Internal combustion engines (basic operation)

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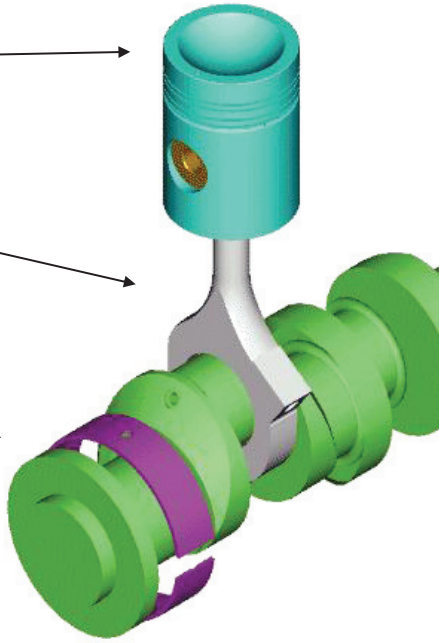
Sistemas Automóveis

Summary

- Type of movement
- Functioning mode
- Type of fuel
- Mixture formation
- Configuration and number of cylinders
- Type of cooling
- Lubrification system
- Type of valve actuation
- Ignition type
- Future perspectives

Main components of the engine

- Piston – Transmits the movement to the rod
- Connecting Rod – Transmits the movement to the crankshaft
- Crankshaft – Transforms the alternative movement in circular movement [10]

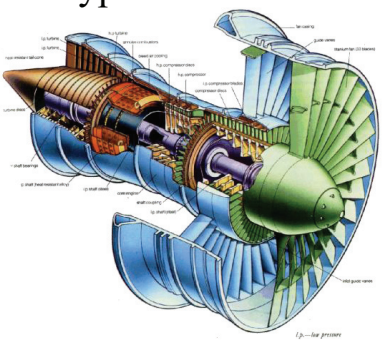


Main engine components [10]

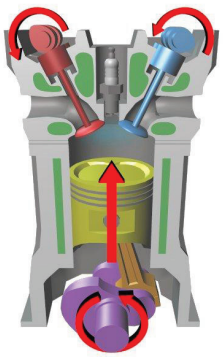
Sistemas Automóveis

Type of movement

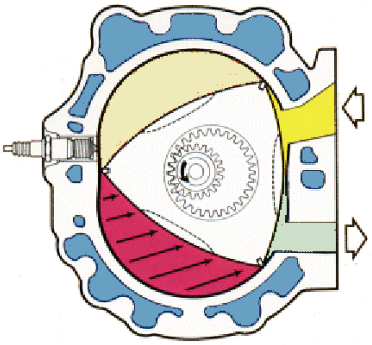
- Engines can be divided by the following movement types:
  - Piston engine with alternating movement
  - Engine with rotary piston (Wankel)
  - Turbine engine
  - Jet engine



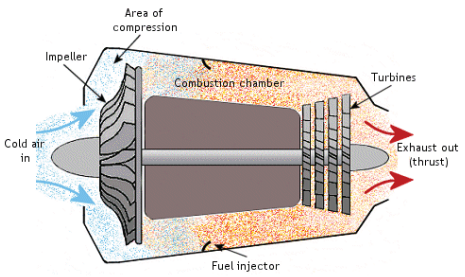
Turbine engine [3]



Piston engine [1]



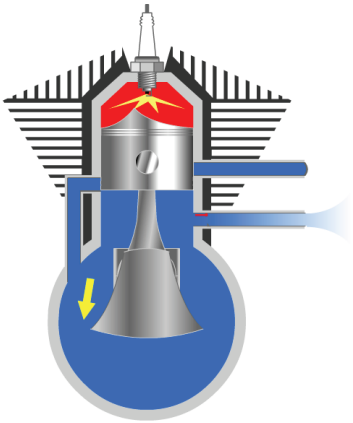
Wankel engine [2]



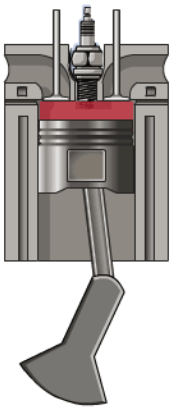
Jet engine [4]

Functioning mode

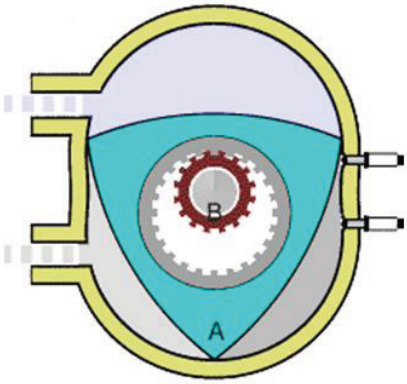
- Engines have two types of functioning modes:
  - 4 stroke
  - 2 stroke



2 stroke engine [5]

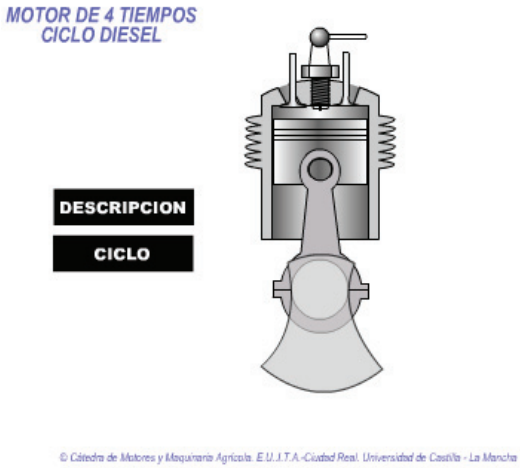


4 stroke engine [6]



4 stroke engine [9]

Functioning mode (4 stroke Diesel engine)

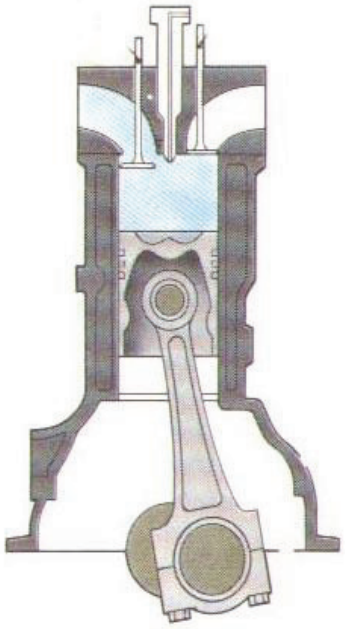


4 stroke diesel engine [5]

- 4 stroke Diesel cycle :
  - Intake
  - Compression
  - Injection + Expansion
  - Exhaust

Functioning mode (4 stroke Diesel engine)

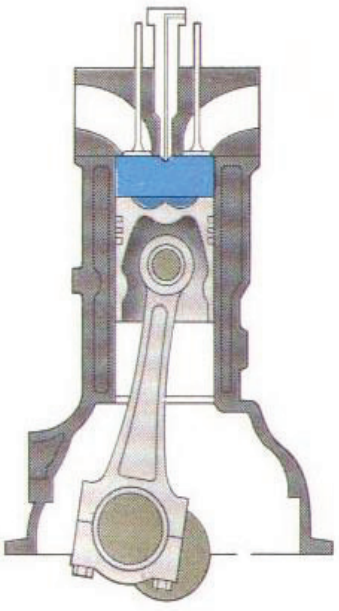
- Intake
  - The piston starts at the top
  - The intake valve opens, and the piston moves down to let the engine take in a cylinder-full of air . This is the intake stroke [10] [7].



