MARMARA UNIVERSITY

FACULTY OF ENGINEERING

DESIGN OF CRANK MECHANISM AND CYLINDER BLOCK OF THREE-CYLINDER DIESEL ENGINE

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Müdek Final Project Commission			
The essential features of an acceptable design Project			
		Satisfied	Unsatisfied
1	Mechanical or Thermal Design	✓	
2	Report writing technique	✓	
3	Development of student creativity		✓
4	Use of open-ended problems		✓
5	Formation of design	✓	
6	Problem statement and specification	✓	
7	Synthesis of alternative solutions	✓	
8	Feasibility	✓	
9	Detailed system description	✓	
10	Consideration of constraints (e.g. economic, safety, reliability, etc.)	✓	
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by

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SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING I N PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

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DESIGN OF THREE-CYLINDER DIESEL ENGINE DESIGN

By

EMİR TALHA ŞAHIN and HAKAN SÖKMEN

MECHANICAL ENGINEERING THESIS

MARMARA UNIVERSITY, 2021

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The main purpose of this research thesis is to design a 3-cylinder engine. The content of this thesis, which will change the perspective of 3-cylinder engines, is what the diesel engine is, its history, advantages, whether its use will increase in the future and the factors affecting it, information about design, fuel and fuel systems, who will be used, and some engine examples. While preparing the thesis content, articles written about 3-cylinder engines, expert opinions and data from statistical companies were used. The opinions of the expert opinions and the data of the statistical companies were carefully analyzed and interpreted separately. As a result of the researches, it has been concluded that 3-cylinder engines are more efficient than 4-cylinder engines, while the diesel engine will have a large business volume in the markets for at least 20 to 30 years. As a result, we made our own design compared to the motors in the market

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
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

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1) Introduction

Actually, 3-cylinder engines are not a new technology, it has existed for a long time. Especially in Japan, 3-cylinders, small volume engines are so common, at the same time they are using for motorbikes. Unlike Japan, 3-cylinder engines are not so common in Europe and Turkey. However, using 3-cylinder engines are also increasing in Europe and Turkey market last 3-5 years. We can array main reasons of this increasing like below;

- 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.
- Size of 3-cylinder engines are smaller than 4-cylinder engines.
- 3-cylinder engines increase internal volume of automobiles because they have small size.
- 3-cylinder engines are lighter than 4-cylinder engines.
- 3-cylinder engines provide better fuel economy than 4-cylinder engines.
- 3-cylinder engines have lower cost production than 4-cylinder engines because they have less parts and smaller parts than 4-cylinder engines.

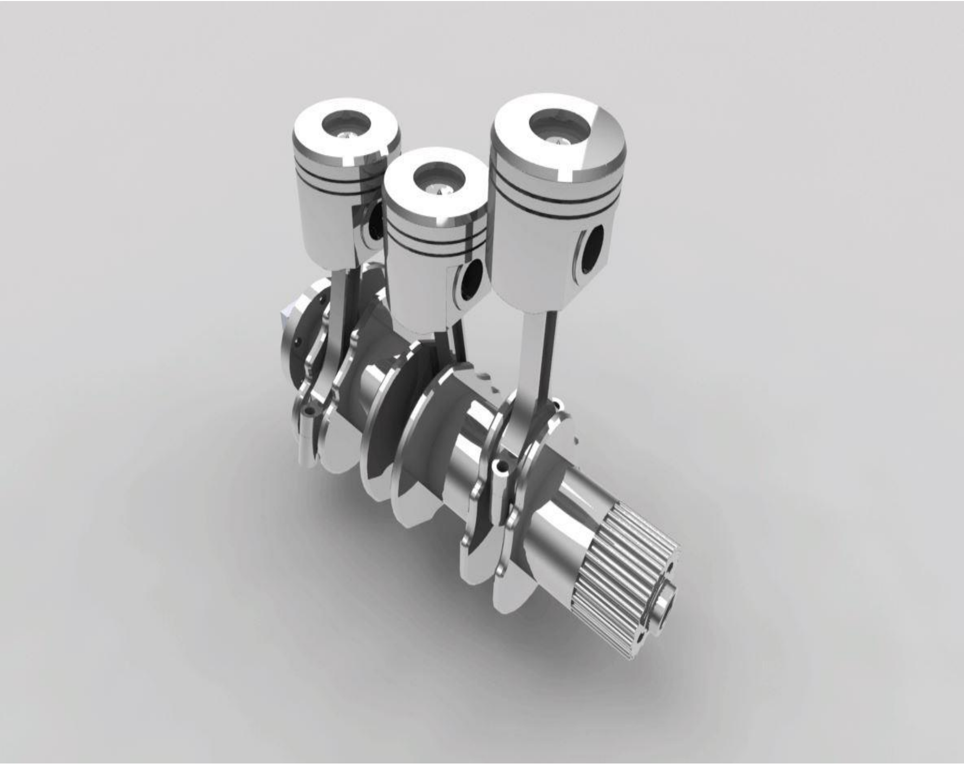

Figure 1- Piston crank and connecting rod mechanism

2) What is 3-Cylinder Engine?

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

Less common than straight-four engines, straight three engines have nonetheless been used in various motorcycles, cars and agricultural machinery.

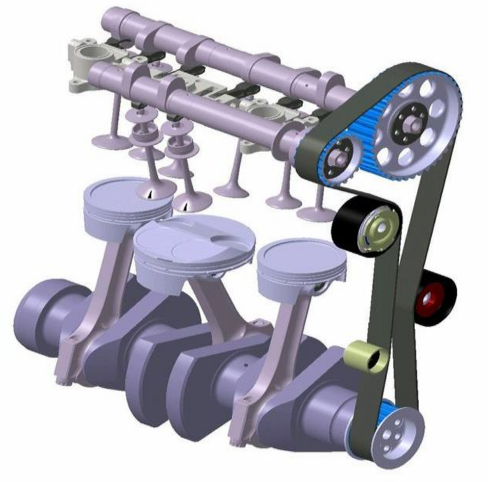

Figure 2- Piston crank and connecting rod mechanism with Valve Mechanism

3) DIESEL ENGINE HISTORY

Diesel engine is an internal combustion engine type. In a more specific definition, a diesel engine is an engine that operates on the principle that a gas containing oxygen (usually atmospheric air) is compressed to high pressure and temperature and the fuel sprayed into the cylinder is ignited and exploded. Therefore, unlike gasoline engines, there is no need for a spark plug for ignition and a carburettor to create a fuel-oxygen mixture.

Discovered by German engineer Rudolf Diesel in 1892 and later patented on February 23, 1893, this process is known as the diesel cycle. The inventor of the engine aimed to make a coal-powered engine to reduce Germany's dependence on oil, which has large coal deposits. However, the ash resulting from the burning of coal dust created great problems, and later on, it was designed to use different fuels in the engine. As a matter of fact, Rudolf Diesel made the presentation of the engine at the World Fair in 1900, using peanut oil (Biodiesel) as fuel.

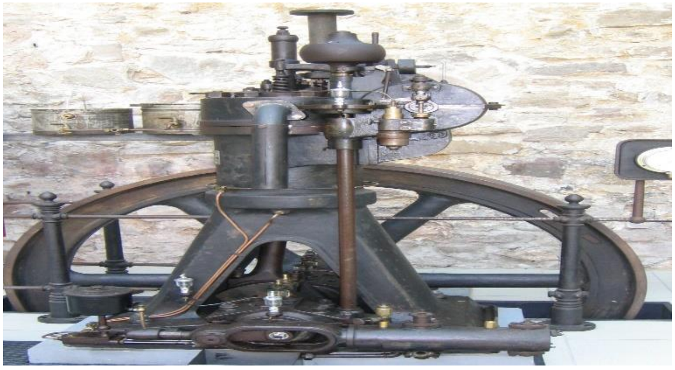

Figure 3- Single cylinder fixed diesel engine

- ***How has the diesel engine developed from past to present? What changes have happened?***

It has been exactly 76 years since the Mercedes-Benz 260 D, the world's first mass-produced diesel passenger car, was exhibited at the Berlin Motor Show in 1936. Until the 1950s, diesel-powered passenger cars were not popular compared to gasoline-powered cars, but these manufacturers did not discourage them. In fact, diesel engines became increasingly important in passenger cars in the post-World War II era. In the same years, diesel-powered passenger cars, thanks to their low cost, became increasingly popular, especially in taxis that had to withstand harsh driving conditions. In diesel engines, respectively; the first electronic control system for row type (in-line) fuel pumps, distributor pumps (star pumps) and distributor and in-line pumps of this type of pump was launched.

In diesel engines, respectively; sequential (row type), distributor pump (star pump) and 'Common Rail injection technologies were used. In 1985, the first electronic control systems for distributor and sequential pumps were introduced to the market. Subsequently, in 1989, the first axial piston pump was used for direct injection in diesel engines. This new technology allowed the fuel to be injected directly into the cylinder at high pressure of around 1000 bar, thereby achieving particularly effective combustion. This meant better high output and better acceleration, combined with lower fuel consumption and emissions. In 2003, the Common Rail injection system with "piezo" injectors was launched. Compared to previous models, this system reduced the diesel engine's fuel consumption and exhaust emissions while also reducing engine noise.

Better efficiency for economical, environmentally friendly diesel engines With the transition from Euro 5 to the Euro 6 emission standard, which means that Nitrogen Oxide (NOX) emissions should be reduced by more than half, fuel consumption reduction targets have become tighter in recent years. Engineers working on diesel fuel systems are currently working on injection systems that can produce more than 2000 bar pressure in order to meet more stringent emission limits and further reduce fuel consumption and carbon dioxide (CO_2) emissions.

4) Will diesel vehicles be used in the future?

In our opinion, and according to our research, diesel engines will have an important business volume in the market for at least 20 years more than the market.

Delphi Technologies sheds light on the future with the studies it has put forth. Delphi Technologies, which addressed the speculations and changes in consumer attitudes about diesel vehicles in recent years, presented concrete findings to eliminate the information pollution that occurred in this regard. The company emphasized once again the pioneering role of diesel in emission reduction with the numerical data obtained from expert test organizations, and once again demonstrated that diesel is an important part of the product range of vehicle manufacturers and that it will continue to be a popular choice for vehicle owners.

- ***Lowest carbon dioxide (CO2) emission***

The fact that diesel fuel has the highest energy content per litter compared to other fuels used shows itself in the preference of diesel vehicles produced for both individual and freight and passenger transportation. Therefore, diesel engines, which are more thermodynamically efficient, can convert more of this energy to "usable jobs" compared to other fuels. However, diesel vehicles consume 25% less fuel volumetrically than equivalent gasoline vehicles. Again, diesel vehicles have 15% less CO2 emission per kilometre than equivalent gasoline vehicles.

Figure 4- Exhaust gas discharge

- ***Contribution to the environment***

Percentage20 of greenhouse gases, especially CO2, are generated during road transportation. Diesel vehicles play a key role in many vehicle manufacturers' strategies to reduce CO2 emissions and meet increasingly stringent regulations. Therefore, when diesel is used together with the emission control systems found in modern vehicles, it helps to meet the CO2 emission amounts far below the targets accepted by the European Union in December 2018. However, with the decrease in new diesel vehicle sales and the increasing popularity of SUVs, it is seen that the average CO2 emissions of new vehicles increased by 2.4 g CO2 / km in 2018, reaching 120.5 g CO2 / km. This rate stands out as the highest average of the last 4 years.

Figure 5- New clean diesel technology schema

- ***Low cost and most popular solution!***

While the high fuel economy of diesel provides lower fuel costs, it also increases the time between fuel purchases. In addition, conditions that require both permanent and instantaneous power such as safe overtaking, trailer and trailer towing and cargo transportation are possible thanks to the high torque produced by diesel. This shows that diesel remains the dominant fuel source for heavy and light commercial vehicles.

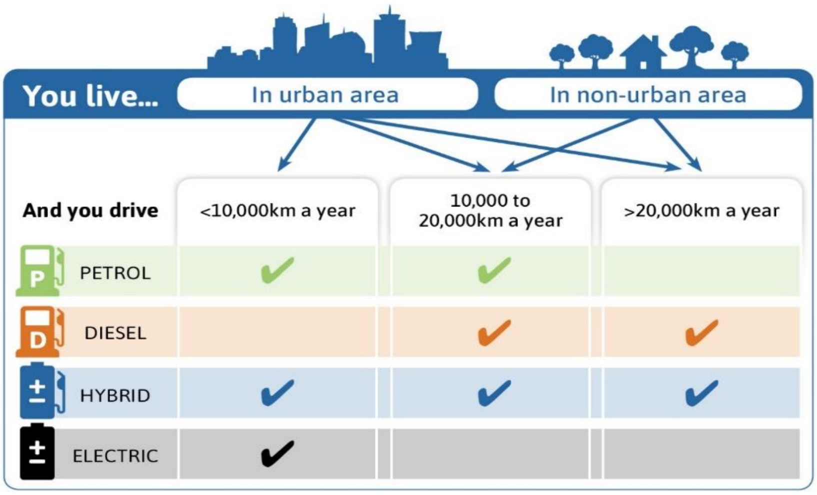

Figure 6- Comparing of usage range of motors, which are according to fuel type

- ***Diesel technology controls emissions!***

According to European emission standards, it is stated that particulate matter emission (PM), including soot, decreased 97% from 140 mg / km in Euro 1 norm engines to 4.5 mg / km in Euro 6 norm. Similarly, it is seen that nitrogen oxide (NOx) emission levels decreased by 84%, while it was 500 mg / km in Euro 3 normed engines (when NOx was first measured), to 80 mg / km in Euro 6 normed engines. “Real Driving Emissions” tests, which are implemented to reflect the real emission performance of vehicles on the roads, also play a major role in the use of highly efficient nitrogen oxide emission reduction technologies. According to the automobile club ADAC, known for its tests on vehicles; Diesel vehicles that meet the Euro 6d-TEMP emission standards emit an average of 76% less NOx (Nitrous Oxide) compared to Euro 6b (before RDE) diesel vehicles and 85% less than Euro 5 diesel vehicles.

Delphi Technologies examines the decline in diesel car sales and reveals why, contrary to popular opinion, diesel cars still have potential for both automakers and aftermarket services. Many diesel emission scandals in recent years continue to negatively affect both the consumer attitude towards diesel and the use of diesel in passenger cars and light commercial vehicles. On the other hand, this clean and efficient fuel continues to form the basis of many automakers' strategies to reduce their CO2 emissions. The world's leading automobile manufacturers such as Ford, General Motors, BMW, Volkswagen and Mercedes have recently made moves and investments that show their belief that diesel-powered vehicle will exist together with gasoline and electric vehicles for many years.

For example, Ford recently introduced a diesel engine for Ford Ka and a new 1.5-liter diesel engine option for the Eco Sport. General Motors introduced a new inline-six turbo diesel engine on the Chevrolet Silverado 1500 and GMC Sierra 1500. Mercedes-Benz has launched a new generation of diesel engines in its A, E and S-Class models and has invested three billion euros in this process.

Despite being under intense pressure due to the diesel scandal, Volkswagen continues to emphasize the importance of diesel engines in its product range. The brand introduced the EA288 Evo engine in 2018, which offers all the advantages of past TDI engines without high emission values. The newly developed in-line four-cylinder 2.0-liter turbodiesel engine is also compatible with mild hybrid use and will find use in future VAG Group models including Volkswagen, Audi, Skoda and Seat.

- ***Diesel car sales falling?***

Although diesel engines are an important technology for many vehicle manufacturers, the diesel scandal negatively affects the sales of new diesel cars. In the last few years, there has been a significant decline in the share of diesel in the total market. In 2015, more than 50% of the European market preferred diesel. In 2019, the share of diesel decreased to 32%. With this ratio being more than one third of the market, it represents the lowest level since the early 2000s when diesel was newly launched.

If we examine the five largest markets, the share of diesel cars in the French market, which was 70% in 2010, well above the EU average, fell to 34% in 2019, as the French government equalized the fuel tax on diesel and gasoline. Although not as obvious as in France, there is a serious recession in Spain and the UK. The share of diesel in new vehicle sales has declined to 28% in Spain and 25% in the UK.

But the news isn't all bad. While the diesel vehicle park in Italy maintains its strength with 40% in 2019, we see that the growth is realized in Central and Eastern Europe to a great extent. The diesel car market in Germany, which preserved its weight in the market until 2017 and decreased from 50% to 32% in 2017, tends to recover in 2019. Considering the fact that 4.5 million new diesel vehicles were registered in Europe in 2019, the dominance of diesel-powered vehicles on European roads continues despite the negative pressure on them.

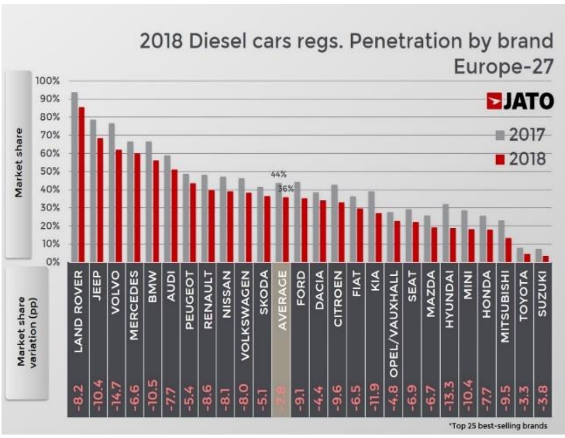

Figure 7-2018 diesel cars regs. Penetration by brand Europe-27

5) Increased aftermarket opportunities for passenger diesels

For the aftermarket, the news is even more promising. The decline in new diesel car sales is sudden but will not take effect immediately. This indicates that the after-sales service opportunity for diesel vehicles will continue to grow. How Does? Actually, it is 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. A few years ago, diesel-powered vehicles accounted for 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 around 6.7 in its current form. Therefore, these vehicles have a longer service life ahead. Because 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 after-sales market in the short term. According to the data, there will still be more than 113 million diesel passenger cars on European roads by 2024.

Today, there are more than 14 million diesel vehicles under 3 years old on European roads. These younger vehicles will need more repairs as they get older. This will create important opportunities for those who provide service to them. For example, the most current common-rail injector systems are subject to much faster wear as they perform multiple injections and inject fuel at much higher pressures. This leads to much more complex and costly repairs.

However, it is not just diesel fuel injection components, which benefit aftermarket space. Diesel vehicle drivers, on average, drive more kilometres than gasoline vehicle users. This means additional opportunities in terms of wear and tear repairs.

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

6) What Is the Design of 3-Cylinder Engines?

Generally, 3-cylinder engines use crankshaft, which is crankshaft angle 120 degrees because this crankshaft degree supply evenly spaced firing interval. One of benefits of this configuration is that this configuration provides perfect primary and secondary balance, but there are end-to-end rocking couple since there is no symmetry in the middle point of the engine so engine wants to revolute around its own axis. This is one of reasons of vibration. For old 3-cylinder engines manufacturers used a balance shaft and this balance shaft rotates twice speed of crankshaft in the engine and ensure balance. However, this balance shaft increase fuel consumption and stealing from the power of engine. Therefore, there is no balance shaft for new 3-cylinder engines. The manufacturer maintains the main balance by producing the crankshaft, flywheel or any rotating part in a calculated way more unbalanced. Advantage of this method is that there are reducing on main weight of engine so this supply more power.

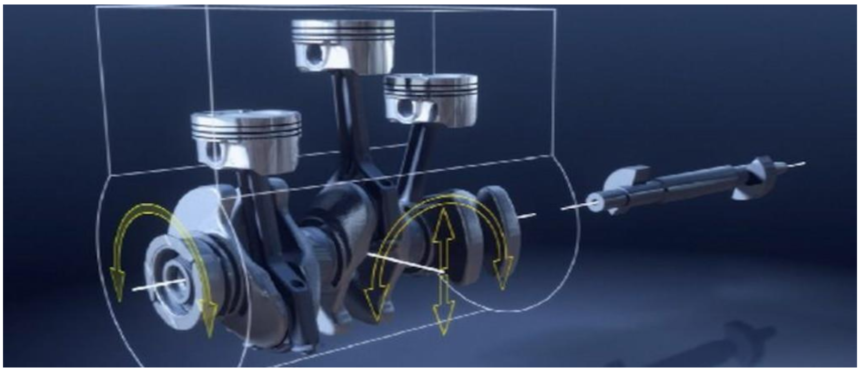

Figure 8- Vibration schema of 3 cylinders piston crank connecting rod mechanism

Manufacturers sometimes use different crankshaft, which have different angles. For example,

The 1976-1981 Laverda Jota motorcycle used a 180 degrees crankshaft, where the outer piston 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. We can give one more example; 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. There are many different type of design for 3-cylinder engine but all of them similar working process.

