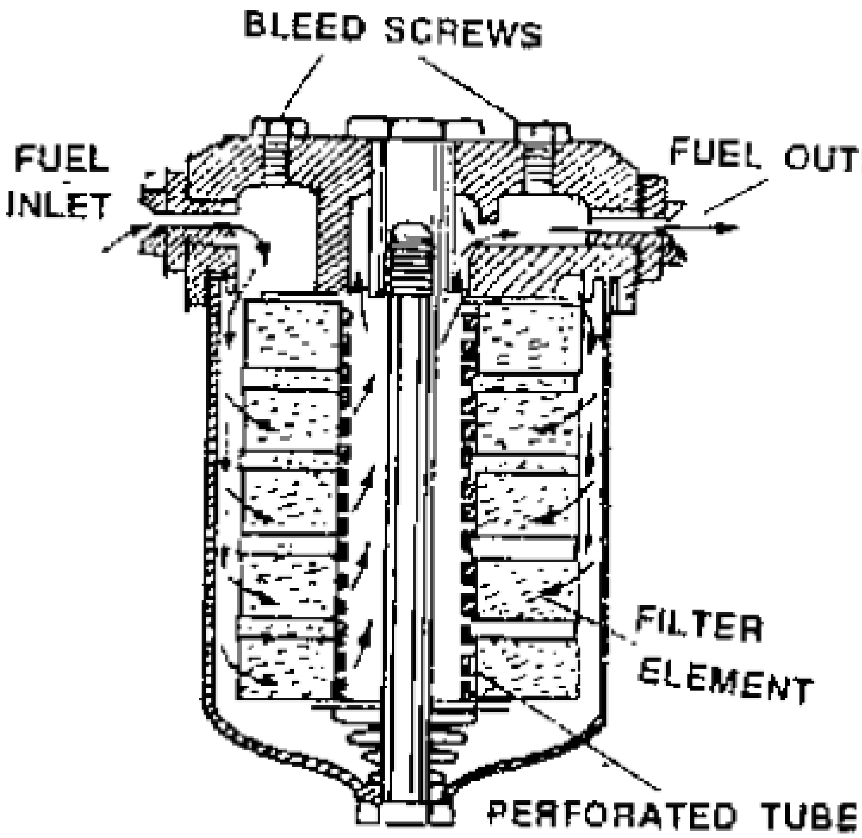


Figure 10.10 *Fuel filter for Diesel Engine*

10.7.1 The components of diesel fuel systems

A basic diesel fuel system is made up of five essential components. These are the tank, the fuel transfer pump, filters, the injection pump, and the injection nozzles.

The fuel tanks in diesel systems are typically crafted from aluminum alloys or sheet metal. The tanks are designed to contain the diesel fuel and survive its long-term corrosive effects.

The transfer pump sucks the diesel fuel out of the tank to move it into the injection pump. The transfer pump is generally located outside of the fuel tank or on the rear of the injection pump. In a few situations, transfer pumps are also located within the tank.

Diesel, like gasoline, is always mixed with contaminants that can damage the combustion system. The fact that diesel is refined, stored, transported on trucks, then stored again at gasoline stations ensures that contaminants will enter the fuel. To address these concerns, filters are placed between the transfer pump and injection system. The filter removes dirt and other contaminants that could easily damage the fuel injection system.

The injection pump compresses the fuel in preparation for injection. Injection nozzles spray diesel into the combustion chamber of the cylinders. The combustion chamber enables the car to convert the miniature combustions (explosions) into mechanical energy that turns the vehicle's wheels.

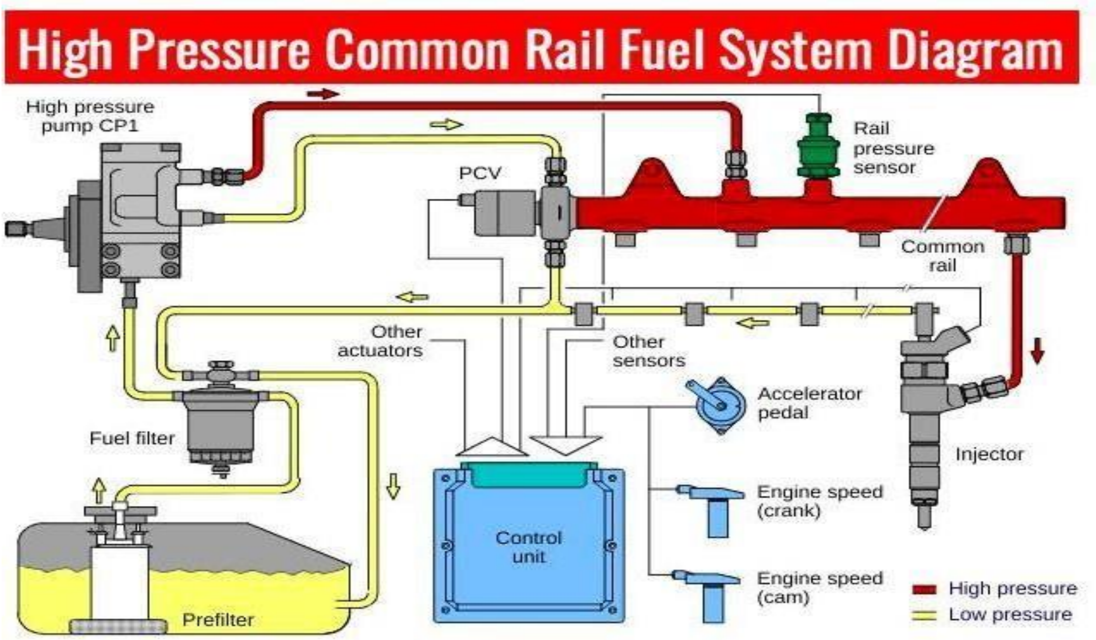


Figure 10.11 *Hight Pressure Common Rail Fuel System Diagram*

10.7.2 What is Common Rail System?

Common rail is a fuel injection system found in modern diesel engines. Common rail systems provide a level of flexibility which can be exploited for class leading emission control, power and fuel consumption. This enables Original Equipment Manufacturers (OEMs) to design for optimum performance and exceptional end-user value across a range of machines and applications.

An increasing number of modern diesel engines employ common rail direct injection (CRDi) fuel systems for the flexibility they provide while meeting the most stringent emission control standards.

In common rail systems, the fuel is supplied to the engine under pressure with electronically controlled precision. This provides a level of flexibility which can be exploited for class leading levels of emission control, power and fuel consumption.

Perkins applies CRDi technology to its electronic product offerings in the 400, 850, 1100 and 1200 Series.

10.7.3 How does CRDi work?

The fuel in an electronically controlled engine is stored at variable pressure in a cylinder or ‘rail’ connected to the engine’s fuel injectors via individual pipes, making it a ‘common rail’ to all the injectors. The pressure is controlled by a fuel pump but it is the fuel injectors, working in parallel with the fuel pump, that control the timing of the fuel injection and the amount of fuel injected. In contrast earlier mechanical systems rely on the fuel pump for pressure, timing and quantity.

A further advantage of the CRDi system is that it injects the fuel directly into the combustion chamber. The indirect injection (IDI) system in older engines injected fuel into a pre-combustion chamber which then fed the main combustion chamber.

10.7.4 What is the advantage of CRDi?

CRDi ensures the fuel injection timing, quantity of fuel and atomisation or fuel spray are controlled electronically using a programmable control module. This allows multiple injections at any pressure at any time (within pre-defined limits), providing a level of flexibility which can be exploited for better power, fuel consumption and emission control.

Perkins has a great deal of experience with applying CRDi to its electronically controlled engines. The experience gained over the past 10 years ensures we deliver a competent and capable product at the forefront of prime mover solutions.

10.7.5 How will you notice the benefits of common rail?

Noise, vibration and harshness (NVH) are improved with CRDi as a result of the timing flexibility. Your engine sounds quieter and has a better quality of sound. It also runs smoother. You will see fuel consumption benefits as well because greater injection pressure produces a finer spray of fuel (atomisation) that burns more efficiently.

Better combustion efficiency is a key part of meeting emission standards. Less fuel is wasted as soot or particulates in the exhaust and deposits in the engine. A cleaner running engine is good for the environment – and for the cost of ownership. Cleaner running improves the long-term durability and reliability of your engine.

We have designed our engines to deal with more stringent operating requirements. For example, improved fuel filtration ensures a higher level of purity in the fuel injected from the common rail. Clean servicing procedures are necessary to keep your engine running efficiently and within the limits of the applicable emission standards.