Intake [10]

Functioning mode (4 stroke Diesel engine)

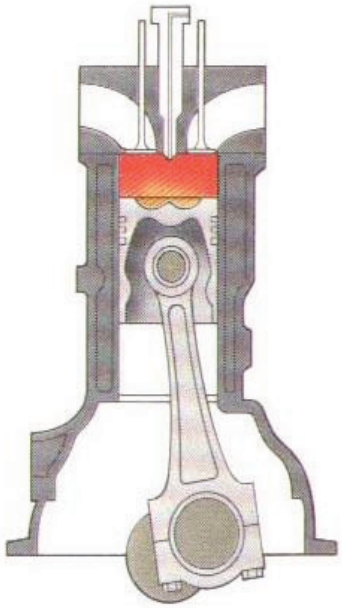
- Compression
  - With all the valves closed, the piston goes up, compressing the air inside the cylinder
  - There's an increase in air temperature and pressure [10] [7].



Compression [10]

Functioning mode (4 stroke Diesel engine)

- Injection + expansion
  - Fuel is injected into the cylinder at high pressure, after compressing the air (direct injection).
  - Fuel inflames when it contacts with the hot air.
  - The mechanical delivered the engine is now generated [10] [7].

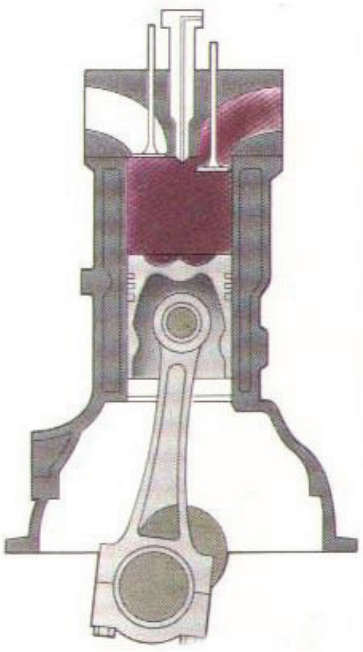


Injection + expansion [10]

Sistemas Automóveis

Functioning mode (4 stroke Diesel engine)

- Exhaust
  - Once the piston hits the bottom of its stroke the exhaust valve(s) opens.
  - The exhaust leaves the cylinder and goes out through the tailpipe [10] [7].



Exhaust [10]

Functioning mode (4 stroke Gasoline engine)

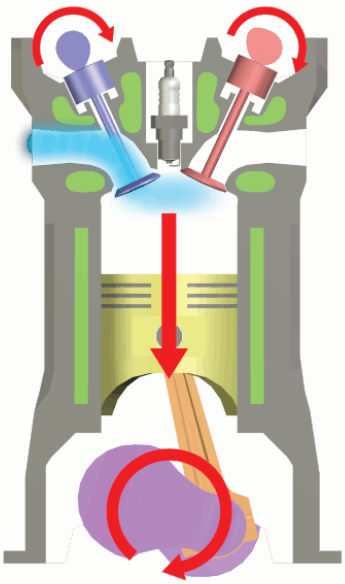
- 4 stroke Gasoline cycle
  - Intake
  - Compression
  - Explosion
  - Exhaust

4 stroke Gasoline engine (Otto cycle) [5]

Sistemas Automóveis

Functioning mode (4 stroke Gasoline engine)

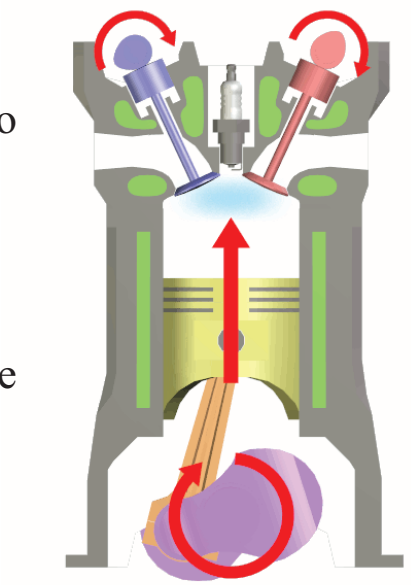
- Intake
  - The piston starts at the top
  - the intake valve opens, and the piston moves down to let the engine take in a cylinder-full of air and gasoline (indirect injection).
  - Only the tiniest drop of gasoline needs to be mixed into the air for this to work [7].



Intake [9]

Functioning mode (4 stroke Gasoline engine)

- Compression
  - Then the piston moves back up to compress this fuel/air mixture.
  - Compression makes the explosion more powerful [7].

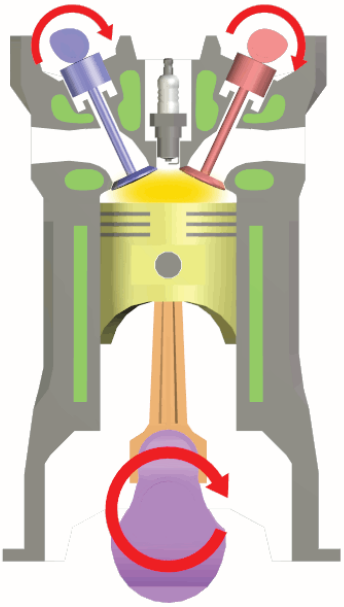


Compression [9]

Sistemas Automóveis

Functioning mode (4 stroke Gasoline engine)

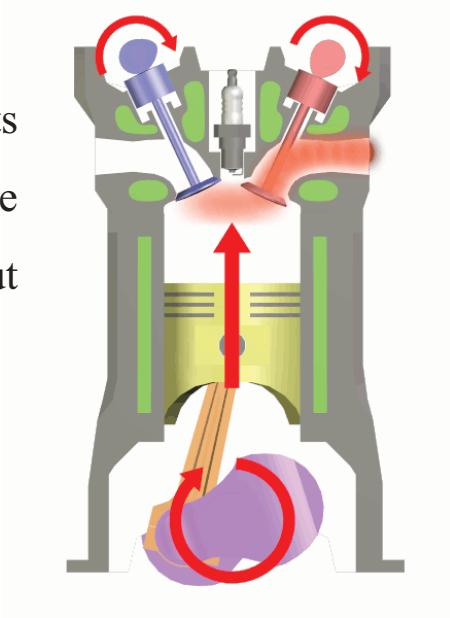
- Explosion
  - When the piston reaches the top of its stroke, the spark plug emits a spark to ignite the gasoline.
  - The gasoline charge in the cylinder explodes, driving the piston down [7].



Explosion [9]

Functioning mode (4 stroke Gasoline engine)

- Exhaust
  - Once the piston hits the bottom of its stroke, the exhaust valve opens and the exhaust leaves the cylinder going out through the tailpipe [7].



Exhaust [9]

Sistemas Automóveis

Functioning mode (2 stroke Gasoline engine)

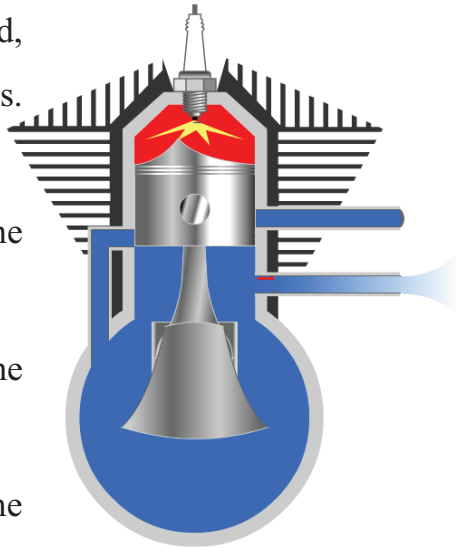
- 2 stroke gasoline cycle:
  - Compression stroke
  - Combustion stroke

2 stroke gasoline engine [5]

Functioning mode (2 stroke Gasoline engine)

- # Sparks fly

  - Fuel and air in the cylinder have been compressed, and when the spark plug fires the mixture ignites. The piston is driven downwards.
  - As it moves it compresses the air/fuel mixture in the crankcase.
  - When it approaches the bottom of its stroke, the exhaust port is uncovered.
  - The pressure in the cylinder drives most of the exhaust gases out of cylinder [7].