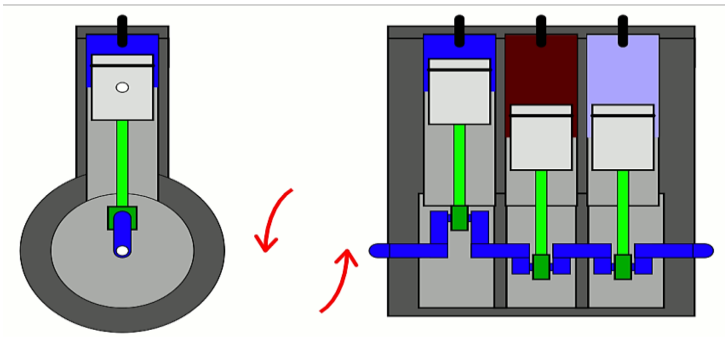

Figure 9- Firing order 3 cylinders engine

7) Vibration of 3-Cylinder Engine

You can also observe this; at most, 3-cylinders idle instantaneous. It was a little more noticeable in the old atmospheric 3-cylinders. However, you do not feel that much in the new generation Turbo. Because they are designing their engines much better. When you open the hood of the car and look at it, the engine is at idle mode due to the power cut. This tip is to avoid a problem, as the current 3-cylinders usually have a slightly higher idle speed. When you are looking at an atmospheric, 4-cylinder engine, its Idle is not too high. After warming up close to 500 - 600 revolutions, it catches the idle speed. However, this cut power is getting a little higher in general on 3-cylinders to reduce this excitement a little bit. It can be kept in a place that rises up to 750, 800, 900 cycles. Again, this unsymmetrical structure has another disadvantage. It is also about vibration. 3-cylinder engines Number 4 is on the same cylinders, we mentioned. With respect to the middle of the engine, these pistons do not try to rotate the engine in a symmetrical movement. These two forces cancel each other out. Therefore, Neutrals and motor can work in a balanced way. In 3-cylinders, the engine wants to turn a little in its own minus for such a movement. The movement of these pistons tries to rotate the engine continuously right and left. This is again one of the sources of vibration. In the old generation 3-cylinders, one more Balancing shaft was connected to compensate for these vibrations and make them not felt. This balance shaft used to rotate 2 times of the crank inside the motor to prevent these vibrations.

8) What kind of fuel system do they use?

Fuel Systems in 3-cylinder Gasoline Engines

1- Carburettor Engines

2- Engines with Single Point Injection System (Single Point Injection - SPI)

3 - Engines with Multi Point Injection System (Multi Port Injection - MPI)

4 - Direct Gasoline Injection Engines (Gasoline Direct Injection - GDI)

Fuel Systems in 3-cylinder Diesel Engines

1. Common Rail

What is Common Rail System?

A. Fuel Systems in Gasoline Engines

Fuel injection is the system that sends fuel to the cylinders in gasoline engines. Injection systems in modern engines have taken over the work done by the carburettor system in old type engines. Injection systems are now used in new generation gasoline atmospheric or charged engines. With the developing technology, today's injection systems provide serious fuel savings. At the same time, emission values are lowered to protect the environment and atmosphere.

- Carburettor Systems - Engine fuel systems used in old model cars. It is a system that takes fuel from the fuel chamber with the vacuum effect of the air entering the intake manifold and sends it to the intake manifold and then to the cylinders.
- Single Point Injection (SPI) - Similar to carburettor system. The difference is that it uses injectors to deliver fuel. The injector connected to the throttle sprays the fuel over the throttle.
- Multi-Port Injection System (MPI) - It is produced to have one injector in each cylinder. It sprays the fuel into each cylinder where the intake valve is located.
- Gasoline Direct Injection (GDI) - It is the most advanced and efficient injection system. It gives fuel directly to the combustion chamber of the engine. It can spray fuel at the time of suction, compression and even combustion.

- ***Carburettor Engines***

The air absorbed by the suction power of the pistons in the cylinder, while passing through the carburettor, drags some gasoline with it and evaporates it, and the resulting gas mixture enters the cylinders and is ignited by the spark scattered from the spark plugs. The carburettor automatically adjusts the air to be sucked and the proportion of gasoline to be mixed with additional equipment.

- ***How Do Carburettor Engines Work? - What Does a Carburettor Do?***

The carburettor simply consists of an air pipe narrowing in the middle and a gas tank connected to this pipe by a few thin channels. The air tube is called throat, and the narrowed part of the throat is called venturi. According to the laws of physics, the air sucked into the engine gains speed as it passes through the venturi and creates low pressure in this section. The low pressure (vacuum) that occurs enables the fuel in the gasoline chamber to be sucked and mixed with the air to move towards the cylinder or cylinders. Therefore, the main fuel channel opens to the venturi. There is a throttle valve that adjusts the amount of air to be taken into the engine, hence the air-fuel mixture, in the part of the throat after the venturi according to the direction of airflow. The throttle works by the action of the accelerator pedal in cars. By pressing the accelerator pedal, the driver actually increases the opening of the throttle.

Gasoline is sent to the reservoir in the carburettor via the gas pump. There is a float valve here to keep the amount of gasoline in the reservoir at a constant level. Modern carburettors are equipped with many complex systems in order to ensure that gasoline engines used in cars can operate at the desired power and speed according to changing conditions. Since the density and other physical properties of gasoline and air are different, only the throttle cannot control the amount and ratio of the air-fuel mixture. Despite the many systems developed, it was understood that carburettors could not be obtained at a perfect level, and most modern vehicles replaced the fuel injection system today.

- ***Engines with Single Point Injection System***

We can describe single point injection systems as a slightly improved carburettor. Thanks to an injector attached to the throttle valve, fuel is sprayed into the intake manifold. This sprayed fuel is mixed with air and given to the cylinders through the intake valves.

Figure 10- Single point injection system

This system, which started to be used in the 1980s, was generally used in American-made cars and vans. Used in a small number of European cars, these system parts have not been reproduced due to their costs. It was not produced considering the costs of the parts, as it does not have more advantages over the carburettor.

- ***Engines with Multi Point Injection System (Multi Port Injection - MPI)***

Another name for the multi-point injection system is port fuel injection (PFI). It started to be produced in the 2000s. Each cylinder has a special injector. These injectors spray the fuel into the intake valve. By opening the intake valve, air fuel mixture is given to the cylinder. In this system, injectors spray at the same time. However, the Sequential Fuel Injection - SFI, produced later, sprays in the injector when it is time to intake. In the sequential injection system, the engine control unit opens each injector separately.

Figure 11- Multiport injection system

The low-pressure fuel pump in the gasoline tank sends the fuel to the fuel log where the injectors are connected. Thanks to the pressure-regulating valve, the fuel stays at a constant pressure in the pressure register. Receiving command from the engine control unit, the injector opens and sprays the fuel at the point where the intake manifold and cylinder head meet, just before the intake valve.

In this injection system, the fuel pressure is at low pressure, which is around 3-5 bar, as in the single row system. This pressure is sufficient for the fuel to be injected.

- ***Direct Gasoline Injection Engines (Gasoline Direct Injection - GDI)***

Gasoline direct injection systems are the most advanced and efficient injection systems. The main difference of this system from other injection systems is that it sprays the fuel directly into the combustion chamber. So how does this injection system work? The low-pressure fuel pump pressurizes the fuel from the fuel tank a little and gives it to the high-pressure pump that works coupled to the engine and takes its motion from the crankshaft. Thanks to the high-pressure pump, the fuel reaches the value of 50-120 bar. There are injectors connected to the combustion chamber of each cylinder. These injectors are operated by means of a solenoid. The solenoid actually acts as a valve. Injectors are engine parts with springs and needle valves. By opening the solenoid, the fuel coming to the injector overcomes the spring pressure inside, and by pushing the needle valve up, it pulverizes the fuel into the combustion chamber through nozzles. Then the solenoid valve closes and cuts the fuel coming to the injector.

Figure 12- Gasoline direct injection

Sensors that calculate the combustion quality and engine load in the car send the information to the engine control unit. Upon this information, the engine control unit decides how much fuel will be sent to the combustion chamber by opening the solenoids of the injectors. In other words, the engine control unit (ECU - Engine Control Unit) adjusts the solenoid's opening time and open time according to the load of the engine. The parts that determine the load of the engine are examined under the heading of air systems. These are MAF and MAP sensors. To put it briefly, the MAF sensor measures the mass of the air entering the engine. The MAP sensor measures the vacuum value in the manifold and sends a signal to the engine control unit. In addition, oxygen sensors connected to the exhaust manifold outlet measure the combustion quality and report the amount of air fuel mixture to the engine control unit.

B. Fuel Systems in Diesel Engines

Combustion in diesel engines occurs when the diesel is sprayed into the cylinders with high-pressure and combined with the compressed hot and compressed air in the cylinder. Diesel coming out of the high-pressure pump comes to the injector with high pressure and waits for the burning time. The fuel, which is sprayed, pulverized from the injector of the cylinder when it is coming to burn, combines with the air and creates the burning time.

Figure 13- Fuel burning

In fact, injectors are structurally opening valves whose opening pressure value can be adjusted. When the fuel pressure reaches this set pressure value, the injector opens and the fuel is sprayed in a pulverized way through the holes on the injector tip. In addition to facilitating the combustion of the pulverized fuel, it facilitates the distribution of fuel particles to each side of the cylinder combustion chamber. The better the pulverization, the better quality it is in combustion. For this reason, injectors may malfunction from time to time. The biggest problem in diesel engines is actually injector malfunctions because their maintenance is expensive. Decrease in injector opening pressure or worsening of pulverization will cause bad combustion in the engine, causing the engine to emit black smoke and reduce its draft.

- ***What is Common Rail System?***

Common Rail is a fuel injection system used in diesel engines, meaning "holder injection" or "common pipe". It is a superior system in terms of fuel consumption, exhaust gas emission, working system and noise generation compared to the same type of systems used until today. Unlike directly driven block or single pump systems, pressure build-up and spraying are separated in Common-Rail. While conventional diesel direct sprayers operate with a pressure of about 900 bar, the Common-Rail System distributes the fuel to the injectors over a common pipe with a pressure rising up to 1500 bar. The electronic engine control adjusts this high pressure depending on the speed and load of the engine.

Quickly switched solenoid valves on the injectors provide the spraying. This provides new possibilities in terms of shaping the spray, measuring the amount of spraying and fuel injection. Also, thanks to these possibilities, Pilot (front) Spraying, which is an excellent advantage of the new system, emerges.

- ***What is Pilot (Pre) Spray? What does it do?***

Pilot spraying occurs before the actual main spray, greatly improving output rates for fuel combustion. Pre- or multiple spraying is created by actuating the fast solenoid valves multiple times. Thus, both the emission of harmful substances and noise and the consumption values of diesel engines are further reduced. Common-Rail system can replace the used spray system without any major changes to the engine.

The only requirement for the separation of pressure generation and spraying is the High Pressure Restraint, which consists of a distributor pipe (rail) and pipes leading to the injectors. The core part of the system is a magnetic valve operated injector. The spraying event is initiated by a signal from the brain to the magnetic valve. Meanwhile, the amount sprayed depends on both the opening time of the solenoid valve and the system pressure. The high-pressure piston pump creates the system pressure. Said pump operates with low drive torque, which reduces the load on the pump drive. Distributor type pumps in passenger cars for pressure build-up; row type pumps are foreseen in commercial vehicles. In common-rail systems, the brain, sensors, and most system functions are equivalent to the time-dependent single pump systems such as the pump-nozzle-unit and pump-pipe-nozzle found in others. Improvements reached with the common-rail technique can be heard and measured. Thanks to pre-spray, this direct sprayer operates with the low noise level of the engine with pre-combustion chamber, while also complying with the strictest exhaust gas emission rules.

9) Who use 3-cylinder engines?

3-cylinder engine technologies, which have been used in both motorcycles and vehicles for many years, are widely used in vehicles called small vehicle class, especially in Japan. However, European markets and in Turkey could not be so accustomed to this type of engine. We can say that traditional 4-cylinder atmospheric gasoline or turbo-charged diesel engines are ingrained in our culture. However, 3-cylinder engines continue to increase in popularity every day due to reasons such as compliance with exhaust emission criteria and competition in fuel efficiency.

These engines, which have started to be seen especially in A, B and C segment vehicles, try to achieve high performance values with small volume but turbocharged systems in today's technologies. As you know, the engine size of old model vehicles would be large, but their performance would be low. The vehicles would be much heavier and stouter. Now, vehicles are much lighter, and at the same time with small engines, namely turbochargers in 1.0, 1.2, 1.6 litter volumes, they can catch and even exceed the same torque values as the 2.0, 2.5, 3.0 litter volume of old generation vehicles. Ford has a three-cylinder unit called Eco boost.

10)A Brief History of Using 3-cylinder Engine in Cars

The straight 3-cylinder, which is two stroke, was first used in DKW-F91 in the 1953-1955, and it powered 900 cc. Then, Saab introduced its 3-cylinder straight engine which is two stroke in the between 1956-1960. This engine powered 750 cc and was used in Saab 95 and Saab 96 until 1980. The Wartburg cars and FSO Syrena also used straight-three engines.

Figure 15- SAAB 3 cylinders engine

Figure 14- DKW-F91

Moreover, in 1967, Suzuki used a two-stroke 3-cylinder engine, which is powered 256 cc and Suzuki used this engine in Suzuki Fronte 360. Later, they improved their 3-cylinder engine, they made it four-stroke, and this four-stroke engine powered 543 cc.

The Subaru EF engine is a 4-stroke petrol engine, which was introduced in 1984 and used in the Justy and the Sumo.

The Ford Company introduced its straight 3-cylinder engine, which is Ford Eco Boost Engine- a turbocharged 1.0 L petrol engine in 2012. It uses of 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 balancer shafts. In 2016, cylinder deactivation was added, claimed to be a world first for three-cylinder engines.

11) Why companies start to prefer 3-cylinder engine instead of 4-cylinder engine

In general, there are differences in engine interiors as well, as it has one cylinder missing from 4-cylinder engines. Especially in these engines, which differ in terms of crank placement, positioning is made at an angle of 120 degrees. In three-cylinder engines, the pistons move independently in time and the biggest difference from the 4-cylinder is that they do not fire continuously. "3-cylinder engines shake." This is how the interpretation is technically explained. In other words, since there is no continuous ignition time, 3-cylinder engines experience a delay in the moment of detonation, which is why the experience of "tremors" felt at idle. This feeling has become less in the new generation turbocharged vehicles, because they are improving the engine ears. As the engine becomes more compact, an advantage in weight is provided. It also contributes to volume. At the same time, they provide fuel efficiency as friction and weight decrease. As the parts are reduced, there is a decrease in the production cost, so an advantage is obtained in terms of price. At the same time, we can say that the exhaust sound is much more pleasant than the half of the row 6 cylinders. When we think why 3-cylinder engines have better fuel economy we will see that answer the main reasons of fuel efficiency are that firstly, reduced frictional force and secondly, lighter weight. Since there is one cylinder less, the frictional losses caused by metal surfaces coming in contact within the engine block is lesser. This translates to more force production for lesser fuel. Adding to that, due to the absence of one cylinder, the engine block is much lighter. Even the crankshaft constructed to hold the pistons is lighter. There is a good amount of overall weight savings. Both of these factors combined give three cylinder engines an upper hand in terms of fuel efficiency. Considering all the above results, we understand why companies have started to prefer 3-cylinder engines.

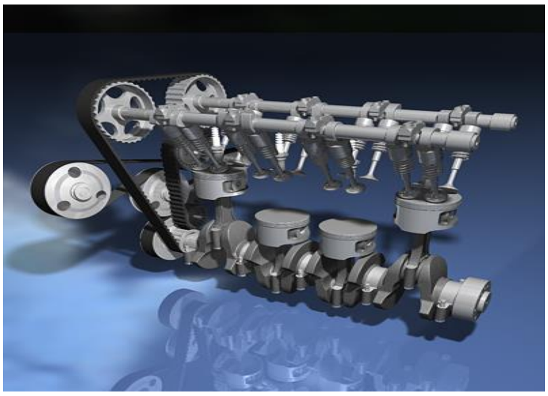

Figure 17- Piston crank and connecting rod mechanism with Valve Mechanism

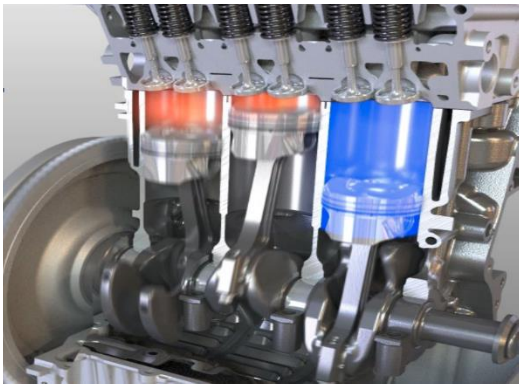

Figure 16- Firing order

12) What is the advantages of the 3-cylinder engines?

- Less vibration compared to engines without three cylinders in new models.
- A 3-cylinder engine can give you everything a 4-cylinder engine can give you.
- Fuel efficiency is high.
- The best way to save fuel is to use less fuel. By downsizing the cylinder volume, emission and consumption values can be reduced.
- Engines with decreasing volume become lighter and provide less fuel consumption.

13) SOME EXAMPLES OF 3-CYLINDER ENGINE

A. Ford Eco Boost:

The award-winning 1.0 litter Eco Boost engine has three different power combinations of 100PS, 125PS, and 140PS. Our Focus, C-MAX, Kuga and Mondeo models offer the Eco Boost 1.5-liter variant, the Fiesta ST 2.0-liter, the Mustang and Focus RS a 2.3-liter, and the GT 3.5-liter variant.

Eco Boost engine technology that produces high power from low volume; Available in Fiesta, Fiesta ST, Focus, Focus RS, C-MAX, Kuga, Mondeo, Mustang and GT models.

Type of internal combustion engine	Four-stroke, turbocharged
Cylinder block material	Cast Iron
Cylinder head material	Aluminium
Fuel type	Gasoline
Fuel system	Direct fuel injection
Configuration Stroke Bore Ratio	Inline 1.14
Number of cylinders	3
Valves per cylinder	4
Displacement, cc	999 cc
Compression Ratio	10.0:1
Power, hp	100-125 hp
Torque, lb ft	130-150 lb-ft
Engine weight	97 kg
Firing order	1-2-3

Table 1- Properties of Ford Ecoboost Engine

Figure 18- Ford Ecoboost Engine

B. Renault H4B 0.9 TCE Engine

The small 0.9-liter turbocharged three-cylinder engine H4Bt was developed jointly with Nissan Company (Renault named all these engines as H series and Nissan - HR series). The engine combined all modern technology for today available in the low-cost market segment. Renault pursued the strategy of downsizing in the engine development and the using of turbocharging for increasing engine efficiency.

Type of internal combustion engine	Four-stroke, turbocharged
Cylinder block material	Aluminium
Cylinder head material	Aluminium
Fuel type	Gasoline
Fuel system	fuel injection
Configuration	Inline
Stroke Bore Ratio	1.01
Number of cylinders	3
Valves per cylinder	4
Displacement, cc	898 cc
Compression Ratio	9.5:1
Power, hp	90/5000 (66kW)
Torque, lb ft	100/2000-3500 (135 N m)
Engine weight	------------
Firing order	1-3-2

Table 2- Properties of Renault H4B Engine

Figure 19- Renault H4B Engine

C. Volkswagen 3 cylinder 1.4 litter TDI engine:

The new three-cylinder 1.4 TDI engine belongs to the EA288 series. It moved out the 1.2-liter 3-cylinder EA189 engine. However, it also able to replace some versions of the four-cylinder such as the 1.6 TDI. The 1.4 TDI uses four-cylinder engine components reconfigured for the three-cylinder layout. That is the example of the new VW development system - modular diesel engine or MDB.