11 WHO USE 3-CYLINDER ENGINES?

11.1 Usage in Cars

Among the first cars to use a straight-three engine is the 1953-1955 DKW F91, powered by a 900 cc (55 cu in) two-stroke engine. The 1956-1960 Saab 93 saw the introduction of Saab's 750 cc (46 cu in) two-stroke engine, which was also used in the Saab 95, Saab 96and Saab Sonett until 1968 after which it was replace by the Ford Taunus V4 engine.

The Wartburg cars (manufactured in East Germany) and FSO Syrena (manufactured in Poland) also used straight-three engines.

The 1967 Suzuki Fronte 360 uses a 256 cc (16 cu in) two-stroke engine. In 1980, Suzuki began production of a 543 cc (33 cu in) four-stroke engine, which was introduced in the Alto and Fronte models.

The Subaru EF engine is a 4-stroke petrol engine which was introduced in 1984 and used in the Justy and the Sumo (the export version of the Sambar).

The straight-three versions of the Ford EcoBoost engine - a turbocharged 1.0-litre petrol engine - was introduced in the 2012 Ford Focus. It uses an unbalanced flywheel to shift the inherent three-cylinder imbalance to the horizontal plane where it is more easily managed by engine mounts, and so remove the need to use balance shafts. In 2016, cylinder deactivation was added, claimed to be a world first for three-cylinder engines.

Figure 11.1 *Circa-1960 Saab two-stroke engine*

Figure 11.2. *2010 Suzuki K10B engine*

11.2 Usage in Motorcycle

The advantages of a straight-three engine for motorcycles are that it has a shorter length than an inline-four engine and produces less vibration than a straight-twin engine.

11.2.1 Four-stroke

Four-stroke straight-three engines have been used in road bikes and racing bikes by several companiesFrom 1985-1995, the BMW K75 was produced with a straight-three engine (based on the straight-four engine from the BMW K100). Also Japanese motorcycle companies focused on the three cylinder as well. Such as Yamaha CP3 block that placed on the MT (Master of Torque) series. The British company Triumph has produced several models with transversely mounted straight-three engines, such as the 1994-present Triumph Speed Triple and the 2004-present Triumph Rocket III and this block is the biggest fabrication motor block (2500cc).

Figure 11.3 *2004-present Triumph Rocket IIIengine*

11.2.2 Two-stroke

Two-stroke designs are less common in straight-three engines than four-stroke designs, however several were produced by Japanese manufacturers in the late 1960s through to 1980s.

The Kawasaki triple engine was produced from 1968 to 1980 and was used in various road bikes and racing bikes. Most versions were air-cooled; however, several were water-cooled. Similarly, the 1972-1980 Suzuki GT series engines were used for both road bike and racing bikes and were available in both air-cooled and water-cooled versions.

Figure11.4. *1969-1975 Kawasaki H1 Mach III*

11.3 Other Uses

11.3.1 Agriculture

An example of an agricultural application is the *Fairbanks-Morse 32E14* low-speed diesel engine, which is shown in the picture to the right coupled to a water pump.

The straight-three layout is common for diesel tractor engines, such as the *Perkins AD3.152*. This engine was used in the Massey Ferguson 35 and Fordson Dextra tractors, as well as for marine and stationary applications.

11.3.2 Aviation

The Hewland AE75 is a 750 cc two-stroke aircraft engine that was produced in the mid-1980s. It was an inverted three-cylinder design with liquid-cooling that produced 75 bhp (56 kW).

Figure 11.5 *1940s Fairbanks-Morse straight-three diesel engine*

12 WHY COMPANIES START TO PREFER 3-CYLINDER ENGINE INSTEAD OF 4-CYLINDER ENGINE?

During the second half of eighties and nineties, three-cylinder engines ruled Indian roads. But by the beginning of new millennium cars with four-cylinder engines captured back the Indian market. But some recent introductions give a feeling that whether the industry is swinging back to three-cylinder engines - especially with the introduction of cars like Maruti Astar, Skoda Fabia, Maruti Estillo (2009) etc.

An average prospect is already confused with multiple market offers by automobile companies and now one more confusing choice - Car with four-cylinder engine or three-cylinder engine?

Apart from this basic question there are a dozen of queries which are unanswered or guided in the wrong directions. Some of them are:

Are we growing or going back to underpowered engines?

How these three-cylinder engines are better than four-cylinder ones?

Is it introduced to reduce manufacturing expenses?

Why are some brands charging more for cars with three cylinders on than four-cylinder ones?

Through this article we will trying to find out answers to many of these questions and try to explain the relative advantages and disadvantages of both.

No, we are not going back to underpowered engines; Indian car market is growing to maturity with better market offerings.

The power output of an engine is irrespective of the number of cylinders. Theoretically even a single cylinder engine can deliver the same power as a four- or six-cylinder engine, if designed accordingly. More than power delivered, the way in which the power delivered makes the difference and have greater impact in a practical scenario.

On manufacturing cost aspect, I don’t think, the manufacturer is gaining nothing (other than some material cost) for delivering a three-cylinder engine instead of a four cylinder one. Then why should the companies reduce the number of cylinders?

The answer is very simple – fuel efficiency.

Next to product cost, one of the most important aspects in Indian market is the mileage / fuel efficiency. People, especially the middle class want to reduce operating expenses by buying a car which gives better mileage. Lots of research happens to improve the fuel efficiency – one way to achieve this is by reducing the number of cylinders. But how? The answer is given in the "Fuel Efficiency" section.

Whether mileage is the only factor a customer is looking for?

No, mileage is one important factor, but there are many other factors like comfort, ride quality, acceleration etc., which all depends on the engine.

Let's evaluate two important performance aspects for both three- and four-cylinder engines:

a. **Pulling Power**
b. **Fuel Efficiency**

Pulling Power:

Generally, people have an impression that three-cylinder engines are underpowered than four-cylinder engines, especially when using AC. The feeling comes from experience in using certain vehicles with 800cc three port engines. 800cc engines are underpowered while using an Air-condition, not only because of the number of cylinders, but because of the displacement capacity. But a bigger three port engine can deliver the same power as a four cylinder one. But the real difference is this:

A four cylinder deliver the power during all the four strokes in an engine cycle

A three-cylinder engine deliver the same power in a different way.

12.1 Three Cylinder Engine

In three-cylinder four stroke engines, one engine cycle consists of two rotations i.e., while power is delivered from all the cylinders, the crank shaft rotates two times (720 degrees). The timing between the combustion phases of all the three cylinders is 240 degrees. But the combustion phase lasts only for a rotation of 180 degrees only. So, for the time of rotating remaining 60 degrees, power is not delivered by any of the cylinders and during that period the engine is driven purely by the on inertia of motion.

240 degrees = 180-degree combustion + 60 degrees idle

So, in every engine cycle, the power output is zero for 180 degrees of turning

Note: For ease of representation and understanding, a 720-degree cycle is shown in a single cycle in the illustration. Please note the actual shape of the curve may vary from what is given I the diagrams.

