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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3-CYLINDER SMALL SIZE DIESEL ENGINE

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Design of Three-Cylinder Diesel Engine

By

Ahmet Yasin Baş and Ardan Nuralp Pakyürek

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The goal of this thesis is designing a 3-cylinder engine. In order to design 3-cylinder engine, we need to define what is an IC engine, its history, type of engines, pros and cons of 3-cylinders engines, does usage will increase or decrease in the future, fuel type and fuel systems. This thesis mostly contains about 3-cylinders engine, statistical data from companies (such as vibration data). And this thesis explain why 3-cylinders engine is more advantageous than the 4-cylinder engine. What is the benefit of diesel engine to gasoline engine what is the market value of the diesel engine. And finally comparing our design to automobile market.

ABBREVIATIONS

AMG	Aufrecht Melcher Großaspach
CNG	Compressed Natural Gas
ECU	Engine Control Unit
EU	Europe
GDI	Gasoline Direct Injection
GHG	Green House Gas
HEV	Hybrid Electric Vehicle
IC	Internal Combustion
MHT	Mild-Hybrid Technology
MPFI	Multi-Point Fuel Injection
RDE	Real Driving Emissions
SPI	Single Point Injection
TBI	Throttle Body Injection
TDI	Turbocharged Direct Injection
US	United States
VAG	Volkswagen Automobile Group
VTEC	Variable Valve Timing and Lift Electronic Control System
WLTP	Worldwide Harmonized Light-duty Vehicles Testing Procedure

1. INTRODUCTION

Today, 3-cylinder engines are not regarded as a particularly cutting-edge technology. About 70 years ago is when 3-cylinder engines first appeared in cars. Towards the end of the 1960s, it was also employed for the first time in mass-produced motorcycle engines. Up until the end of the 1990s, three-cylinder engines were mostly produced and used in Japan and neighbouring Asian nations. The development of 3-cylinder engines by various European manufacturers began during the end of the 1990s, and this marked the beginning of the spread of these engines throughout Europe. On the other hand, the Turkish market was first exposed to vehicles with 3-cylinder engines around the same time (late 1990s/early 2000), particularly with the imports of Japanese firms.[1]

The three-cylinder engine has been developed as a result of the increasing internal combustion engine efficiencies with current technology, the widespread use of turbocharger and hybrid systems, the ever-tightening emission norms, and the companies' efforts to reduce production costs in order to increase production capacity, even though the first examples are typically found in A and B segment cars. Engines may now be employed in D segment cars at a reasonable power level. Three-cylinder engines have mostly taken the role of 4-cylinder engines in the production of A and B category automobiles.

In this report, the historical development of 3-cylinder engines, which mainly work with diesel fuel, and the factors that cause them to become widespread in the sector will be examined.

2. LITERATURE REVIEW

2.1. Three-Cylinder Engine

An inline-triple or inline-three engine, sometimes known as a straight-three engine, has three pistons placed in a line along a single crankshaft. The crankshaft angle forms a position of 120 degrees using the three-straight engines. As a result, their firing intervals contain even spacing.

Figure 1, three-cylinder engine section view

Due to its shorter crankshaft and fewer pistons, 3-cylinder engines have fewer moving components than those with 4 or more cylinders. Three-cylinder engine manufacture also uses less raw material than four-cylinder engine production. As a result of the increased market competitiveness in the automobile industry, it has developed into a viable alternative to the manufacturers' objective of producing vehicles in greater quantities and at cheaper costs. Additionally, three-cylinder engines' fuel economy and emission control are improving in comparison to alternatives with more cylinders as a result of their smaller size.

2.1.1. History of the 3-Cylinder Engine

The use of three-cylinder engines in automobiles has been realized in the Japanese market with A and B segment models. And the first three-cylinder Japanese car was the Suzuki Cervo/SC100.

Figure 2, Suzuki Cervo

The 1998 Smart ForTwo two-seater city vehicle from Mercedes was Europe's first prominent experiment with the three-cylinder engine, but the continent's first significant change occurred at the beginning of the previous decade when ever-stricter pollution standards triggered an age of engine reduction.

In contrast to the loud, shaky engines people had grown accustomed to in the micro-vehicle class, Volkswagen's 2011 Up! mini city car featured a tractable and enjoyable normally aspirated 1.0-litre that, while only generating 55 kW, already signalled considerable development for the three-cylinder.

Figure 3, Volkswagen Up

Strong acceleration required some effort, though, and Ford of Europe's 1.0-liter "EcoBoost" engine that same year showed off the engine's full capability. For flexible performance and good fuel efficiency, the high-tech three-cylinder engine included direct fuel injection, dual variable valve timing, and turbocharging.

Peugeot unveiled its new 208 city vehicle around the same time, replacing a four-cylinder model with a 1.2-litre turbocharged three-cylinder that was better in many ways. Before adopting the 208's turbo version in its 2015 C4 line-up, its sibling company Citroen provided a 1.2L three with naturally aspirated in its 2013 C3 city vehicle.

2017 saw Honda create their smallest VTEC engine, a 1.0-litre three-cylinder that was used in cars like the Civic but was never exported to Australia. Despite having a displacement that was almost half that of the four-cylinder it replaced, it nonetheless generated higher torque and less pollutants.

The 116i and 118i (of which only the latter was made available in Australia) and the 318i base-model 3 Series were created by BMW using its 1.5-litre turbocharged triple from its Mini brand, marking a significant year for the first appearances of three-cylinder cars from the luxury brands.

With its plug-in Countryman, Mini is one of the few automakers to create a hybrid car that seamlessly combines an effective three-cylinder gasoline engine with a zero-emission electric motor.

In the current market, 3-cylinder engines are available in almost all A and B segment vehicles, and in the vast majority of C segment vehicles. We can see examples of 3-cylinder engines in higher segment vehicles as well.[3]

2.1.2. Advantages of 3-Cylinder Engines

Optimized Fuel Efficiency

A 3-cylinder engine uses fewer engines than a 4-cylinder engine, therefore it uses less fuel to operate the car. The engine becomes more fuel-efficient as a consequence and functions flawlessly in smaller automobiles.

Less Friction

Because there are fewer engines utilized in this kind, there is less friction caused by the engines moving against each other as they move. As a result, there is less need for fuel consumption and improved performance.

Low Cost

The engine is one of the most important components used in the construction of a car; thus, if a manufacturer uses one fewer engine, the cost of production is multiplied by many. As a result, automobiles equipped with them are less expensive than those with 4-cylinder engines. [20]

2.2. Diesel Engine

Any internal combustion engine that uses diesel fuel that is fed into the cylinder and heated to a temperature high enough to ignite the fuel ignites a diesel engine. The combustion and expansion of the fuel act to move a piston. It transforms the chemical energy contained in the fuel into mechanical energy that may be utilized to drive maritime boats, heavy tractors, freight trains, and locomotives.[4]

Four-stroke combustion cycles are used to power diesel engines. These consist of:

Intake stroke

The pistons descend as air enters the cylinders through the intake valve.

Compression stroke

The air is compressed as the pistons rise.

Combustion stroke

Fuel is injected and ignited which forces the pistons to descend once again.

Exhaust stroke

Exhaust produced during the combustion process is pushed out when the pistons travel back toward the top.

2.2.1. History of the Diesel Engine

Rudolf Diesel was born in Paris, France, in 1858, and is most known for creating the engine that carries his name. When he made his innovation, huge businesses were mostly powered by the steam engine.

Diesel opened his first business in 1885 in Paris to start working on the compression ignition engine. 13 years would pass during the procedure. He created an effective, slow-burning, compression-ignition internal combustion engine, for which he was granted a number of patents in the 1890s. Diesel furthered his research at Maschinenfabrik-Augsburg AG (becoming Maschinenfabrik-Augsburg-Nürnberg or MAN) from 1893 to 1897. Along with MAN, the Swiss company Sulzer Brothers showed early interest in Diesel's work by purchasing some of the invention's rights in 1893.

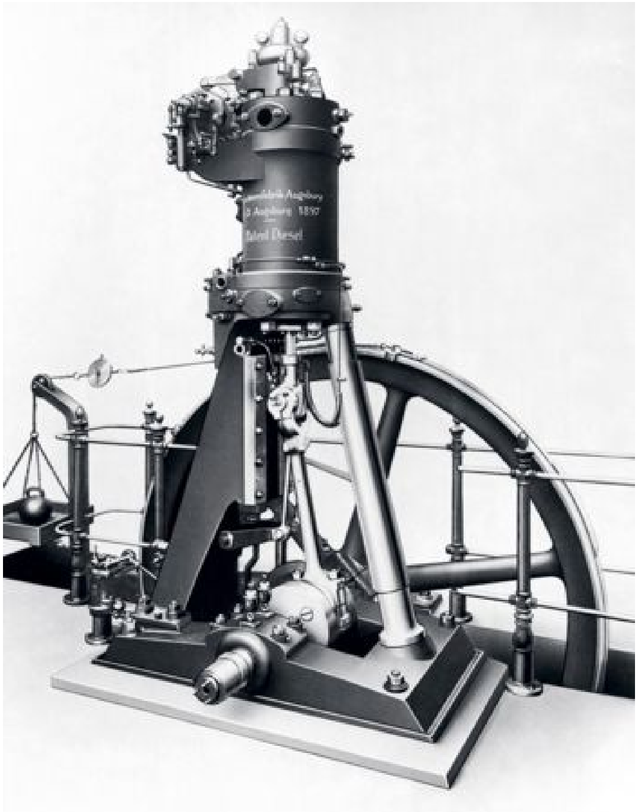


Figure 4, Diesel’s third test engine used in the successful 1897 acceptance test

On August 10, 1893, prototype testing at MAN in Augsburg started with a 150 mm bore/400 mm stroke design. Although the initial engine test was unsuccessful, improvements and subsequent tests eventually led to a successful test on February 17, 1897, when Diesel demonstrated an efficiency of 26.2% with the engine, Figure 2, under load. This was a noteworthy accomplishment given that the then-common steam engine had an efficiency of about 10%. In June 1898, the first diesel engine made by Sulzer fired up.

Alfred Büchi, a Swiss engineer and inventor, was able to boost a diesel engine's efficiency by more than 40% in 1925 by integrating his turbocharging technique. The vast majority of contemporary diesel engines are turbocharged and operate on Büchi's ideas.

German manufacturer and inventor Robert Bosch made improvements to and launched fuel-injection pumps in 1927, which helped the engines run more efficiently and efficiently on gasoline. Mercedes-Benz introduced the first passenger car with a diesel engine in 1936.

By the 1960s, diesel engines were the predominant form of propulsion for commercial trucks. In order to comply with these regulations, the United States passed the Clean Air Act in 1963. Over the years, the diesel engine underwent modifications and evolutions.

Since the middle of the 2000s, new elements have been added to diesel engines to assist lower emissions and make them more ecologically friendly. In 2017, Cummins announced next-generation diesels with improved fuel efficiency and revised pollution controls.[5],[6]

2.2.2. Turkey's meeting with Diesel Engine

Although the introduction of the diesel engine in Turkey may give the impression that it was a simple and quickly adopted technology given the prevalence of the technology today, the process has actually been difficult due to the initial negative experiences, which for a while led to a prejudicial attitude toward cars with diesel engines.

The government-initiated a less expensive diesel engine project for cars in 1985 in response to rising oil costs and foreign exchange rates, and it also urged Turkish automakers to create diesel-powered vehicles. At that time, Turkey was a nation and a civilization with highly stringent import restrictions that relied only on domestic manufacture to live and thrive. The automobile industry was at the forefront of these areas. Ford, Renault, and Tofaş were the three largest of them. Commercial cars were being produced by BMC at İzmir under license from Leyland.

After Tofaş received the special import licence in 1985, Fiat, a partner with whom it had developed manufacturing licenses, came on his door. Fiat recommended the Lancia diesel engine, which it utilized in the Regata model which was built in Italy for a very brief period of time.

Figure 5, Brochure of diesel engine Tofaş

The first Tofaş Şahin with a diesel engine left the factory in 1988. However, the price at when it was made available for purchase was 75% greater than that of the model's gasoline variant. The chassis built for the gasoline engine was not reinforced enough, which resulted in the center of gravity approaching forward and lower traverse issues and stability problems at the braking with the diesel engine, which was 200 kilograms heavier. Not only that, but the used 1.93-liter Lancia diesel engine's flawed design, which was also endorsed by outside groups, resulted in ongoing issues including overheating, cylinder block splitting, and piston rods separating from the engine block and coming out. When the problems in the supply of spare parts were added to all these, diesel engine Tofaş Şahin customers began to remove the diesel engine in their cars and convert it to the engine used in the gasoline version as soon as the issues with the availability of replacement parts were added to all of these. Due to these factors, Turkey's diesel automotive experience was brief, and the diesel engine had a terrible reputation in the nation until the arrival of diesel-powered cars made by French and German companies.[7]

2.2.3. Future of Diesel Engine

Future regulations on emissions in the car industry are anticipated to tighten even more, with the US and EU setting the standard. In the EU, nearly 50% of new automobile registrations each year are diesels. Despite this, we cannot overlook the reality that year over year, less new diesel-powered vehicles are being sold in Europe.[10]

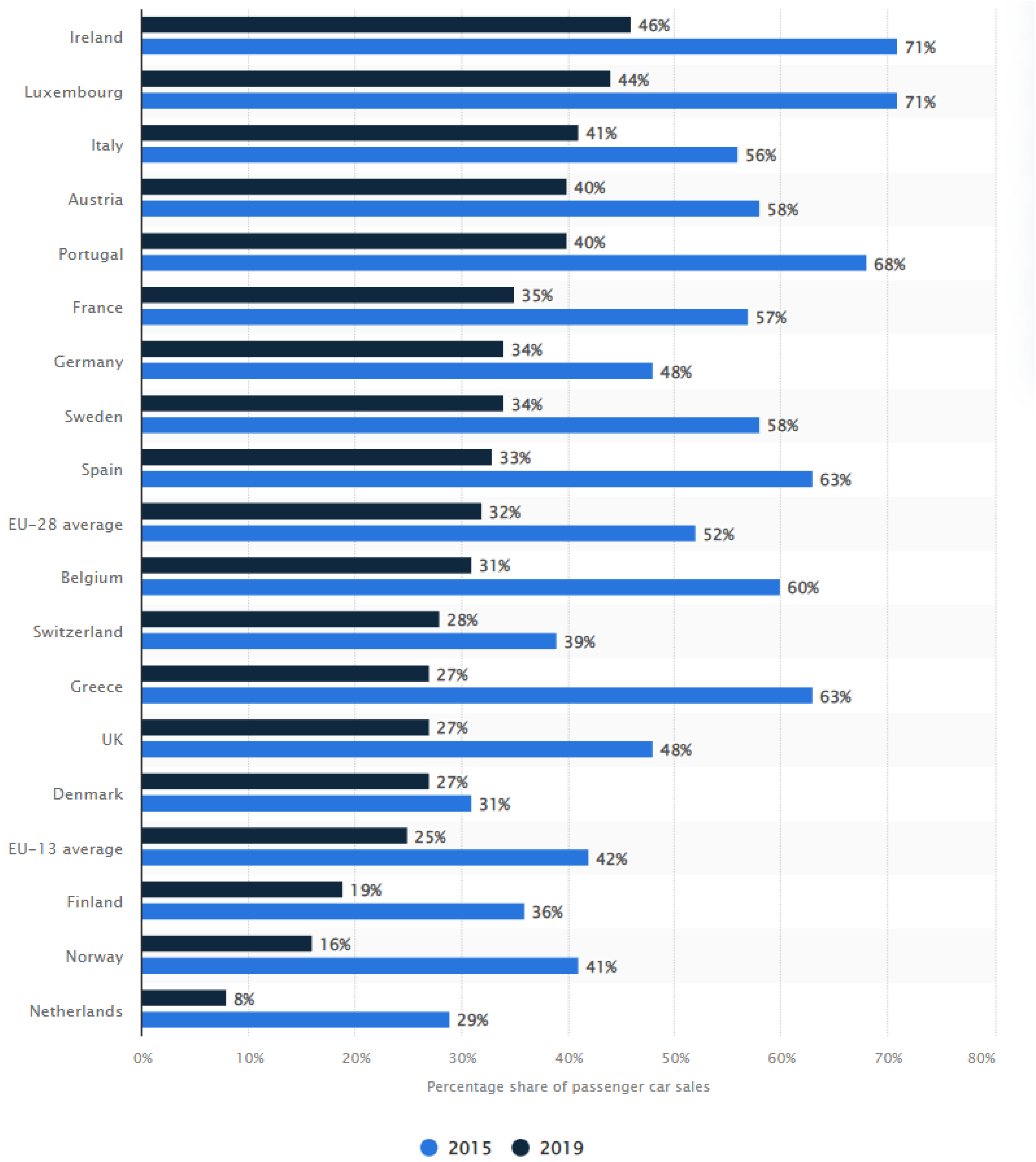


Figure 6, Graph of percentage share of diesel passenger car sales in Europe

The French market's percentage of diesel vehicles, which was 70% in 2010 and significantly higher than the EU average, fell to 34% in 2019 as a result of the French government's decision to equalize the fuel tax for gasoline and diesel. Although less obvious than in France, there is also a significant fall in Spain and England. In Spain and the UK, diesel's percentage of new car sales has fallen to 28% and 25%, respectively.

Considering the Turkish market, during the year 2022:

- 69% share in gasoline car sales with 408,920 units,
- 17.4% share in diesel automobile sales with 103,311 units,
- 10.9% share in hybrid automobile sales with 64,387 units,
- LPG-powered automobile sales took a 1.4% share with 8,309 units
- 7,733 electric cars were sold.

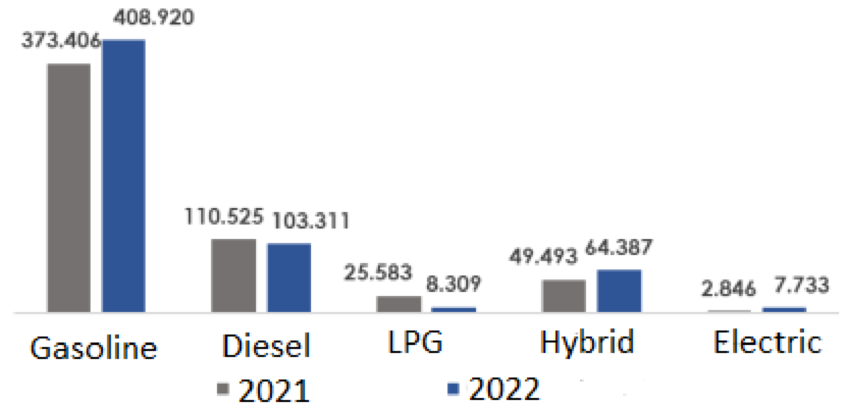


Figure 7: Comparison of the 2021 and 2022 vehicle sold in Turkey

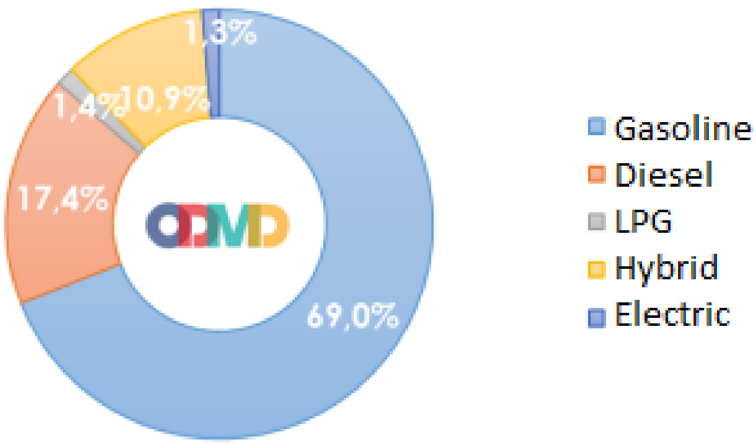


Figure 8: Comparison of the market share of vehicles sold in Turkey in 2022 by fuel type

Recent diesel pollution scandals have had a detrimental effect on public perceptions of diesel as well as the use of diesel in light trucks and passenger automobiles. On the other hand, many automakers' CO_2 emission reduction plans continue to be built around this efficient and clean fuel. Ford, General Motors, BMW, Volkswagen, and Mercedes, some of the top automakers in the world, have recently taken actions and made investments that demonstrate their belief that diesel-powered vehicles will continue to be produced for many years to come alongside gasoline- and electric-powered vehicles.

