

Original Research Paper

Contributions to the Stirling Engine Study

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Abstract: In the process of transforming thermal energy into mechanical work, among the known thermal machines, the Stirling engine is the one that can achieve the highest yield (theoretically up to the maximum yield of the Carnot cycle), although in practice it is reduced by the properties of gas and materials used such as friction coefficient, thermal conductivity, melting point, breaking strength, plastic deformation, etc. This type of engine can operate on the basis of a heat source irrespective of its quality, whether it is solar, chemical, nuclear, biological, etc. Unlike internal combustion engines, the Stirling engines can be economical, quieter, safer and less maintenance-free. They are preferred in specific applications where these advantages are reaped, especially if the main objective is not to minimize investment costs per unit of power (RON/kW) but to those per unit of energy (RON/kWh). Compared to internal combustion engines of a given power, the Stirling engines require higher capital expenditure, are larger and heavier, for which reason, viewed from this point of view, this technology is uncompetitive. For some applications, however, a sound analysis of the earnings-to-revenue ratio may favor Stirling engines versus internal combustion engines. More recently, Stirling's benefits have become visible compared to rising energy costs, lack of energy resources and environmental issues such as climate change. Increasing interest in Stirling engine technology has spurred research and development in this area lately. Uses a range of water pumping to astronautics and power generation based on rich sources of energy incompatible with internal combustion engines such as solar energy, or plant and animal scraps. In this respect, the four-stroke four-stroke engine type Stirling is the most advantageous, being driven continuously from the piston. For this reason, it has a stranger load feature, which is said to be inappropriate for car use (the more crankshaft driven crankshaft, although having less mechanical efficiency, have a much longer stable and respond quickly to changes in the working regimes required by a vehicle, especially due to the large inertial help of the shaft, plus the steering wheel, which are more "nerve-wise" and therefore more dynamic). This can, however, be easily corrected in Stirling engines by using multiple cylinders simultaneously, trapped on the same shaft (multi-cylinder Stirling), the shaft having a high inertia, which can be further enhanced by -a wheel. Even though the cylinders work most of the time in motor regimes, they are permanently connected to the output shaft which must have a very high inertia in construction, the movement at the output of the motor being picked from the shaft.

Keywords: Stirling Engine, Thermal Machines, Multi-Cylinder Stirling, Thermal Motors, Efficiency, Yield, Dynamic Kinematics

Introduction

The engine is a machine that converts some form of energy into mechanical energy.

The following types of engines are distinguished:

Electric, magnetic, electromagnetic, sonic, pneumatic, hydraulic, wind, geothermal, solar, nuclear, reaction (Coanda, ionic, ionic, electromagnetic, plasma, photonic).

Being the oldest, most widely used and most common motors, thermal motors (which convert thermal energy into mechanical energy) can also be classified into two broad categories: External combustion engines and internal combustion engines (Petrescu and Petrescu, 2016a; 2016b; 2016c, 2013a; 2013b, 2012a; 2012b; 2012c, 2011; 2005a; 2005b; 2005c; 2005d; 2005e, 2003, 2002a; 2002b, 2000a; 2000b, 1997a; 1997b; 1997c, 1995a; 1995b, Petrescu, 2015a; 2015b; 2012; 2011; Petrescu *et al.*, 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae; 2016; 2009).

Among the most famous external combustion engines we mention: Steam engines and Stirling engines.

The category of internal combustion engines being the most common, most used and most important, includes several subcategories, of which we will try to list a few:

The Lenoir engine, the Otto four-stroke engine, the Diesel engine, the Wankel rotary engine, the Atkinson rotary engine, the biodiesel engines, the hydrogen engines and so on.

The most common external combustion engines are steam engines. Although initially used as a naval engine, the emergence and development of steam engines (as well as the first cam mechanism) are closely related to the emergence and development of tissue wounds (automatic tissue machines).

In 1719, in England, some John Kay opens in a five-story building a filth. With a staff of over 300 women and children, this would be the world's first factory. He also becomes famous by inventing the flying sail, which makes the tissue much faster. But the machines were still manually operated. It was not until 1750 that the textile industry was to be revolutionized by the widespread application of this invention. Initially the weavers opposed it, destroying flying sails and banishing the inventor (Petrescu and Petrescu, 2012a).

By 1760 the wars of the weaving and the first factories appeared in the modern sense of the word. It took the first engines. For more than a century, Italian Giovanni Branca (1571-1645) proposed the use of steam for the operation of turbines (the first modern steam engine with steam combustion built by the engineer and Italian architect Giovanni BRANCA was a steam turbine).

Subsequent experiments were not satisfying. In France and England, inventors such as Denis Papin (1647-1712, French mathematician and inventor, pioneer of steam engines, whose first steam engine was built in 1679) or the Worcester Marquis (1603-1667), with us and new ideas.

At the end of the seventeenth century, Thomas Savery (1650-1715) had already built the "friend of the miner", a steam engine (patented, with no mechanism, no moving parts, he was a sort of compressor, a pressure bottle pushing the water out of the cylinder through a hole when it was open) that puts a pump into the water to remove the water from the galleries, or was mounted on the fire-fighting vehicles to pump the water to fire.

Thomas Newcomen (1664-1729) built the commercial steamer version and engineer James Watt (1736-1819) develops and adapts a speed regulator that improves the net steam engine (Petrescu and Petrescu, 2012a).

J. Watt - 1763 has greatly improved the machines achieved so far by reducing the heat and energy losses in coal-fired steam boilers (Fig. 1 shows James Watt's original steam engine, an invention that would change the face of the world, designed in 1769 and improved in 1774). The steam engine invented by Watt later benefited from three other French inventions: M. Seguin's 1817 tubing boiler, E. Bourdon's manometer - 1849 and T. Gifford's injector - 1858 (Petrescu and Petrescu, 2012a).



Fig. 1: James Watt's original steam engine, an invention that would change the face of the world, designed in 1769 and improved in 1774

The steam engine has allowed factories to be located not only in the vicinity of watercourses but also where their products were needed - shopping centers, cities (The first practical application was in me, followed by the cotton, beer, etc. industry. Britain, in the west of the continent and then in the 19th-20th centuries around the world).

James Watt was born in Greenock, Scotland. He completed his studies in London, England and began working as a mathematical tool maker (1754). He returned to his native lands in Glasgow, Scotland. He was the manufacturer of mathematical tools used by the University of Glasgow (Petrescu and Petrescu, 2012a).

Here he was given the opportunity (destiny) to repair a steam car, which helped him to improve it; so the "steam condensing chamber" (1769) and the "steam machine speed controller" (1788) appeared. In the machine invented in 1769, the steam passed into a separate room for condensation.

Since the cylinder was not heated and cooled alternately, the heat loss of the machine was relatively low. Also, Watt's car was faster, because more steam could be allowed in the cylinder once the piston had returned to its original position. This and other improvements designed by Watt have made the steam machine can be used in a wide range of applications (Petrescu and Petrescu, 2012a).

He later moved to England in Birmingham. Here he enters a club, the "Lunar Society," which - despite its deceptive name - was in fact a scientific club made up of inventors. Many of his original works are at the Birmingham Cultural Library (Birmingham Central Library).

James Watt, along with a British industrialist, Matthew Boulton, succeeded in creating an enterprise for the manufacture of what was called Watt's Improved Steam Machine (1774). Here, along with another Scottish inventor William Murdoch, he will realize a rotary motion conversion gear (1781). Subsequently, he made a double-action car (1782).

Its greatest achievement is considered to be the patenting of the steam locomotive in 1784 (Fig. 2). As a matter of fact, in that year, in 1784, transport was born on the railway (Petrescu and Petrescu, 2012a).

Together with Mathiew Boulton, Scottish engineer James Watt builds the first steam-powered steam engines (Fig. 3) and in less than half a century, the wind that fed over 3,000 years ago, propulsion power at sea now only blooms pleasure boats.

Interestingly, Watt's first steam engine (the first version of 1769) was taken over by the French engineer Nicolas Joseph Cugnot and originally adapted (Fig. 4) for use in the very same year (1769) when building the first vehicle, originally intended for military and armament transport, but also heavy towing, heavy cannon. The

maximum speed of this first vehicle (improved version) at maximum load (four in-vehicle vehicles plus towed heavy tolls of no more than 4t) was 5km per hour and at a half load it touched dry roads 8.5 km/h.

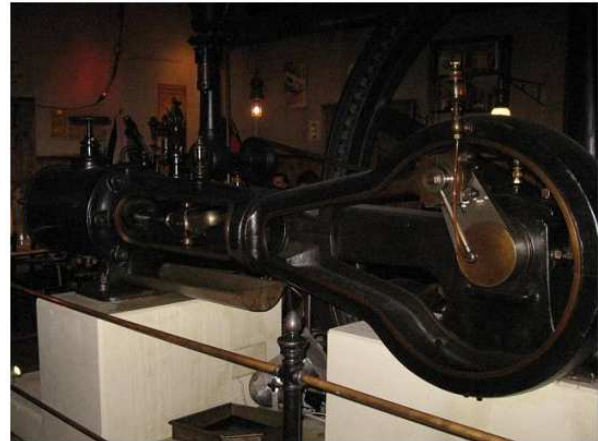


Fig. 2: The James Watt's patenting of the steam locomotive in 1784



Fig. 3: First steam-powered engines



Fig. 4: Joseph Cugnot's (1769) first vehicle

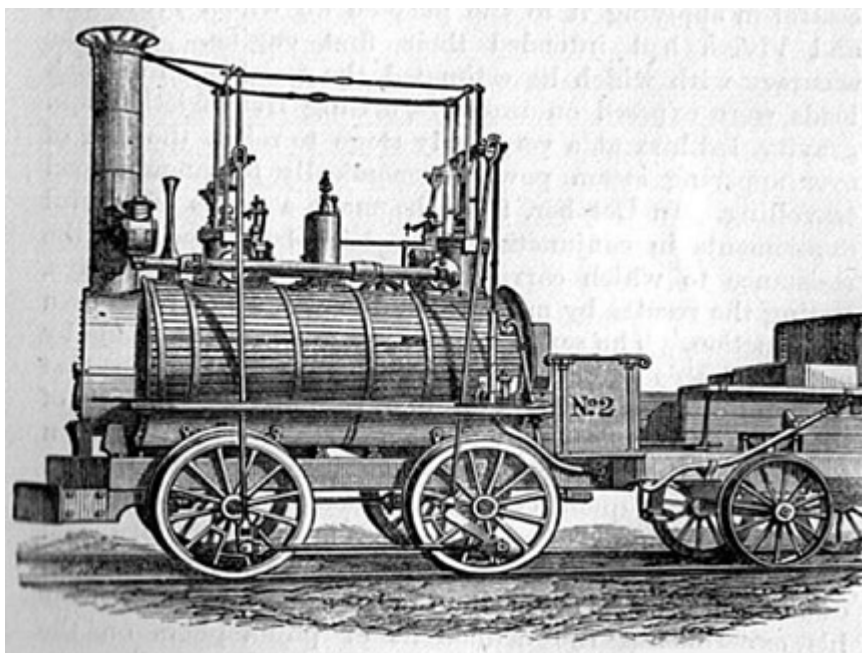


Fig. 5: The first steam locomotive, built on the railroad, was built based on Watt's model, by British engineer George Stephenson in 1814

The first steam locomotive, built on the railroad, was built based on Watt's model, by British engineer George Stephenson (1781-1848), only in 1814 (Fig. 5), (Petrescu and Petrescu, 2012a).

Robert Fulton (who is incorrectly assigned to construct and construct the first motorized vessels 1803-1807) can be credited to have been the author of the plans and the actual builder (1798) of the first functional submarine, commissioned by Napoleon Bonaparte, named Nautilus, in 1800 in France by Fulton himself with three mechanics, sinking to the depth of 25 feet (Petrescu and Petrescu, 2012a).

In 1785 came into operation, the first steam driven steamer, followed quickly by a few dozen.

The development of ship engines, trains, cars and automated weaving engines has led to the development of the European and American steel industry (and later also the world).

It is remarkable that the first motorized vehicle (equipped with a steam engine) was a car, followed by a submarine, various ships and then trains. Steam engines have been used (and are still used today) as stationary thermal motors in plants, acting on pumps, reducers and machine tools.

One of the oldest steam engines used (including locomotives), first adapted by Watt, is the "steam engine with three expansion tanks" (Fig. 6). Not only have some engines been kept, but they have begun to be reused due to the low pollution they produce and good performance. Their main disadvantage, for which they almost disappeared in the "black oil era" (dominated by oil),

was the lack of compaction. But their advantage is that, as they have started, they can use various fuels, which can be useful to reduce the consumption of petroleum products and remain alive even when oil falls to its disappearance (Petrescu and Petrescu, 2012a).

As external combustion engines, they can be adapted to use various fuels such as biofuels, alcohols, hydrogen, vegetable oils, seeds, soybeans, peanuts, or extracts from various plants, or biofuels extracted from seaweed and oceanic, etc. We no longer have to feed these "noble horsepower" only with poor quality coal and then say that these engines smoke "smelly smoke" (coal was a polluting fuel of the planet).

Let's imagine these modernized "grandparents and grandparents", imagine these "naftaline" engines, beautifully polished, redesigned on modern principles, reshaped to modern (compacted) fuels, made of modern materials (ceramics, super metals, special alloys, etc.) and we think that they can become a real alternative transport and motor source even when oil is no longer alongside modern electric motors with internal combustion engines on hydrogen together with the other types of external combustion thermal engine (Stirling).

We can still imagine the heated water to the vapor state with the help of modern electrical induction, induction, microwave, or various modern means, using the solar electric power, captured and stored in modern accumulators. The result... strong, robust, dynamic, compact, non-smokeless, oil-free, smoke-free thermal motors, working at high efficiency (not only mechanical but also thermal).