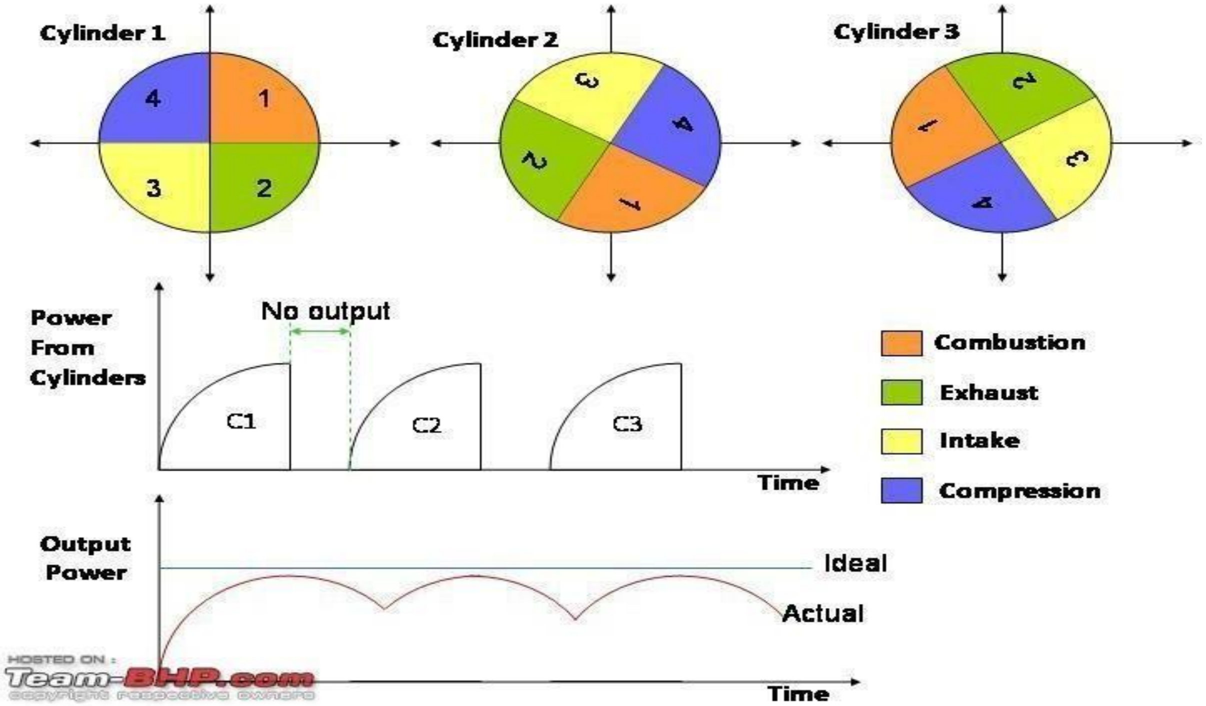


Figure 12.1 timing of the pistons in a 3-cylinder engine

Observe the power output curve; even though the total power is same, the delivery is in an uneven way, much different from the ideal. So, at lower rpm, there will be more engine idle time. Thus, the engine is underpowered, which affects the pulling power. But as the rpm increase, the engine will execute more cycles and the idle time is reduced power will be much better. This makes the engine smoother to drive at higher rpm. Hence the car will be much better to drive in highways than in a city.

12.2 Four Cylinder Engine

For four cylinder - four stroke engines, the power output characteristics are much better than a three cylinder one. The main difference is that in four-cylinder engines; one combustion phase happens at every 180 degrees, without leaving any ideal period. So, the power output is continuing. Hence the engine will have better response even at a lower rpm than a three-cylinder engine. Thus, the engine gives better power at a lower rpm and the car is easy to ride at a lower speed.

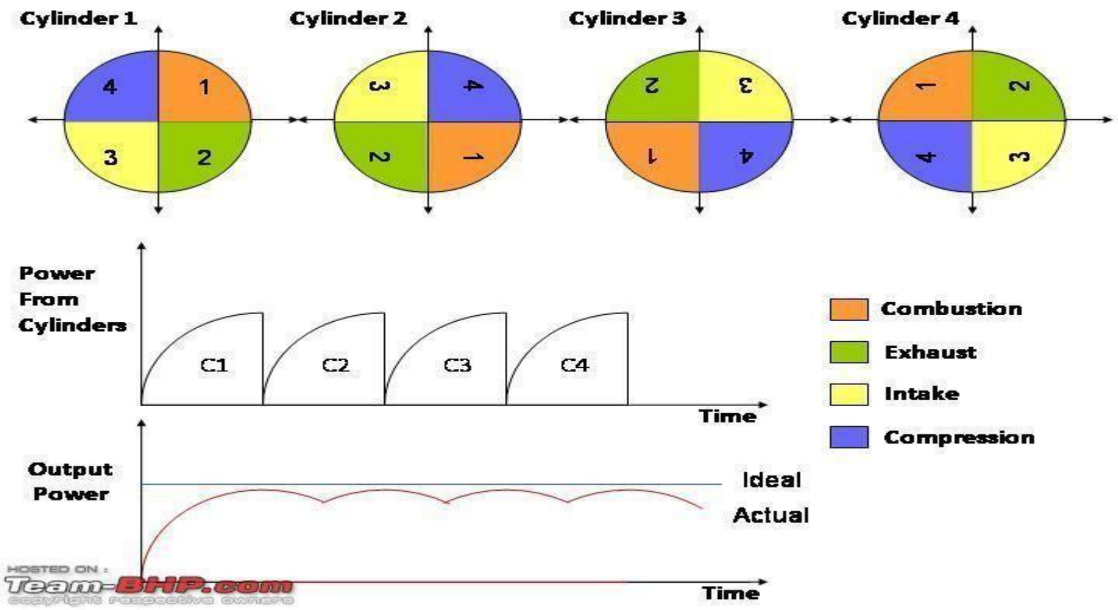


Figure 12.2 timing of the pistons in a 4-cylinder engine

Fuel efficiency:

It's already mentioned that three-cylinder engine gives better fuel efficiency than four-cylinder engine, for the same power output and operating conditions. This section gives a theoretical explanation of how this happens by reducing a cylinder. To explain these two engines with same capacity (say 1L) is taken - one a four-cylinder engine and the second one a three-cylinder engine.

Assumptions

- Both engines deliver same power
- Same fuel
- Operated under identical operating conditions
- Stroke length / bore height of all cylinders are identical
- No units are used as the case is hypothetical, so I put the measure as “unit”.

Formulas used:

Since the piston and cylinder cross section are circular.

Circumference of a Circle = 2 x pi x r

Area of a circle= pi x r x r

Case 1: Four-Cylinder Engine

The power output of each piston – cylinder unit is directly proportional to the displacement volume, i.e., the height and cross-sectional area of the cylinder.

The contact area between the piston and the cylinder can be calculated by calculating the circumference of the piston

Circumference

Circumference of one piston = 2 x 3.14 x 1 = 6.28 units

No of cylinders = 4

Total circumference for all the four cylinders = 6.28 x 4 = 25.12 units

Case 2: Three-cylinder Engine

In order to generate the same power output in a three-cylinder engine, the volume dispersed during combustion phase should be equal to the volume dispersed by all the four cylinders. Since we keep bore height constant in both engines, the only variable is piston radius. The new piston radius to generate the same power output is calculated as follows.

Calculation of new piston radius

Total cross section area of four-cylinder engine = Total cross section area of three-cylinder engine

4 x pi x r x r = 3 x pi x r x r

12.56 = 3 x pi x r x r

r = pi (12.56/ 3 x 3.14) = 1.154 unit

Thus, the radius of each piston should be 1.154 unit.

Total circumference of all three pistons = 3 x 2 x pi x r

= 3 x 2 x 3.14 x 1.154 = 21.74units

Ratio of piston circumference (surface contact) in a four-cylinder engine compared to a three-cylinder engine = 25.12 / 21.74 = 1.16

This means the surface area of the piston touching the cylinder in a four-cylinder engine will be 1.16 times more than that in a three-cylinder engine. Thus, a four-cylinder engine needs to work against more friction than a three-cylinder engine in every engine cycle. Apart from friction inside cylinder, there are multiple frictions at every surface interface from crankshaft to valves. Thus, a certain amount of output power generated by is used to compensate for these loses. As the number of cylinders goes up, more and more energy is utilized to overcome the frictional losses.

Thereby theoretically, a three-cylinder engine is using less power to maintain the engine operation. Thus, the engine needs to generate only lesser energy during an engine cycle, for the same power output. Less energy generated means less fuel consumed. Thereby the fuel consumption in an engine cycle is less and the vehicle could give better mileage.

13 3-CYLINDER: ADVANTAGES & DISADVANTAGES

13.1 -Cylinder Engines | Advantages

1. **Better Fuel Efficiency**: The 3-cylinder engines, due to the lesser number of cylinders than a 4-cylinder engine consumes a lesser amount of fuel in running the engine. The lesser number of cylinders makes it fuel-efficient and hence a vital choice for smaller cars which market themselves based upon their mileage.
2. **Lower Costs:** The engine is one of the most vital parts of a car, and when the manufacturer must use one lesser amount of cylinder in building the engine, the cost comes down drastically. Hence, cars with three cylinders tend to be less costly.
3. **Bigger Interiors**: The engines with fewer cylinders, make the engine smaller, making the engine bay smaller and leaving more space for the manufacturer to work on the interiors and making it roomier.
4. **Lower Frictional Losses**: The lesser number of cylinders doing metal to metal movements makes the amount of friction go down, therefore reducing the fuel consumption and a better and efficient movement.