For instance, Ford just added a new 1.5-liter diesel engine choice for the EcoSport and a diesel engine option for the Ford Ka+. The Chevrolet Silverado 1500 and GMC Sierra 1500 now have a new inline-six turbodiesel engine from General Motors. On the other side, Mercedes-Benz committed three billion euros to bring next generation diesel engines in the A, E, and S-Class cars.

Volkswagen continues to stress the significance of diesel engines in its product lineup despite being under a lot of criticism as a result of the diesel disaster. The firm debuted the EA288 Evo engine in 2018, which gives all the benefits of previous TDI engines without having excessive pollution levels. The newly developed inline-four-cylinder 2.0-liter turbodiesel is also compatible with mild-hybrid use and will find use in future VAG Group models including Volkswagen, Audi, Skoda and Seat.

A belief that diesel engines pollute the environment more than gasoline engines affects vehicle sales. Diesel fuel has more energy per liter than gasoline, and a compression-ignition diesel engine is thermally more efficient than a spark-ignition gasoline engine.

It is difficult to determine whether a petrol or diesel engine is dirtier, as other factors also play a role, such as the age of the vehicle, where and how it is used, mileage and type of fuel. British exhaust testing specialist Emissions Analytics found in 2018 that EU-regulated diesels emit, on average, seven percent fewer particles and 18 percent less carbon dioxide than their gasoline equivalents.

Even more encouraging news is provided for the aftermarket. Although the decrease in new diesel car sales is abrupt, it won't happen right away. This suggests that there will be a growing market for diesel car after-sales services. More than half of all automobiles on the road today are powered by diesel. The average age of the automobiles sold on the market now is around 6.7 years old, while the service life of diesel vehicles is over 13 years. These cars will thus have a longer service life. It is not anticipated that the diesel vehicle park would separate from the after-sales market in the near future given that the market's diesel vehicle park is at a relatively new level and diesel vehicle sales are still at a major level. By 2024, there would still be more than 113 million diesel passenger cars on European roads, according to the figures.

More than 14 million diesel cars under the age of three are now on European roads. As they age, these newer automobiles will require more maintenance. Significant possibilities will be created as a result for service providers. For instance, the majority of modern common-rail injector systems are vulnerable to substantially quicker wear since they pump fuel more often and at much greater pressures. This results in far more involved and expensive repairs.

But the aftermarket doesn't merely gain from diesel fuel injection parts. On average, diesel car drivers log more miles than petrol car drivers. Additional chances for wear-and-tear fixes result from this.[8],[9]

2.3. Solution to Lower Emissions From IC Engines

The EU is actively striving to improve testing techniques for pollutant emissions and fuel consumption of light-duty cars in addition to tightening emission reduction regulations (standard Euro 6 up to Euro 6d). Real Driving Emissions (RDE) for measuring regulated pollutants and the Worldwide Harmonized Light-duty Vehicles Testing Procedure (WLTP) for measuring CO_2 emissions are two new testing methods being developed to evaluate the performance of vehicles under real-world conditions. Light-duty vehicles have significantly higher emissions when actually on the road compared to tests conducted in laboratories.

A non-linear percentage is used to analyse NO_x emissions from diesel vehicles and associated emission-control costs: The cost of emission control to comply with the EURO 6 criteria is more than three times that of the EURO 3 limits.

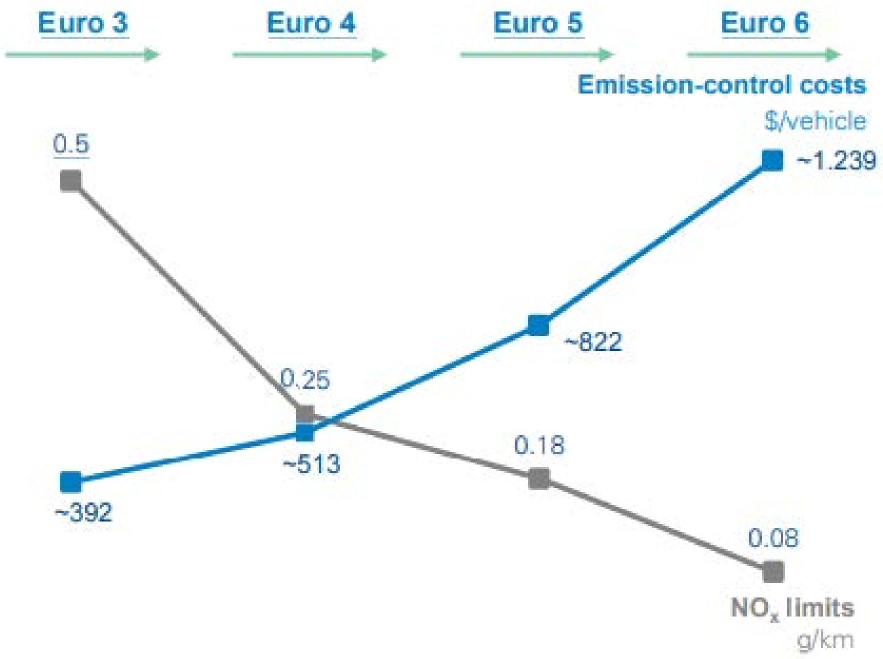


Figure 9: NOx limits of diesel cars and related emission control costs

Compared to gasoline engines, diesel engines cost more to manage and decrease pollutant emissions. Air-fuel control and catalytic after-treatment are two emission-control technologies for gasoline engines that have advanced to a high level of maturity. Even with stricter regulations, the extra cost of compliance is minimal. On the other hand, diesel-specific emission-control methods (including air management, fuel injection, and after-treatment) are more expensive and complex.

2.3.1. Usage of Renewable Fuels

The use of advanced diesel engines, biodiesel, and renewable diesel are crucial tactics in the fight against climate change. Because they are suitable for both new and used vehicles, high-quality biofuels are readily accessible, affordable, and proven to significantly reduce GHG and other emissions over the short term in a variety of economic sectors that currently and in the foreseeable future heavily rely on diesel engines.

The majority of heavy-duty diesel engines, including those seen in commercial vehicles, can run on biodiesel mixes up to 20%. (B20). Some diesel engines are authorized to run on greater mix levels in fleet applications. Renewable diesel fuel may be used as a 100 percent substitute for petroleum since it is manufactured to the same technical standards as petroleum diesel fuel.

2.3.2. Hybrid Systems

Automobile manufacturers started looking for innovative solutions to comply with the new emission standards in order to lower the emission standards and carbon emissions. Hybrid power systems, which mix electric power with internal combustion engines, were the most widely used of these techniques. In actuality, hybrid power systems have a lengthy history dating back before pollution standards were implemented.

Ferdinand Porsche, an engineer, created the first hybrid vehicle in the year 1899. The system, dubbed the System Lohner-Porsche Mixte, used a gas engine to fuel an electric motor that turned the car's front wheels. Due to the Mixte's popularity, more than 300 were made. But when Henry Ford introduced the first vehicle production line in 1904, interest in hybrids started to decline. The market for hybrid vehicles was drastically reduced by Ford's capacity to make gasoline-powered automobiles and provide them at affordable rates. The Mixte's technology allowed hybrids to be created long into the 1910s, but most of them failed to find a market since they were more expensive and less powerful than their gasoline-powered counterparts. Hybrids quickly went out of style, setting off a nearly 50-year era during which they were only an afterthought.[11]

In an effort to lessen air pollution, the US Congress passed laws in the 1960s encouraging the usage of electric cars. Although the government made efforts to increase public interest in hybrids, it wasn't until the Arab oil embargo of 1973 that it really took off. Due to the oil crisis, gasoline prices skyrocketed as supplies sharply decreased. Nearly 85% of all American employees commuted by car at the time, thus rising petrol prices and dwindling supply were big issues.

A few completely electric cars were released in the late 1990s, including the Toyota RAV 4 EV and the General Motors EV1. These all-electric cars did not garner a lot of attention and were quickly taken off the market. The Toyota Prius was not a practical alternative to gas-powered automobiles until it was debuted in Japan in 1997.

The Honda Insight was the country's first HEV to be launched in substantial quantities in 1999. Although the Toyota Prius car, which was introduced in the United States in 2000, provided hybrid technology the foothold it needed, the two-door, two-seat Insight may have been the first. Since its debut in the United States, the Prius has come to represent the word "hybrid." It is the most well-liked HEV ever created, and numerous more automobiles have been built using its technology by automakers all over the world.

Figure 10: 1997 Toyota Prius

The Prius may face tough competition in an era of rising environmental consciousness. Chevrolet unveiled the Volt, and Honda unveiled the Insight of the second generation. Hybrid technology will continue to advance and gain more traction in the global automotive industry. Whatever the future holds, one thing is for certain: automakers will continue to create hybrid vehicles in the same way they did in the past.

We may categorize hybrid power systems in today's technology into 4 groups:

- Micro Hybrid
- Mild Hybrid
- Full Hybrid
- Plug-in Hybrid

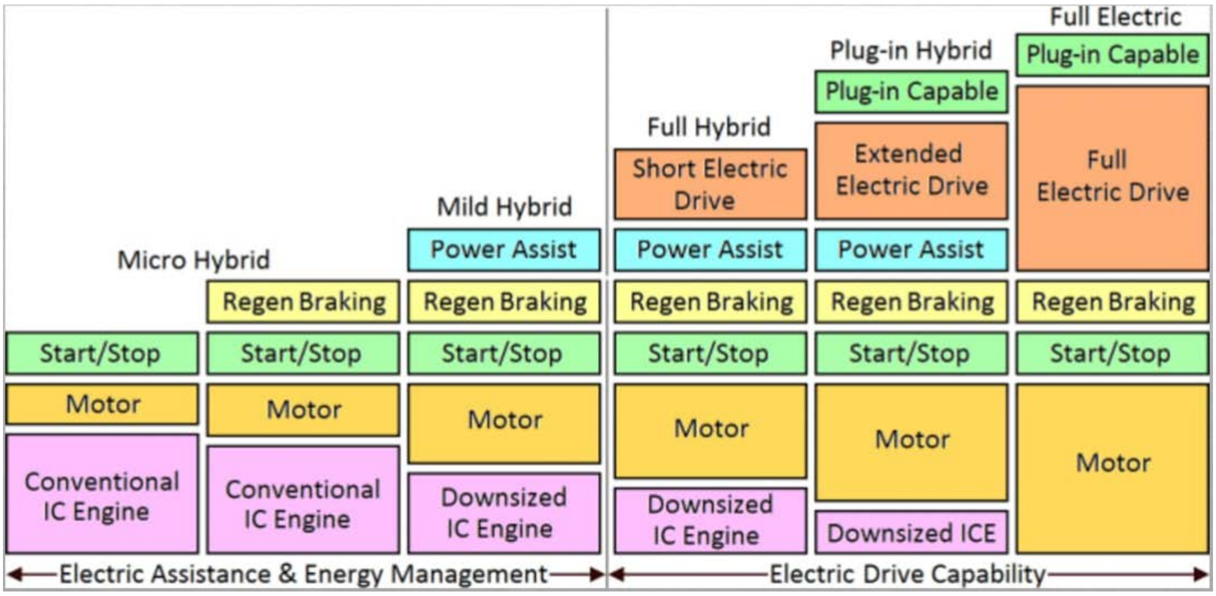


Figure 11: Diagram of Hybrid Systems

Micro Hybrid

These systems also include an electric motor that can propel the car from a stop in addition to internal combustion engines. Additionally, the start-stop technology stops the internal combustion engine while the car is halted in heavy traffic, reducing fuel usage. Since internal combustion engines use a lot of fuel when they initially start up, micro hybrid cars' initial starting and stabilizing time is decreased from 800 milliseconds to 200 milliseconds, saving extra fuel. Regenerative braking, also known as brake energy recovery, is utilized to supply the electric motor with the necessary power.

Mild Hybrid

Cars using electrical technology that supports the engines of vehicles with traditional internal combustion engines and minimizes fuel consumption are known as hybrid vehicles, regardless of whether they have gasoline or diesel engines. Typically powered by a 48-volt battery, this booster electric motor serves as the vehicle's starter.[13]

With the electrical energy they contain during takeoffs, semi-hybrid automobiles may take off without the need to ignite the gasoline and react quicker than their rivals. In addition, since gasoline is not used at low speeds, the overall cost is decreased. When your car requires more power while you're driving, it turns on the electric motor, giving you access to more power and delivering great performance. At the same time, it maintains the ideal amount of fuel usage. During deceleration, the 48-volt hybrid battery is charged and it is ensured that the energy generated in braking is not wasted.

Full Hybrid

Vehicles with this technology can only run and move with electric motor energy, and to do this they need to have more powerful electric motors and larger battery capacities. However, the distance they can move using only the electric motor is very limited (generally less than 10 kilometers).

Plug-in Hybrid

Other than braking and the energy generated by traditional engines, the batteries in these cars may be charged with the power we use at home. They require bigger batteries and electric motors as a result. Batteries have a certain charging time based on the kind of external power source, much like in electric vehicles.

Examples of Hybrid Systems:

Honda's Hybrid Technology

Figure 12: Honda's Hybrid Power Engine

A strong drive motor, a motor/generator, and a lithium-ion (Li-Ion) battery pack make up this system. The gasoline engine's three primary tasks are driving the generator that generates energy for the drive motor, directly driving the front wheels, and recharging the battery pack.

In contrast, the motor/generator only functions as a motor to start the engine and instead constantly drives a large generator. The generator spins and recharges the battery while the standard gasoline engine is running.

All Honda hybrid vehicles also come equipped with the cutting-edge regenerative braking system. These sophisticated technologies are able to store the energy for later use inside the battery in an effort to recover energy that is generally wasted during the braking process. [12]

Nissan e-Power Technology

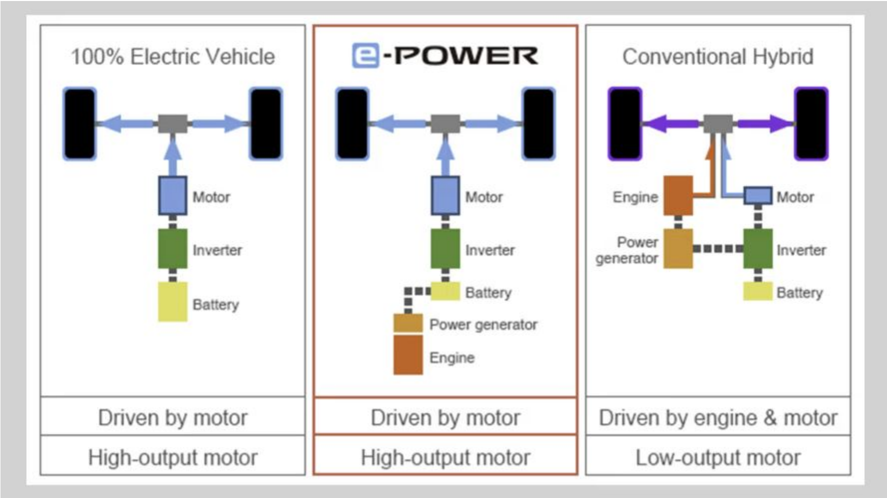


Figure 13: Scheme of e-Power Technology

Unlike other hybrids, Nissan's exclusive e-POWER technology employs a gasoline engine generator to recharge the battery, which then powers an electric motor to move the wheels by itself. Despite having less exhaust emissions and running expenses than a traditional internal combustion engine, it reacts similarly to an electric automobile, offering quick torque and not requiring a plug. Regenerative braking is used by e-POWER in addition to the gasoline engine to aid in maintaining the battery's charge.

BMW’s Plug-in Hybrid Technology

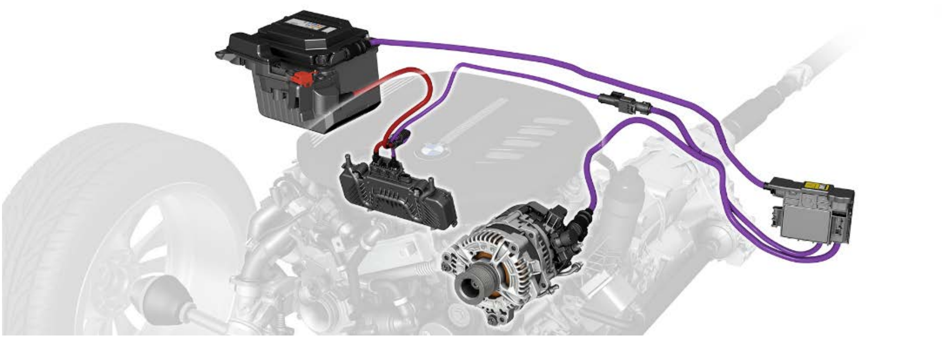


Figure 14: BMW Plug-in Hybrid System

With mild hybrid technology installed, a BMW features a not only gasoline engine it also with diesel engine as well as a 48-volt battery that serves as a generator rather of the more conventional starting motor. Although it doesn't produce enough electricity to operate the car on its own, the battery will enhance the automobile's fuel economy by improving MPG while also enhancing performance and acceleration.

It functions by recapturing energy lost while braking and using it to generate additional power. Therefore, the MHT can offer that extra boost of acceleration when needed. Stopping and restarting the engine has another performance benefit. Both actions are carried out more smoothly.

Additionally, there are financial advantages because MHT lowers CO_2 emissions from the vehicle when it is in motion. Compared to a petrol or diesel model lacking such equipment, a mild hybrid car is more environmentally friendly.

Mercedes-Benz AMG E-Performance Technology

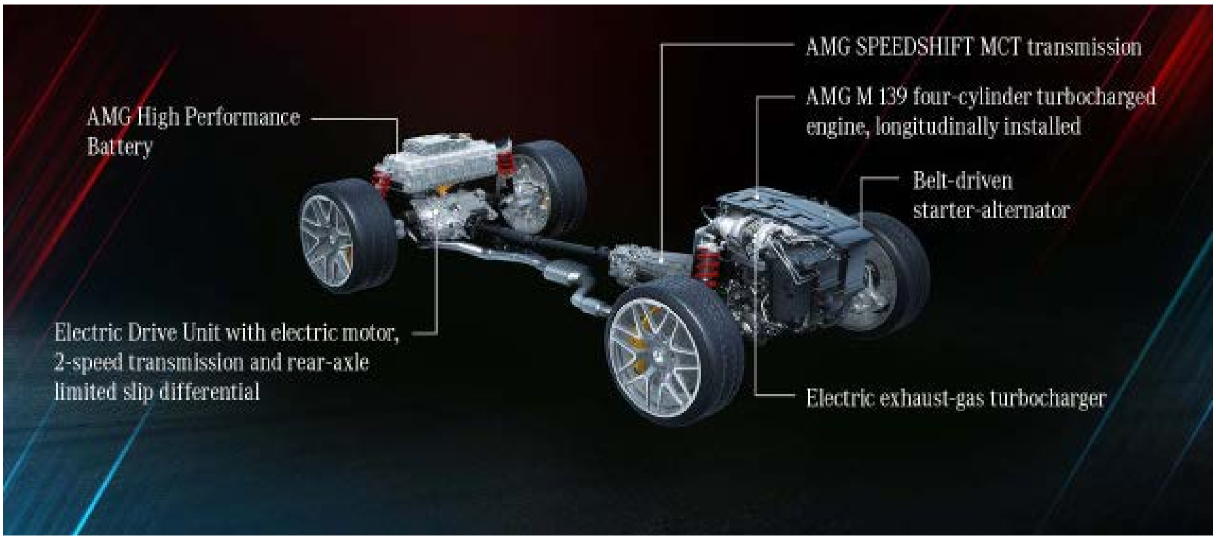


Figure 15: Scheme of AMG E-Performance

AMG, the performance car manufacturing department of Mercedes Benz, uses a battery and electric motor combination positioned on the rear axle in addition to the smaller internal combustion gasoline engine in its new generation vehicles. A 2-speed gearbox, an electronic limited-slip differential, and the motor will be mounted on the back axle.