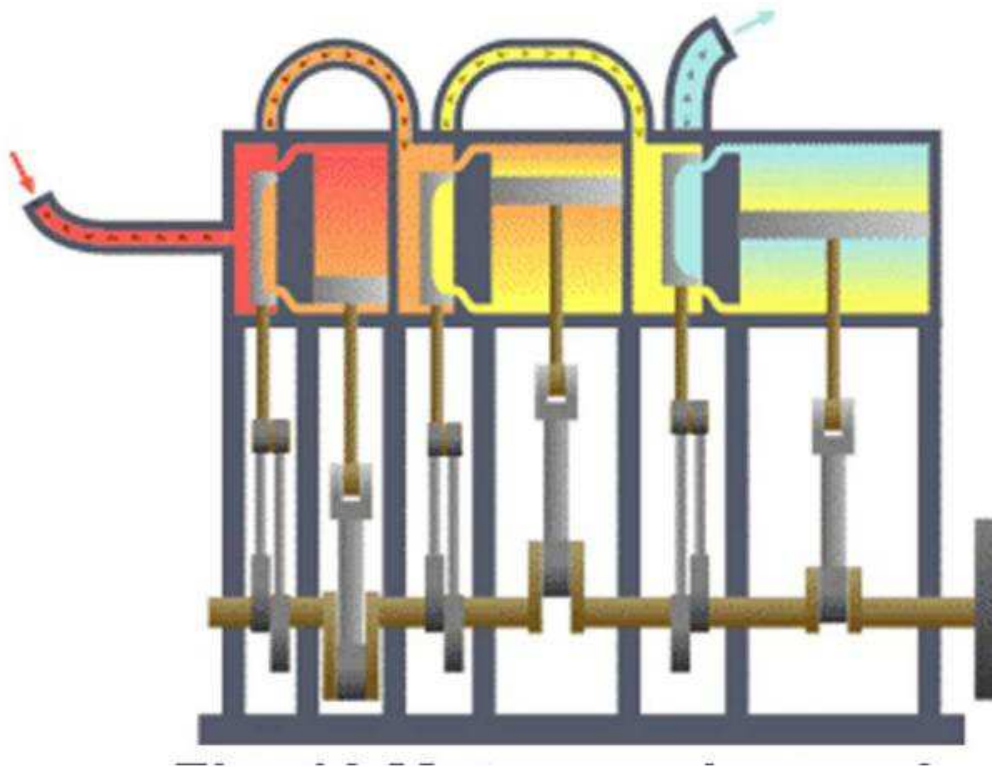


Fig. 6: The oldest steam engines used (including locomotives), first adapted by Watt, is the "steam engine with three expansion tanks"

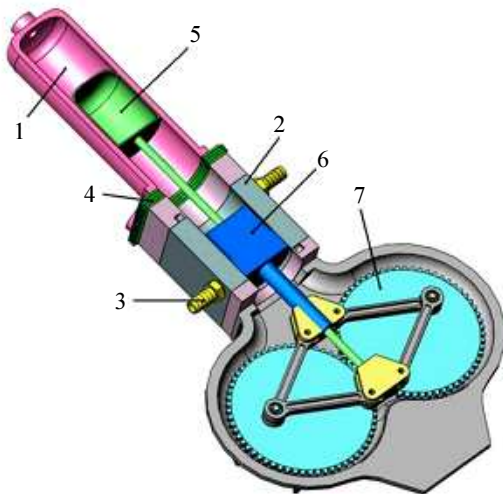


Fig. 7: A section of a Beta Stirling type engine with a rhombic bead mechanism

Also in this context are the modern Stirling engines.

Figure 7 shows a section of a Beta Stirling type engine with a rhombic bead mechanism (Petrescu and Petrescu, 2012a).

[1 - the hot wall of the cylinder, 2 (dark gray) - the cold wall of the cylinder (with 3 cooling joints), 4 - the thermal insulation separating the ends of the two cylinders, 5 - the discharge piston, 7 - volts; Unrepresented: External power supply and cooling radiators. In this drawing the discharge piston is used without a regenerator.]

A Beta Stirling engine has a single cylinder in which a working piston and a discharge piston are mounted on the same shaft. The discharge piston is not leak-tight and does not serve to extract mechanical work from the expanding gas, with only the role of operating the working gas between the hot and cold heat exchanger. When working gas is pushed to the hot end of the cylinder, it expands and pushes the plunger. When pushed to the cold end, the inertia moment of the engine, usually increased by a steering wheel, shakes the working piston in the opposite direction to compress the gas. Unlike the Alfa type, the technical problems related to the hot piston sealing rings are avoided in this case. The four operating times of the Beta Stirling engine can be seen in Fig. 8 (Petrescu and Petrescu, 2012a). An Alfa Stirling model can be seen in Fig. 9.

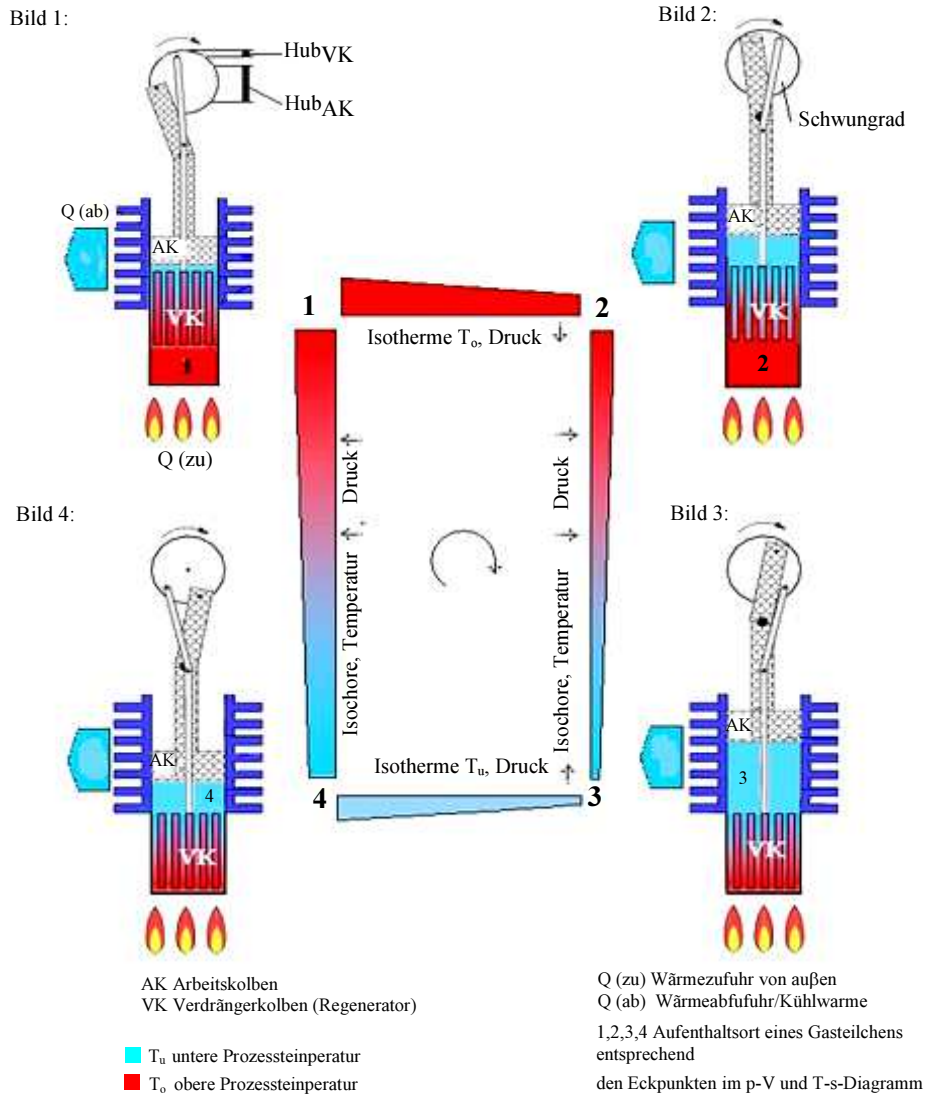


Fig. 8: The four operating times of the Beta Stirling engine

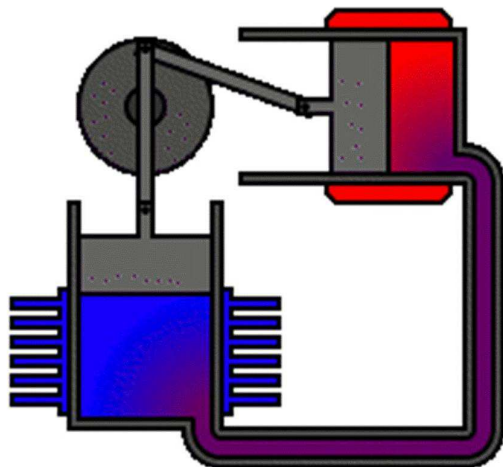


Fig. 9: An Alfa Stirling model

An Alfa Stirling engine contains two working pistons, one hot and one cold, located separately in one cylinder. The cylinder of the hot piston is located inside the high temperature heat exchanger and the cold piston in the low temperature heat exchanger. This type of motor has a very high literal power but has technical difficulties due to the very high temperatures in the area of the hot piston and its sealing. The Alfa Stirling engine can be described in four ways:

- Time 1: Most of the working gas is in contact with the wall of the hot cylinder; as a result, heats up his volume and pushes the piston towards the end of the cylinder. The dilatation continues also in the cold cylinder whose piston has a 90° downshift

motion relative to the piston of the hot cylinder, with further mechanical extraction (Petrescu and Petrescu, 2012a)

- Time 2: The working gas has reached the maximum volume. The piston in the hot cylinder begins to push most of the gas into the cold cylinder where it loses its accumulated temperature and the pressure drops
- Time 3: Almost all the amount of gas is in the cold cylinder and continuous cooling. The cold piston, driven by the inertia moment of the flywheel or another pair of pistons on the same shaft, compresses the gas
- Time 4: The gas reaches the minimum volume and the piston in the hot cylinder will allow the vehicle to travel to this cylinder where it will be heated again and the mechanical workout to the working piston will start

The Gamma Stirling model can be seen in Fig. 10.

A Stirling Range Engine is a Stirling Beta in which the working piston is mounted in a separate cylinder adjacent to the discharge cylinder but is connected to the same steering wheel. The gas in the two cylinders circulates freely between them. This variant produces a lower compression ratio but is constructively simpler and is often used in Stirling with several cylinders (Fig. 11 shows a 4-cylinder alpha-Stirling engine with high efficiency, power, speed and torque being high and the action is done by simultaneously burning four candles).

"Stirling engine enthusiasts of this kind must make a reserve of candles!" (Petrescu and Petrescu, 2012a).

Gamma Stirling model Engine Operation Stirling Range (Petrescu and Petrescu, 2012a):

- Time 1: During this phase the working piston performs a minimum stroke, the total volume is minimal. Instead, the discharge spout performs a long stroke and the working gas heats up
- Time 2: The discharge piston has a short stroke, while the piston performs more than 70% of its total stroke. It generates mechanical energy
- Time 3: The discharge piston performs most of its run: The gas is cooled. The piston has a short stroke
- Time 4: The discharge piston remains at the top of the cylinder: The gas is completely cooled. Instead, the plunger travels most of his stroke: Compresses the gas and gives up mechanical work for that purpose

A special field is Stirling "free piston" engines, including those with liquid piston and diaphragm (Fig. 12), (Petrescu and Petrescu, 2012a).

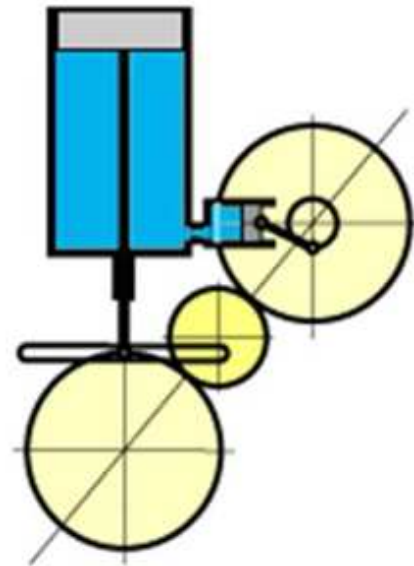


Fig. 10: The Gamma Stirling model



Fig. 11: A 4-cylinder alpha-Stirling engine with high efficiency, power, speed and torque being high and the action is done by simultaneously burning four candles

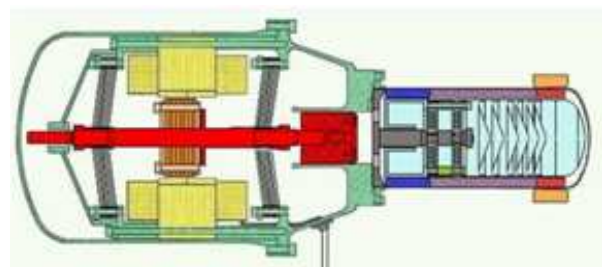


Fig. 12: Stirling "free piston" engines, including those with liquid piston and diaphragm

In 2010, more than 800 million vehicles circulate across the planet (Frățilă *et al.*, 2011; Pelecudi, 1967; Antonescu, 2000; Comănescu *et al.*, 2010; Aversa *et al.*, 2016a; 2016b; 2016c; 2016d; 2017a; 2017b; 2017c; 2017d; 2017e; Mirsayar *et al.*, 2017; Cao *et al.*, 2013; Dong *et al.*, 2013; De Melo *et al.*, 2012; Garcia *et al.*, 2007; Garcia-Murillo *et al.*, 2013; He *et al.*, 2013; Lee, 2013; Lin *et al.*, 2013; Liu *et al.*, 2013; Padula and Perdereau, 2013; Perumaal and Jawahar, 2013; Petrescu and Petrescu, 1995a; 1995b; 1997a; 1997b; 1997c; 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e, 2016a; 2016b; 2016c; 2016d; 2016e; 2013; 2012a; 2012b; 2011; Petrescu *et al.*, 2009; 2016a; 2016b; 2016c; 2016d; 2016e; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae; Petrescu and Calautit, 2016a; 2016b; Reddy *et al.*, 2012; Tabaković *et al.*, 2013; Tang *et al.*, 2013; Tong *et al.*, 2013; Wang *et al.*, 2013; Wen *et al.*, 2012; Antonescu and Petrescu, 1985; 1989; Antonescu *et al.*, 1985a; 1985b; 1986; 1987; 1988; 1994; 1997; 2000a; 2000b; 2001; List the first flights, From Wikipedia; Chen and Patton, 1999; Fernandez *et al.*, 2005; Fonod *et al.*, 2015; Lu *et al.*, 2015; 2016; Murray *et al.*, 2010; Palumbo *et al.*, 2012; Patre and Joshi, 2011; Sevil and Dogan, 2015; Sun and Joshi, 2009; Crickmore, 1997; Donald, 2003; Goodall, 2003; Graham, 2002; Jenkins, 2001; Landis and Dennis, 2005; Clément, Wikipedia; Cayley, Wikipedia; Coandă, Wikipedia; Gunston, 2010; Laming, 2000; Norris, 2010; Goddard, 1916; Kaufman, 1959; Oberth, 1955; Cataldo, 2006; Gruener, 2006; Sherson *et al.*, 2006; Williams, 1995; Venkataraman, 1992; Oppenheimer and Volkoff, 1939; Michell, 1784; Droste, 1915; Finkelstein, 1958; Gorder, 2015; Hewish, 1970; Wiederrich and Roth, 1974; Fawcett and Fawcett, 1974; Jones and Reeve, 1974; Tesar and Matthew, 1974; Sava 1970; 1971; Koster, 1974).