13.2 Cylinder Engines | Disadvantages

1. **Less Responsive Engine**: The lower number of cylinders makes the engine respond in a bit delayed manner. Although the difference seems to be negligible, the difference can be felt to someone who has driven or is used to driving a 4 cylinder.
   Due to the difference in the way the pistons are arranged in a 3-cylinder design, which brings in the delay of half a cycle between the power strokes.
2. **Not Refined:** A 3-cylinder engine requires more work than a 4-cylinder engine due to the lower number of cylinders present. The 3 cylinders perform most of the work against the 4 cylinders which makes them a tad bit noisier than their 4-cylinder counterparts.

14 LOTUS ENGINEERING ANALYSIS OF THE ENGINE

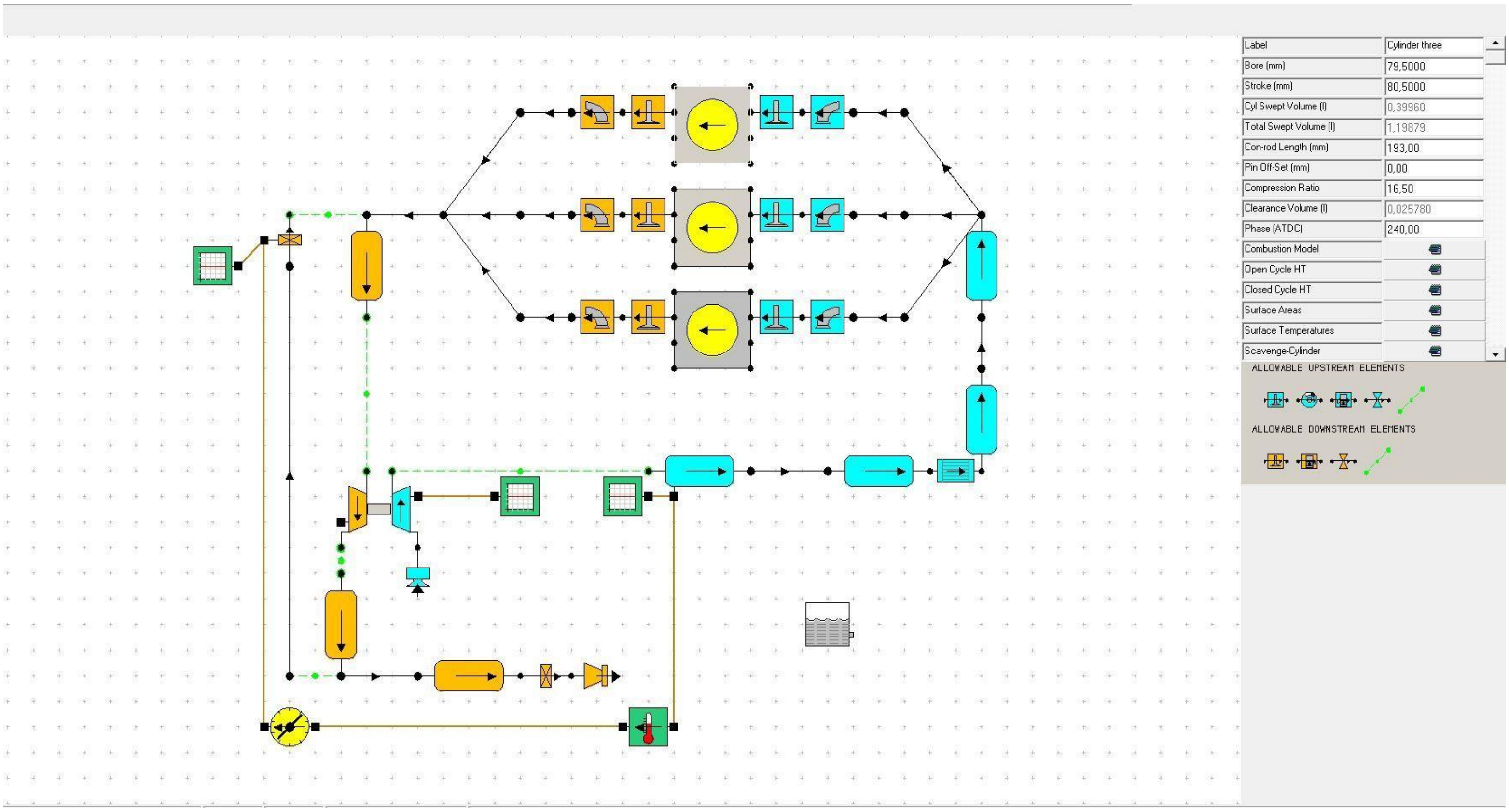
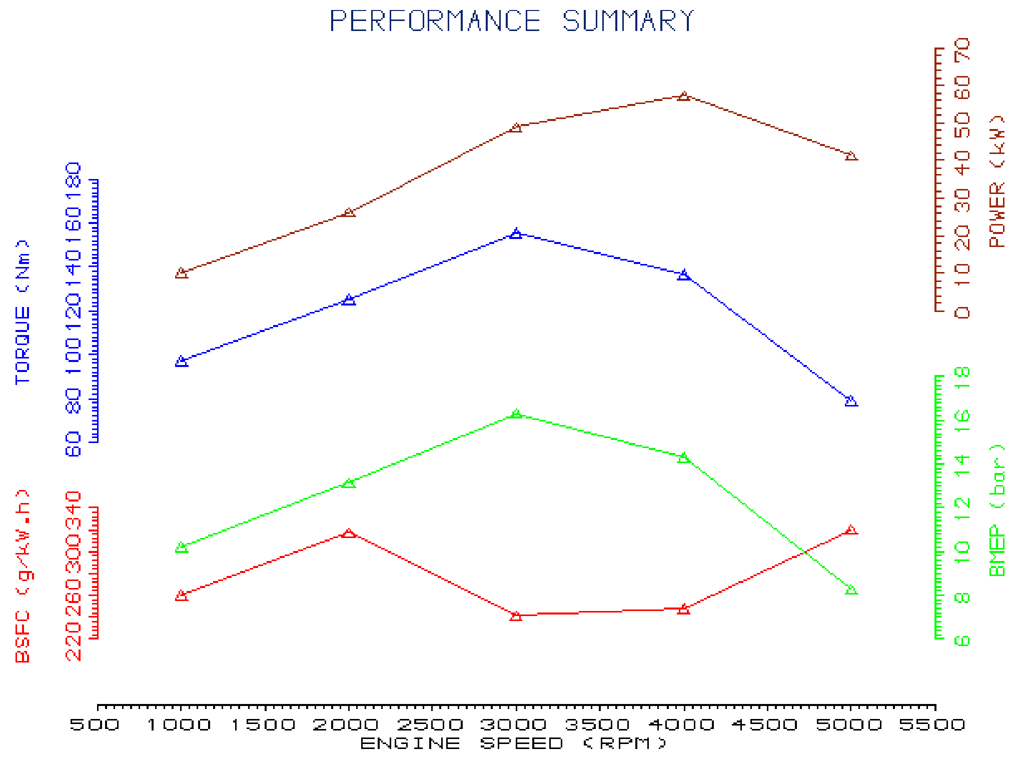


Fig 14.1 Engine Set-up by using Lotus Engineering Program


PERFORMANCE SUMMARY
TORQUE (Nm)
60 80 100 120 140 160 180
BSFC (g/kW.h)
220 260 300 340
POWER (kW)
0 10 20 30 40 50 60 70
BMEP (bar)
6 8 10 12 14 16 18
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500
ENGINE SPEED (RPM)