The motor can only spin up to 13,500 rpm, and the transmission is required because it allows the motor to contribute extra power at speeds greater than 87 mph. When the back tires start to slide, according to Mercedes-Benz AMG, the electric motor will transfer its power to the front wheels via the 4Matic+ all-wheel-drive system.

According to AMG, the 2.0-liter turbo-4 will produce at least 643 horsepower when paired with the plug-in hybrid powertrain, which is 140 hp more than the before model.

3. DESIGNING 3-CYLINDER ENGINES

Any type of 3-cylinder engine is neither gasoline or diesel engine that has three cylinders. Mostly these type of engines use in small cars because it is fuel efficient, also it has less part than 4-cylinder engine which means much cheaper to manufacture. Also 3-cylinder engine vehicles much more suitable for the cities, metropoles etc.

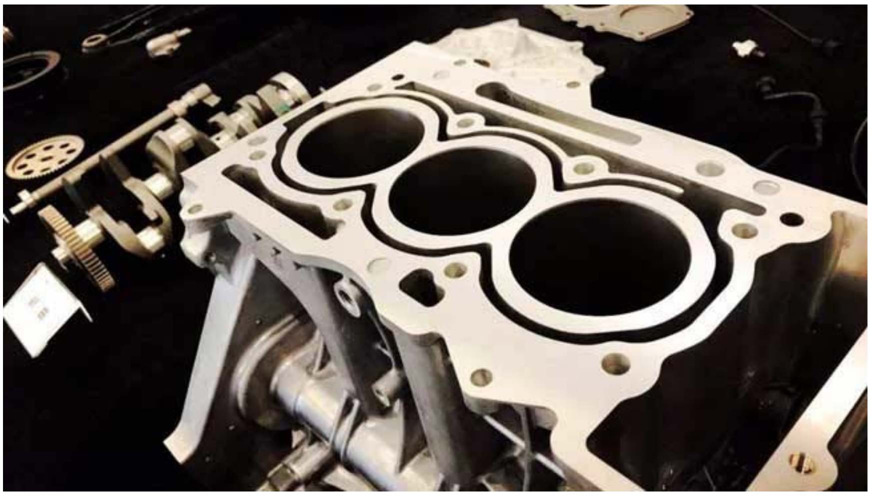


Figure 16, three-cylinder engine block

3-cylinder engine has crankshaft like other type of engines, in the market mostly 120-degree engines used however this causes unbalanced dynamic forces which is a reason for vibration. Old manufacturer dealing this problem with using a balance shaft however it is extra cost for the manufacturing also balance shaft is a parasitic load which means it stoles power from the engine, also decreasing the fuel efficiency.

Manufacturer dealing this problem with manufacturing the rotating parts much unbalanced than calculated, this method eliminating vibration while maintaining weight of the engine.[14]

Figure 17, three-cylinder engine

4. VIBRATION OF 3-CYLINDER ENGINE

One of the main problem of the 3-cylinder engines are vibration, the main reason of the vibration is unbalanced forces because of the odd number cylinder, It is not a easy thing to balance forces in 3-cylinder engine because the cylinder numbers are not even, also five-cylinder engine has this problem.

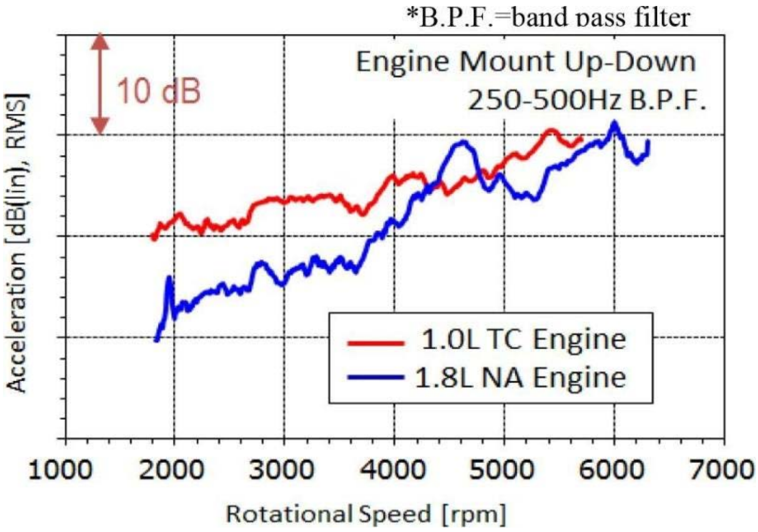


Figure 18,3-cylinder (red) vibrates more than 4-cylinder (blue). The gap closes at higher RPM. (Research by Honda)

There are many solution to this problem like as using counterweighted crankshaft, balance shaft etc. however these solutions are old fashioned further solution could take into the measure like reducing weight of rotating parts (e.g. Honda 1.0 turbo) and asymmetrical oil pump impellers (e.g. Proton 3-cylinder).[15]

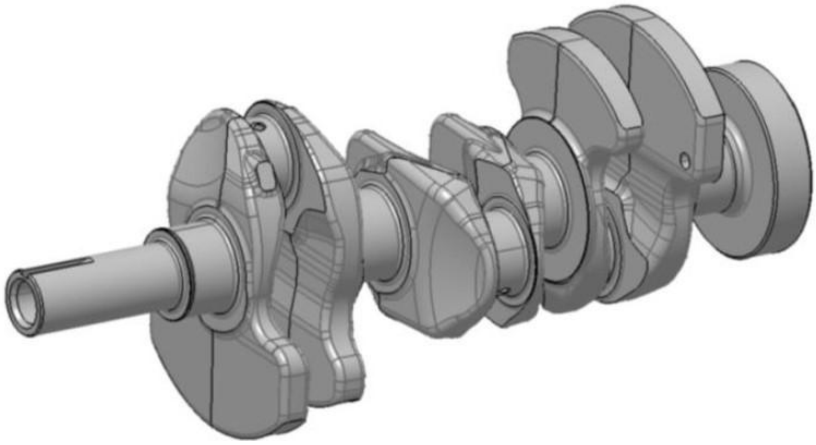


Figure 19, The Thai-spec Honda City 1.0 Turbo's crankshaft is smaller and lighter. (to reduce weight of reciprocating parts).

5. TYPES OF THE FUEL SYSTEM OF 3-CYLINDER ENGINE

Fuel systems in Gasoline Engines

- Carburettor
- Single-Point Fuel Injection or Throttle body injection
- Multi-Point Fuel Injection or Port Injection
- Sequential Fuel Injection
- Direct Injection

Fuel systems in Diesel Engines

- High Pressure Common Rail Fuel System

5.1. Fuel Systems in Gasoline Engines

Without gasoline, the combustion engine in our automobiles could not run. The fuel injection systems deliver this necessary fuel into the combustion chambers. The kind of fuel injection system your automobile has, as well as other factors like mileage, ride quality, engine life, etc., greatly affect a number of its characteristics. In order to feed the engine with gasoline of the ideal volume, fuel injection systems are mechatronic circuits, which combine mechanical and electrical circuits.[17]

5.1.1. Carburettors

An internal combustion engine uses a carburettor to regulate and mix the air and fuel that enter the engine. The Venturi tube in the main metering circuit serves as the principal means of adding fuel to the intake air, although in some situations, more fuel or air may also be supplied by other components.

Fuel injection has generally taken the place of carburettors in automobiles and trucks since the 1990s, however certain small engines (such as lawnmowers, generators, and concrete mixers and motorcycles still utilize carburettors). Fuel injection has long been the preferred fuel delivery system for diesel engines.

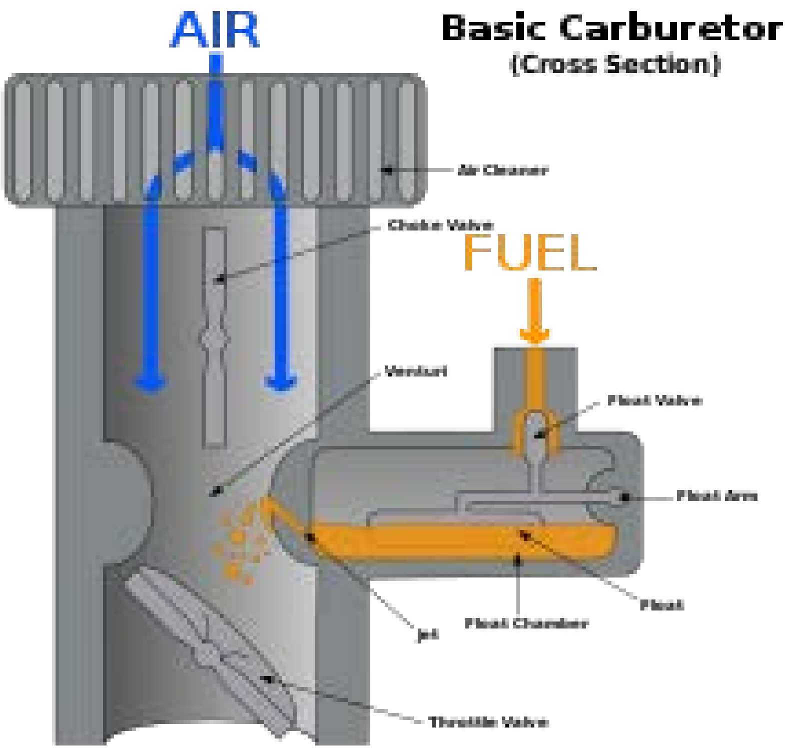


Figure 20, Carburettor

Based on the Bernoulli principle, the carburettor draws more gasoline into the airstream as engine speed increases because the static pressure of the intake air decreases. Most of the time, when a driver presses the throttle pedal, less gasoline enters the engine (with the exception of the accelerator pump). Instead, the amount of gasoline pulled into the intake mixture grows together with the airflow through the carburettor.[18]

5.1.2. Single-Point Fuel Injection or Throttle body Injection

A single fuel injector is used by all the cylinders in the engine's combustion chamber in a single-point injection system. This is the earliest and most basic fuel injection system design. The single-point injection, also known as throttle body injection (TBI), employs one or two fuel injector nozzles in the throttle body in place of the carburettor.

In contrast to the carburettor jet, the gasoline is sprayed simultaneously into all cylinders by an injector, which may be controlled electronically (ECU). While it has an advantage over a carburettor, it also has a tiny drawback in that it only employs one injector, which interferes with engine performance at high RPMs and results in a bumpy ride since the necessary fuel supply isn't provided. Additionally, a little amount of gasoline condenses outside the cylinders' intake manifold, resulting in fuel waste.

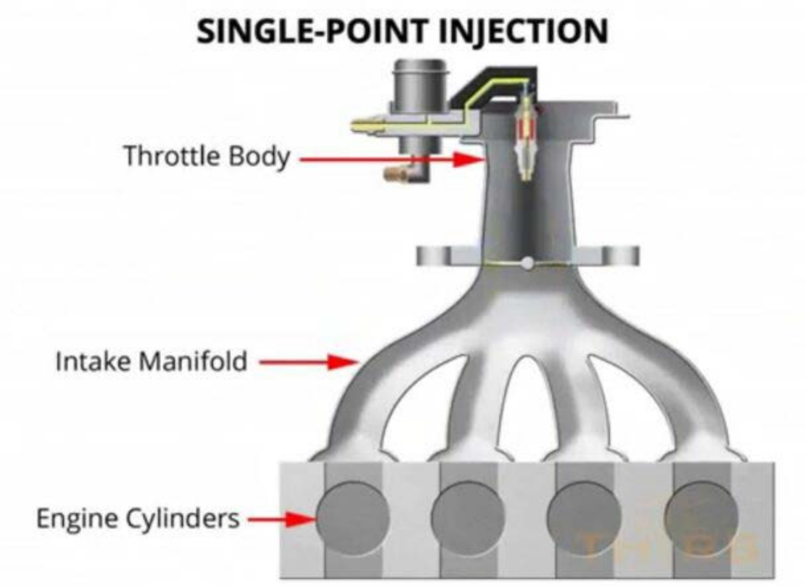


Figure 21, SPI

5.1.3. Multi-Point Fuel Injection or Port Injection

Multi-point fuel injection (MPFI) technology, commonly known as "Port Injection," places an injector in front of each cylinder's inlet valve (outside the intake port) in the engine's combustion chamber.

Each cylinder receives a more accurate amount of fuel from each injector at the same time, reducing the chance of fuel condensation outside the intake manifold. Despite the fact that MPFI uses less gasoline than TBI, because all the cylinders receive the same amount of fuel at the same time, the pistons' rotation is not correctly synchronized. In spite of this, MPFIs perform significantly better than TBIs in terms of performance.

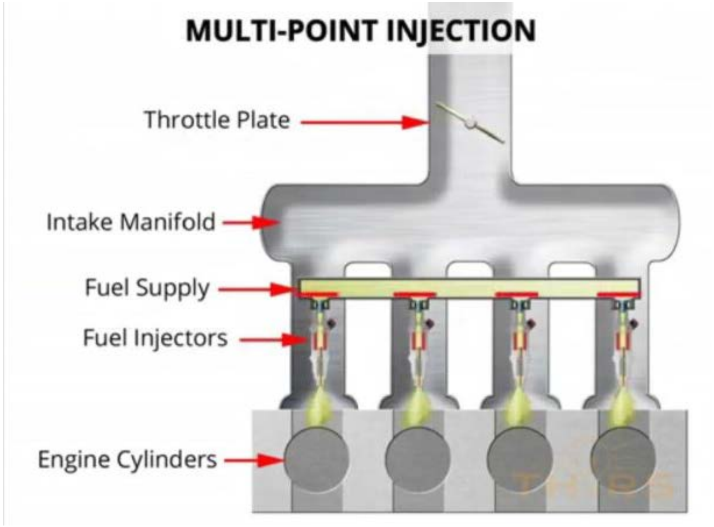


Figure 22,MPI

5.1.4. Sequential Fuel Injection

The most popular fuel injection technique in use today, sequential fuel injection addresses the one drawback of MPFI. The fuel injectors work in relation to the cylinders they are attached to in a sequential fuel injection system. Only until the cylinder's intake valve opens does each injector begin to inject fuel. For the remaining actions, it does nothing. An ECU tracks the motion of the cylinders and only activates the injectors when necessary. Of all the fuel injection methods now offered in the automobile industry, sequential fuel injection is the most effective and efficient.

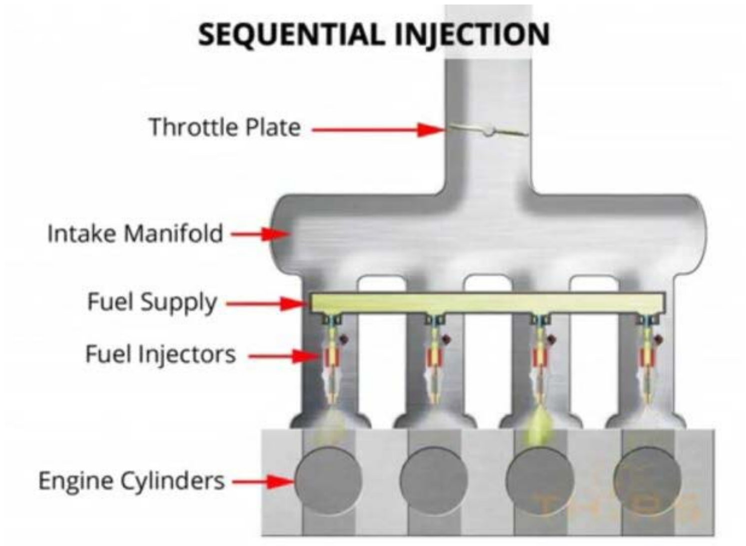


Figure 23,Sequential Injection

5.1.5. Direct Injection

With direct fuel injection, the intake valve or manifold are not used; instead, the injector is placed inside the cylinder to inject fuel directly. While often found in diesel engines, this kind of fuel injection system also has a substantial presence in gasoline engines, where it is known as GDI (gasoline direct injection).

The fuel is sprayed on the intake with the methods mentioned, therefore there is always a chance of fuel condensation. The major benefit of the DI system is that all of the gasoline is directly injected into the cylinder, resulting in optimum fuel efficiency. Direct fuel injection has been utilized in diesel engines since the 1920s, while it has been employed in petrol engines from about World War II. Additionally, GDI engines have been discovered by[16] automakers to be comparatively more powerful and extremely practical for higher CNG fuel economy.

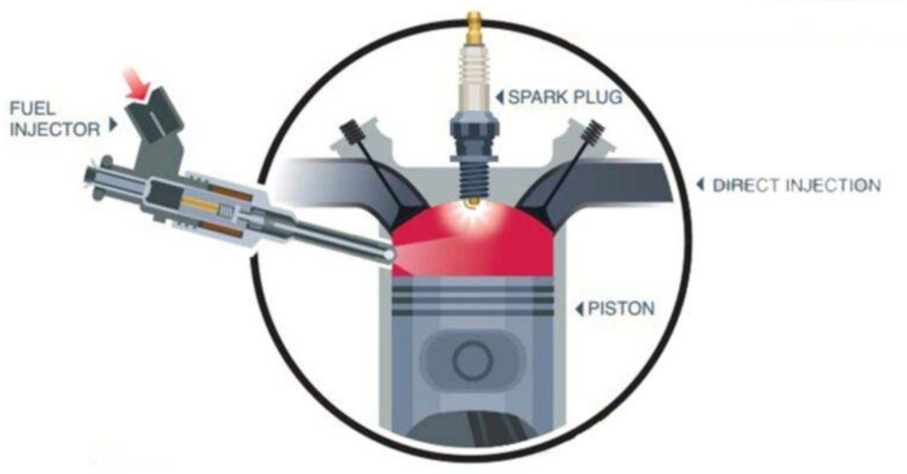


Figure 24,Direct Injection

5.2. Fuel Systems in Diesel Engines

There are five fundamental parts that make up a basic diesel fuel system. Tank, fuel transfer pump, filters, injection pump, and injection nozzles are among them.

In diesel systems, the fuel tanks are commonly made of sheet metal or aluminium alloys. The tanks are made to hold the diesel fuel and withstand its corrosive effects over an extended period.

To get diesel fuel into the injection pump, the transfer pump suctions it out of the tank. The transfer pump is often found on the back of the injection pump or outside the gasoline tank. Transfer pumps are occasionally also housed within the tank.

Diesel is constantly blended with impurities that might harm the combustion system, much like gasoline. Contaminants will inevitably get into diesel since it is refined, stored, carried on trucks, and then stored once more at petrol stations. Filters are positioned in between the injection system and the transfer pump to solve these issues. The filter gets rid of debris and other impurities that might harm the fuel injection system easily.

In order to prepare the gasoline for injection, the injection pump compresses the fuel. Diesel is injected by injection nozzles into the cylinders' combustion chambers. With the aid of the combustion chamber, the automobile is able to transform the miniaturized combustions (explosions) into mechanical energy that drives the wheels.