Materials and Methods

In the process of transforming thermal energy into mechanical work, among the known thermal machines, the Stirling engine is the one that can achieve the highest yield (theoretically up to the maximum yield of the Carnot cycle), although in practice it is reduced by the properties of gas and materials used such as friction coefficient, thermal conductivity, melting point, breaking strength, plastic deformation, etc. This type of engine can operate on the basis of a heat source irrespective of its quality, whether it is solar, chemical, nuclear, biological, etc (Aversa *et al.*, 2017a; 2017b, 2016a; 2016b; 2016c; 2016d; 2016e; 2016f; Mirsayar *et al.*, 2017; Petrescu *et al.*, 2017).

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More recently, Stirling's benefits have become visible compared to rising energy costs, lack of energy resources and environmental issues such as climate change. Increasing interest in Stirling engine technology has spurred research and development in this area lately. Uses range from water pumping to astronautics and power generation based on rich sources of energy incompatible with internal combustion engines such as solar energy, or plant and animal scraps.

Another feature of the Stirling engines is their reversibility. Mechanically operated, they can act as heat pumps. Tests were conducted using wind energy to drive a Stirling cycle heat pump to heat and condition air for dwelling in cold weather.

Stirling's aircar was invented by clergyman Robert Stirling and patented by him in 1816. The date when the simplified name of the Stirling engine was established is not known, be estimated in the mid-twentieth century when Philips began research on non-airborne fluids (MP1002CA is still referred to as the 'air engine' in the operating instructions). The main theme of the patent referred to a heat exchanger that Stirling called it "economizer" because it can contribute to saving fuel in various applications. The patent thus described in detail the use of a form of economiser in an air car, which is now known as a regenerator. A Stirling engine was used in a stone quarry for water pumping in 1818. Subsequent patents by Robert Stirling and his brother, engineer James Stirling, concerned various improvements to the original car's construction, including raising internal pressure which led to a significant increase in power so that in 1845 all Dundee steel melting machines could be trained (Petrescu and Petrescu, 2012a).

In addition to saving fuel, the inventors also envisaged creating a safer engine than the steam engine, at which time the boiler exploded slightly (due to poor quality materials and various workshop technologies used at that time), often causing accidents and even loss of life.

However, obtaining a much higher Stirling engine yield, possibly by providing very high temperatures, has long been limited by the quality of the materials available at that time and the few ones built have had a reduced lifetime.

The engine's hot engine faults were more frequent than could be expected, but with less disastrous consequences than the boom of a steam car.

Though it eventually lost steam competition with regard to the machinery drive, at the end of the nineteenth and early twentieth centuries, a large number of Stirling hot air engines (the difference between the two types is blurred if in many of them the generator is doubtful or lacking in efficiency), finding its use everywhere where medium or small but reliable power is needed, most often in pumping water. They were operating at low temperatures, so they did not demand too much of the available materials, so they became quite ineffective, the advantages of steam machines being simple operation being handled by domestic personnel and the elimination of the danger of possible dangerous explosions. Over time, their role has been taken over by electric motors or internal combustion engines of smaller size, so that in the late 1930s the Stirling engine fell into oblivion, being just a technical curiosity represented by a few toys and ventilation systems. Meanwhile, Philips, the Dutch electric and electronic component company, has begun research on this type of engine. In an attempt to expand the market for its radio equipment in areas where there is no electricity grid and the battery life of short battery life was uncertain, the company's management concluded that a low power portable generator was needed, a group of engineers from his Eindhoven laboratories with research. Studying different older and newer drive motors, they were rejected for one reason or another until the choice fell on the Stirling engine. Silently built and nonselective to the heat source (cheap and available light bulb) the Stirling engine seemed to offer real possibilities. Encouraged by their first experimental engine that produced 16 watts of power on a shaft with a 30 mm diameter cylinder and a 25 mm stroke, they started a development program.

Amazingly, the work continued during World War II, so that at the end of the 1940s the Type 10 engine was finite enough to be handed over to the Johan de Witt branch in Dordrecht for serial production within a equipment for generating electricity according to the initial plan. The project was developed with prototypes 102 A, B and C, reaching a power of 200 W (power) on a 55 mm diameter cylinder and a stroke of 27 mm on the MP1002CA (Petrescu and Petrescu, 2012a).

The production of the first batch began in 1951, but it became clear that it could not be produced at an acceptable price on the market, which added to the appearance of transistor radio appliances that had a much lower consumption (going on batteries or miniaculators) what made the initial reason for development disappear. Although the MP1002CA was a dead line, it is the start of the new era of Stirling engine development (in real terms it was a second missed start of the Stirling engine).

Thanks to the money invested and the finalized research, Philips developed the Stirling engine for a wide range of applications, but commercial success had only the Stirling engine in reverse mode used in the cold technique. Actually used backwards, it is no longer a Stirling engine but a heat product machine (as an internal combustion engine used inversely becomes a simple compressor, a pump, etc.).

However (Philips specialists) have obtained a number of patents and have accumulated a great deal of knowledge about Stirling engine technology, which was later sold as a license to other companies (Petrescu and Petrescu, 2012a).

Because the Stirling engine cycle is closed, it contains a determined amount of gas called "working fluid," most of which air, hydrogen or helium. In normal operation, the engine is sealed and gas is not exchanged inside.

Its great advantage over other types of motors is that no valves are required (it does not require one or more distribution mechanisms, which, for Otto or Diesel engines, take from 10 to 25% of the engine power, produce vibrations and noises in operation, increase the final gauge of the engine, often produce characteristic noise, higher in Diesel engines, known by specialists as beatings, or tangled by tachets, although it is due more to the cultivating mechanism; the distribution mechanisms, although built solidly, all have high elasticity in their kinematic chain, which causes large deformations in operation, making dynamic operation suffer much).

The gas exchange of internal combustion engines, via valves or windows, produces additional power losses, additional vibrations and noise and higher emissions, with the Stirling engine being superior.

Even the lack of these gas exchanges with the external environment, ensures Stirling engines a higher efficiency, a much reduced pollution, a much lower fire or explosion hazard, compared to internal combustion or steam combustion engines and a much stronger seal that enables them to operate more securely even in toxic, chemical, nuclear, marine, underwater, wet, flammable, cosmic, unknown, unsafe environments (Petrescu and Petrescu, 2012a).

Stirling's engine, similar to other thermal machines, goes through a cycle of 4 transformations (times): Heating, re-cooling, cooling and compression. The cycle occurs by moving the gas back and forth between the hot and cold heat exchangers.

The hot heat exchanger is in contact with an external heat source, for example a fuel burner and the cold heat exchanger is connected to an external radiator, for example an air heater. A change in gas temperature results in a change in pressure, while the piston movement contributes to the compression and alternate expansion of the gas.

The behavior of the working fluid is in accordance with perfect gas laws that describe the relationship

between pressure, temperature and volume. When the gas is in a closed space, heating will produce a pressure increase that will act on the working piston causing it to move. When cooling the gas, the pressure drops, so it will take less mechanical work to compress it when the piston moves in the opposite direction, resulting in a surplus of mechanical energy (Petrescu and Petrescu, 2012a).

Many high-performance Stirling engines are pressurized, i.e. the average indoor pressure is higher than the atmospheric pressure. Thus the mass of the working fluid is higher, as a result of the amount of caloric energy transmitted, so the engine power will be higher. Increasing pressure also causes other changes such as increasing the capacity of heat exchangers as well as regenerator. This in turn can increase unused spaces as well as hydrodynamic resistance with negative effect on developed power. The construction of the Stirling engine is thus a problem of engineering optimization of several contradictory requirements.

Air pressure experiments were the ones that led Philips to move from air to other gas as a working fluid. At high temperatures, oxygen in the air tended to react with engine lubricants, which were removed from the sealing segments, clogging the heat exchangers and even presenting an explosion hazard. Later, it has been found that certain gases such as hydrogen and helium have other advantages over the air.

If one end of the cylinder is open, the operation is slightly different. When the closed volume between the piston and the cylinder heats up, a dilation occurs in the heated part, resulting in a pressure increase, which results in the piston moving. Upon reaching the cold surface, the volume of the gas is reduced resulting in pressure drop below atmospheric pressure and thus the piston movement is reversed.

In conclusion, the Stirling engine uses the temperature difference between the two hot and the cold zones to create a gas expansion-contraction cycle of a given mass gas inside a machine to convert thermal energy into mechanical work. The larger the difference between the temperatures of the two areas, the higher the cycle yield (Petrescu and Petrescu, 2012a).

Powerful stationary or mobile generators (Fig. 13) are built today using the Stirling engines, which operate an electric generator, thus obtaining heat and electricity in isolated places, hospitals, factories, hotels, institutions, etc., whether isolated or in the event of a power failure in certain special situations (incidents, earthquakes, storms, floods, power grid failure or transformer failure, etc.).

Small experimental engines (Fig. 14) have been built to operate at low temperature differences of up to 7°C that occur, for example, between the palm of the hand and the environment or between room temperature and ice melting temperature (Petrescu and Petrescu, 2012a).



Fig. 13: Powerful stationary or mobile generators



Fig. 14: Small experimental engines built to operate at low temperature differences of up to 7°C that occur, for example, between the palm of the hand and the environment

The regenerator was the key element invented by Robert Stirling and his presence or absence makes the distinction between the true Stirling engine and another hot air car. On the basis of this, many engines that do not have a low-reserve visible regenerator can be categorized as Stirling engines in the sense that in the beta versions and the non-segmental discharge piston range, it and the cylinder surface make a regular heat exchange with the gas providing some recovery effect. This solution is often found in small models and LTD models where

extra flow and unused volumes may be counterproductive and the lack of regenerator may be the optimal option (Petrescu and Petrescu, 2012a).

In a Stirling engine, the regenerator holds within the thermodynamic system a portion of the thermal energy at an intermediate temperature that would otherwise be changed to the environment, which will help bring the engine efficiency closer to that of the Carnot cycle by working between maximum and minimum temperatures.

The regenerator is a kind of heat exchanger in which the working fluid changes its flow direction periodically - not to be confused with a countercurrent heat exchanger in which two separate streams of fluid circulate in opposite directions on one side and the other Dividing Wall.

The purpose of the regenerator is to significantly increase efficiency by "recycling" the thermal energy in the cycle to reduce the heat fluxes in the two heat exchangers, often allowing the engine to provide more power with the same heat exchangers.

The regenerator is typically made up of an amount of metallic wires, preferably of low porosity to reduce unused space, with the axis placed perpendicular to the direction of the gas flow, forming a nipple filling. The regenerator is located in the gas circuit between the two heat exchangers. During the transfer of gas between the hot and the cold heat exchanger, 90% of

its thermal energy is temporarily transferred to or recovered from the regenerator.

The regenerator mainly recycles unused heat, which reduces heat flows transmitted by the two heat exchangers (Petrescu and Petrescu, 2012a).

There is a need to give up some advantages in favor of others, especially in high-power (high-power and cylinder) motors (HTD engines), so the regenerator will need to be carefully designed to achieve high heat transfer at low losses due to hydrodynamic resistances and an unused space as small as possible. As with hot and cold heat exchangers, achieving a performance regenerator is an optimization problem between the three above-mentioned requirements.

The ideal Stirling cycle (Fig. 15) is a thermodynamic cycle with two isochoric and two isotherms. It is the most efficient thermodynamic cycle that is practically known to date, its theoretical efficiency equaling the hypothetical of a Carnot (ideal) cycle. However, the technical problems that appear to reduce the efficiency in its realization (the practical) - the construction of a simpler mechanism is more advantageous compared to the possibility of realizing a cycle as close as possible to the theoretical one (Petrescu and Petrescu, 2012a).

The working gas undergoes a series of successive dilations and compressions, consisting of two isothermal transformations and two isochoric transformations.

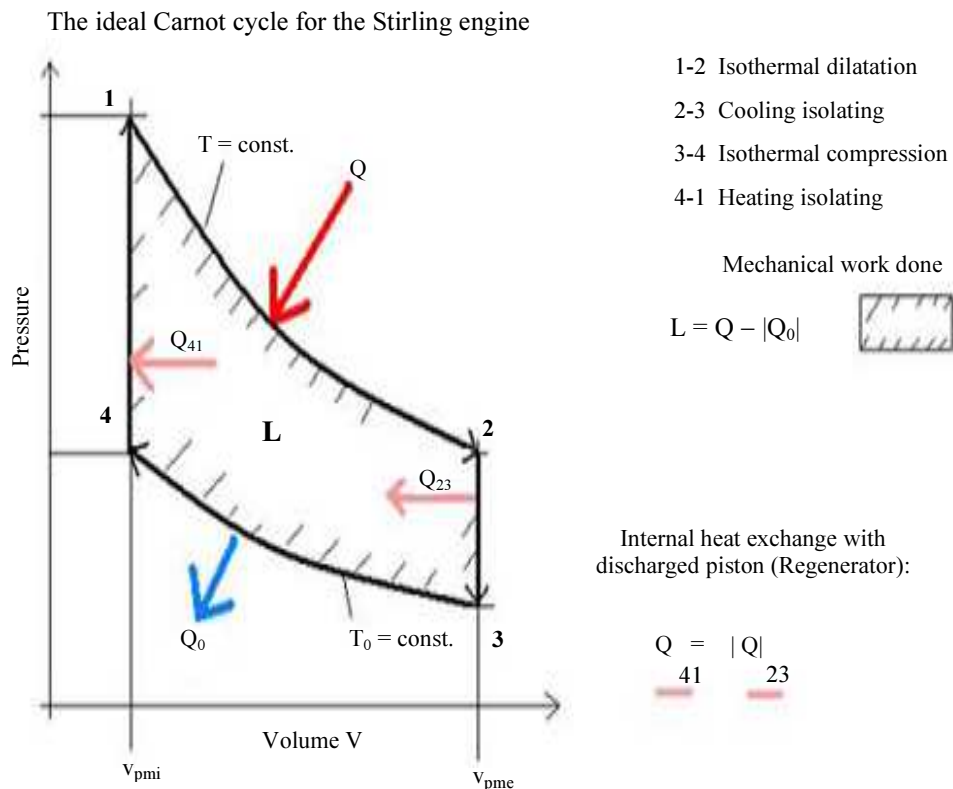


Fig. 15: The ideal stirling cycle

Time 1: 1-2 on the graph is an isothermal (constant temperature) degradation during which the gas performs mechanical work on the environment. The heat absorbed Q and the L12 mechanical work are linked by formula (I) (Petrescu and Petrescu, 2012a):

$$Q_{12} = L_{12} = n \cdot R \cdot T \cdot \ln \frac{V_2}{V_1} \quad (I)$$

Time 2: 2-3 on the graph is an isochoric cooling (at constant volume) during which the gas is brought to its initial state by heat transfer to the regenerator. The cured heat is determined by the formula (II):

$$Q_{23} = n \cdot C_v \cdot (T - T_0) \quad (II)$$

Time 3: 3-4 on the graph is an isothermal compression (it is constantly constant at constant temperature), where the mechanical work required to modify the volume L34 is equal to the cured heat, Q_0 (relation III):

$$Q_0 \equiv Q_{34} = L_{34} = n \cdot R \cdot T \cdot \ln \frac{V_3}{V_4} \quad (III)$$