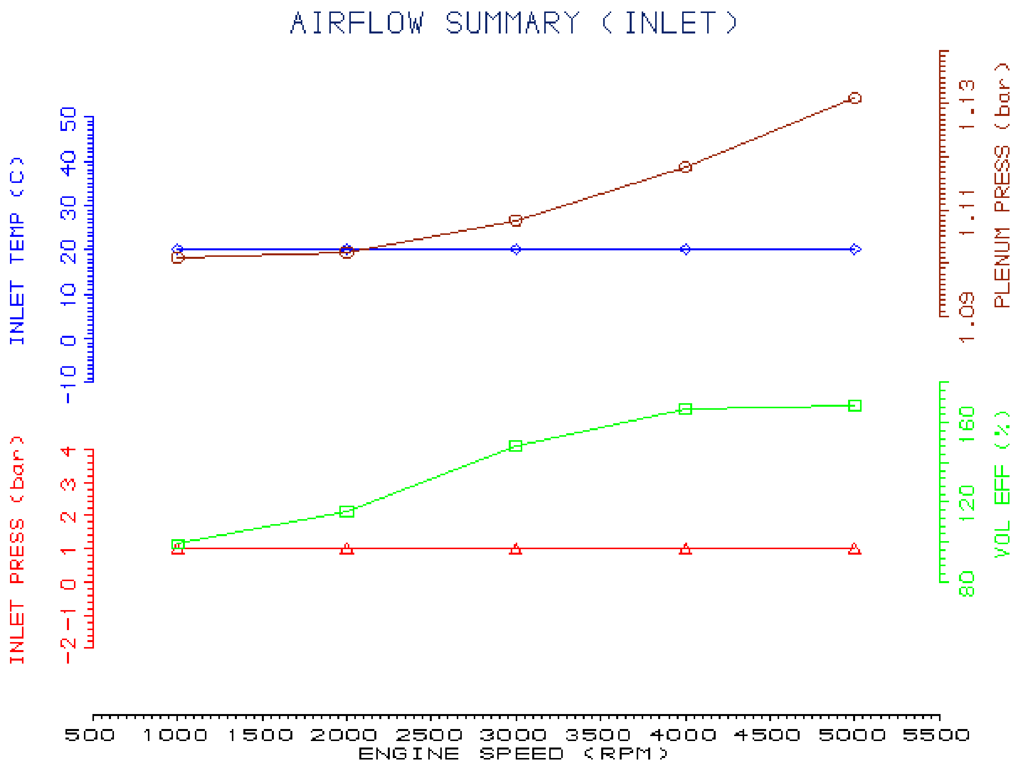
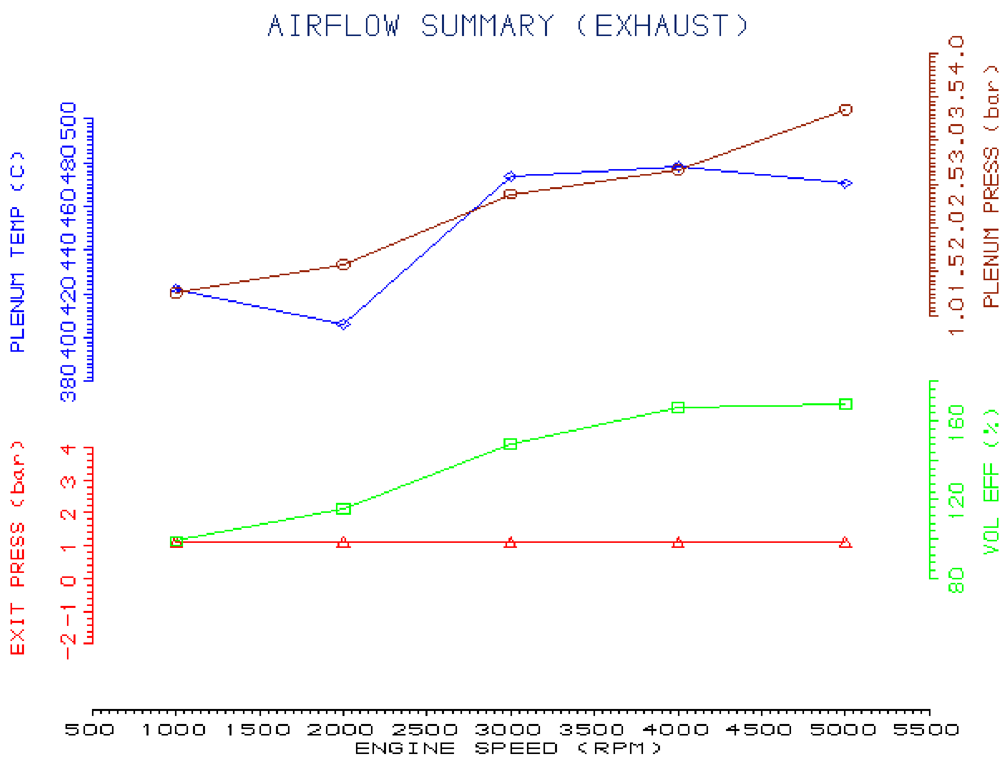

AIRFLOW SUMMARY (INLET)
INLET TEMP (C)
-10 0 10 20 30 40 50
INLET PRESS (bar)
-2 -1 0 1 2 3 4
PLENUM PRESS (bar)
1.09 1.11 1.13
VOL EFF (%)
80 120 160
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500
ENGINE SPEED (RPM)

Fig 14.2


AIRFLOW SUMMARY (EXHAUST)
PLENUM TEMP (C)
380 400 420 440 460 480 500
EXIT PRESS (bar)
-2 -1 0 1 2 3 4
1.0 1.5 2.0 2.5 3.0 3.5 4.0
PLENUM PRESS (bar)
80 120 160
VOL EFF (%)
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500
ENGINE SPEED (RPM)

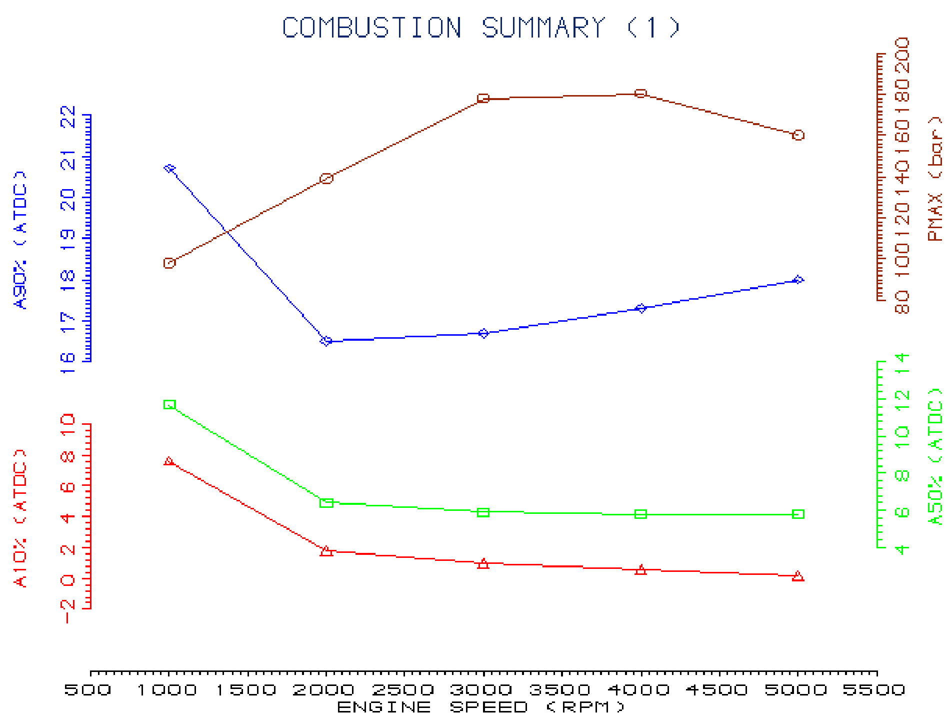
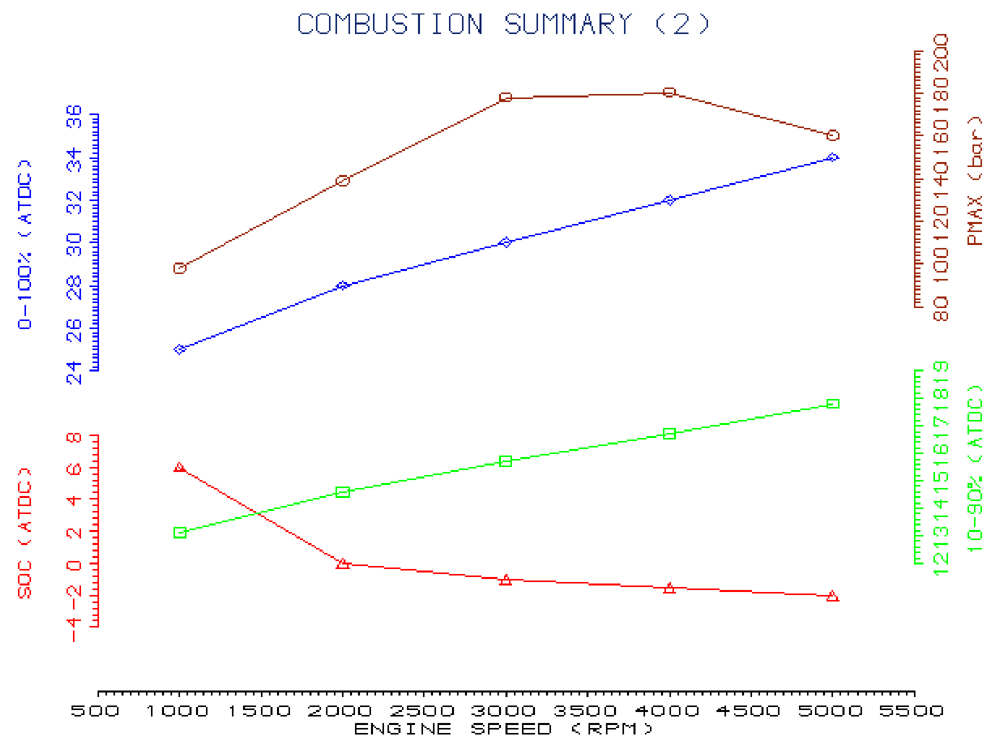