The crankcase or cylinder block is made of gravity-die-cast AlSiCu3 alloy for weight reduction. The new material allowed reducing the weight by 11 kg compared the previous 1.2l TDI engine. It also almost 27 kg lighter than the 1.6 TDI. The engine has balancing shaft, which driven by a single speed 1:1 gear in the opposite direction to the crankshaft.

Figure 20- Volkswagen 1.4 TDI engine

Type of internal combustion engine	Four-stroke, turbocharged
Cylinder block material	Aluminium
Cylinder head material	Aluminium
Fuel type	Diesel
Fuel system	Common Rail
Configuration	Inline
Stroke Bore Ratio	1.20
Number of cylinders	3
Valves per cylinder	4
Displacement, cc	1422 cc
Compression Ratio	16.1:1
Power, hp	75/3000-3750 - 50kW 90/2750-3250 - 66kW 104/3500-3750 - 77kW
Torque, lb ft	155/1500-2000 170/1500-2500 184/1500-2500
Engine weight	------------
Firing order	1-2-3

Table 3- Properties of Volkswagen 1.4 TDI engine

1.4 TDI Volkswagen Engine Problems and Reliability

The issues and problems are the same as four-cylinder EA288 engines have. This engine produces more vibrations due to the three-cylinder layout. In addition, the aluminium crankcase is not repairable as cast iron crankcases.

D. Volkswagen Audi 1.0 TSI EA211

The 1.0 TSI is the smallest engine from the EA211 family. The Volkswagen introduced the engine in 2015 as another step of its downsizing strategy. It is a 1.0-liter 3-cylinder gasoline turbocharged engine planed for the VW Polo Mk6, Golf Mk7, and other cars of the Volkswagen AG in different output versions.

The cylinder block for 1.0l TSI is made from die-cast aluminium alloy and has an open-deck design with rough-cast cylinder liners. The engine has a forged steel crankshaft with small crankshaft bearings (45 mm) and connecting rod bearings (47.1 mm) for vibration and friction reduction. The optimized moving masses of the forged connecting rods and aluminium pistons, the unique vibration damper and the flywheel with drilled holes allowed eliminate a balance shaft, despite the 3-cylinder design

Figure 21- EA 211 engine

Type of internal combustion engine	Four-stroke, turbocharged
Cylinder block material	Aluminum
Cylinder head material	Aluminum
Fuel type	Gasoline
Fuel system	Direct fuel injection
Configuration	Inline
Stroke Bore Ratio	1.03
Number of cylinders	3
Valves per cylinder	4
Displacement, cc	999 cc
Compression Ratio	10.5:1
Power, hp	75-115 hp (50-85 kW)/ 5,000-5,500
Torque, lb ft	118-147 lb-ft (160-200 Nm)/ 1,500-3,500
Engine weight	------------
Firing order	1-2-3

Table 4- Properties of EA 211 engine

E. Volkswagen Audi 1.2 TDI CR EA189

The 1.2 TDI-CR 3-cylinder diesel engine appeared first in 2009 as the new engine for the VW Polo. This engine is the result of downsizing in the engine development. The 1.2 TDI is derived by cutting one cylinder of the four-cylinder 1.6 TDI-CR engine.

The cast iron cylinder block is similar to the 1.6-liter version, but without one cylinder, it is shorter and lighter. The cylinder bore and stroke are the same. The forged steel crankshaft has counterweights for the first and third cylinder. The engine got balancing shaft driven by chain from the crankshaft. Balancing shaft is placed under the crankshaft in the crankcase.

Type of internal combustion engine	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	75/4200 (55kW) - CFWA
Torque, lb ft	132 lb-ft. (180 Nm)/2,000
Engine weight	------------
Firing order	1-2-3

Table 5- Properties of EA 189 engine

Figure 22- EA 189 engine

F. Hyundai KIA 1.0 MPi/T-GDi Engine

The Hyundai 1.0L MPi engine out of the Kappa family is a three-cylinder gasoline engine with multi-point fuel injection, and a part of the Hyundai-Kia product strategy directed to a high achievement with fuel efficiency. The engine was announced in 2011 and it is still a popular power plant for the Hyundai i10 and KIA Picanto.

The cylinder block is aluminium and designed as an open-deck type with cast iron liner. There is also a cast iron crankshaft. The shape of counterweights was optimized to minimize vibrations of a three-cylinder engine, which made it possible to exclude balance shaft from the design. The crankshaft seats in the block with the 11 mm offset against the cylinders line. For friction reduction, optimized lightweight pistons with a compression height of 24.7 mm and a short skirt length were applied. Piston rings are coated with Physical vapour Deposition (PVD); piston skirts are MoS2-coated.

Figure 23- Hyundai KIA 1.0 MPI/T-G Engine

Type of internal combustion engine	Four-stroke, naturally aspirated/turbocharged
Cylinder block material	Aluminium
Cylinder head material	Aluminium
Fuel type	Gasoline
Fuel system	Multi-point fuel injection; Direct injection
Configuration	Inline
Stroke Bore Ratio	1.18
Number of cylinders	3
Valves per cylinder	4
Displacement, cc	998 cc
Compression Ratio	10.5:1 - MPi 10.0:1 - T-GDi
Power, hp	66 hp (48 kW) /5,500 - MPi 68 hp (49 kW) /6,200 - MPi LPG version 100 hp (74 kW) /4,500 - T-GDi 120 hp (88 kW) /6,000 - T-GDi
Torque, lb ft	70 lb-ft (95 Nm)/ 3,500 - MPi 66 ft-lb (90 Nm)/ 3,500 - MPi LPG version 127 ft-lb (172 Nm)/ 1,500-4,500 - T-GDi
Engine weight	71.4 kg
Firing order	1-3-2

Table 6- Properties of Hyundai KIA 1.0 MPI/T-G Engine

Hyundai Kia 1.0L MPi/T-GDi Engine Problems and Reliability

Despite the fact that a lot of effort was put into operation optimization of the three-cylinder engine, many owners complain of high levels of vibration and noise. In addition, real fuel consumption does not always correspond to the declared by the manufacturer. Small engines are sensitive to increased loads due to a small torque, which leads to increased fuel consumption. The most dangerous problem is that Hyundai's 1.0-liter three-cylinder engine overheats easily if you do not keep an eye on the condition of the radiator.

In general, Kappa engines are very reliable and the shortcomings are related to exploitation for the most part. Average engine life for both power units is about 120,000 miles (200,000 km).

G. HONDA E07A

There were three versions of fuel supply systems for this motor: Carburettor (PGM-CARB), fuel injection (PGM-FI) and MTREC (Multi Throttle Responsive Engine Control). The MTREC version of this engine has the highest power output of the various configurations.

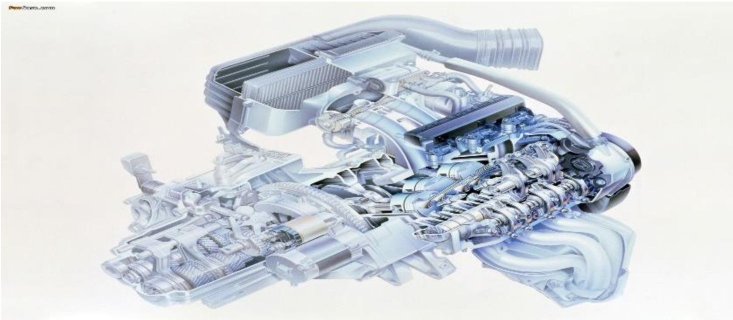

Figure 24- E07A engine

Type of internal combustion engine	Water-cooled 3-cylinder
Cylinder block material	Aluminum
Cylinder head material	Aluminum
Fuel type	Gasoline
Fuel system	SOHC 12 Valve CV carburetor
Configuration	Inline
Stroke Bore Ratio	0.96
Number of cylinders	3
Valves per cylinder	---------
Displacement, cc	656 cc
Compression Ratio	10.5:1 - MPi 10.0:1 - T-GDi
Power, hp	42 PS (31 kW; 41 hp) / 6,000 rpm
Torque, lb ft	5.4 kg·m (53 N·m; 39 lb·ft) / 5,000 rpm
Engine weight	----------
Firing order	-----------

Table 7- Properties of E07A engine

H. Daihatsu K – series engine:

The Daihatsu K-series engine is a series of three unrelated engine families (KF, KR and K3/KJ), even though named with same initial "K" letter code. These engines were built in DOHC 12-valve inline three (KF & KR) and DOHC 16-valve inline four (K3/KJ) engine layout, ranging from 0.66 L, 1.0 L and up to 1.3 L. All engine families are available in naturally aspirated and turbocharged form.

Figure 25- DAIHATSU K engine

Type	Displacement	Bore x Stroke	Bore Pitch	Cylinders	Compression	Power	Torque	Application
KF-DE	658 cc	63 x 70.4 mm	78 mm	3	11.5	50 PS (49 hp; 37 kW) at 6,900 rpm	60 N·m (6.1 kg·m; 44 lbf·ft) at 3,600 rpm	• Not available
KF-VE (with DVVT)						50 PS (49 hp; 37 kW) at 5,700 rpm	64 N·m (6.5 kg·m; 47 lbf·ft) at 4,000 rpm	• S200 Daihatsu Hijet Truck/Toyota Pixis Truck/Subaru Sambar • S320 Daihatsu Hijet Cargo/Toyota Pixis Van/Subaru Sambar Van
						53 PS (52 hp; 39 kW) at 7,000 rpm		• S200 Daihatsu Hijet Truck/Toyota Pixis Truck/Subaru Sambar • S320 Daihatsu Hijet Cargo/Toyota Pixis Van
						58 PS (57 hp; 43 kW) at 7,200 rpm	65 N·m (6.6 kg·m; 48 lbf·ft) at 4,000 rpm	• L175 Daihatsu Move • L255 Daihatsu Esse • L275 Daihatsu Mira/Subaru Pleo • L375 Daihatsu Tanto • L455 Daihatsu Tanto Exe/Subaru Lucra • L575 Daihatsu Move Conte
						52 PS (51 hp; 38 kW) at 7,200 rpm	60 N·m (6.1 kg·m; 44 lbf·ft) at 4,000 rpm	• L275 Subaru Pleo • LA100 Daihatsu Move/Subaru Stella • LA250 Daihatsu Cast/Toyota Pixis Joy • LA700 Daihatsu Wake/Daihatsu Hijet Caddie/Toyota Pixis Mega • L575 Daihatsu Move Conte/Toyota Pixis Space
					11.3	52 PS (51 hp; 38 kW) at 6,800 rpm	60 N·m (6.1 kg·m; 44 lbf·ft) at 5,200 rpm	• LA300 Daihatsu Mira e:S/Toyota Pixis Epoch/Subaru Pleo Plus • LA550 Daihatsu Mira Tocot • LA600/650 Daihatsu Tanto/Subaru Chiffon • LA800 Daihatsu Move Canbus
						46 PS (45 hp; 34 kW) at 5,700 rpm	60 N·m (6.1 kg·m; 44 lbf·ft) at 4,000 rpm	• S320 Daihatsu Hijet Cargo/Toyota Pixis Van/Subaru Sambar Van • S500 Daihatsu Hijet Truck/Toyota Pixis Truck/Subaru Sambar Truck
						53 PS (52 hp; 39 kW) at 7,200 rpm		• S320 Daihatsu Hijet Cargo/Toyota Pixis Van/Subaru Sambar Van • S500 Daihatsu Hijet Truck/Toyota Pixis Truck/Subaru Sambar Truck
					12.2	49 PS (48 hp; 36 kW) at 6,800 rpm	57 N·m (5.8 kg·m; 42 lbf·ft) at 5,200 rpm	• LA350 Daihatsu Mira e:S/Toyota Pixis Epoch/Subaru Pleo Plus
KF-VE (CNG with DVVT)					12.8	45 PS (44 hp; 33 kW) at 7,200 rpm	64 N·m (6.5 kg·m; 47 lbf·ft) at 4,000 rpm	• L275 Daihatsu Mira Van (Gas powered car)
						39 PS (38 hp; 29 kW) at 6,400 rpm	52 N·m (5.3 kg·m; 38 lbf·ft) at 4,000 rpm	• S320 Daihatsu Hijet Cargo (Gas powered car)
KF-DET (turbocharged)					9.0	64 PS (63 hp; 47 kW) at 6,000 rpm	103 N·m (10.5 kg·m; 76 lbf·ft) at 3,000 rpm	• L175 Daihatsu Move (Custom R/R Limited/RS) • L375 Daihatsu Tanto Custom RS • L405 Daihatsu Sonica • L575 Daihatsu Move Conte/Toyota Pixis Space Custom RS
						64 PS (63 hp; 47 kW) at 5,700 rpm	103 N·m (10.5 kg·m; 76 lbf·ft) at 2,800 rpm	• LA100 Daihatsu Move • L275 Daihatsu Mira/Subaru Pleo Custom RS • L455 Daihatsu Tanto Exe/Subaru Lucra Custom RS • S320 Daihatsu Atrai/Subaru Dias Wagon • S320 Hijet Cargo Cruise Turbo/Toyota Pixis Van Cruise Turbo/Subaru Sambar Van VC Turbo
						64 PS (63 hp; 47 kW) at 6,400 rpm	95 N·m (9.7 kg·m; 70 lbf·ft) at 4,000 rpm	• LA150 Daihatsu Move/Subaru Stella Custom RS • LA700 Daihatsu Hijet Caddie
						64 PS (63 hp; 47 kW) at 6,400 rpm	95 N·m (9.7 kg·m; 70 lbf·ft) at 3,200 rpm	• LA400 Daihatsu/Toyota Copen GR Sport • LA600/650 Daihatsu Tanto/Subaru Chiffon Custom RS
KF-VET (with DVVT)					9.5	64 PS (63 hp; 47 kW) at 6,000 rpm	103 N·m (10.5 kg·m; 76 lbf·ft) at 3,000 rpm	• LA250 Daihatsu Cast (G Turbo/Sport)/Toyota Pixis Joy (G Turbo/S) • LA700 Daihatsu Wake/Toyota Pixis Mega X/G

Figure 26- Properties DAIHATSU K types Engines

i. Mercedes-Benz OM639 engine

The OM639 is based on the four-cylinder OM640 engine and features a dual mass flywheel, exhaust gas recirculation, and Euro 4 emission standard compliance. It is transversely mounted behind the front axle and inclined 60 degrees due to the sandwich floor design used in the Smart and Mitsubishi models, so the engine slides underneath the floorplan instead of into the cabin in the event of a head-on collision to improve safety.

Figure 27- OMG 639 Engine

Type of internal combustion engine	3-cylinder- single turbo
Cylinder block material	Aluminium
Cylinder head material	Aluminium
Fuel type	Diesel
Fuel system	Direct injection Common rail
Configuration	Inline
Stroke Bore Ratio	1.10
Number of cylinders	3
Valves per cylinder	---------
Displacement, cc	1493 cc
Compression Ratio	18:1
Power, hp	50-70 kW (67-94 hp)
Torque, lb ft	160-210 N.m (118-155 lb.ft)
Engine weight	----------
Firing order	-----------

Table 8- Properties of OMG 639 Engine

J. BMW B37

The BMW B37 is a 1.5-litre (1,496 cc), diesel, 3-cylinder engine with a single, mono-scroll and VTG turbocharger. The compression ratio is 16.5:1. It is the second engine from BMW's modular engine plan sharing most of its components with the B38 petrol engine. Power output is either 95 or 116 PS (70 or 85 kW).

Figure 28- B37 Engine

Type of internal combustion engine	3-cylinder- single turbo
Cylinder block material	Aluminium
Cylinder head material	Aluminium
Fuel type	Diesel
Fuel system	Direct injection Common rail
Configuration	Inline
Stroke Bore Ratio	1.07
Number of cylinders	3
Displacement, cc	1496 cc
Compression Ratio	16.5:1
Power, hp	95-116 kW (70-85 hp)
Torque, lb ft	220-270 N.m (162-199 lb.ft)
Engine weight	----------
Firing order	-----------

Table 9- Properties of B37 Engine

K. Mercedes-Benz OM660 engine

The OM660 is a turbocharged straight-three engine produced by Mercedes-Benz for use in Smart vehicles, from 1999 to 2014.

The OM660 features a single-overhead camshaft with two valves per cylinder and an aluminium alloy cylinder block and head. It is turbocharged and features an exhaust gas recirculation system. The OM660 was updated in 2007 receiving increased performance due to a new common rail fuel system with increased boost pressure, and again in 2011 featuring further performance and efficiency improvements.

Figure 29- OM 669 Engine

Type of internal combustion engine	3-cylinder- single turbo
Cylinder block material	Aluminium
Cylinder head material	Aluminium
Fuel type	Diesel
Fuel system	Direct injection Common rail
Configuration	Inline
Stroke Bore Ratio	1.21
Number of cylinders	3
Valves per cylinder	2
Displacement, cc	799 cc
Compression Ratio	18.5:1
Power, hp	30-40 kW (40-54 hp)
Torque, lb ft	100-130 N.m (74-96 lb.ft)

Table 10- Properties of OMG 660 Engine

14) CHOSING A REFERANCE ENGINE

After we analyze all above engines, we make a choice to be reference engine. Later, we chose the EA189 engine as our reference engine and started to work on it.

- ***Why We Chose EA189 Engine?***

We chose the EA189 engine because it is more innovative and more efficient than the other 3-cylinder diesel engines. In addition, accessing your data is a bit easier than others are.

EA189 is a TDI engine. TDI engine is one of the engine types whose fuel type is diesel. It is also known as an injection turbo diesel engine. It has an engineering structure that can convert a very high proportion of the energy in the fuel into motion energy. The TDİ system, which consists of the initials of the words Turbocharged Direct Injection, works by the method of directly spraying the fuel to the engine. It is necessary to take care not to use bad fuel in TDİ engines, the smallest of which is two cylinders and the largest is 12 cylinders. The TDI engine type is a type of engine produced by the Volkswagen brand. Today it is used in a wide range of automobile segments, including other brands belonging to the group. These engines operating with a turbocharger system are used in diesel vehicles. TDİ type engines, which are a very durable engine type, also optimize fuel consumption well.

- ***Some Measurement of EA189 Engine***
    - **Connecting Rod**

We designed connecting rod according the crank pin and piston head and we draw as bellow.

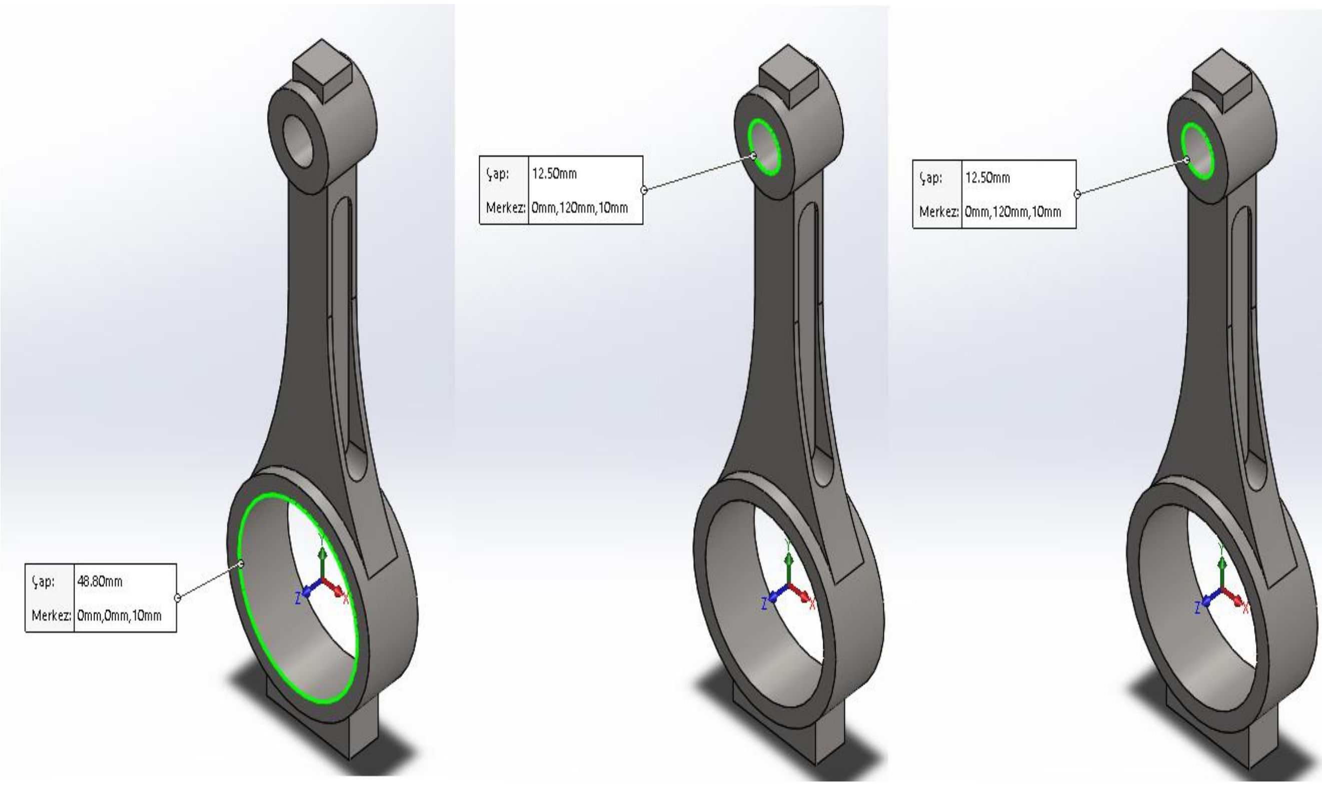

Figure 30-measurements of connecting rod

❖ Crank Shaft

We took crankshaft measurements from industry. We measured them with by measurement devices such as micrometer; caliper and we get below measurements.

