Introduction

Most DOE facilities require some type of prime mover to supply mechanical power for pumping, electrical power generation, operation of heavy equipment, and to act as a backup electrical generator for emergency use during the loss of the normal power source. Although several types of prime movers are available (gasoline engines, steam and gas turbines), the diesel engine is the most commonly used. Diesel engines provide a self-reliant energy source that is available in sizes from a few horsepower to 10,000 hp. Figure 1 provides an illustration of a common skid-mounted, diesel-driven generator. Relatively speaking, diesel engines are small, inexpensive, powerful, fuel efficient, and extremely reliable if maintained properly. Because of the widespread use of diesel engines at DOE facilities, a basic understanding of the operation of a diesel engine will help ensure they are operated and maintained properly. Due to the large variety of sizes, brands, and types of engines in service, this module is intended to provide the fundamentals and theory of operation of a diesel engine. Specific information on a particular engine should be obtained from the vendor's manual.

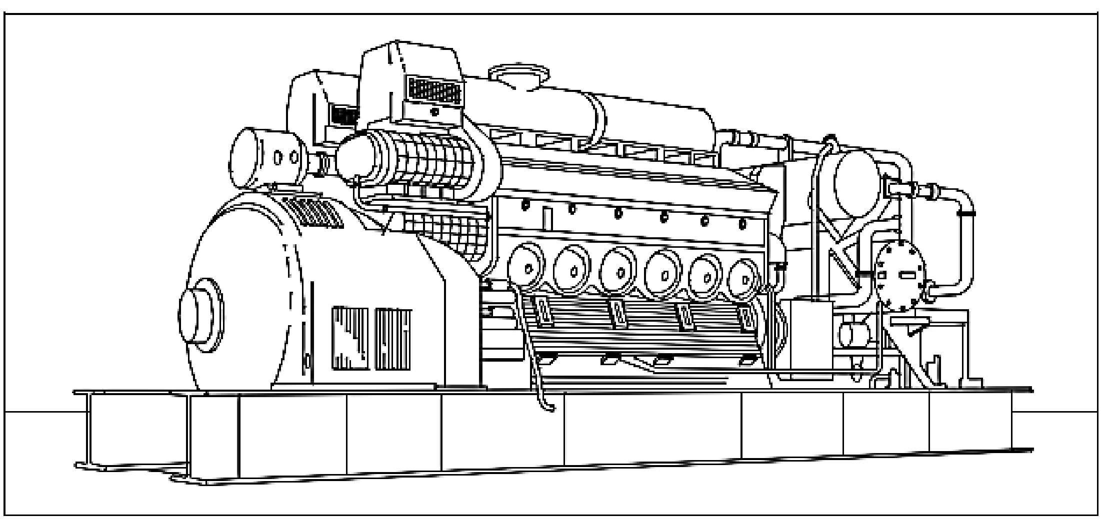

Figure 1 Example of a Large Skid-Mounted, Diesel-Driven Generator

History

The modern diesel engine came about as the result of the internal combustion principles first proposed by Sadi Carnot in the early 19th century. Dr. Rudolf Diesel applied Sadi Carnot's principles into a patented cycle or method of combustion that has become known as the "diesel" cycle. His patented engine operated when the heat generated during the compression of the air fuel charge caused ignition of the mixture, which then expanded at a constant pressure during the full power stroke of the engine. Dr. Diesel's first engine ran on coal dust and used a compression pressure of 1500 psi to increase its theoretical efficiency. Also, his first engine did not have provisions for any type of cooling system. Consequently, between the extreme pressure and the lack of cooling, the engine exploded and almost killed its inventor. After recovering from his injuries, Diesel tried again using oil as the fuel, adding a cooling water jacket around the cylinder, and lowering the compression pressure to approximately 550 psi. This combination eventually proved successful. Production rights to the engine were sold to Adolphus Bush, who built the first diesel engines for commercial use, installing them in his St. Louis brewery to drive various pumps.

Diesel Engines

A diesel engine is similar to the gasoline engine used in most cars. Both engines are internal combustion engines, meaning they burn the fuel-air mixture within the cylinders. Both are reciprocating engines, being driven by pistons moving laterally in two directions. The majority of their parts are similar. Although a diesel engine and gasoline engine operate with similar components, a diesel engine, when compared to a gasoline engine of equal horsepower, is heavier due to stronger, heavier materials used to withstand the greater dynamic forces from the higher combustion pressures present in the diesel engine[1].

Four Stroke Cycle Engines

A four-stroke cycle engine is an internal combustion engine that utilizes four distinct piston strokes (intake, compression, power, and exhaust) to complete one operating cycle. The piston make two complete passes in the cylinder to complete one operating cycle. An operating cycle requires two revolutions (720°) of the crankshaft. The four-stroke cycle engine is the most common type of small engine. A four-stroke cycle engine completes five Strokes in one operating cycle, including intake, compression, ignition, power, and exhaust Strokes.