Time 4: 4-1 on the graph is an isocorous heating (takes place at constant volume) during which the heat absorbed by the regenerator during the regenerator is ceded to the gas (relation IV), its value being:

$$Q_{41} = n \cdot C_v \cdot (T - T_0) \quad (IV)$$

The useful mechanical work appears in the pV diagram of Fig. 15, it being the area or area closed by the cycle curve, whereas in a Ts (entropy-temperature) diagram it would appear as a result of the difference between the absorbed and the calorific energy, being the one that produces the useful power W_t , (relationship V):

$$\begin{cases} Q = Q_0 + L \\ L = Q_{abs} - Q_{ced} = Q - Q_0 \end{cases} \quad (V)$$

Using the formulas above for Q and Q_0 , the useful mechanical work takes the form of VI:

$$\begin{cases} L = n \cdot R \cdot T \cdot \ln \left(\frac{V_2}{V_1} \right) - n \cdot R \cdot T \cdot \ln \left(\frac{V_3}{V_4} \right) \\ \Rightarrow L = n \cdot R \cdot \left(T \cdot \ln \left(\frac{V_2}{V_1} \right) - T_0 \cdot \ln \left(\frac{V_3}{V_4} \right) \right) \\ \frac{V_2}{V_1} = \frac{V_3}{V_4} = \frac{V_{pme}}{V_{pmi}} \Rightarrow \\ L = n \cdot R \cdot \ln \left(\frac{V_{pme}}{V_{pmi}} \right) \cdot (T - T_0) \end{cases} \quad (VI)$$

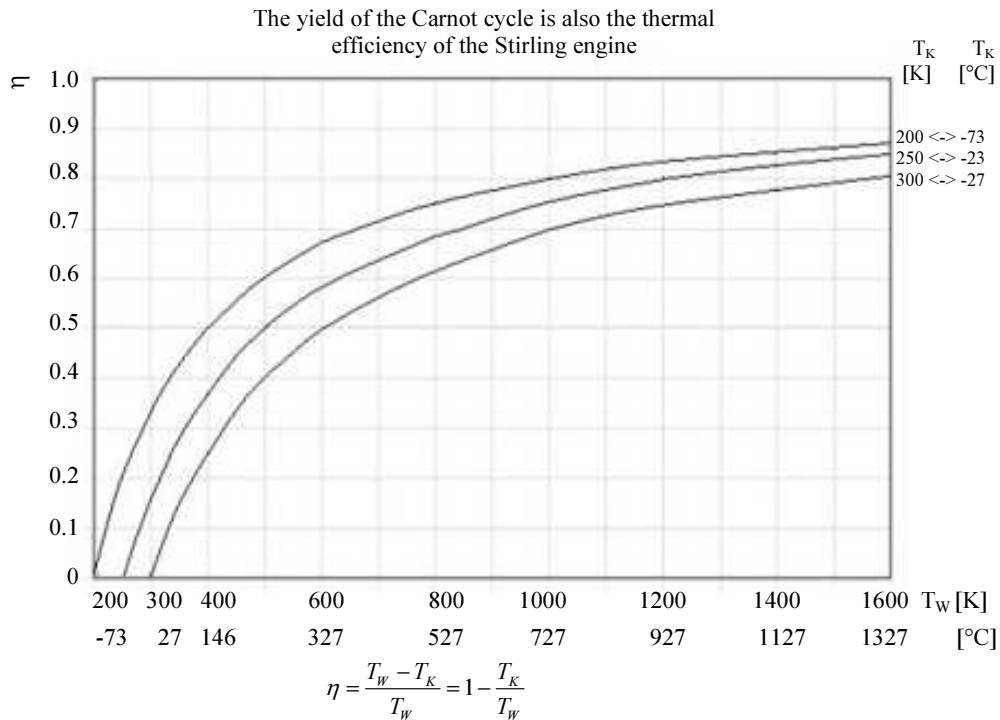


Fig. 16: The yield of the Carnot cycle is also the thermal efficiency of the Stirling engine

The weakly stated point of the Stirling engines is the energy cycle yield (Carnot cycle yield). In principle, the Stirling engines can not achieve a high Carnot yield (Fig. 16), because the maximum working temperature is limited by the hot source temperature. In practice, the working gas cannot be heated above 800 [°K] (527 [°C]). At these low temperature differences the Carnot yield is about 66% and is thus much lower than that of the internal combustion engines. Internal combustion engines frequently reach temperatures of 727 [°C] (1000 [°K]), for which Carnot's energy efficiency is about 76%.

This problem also occurs in thermal power stations equipped with steam generating turbines that reach 66% of their Carnot yield, resulting in an effective efficiency of just over 40%. The current Stirling engines reach 50-60% of their Carnot yield and work with a correspondingly lower effective efficiency.

We aim to bring some improvements to the Stirling engine from a mechanical point of view, improvements that will also affect its thermal performance, so these improvements can create a new Stirling engine that works with a superior mechanical efficiency (Petrescu and Petrescu, 2012a).

Improvements of the proposed mechanical nature will be presented in the Results section.

Results

Determination of Mechanical Efficiency in Piston-Rod-Crank System

The piston crank shaft has many uses, being used mainly in two main ways, as a motor or compressor. In four-stroke internal combustion engines, the piston crank shaft mechanism is a single-stroke engine of the total of four (Grunwald, 1980). In the other three times, the mechanism behaves like a compressor, receiving the power (being driven) from the crank (crankshaft) and pushing the piston (in the two compression or discharge times) or pulling it (at the intake). Practically, the four-stroke engine power cycle is completed in two complete kinematic cycles (Petrescu and Petrescu, 2012a).

The efficiency of the motor mechanism (driven by piston power) differs from that of the compressor mechanism (driven by the crankcase) (Grunwald, 1980; Hargreaves, 1991; Hometescu, 2003; Martini, 1978; Petrescu and Petrescu, 2014a; 2014b; 2014c; 2012a; 2005a; 2005b; 2003; Petrescu, 2012).

For this reason, the two distinct cases will be studied separately:

- A. When the mechanism works in the engine mode, being driven by the piston
- B. When the mechanism works in the compressor (or pump) mode, it is driven by the crankshaft

Figure 17 shows the kinematic diagram of the piston crank shaft mechanism. The constructive parameters of the mechanism are: r , the crank radius (or the distance from the spindle spindle axis to the spindle spindle axis); l , spike length (distance from spindle spindle axis to spindle pin spindle); e , the eccentricity (distance from the spindle spindle axis to the piston guide axis). The mechanism is positioned by the angle, j , which represents the angle of rotation and positioning of the crank. White is positioned at one of the two angles, α or γ (Fig. 17). The distance from the center of rotation of the crank O to the center of the piston bolt B, projected on the translation axis of the piston, is marked with the variable y_B (Petrescu and Petrescu, 2012a).

We design the vector equation of the contour of the mechanism on two rectangular planar axes Ox and Oy and obtain the two scalar positions of the mechanism given by the position system 1 (Fig. 17):

$$\begin{cases} r \cdot \cos \varphi + l \cdot \cos \psi = -e \\ r \cdot \sin \varphi + l \cdot \sin \psi = y_B \end{cases} \quad (1)$$

It is customary to solve the disconnected position system (1), from the first relation of the system to the y-axis cosine (according to relation 2) and the second one to isolate the displacement s of the piston (according to relation 3):

$$\cos \psi = -\frac{e + r \cdot \cos \varphi}{l} \quad (2)$$

$$s = y_B = r \cdot \sin \varphi + l \cdot \sin \psi \quad (3)$$

By deriving the position system (1), the speed system (4) is obtained:

$$\begin{cases} -r \cdot \dot{\varphi} \cdot \sin \varphi - l \cdot \dot{\psi} \cdot \sin \psi = 0 \\ r \cdot \dot{\varphi} \cdot \cos \varphi + l \cdot \dot{\psi} \cdot \cos \psi = \dot{y}_B \end{cases} \quad (4)$$

From the first relation of the system (4) the angular velocity (according to relation 5) is calculated and the linear velocity of the piston (relation 6) is determined from the second velocity (4) equation:

$$\dot{\psi} = -\frac{r \cdot \sin \varphi}{l \cdot \sin \psi} \cdot \dot{\varphi} \quad (5)$$

$$\dot{y}_B = r \cdot \dot{\varphi} \cdot \cos \varphi + l \cdot \dot{\psi} \cdot \cos \psi \quad (6)$$

The velocity system (4) is also derived in order to obtain the acceleration system (7):

$$\begin{cases} -r \cdot \ddot{\varphi} \cdot \cos \varphi - l \cdot \ddot{\psi} \cdot \cos \psi - l \cdot \dot{\psi}^2 \cdot \sin \psi = 0 \\ -r \cdot \ddot{\varphi} \cdot \sin \varphi - l \cdot \ddot{\psi} \cdot \sin \psi - l \cdot \dot{\psi}^2 \cdot \cos \psi = \ddot{y}_B \end{cases} \quad (7)$$

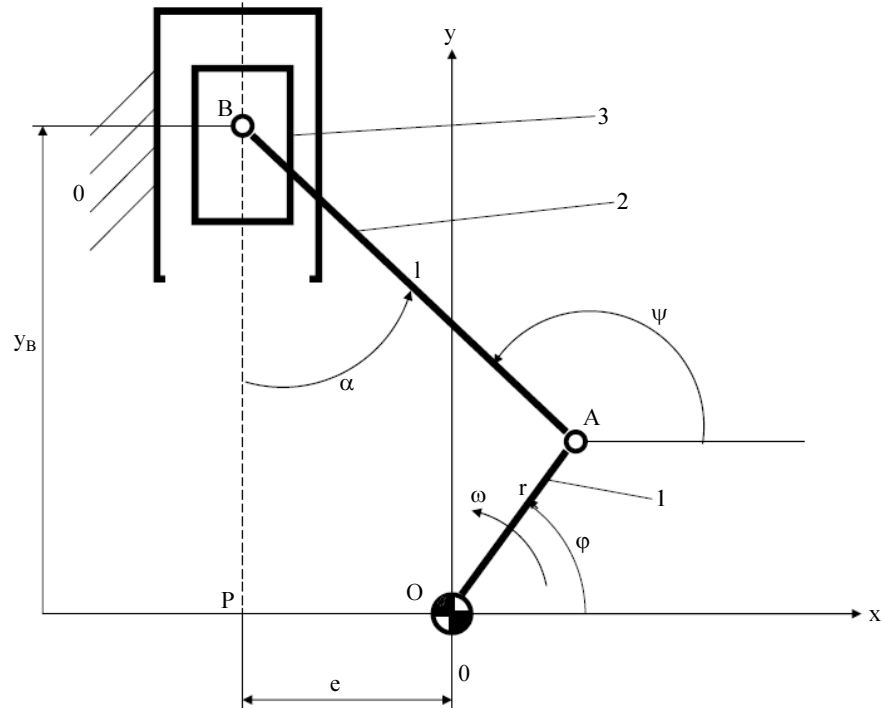


Fig. 17: The kinematic scheme of the piston crankshaft mechanism

From the first equation of the system (7) the angular acceleration $\ddot{\psi}$ (according to relation 8) is calculated and from the second equation of the system (7) the linear acceleration of the piston \ddot{y}_B , (relation 9) is determined:

$$\ddot{\psi} = -\frac{r \cdot \dot{\varphi}^2 \cdot \cos \varphi + l \cdot \dot{\psi}^2 \cdot \cos \psi}{l \cdot \sin \psi} \quad (8)$$

$$\ddot{y}_B = l \cdot \ddot{\psi} \cdot \cos \psi - r \cdot \dot{\varphi}^2 \cdot \sin \varphi - l \cdot \dot{\psi}^2 \cdot \sin \psi \quad (9)$$

Angle α is expressed according to the angle ψ , according to the expression (10):

$$\alpha = \psi - 90 \quad (10)$$

The links between the basic trigonometric functions of these angles are expressed by system relations (11):

$$\begin{cases} \cos \alpha = \sin \psi \\ \sin \alpha = -\cos \psi \end{cases} \quad (11)$$

The sinus of the angle α , $\sin \alpha$ is expressed by the relationship (2) and the second equality in the system (11), obtaining the relation of the form (12):

$$\sin \alpha = \frac{e + r \cdot \cos \varphi}{l} \quad (12)$$

The speed of the piston takes shape (13) (Petrescu and Petrescu, 2012a):

$$\begin{cases} v_B = \dot{y}_B = r \cdot \dot{\varphi} \cdot \cos \varphi + l \cdot \dot{\psi} \cdot \cos \psi \\ = r \cdot \dot{\varphi} \cdot \cos \varphi - \frac{r \cdot \dot{\varphi} \cdot \sin \varphi \cdot \cos \psi}{\sin \psi} \\ = \frac{r \cdot \dot{\varphi}}{\sin \psi} \cdot (\cos \varphi \cdot \sin \psi - \sin \varphi \cdot \cos \psi) \\ = r \cdot \dot{\varphi} \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} = r \cdot \omega \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} \\ v_B = r \cdot \omega \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} \end{cases} \quad (13)$$

The piston crank shaft mechanism works in the engine mode for a single time in the four (or two) times of the power cycle of the four-stroke Otto or Diesel engine (or two-stroke engines respectively type Stirling).

The engine time has a corresponding crank movement of about 180 degrees (about π radians) when the piston moves from the dead point to the distant dead point (i.e., when the piston moves between its two extreme positions, but necessarily from the minimum volume to the maximum working volume of the respective cylinder – Fig. 18), the crank from position a (in extension to white) and reaching position b (overlaid over white); this is the driving time of the energy cycle.