MAIN BEARING JOURNAL	ROD BEARING JOURNAL
$54.00^{-0.022}_{-0.042}$	$47.80^{-0.022}_{-0.042}$

Table 11-Measurements of crankshaft

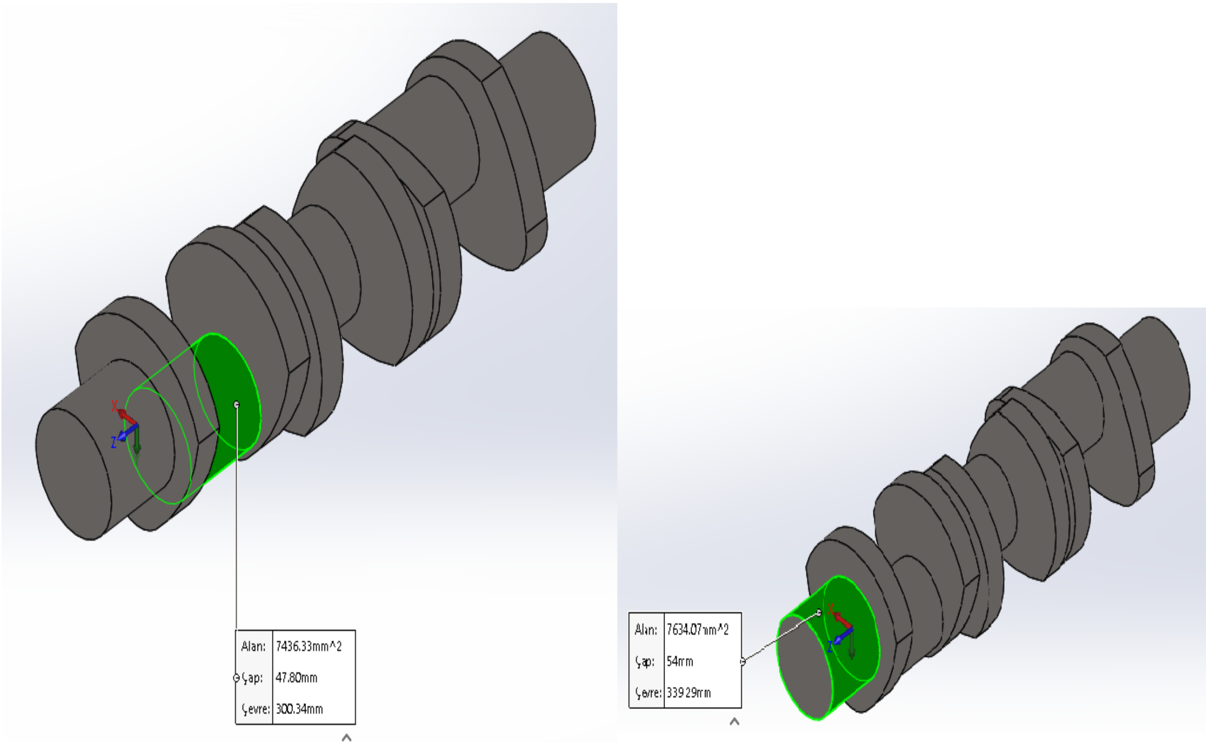

Figure 31- measurements of crankshaft on drawing

❖ **Piston – Cylinder Hole**

We took piston measurements from industry. We measured them with by measurement devices such as micrometer; caliper and we get below measurements.

PISTON Ø	CYLINDER HOLE Ø
90	30

Table 12- measurements of piston and cylinder hole

❖ **Piston mile**

We designed piston mile according the piston head and connecting rod and we draw as bellow.

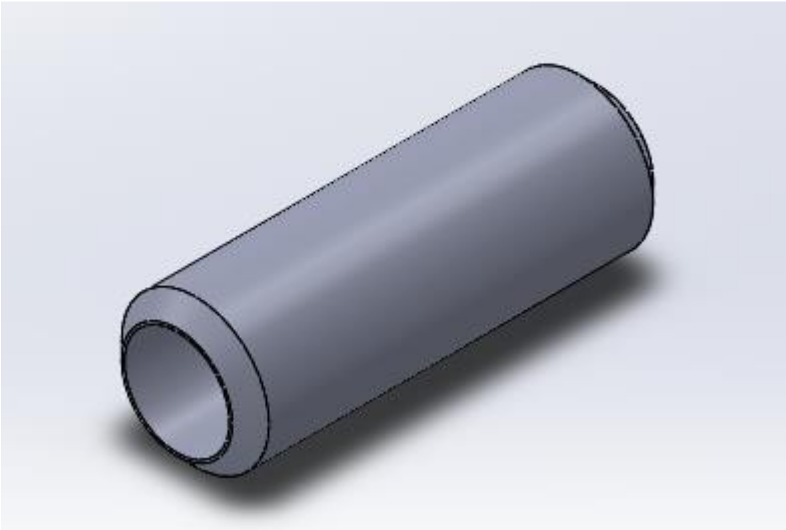

Figure 32-measurements of the piston mile

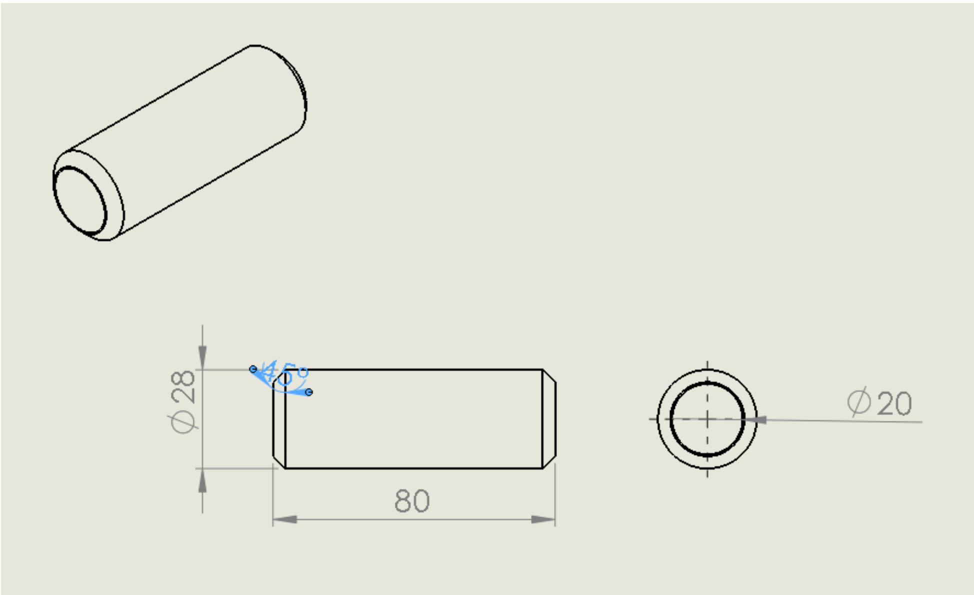

Figure 33-technical drawing of piston mile

❖ Lower Case

We designed lower case according the crankshaft, upper case and cylinder hole and we draw as bellow.

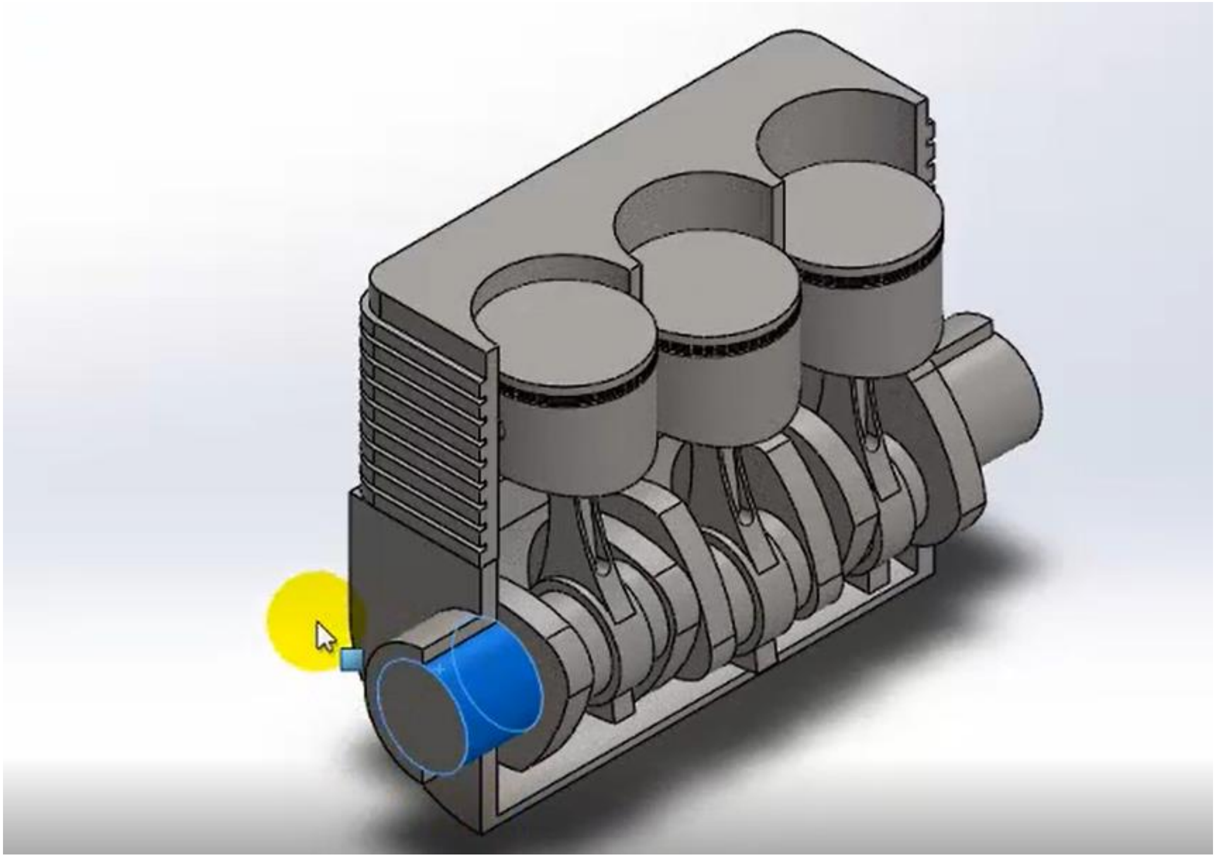

Figure 34-assembly of crankshaft-piston mechanism

Those all above figures are for show measured measurement. Measurements are shown in figure to understand clearly.

After those parts completed and measurements are shown now our designed, which is cylinder block and crank mechanism of a 3-cylinder diesel engine can be describe more clearly.

15) DESIGNED 3-CYLINDER DIESEL ENGINE

In this study, crankshaft mechanism and cylinder block of a 3-cylinder diesel engine is designed. In the beginning of this study, after the literature review and sample engine examinations, the design to be made was decided. During the literature review, it was understood that the main problem of the 3-cylinder engine was vibration, which try to rotate engine around its axis. As known, internal combustion engines generally have even number cylinder such as 4-cylinder or 6-cylinder. Therefore, when they are analyzed, it can be realized engine is produced like mirroring from the midpoint of it so applied forces and moment distribute equally both side of engine. Hence, the vibration, which try to rotate engine around, its axis is not occurred. Nevertheless, this is not the case for 3-cylinder engines because they have an odd number of cylinders, such as three. For this reason, vibration, which try to rotate engine around its axis, is occurs for 3-cylinder engines. There are two different way of prevent vibration. One of them is adding a balance shaft as shown below figure.

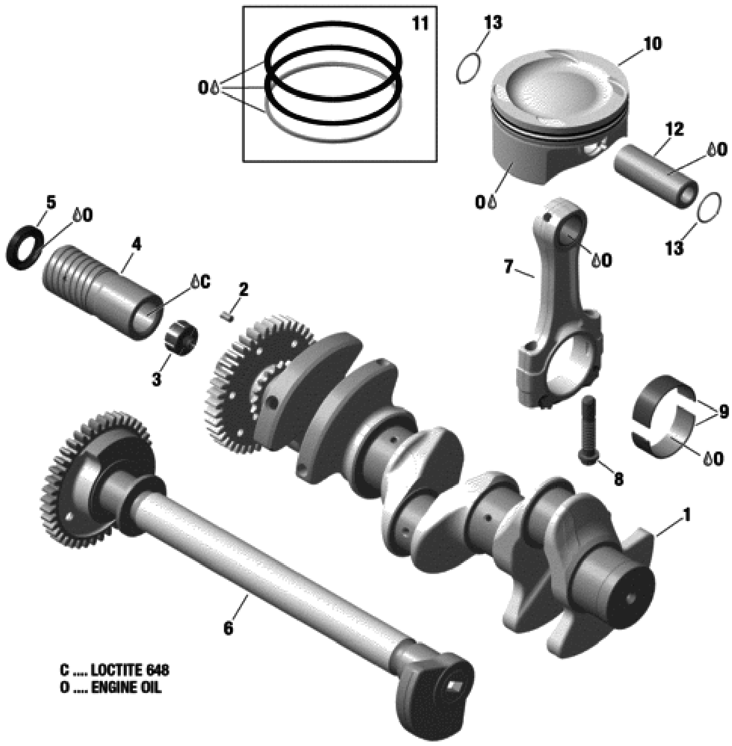

Figure 35-Crank Mechanism for 3-cylinder engine with balance shaft

As we see in above figure number 6 is represent a balance shaft. Purpose of this balance shaft is that the operating principle of a balance shaft system is that two shafts carrying identical eccentric weights rotate in opposite directions at twice the engine speed. The phasing of the shafts is such that the centrifugal forces produced by the weights cancel the vertical second-order forces (at twice the engine RPM) produced by the engine. The horizontal forces produced by the balance shafts are equal and opposite, and so cancel each other. However, there are some disadvantages of balance shaft;

- There are an extra rotating part in engine so this mean that it consume more fuel.
- As you know, this rotating balance shaft will steal power from the engine and perform the rotational movement, which reduces the power to the wheels.

The other way of prevent vibration is that, reducing weight of some part such as crankshaft, flywheel etc. This method is better than previous one because when we apply this method instead of previous one the lighter engine will be obtained. Therefore, more power will be obtained with the same amount of fuel consumption because the overall weight is reduced.

When advantages and disadvantages of both methods are considered, the second one method is better than the first one so the second method was used in this design to prevent vibration, which try to rotate engine around its axis.

There are six different types of engine lubrication as following;

- Petroil system
- Splash system
- Pressure system
- Semi-pressure system
- Dry sump system
- Wet sump system

When working type of 3-cylinder engines and engine speed of its considered the best lubrication type is semi-pressure system for it. Therefore, in this design semi-pressure system was used. Semi-pressure system works as following,

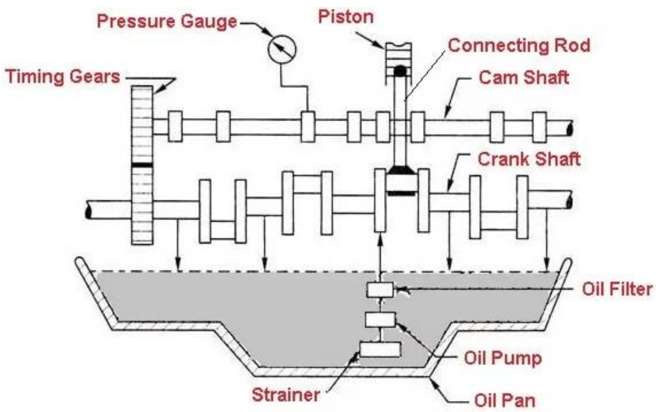

Figure 36-Semi-Pressure system

It is the combination of a splash system and pressure system of the lubrication system. Some parts are lubricated by splash system and some parts by a pressure system. Almost all four-stroke engines are oiled or lubricated by this semi-pressure system.

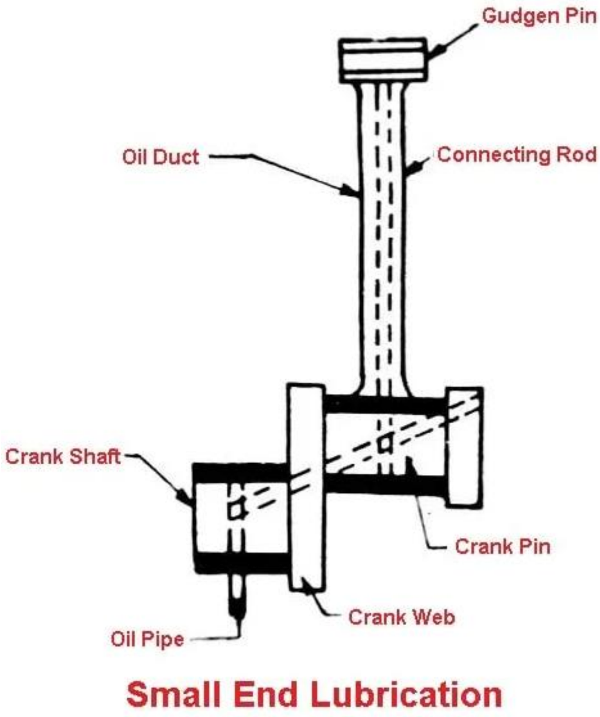

Figure 37-Lubrication channels

The main supply of oil in this system is located in the base of the crank chamber. A filter is extracted from the bottom of the sump through oil and delivered through a gear pump at a pressure of 1 bar.

Larger bearing ends are lubricated through a nozzle spray. Consequently, the oil also oils or lubricates crankshaft bearings, cams, cylinder walls and timing gears.

The oil supply is measured with the help of oil pressure gauges. This system is less costly to install. This enables high bearing loads and engine speed to be applied than the splash system.

Now each designed part will be described in below section you can see technical drawing of them and some design details.

A. Connecting Rod

The connecting rod is defined as it is a mechanical component that helps to connect the piston and crankshaft of the engine. Function of connecting rod can be described as following;

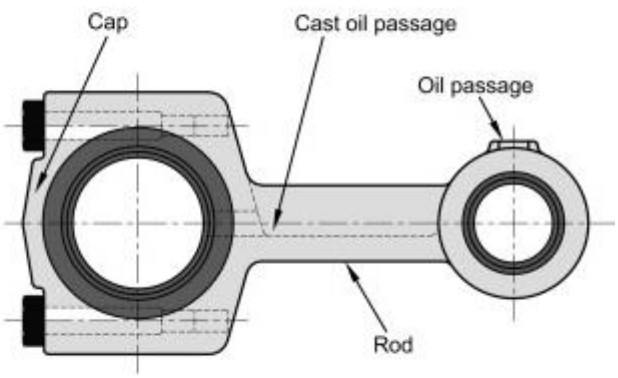

Figure 38-Connecting Rod

The pull and push in the piston receive the piston pin, then the connecting rod acts as the transfer of the pull and pushes from the piston pin to the crank pin. That is, in any internal combustion engine with the help of it, the reciprocating motion is converted to rotary motion.