Intake Stroke

The intake event is when the air-fuel mixture is introduced to fill the combustion chamber. The intake event occurs when the piston moves from TDC to BDC and the intake valve is open. The movement of the piston toward BDC creates a low pressure in the cylinder. Ambient atmospheric pressure forces the air-fuel mixture through the open intake valve into the cylinder to fill the low pressure area created by the piston movement. The cylinder continues to fill slightly past BDC as the air-fuel mixture continues to flow by its own inertia while the piston begins to change direction. The intake valve remains open a few degrees of crankshaft rotation after BDC. Depending on engine design. The intake valve then closes and the air-fuel mixture is sealed inside the cylinder.

[1] Diesel Engine Fundamentals 2020 Instructor: Lawrence J. Marchetti, P.E.

Compression Stroke

The compression stroke is when the trapped air-fuel mixture is compressed inside the cylinder. The combustion chamber is sealed to form the charge. The charge is the volume of compressed air-fuel mixture trapped inside the combustion chamber ready for ignition. Compressing the air-fuel mixture allows more energy to be released when the charge is ignited. Intake and exhaust valves must be closed to ensure that the cylinder is sealed to provide compression. Compression is the process of reducing or squeezing a charge from a large volume to a smaller volume in the combustion chamber. The flywheel helps to maintain the momentum necessary to compress the charge.

When the piston of an engine compresses the charge, an increase in compressive force supplied by work being done by the piston causes heat to be generated. The compression and heating of the air-fuel vapor in the charge results in an increase in charge temperature and an increase in fuel vaporization. The increase in charge temperature occurs uniformly throughout the combustion chamber to produce faster combustion (fuel oxidation) after ignition.

The increase in fuel vaporization occurs as small droplets of fuel become vaporized more completely from the heat generated. The increased droplet surface area exposed to the ignition flame allows more complete burning of the charge in the combustion chamber. Only gasoline vapor ignites. An increase in droplet surface area allows gasoline to release more vapor rather than remaining a liquid.

The more the charge vapor molecules are compressed, the more energy obtained from the combustion process. The energy needed to compress the charge is substantially less than the gain in force produced during the combustion process.

For example, in a typical small engine, energy required to compress the charge is only one-fourth the amount of energy produced during combustion.

The compression ratio of an engine is a comparison of the volume of the combustion chamber with the piston at BDC to the volume of the combustion chamber with the piston at TDC. This area, combined with the design and style of combustion chamber, determines the compression ratio. Gasoline engines commonly have a compression ratio ranging from 6:1 - 10:1. The higher the compression ratio, the more fuel-efficient the engine. A higher compression ratio normally provides a substantial gain in combustion pressure or force on the piston. However, higher compression ratios increase operator effort required to start the engine. Some small engines feature a system to relieve pressure during the compression stroke to reduce operator effort required when starting the engine[2].

Ignition Event

The ignition (combustion) event occurs when the charge is ignited and rapidly oxidized through a chemical reaction to release heat energy. Combustion is the rapid, oxidizing chemical reaction in which a fuel chemically combines with oxygen in the atmosphere and releases energy in the form of heat.

Proper combustion involves a short but finite time to spread a flame throughout the combustion chamber. The spark at the spark plug initiates combustion at approximately 20° of crankshaft rotation before TDC (BTDC). The atmospheric oxygen and fuel vapor are consumed by a progressing flame front. A flame

[2]https://courses.washington.edu/engr100/Section_Wei/engine/UofWindsorManual/Four%20Stroke%20Cycle%20Engines.htm

front is the boundary wall that separates the charge from the combustion by-products. The flame front progresses across the combustion chamber until the entire charge has burned.

Power Stroke

The power stroke is an engine operation Stroke in which hot expanding gases force the piston head away from the cylinder head. Piston force and subsequent motion are transferred through the connecting rod to apply torque to the crankshaft. The torque applied initiates crankshaft rotation. The amount of torque produced is determined by the pressure on the piston, the size of the piston, and the throw of the engine. During the power Stroke, both valves are closed.

Exhaust Stroke

The exhaust stroke occurs whenspent gases are expelled from the combustion chamber and released to the atmosphere. The exhaust stroke is the final stroke and occurs when the exhaust valve is open and the intake valve is closed. Piston movement evacuates exhaust gases to the atmosphere.

As the piston reaches BDC during the power stroke combustion is complete and the cylinder is filled with exhaust gases. The exhaust valve opens, and inertia of the flywheel and other moving parts push the piston back to TDC, forcing the exhaust gases out through the open exhaust valve. At the end of the exhaust stroke, the piston is at TDC and one operating cycle has been completed.