5.2.1. Common Rail Injection System Pressure Control

As opposed to a low-pressure fuel pump feeding unit injectors, a common rail direct fuel injection system is constructed around high-pressure fuel rail feeding solenoid valves. By injecting gasoline as a greater number of tiny droplets, delivering a significantly higher ratio of surface area to volume, high-pressure injection outperforms previous lower pressure fuel injection in terms of power and fuel economy. Improved fuel droplet surface vaporization results in more effective ambient oxygen mixing with evaporated fuel, which results in a more thorough burning.[19]

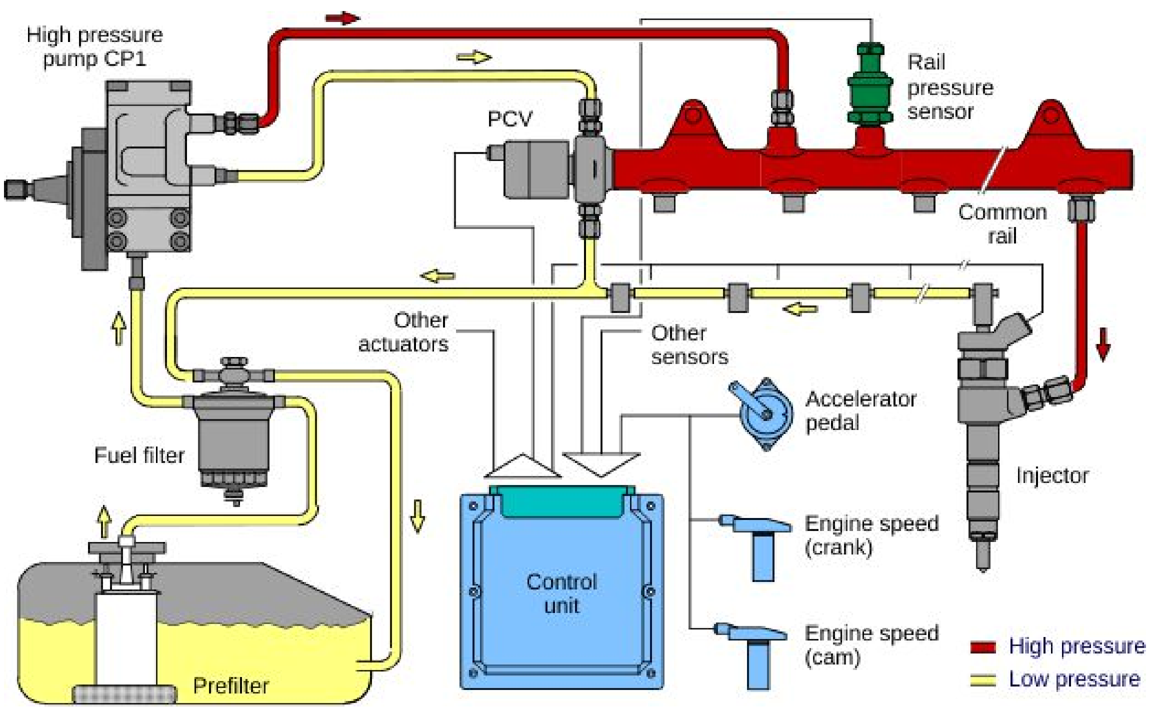


Figure 25,Common Rail

6. TYPE OF 3-CYLINDER USERS

3- cylinder engines are using by cars and motorcycle, in cars 3-cylinder engine mostly using for small cars (like Ford EcoBoost Dragon (2018)) in comparison to 4-cylinder engine, 3-cylinder engine have some pros like Fuel efficiency, Emission standards, small size means more space for the user of car, cheaper to manufacture because it has fewer parts, It is also cheap to maintain.[2]

Also 3-cylinder engines have cons like excessive vibration and noise and it is working hardly at low speed, and it produces low power. 3-cylinder engine most suitable for urban people because in urban area performance is not first choice therefore better fuel efficiency and exhaust emission would be better option for the budget.

Figure 26 Ford 1.0 Ecoboost Engine

7. REFERENCE ENGINE SPECIFICATIONS

Figure 27 VW EA189

Table 1, Specifications of EA189

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

8. CAD MODELS AND TECHNICAL DRAWINGS

Figure 28 Assembly of the Engine

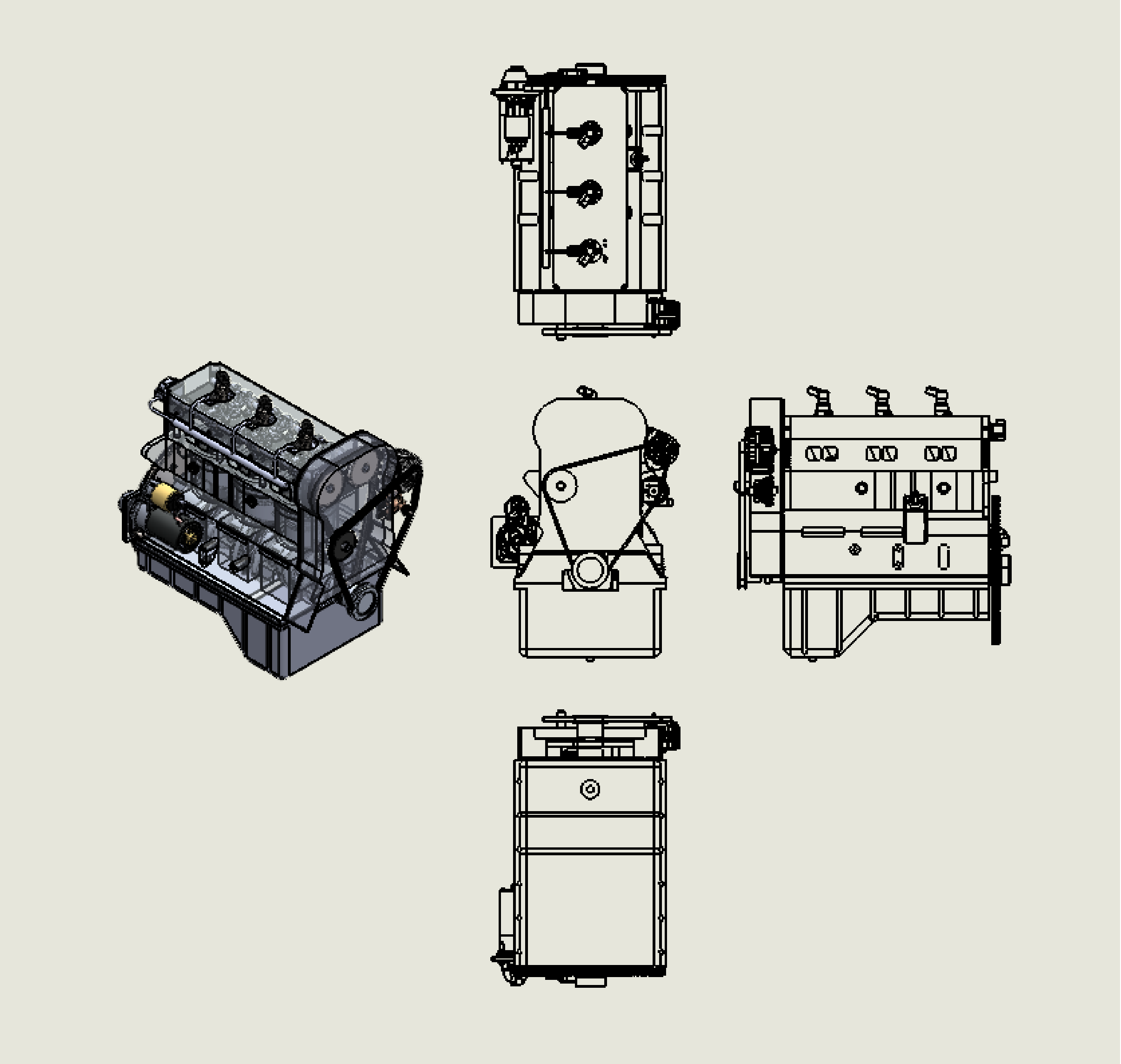


Figure 29, Technical Drawing of the Engine

Table 2, Bill of Materials

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	cylinder block		1
2	Crankshaft		1
3	Nuts		6
4	Bolt		6
5	Segment		6
6	cap end		3
7	Pin		3
8	Main body		3
9	Bushing		3
10	Piston		3
11	Chead		1
12	Bearing housing		8
13	Valve		12
14	Camshaft 1		1
15	Camshaft 2		1
16	Rocker		12
17	Arm		24
18	Pin arm		24
19	Arm 2		12
20	Screw		12
21	Spring		12
22	ISO 15 ABB - 3815 - 18,SI,NC,18_68		8
23	Valve cover		1
24	ISO 4016 - M5 x 25 x 16-WN		4
25	Injector common rail		3
26	ISO - Spur gear 1M 90T 20PA 12FW --- S90A75H50L15.0S1		2
27	ISO - Spur gear 1M 45T 20PA 12FW --- S45A75H50L25.0R1		1
28	Cam key		2
29	Crank key		1
30	Common rail		1
31	Gear box		1
32	Tensioner base		1
33	Tensioner slider		1
34	ISO 4014 - M5 x 50 x 50-N		1
35	Pulley		1
36	ISO 4014 - M5 x 30 x 16-N		1
37	ISO 4017 - M6 x 30-N		1
38	ISO 4014 - M4 x 25 x 14-N		6
39	Belt (Timing)		1
40	Alternator		1
41	Gear box lid		1

42	ISO 4014 - M3 x 25 x 12-N		2
43	70106-4	MOUNT , PUMP	1
44	70106-1	BODY	1
45	70106-7	NUT	1
46	70106-3	SHAFT	1
47	70106-2	IMPELLER	1
48	70106-5	COVER	1
49	70106-6	5BA X 1/4" LONG	10
50	Pump pulley		1
51	Idler pulley		1
52	Belt (v-belt)		1
53	Nose Cone	STARTER	1
54	Case	STARTER	1
55	Shaft starter	STARTER	1
56	Pinion	STARTER	1
57	Solenoid	STARTER	1
58	EndCap	STARTER	1
59	ShaftCap	STARTER	1
60	RubberStopper	STARTER	1
61	Bolt_starter	STARTER	2
62	CapScrew	STARTER	2
63	SolenoidScrew	STARTER	3
64	Insulator	STARTER	1
65	ISO - Spur gear 2M 160T 20PA 15FW --- S160A75H50L150.0N		1
66	Oil sump		1
67	ISO 4014 - M8 x 40 x 22-N		2
68	ISO - 4032 - M8 - W - N		2
69	Oil sump lid		1

.