In the design requirements of the rod, the bearings are connected with the cap so that we have accurate and smooth rotation. Same as bush near the smaller end to fit to get accurate and smooth motion.

Therefore, it is connected to the piston pin or gudgeon pin on one side. In addition, connected to the crankshaft on the other side, so the movement of the piston gives to the crank through the rod. Moreover, connecting rod transfer lubrication oil from crank pin to piston pin.

Connecting rod contain below parts;

- Big end (Cap)
- Small end
- Bolt and Nut
- Shank (I-beam)
- Bearing

In this design connecting rod material is chosen as medium carbon steel (0.35-0.45% Carbon). This connecting rod can be produced by FORGING method. Forging method supply below advantages;

- Dimensional consistency and accuracy
- Reduced mass by 10%
- Consume less energy

- Provides longer tool life smother running in the engine
- High production rate
- Less time consumes
- Reduced cost about 25%

The applied manufacturing method following below steps,

I. **Cutting of materials**: cut the materials a little greater than the required due to further process.

II. **Heating Billets:** Billet is heated in the furnace at 500-600^{o}C

Figure 39-Heating Billets

III. **Hot Forging:** Hot forging is defined as working a metal above its recrystallization temperature. The main advantages of hot forging is that as the metal is deformed the strain-hardening effect are negated by the recrystallization process.

IV. **Piercing:**

V. **Trimming**

VI. **Shot peening**

VII. **Machining**

VIII. **Fracture Splitting**

IX. **Assembly**

X. **Insertion of Bearing Shell**

XI. **Insertion of bearing Bushes**

XII. **Inspection**

Now let's continue with design of part of connecting rod.

- SHANK (I-type)

It is also called the body and may take up different forms. In our design, shank has I-type forms. It has drilling throughout its length.

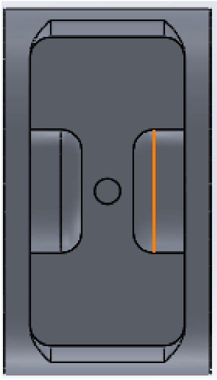

Figure 41-I-type

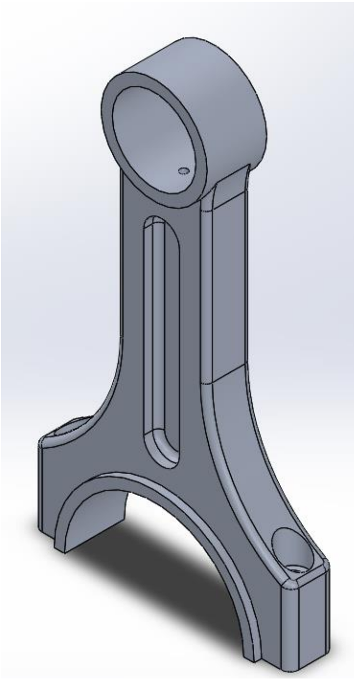

Figure 40- Connecting Rod Body

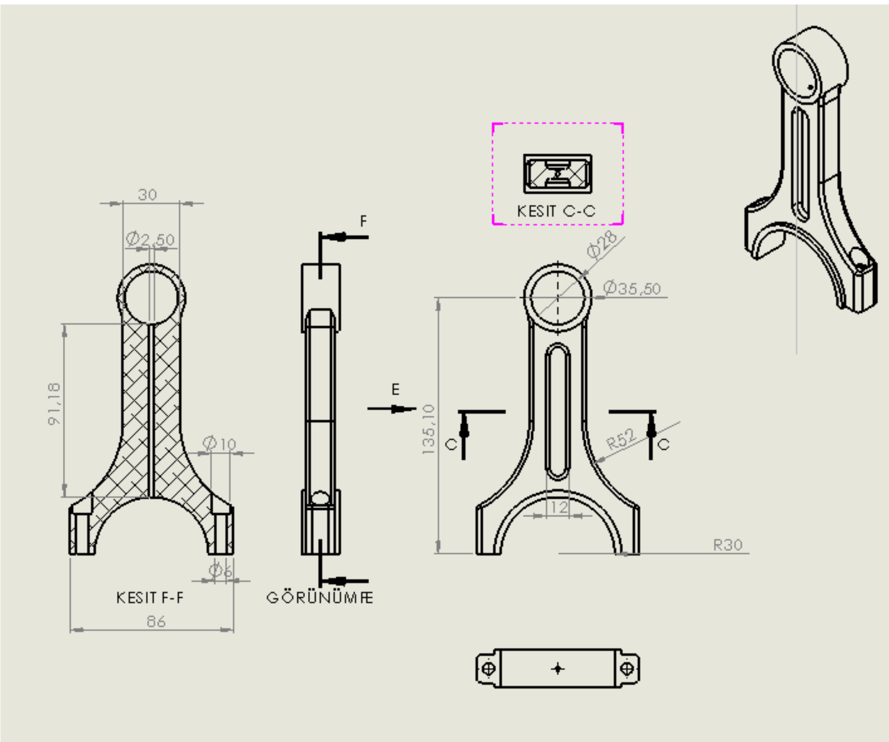

Figure 42- Technical Drawing of Body

- Big End (Cap)

Big end is a part, which is on the crank side is termed. Function of this part is assemble the connecting rod to crankshaft.

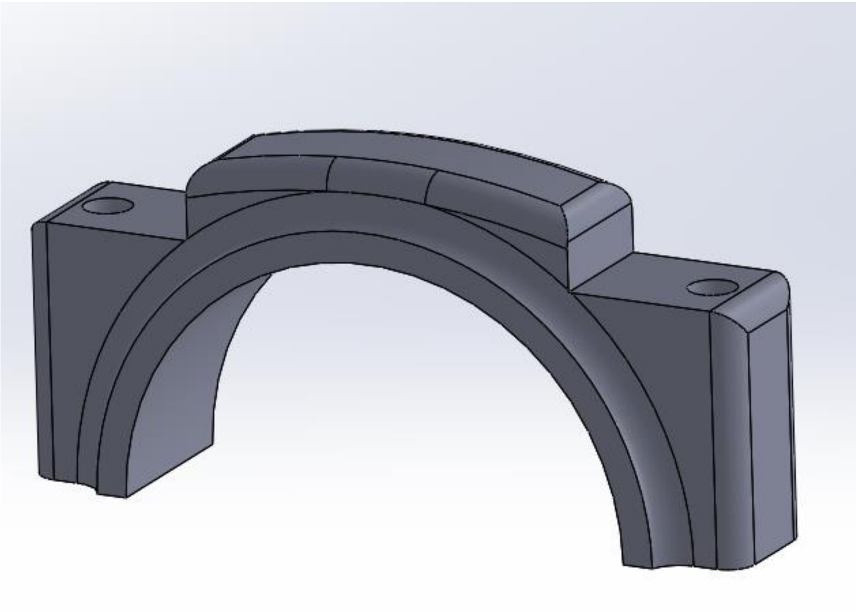

Figure 43-Big End

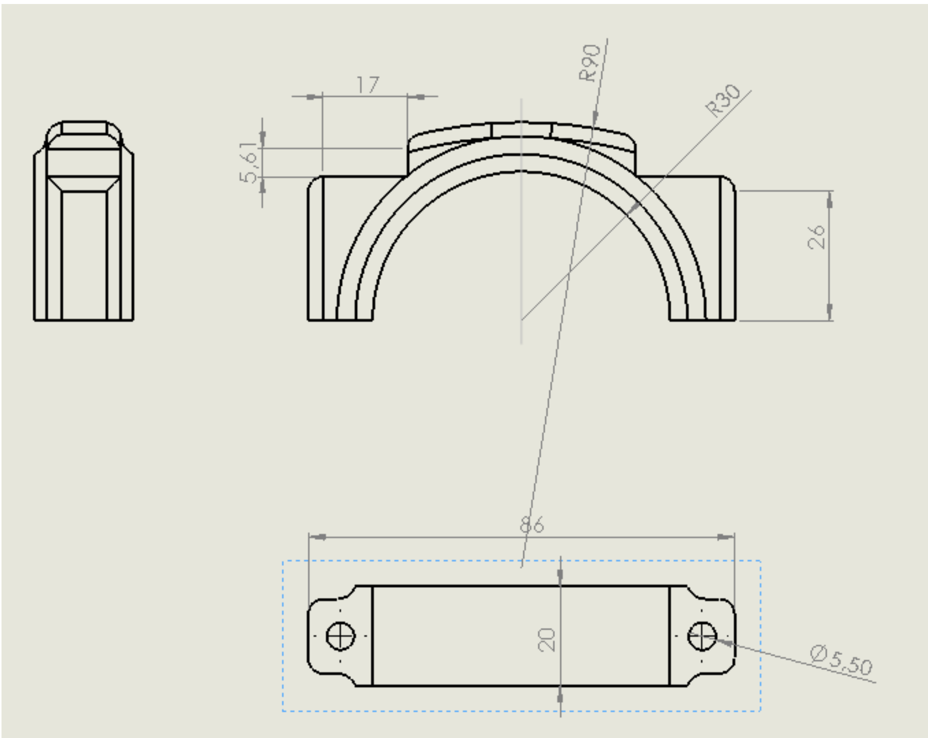

Figure 44-Big End Technical Drawing

- Bearing

This part is placed between connecting rod and crankshaft to supply smooth motion.

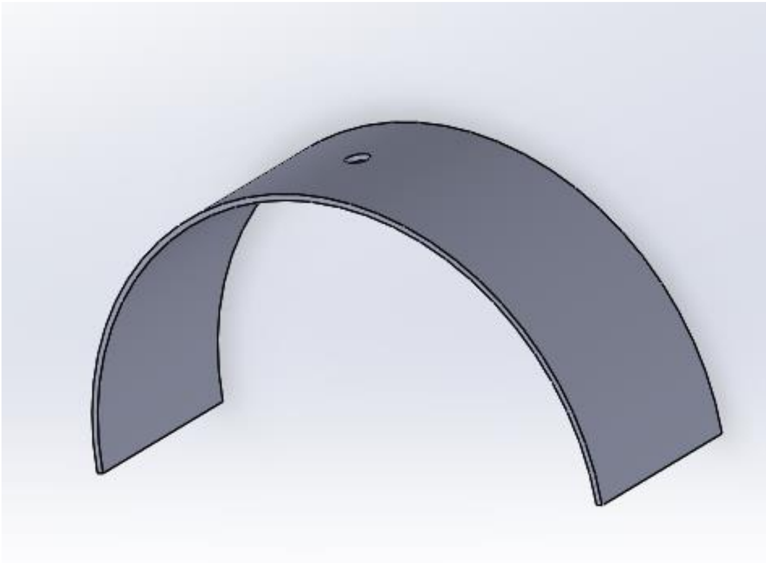

Figure 45-Bearing

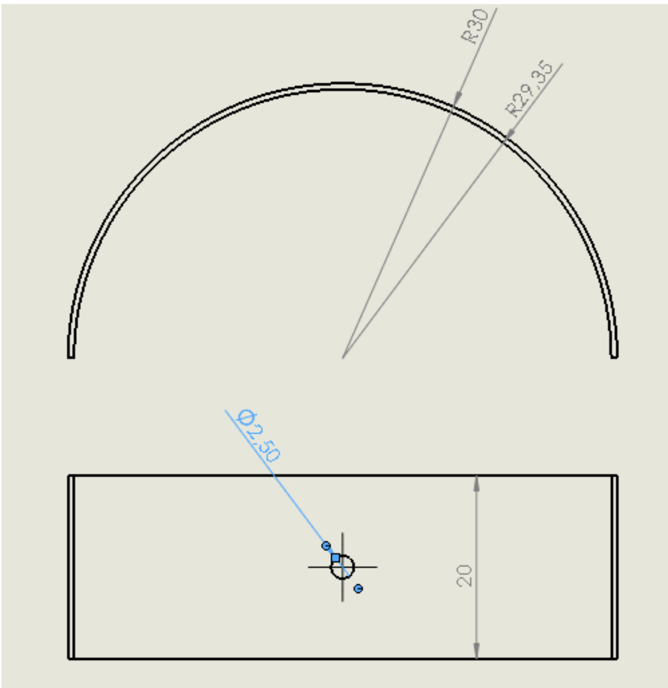

Figure 46-Bearing Technical Drawing

- Bolts and Nuts

Bolts and nuts are connecting part. They are using for connecting two part each other.

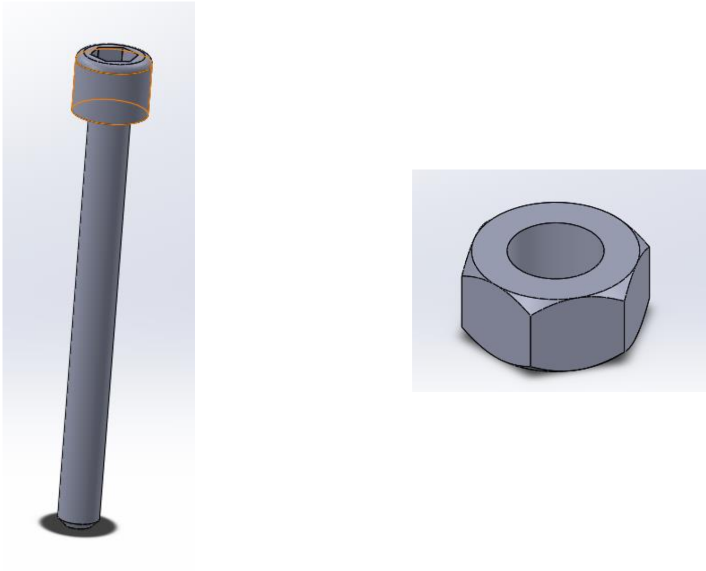

Figure 47-Bolt and Nut

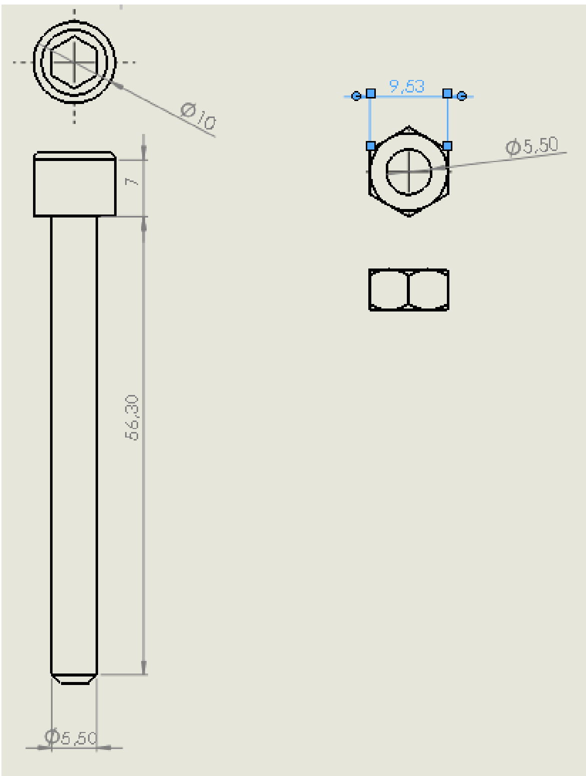

Figure 48-Bolt and Nut Technical Drawing

B. Crank Shaft

The crankshaft is essentially the backbone of the internal combustion engine.
The crankshaft is responsible for the proper operation of the engine and converting a linear motion to a rotational motion.

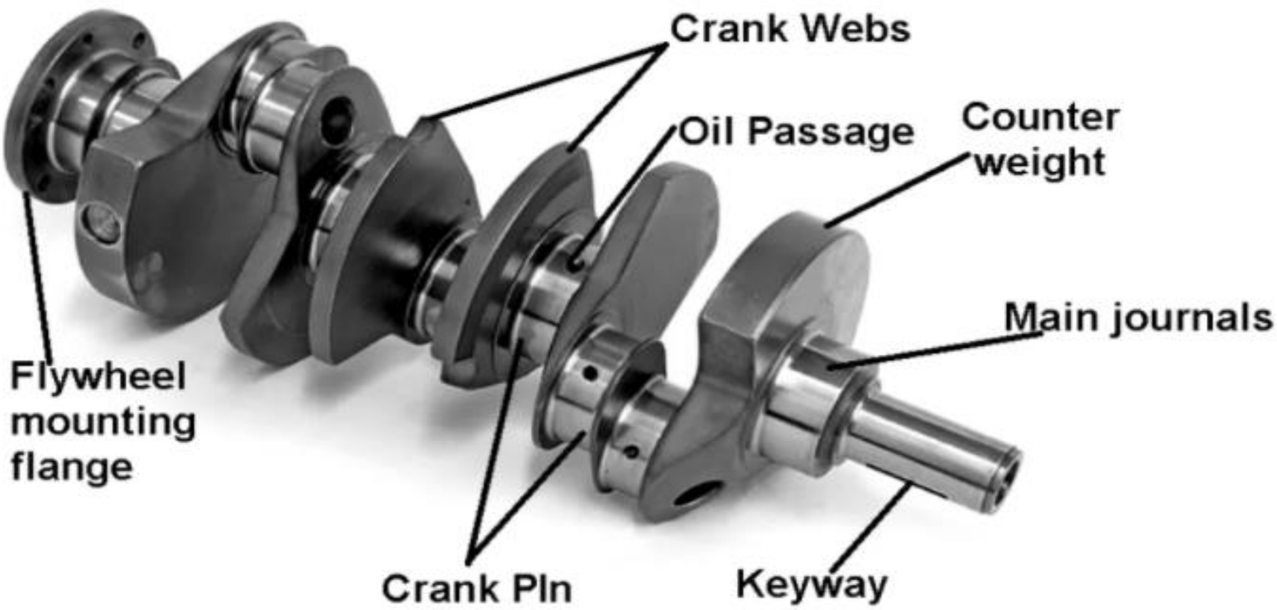

Figure 49-Crank Shaft

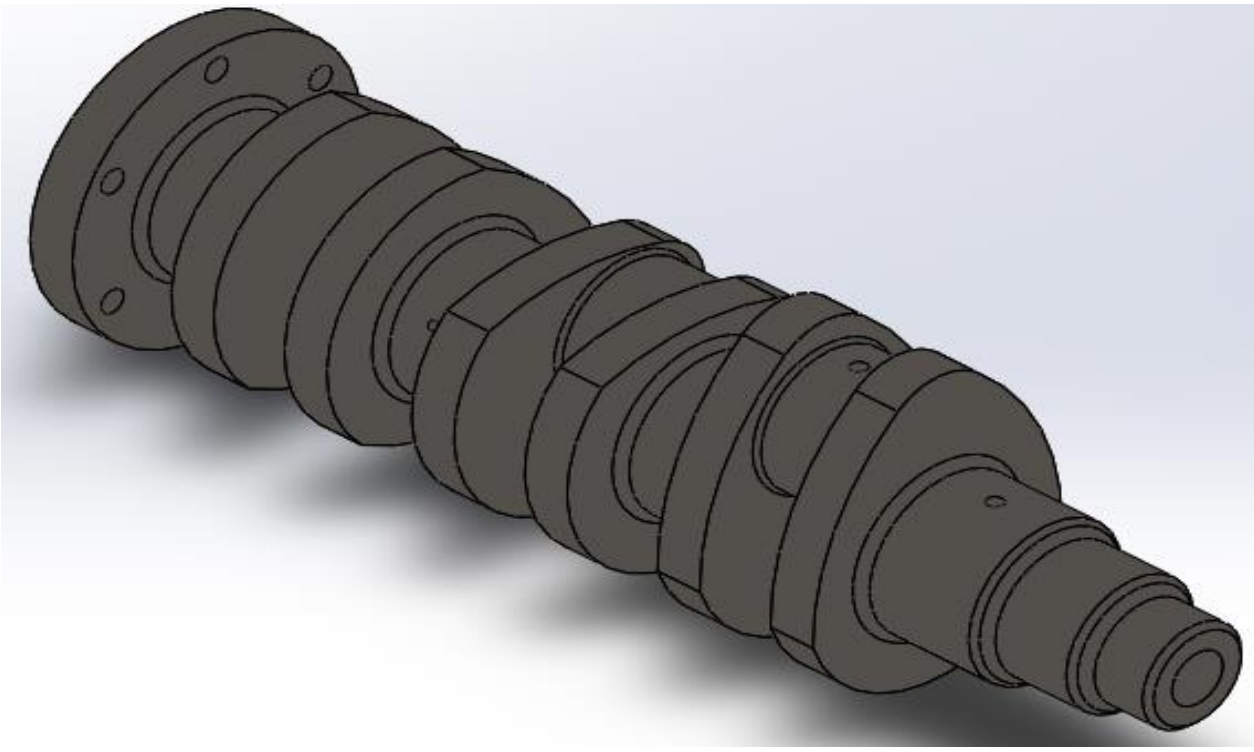

Figure 50- Crank Shaft CAD Design

A crankshaft is a shaft driven by a crank mechanism, consisting of a series of cranks and crankpins to which the connecting rods of an engine is attached. It is a mechanical part able to perform a conversion between reciprocating motion and rotational motion. In a reciprocating engine, it translates reciprocating motion of the piston into rotational motion, whereas in a reciprocating compressor, it converts the rotational motion into reciprocating motion. In order to do the conversion between two motions, the crankshaft has "crank throws" or "crankpins", additional bearing surfaces whose axis is offset from that of the crank, to which the "big ends" of the connecting rods from each cylinder attach.