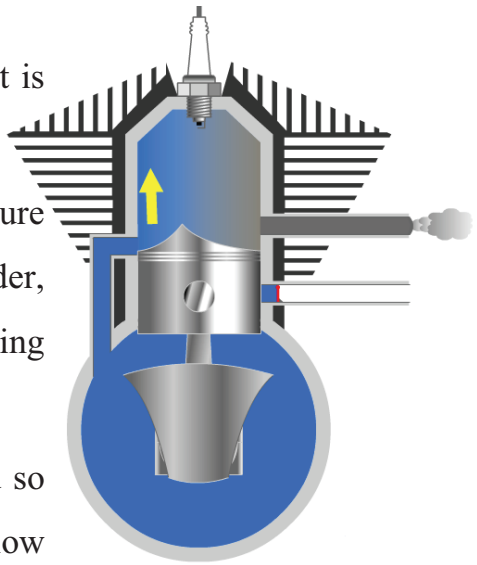
Sparks fly[5]

Sistemas Automóveis

Functioning mode (2 stroke Gasoline engine)

- # Fuel intake

  - As the piston finally bottoms out, the intake port is uncovered.
  - The piston's movement has pressurized the mixture in the crankcase, so it rushes into the cylinder, displacing the remaining exhaust gases and filling the cylinder with a fresh charge of fuel .
  - In many two-stroke engines the piston is shaped so that the incoming fuel mixture doesn't simply flow right over the top of the piston and out the exhaust port [7].



Fuel intake [5]

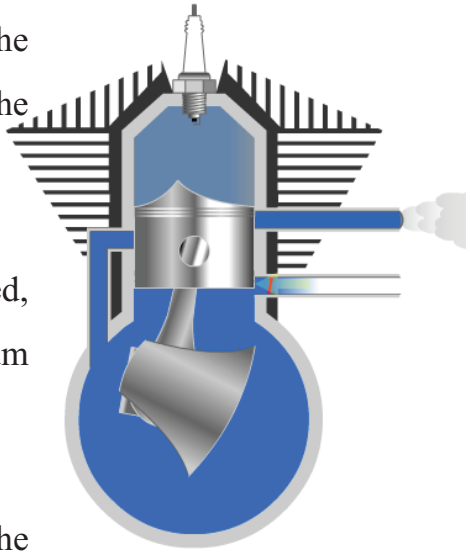
Functioning mode (2 stroke Gasoline engine)

- # Compression Stroke

  - The momentum in the crankshaft starts driving the piston back toward the spark plug for the compression stroke.

  - As the air/fuel mixture in the piston is compressed, a vacuum is created in the crankcase. This vacuum opens the reed valve and sucks in air/fuel/oil .

  - Once the piston makes it to the end of the compression stroke, the spark plug fires again [7].



Compression stroke [5]

Sistemas Automóveis

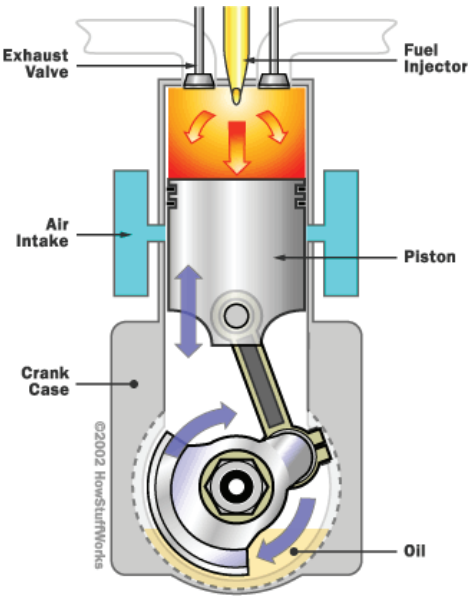
Functioning mode (2 stroke Diesel engine)

- # 2 stroke Diesel engine

  - When the piston is at the top of its travel, the cylinder contains a charge of highly compressed air.

  - Diesel fuel is sprayed into the cylinder by the injector and immediately ignites because of the heat and pressure inside the cylinder

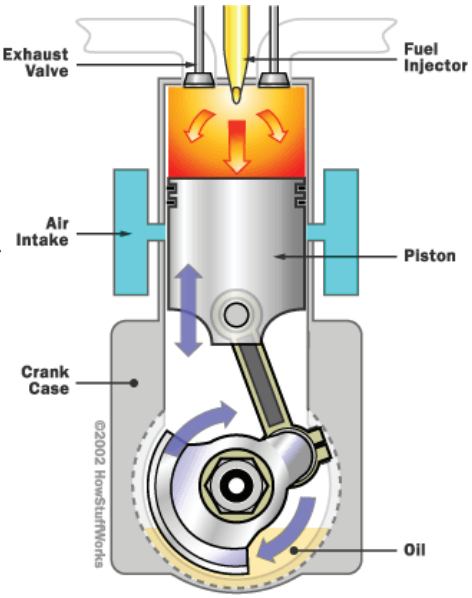
  - The pressure created by the combustion of the fuel drives the piston downward. This is the power stroke [7].



2 stroke Diesel engine [7]

Functioning mode (2 stroke Diesel engine)

- 2 stroke Diesel engine
  - The pressure created by the combustion of the fuel drives the piston downward (power stroke).
  - As the piston nears the bottom of its stroke, all of the exhaust valves open. Exhaust gases rush out of the cylinder, relieving the pressure

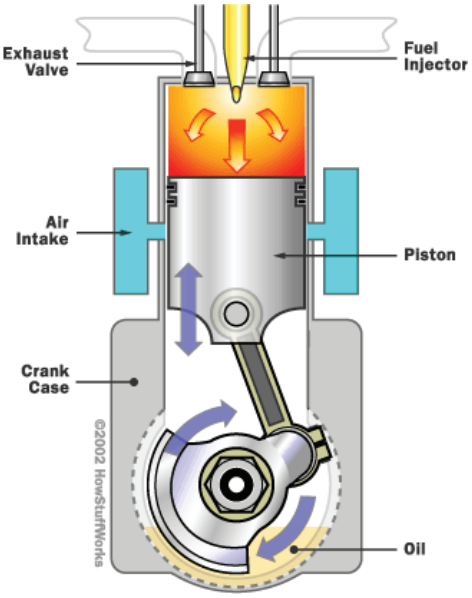


2 stroke Diesel engine [7]

Sistemas Automóveis

Functioning mode (2 stroke Diesel engine)

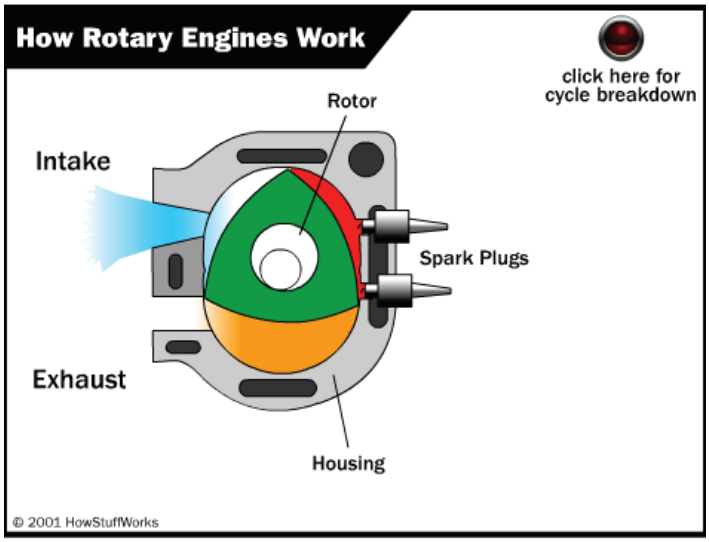
- 2 stroke Diesel engine
  - As the piston bottoms out, it uncovers the air intake ports. Pressurized air fills the cylinder, forcing out the remainder of the exhaust gases.
  - The exhaust valves close and the piston starts traveling back upward, re-covering the intake ports and compressing the fresh charge of air. This is the compression stroke [7].