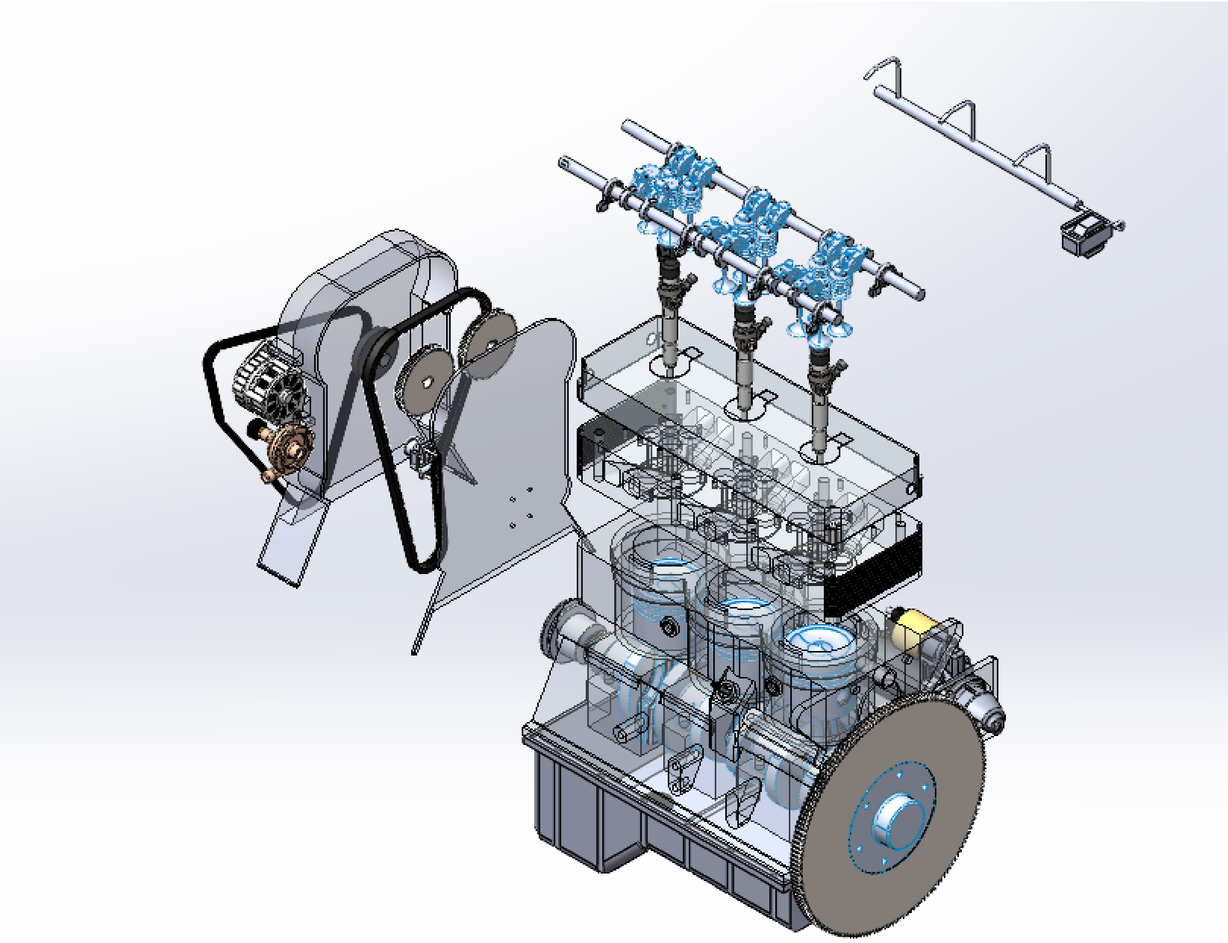


Figure 30 Exploded view of the Engine

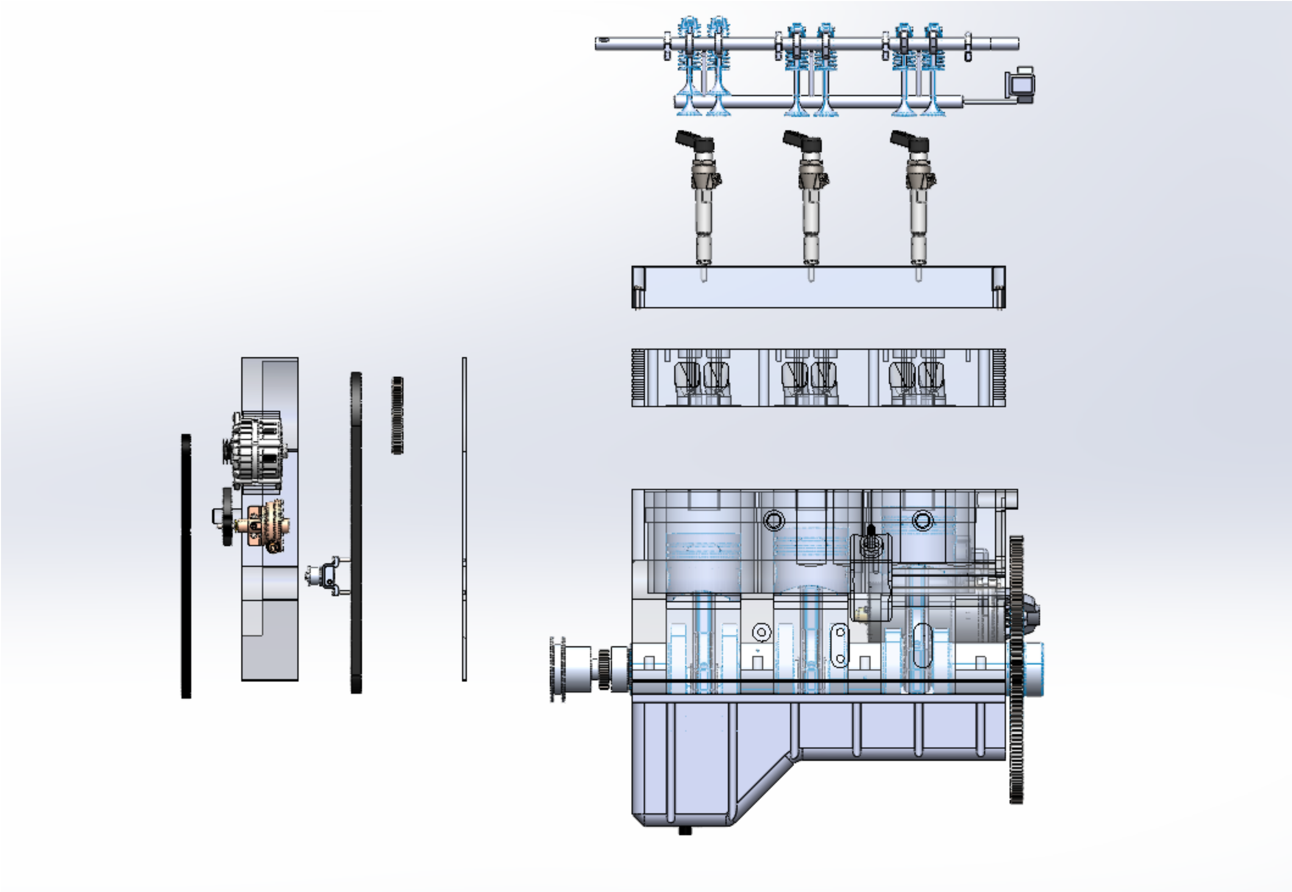


Figure 31 Side view of the exploded view

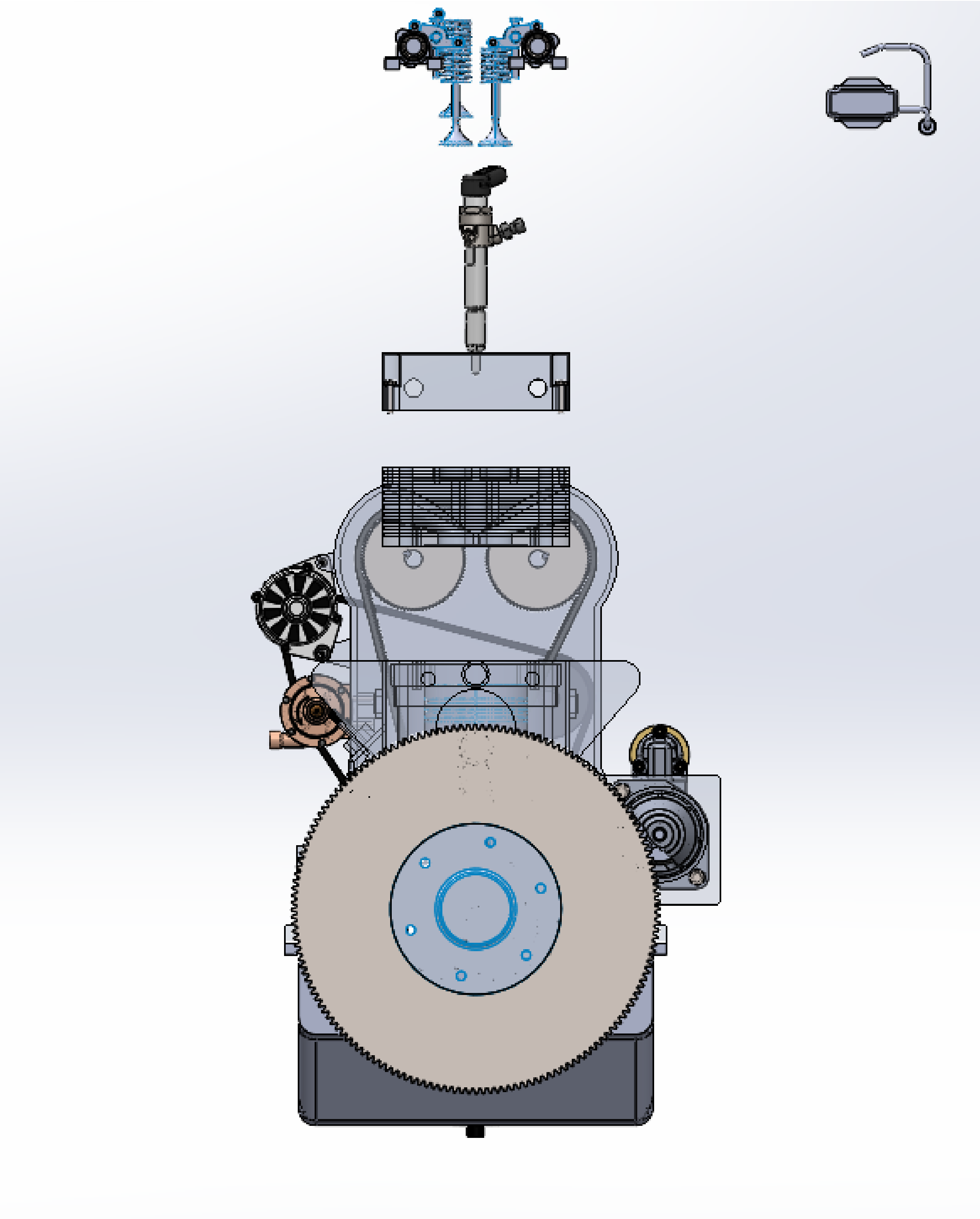


Figure 32 Front view of the exploded view

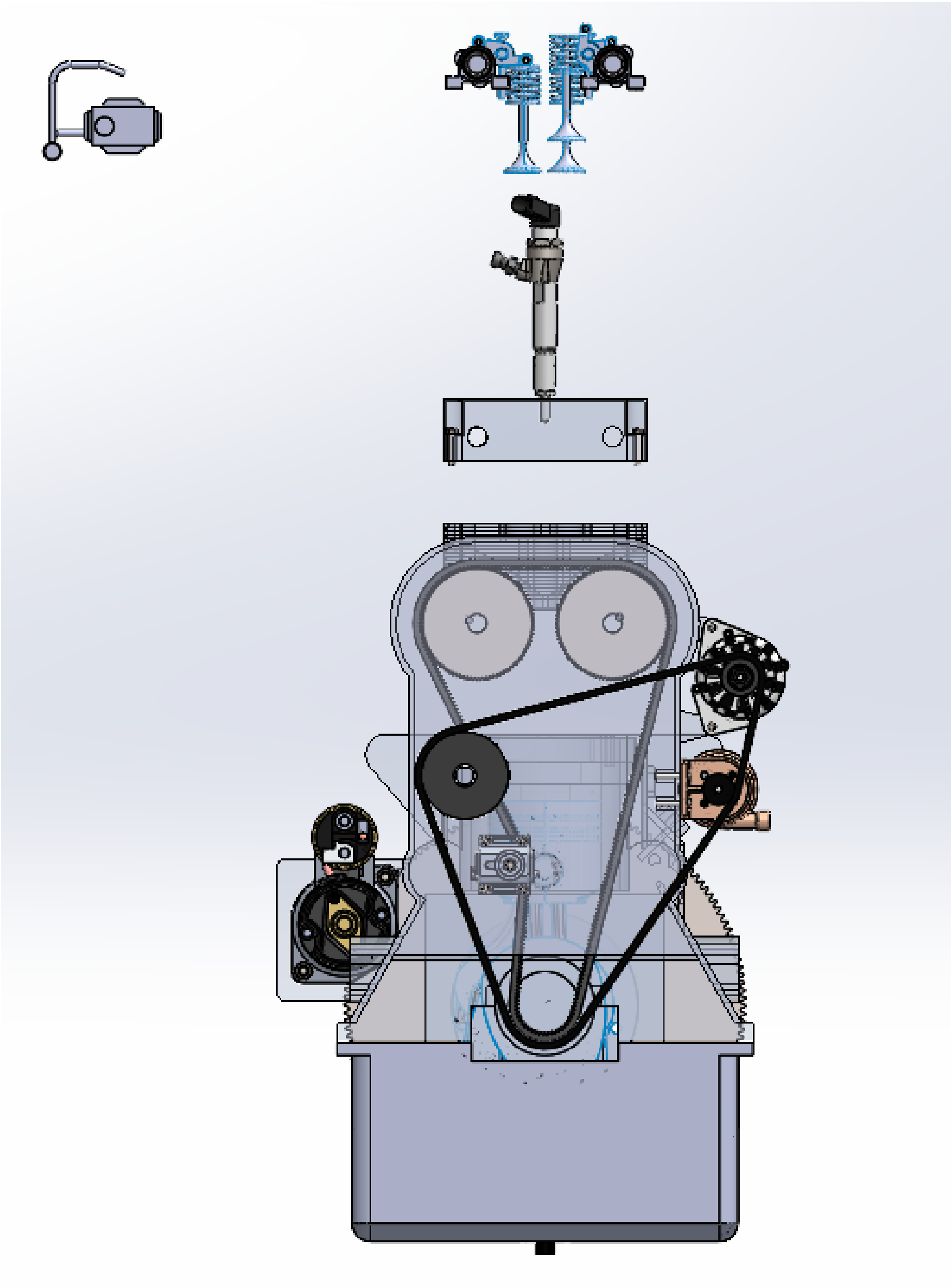


Figure 33 Back view of the exploded view

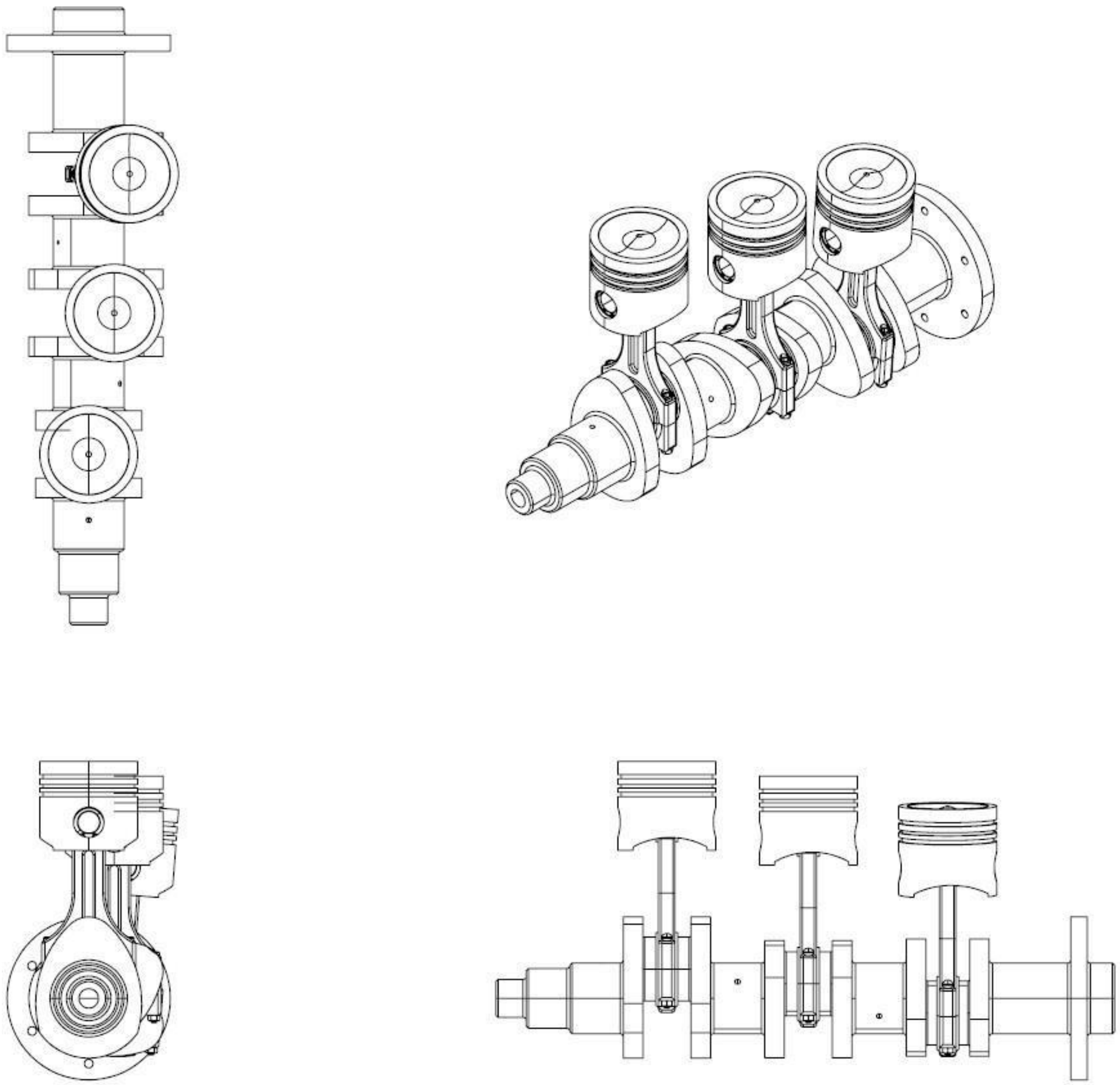


Figure 34 Crank-Piston Subassembly

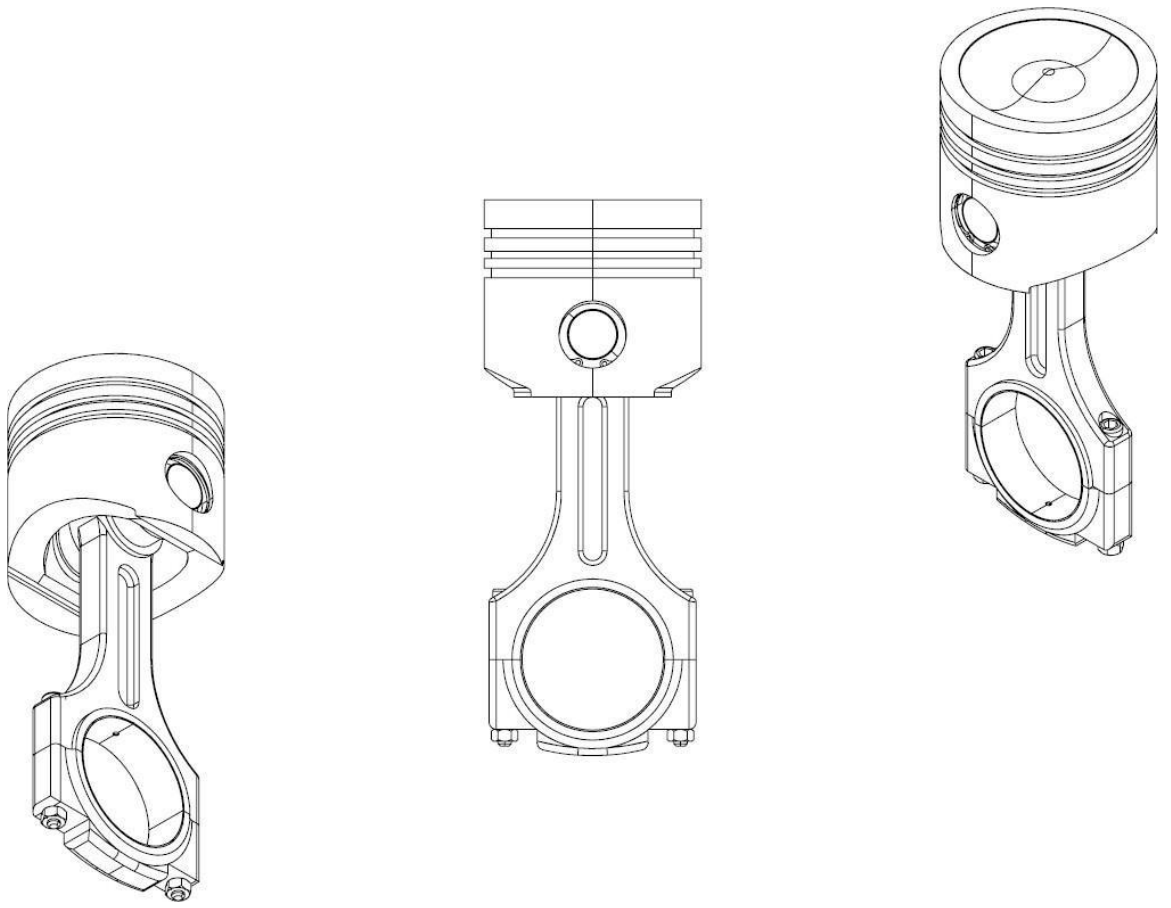


Figure 35 Piston-rod subassembly

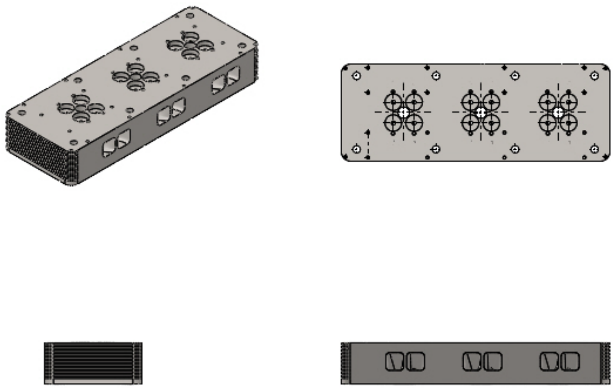


Figure 36 Cylinder-Head

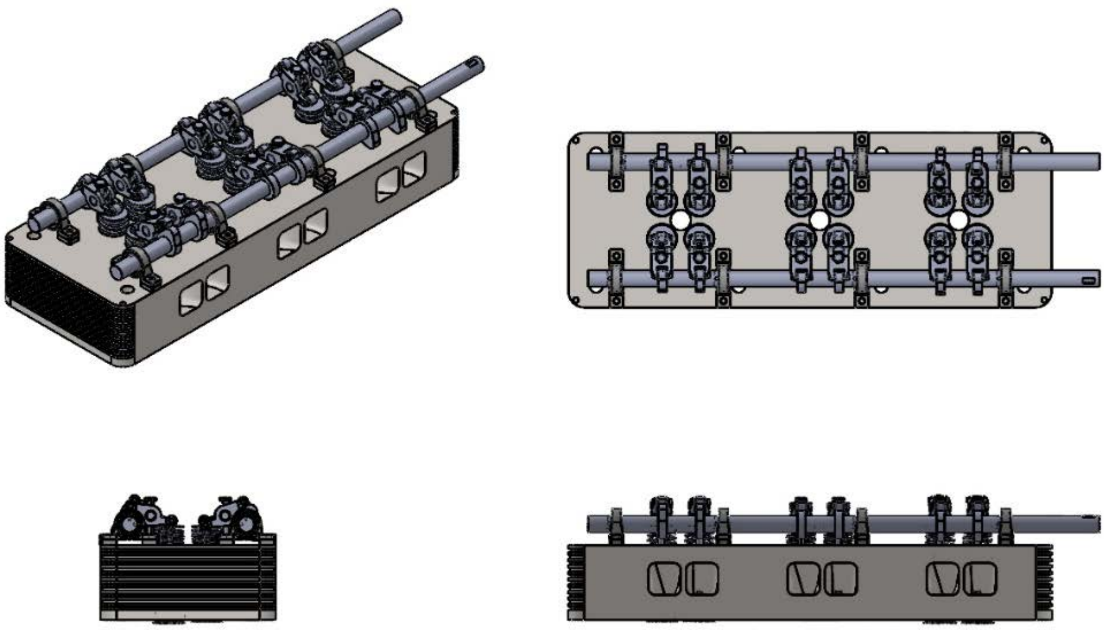


Figure 37 Cylinder-Head subassembly

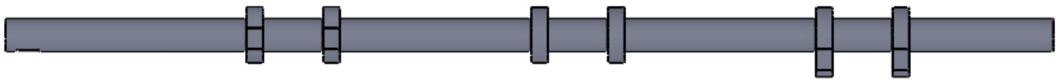


Figure 38 Camshaft

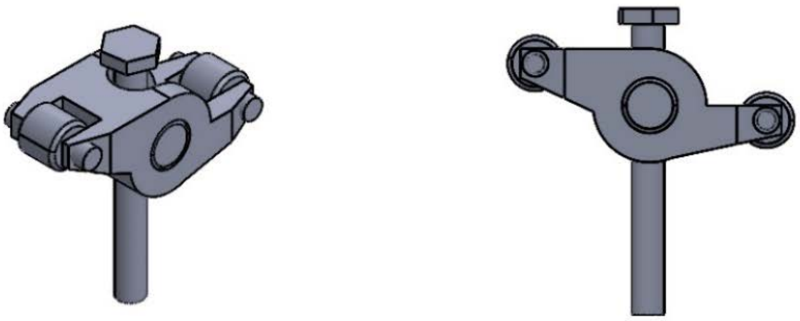


Figure 39 Rocker subassembly

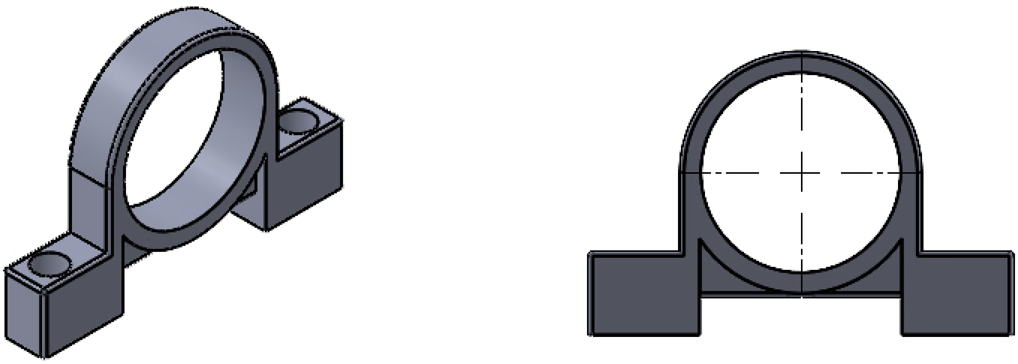


Figure 40 Bearing Housing

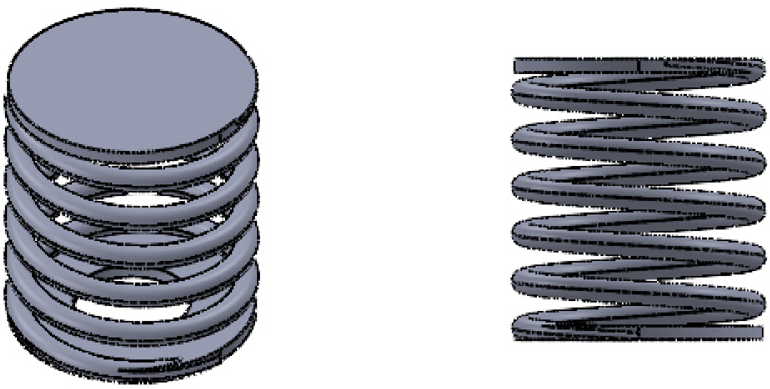


Figure 41 Valve Spring

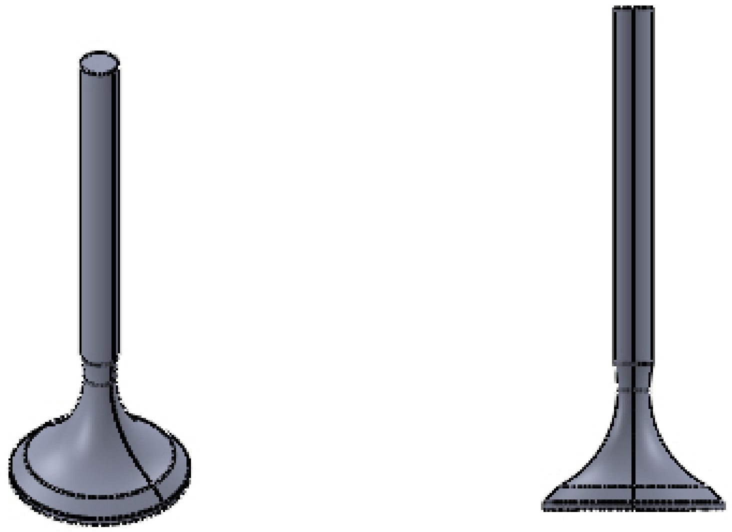


Figure 42 Valve

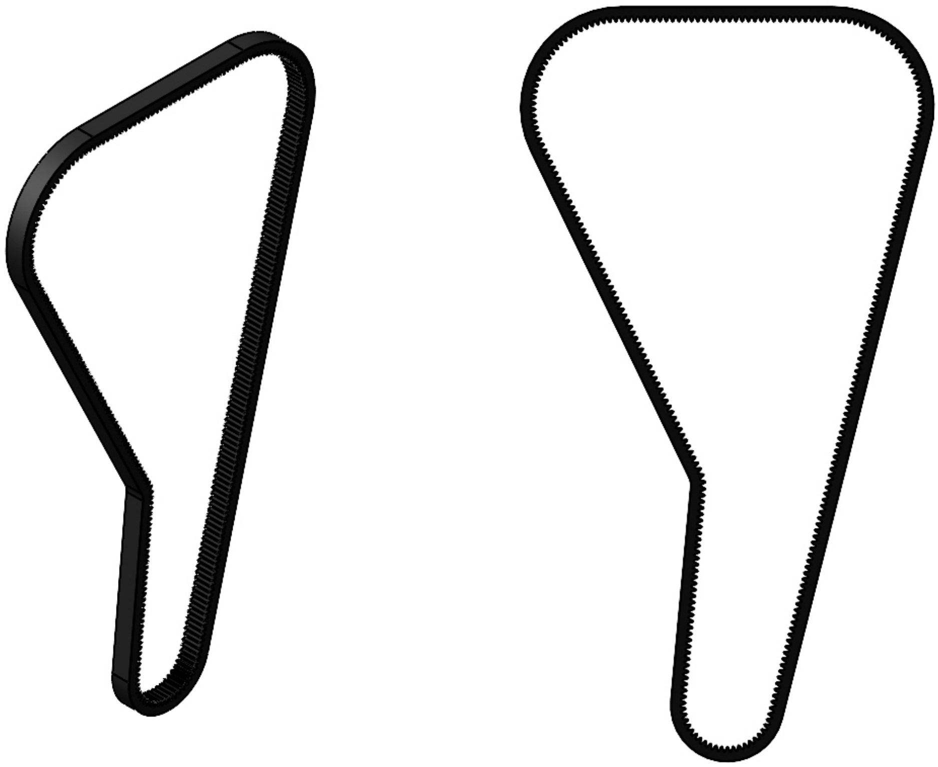


Figure 43 Timing Belt