Crankshaft Parts:

Main journals

The main bearing journals, or just main journals, are clamped into the engine block and it is around these journals that the engine rotates. All crankshaft journals will be machined perfectly smooth and round, and often hardened the main journals are secured into saddles, in which a replaceable bearing insert will sit. The bearing is softer than the journal, and can be replaced as it wears and is designed to absorb small amounts of contaminants, if there are any, to save damaging the crankshaft. A main bearing cap is then bolted over the journal and tightened to an exact torque specification.

The journals run on a film of oil which is forced into the space between the journal and the bearing through a hole in the crankshaft saddle and a corresponding hole in the bearing insert. With the correct oil pressure and supply of oil, the journal and the bearing should not make contact.

Connecting rod journals

The connecting rod journals are offset from the axis of rotation, and are attached to the big ends of the pistons’ connecting rods. Confusingly, they are commonly also called crank pins or rod bearing journals. A feed of pressurized oil comes through an angled oil passage drilled from the main journal.

Some connecting rods have an oilway drilled through them to allow oil to be sprayed onto the cylinder wall. When this is the case, the connecting rod journal bearings will have a groove to allow a feed of oil into the connecting rod.

Crankshaft lubrication

Metal-to-metal contact is the enemy of an efficient engine, therefore the main journals and rod journals both ride on a film of oil that sits on the bearing surface.

Supplying oil to the main journal bearing is easy: Oil galleries from the engine block leads to each crankshaft saddle, and a matching hole in the bearing shell allows this oil to reach the journal.

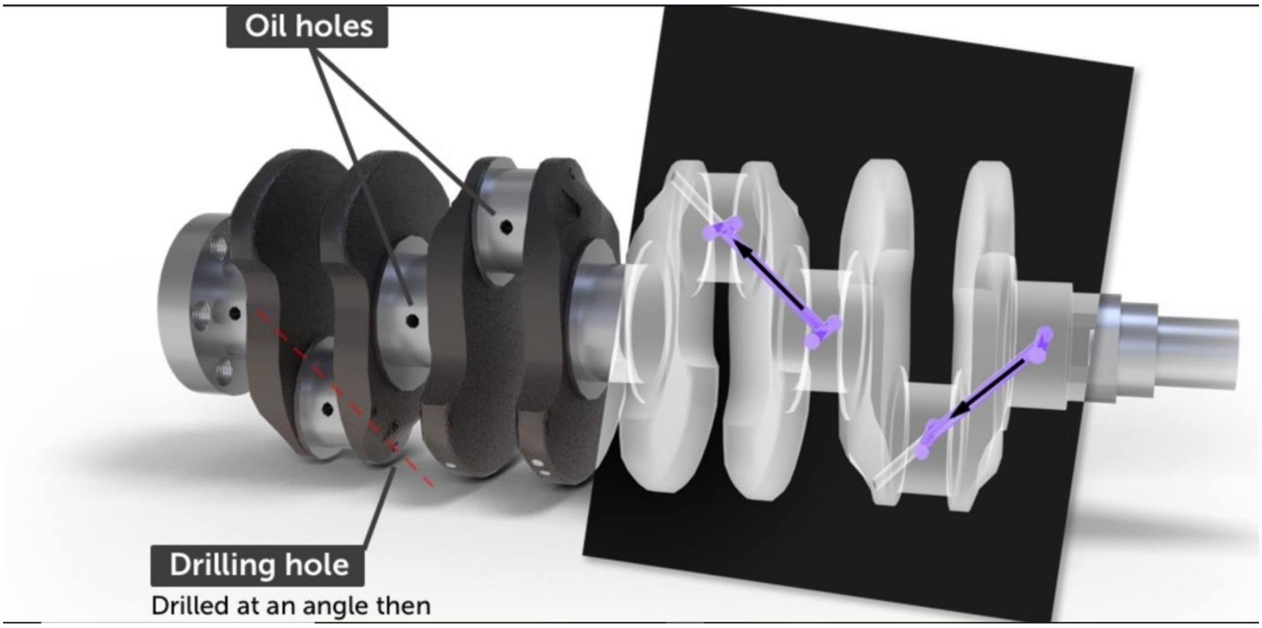

Figure 51-Oil Holes

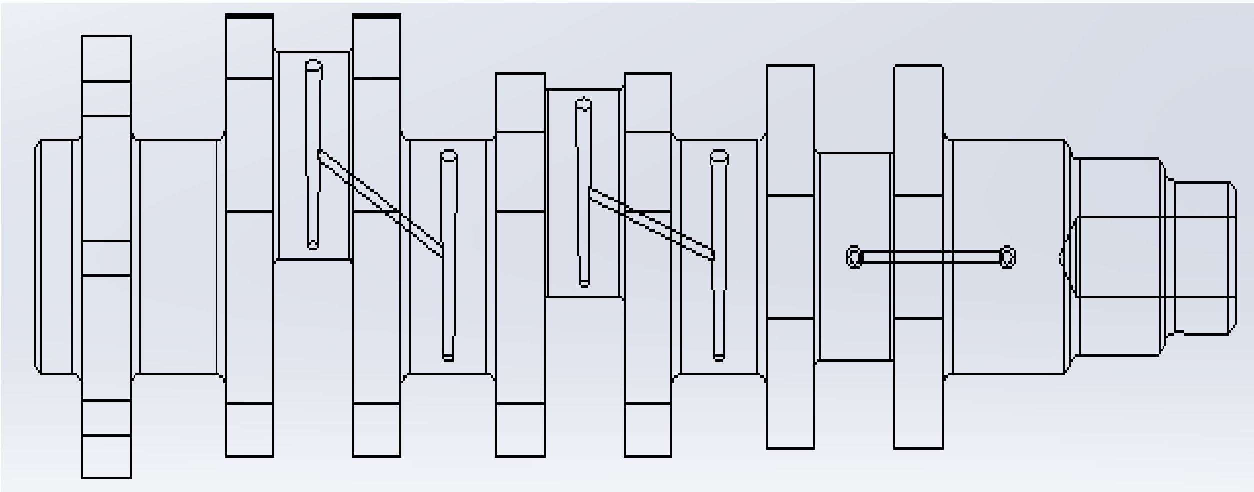

Figure 52-Designed Oil Holes

Modifications and Upgrades

Crankshaft grinding

Journals wear over time. They may develop a rough surface, or become out-of-round or tapered. In these cases, their surface can be restored in a process called crankshaft grinding. When a crankshaft is ground its journals will be reduced in diameter and so oversized, thicker bearings will need to be installed.

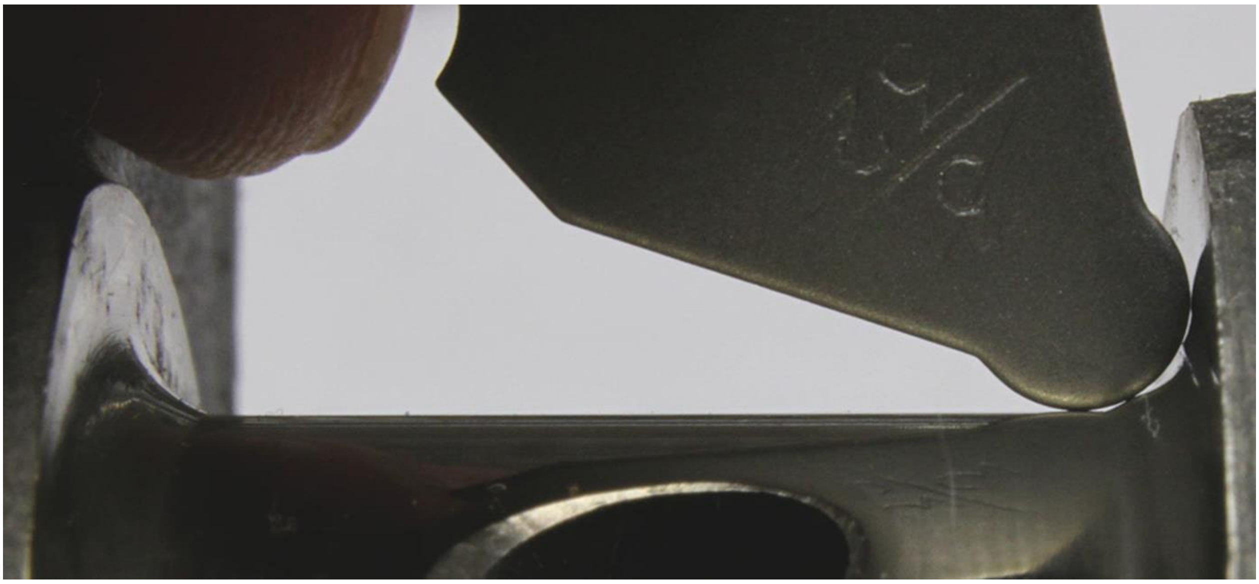

Figure 53- Radius

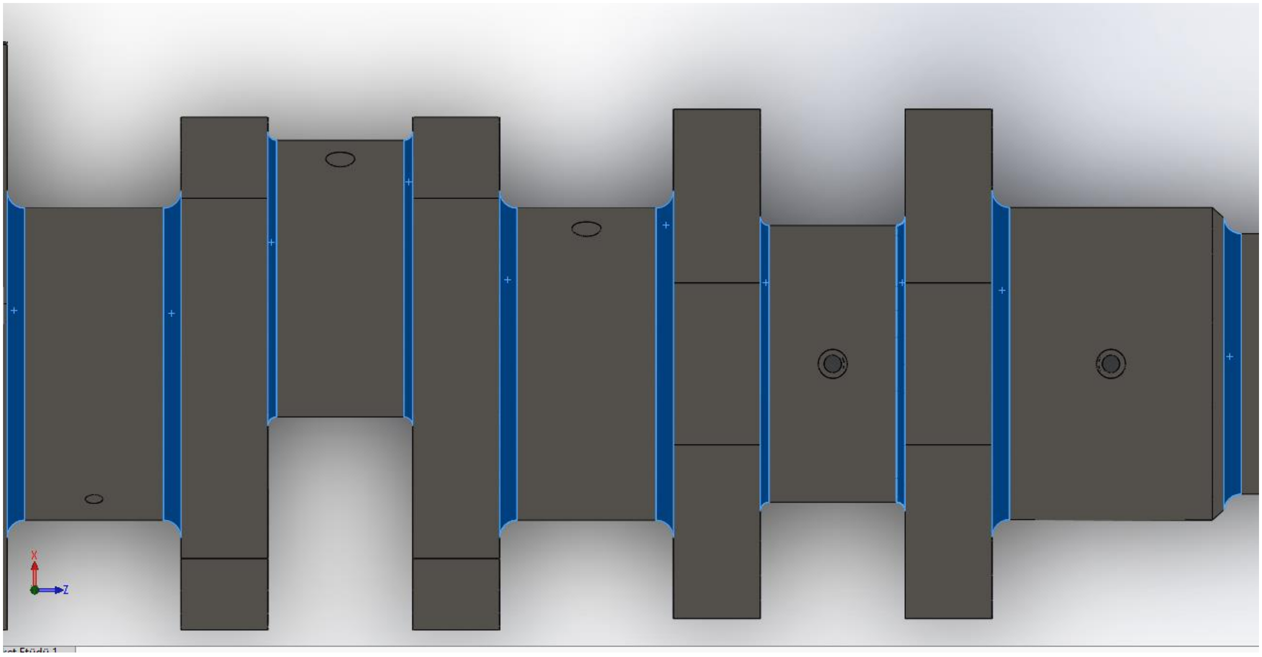

Figure 54- CAD Design Radius

How a crankshaft is made?

Most production engines use a cast iron crankshaft which is made by pouring molten iron into a mold. Forged crankshafts are used in some performance engines. A forged crankshaft is made by heating a block of steel until red hot, and then using extremely high pressure to form it into shape.

Figure 55-Heating Process

Once a crankshaft has been forged or cast, its journals and bearing surfaces are machined perfectly smooth. Oil passageways, or oilways, are drilled. Production engines will generally leave the webs with their original rough casting finish but performance engines will machine every part of the crankshaft to reduce oil drag.

The journals must be harder than their bearings to ensure that any wear occurs on the replaceable bearings and not the crankshaft, which should last for the lifetime of the engine. The manufacturing process will include hardening of these areas through nitriding or heat treatment.

Extremely high performance and custom crankshafts, are machined from a block of solid material, producing a billet crankshaft. Producing a one-off crankshaft by this process would cost a minimum of around $3,000 so it is reserved for competition racing and restoration situations.

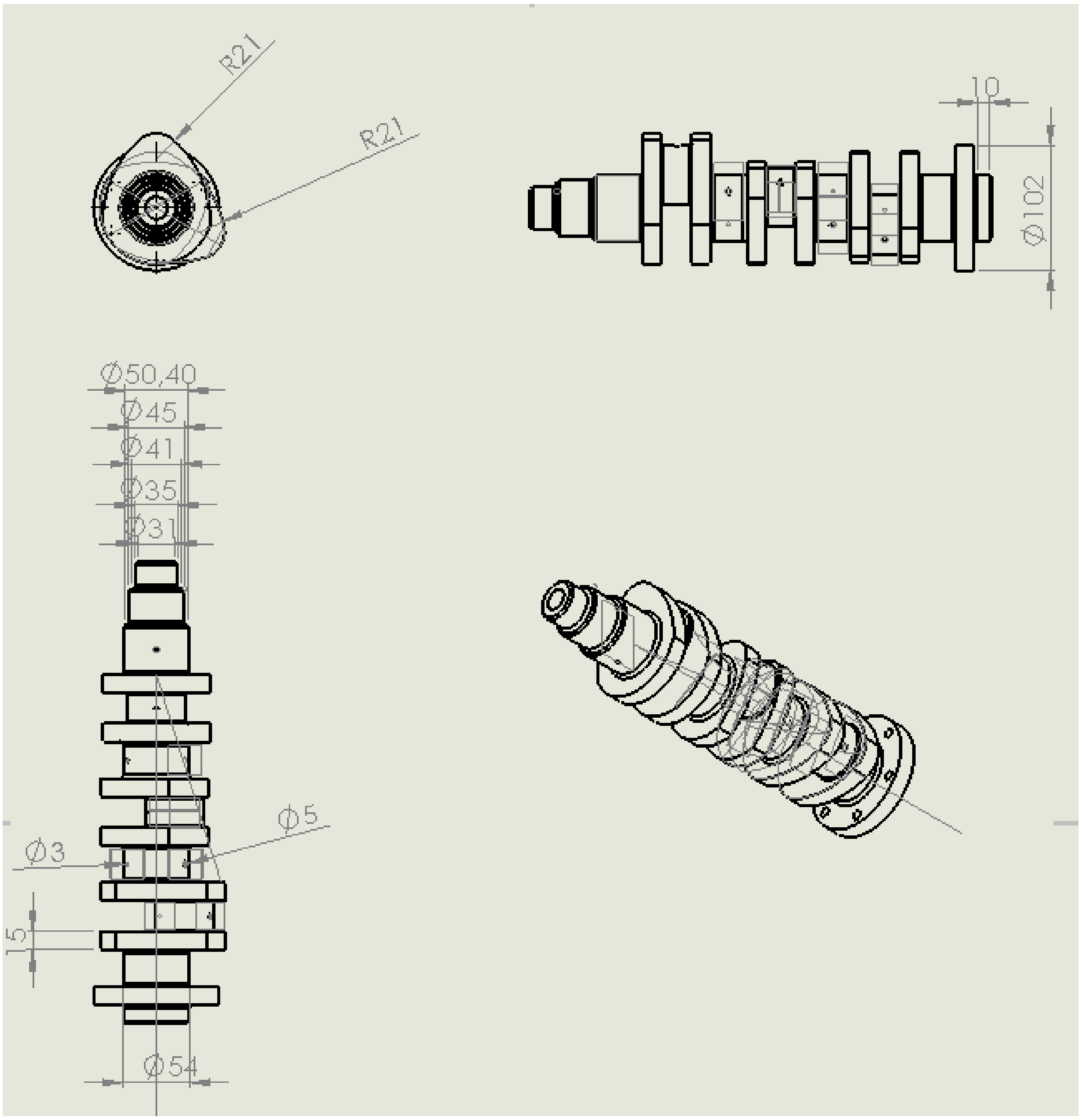

Figure 56- Technical Drawing of Crank Shaft

Design details

In this shaft design, the diameter of the lubricating channels starts from 5 mm and ends with 3 mm. The main reason for this is to ensure that the oil circulates in the channels. If we make the beginning and the end of the lubrication channels at the same diameter value, the high pressure oil that will come here would come out directly without any side channels. In order to allow it to pass through the side channels, either the oil channel will have an entrance, the other part will be closed or the oil channel diameter will narrow. Here, we applied the second mentioned part to our own design. Since the oil channel narrows, the oil coming with high pressure will accumulate and fill in the channel. It will then pass into the horizontal oil channels on the side. In addition to all these, the heated oil will leave the narrow mouth and mix with the cooling process again.