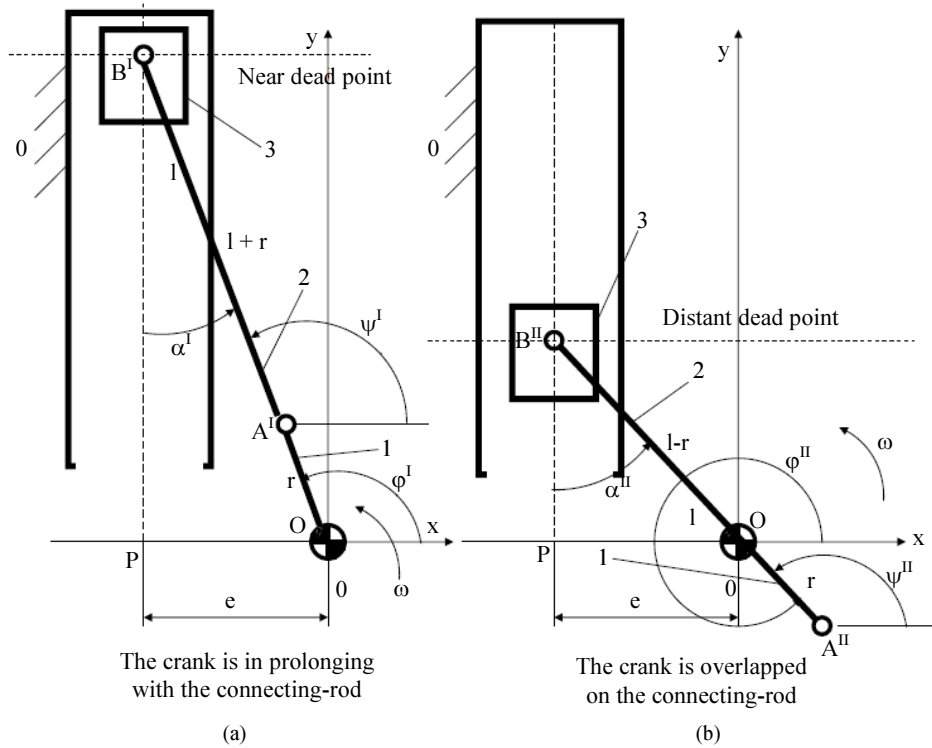


Fig. 18: Kinematic schemes of the engine mechanism in extreme positions (a) When the crank is in the extension of the bar (b) When the crank overlaps over the bar

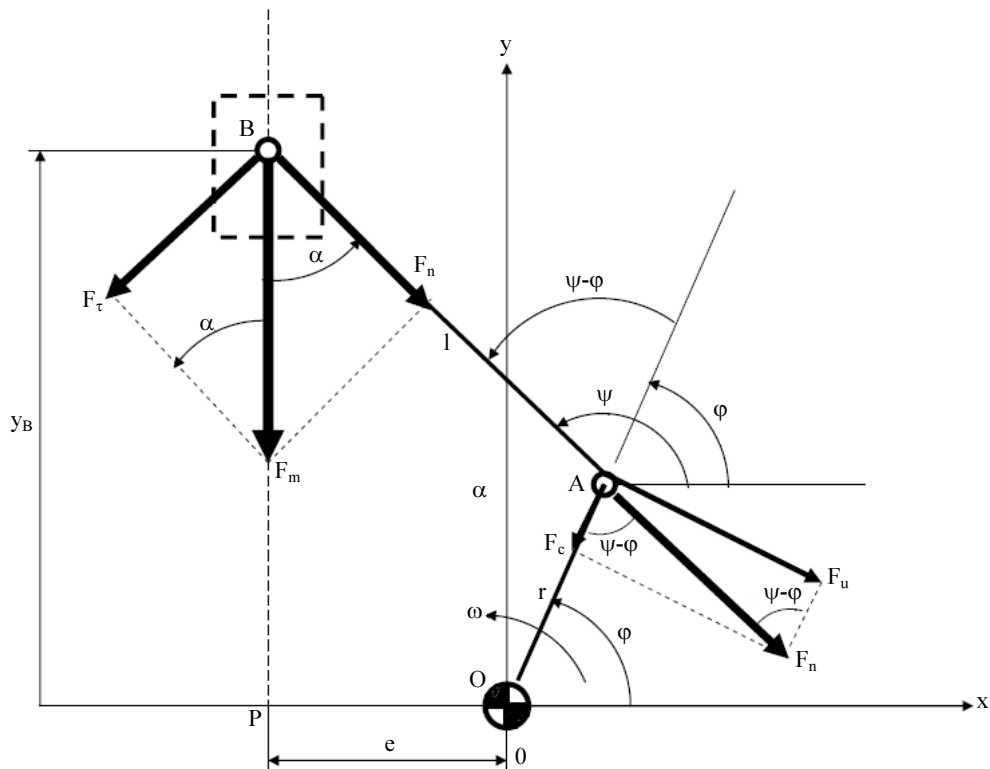


Fig. 19: The forces in the piston crank mechanism, when the power (the driving force) is transmitted from the piston to the crank

For Otto or Diesel engines, the energy cycle contains two kinematic cycles (the big disadvantage of these engines), while the Lenoir, Stirling, Wankel, Atkinson engines overlap with the kinematic (the big advantage of these engines).

To determine the efficiency of the piston crank shaft mechanism when working as a motor, it is necessary to determine the force distribution in the mechanism going from the piston to the crank (Fig. 19).

The engine power, consumed (input force) F_m , is divided into two components: (1) F_n - normal force (oriented along the rod); (2) F_τ - tangential force (perpendicular to B, per bar); see system (14); (Fig. 18 ω is negative, the crank being printed with an hourly rotation):

$$\begin{cases} F_n = F_m \cdot \cos \alpha = F_m \cdot \sin \psi \\ F_\tau = F_m \cdot \sin \alpha = -F_m \cdot \cos \psi \end{cases} \quad (14)$$

F_n is the only force transmitted through the bead (along it) from B to A (because the bar has its characteristic, general, rotary, roto-translational movement, having no direct link to the bead; when the bar has a connection, a coupling to the fixed element, it turns from the bar to the rocker and it can only transmit moment, the third possible case is that of a bar that slides in a cylinder that also has a rotation lock with the bar, there is a multiple rotation and translation coupling, in which case the bar will have a movement of the rod passing through it along a force, but there will also be a rotation movement around the coupling with the beam thus transmitting momentum).

In A, the force F_n is also divided into two components: 1. F_u - the force that is perpendicular to the crank; and 2. F_c - compressive or tensile force acting along the crank. See system (15):

$$\begin{cases} F_u = F_n \cdot \sin(\psi - \varphi) = F_m \cdot \sin \psi \cdot \sin(\psi - \varphi) \\ F_c = F_n \cdot \cos(\psi - \varphi) = F_m \cdot \sin \psi \cdot \cos(\psi - \varphi) \end{cases} \quad (15)$$

The useful power P_u can be written as (16):

$$\begin{aligned} P_u &= F_u \cdot v_A = F_u \cdot r \cdot \omega \\ &= F_m \cdot r \cdot \omega \cdot \sin \psi \cdot \sin(\psi - \varphi) \end{aligned} \quad (16)$$

The power consumed by P_c takes the form of the expression (17):

$$P_c = F_m \cdot v_B = F_m \cdot r \cdot \omega \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} \quad (17)$$

The instantaneous η_i mechanical yield can be expressed using the relation (18):

$$\begin{cases} \eta_i = \frac{P_u}{P_c} = \frac{F_m \cdot r \cdot \omega \cdot \sin \psi \cdot \sin(\psi - \varphi)}{F_m \cdot r \cdot \omega \cdot \sin(\psi - \varphi) \cdot \frac{1}{\sin \psi}} \\ = \sin^2 \psi = \cos^2 \alpha = 1 - \frac{(e + r \cdot \cos \varphi)^2}{l^2} \end{cases} \quad (18)$$

In order to calculate the mechanical efficiency η , the expression of the instantaneous efficiency η_i from the near dead point to the distant dead point, from φ^I to φ^{II} (Fig. 19, system 19) can be integrated:

$$\begin{cases} \varphi^I \equiv \varphi_i = \pi - a \cos\left(\frac{e}{l+r}\right) \\ \varphi^{II} \equiv \varphi_f = 2 \cdot \pi - a \cos\left(\frac{e}{l-r}\right) \end{cases} \quad (19)$$

It is possible to determine more easily the mechanical efficiency starting from the system (18) but not using the variable φ with the limits given by (19), but the variable α , when the extreme values of the angle α , α_M and α_m are known (or can be determined) (relations 20-22).

The misalignment e reduces yield, so it will take $e = 0$.

A ratio $r/l = \lambda$ can be adopted so small that a convenient yield is achieved at the engine mechanism. As typically λ is constructively chosen less than 0.3, the mechanical efficiency of the engine mechanism (the piston crank engine during engine) is more than 96%, provided that the deaeration is zero. The piston crank shaft mechanism, when working in the engine, has a very good mechanical (very high) efficiency:

$$\begin{cases} \eta = \frac{1}{\Delta \alpha} \cdot \int_{\alpha_m}^{\alpha_M} \eta_i \cdot d\alpha = \frac{1}{\Delta \alpha} \int_{\alpha_m}^{\alpha_M} \cos^2 \alpha \cdot d\alpha \\ = \frac{1}{\Delta \alpha} \int_{\alpha_m}^{\alpha_M} \frac{\cos(2 \cdot \alpha) + 1}{2} \cdot d\alpha \\ = \frac{1}{2 \cdot \Delta \alpha} \int_{\alpha_m}^{\alpha_M} (\cos(2\alpha) + 1) \cdot d\alpha \\ = \frac{1}{2 \cdot \Delta \alpha} \cdot \left[\frac{1}{2} \cdot \sin(2 \cdot \alpha) + \alpha \right]_{\alpha_m}^{\alpha_M} \\ = \frac{1}{2 \cdot \Delta \alpha} \left[\frac{\sin(2\alpha_M) - \sin(2\alpha_m)}{2} + \Delta \alpha \right] \\ = \frac{\sin(2 \cdot \alpha_M) - \sin(2 \cdot \alpha_m)}{4 \cdot \Delta \alpha} + 0.5 \\ = \frac{\sin(2 \cdot \alpha_M) - \sin(2 \cdot \alpha_m)}{4 \cdot (\alpha_M - \alpha_m)} + 0.5 \\ = 0.5 + \frac{\sin \alpha_M \cos \alpha_M - \sin \alpha_m \cos \alpha_m}{2 \cdot (\alpha_M - \alpha_m)} \end{cases} \quad (20)$$

$$\begin{cases} \text{For } l > r + e \Rightarrow \alpha_M = \arcsin\left(\frac{r + e}{l}\right) \\ \text{For } r > e \Rightarrow \alpha_m = 0 \end{cases} \quad (21)$$

$$\begin{cases} \text{For } \lambda \leq 0,1(6) \Rightarrow \eta \geq 0,99 \equiv 99\%; \\ \text{For } \lambda = 0,(3) \Rightarrow 0,962 \equiv 96,2\%; \\ \text{For } \lambda = 0,5 \Rightarrow \eta = 0,913 \equiv 91,3\% \end{cases} \quad (22)$$

The piston crank shaft mechanism (system) works as a motor mechanism (with piston actuation), as we have shown in one time, a single stroke within an energy cycle, the other one or three times being working times in the regimen crank (with crank drive - from crankshaft).

On two-stroke cylinders (cylinders), one of the times is the engine and at the other time the engine is driven from the crank. Four-stroke engine cylinders except for the Stirling have one engine time out of the four, all three other with crank drive, which greatly reduces the efficiency of these engines because the mechanical efficiency of crank drive is about two times lower than that of an actual engine time, as will be seen immediately.

In this respect, the four-stroke four-stroke engine type Stirling is the most advantageous, being driven

continuously from the piston (thus always having a maximum drive motor drive).

For this reason, it has a stranger load feature, which is said to be inappropriate for car use (the more crankshaft driven crankshaft, although having less mechanical efficiency, have a much longer stable and respond quickly to changes in the working regimes required by a vehicle, especially due to the large inertial help of the shaft, plus the steering wheel, which are more "nerve-wise" and therefore more dynamic).

This can, however, be easily corrected in Stirling engines by using multiple cylinders simultaneously, trapped on the same shaft (multi-cylinder Stirling), the shaft having a high inertia, which can be further enhanced by -a wheel.

Even though the cylinders work most of the time in motor regimes, they are permanently connected to the output shaft which must have a very high inertia in construction, the movement at the output of the motor being picked from the shaft.

Further, the piston rod crank system, if it is driven from the crank (from the crankshaft, Fig. 20), will be studied.

We determine the distribution of forces and on the basis of them and the known speeds we will already be able to calculate the powers and the mechanical efficiency of the system.

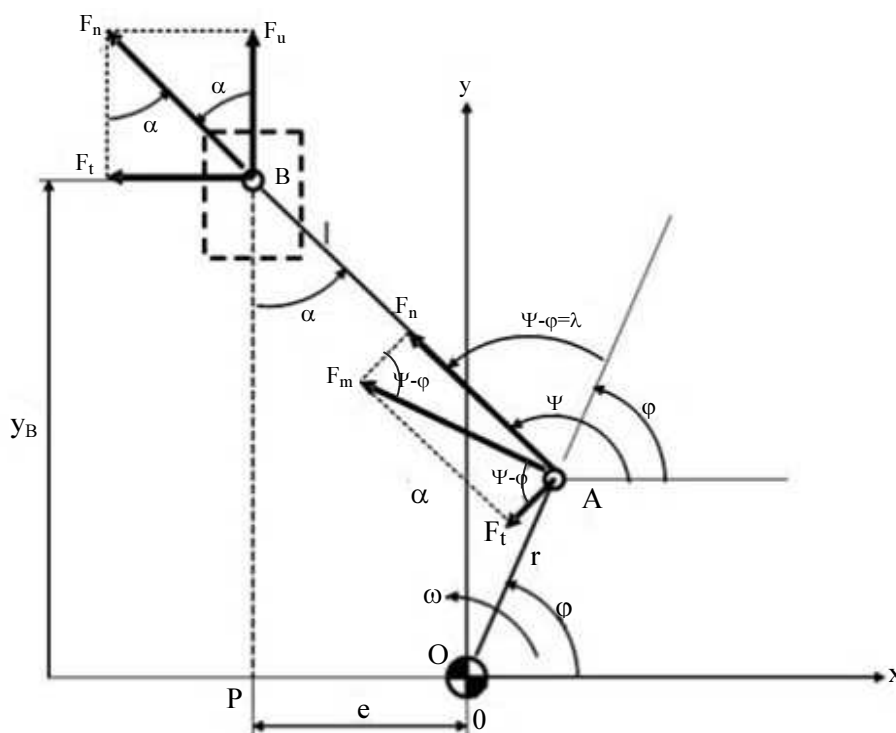


Fig. 20: The forces in a piston crankshaft, when it is driven from the crank

The input force, the driving force (consumed motor force), F_m , perpendicular to A on the crank OA (r), is divided into two components: 1. F_n - the normal force representing the active component, the only component transmitted from the coupling A to Coupling B through the bead (where forces are transmitted only along it); 2. F_τ - tangential force, which, although not transmitted by the bead, can rotate and deform it elastically at the same time (bending); the equations to determine the two components are given by the system (23):

$$\begin{cases} F_n = F_m \cdot \sin(\psi - \varphi) \\ F_\tau = F_m \cdot \cos(\psi - \varphi) \end{cases} \quad (23)$$