COMBUSTION SUMMARY (1)
A90% (ATDC)
16 17 18 19 20 21 22
A10% (ATDC)
-2 0 2 4 6 8 10
80 100 120 140 160 180 200
PMAX (bar)
4 6 8 10 12 14
A50% (ATDC)
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500
ENGINE SPEED (RPM)

Fig 14.3


COMBUSTION SUMMARY (2)
0-100% (ATDC)
SOC (ATDC)
PMAX (bar)
10-90% (ATDC)
ENGINE SPEED (RPM)

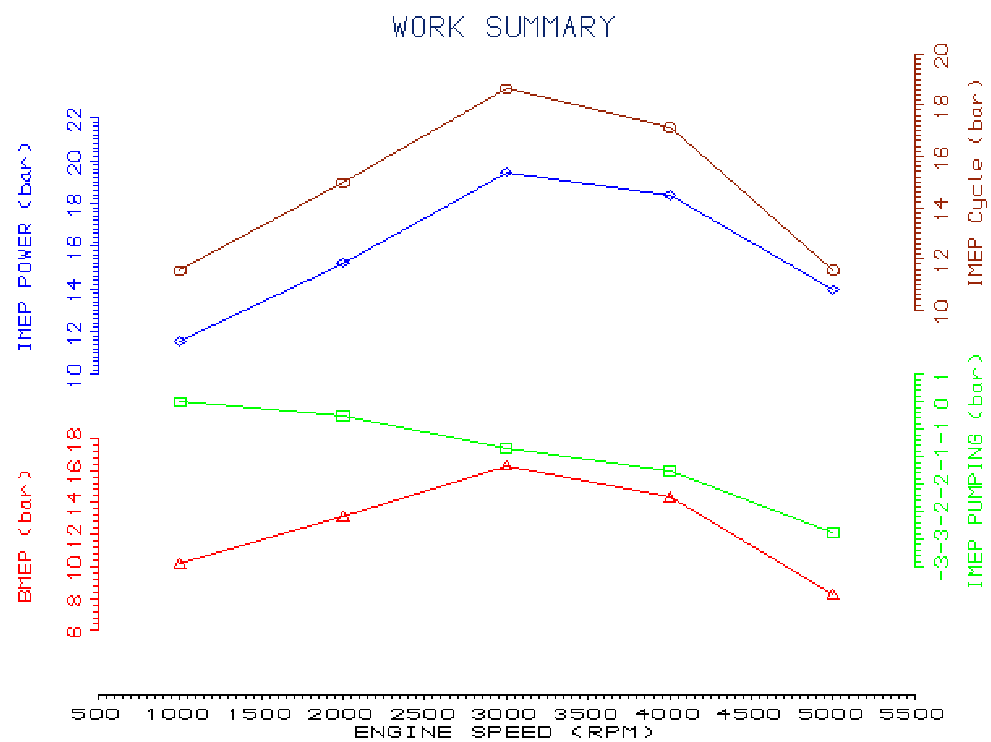

WORK SUMMARY
IMEP POWER (bar)
BMEP (bar)
IMEP Cycle (bar)
IMEP PUMPING (bar)
ENGINE SPEED (RPM)

Fig 14.4

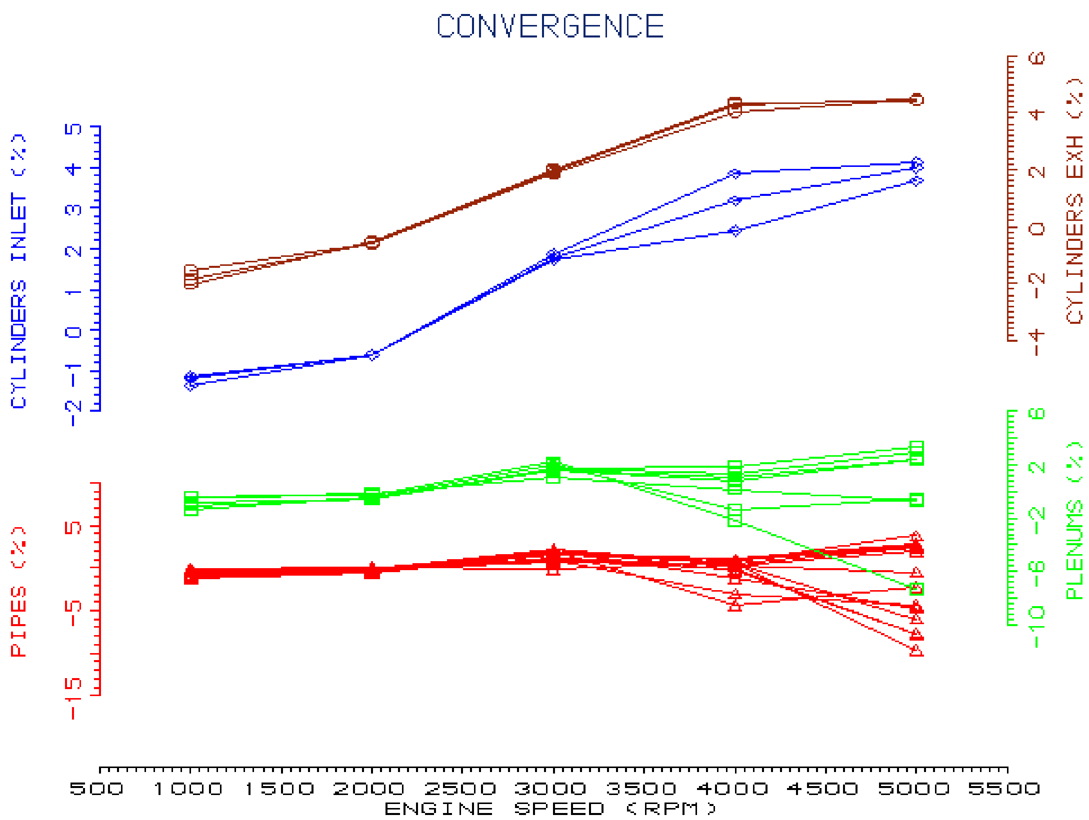

CONVERGENCE
CYLINDERS INLET (%)
CYLINDERS EXH (%)
PIPES (%)
PLENUMS (%)
ENGINE SPEED (RPM)
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500