2 stroke Diesel engine [7]

Functioning mode (4 stroke Wankel engine)

- 4 stroke Wankel engine:



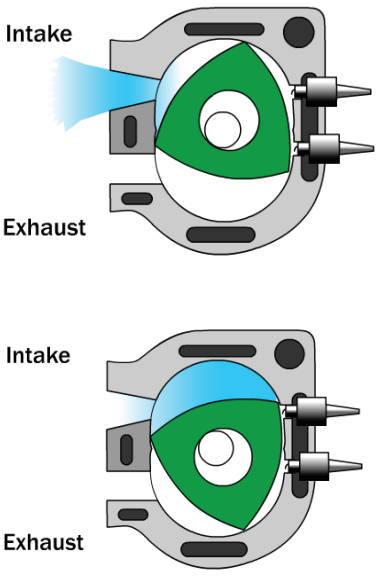
- Intake
- Compression
- Combustion
- Exhaust

4 stroke Wankel engine [7]

Sistemas Automóveis

Functioning mode (4 stroke Wankel engine)

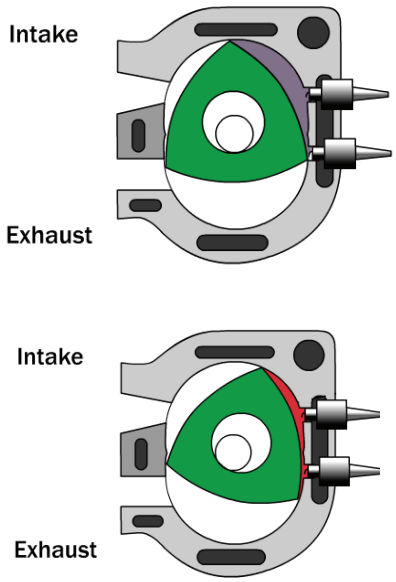
- Intake
  - intake starts when the tip of the rotor passes the intake port.
  - the intake port is exposed to the chamber, the volume of that chamber is close to its minimum.
  - As the rotor moves past the intake port, the volume of the chamber expands, drawing air/fuel mixture into the chamber [7].



Intake [7]

Functioning mode (4 stroke Wankel engine)

- Compression
  - As the rotor continues its motion around the housing, the volume of the chamber gets smaller and the air/fuel mixture gets compressed.
  - When it reaches the spark plugs, the volume of the chamber is close to its minimum.
  - This is when combustion starts [7].

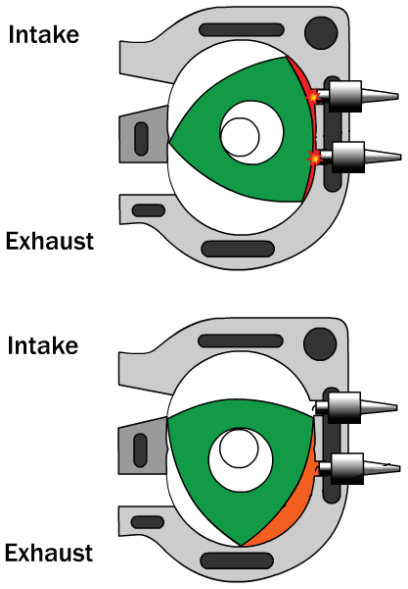


Compression [7]

Sistemas Automóveis

Functioning mode (4 stroke Wankel engine)

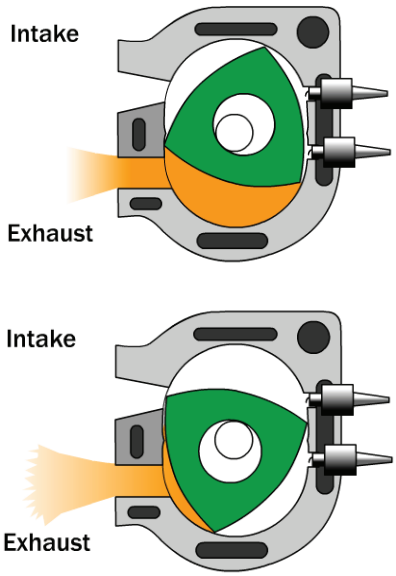
- Combustion
  - Most rotary engines have two spark plugs.
  - The combustion chamber is long, so the flame would spread too slowly if there were only one plug.
  - When the spark plugs ignite the air/fuel mixture, pressure quickly builds, forcing the rotor to move [7].



Combustion [7]

Functioning mode (4 stroke Wankel engine)

- Exhaust
  - Once the peak of the rotor passes the exhaust port, the high-pressure combustion gases are free to flow out the exhaust.
  - As the rotor continues to move, the chamber starts to contract until it reaches its minimum, forcing the remaining exhaust out of the port [7].



Exhaust [7]

Type of Fuel

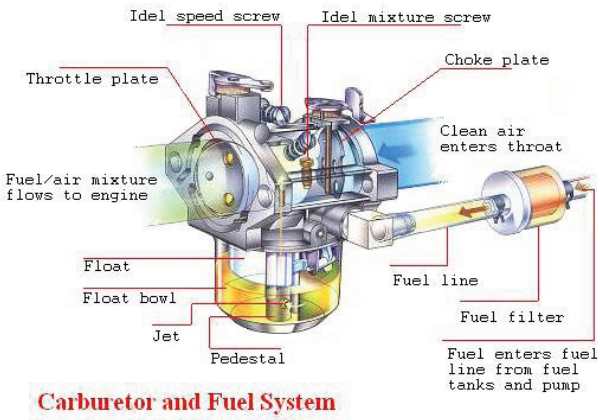
- The most important types of fuel internal combustion engines run on are:
  - Gasoline
  - Diesel
  - Liquefied petroleum gas (LPG)
  - alcohol
  - Engines that run using multiple types of fuels
- Diesel and gasoline engines are the most commonly used fuels [19].

Type of Fuel

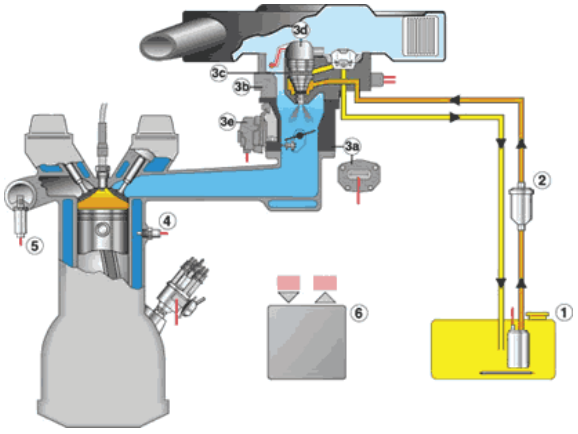
- Advantages of Diesel engines:
  - Better energy efficiency: Use less fuel/energy (work with higher compression ratios)
- Advantages of Petrol engines:
  - Better cold start
  - Less noise and vibrations
  - More elasticity (higher engine speeds)
  - Lighter
  - More power for the same engine size [10]

Mixture Formation

- Internal combustion engines can be divided by their mixture formation type. There are two types:
  - Carburetor engines
  - Injection engines