In Coupling B, the transmitted F_n force is divided into two components: 1. F_u - force; 2. F_r - a normal force on the guide axis (the axis of the guide); see the equation system (24):

$$\begin{cases} F_u = F_n \cdot \cos \alpha = F_n \cdot \sin \psi = F_m \cdot \sin(\psi - \varphi) \cdot \sin \psi \\ F_r = F_n \cdot \sin \alpha = -F_n \cdot \cos \psi = -F_m \cdot \sin(\psi - \varphi) \cdot \cos \psi \end{cases} \quad (24)$$

The useful power can be written in the form (25) and the one consumed takes shape (26):

$$\begin{aligned} P_u &= F_u \cdot v_B = F_m \cdot \sin(\psi - \varphi) \cdot \sin \psi \cdot \frac{r\omega \sin(\psi - \varphi)}{\sin \psi} \\ &= F_m \cdot r \cdot \omega \cdot \sin^2(\psi - \varphi) \end{aligned} \quad (25)$$

$$P_c = F_m \cdot v_A = F_m \cdot r \cdot \omega \quad (26)$$

The instantaneous mechanical efficiency of the crank-shaft crankshaft driven by the crank can be determined by the relationship (27):

$$\begin{aligned} \eta_i &= \frac{P_u}{P_c} = \frac{F_m \cdot r \cdot \omega \cdot \sin^2(\psi - \varphi)}{F_m \cdot r \cdot \omega} = \sin^2(\psi - \varphi) \\ &= \frac{\left[\sqrt{l^2 - (e + r \cdot \cos \varphi)^2} \cdot \cos \varphi + (e + r \cdot \cos \varphi) \cdot \sin \varphi \right]^2}{l^2} \end{aligned} \quad (27)$$

In order to determine the mechanical efficiency of the crankshaft system, it would be difficult to integrate the middle expression of the system (27) when the integration variable is the angle φ (integration being possible only by approximate methods, which would not allow for a final expression).

Using the angles ψ and φ as the variable, the integrated relationship (the first part of the system 27) is simplified. But it is even easier to integrate the relation (27) from the bottom when we have a single variable, λ (relation 28):

$$\begin{aligned} \eta &= \frac{1}{\Delta \lambda} \cdot \int_{\lambda_m}^{\lambda_M} \eta_i \cdot d\lambda = \frac{1}{\Delta \lambda} \int_{\lambda_m}^{\lambda_M} \sin^2 \lambda \cdot d\lambda \\ &= \frac{1}{\Delta \lambda} \int_{\lambda_m}^{\lambda_M} \frac{1 - \cos(2 \cdot \lambda)}{2} \cdot d\lambda = \frac{1}{2 \cdot \Delta \lambda} \int_{\lambda_m}^{\lambda_M} (1 - \cos(2 \cdot \lambda)) \cdot d\lambda \\ &= \frac{1}{2 \cdot \Delta \lambda} \cdot \left[\lambda - \frac{1}{2} \cdot \sin(2 \cdot \lambda) \right]_{\lambda_m}^{\lambda_M} \\ &= \frac{1}{2 \cdot \Delta \lambda} \left[\Delta \lambda - \frac{\sin(2 \lambda_M) - \sin(2 \lambda_m)}{2} \right] \\ &= \frac{1}{2} \cdot \frac{\sin(2 \cdot \lambda_M) - \sin(2 \cdot \lambda_m)}{4 \cdot \Delta \lambda} \\ &= 0,5 \cdot \frac{\sin(2 \cdot \lambda_M) - \sin(2 \cdot \lambda_m)}{4 \cdot (\lambda_M - \lambda_m)} \\ &= 0,5 \cdot \frac{\sin \lambda_M \cdot \cos \lambda_M - \sin \lambda_m \cdot \cos \lambda_m}{2 \cdot (\lambda_M - \lambda_m)} \end{aligned} \quad (28)$$

As it results from the final relations (28), the mechanical efficiency of the crankcase crankshaft driven by the crankshaft (motor shaft) cannot exceed the maximum value of 50%.

So, at optimal design, the efficiency of the crank shaft crankshaft piston system is approaching 100% and that of the crankshaft (the motor shaft) is below 50%, it follows that the best cylinder system is the one that is permanently driven from the piston, i.e. the Stirling engine.

In a stirring engine, the mechanical efficiency over the entire energy cycle (which coincides with the kinematic cycle) is about 80-99.9% depending on the design mode. The thermal yield (of the Carnot cycle) for optimal high temperature operation (as seen in the first chapter) reaches 55-65%.

It results that the total (final) yield of a well-designed Stirling, with a hot source of high temperatures, reaches between 44% and 65%, which means a lot. No other thermal engine reaches such values.

Because some say that Stirling has lower returns than Otto or Diesel and others, on the contrary, that Stirling's performance is its strong point, we need to make a more detailed discussion at this point. What benefit does Otto and Diesel achieve at a heat output of 65-75% compared to only 55-65% in the Stirling engines, if the final output of an engine is the product of its thermal and mechanical efficiency and in terms of mechanical efficiency a Stirling in a four-stroke, well-designed, can achieve theoretically 99.999% (i.e., almost 100%), while a four-stroke Diesel or Otto will practically achieve a mechanical efficiency of no more than 56% (3*45%+90%): 4] so that the total (final) output of an Otto or Diesel will be only about 39% (56*70), well below the maximum of a Stirling, 65%.

Let's recall that for a long time the Otto or Diesel engines were running at a final yield of only 12-20% and with a high weight they reached the final yields of 25-30%, while the Stirling engines reached 50-65%?

However, engines in V are able to achieve higher overall yields. With a mechanical efficiency of about 70% and a maximum thermal level of 75%, an Otto or Diesel engine in V can achieve a final yield of about 52- 53%.

Constructively, a piston cylinder version with the piston stroke as small as possible and the largest bore should be adopted.

Dynamic Kinematic of the Rod Piston Crank System

The cinematic of the piston crankshaft mechanism of Fig. 21 is generally known to be solved by the relationships (A1-A13):

$$\begin{cases} r \cdot \cos \varphi + l \cdot \cos \psi = -e \\ r \cdot \sin \varphi + l \cdot \sin \psi = y_B \end{cases} \quad (A1)$$

$$\cos \psi = -\frac{e + r \cdot \cos \varphi}{l} \quad (A2)$$

$$s = y_B = r \cdot \sin \varphi + l \sin \psi \quad (A3)$$

$$\begin{cases} -r \cdot \dot{\varphi} \cdot \sin \varphi - l \cdot \dot{\psi} \cdot \sin \psi = 0 \\ r \cdot \dot{\varphi} \cdot \cos \varphi + l \cdot \dot{\psi} \cdot \cos \psi = \dot{y}_B \end{cases} \quad (A4)$$

$$\dot{\psi} = -\frac{r \cdot \sin \varphi}{l \cdot \sin \psi} \cdot \dot{\varphi} \quad (A5)$$

$$\dot{y}_B = r \cdot \dot{\varphi} \cdot \cos \varphi + l \cdot \dot{\psi} \cdot \cos \psi \quad (A6)$$

$$\begin{cases} -r \cdot \dot{\varphi}^2 \cdot \cos \varphi - l \cdot \dot{\psi}^2 \cdot \cos \psi - l \cdot \ddot{\psi} \cdot \sin \psi = 0 \\ -r \cdot \dot{\varphi}^2 \cdot \sin \varphi - l \cdot \dot{\psi}^2 \cdot \sin \psi + l \cdot \ddot{\psi} \cdot \cos \psi = \ddot{y}_B \end{cases} \quad (A7)$$

$$\ddot{\psi} = -\frac{r \cdot \dot{\varphi}^2 \cdot \cos \varphi + l \cdot \dot{\psi}^2 \cdot \cos \psi}{l \cdot \sin \psi} \quad (A8)$$

$$\ddot{y}_B = l \cdot \ddot{\psi} \cdot \cos \psi - r \cdot \dot{\varphi}^2 \cdot \sin \varphi - l \cdot \dot{\psi}^2 \cdot \sin \psi \quad (A9)$$

$$\alpha = \psi - 90 \quad (A10)$$

$$\begin{cases} \cos \alpha = \sin \psi \\ \sin \alpha = -\cos \psi \end{cases} \quad (A11)$$

$$\sin \alpha = \frac{e + r \cdot \cos \varphi}{l} \quad (A12)$$

$$\begin{cases} v_B = \dot{y}_B = r \cdot \dot{\varphi} \cdot \cos \varphi + l \cdot \dot{\psi} \cdot \cos \psi \\ = r \cdot \dot{\varphi} \cdot \cos \varphi - \frac{r \cdot \dot{\varphi} \cdot \sin \varphi \cdot \cos \psi}{\sin \psi} \\ = \frac{r \cdot \dot{\varphi}}{\sin \psi} \cdot (\cos \varphi \cdot \sin \psi - \sin \varphi \cdot \cos \psi) \\ = r \cdot \dot{\varphi} \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} = r \cdot \omega \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} \\ v_B = r \cdot \omega \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} \end{cases} \quad (A13)$$

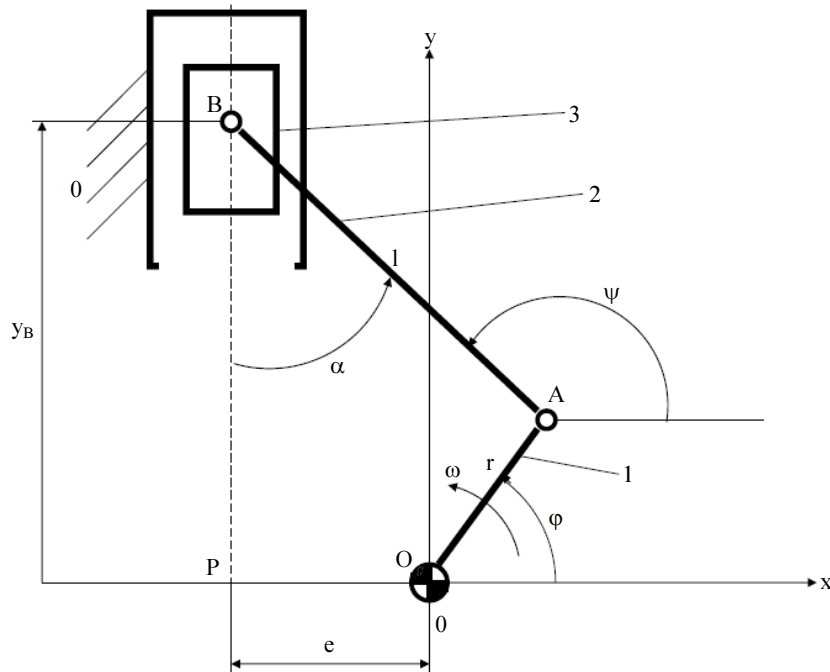


Fig. 21: The kinematic scheme of the piston crankshaft mechanism

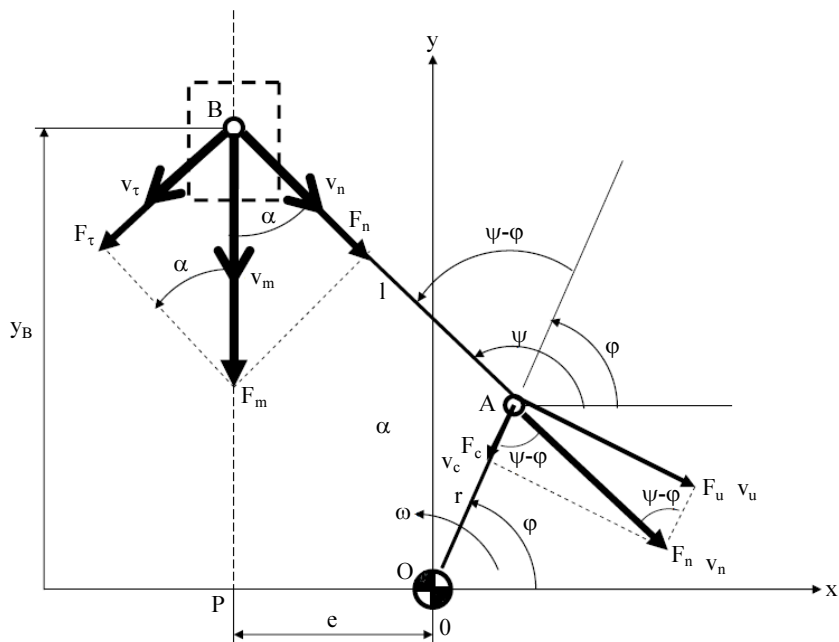


Fig. 22: Dynamic forces and speeds in the piston crank shaft mechanism, when power is transmitted from the piston to the crank

In Dynamic Cinematic, the (dynamic) velocities are aligned in the direction of the forces as is natural, so that they no longer coincide with the kinematic speeds imposed by the couplings of the mechanism (Fig. 22). Dynamic speeds due to forces occur, speeds that represent the dynamic kinematics (the influence of inertial forces, influence that determines the final dynamic aspect of speeds).

The dynamic kinematics is therefore the kinematic study of the displacements, speeds and accelerations resulting from the direction of operation of the velocities following the direction of the forces. The expressions of velocity in the dynamic kinematics are easily obtained, it is derived in relation to the time to determine the expressions of the accelerations in the dynamic kinematics and the expressions of the velocities are integrated in order to obtain the corresponding movements. Determining the movements in the dynamic cinematic becomes therefore more difficult.

To begin with, we will determine the velocities in the dynamic kinematics for piston crank shaft mechanism actuated by the piston (Fig. 22). We can write the relationships (A14-A16):

$$v_B = v_m \tag{A14}$$

$$v_n = v_m \cdot \cos \alpha = v_m \cdot \sin \psi \tag{A15}$$

$$v_u = v_n \cdot \sin(\psi - \phi) = v_m \cdot \sin \psi \cdot \sin(\psi - \phi) \tag{A16}$$

We also want to find out the dynamic performance, more precisely the mechanical efficiency instantly when

the mechanism has dynamic regimes and the speeds are those in the dynamic cinematic, the actuation of the mechanism being of the motor type, i.e., from the piston.