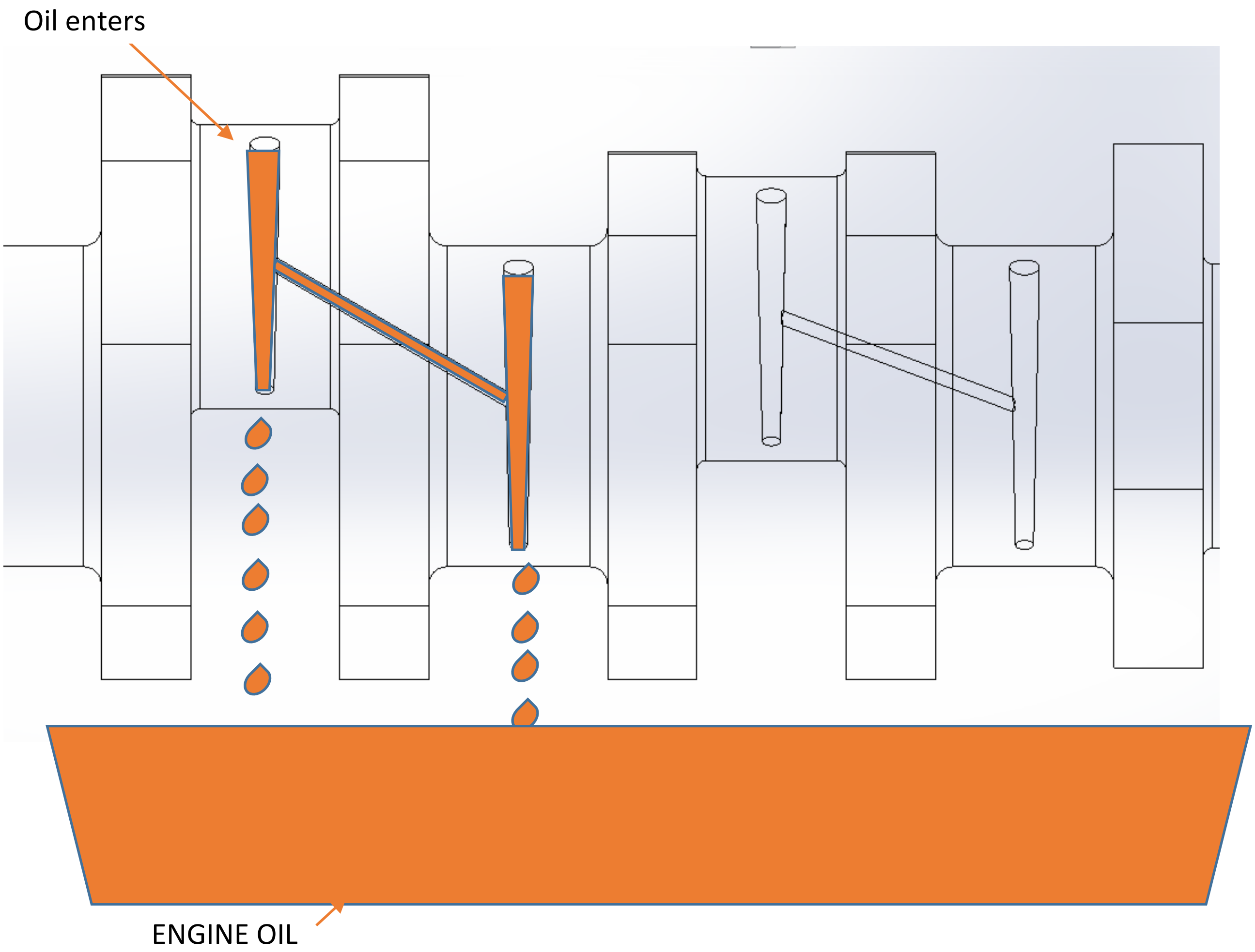

Figure 57-Designed Oil Channels

C. Cylinder Block

An engine block is the structure which contains the cylinders, and other parts, of an internal combustion engine. In an early automotive engine, the engine block consisted of just the cylinder block, to which a separate crankcase was attached. Modern engine blocks typically have the crankcase integrated with the cylinder block as a single component. Engine blocks often also include elements such as coolant passages and oil galleries.

Figure 58-Cylinder Block

Cylinder Block Functions:

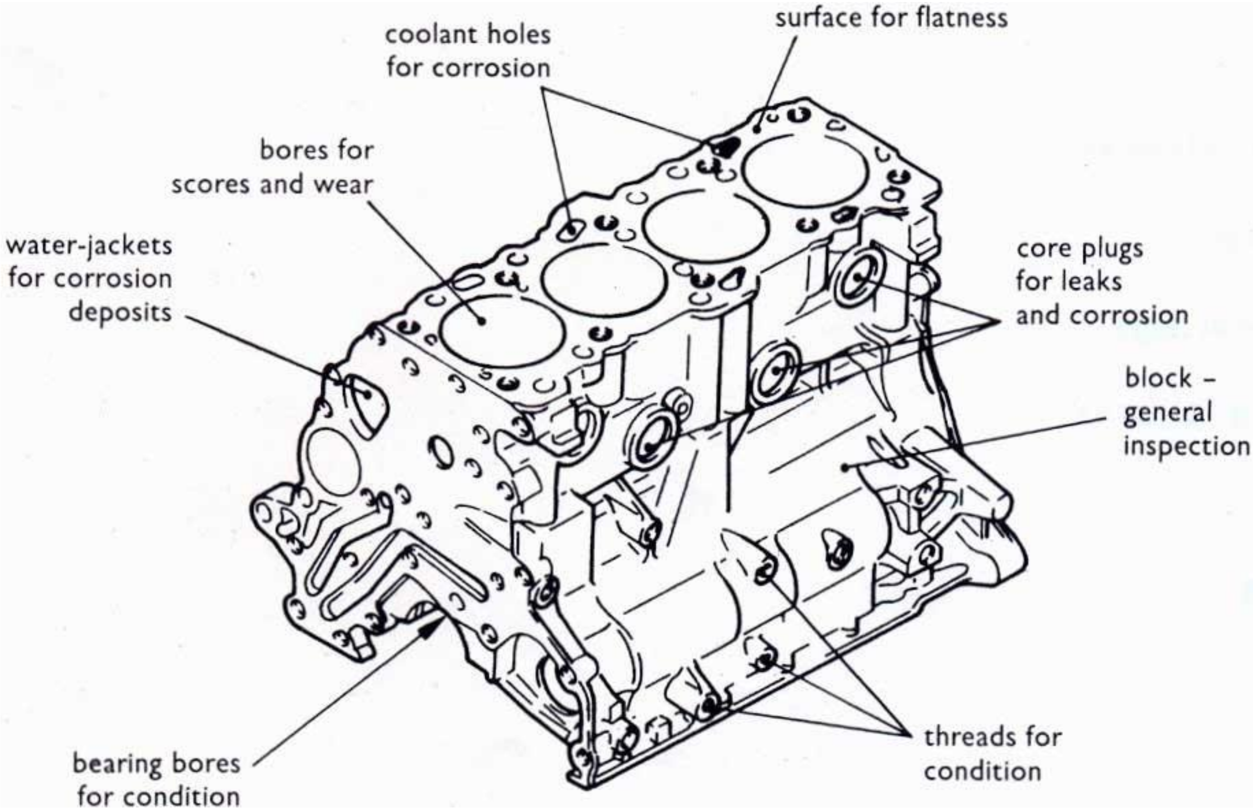

Figure 59- Some Part Name of Cylinder Block Parts

Although mostly unknown, the cylinder head plays an important role in the general operation of a motor vehicle. It is a complex structure consisting of many passageways. Each of these ports has a purpose to serve, and their collective roles define the importance of this engine part. Among the main cylinder head function in an engine are:

- Provide the mounting structure for various components such as the inlet and outlet exhaust valves and ducts, spark plugs, injectors, and (in some head designs), the camshaft.
- Contain the passages for coolant, oil, and combustion gases
- Dissipate the heat produced by the engine and, therefore, produce cooling
- Act as the combustion chamber seal and the engine's mechanical control powerhouse
- Take the compression resulting from combustion pressure

A cylinder head contains intake air, exhaust, Copland, and oil passageways.

One of the functions of a cylinder head is cooling the engine. The head achieves that using two main methods; water or air.

Water-cooled heads are the most popular, and many modern engines are of this type. In this type of engine, water is mixed with antifreeze to prevent the formation of ice. An anti-corrosion agent is also introduced to prevent the corrosive action of water. Water-cooled cylinder heads are more efficient and produce excellent results.

Air-cooled cylinder heads use large fins that fan the air to bring about cooling. They feature no cylinder head engineering complexities, which makes them inexpensive to make. Because cooling by air can occur in extremely low temperatures without the risk of freezing, air cooled-heads are more reliable. They are also lightweight and easy to repair.

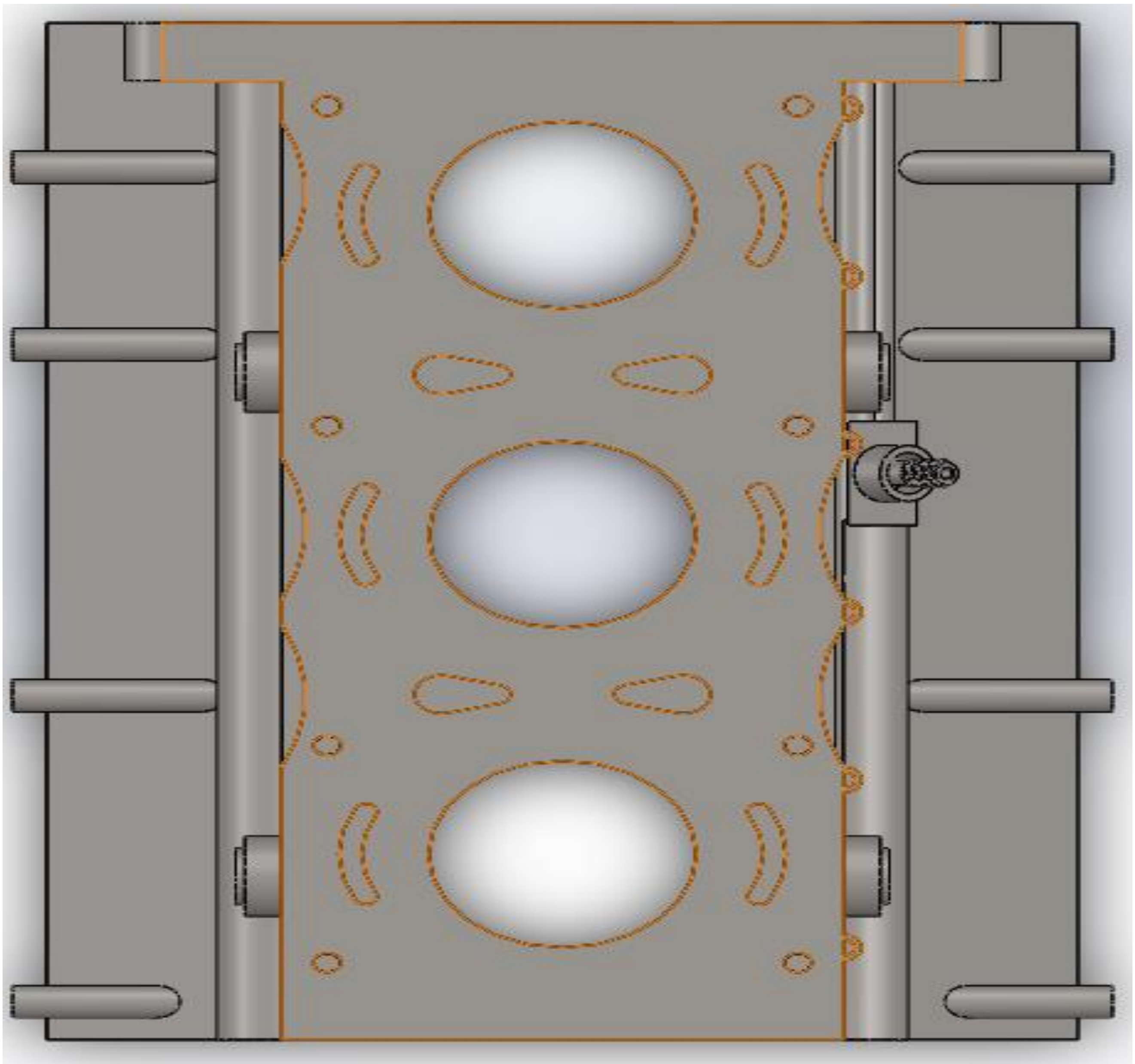

Figure 60- CAD Design of Cylinder Block

Cylinder Block Materials and Manufacturing

Auto cylinder blocks are cast from molten metal. Usually, manufacturers use the LFC, lost-foam casting, for the cylinder block casting. The method uses polystyrene foam to produce the required pattern. It is one of the simplest processes for complex castings but also one that produces excellent results. Lost-foam casting has the advantage of dimensional accuracy and good finish, among other benefits.

Cylinder blocks can be made from iron or aluminum. It depends on the required performance, durability, and other factors. Each material offers specific advantages that suit particular situations, as we shall see next.

Aluminum cylinder blocks

Aluminum produces lightweight blocks that also dissipate heat more efficiently. However, cylinder blocks made of aluminum are more expensive. In addition to the high cylinder block cost when aluminum is used, there is the issue of durability. Aluminum cylinder blocks are weak structurally. They are easily damaged by temperature extremes, corrosive materials, and impacts.

Because they give better fuel economy and heat transfer, aluminum blocks are often used in performance and race cars. In these cars, weight saving and rapid engine cooling are necessary features. Most gasoline engines use aluminum cylinder blocks.

Iron cylinder blocks

Iron cylinder blocks are less expensive than those made from aluminum are. They are also high-strength and durable. The problem with engine cylinder blocks cast from iron is that they are too heavy. They add to a vehicle’s weight and contribute to poor fuel economy.

Iron heads also transfer heat poorly and do not fit demanding applications such as race cars. These types of heads are mostly used in diesel. A diesel engine cylinder block costs less, stands up to damage better, and lasts a long time. Unless situation demands it, these are most preferred type of blocks.

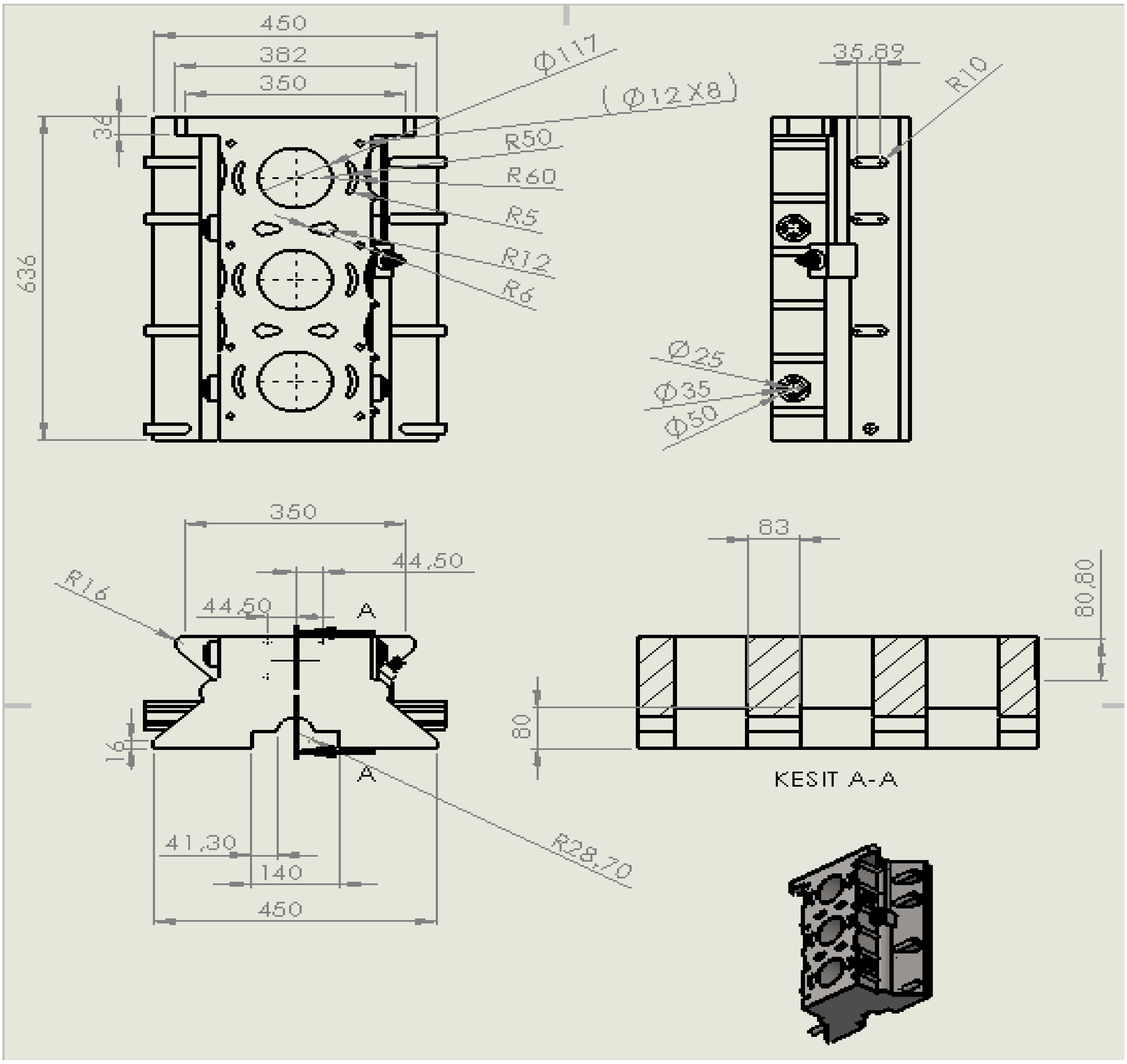

Figure 61-Technical Drawing Of Cylinder Block

D. PISTON

A piston is a disc-shaped component that is inserted into a cylinder at a rate of 7 cavities per 1000. This item is used in conjunction with a connecting rod. The piston's primary function is to transfer chemical energy into mechanical energy. The combustion chamber's movable end is the piston. The cylinder head is the combustion chamber's stationary end. For great and lightweight heat conductivity, pistons are often built of a cast aluminum alloy.

In cases of high thermal and mechanical stress, the piston is one of the priority parts to break. This is due to the fact that the piston must strike a balance between mass, mechanical, and thermal stress resistance. Because of the engine volume, the geometric structure of the piston is constrained. As a result, increasing the mass of a piston is the greatest approach to enhance its mechanical and thermal resistance. This is not recommended, however, because a large-mass piston has a lot of inertia, which translates to a lot of dynamic force at high engine speeds. Geometry modification can improve the piston's resistance, but there will always be a trade-off between mass, mechanical, and thermal resistance.

Since the engine we have designed is a diesel engine, the designed piston must be resistant to high pressure and temperature. That's why it's bigger and heavier than a regular gasoline engine piston. Considering these reasons, diesel engine pistons should be made of aluminum alloys, steel or a combination of both. The designed piston is made of alloy cast iron material in order to obtain high thermal and mechanical strength.

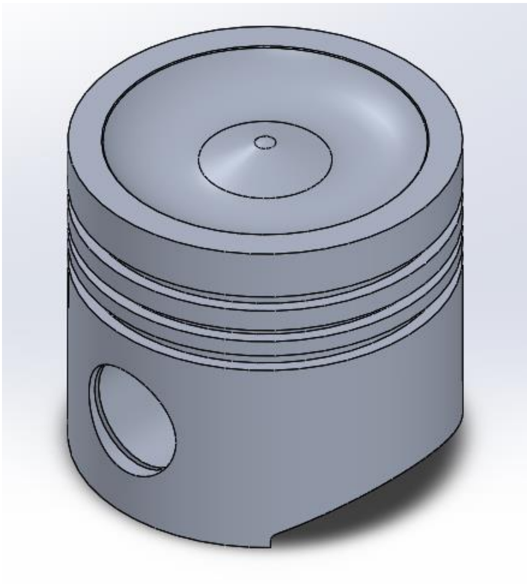

Figure 62-CAD Design of Piston

Figure 63-Piston

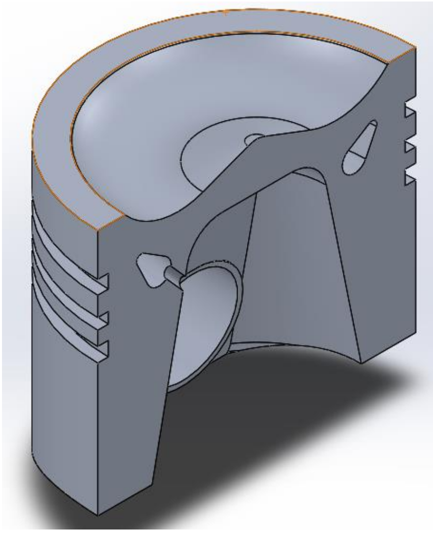

Figure 64-Section view of Designed Piston

Technical drawing of designed piston can be shown as below;

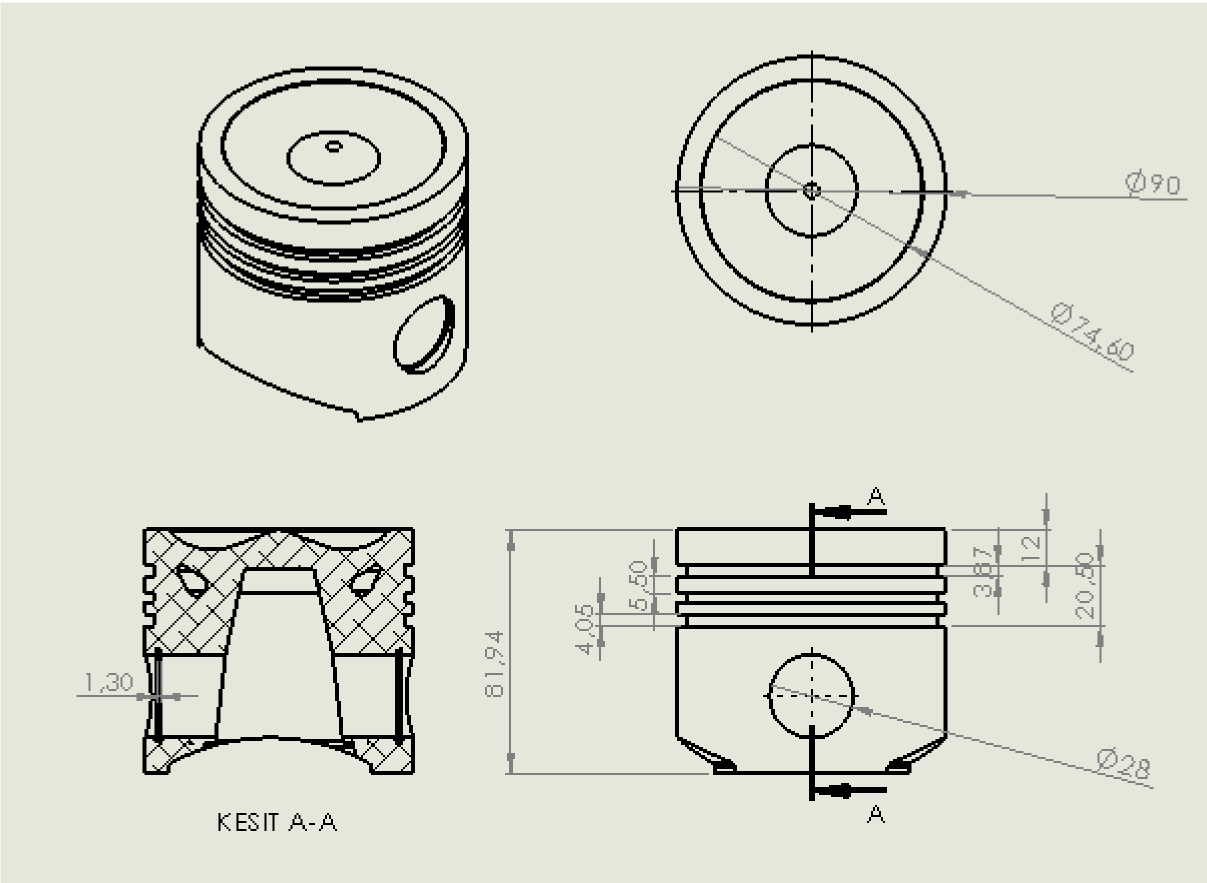

Figure 65-Technical Drawing of Piston

,

- Piston Pin

This part is a connecting part. Function of this part is assemble the connecting rod and piston each other.