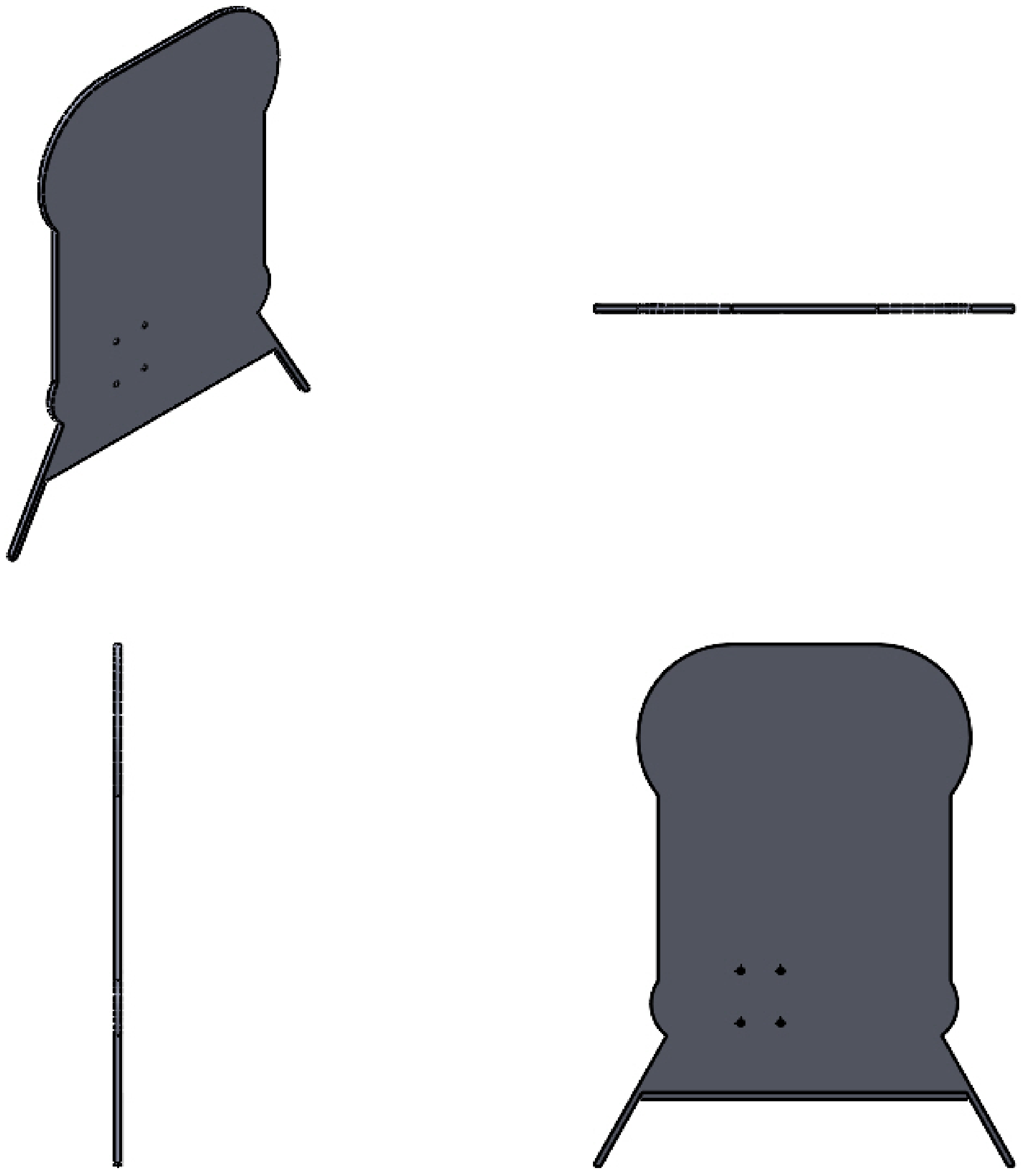


Figure 44 Timing gear cover

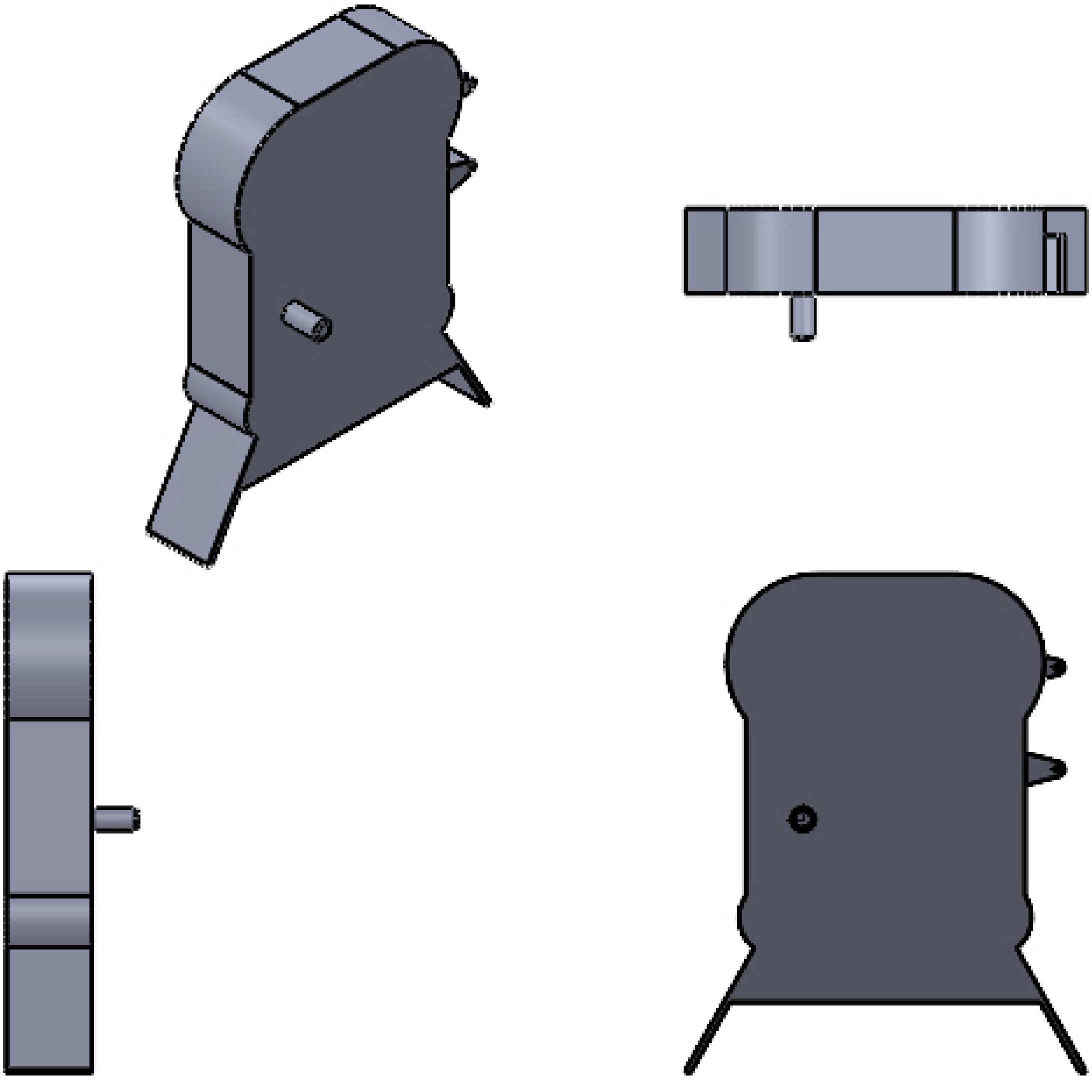


Figure 45 Timing gear cover lid

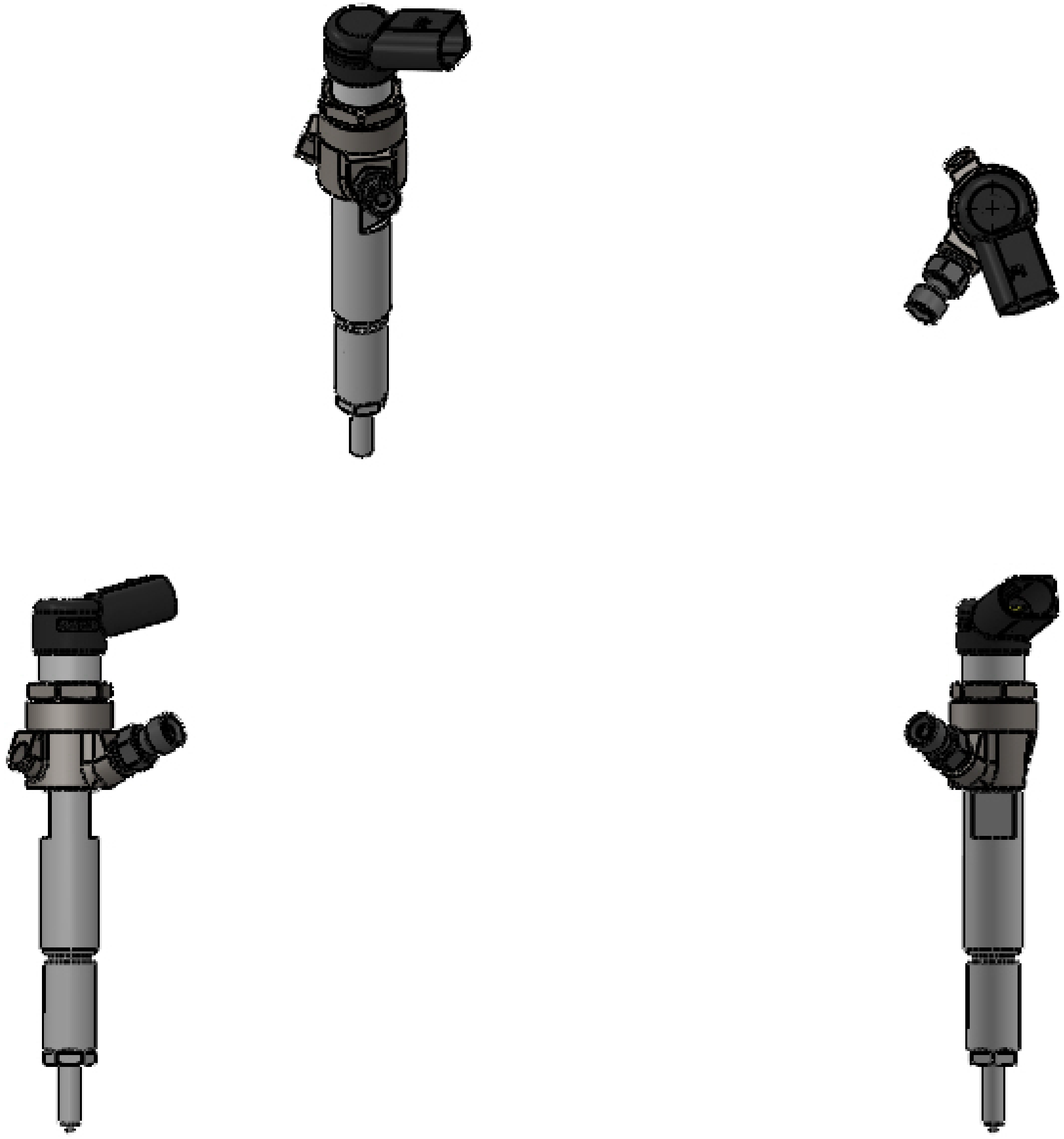


Figure 46 Siemens A2C59511610 Common-Rail Injector

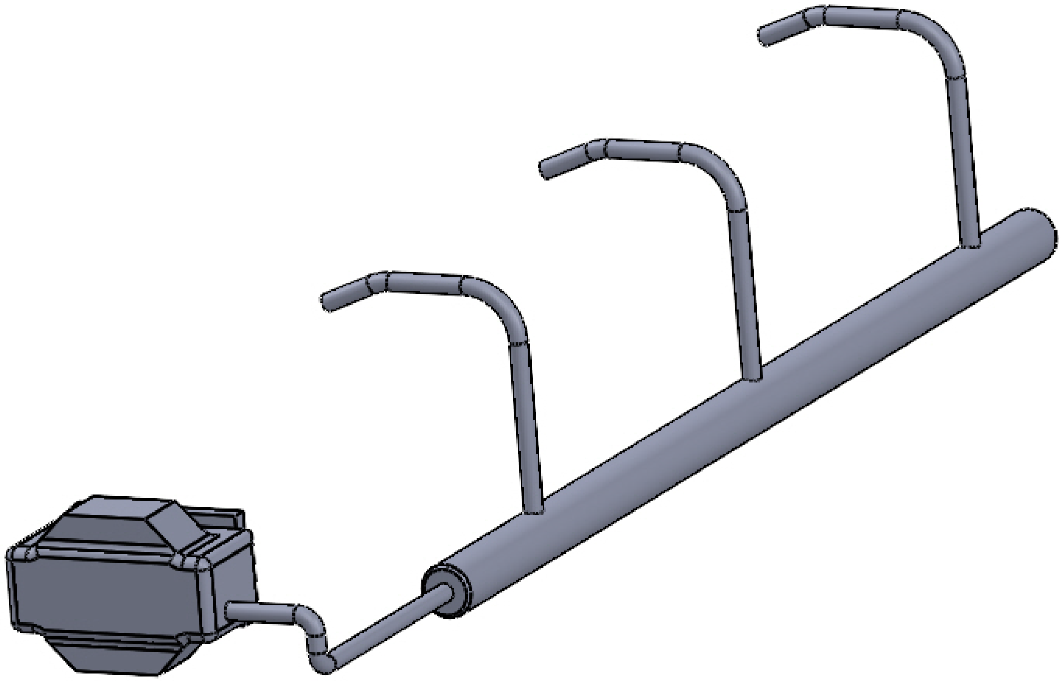


Figure 47 Common Rail

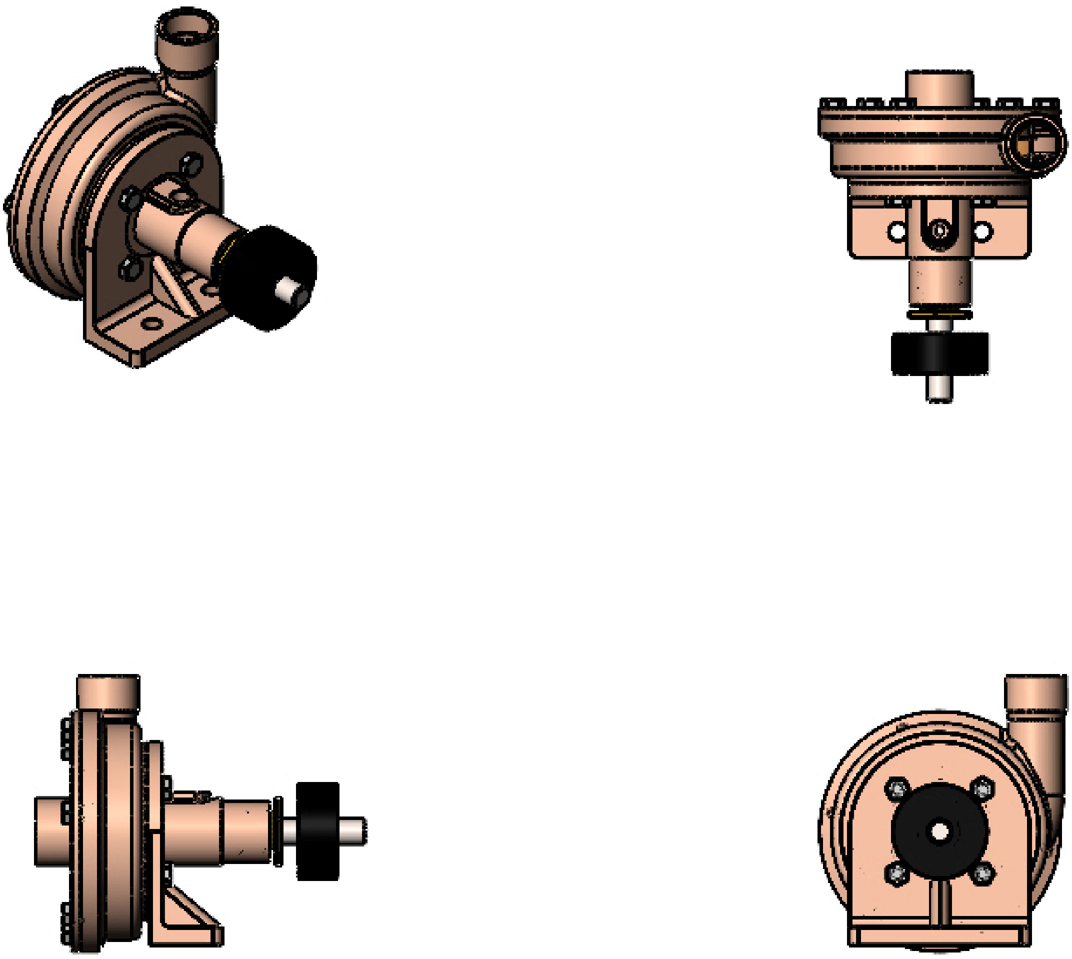


Figure 48 Centrifugal water pımp

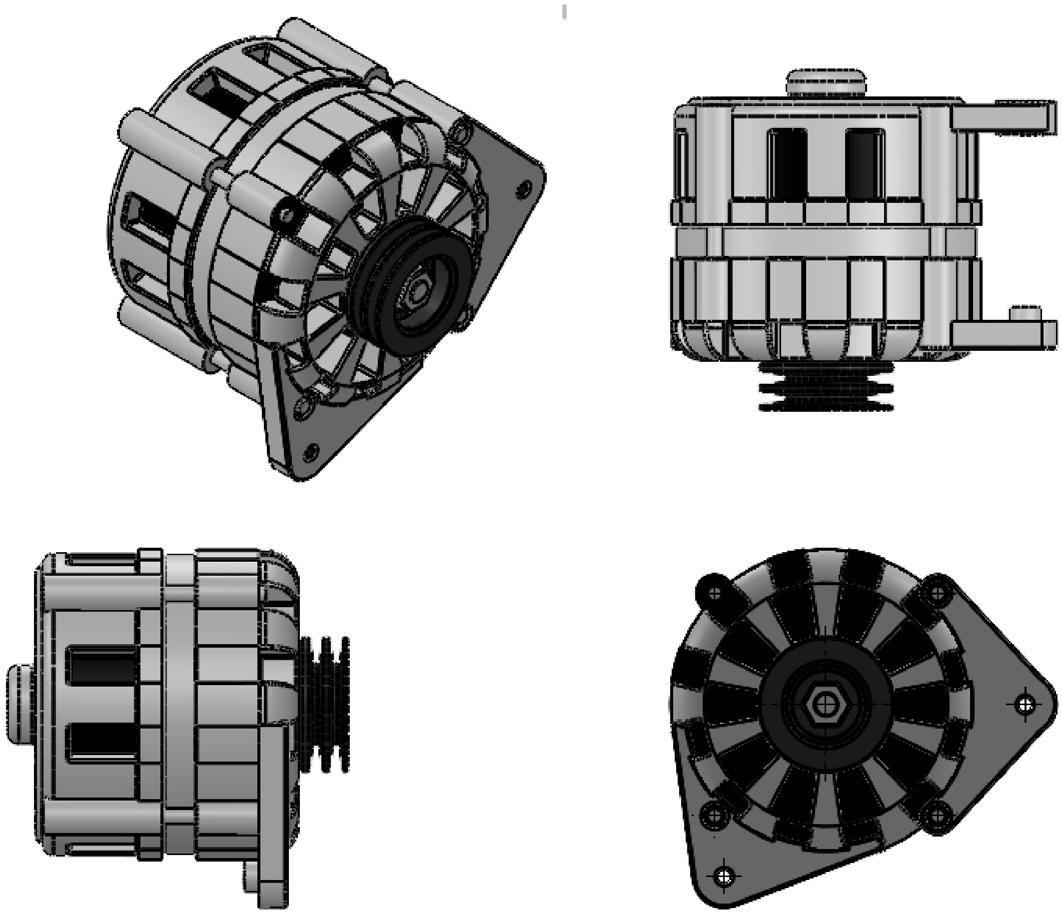


Figure 49 Alternator

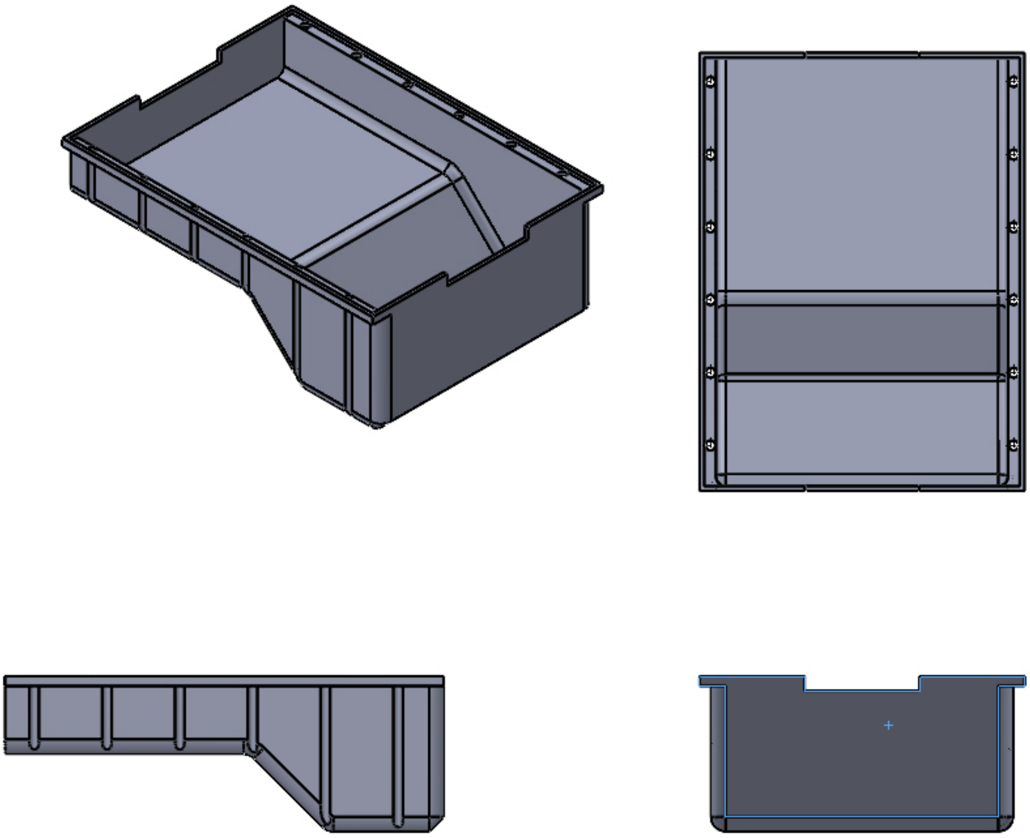


Figure 50 Oil Sump

9. LOTUS ENGINEERING ANALYSIS

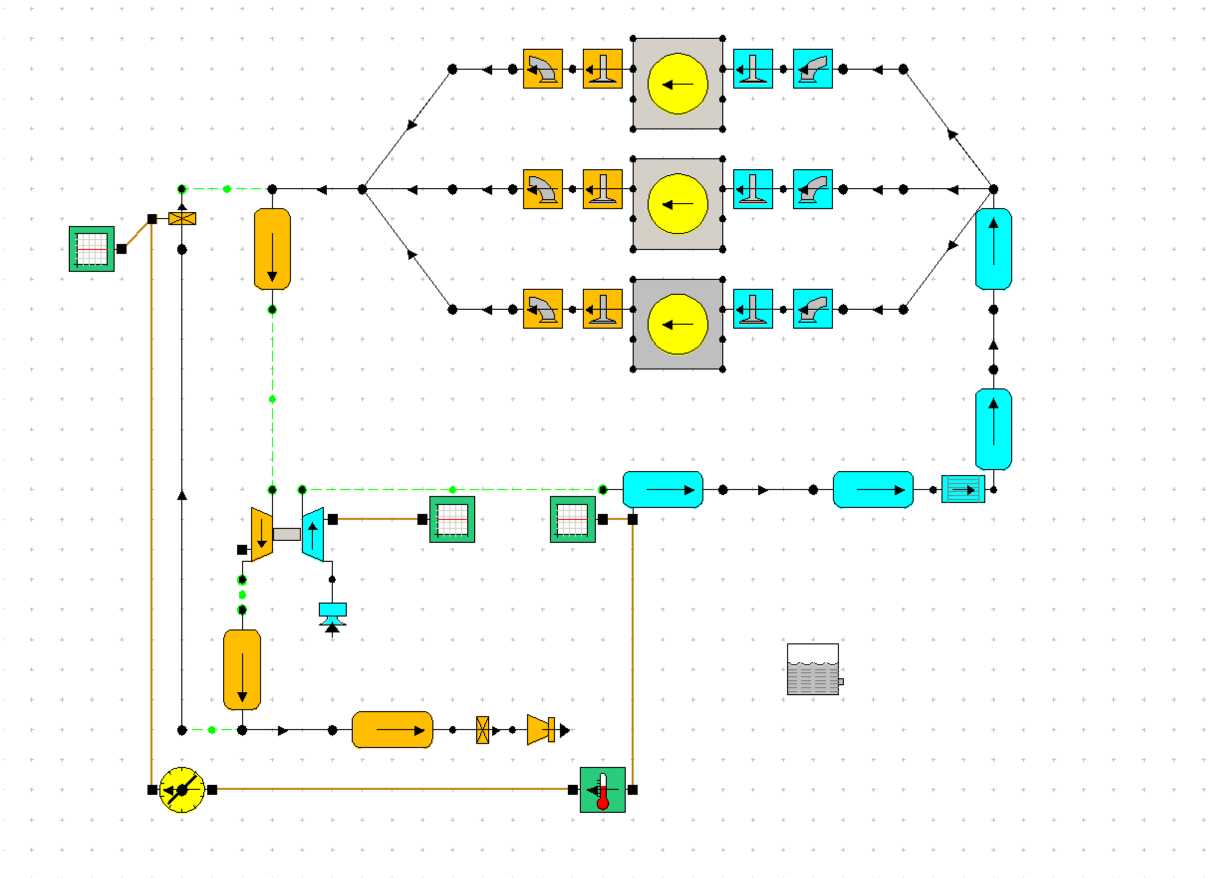


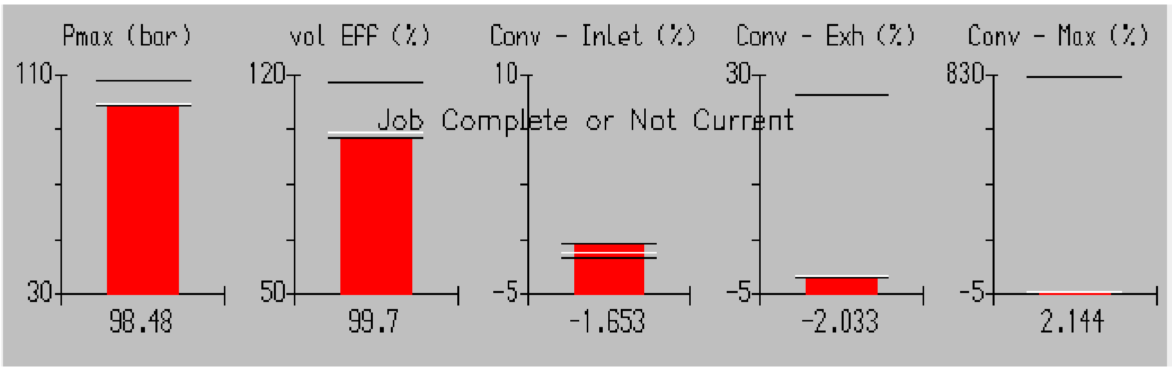
Figure 51 Schematic of the engine in LOTUS ENGINEERING SIMULATION

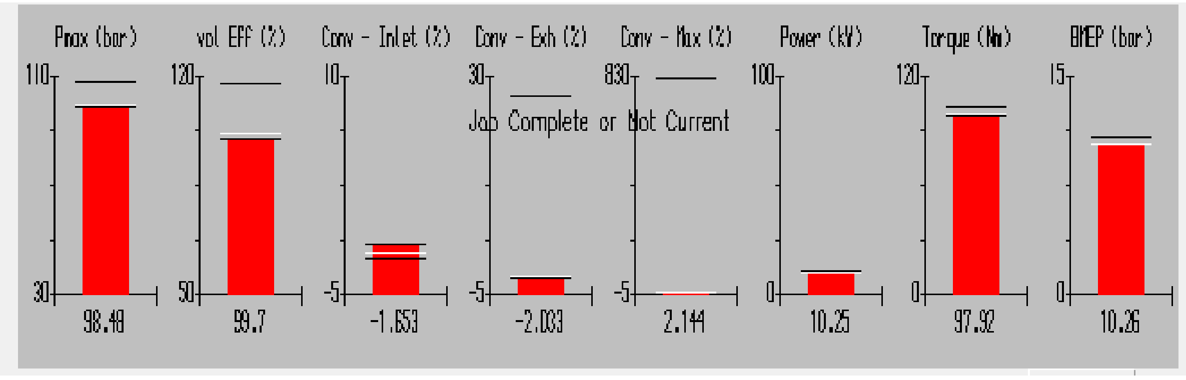
Label	Cylinder one
Bore (mm)	79,5000
Stroke (mm)	80,5000
Cyl Swept Volume (l)	0,39960
Total Swept Volume (l)	1,19879
Con-rod Length (mm)	193,00
Pin Off-Set (mm)	0,00
Compression Ratio	16,50
Clearance Volume (l)	0,025780
Phase (ATDC)	0,00
Combustion Model	
Open Cycle HT	
Closed Cycle HT	
Surface Areas	
Surface Temperatures	