The useful force is determined by the relation (A17) presented in the previous chapter:

$$F_u = F_n \cdot \sin(\psi - \phi) = F_m \cdot \sin \psi \cdot \sin(\psi - \phi) \tag{A17}$$

The useful power is written in this case in form A18:

$$\begin{cases} P_u = F_u \cdot v_u \\ = F_m \cdot \sin \psi \cdot \sin(\psi - \phi) \cdot v_m \cdot \sin \psi \cdot \sin(\psi - \phi) \\ = F_m \cdot v_m \cdot \sin^2 \psi \cdot \sin^2(\psi - \phi) \end{cases} \tag{A18}$$

Expression of power consumed is given by relationship A19:

$$P_c = F_m \cdot v_m \tag{A19}$$

We can now determine the dynamic yield, more precisely the dynamic dynamic dynamics (relationship A20):

$$\eta_i^{DM} = \frac{P_u}{P_c} = \sin^2 \psi \cdot \sin^2(\psi - \phi) = \eta_i \cdot D^M \tag{A20}$$

where, η_i is the instantaneous mechanical efficiency of the crank shaft piston actuated by the piston and D^M is a dynamic coefficient, which for the piston-driven piston crank mechanism (in Motor mode) has the expression A21:

The inlet force F_m and the inlet velocity v_m decompose generating the component along the line F_n and v_n respectively. Forces are the real forces acting on the mechanism and these cinematic-dynamic velocities are the natural ones that follow the trajectories (directions) imposed by the forces. Generally, they overlap and impose over known kinematic (static) velocities, which are calculated on the basis of the links imposed by the kinematic couple of the mechanism (depending on the kinematic chain). You can write for speeds A27:

$$\begin{cases} v_B = v_A \cdot \frac{\sin(\psi - \varphi)}{\sin \psi}; v_B^D = v_B \cdot D^C = v_A \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} \cdot D^C \\ v_u = v_n \cdot \cos \alpha = v_n \cdot \sin \psi = v_m \cdot \sin \psi \cdot \sin(\psi - \varphi) \\ = v_A \cdot \sin \psi \cdot \sin(\psi - \varphi) \\ v_u = v_B^D \Rightarrow v_A \cdot \sin \psi \cdot \sin(\psi - \varphi) = v_A \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} \cdot D^C \\ \Rightarrow D^C = \sin^2 \psi \end{cases} \quad (A27)$$

For forces, powers and yields, the following relationships are written (A28-A34):

$$\begin{cases} F_n = F_m \cdot \sin(\psi - \varphi) \\ F_\tau = F_m \cdot \cos(\psi - \varphi) \end{cases} \quad (A28)$$

$$\begin{cases} F_u = F_n \cdot \cos \alpha = F_n \cdot \sin \psi = F_m \cdot \sin(\psi - \varphi) \cdot \sin \psi \\ F_r = F_n \cdot \sin \alpha = -F_n \cdot \cos \psi = -F_m \cdot \sin(\psi - \varphi) \cdot \cos \psi \end{cases} \quad (A29)$$

$$\begin{cases} P_u = F_u \cdot v_B = F_m \cdot \sin(\psi - \varphi) \cdot \sin \psi \cdot \frac{r \cdot \omega \cdot \sin(\psi - \varphi)}{\sin \psi} \\ = F_m \cdot r \cdot \omega \cdot \sin^2(\psi - \varphi) = F_m \cdot v_A \cdot \sin^2(\psi - \varphi) \end{cases} \quad (A30)$$

$$P_c = F_m \cdot v_A = F_m \cdot r \cdot \omega \quad (A31)$$

$$\eta_i = \frac{P_u}{P_c} = \frac{F_m \cdot v_A \cdot \sin^2(\psi - \varphi)}{F_m \cdot v_A} = \sin^2(\psi - \varphi) \quad (A32)$$

$$\begin{cases} P_u^D = F_u \cdot v_B^D \\ = F_m \cdot \sin(\psi - \varphi) \cdot \sin \psi \cdot v_A \cdot \sin \psi \cdot \sin(\psi - \varphi) \\ = F_m \cdot r \cdot \omega \cdot \sin^2(\psi - \varphi) \cdot \sin^2 \psi \\ = F_m \cdot v_A \cdot \sin^2(\psi - \varphi) \cdot \sin^2 \psi \end{cases} \quad (A33)$$

$$\begin{aligned} \eta_i^{DC} &= \frac{P_u^D}{P_c} = \frac{F_m \cdot v_A \cdot \sin^2 \psi \cdot \sin^2(\psi - \varphi)}{F_m \cdot v_A} \\ &= \sin^2(\psi - \varphi) \cdot \sin^2 \psi = \eta_i \cdot D^C \end{aligned} \quad (A34)$$

The first conclusion that can be drawn is that the instantaneous dynamic mechanical efficiency (which is closer to the real mechanism) is less than the ordinary mechanical mechanics, because the dynamic yield is

even the classic mechanical efficiency multiplied by the dynamic coefficient which being subunitarily results that the dynamic yield will be smaller or at most equal to the classic one.

In addition, the dynamic yield is the same for crank drive and piston engine actuation and will have the same value regardless of the drive type. The dynamic yield is practically uniform, but not all operating modes of the thermal motors are completely dynamic. This makes the Stirling engine or the two-stroke engine (Lenoir) real mechanical performance not much higher than the four-stroke Otto or Diesel engines. The higher the working speeds, the operating modes become almost completely dynamic.

Today, with high and very high working speeds, four-stroke internal combustion engines reach comparable performance to those of the Stirling engine or two-stroke engines. The more working regimes take place at higher speeds, the benefits of Stirling or Lenoir decrease.

Although the dynamic mechanical performance (closest to the real) is practically calculated with the same formula regardless of the drive type, the dynamic speeds and accelerations in the couplings differ depending on the drive mode, even for the same coupling.

Thus dynamic velocities (in the dynamic kinematics) of point B are calculated with relations A35.

Even if the output dynamically becomes uniform, the speeds and accelerations are more linear in the crank and sharper (and vibrational) drives during the piston stroke, so four-stroke internal combustion engines are more advantageous at this point view, followed by the two-stroke (Lenoir), the last being the Stirling type engines:

$$\begin{cases} \text{Case A - with action from the piston :} \\ D^M = \sin^2(\psi - \varphi); \eta_i = \sin^2 \psi; \text{regime Motor} \\ v_B^D = v_B \cdot D = v_A \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} \cdot \sin^2(\psi - \varphi) \\ = v_A \cdot \frac{\sin^3(\psi - \varphi)}{\sin \psi} \\ v_A^D = v_A \cdot D = r \cdot \omega \cdot \sin^2(\psi - \varphi) \\ \omega^D = \omega \cdot D = \omega \cdot \sin^2(\psi - \varphi) \\ \text{Case B - with action from the crank} \\ D^C = \sin^2 \psi; \eta_i = \sin^2(\psi - \varphi); \text{regime Compressor} \\ v_B^D = v_B \cdot D = v_A \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} \cdot \sin^2 \psi \\ = v_A \cdot \sin^3(\psi - \varphi) \cdot \sin \psi \\ v_A^D = v_A \cdot D = r \cdot \omega \cdot \sin^2 \psi \\ \omega^D = \omega \cdot D = \omega \cdot \sin^2 \psi \end{cases} \quad (A35)$$

Dynamic accelerations are determined with relationships A36, in which the dynamic velocity relationship (appropriately arranged) is derived to obtain dynamic acceleration expression.

$$\left\{ \begin{aligned}
 v_B^D &= v_A \cdot D \cdot \frac{\sin(\psi - \varphi)}{\sin \psi} \Rightarrow v_B^D \cdot \sin \psi = v_A \cdot D \cdot \sin(\psi - \varphi) \\
 \dot{v}_B^D \cdot \sin \psi + v_B^D \cdot \cos \psi \cdot \dot{\psi} - v_A \cdot [\dot{D} \cdot \sin(\psi - \varphi) + D \cdot \cos(\psi - \varphi) \cdot (\dot{\psi} - \dot{\varphi})] \\
 \Rightarrow \dot{v}_B^D &= \frac{v_A \cdot [\dot{D} \cdot \sin(\psi - \varphi) + D \cdot \cos(\psi - \varphi) \cdot (\dot{\psi} - \dot{\varphi})] - v_B^D \cdot \cos \psi \cdot \dot{\psi}}{\sin \psi} \\
 \Rightarrow a_B^D &= \frac{v_A}{\sin^2 \psi} \cdot [\dot{D} \cdot \sin \psi \cdot \sin(\psi - \varphi) + D \cdot \sin \psi \cdot \cos(\psi - \varphi) \cdot (\dot{\psi} - \dot{\varphi}) - D \cdot \cos \psi \cdot \sin(\psi - \varphi) \cdot \dot{\psi}] \\
 &= \frac{v_A}{\sin^2 \psi} \cdot [\dot{D} \cdot \sin \psi \cdot \sin(\psi - \varphi) + D \cdot \dot{\psi} \cdot \sin \varphi - D \cdot \dot{\varphi} \cdot \sin \psi \cdot (\psi - \varphi)]
 \end{aligned} \right. \quad (A36)$$

Case A – with action from the piston :

$$D^M = \sin^2(\psi - \varphi); \dot{D}^M = 2 \cdot \sin(\psi - \varphi) \cdot \cos(\psi - \varphi) \cdot (\dot{\psi} - \dot{\varphi})$$

Case B – with action from the crank

$$D^C = \sin^2 \psi; \dot{D}^C = 2 \cdot \sin \psi \cdot \cos \psi \cdot \dot{\psi}$$

Case C – can obtains the normal acceleration with :

$$D = 1; \dot{D} = 0.$$

Through a calculation program, dynamic velocities and accelerations are determined for different types of thermal motors using relations (A35) and (A36).

Figures 24 and 25 are the two-stroke diagrams (Lenoir) in Fig. 24 being the dynamic speeds and in Fig. 25 the dynamic accelerations can be observed.

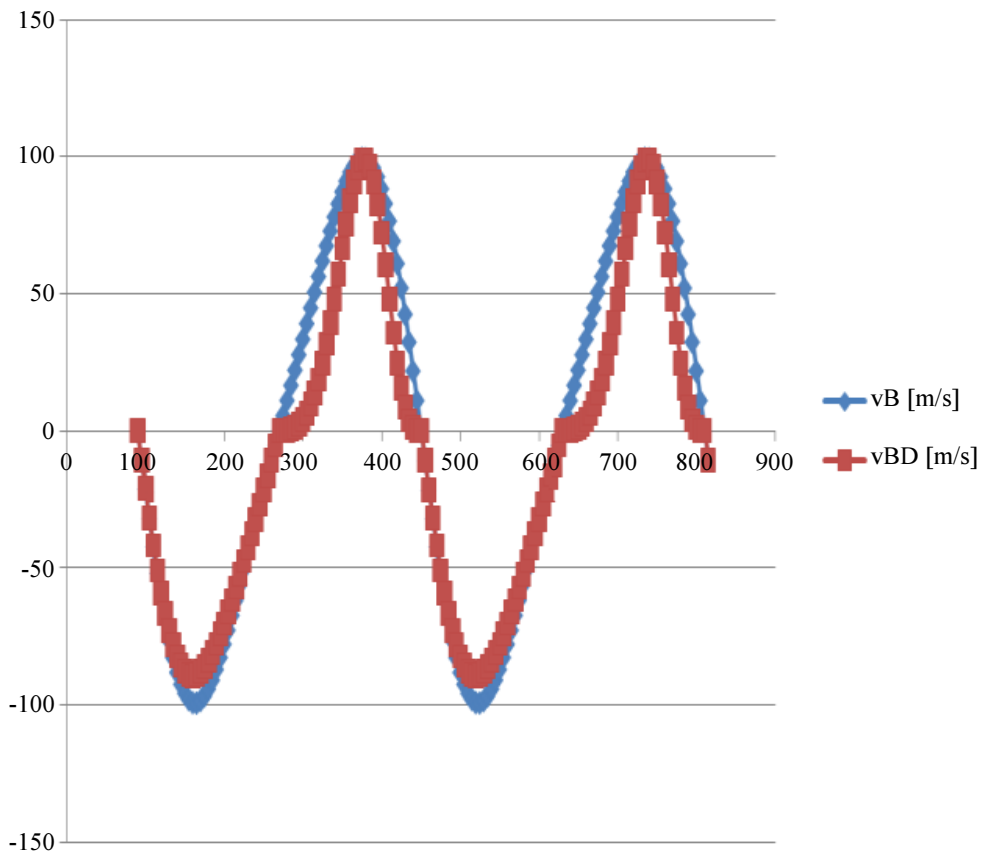


Fig. 24: Dynamic speeds on the Lenoir engine, two-stroke (with larger squares brown color)

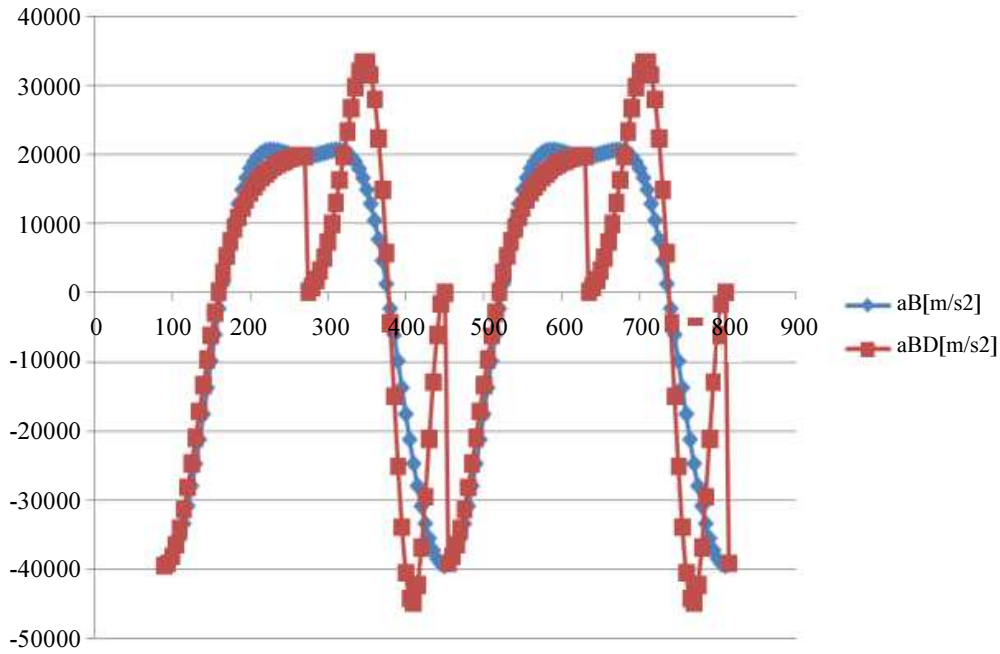


Fig. 25: Dynamic accelerations on the Lenoir engine, two-stroke (with larger squares brown color)