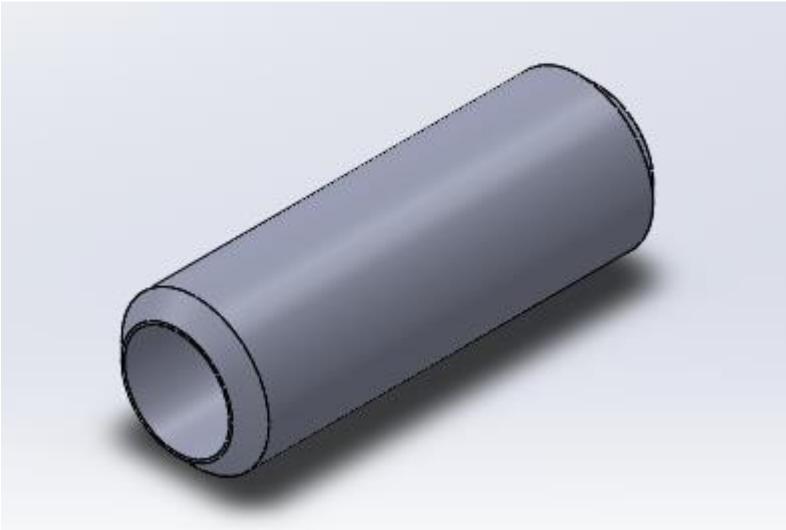

Figure 66-Designed Piston Pin

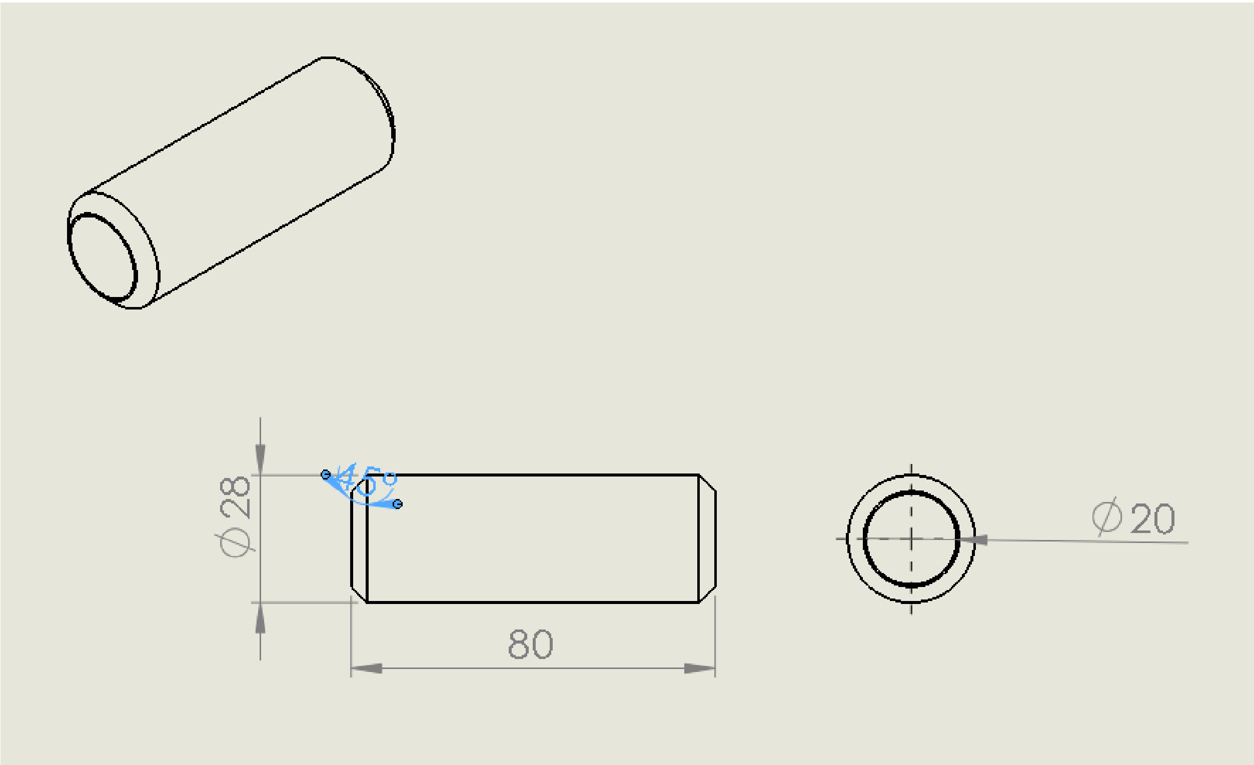

Figure 67-Technical Drawing of Pin

- <u>Segment</u>

This part fix the piston pin in hole.

Figure 68-Designed Segment

Technical Drawing of segment can be shown as below;

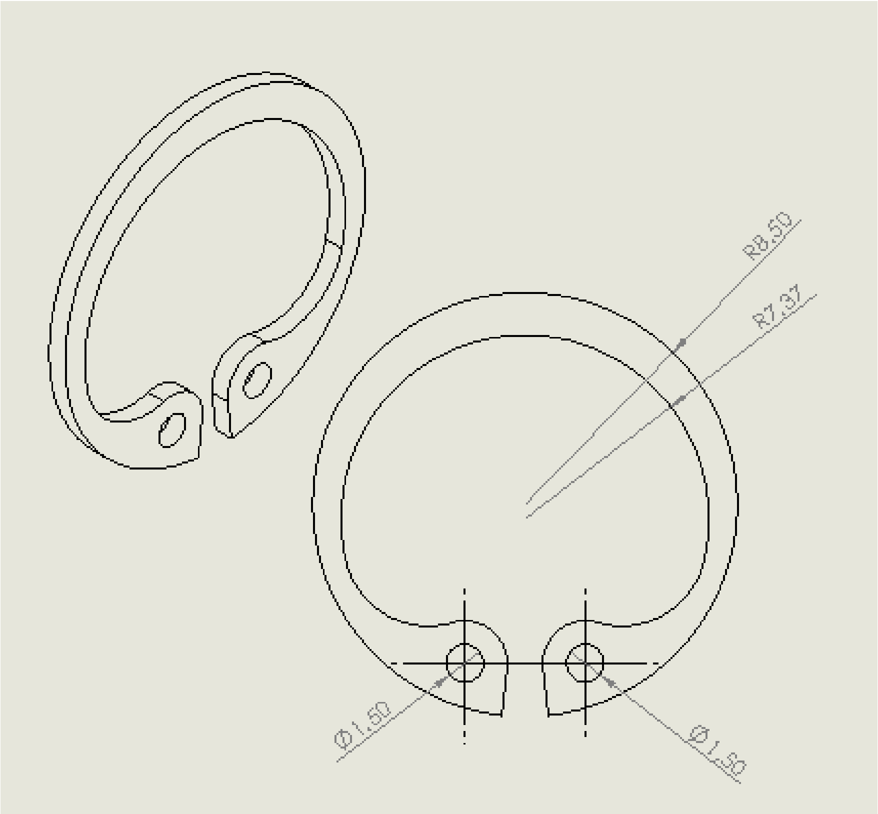

Figure 69-Technical Drawing of Segment

E. ASSEMBLE OF CRANCK MECHANISM AND CYLINDER BLOCK

At this section, all parts in above section are assembled as below figures.

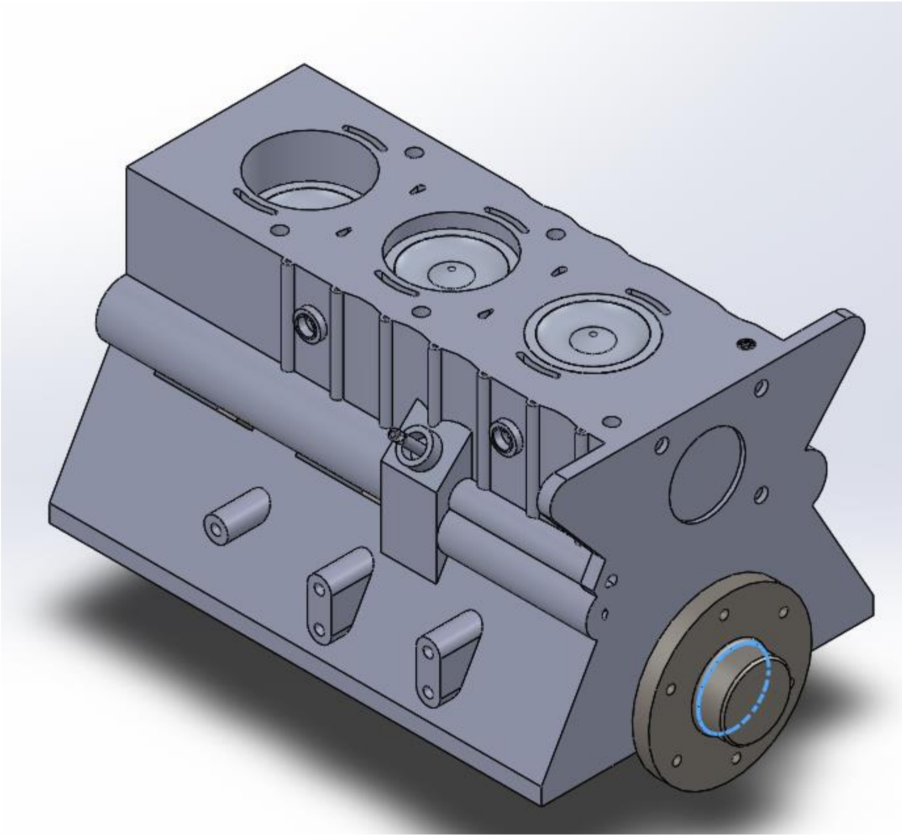

Figure 70- Assemble of Crank Mechanism and Cylinder Block

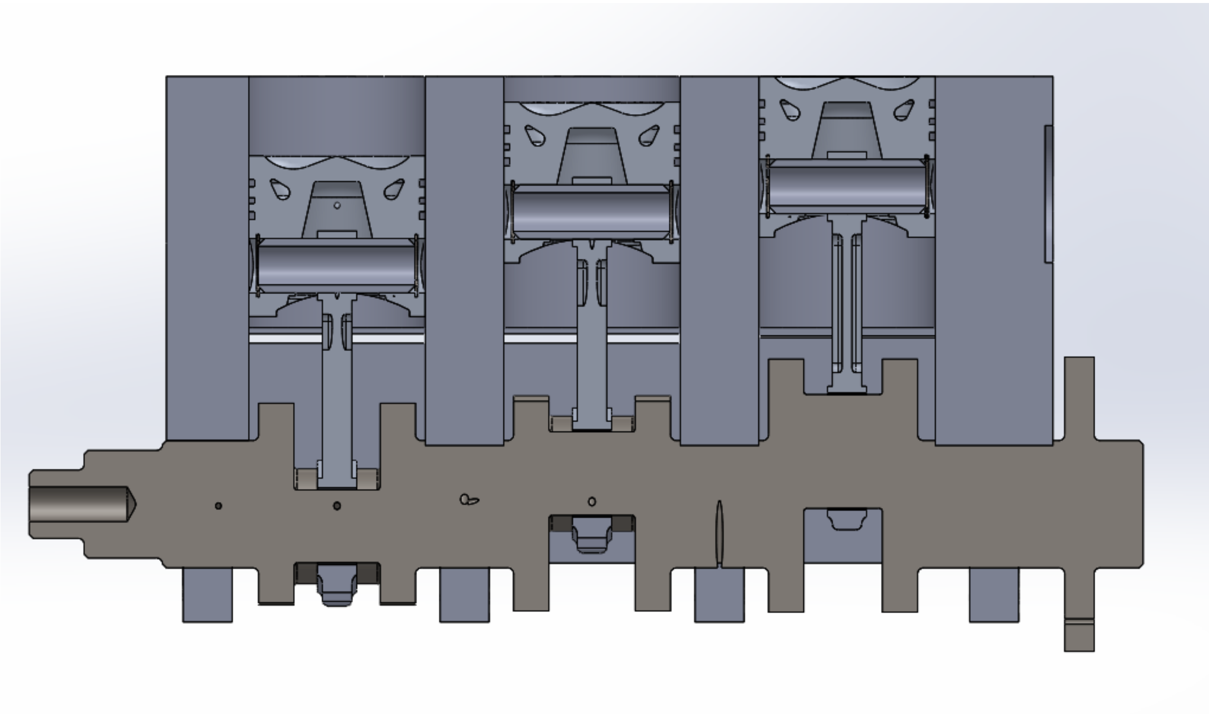

Figure 71- Section view of Assemble of Crank Mechanism and Cylinder Block

16) SUSTAINABILITY

It is clearly known that vehicle motors are one of the most causes of global warming. Cars and trucks radiate carbon dioxide and nursery gasses, which make up five parts of global warming. Greenhouse gases burn warm within the climate, causing temperatures around the world to rise. Without nursery gasses, the Soil would be secured in ice, but global temperature has risen by 0.6 degrees Celsius since pre-industrial times due to over the top burning of fossil fills such as gasoline and diesel. It is one of the expectations that this increment will increment quickly within the coming a long time.
In arrange to dispense with or diminish this circumstance as much as conceivable, power, which is one of the elective utilization sources, has been turned to.
However,the productivity gotten from inside combustion motors has not but been gotten from electric engines, hence, 3-cylinder motors have been begun to be favored in arrange to both get that productivity and minimize the harm to the environment. With the use of 3-cylinder engines, high power with low fuel consumption began to be obtained, thus reducing the amount of carbon dioxide and greenhouse gases emitted from the engine, and there was no reduction in the power obtained from the engine. Thus, the damage done to the environment by the engines has been reduced.

On the other hand, since the 3-cylinder engine uses diesel fuel as fuel, I will consume less fuel than the gasoline engine, and this will further reduce the amount of carbon dioxide and greenhouse gases released into the nature.

Besides global warming, 3-cylinder engines have smaller dimensions compared to other engines. Therefore, there are fewer parts than other engines. Thus, it is produced with the use of less raw materials. Thus, it ensures less consumption of the decreasing mineral reserves in the world.

Figure 72-Exhaust of 3-cylinder engine

17) COST ANALYSIS AND FEASIBILITY

3-cylinder diesel engine feasibility					
Part Names	Progress	Cost	Part Names	Progress	Cost
Crank Shaft	Raw Material	$550,00	Piston Pin	Raw Material	$4,00
	Pouring Process	$200,00		Pouring Process	$4,00
	Machining	$200,00		Machining	$3,00
	Labor Cost	$85,00		Labor Cost	$1,00
Piston	Raw Material	$200,00	Segman	Raw Material	$0,75
	Pouring Process	$50,00		Pouring Process	$1,00
	Machining	$50,00		Machining	$1,00
	Labor Cost	$50,00		Labor Cost	$0,50
Connecting Rod	Raw Material	$20,00	Bearing (Connecting Rod)	Raw Material	$9,00
	Pouring Process	$15,00		Pouring Process	$12,00
	Machining	$10,00		Machining	$10,00
	Labor Cost	$5,00		Labor Cost	$7,00
Cylinder Block	Raw Material	$200,00	Bearing (Cylinder Block)	Raw Material	$2,00
	Pouring Process	$100,00		Pouring Process	$3,00
	Machining	$100,00		Machining	$5,00
	Labor Cost	$50,00		Labor Cost	$2,00
				Total Cost	$1.950,25

Table 13-Cost Analysis

This cost analysis was made by taking 1 reference for each piece. Cost analysis is the amount of cost that is revealed by taking into account the cost at each point, from the purchase of raw materials required to produce a product to the cost of quality control at the end point. Considering this definition, the cost of every detail from raw material to labor cost for the production of each part is given in the table. When the table above is examined in detail, it is clearly seen that three or more of the parts in the table will be ordered, and in the cost analysis made, it can be made for an amount of approximately 2100 dollars.

A. Feasibility

The purpose of a feasibility report is to conclude whether the result obtained because of the studies carried out is applicable in real life or whether it is reasonable to apply even if it is applicable. When the designs in the report prepared because of the studies are examined, it has been shown that there are no obstacles to the realization of the study. In addition, considering the sustainability part, the fact that the effect on the environment is less than other engines, as well as the fact that the power difference between other 4-cylinder engines is negligible, provides consistency in all aspects. Low production cost and less raw material usage are the other two points that support them.

18) CONCLUSION

In this undergraduate thesis, the cylinder block, piston, crankshaft and connecting rod design of a 3-cylinder diesel engine is discussed. First, the history and historical development of the 3-cylinder engine was learned through research. Then, the place of diesel engines in our lives in the future was investigated. In this research, the carbon dioxide emission of the diesel engine, its contribution to the environment, price analysis and sales in recent years are mentioned. A rough engine design was then obtained without any detailing.

It has been researched and decided how to minimize the vibration in 3-cylinder engines and reduce its effect. In addition to these, fuel systems used in diesel engines are discussed.

It has been learned which companies use 3-cylinder diesel engines. The characteristics of each of the engines in these companies are found and tabulated separately. From these engines, we took the Volkswagen EA 189 engine as our reference. Then we designed our own engine.

The measurements obtained in our engine are the measurements we have obtained by measuring from real engines by ourselves. However, we have made changes in these dimensions according to our own design. The most important design made in this design is the lubrication channels of the crankshaft. These channels are opened in the form of a narrowing cylinder. The main purpose of this is that the pressurized oil circulates in all channels of the crank, absorbs heat and reduces friction. Apart from the crankshaft, the lubrication channels and water channels in the connecting rod, cylinder block, and piston have been designed down to the last detail. The working order of the pistons is specified in accordance with reality.

According to the information obtained in the light of the researches and studies above, our 3-cylinder diesel engine design is finished. In addition to these, feasibility, sustainability and cost analysis researches of this engine were also carried out.

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20) APPENDIXES