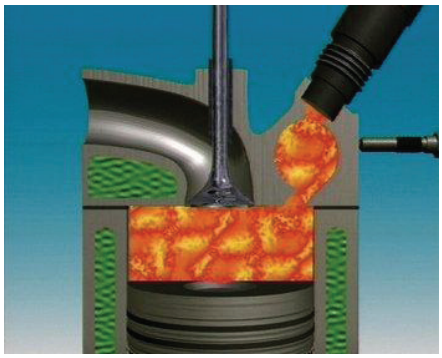
Carburetor engine [14]



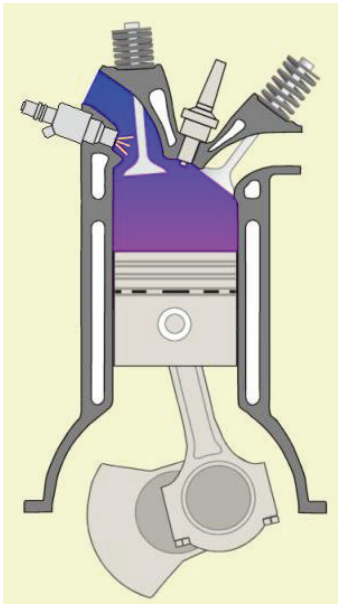
Injection engine [15]

Mixture Formation

- Engines can also be distinguished by the local where the mixture is formed:
  - In the Intake manifold (conventional gasoline engine) and in a separate chamber formed in the head (Diesel engine)



Indirect Injection (Diesel) [13]

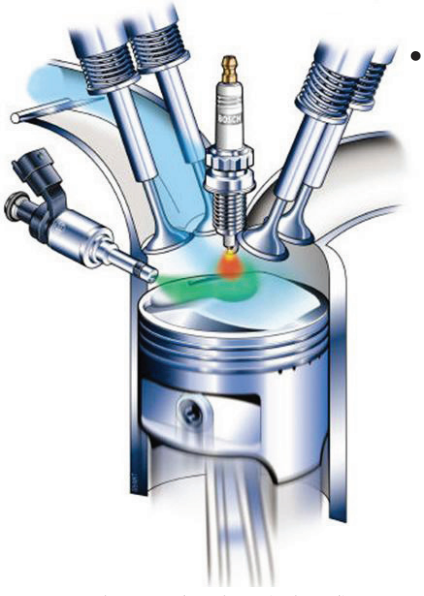


Indirect Injection (gasoline) [12]

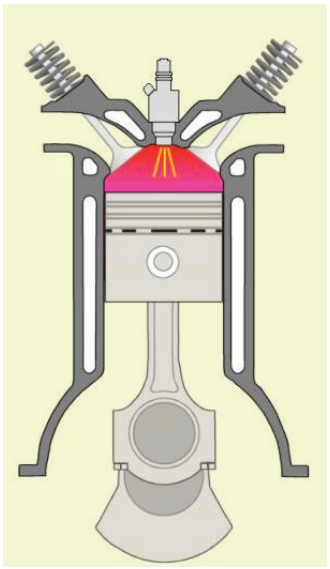
Sistemas Automóveis

Mixture Formation

- Engines can also be distinguished by the local where the mixture is formed:
  - Inside the cylinder (modern diesel and gasoline engines with direct injection)



Direct Injection (Diesel) [11]



Direct Injection (gasoline) [12]

Mixture Formation

- Comparison between direct and indirect injection

	Direct	Indirect
Losses	Lower thermal losses	High thermal losses between chambers
Performance	Higher	Lower
Speed	Slow engine speed	Higher engine speed
Fuel	Demands higher quality fuels	Works with lower quality fuels (viscosity, cetane number)
Injection	Multi-jet (higher injection pressure)	Single-jet (lower injection pressures)

Comparison between direct and indirect injection [10]

Sistemas Automóveis

Mixture Formation

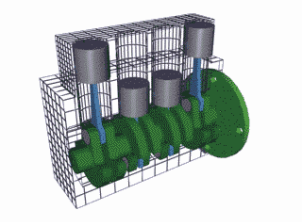
- Advantages and disadvantages of direct injection

Advantages	Inconvenients
Lower fuel consumption	Price
Power	Noise
Cold start	Vibration

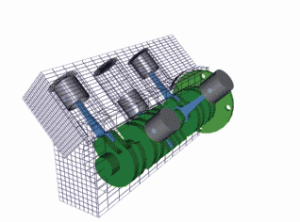
Advantages and disadvantages of direct injection [10]

Configuration and number of cylinders

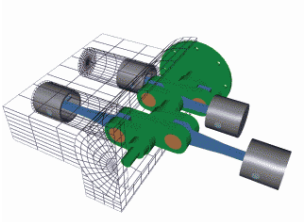
- Internal combustion engines can be divided by their cylinder configuration



In Line configuration [7]

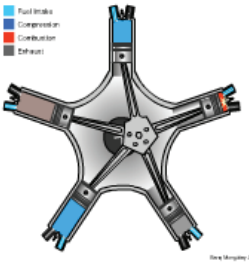


V configuration[7]

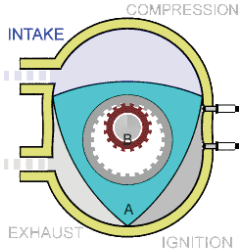


Opposed Horizontal configuration [7]

W configuration [16]



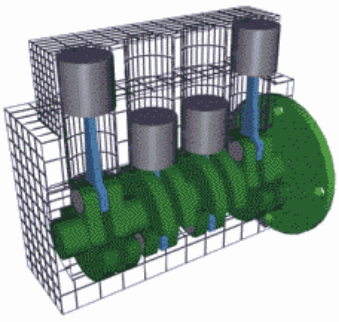
Radial configuration [8]



Wankel engine [9]

Configuration and number of cylinders

- In line configuration

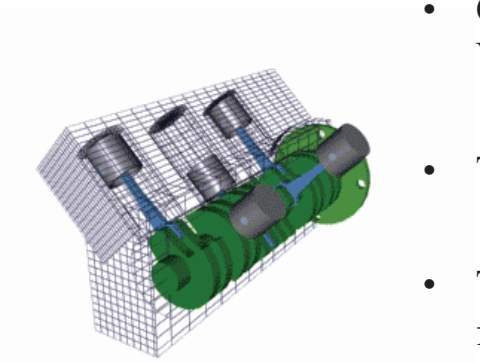


In Line configuration [7]

- The most used configuration for being simple and economic
- It´s a single block where cylinders are aligned
- The main disadvantage in relation to other configurations is having a larger crankshaft

Configuration and number of cylinders

- V configuration



V configuration[7]

- Cylinders are disposed in two blocks joined in a V shape
- The two blocks have a shared crankshaft
- The main advantage is having a shorter crankshaft for the same number of cylinders in relation to the in line configuration
- It is the most used configuration when the number of cylinders is larger than 6

Configuration and number of cylinders

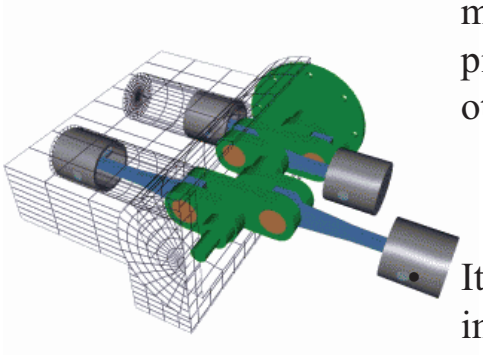
- W configuration

W configuration [16]

- This configuration is similar to the V shape but instead of having 2 blocks of cylinders, it has 3 blocks of cylinders
- This allows to have more cylinders with the same space in relation to other configurations
- This type of configuration is most used with 12 cylinders

Configuration and number of cylinders

- Opposed Horizontal configuration



Opposed Horizontal configuration [7]