Fig 14.5

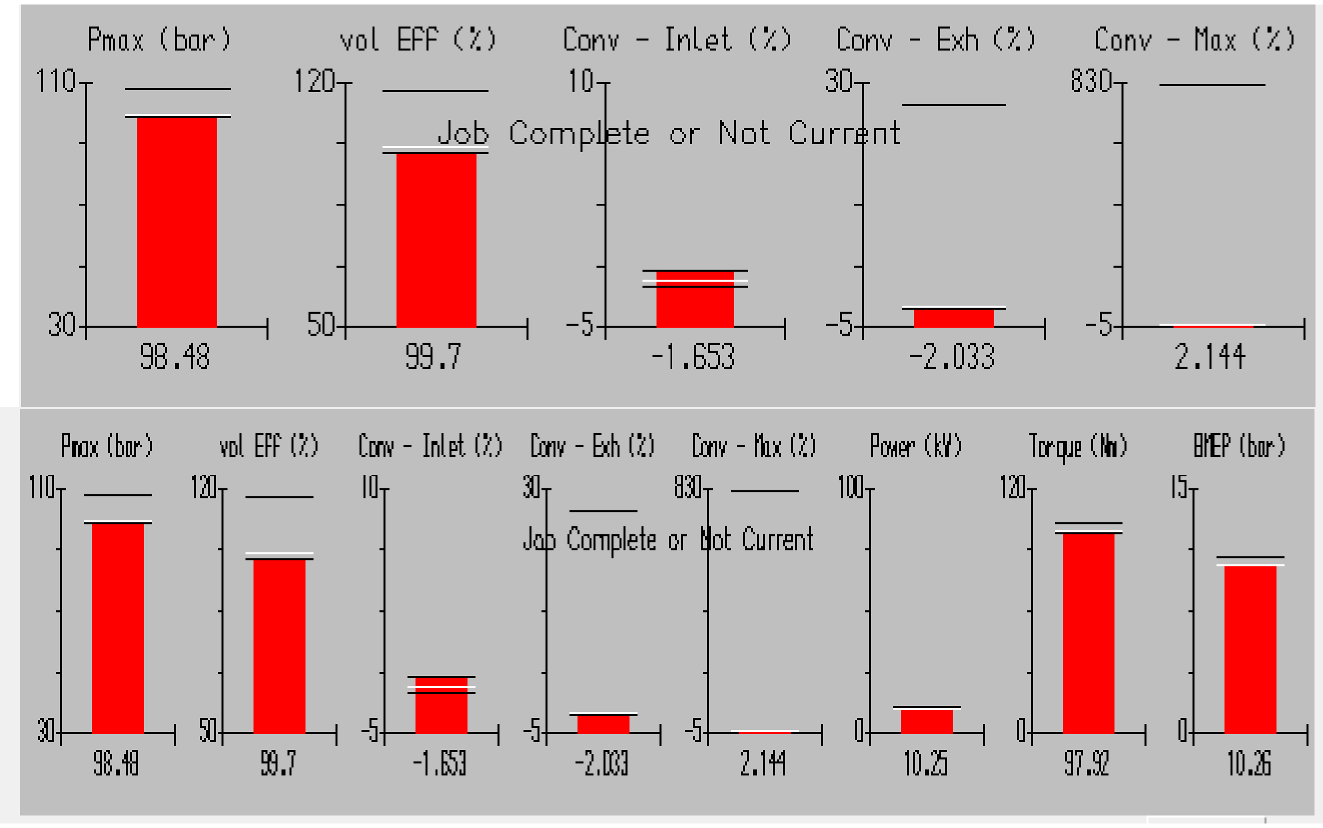


Fig 14.6

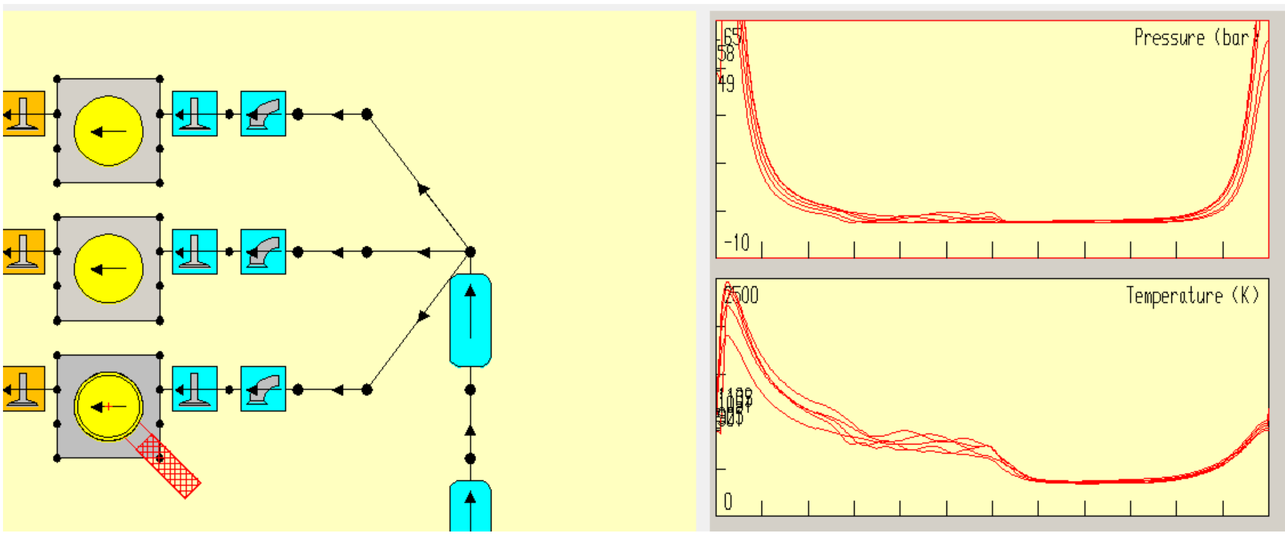


Fig 14.7

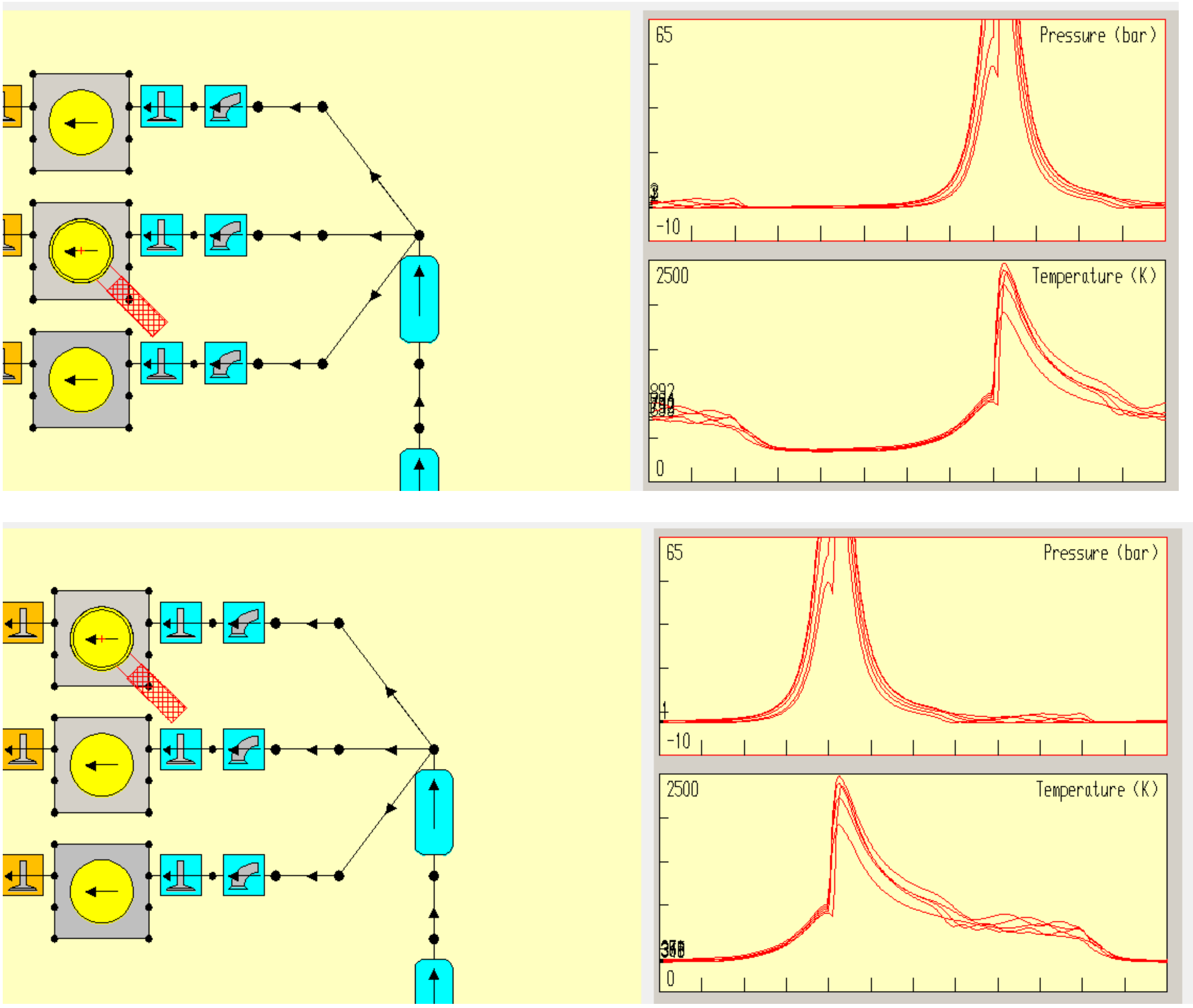

65
Pressure (bar)
-10
2500
Temperature (K)
0
65
Pressure (bar)
-10
2500
Temperature (K)
0

Fig 14.8

15 CONCLUSION

Other than this theoretical view, in a real-life scenario, the performance, comfort and fuel efficiency of a car depends on many other factors starting from the aerodynamics to the passenger weight. There is no generalization that all three-cylinder ones are fuel efficient, and all four-cylinder ones are better to drive. It depends on many other factors like the manufacturer, engine refinement, quality components, performance of the subsystems etc.