How diesel engines work

A diesel engine works differently from a petrol engine, even though they share major components and both work on the four-stroke cycle . The main differences are in the way the fuel is ignited and the way the power output is regulated.

In a petrol engine, the fuel/air mixture is ignited by a spark . In a diesel engine, ignition is achieved by compression of air alone. A typical compression ratio for a diesel engine is 20:1, compared with 9:1 for a petrol engine. Compressions as great as this heat up the air to a temperature high enough to ignite the fuel spontaneously, with no need of a spark and therefore of an ignition system.

A petrol engine draws in variable amounts of air per suction stroke , the exact amount depending on the throttle opening. A diesel engine, on the other hand, always draws in the same amount of air (at each engine speed), through an unthrottled inlet tract that is opened and closed only by the inlet valve (there is neither a carburettor nor a butterfly valve).

When the piston reaches the effective end of its induction stroke, the inlet valve closes. The piston, carried round by the power from the other pistons and the momentum of the flywheel , travels to the top of the cylinder , compressing the air into about a twentieth of its original volume .

As the piston reaches the top of its travel, a precisely metered quantity of diesel fuel is injected into the combustion chamber . The heat from compression fires the fuel/air mixture immediately, causing it to burn and expand. This forces the piston downwards, turning the crankshaft .

As the piston moves up the cylinder on the exhaust stroke , the exhaust valve opens and allows the burned and expanded gases to travel down the exhaust pipe . At the end of the exhaust stroke the cylinder is ready for a fresh charge of air[3].

Diesel vs gasoline engine

You can learn about the processes of the individual engines by clicking these links: Diesel engine, Gasoline engine.

The two main types of engines used in cars right now burn either diesel fuel, or gasoline. While the engines share many of the same parts, including the engine block, the engines have a few distinct differences, namely, ignition, starter motors, and outputs.

Ignition

The most significant difference in a diesel and a gasoline 4 stroke engine is the method of ignition. A gasoline engine relies on a timed spark plug, while a diesel engine relies on spontaneous combustion. Spontaneous combustion is a condition - temperature and pressure - at which a material, in this case, diesel - combusts without a spark. The diesel engine's efficiency can be attributed to its higher compression ratio; i.e. the ratio of the highest volume to the lowest volume in the compression chamber in a diesel engine is much higher.

A diesel engine achieves spontaneous combustion through high pressure and temperature. The temperature of the fuel air is raised as by its compression in the

[3] https://www.howacarworks.com/basics/how-a-diesel-engine-works

cylinder. The pressure is also achieved during the compression. Diesel engines actually require high compression ratios. If the same high compression ratios were to be applied to a gasoline engine, the fuel air mixture would ignite too early in its compression. This would force the engine to change its direction nearly instantaneously. The compression ratio of the gasoline engine is typically much lower than that of a diesel engine.

Starter motors

If you have ever owned a diesel-powered car, and had your battery go flat, you'll know that it is a nightmare to get it going again. This is because the batteries used in diesel engines are much more powerful than those used in gasoline engines. Because diesel engines don't have spark plugs, the starter motor must compress the piston, allowing for spontaneous combustion. Doing so requires a lot more energy than simply lighting a spark plug.

Outputs

As a general rule, diesel engines have a higher specific torque than gasoline engines. This is a ratio of torque output to engine size. For example, the four-cylinder diesel engine on the 2015 Golf TDI produces 236 pound-feet of torque, compared to just 185 for its gasoline counterpart[4]. Also, because diesel engines are able to run higher compression ratios, they tend to be more efficient. For example, the 2014 Golf TDI achieved 8 mpg better on a combined cycle, and 12 mpg better highway.[5]On the flip side of the coin, diesel engines have the potential

[4] www.volkswagen.ca
[5] http://www.fueleconomy.gov/

to pollute more, as diesel fuel can contain harmful chemicals and tend to produce more particulate matter[6].

References

1. Diesel Engine Fundamentals 2020 Instructor: Lawrence J. Marchetti, P.E.
2. https://courses.washington.edu/engr100/Section_Wei/engine/UofWindsorManual/Four%20Stroke%20Cycle%20Engines.htm
3. https://www.howacarworks.com/basics/how-a-diesel-engine-works
4. www.volkswagen.ca
5. http://www.fueleconomy.gov/
6. R. Wolfson, "High-Energy Society," in *Energy, Environment and Climate,* 2nd ed. New York: Norton, 2012, ch. 2, pp. 20–21

[6] R. Wolfson, "High-Energy Society," in *Energy, Environment and Climate,* 2nd ed. New York: Norton, 2012, ch. 2, pp. 20–21