Scavenge-Cylinder	

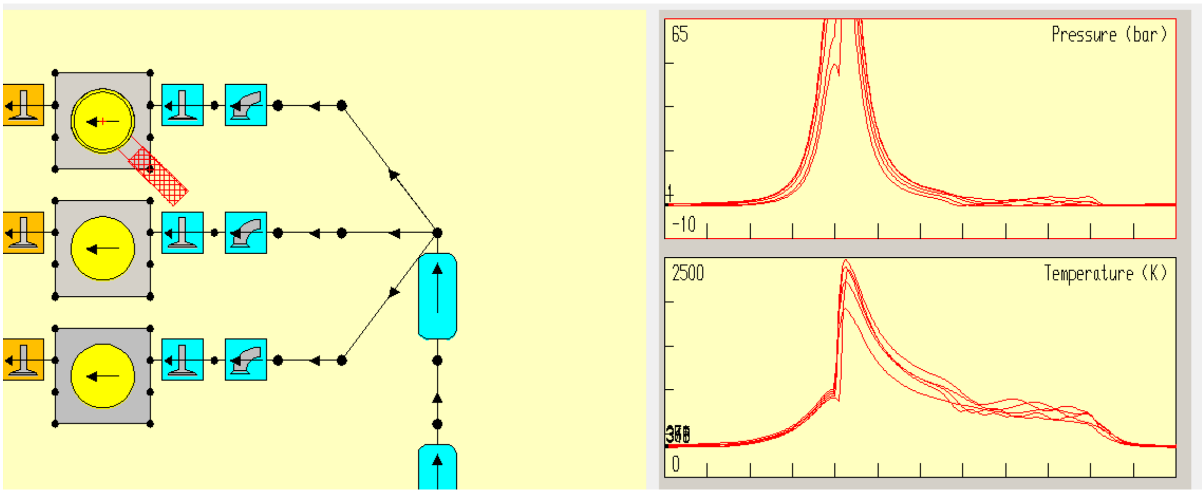
Label	Cylinder two
Bore (mm)	79,5000
Stroke (mm)	80,5000
Cyl Swept Volume (l)	0,39960
Total Swept Volume (l)	1,19879
Con-rod Length (mm)	193,00
Pin Off-Set (mm)	0,00
Compression Ratio	16,50
Clearance Volume (l)	0,025780
Phase (ATDC)	480,00
Combustion Model	
Open Cycle HT	
Closed Cycle HT	
Surface Areas	
Surface Temperatures	
Scavenge-Cylinder	

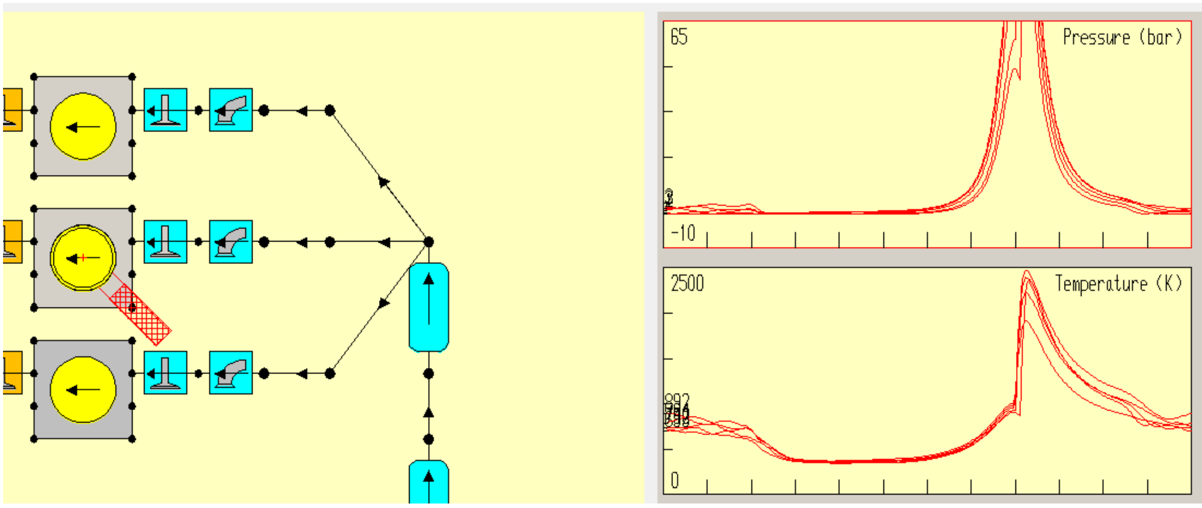
Label	Cylinder three
Bore (mm)	79,5000
Stroke (mm)	80,5000
Cyl Swept Volume (l)	0,39960
Total Swept Volume (l)	1,19879
Con-rod Length (mm)	193,00
Pin Off-Set (mm)	0,00
Compression Ratio	16,50
Clearance Volume (l)	0,025780
Phase (ATDC)	240,00
Combustion Model	
Open Cycle HT	
Closed Cycle HT	
Surface Areas	
Surface Temperatures	
Scavenge-Cylinder	

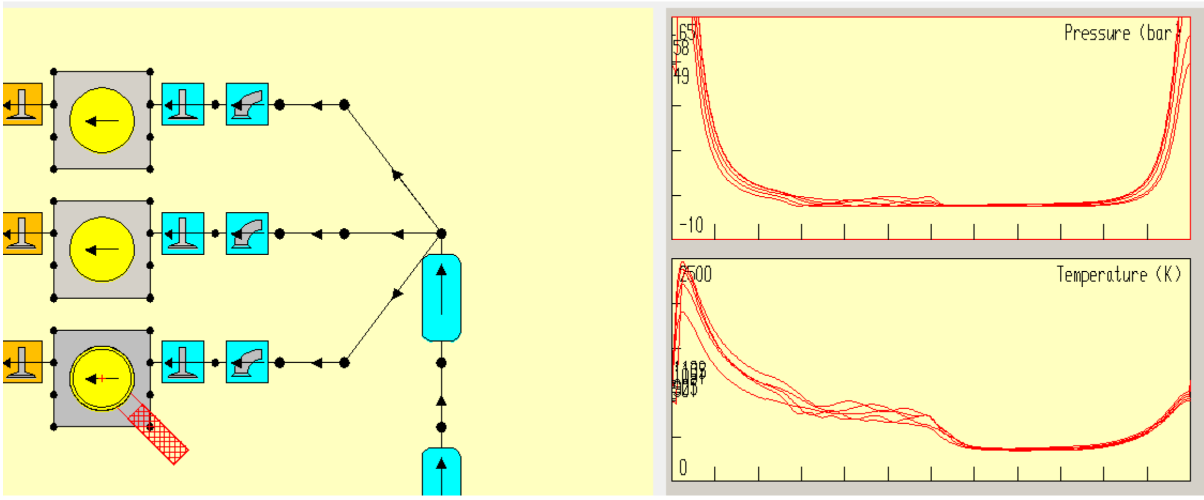
Figure 52 Dimensions of the Engine

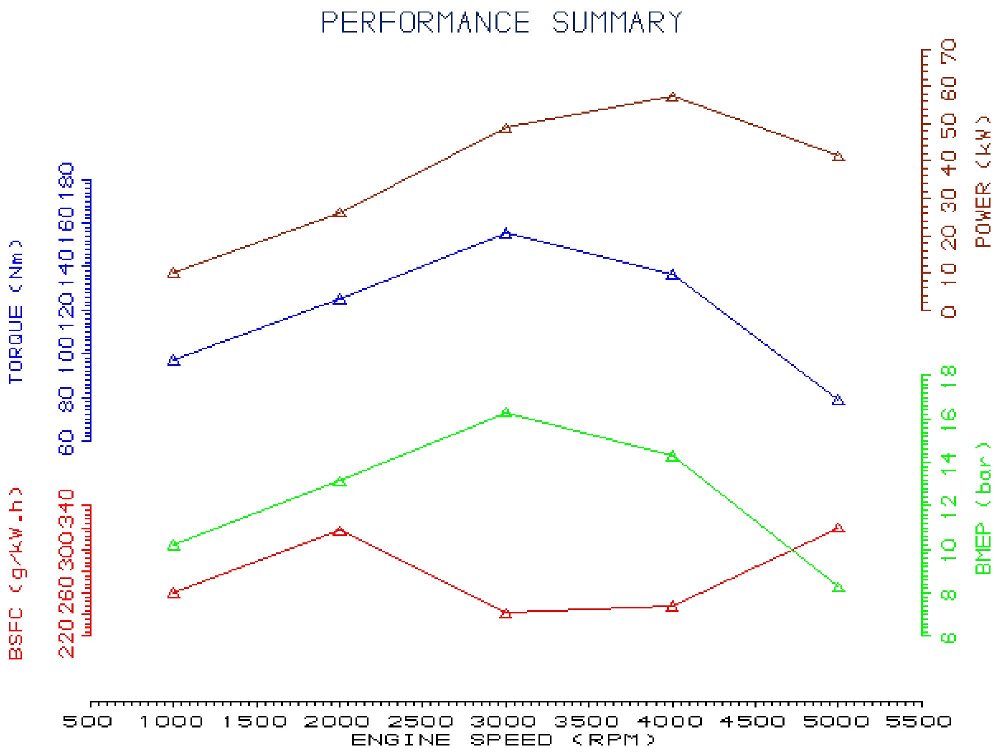

Pmax (bar)
vol EFF (%)
Conv - Inlet (%)
Conv - Exh (%)
Conv - Max (%)
Job Complete or Not Current
98.48
99.7
-1.653
-2.033
2.144