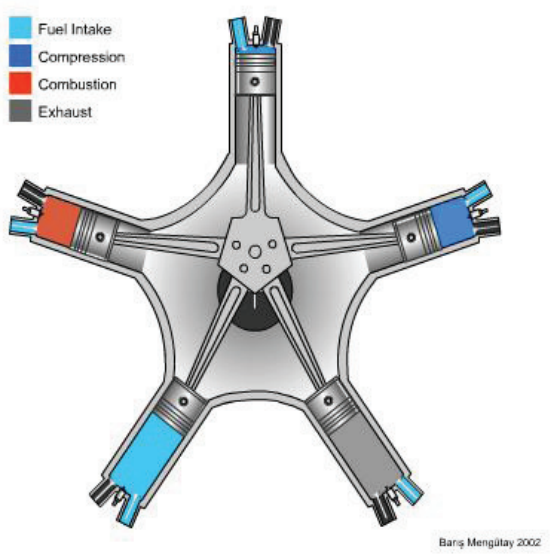
- This type of engine has the advantage of being more balanced because the movement of one piston is compensated by the movement of the other moving in the opposite direction

It allows a lower centre of gravity for the vehicle improving the vehicle handling

- The movement of pistons isn't affected by the force of gravity like in other configurations

Configuration and number of cylinders

- Radial configuration

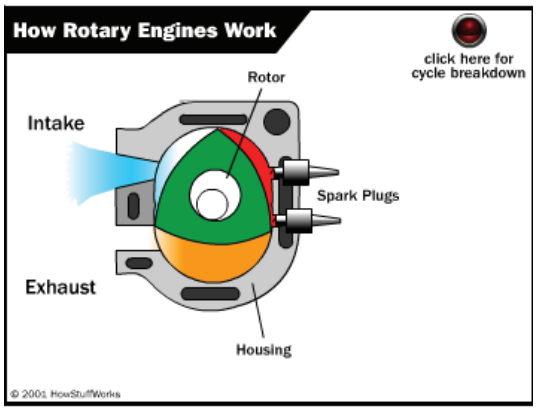


Radial configuration [8]

- The pistons are arranged in a circle around the crankshaft
- Radial engines typically have anywhere from three to nine cylinders
- These types of engines aren´t used in automobiles. They are used in airplanes

Configuration and number of cylinders

- Wankel configuration
  - The rotor follows a path that keeps each of the three peaks of the rotor in contact with the housing, creating three separate volumes of gas.
  - As the rotor moves around the chamber, each of the three volumes of gas alternately expands and contracts.
  - It is this expansion and contraction that draws air and fuel into the engine, compresses it and makes useful power as the gases expand, and then expels the exhaust [7].



Wankel engine [7]

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Configuration and number of cylinders

- In engines with various cylinders there can be considered two scenarios:
  - Engine with many cylinders with small capacity
  - Engine with few cylinders with large capacity
- These two scenarios have advantages and disadvantages [19]

Configuration and number of cylinders

- The main advantages of having more cylinders with small capacity in relation to having fewer cylinders with large capacity is:
  - Better thermal efficiency
  - Larger specific power (relation between the engine capacity and power) augmenting the engine´s maximum regime
  - Greater uniformity of engine torque
  - Better balance of mass in motion, which results in lower engine vibrations [19]

Configuration and number of cylinders

- The main disadvantages of having more cylinders with small capacity in relation to having fewer cylinders with large capacity is:
  - Larger crankshaft length which results in increased problems associated with torsional vibration
  - Increase in volume and weight of the engine
  - Decrease in mechanical efficiency and with it the reduction of power [19]

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Type of cooling

Objectives of the cooling system:

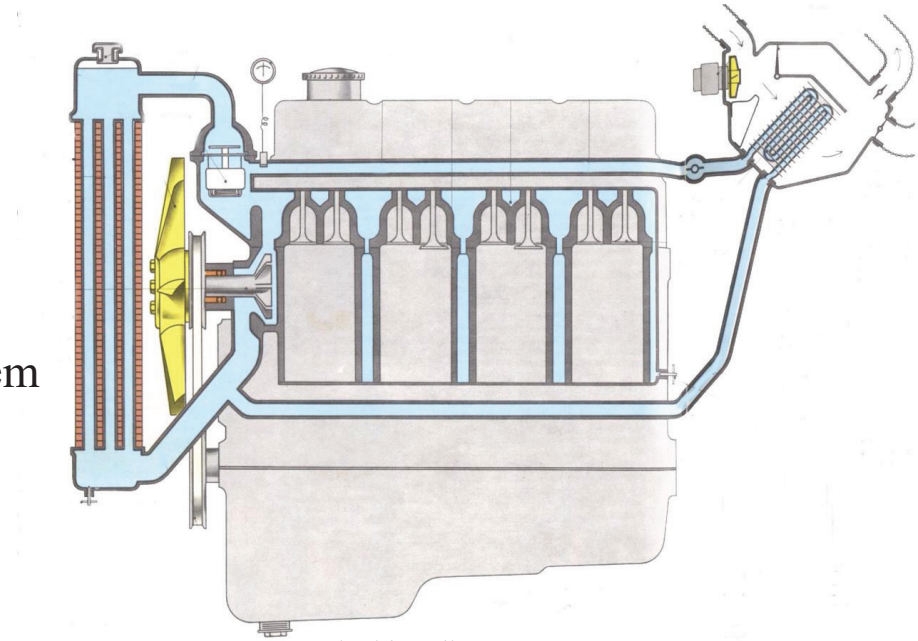
- Cool engine components:
  - keep the engine at a suitable operating temperature (i.e. prevent the melting of components);
  - keep the physical and chemical proprieties of the lubricating oil (can deteriorate with excessive temperature);
- Provide heat to acclimatize the interior of the vehicle
- Improve cold start [19]

Type of cooling

- Engines are divided according to type of cooling as follows:
  - Engine cooled by liquid coolant circuit – There is a circuit for the coolant which cools the various components of the engine.
  - Engine cooled air where the displacement of the surrounding air causes the cooling of the engine components [19].

Cooling systems in a liquid cooled engine

- Water pump
- Thermostat
- Radiator
- Fan
- Heating system



Liquid cooling system [10]

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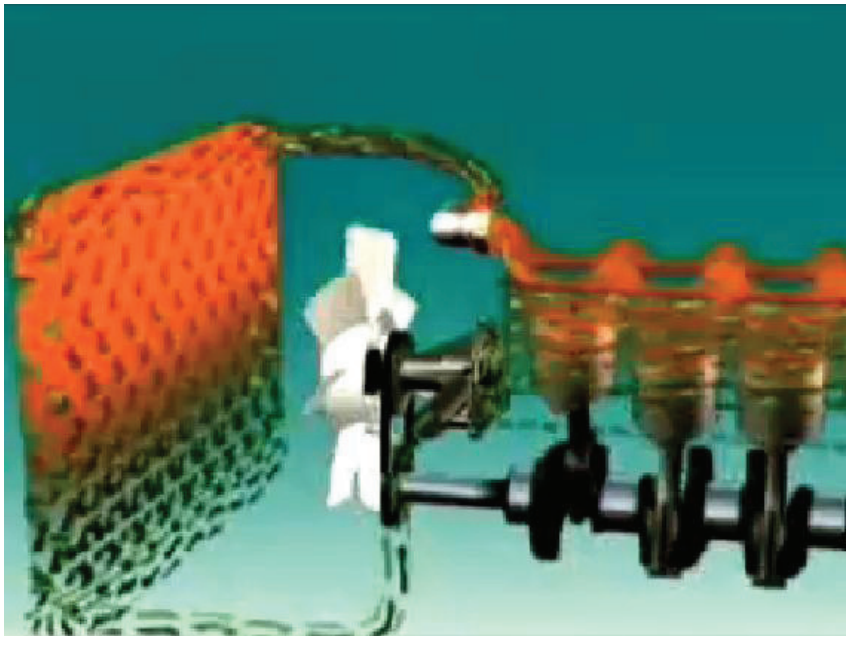
Cooling systems in a liquid cooled engine

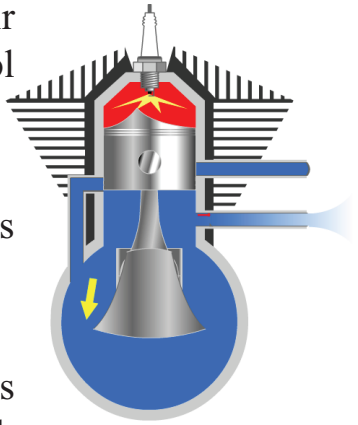


Liquid cooling system [17]

Type of cooling

Air-cooled engine

- Air-cooled engines rely on the circulation of air directly over hot parts of the engine to cool them.
- Heat, generated by an air-cooled engine, is released directly into the air.
- Typically this is facilitated with metal fins covering the outside of the cylinders which increase the surface area that air can act on [9].