Finally, it's a personal choice to go with a car with three cylinder or four cylinders. If somebody values more fuel economy, better operating expense and generally drives in fast lanes it's better to have a three-cylinder engine. At the same time if somebody is buying the car mainly for city driving, driving comfort and use AC most of the time, it's better to have a four cylinder one.

***Figure 15.**3-cylinder vs 4-cylinder Engine*

In an internal combustion engine, it is a machine just like a simple pulley. In fact, an internal combustion engine is a machine made up of many components. As in all machine designs, there are 2 methods in internal combustion engine design, these are traditional methods and computer aided design. In traditional methods: First, the intended use is determined. After that power requirement is determined. According to the power requirement, features such as cylinder volume, number of cylinders, cylinder diameter are calculated. Then mechanisms are prepared and 2d mechanism analysis is applied for each component. For example, after complex number modeling is done for the crankshaft, the distances for 360 degrees are calculated and the output values for the crank are input for the piston, and the positions of all the components are determined accordingly. Then the material type is determined and a safety factor is determined for each component. Dynamic and kinematic calculations are made for each component, so the design is drawn in 3D. The traditional method is reliable and hard way. In computer-aided design, just like in the traditional method, certain things are determined. Then, with the input information, the design is started directly in the CAD program. Solidworks is used in this Project. The mechanism, kinematics and dynamics of a previously ill-designed engine have been improved by preserving some of its features. In this project, innovations such as by-pass factor were also made and the camshaft and crankshaft were redesigned to complement their angular movements. Moreover the edges of the block fillet because of that edges are the point where maximum stress occurs. As fillet the edges we aimed to distribute stresses all around the surface. Previous design had no cooling system in motor block. Cooling canals designed and operated onto block that made this design more realistic and affective. For the previous design there was some allignment problems, dimension problems and etc. these problems are solved. While doing all this, the components were tested for operability in sub-assemblies and final assemblies, and they were designed as computer aided with a kind of trial and error method. There was no need to make dynamic and mechanism calculations of these components separately because it contains CFD in the background of the solidworks program, so a model that is not physically possible cannot be designed in the Solidworks program. What makes computer-aided design easier and faster than the traditional method is precisely that it saves the designer from huge computational burden. Although the engine is thought to be designed for cars, the gear system is not included in the design. You can view drawings of other components with subassembly and final assembly.

16 CHOOSING AND DEVELOPING A REFERENCE ENGINE DESIGN

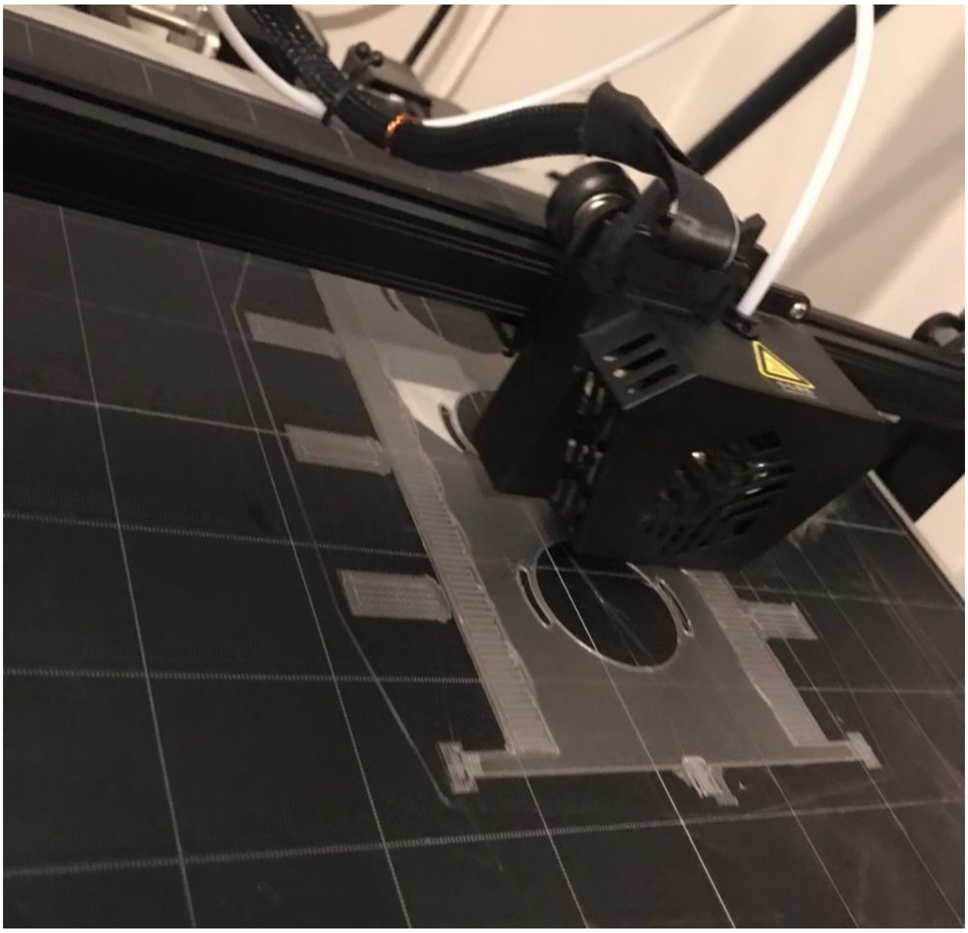
Figure 16. *VW EA189 engine*

VOLKWAGEN AUDI 1.2 TDI CR EA189	
TYPE OF ICE	FOUR-STROKE TURBOCHARGED
CYLINDER BLOCK MATERIAL	CAST IRON
CYLINDER HEAD MATERIAL	ALUMINIUM
FUEL TYPE	DIESEL
FUEL SYSTEM	COMMON RAIL
CONFIGURATION	INLINE
STROKE BORE RATIO	1.01
NUMBER OF CYLINDERS	3
VALVES PER CYLINDER	4
DISPLACEMENT, cc	1199 cc
COMPRESSION RATIO	16.5:1
POWER, HP-kW	75HP(55kW) @4200 rpm
TORQUE, lb-ft.	132 lb-ft. (180 Nm) @ 2000 rpm
FIRING ORDER	1-2-3
BORE, mm	79.5
STROKE, mm	80.5
VALVETRAIN LAYOUT	DOHC

17 3D PRINTING PROCESS

At this step we rechecked our design components to see if it is convinient to print by using 3D printer. We have consulted to some of our teachers and master degree students who have experience on 3D printing. We figured out that our block design is too big to print as it is original sizes so we decided to resize it as 1:2. Eventough we again faced with some problems about printer sizes so we get contact with some proffesional printers to discuss on how to do it.
Then we agreed on a 1:2 scale, but the design was still quite high-density. That means much higher costs and time. As a second step we changed density of the design as 10%. the inside of the parts was printed with a structure with 90% space. Printing process took roughly 72 hours.
There were plastic burrs and residues on the parts coming out of the printer. Because the parts were designed with a low tolerance, they were not ready for assembly in this way. contact surfaces such as piston-cylinder, crank-rod, block-crank were need a sanding process. There was a critical point that needed attention in the sanding process. Since the parts were printed in a 90% void structure, too much sanding could damage the material.
At the last step, components were ready to be assembled.

STAGES OF THE PRINTING PROCESS



Video links from printing
https://drive.google.com/file/d/1-x68iHClv2F0WU1q3tZY5J7FpRbfZLXq/view?usp=sharing
https://drive.google.com/file/d/1vTWQ1CyInIwZHiprPdVVuARQb3y_plFo/view?usp=sharing

Video link after fully assembled
https://drive.google.com/file/d/1meUV9cptFVsgMzH0gt8fifmWN4L37iFQ/view?usp=sharing

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19. APPENDIX

Link of the simulation that shows how does motor Works which we designed.

https://drive.google.com/file/d/1RQ9GweB_vf9yxAkeDss3i6sMw4HLzNTz/view?usp=sharing