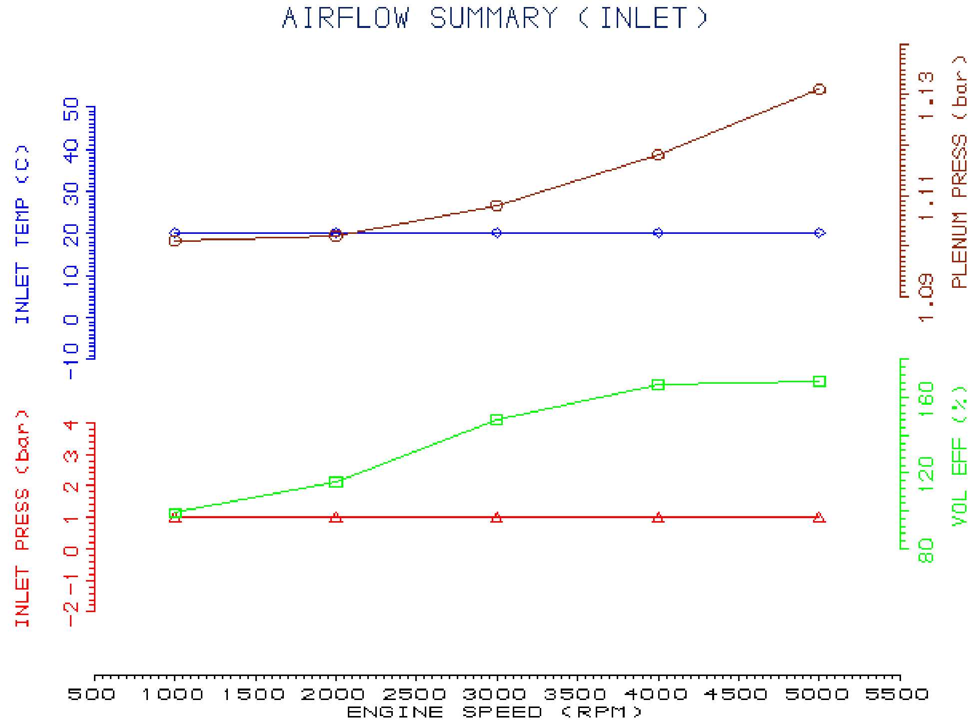

Pmax (bar)
vol EFF (%)
Conv - Inlet (%)
Conv - Exh (%)
Conv - Max (%)
Power (kW)
Torque (Nm)
BMEP (bar)
Job Complete or Not Current
98.48
99.7
-1.653
-2.033
2.144
10.25
97.92
10.26

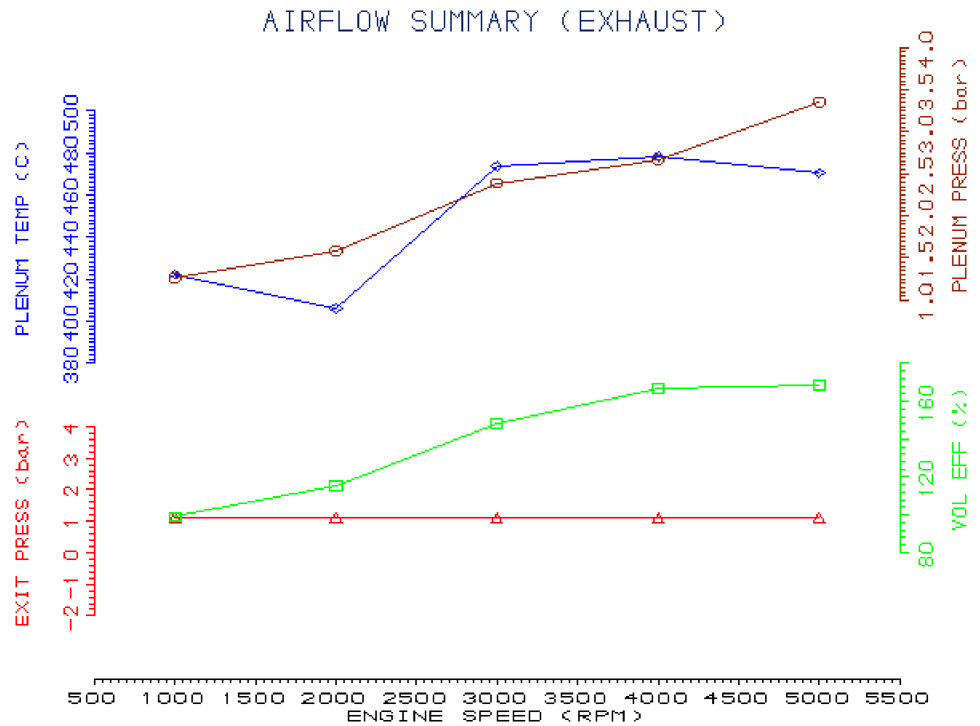

Pressure (bar)
Temperature (K)

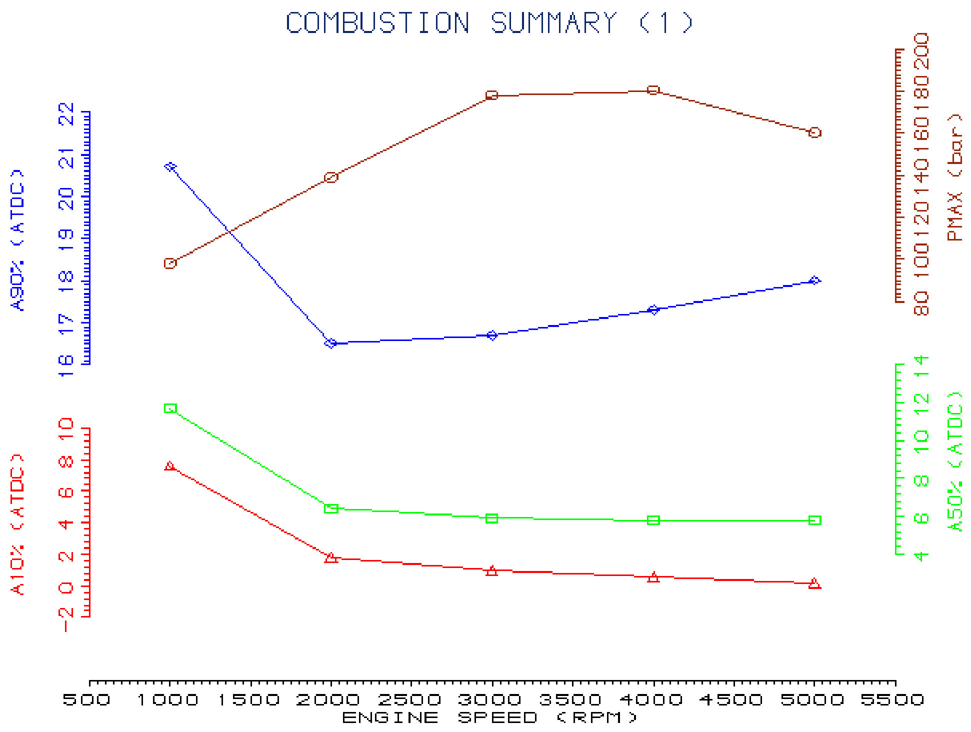

Pressure (bar)
Temperature (K)

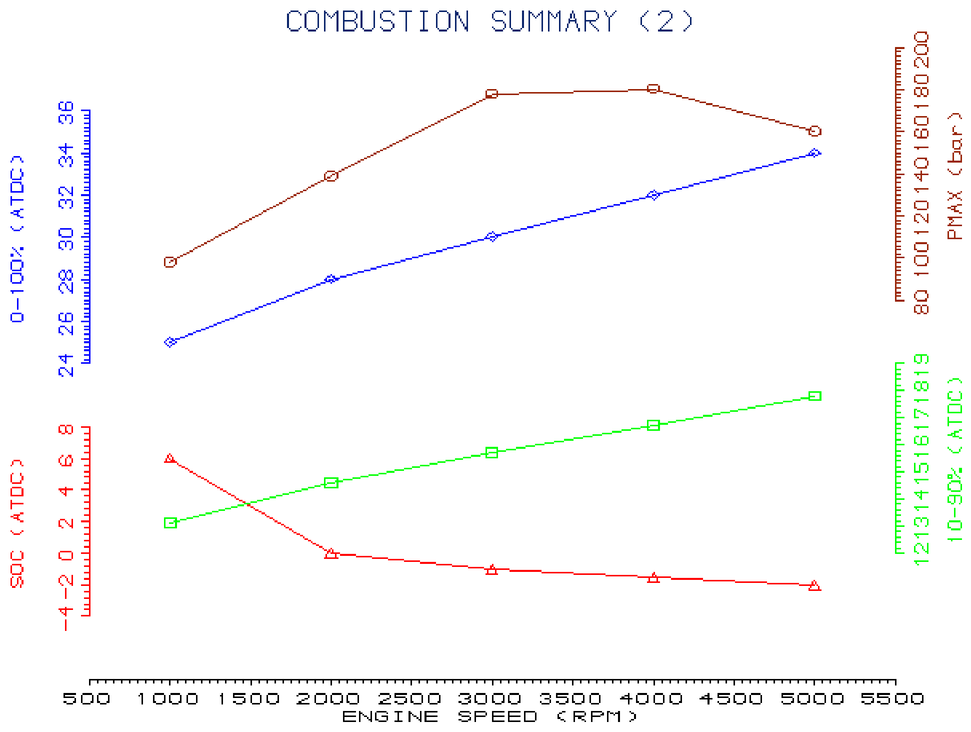

Pressure (bar)
Temperature (K)

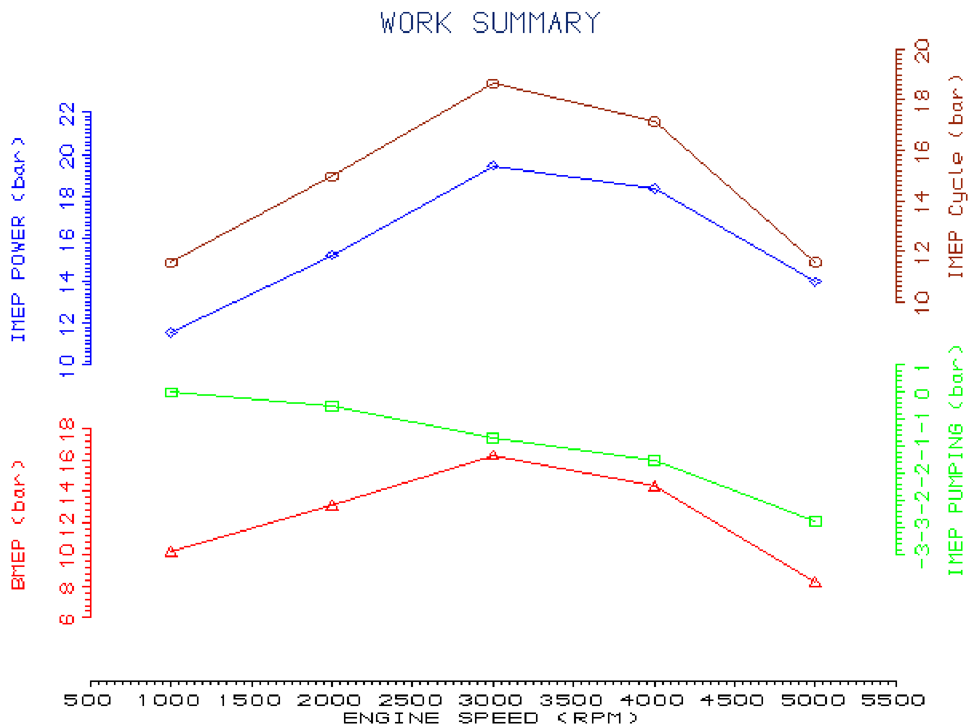

PERFORMANCE SUMMARY
TORQUE (Nm)
BSFC (g/kW.h)
POWER (kW)
BMEP (bar)
ENGINE SPEED (RPM)

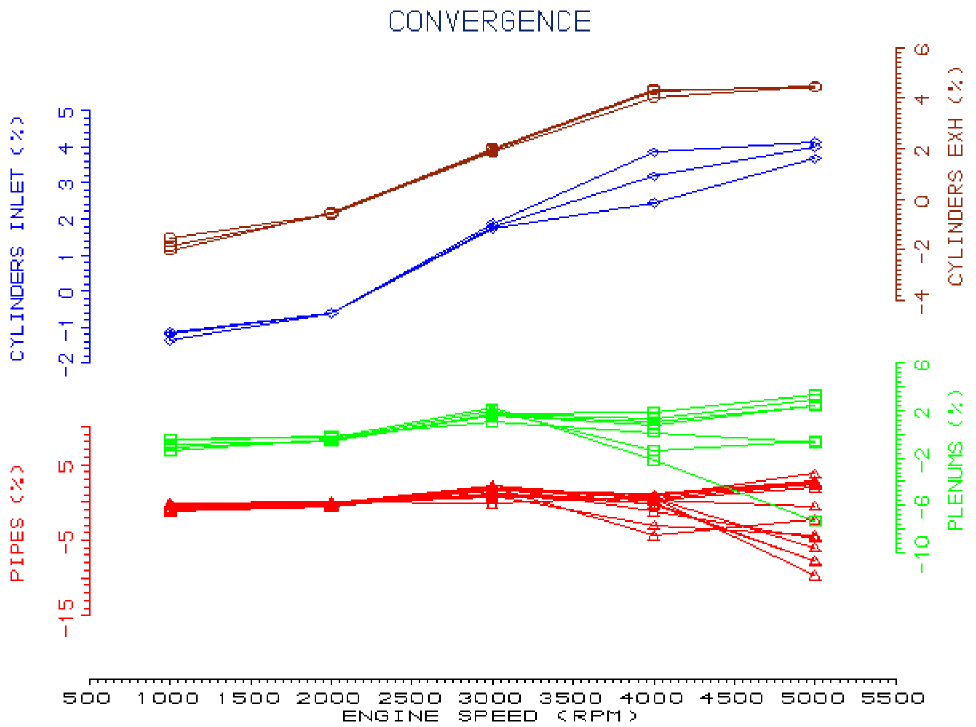

AIRFLOW SUMMARY (INLET)
INLET TEMP (C)
-10 0 10 20 30 40 50
INLET PRESS (bar)
-2 -1 0 1 2 3 4
PLENUM PRESS (bar)
1.09 1.11 1.13
VOL EFF (%)
80 120 160
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500
ENGINE SPEED (RPM)


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


COMBUSTION SUMMARY (1)
A90% (ATDC)
A10% (ATDC)
PMAX (bar)
A50% (ATDC)
ENGINE SPEED (RPM)


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


WORK SUMMARY
IMEP POWER (bar)
10 12 14 16 18 20 22
BMEP (bar)
6 8 10 12 14 16 18
IMEP Cycle (bar)
10 12 14 16 18 20
IMEP PUMPING (bar)
-3 -3 -2 -2 -1 -1 0 1
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500
ENGINE SPEED (RPM)


CONVERGENCE
CYLINDERS INLET (%)
-2 -1 0 1 2 3 4 5
PIPES (%)
-15 -5 5
CYLINDERS EXH (%)
-4 -2 0 2 4 6
PLENUMS (%)
-10 -6 -2 2 6
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500
ENGINE SPEED (RPM)

10. CONCLUSION

Three-cylinder engines have gained popularity due to their potential for improved fuel efficiency and reduced emissions. They offer advantages such as fuel efficiency, lightweight and compact design, lower manufacturing costs, and reduced emissions. However, they also have disadvantages including vibrations and noise, reduced power and performance compared to larger engines, increased engine stress, and limited application in larger or heavier vehicles. Manufacturers are continuously working to address these disadvantages and enhance the performance of three-cylinder engines through design advancements and technology implementation.

In the previous design, the components such as pistons, engine block, and crankshaft were properly designed and assembled to work together harmoniously. Additionally, the cylinder head, valves, valve spring, rocker arm, camshaft, camshaft bearings, and connecting parts were designed and integrated into the main assembly. While there were no issues found with the dimensions of these parts, some problems were identified during the examination of the engine's operation. Initially, efforts were focused on resolving these problems.

One of the issues found was that due to an error in the positioning of the camshaft in the previous design, it would collide with the lower surface of the cylinder head when it reached a specific angle while rotating. To address this problem, the bearing housings of the camshaft were raised, eliminating the collision issue during rotation.

After this stage, the design process began to establish a connection between the crankshaft and the camshaft. Initially, it was considered to establish the connection using gears. This design had the advantage of eliminating the tension adjustment issue that may arise when connecting the crankshaft and the camshaft using a belt or chain. Upon the necessary calculations, it was determined that a minimum of 4 idler gears would be required for the connection. Since the engine was designed with dual overhead camshafts, reducing the number of idler gears would result in the camshaft gears contacting each other and not rotating properly. On the other hand, increasing the number of idler gears would lead to more gears, resulting in power loss. For these reasons, it was decided to use a belt-chain system for the connection between the crankshaft and the camshaft.

Considering the cost-effectiveness and ease of maintenance and repair, it was determined that a belt would be suitable for the connection. During the design process, a gear ratio of 2:1 was taken into account, and the gears were designed according to ISO standards. To prevent the potential risk of the timing belt breaking or coming loose during operation, an adjustable belt tensioner was added. To minimize the exposure of the timing belt to external factors, protective housing was also incorporated.

Subsequently, the selection and placement of other components to be added to the engine were initiated. First, the compatibility with the engine was checked, and an alternator, which ensures the battery's charging during operation, was chosen. Then, a centrifugal pump, responsible for circulating the coolant in the cooling system, was selected. Following these choices, a V-belt design was created to ensure their simultaneous operation, and it was placed on top of the timing belt system. The previous design of the crankshaft only had enough length to accommodate the gear responsible for the connection with the camshaft. To transfer power to the V-belt system, the length of the crankshaft was extended, and a pulley for attaching the V-belt was added to its end. The used alternator and centrifugal pump are currently present as dummy models in the assembly.

Once the power transmission line was completed, the design of the rocker cover, which separates the camshafts from the external environment, was created. As injectors were not present in the previous designs, a suitable injector was researched and selected. An injector with the part code A2C59511610 from Siemens brand was chosen, and suitable clearances were adjusted on the rocker cover for its installation. The use of a common rail diesel injection system, commonly found in similar engines, was considered appropriate to achieve better fuel injection and distribution, more efficient combustion, lower emissions, and precise control. The design of the main fuel line of the common rail system was completed, and its connection with each injector was established. This part was mounted on the side of the rocker cover.

Lastly, the design of the flywheel gear was carried out. Taking the measurements of the flywheel gear from the EA189 engine, which served as a reference, a suitable diameter flywheel gear design was created by ISO standards. Subsequently, the Bosch SR0792N model was selected for the starter motor, and an additional component was added to the engine block for its assembly. The flywheel gear was designed slightly larger than the diameter of the flywheel gear of the reference engine to ensure full contact with the starter motor. Since the previous design did not include an oil pan, an oil pan design, and assembly were made to fit on the upper part of the crankshaft.

The motor design process is a comprehensive and labor-intensive task that requires a significant amount of time and effort. Therefore, this report primarily focuses on the design of the basic components of the engine and their assembly in the appropriate areas. Detailed SOLIDWORKS drawings of the engine are included in the report.

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