Air cooled engine [5]

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Type of cooling

- In all combustion engines, a great percentage of the heat generated (around 44%) escapes through the exhaust, not through either a liquid cooling system nor through the metal fins of an air-cooled engine (12%).
- About 8% of the heat energy finds its way into the oil, which although primarily meant for lubrication, also plays a role in heat dissipation via a cooler. [9]

Type of cooling

- Only the fixed parts of the engine, such as the block and head, are cooled directly by the main coolant system.

- Moving parts such as the pistons, and, to a lesser extent, the crank and rods, must rely on the lubrication oil as a coolant, or to a very limited amount of conduction into the block and thence the main coolant [9].

Type of cooling

- Advantages and disadvantages

  - The coolant used in many liquid-cooled engines must be renewed periodically, and can freeze at ordinary temperatures thus causing permanent engine damage.

  - Air-cooled engines do not require coolant service, and do not suffer engine damage from freezing, two commonly-cited advantages for air-cooled engines.

  - However, coolant based on propylene glycol is liquid to -55 °C, colder than is encountered by many engines. It shrinks slightly when it crystallizes thus, avoiding engine damage and has a service life over 10,000 hours, essentially the lifetime of many engines [9].

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Type of cooling

- Advantages and disadvantages

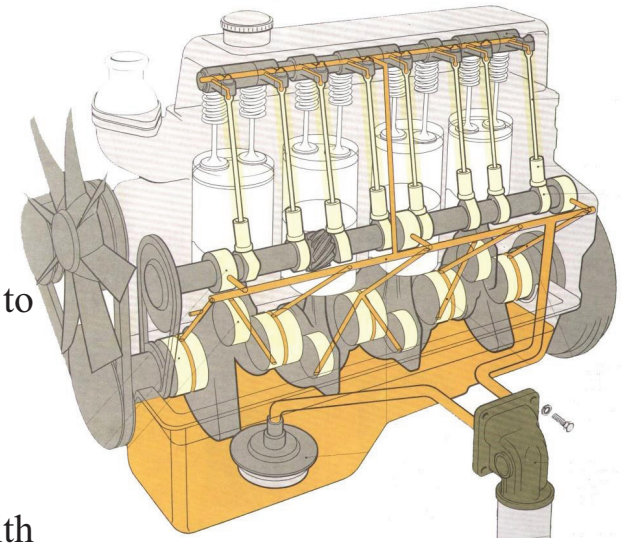
  - The advantages of using water cooling over air cooling include water's higher specific heat capacity, density, and thermal conductivity. This allows water to transmit heat over greater distances with much less volumetric flow and reduced temperature difference.

  - The "water jacket" around an engine is also very effective at deadening mechanical noises, which makes the engine quieter. There is also a disadvantage and this is because it costs more than a air cooled engine system [9].

Lubrification System

- The function of the engine oil is much more than lubricating. The oil must also have:

- High detergent and dispersant power
- High anti-oxidation power
- Good cooling capacity (contributes to engine cooling)
- Good capacity to neutralize acids
- Maintain its properties with temperature change (cold and hot)



Lubrification System[10]

Lubrification System

Lubrification System [17]

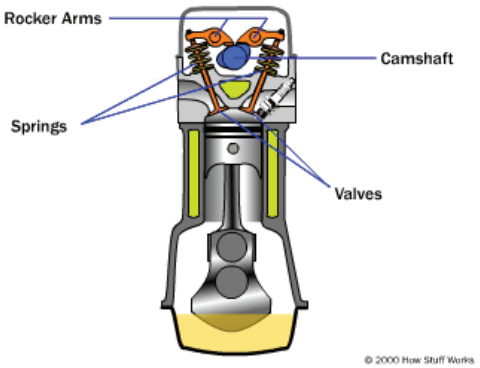
Type of valve actuation

- The camshaft uses lobes (called cams) that push against the valves to open them as the camshaft rotates
- springs on the valves return them to their closed position.
- Any given camshaft will be perfect only at one engine speed. At every other engine speed, the engine won't perform to its full potential.
- A fixed camshaft is, therefore, always a compromise. This is why carmakers have developed schemes to vary the cam profile as the engine speed changes [7].

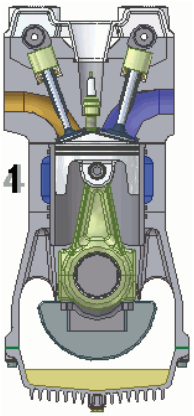
Example of a distribution[10]

Type of valve actuation

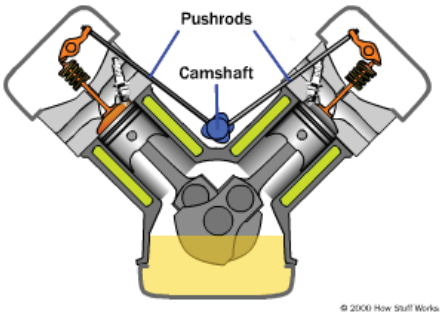
- There are several different arrangements of camshafts on engines. The most common ones are:
  - Single overhead cam (SOHC)
  - Double overhead cam (DOHC)
  - Pushrod



SOHC [7]



DOHC [9]



Pushrod [7]

Ignition type

- There are two types of ignition systems:
  - Spark in a Gasoline engine – sparks are produced with spark plugs.
  - Spontaneous ignition in the Diesel engine – ignition happens when fuel comes in contact with highly compressed hot air.

Future perspectives

- Type of cooling
  - Some high-efficiency engines run without explicit cooling and with only accidental heat loss, a design called adiabatic.
  - For example, 10,000 mile-per-gallon "cars" for the Shell economy challenge are insulated, both to transfer as much energy as possible from hot gases to mechanical motion, and to reduce reheat losses when restarting. Such engines can achieve high efficiency but compromise power output, duty cycle, engine weight, durability, and emissions [9].

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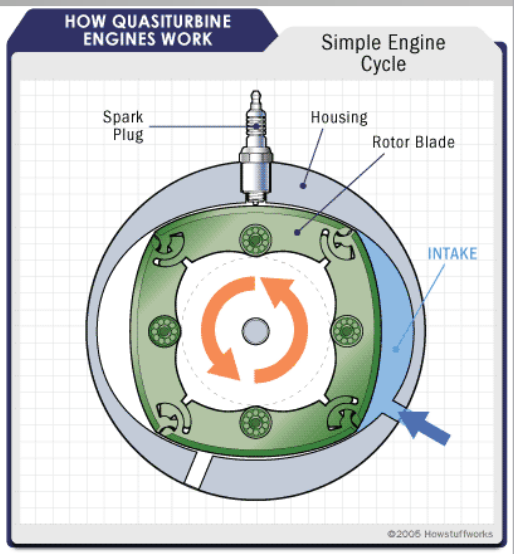
Future perspectives

- Quasiturbine
  - Quasiturbine or Qurbine is a rotary engine patented in 1996, got its name because its operation is almost equal to that of a turbine.
  - It is an evolution of the Wankel engine.



Quasiturbine [7]

  - This engine corrects deficiencies of piston engines and rotary. It's at the stage of development of the prototype [9] [7].

Future perspectives

- Quasiturbine
  - Advantages
    - Lower levels of vibration and noise.
    - At low rpm provides increased torque.
    - With fewer moving parts, reduces the possibility of breakage or wear.
    - Requires less lubrication.
    - The ability to operate in any position. Opera upside down and even underwater.
    - Versatile. Works with various types of fuel, steam, hydrogen, diesel and even compressed air. Can be used as a compressor.
    - Lower emissions.
    - Lower fuel consumption.
    - More power [9] [7].

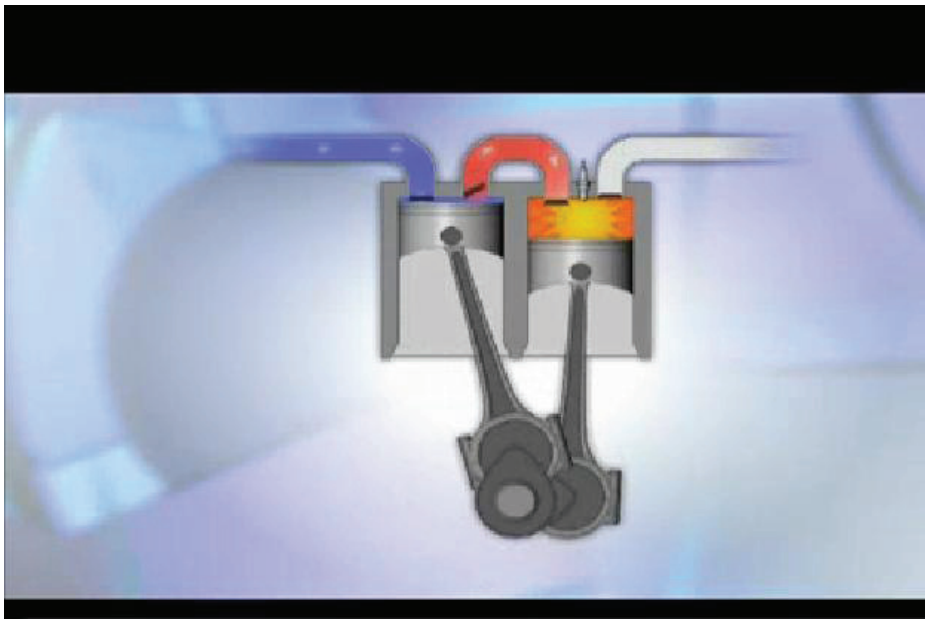
Future perspectives

- Quasiturbine
  - Disadvantages
    - It´s usually constructed of aluminum and iron. When exposed to heat their parts can expand and contract in different ways, which tends to cause some leakage.
    - A similar problem existed in the first generation of Wankel engines, but with technical developments made it possible to control these problems in both cases.

  - Motor Quasiturbine already had some practical uses. Since 1997 has been used in pneumatic saws. Its low level of vibration can prevent the onset of Raynaud's disease in their operators [9] [7].

Future perspectives

- Air Hybrid Engine

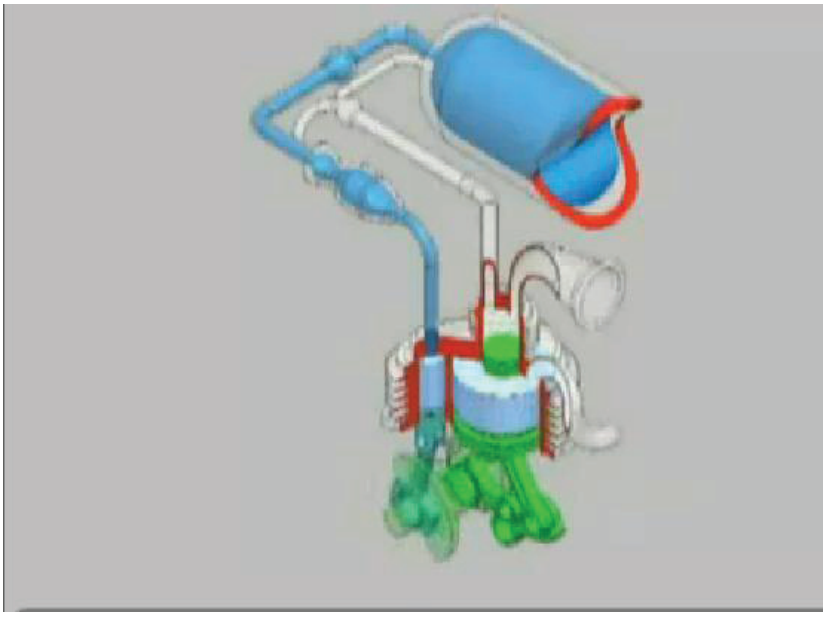


Air Hybrid Engine [17]

Sistemas Automóveis

Future perspectives

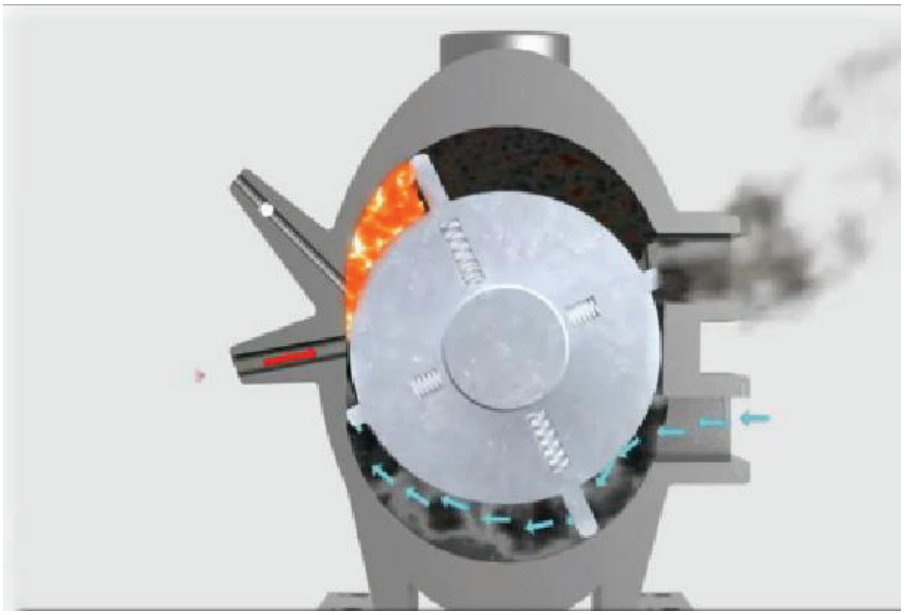
- Air Power



Air Power [17]

Future perspectives

- Rotary Spark Ignited Internal Combustion Engine



Rotary Spark Ignited Internal Combustion Engine [17]

Future perspectives

- Electromechanical valve
  - It accomplishes independent variable valve timing, which operates as a free oscillation system with electromagnets holding the valve in both final positions.
  - Approximately a 15% increase in fuel economy
  - Reduced NOx exhaust gas emissions, due to the control of residual gas fraction
  - Substantially reduced exhaust gas Hydrocarbon (HC) emissions during cold start and warm-up operation
  - Increased low end torque
  - Improved engine transient behavior
  - High potential for idle speed reduction, due to minimal residual gas fraction [18].

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