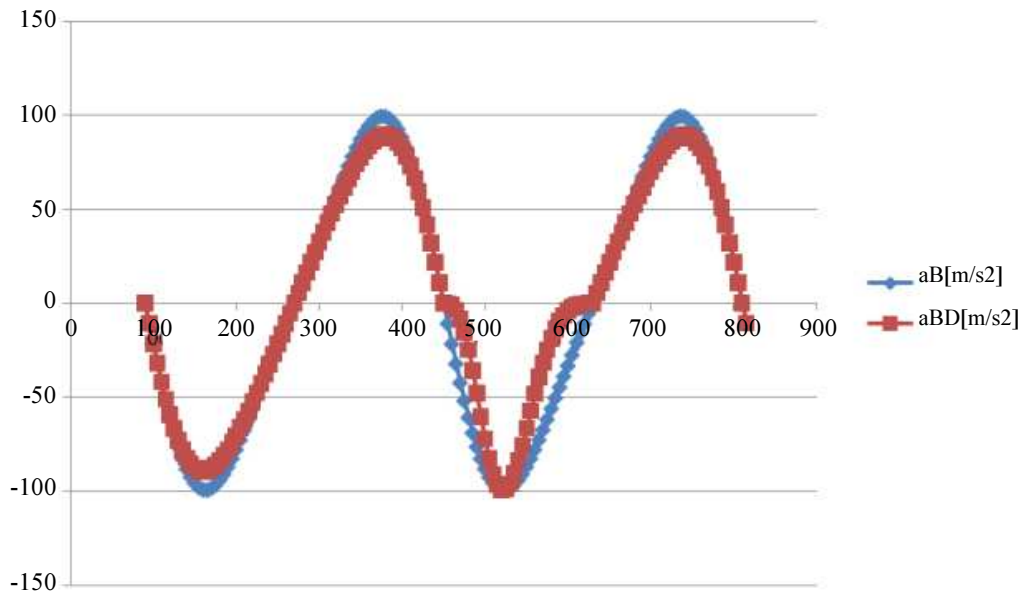


Fig. 26: Dynamic speeds on the four-stroke Otto (or Diesel) engine

In the four-stroke Otto (or Diesel) engine, the energy cycle no longer coincides with the kinematic, so only the fourth part of the entire energy cycle is the engine and only for it the dynamic speeds are shrunk (see below, see diagram in Fig. 26) and dynamic accelerations show shocks, vibrations and noises (follow the diagram in Fig. 27).

In the four-stroke Stirling engine, all times are engines, so the dynamic speeds are shrunk (thin, see the

diagram in Fig. 28) and dynamic accelerations are shocks, vibrations and noises (follow the diagram in Fig. 29) throughout the range.

It is seen that the dynamic disadvantages of thermal motors are in fact a contradiction. The dynamics of their mechanisms is better at crank drive (from the crankshaft), but motor times (which have a lower dynamic kinematics) are virtually the ones needed, the only ones that produce the power (effectively) and which

also generate high returns at the respective thermal engine; on the other hand, however, these motorways produce not only irregular operation with shocks, vibrations and noise on the thermal engine but also

generate disadvantageous features. For this reason, the Stirling four-stroke engine and two phases with each active phase have the most power-and-load characteristic at the most disadvantageous speed.

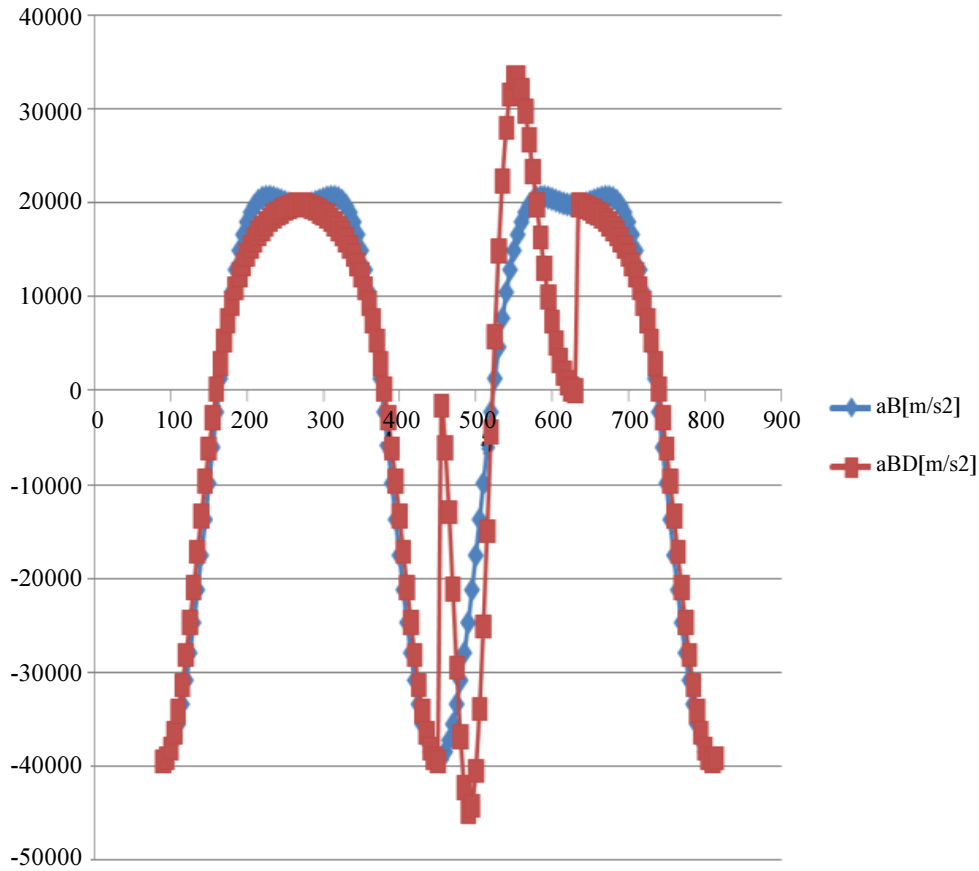


Fig. 27: Dynamic accelerations on the four-stroke Otto (or Diesel) engine

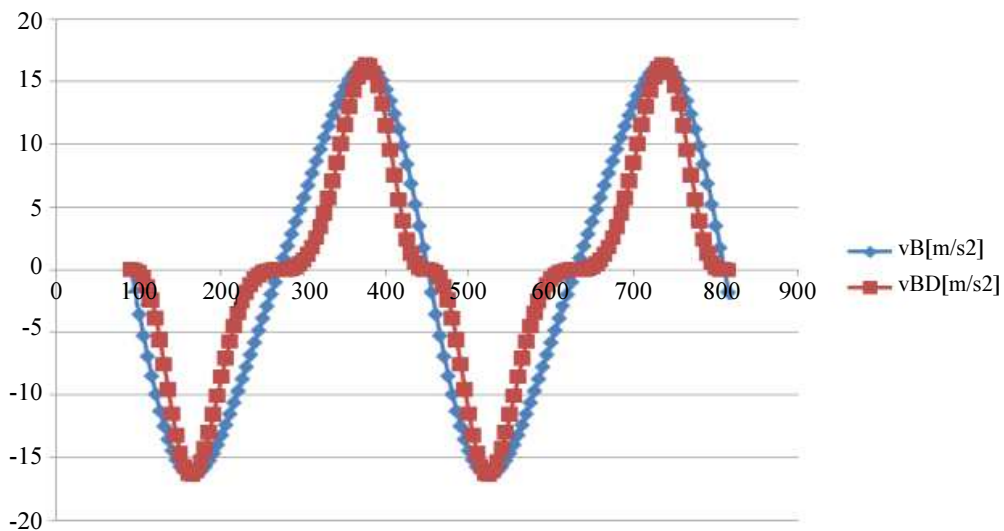


Fig. 28: Dynamic speeds in the Stirling four-stroke engine

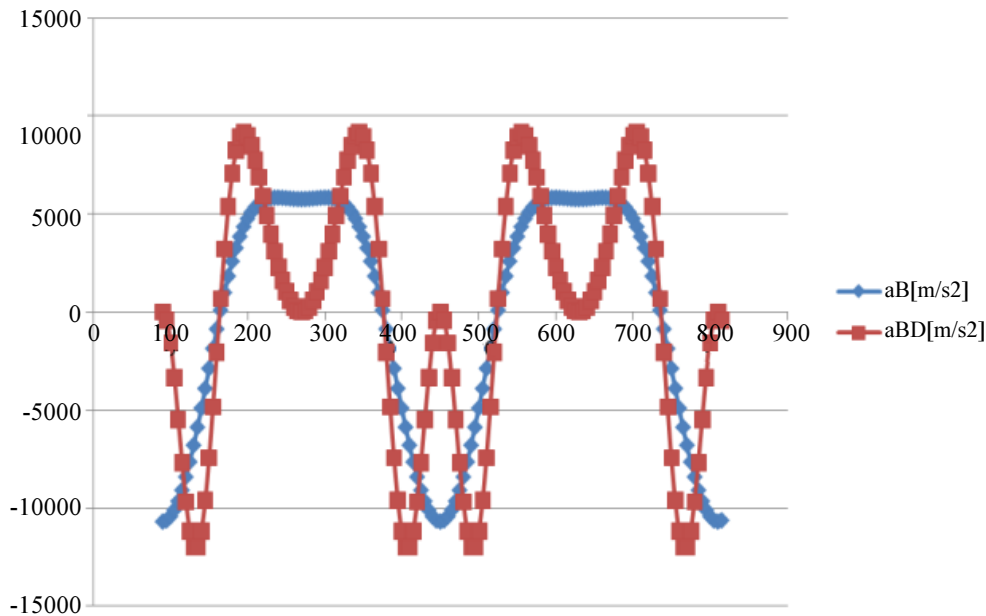


Fig. 29: Dynamic accelerations in the Stirling four-stroke engine

The two-stroke internal combustion engine does not have a very good feature and it also works with vibrations, vibrations and very large noises, which can overcome the known beatings of the four-stroke diesel engines, the traction being shocks (interruptions) even surpass those of the Stirling engines. The Lenoir engine does not make an engine brake, a vehicle equipped with a two-stroke thermal engine is overloaded (the brakes get too hot), the safety of the traffic being very low and the comfort of the passengers in the passenger compartment much diminished.

From this point of view, the four-stroke Otto or Diesel engines are the most advantageous, the first ones actually representing the highest version. For the Otto engines not to lose the advantage of fuel injection, many years ago, carburetors were dropped, Otto engines being gradually fueled by diesel fuel (keeps the ignition, because gasoline does not fire itself as it does diesel).

Discussion

In the process of transforming thermal energy into mechanical work, among the known thermal machines, the Stirling engine is the one that can achieve the highest yield (theoretically up to the maximum yield of the Carnot cycle), although in practice it is reduced by the properties of gas and materials used such as friction coefficient, thermal conductivity, melting point, breaking strength, plastic deformation, etc. This type of engine can operate on the basis of a heat source irrespective of its quality, whether it is solar, chemical, nuclear, biological, etc.

Unlike internal combustion engines, the Stirling engines can be economical, quieter, safer and less maintenance-free. They are preferred in specific applications where these advantages are reaped, especially if the main objective is not to minimize investment costs per unit of power (RON / kW) but to those per unit of energy (RON / kWh). Compared to internal combustion engines of a given power, the Stirling engines require higher capital expenditure, are larger and heavier, for which reason, viewed from this point of view, this technology is uncompetitive. For some applications, however, a sound analysis of the earnings-to-revenue ratio may favor Stirling engines versus internal combustion engines.

More recently, Stirling's benefits have become visible compared to rising energy costs, lack of energy resources and environmental issues such as climate change. Increasing interest in Stirling engine technology has spurred research and development in this area lately. Uses range from water pumping to astronautics and power generation based on rich sources of energy incompatible with internal combustion engines such as solar energy, or plant and animal scraps.

Another feature of the Stirling engines is their reversibility. Mechanically operated, they can act as heat pumps. Tests were conducted using wind energy to drive a Stirling cycle heat pump to heat and condition air for dwelling in cold weather.

Stirling engines today have different uses.

Stirling engines are especially used in natural, unfavorable environments, in isolated locations, etc.

Powerful stationary or mobile generators are built today with the Stirling motors, which operate an electric generator, thus obtaining heat and electricity in isolated places.

In theory, any temperature difference will put into operation a Stirling engine. The heat source can be both the energy emitted by burning a fuel (which justifies using the term external combustion engine) as well as solar, geothermal, nuclear, or even biological origin, in which case the Stirling engine used can no longer be called external thermal combustion engine, but a heat engine with the use of an external power source. As we have already shown, it can work by using a thermal gradient.

This thermal gradient (temperature difference) can be considered in either direction (positive or negative) so that Stirling engines can function not only when the external source of temperature is warmer than the internal source (the environment) but also when it is more cold (than ambient temperature), using ice or snow for this purpose. The cold source appears in the place where cryogenic liquids or ice are used. In order to generate significant power at low temperature differences, it is necessary to transport large amounts of fluid through the external heat exchanger, which will cause additional losses and reduce cycle efficiency. Because the heat source and the working gas are separated by a heat exchanger, a wide range of heat sources including fuels or residual heat from other processes can be used. Since they do not come in contact with internal moving parts, the Stirling engine can also work with siloxane-containing biogas, without the danger of accumulating silicates that would damage components, as is the case with the internal combustion engine which would use the same type of fuel. Lubricant life is significantly higher than the internal combustion engine, which is another significant advantage of the Stirling engines compared to the internal combustion engine.

La "U.S. Department of Energy in Washington, NASA Glenn Research Center "(from Cleveland), a free piston engine (Stirling type) is being studied for a radioactive isotope generator. This device will use a plutonium-based heat source.

The "Los Alamos National Laboratory" developed a "Stirling Thermal Acoustic Wave Machine" without moving parts. This machine converts heat into acoustic power waves (quoted from the indicated source) "can be used directly in acoustic waves or chillers with impulse tubes to produce cold by means of a heat source without using moving parts, or (...) to generate power through a linear generator or other electroacoustic power transformer."

Obviously the Stirling engine is also used here to generate electricity and the heat that is used as a source of energy can be taken from various sources.

On the basis of this principle, we can today take over and transform the excessive heat that occurs day in surface sand in desert areas into electricity. The cold area

is the sand from the greater depth, or even the air in the environment.

In the desert the temperature differences are higher because the surface sand gets very hot on the day.

Sahara with 9,000,000 km² is the largest desert on earth. The Sahara comprises a third of Africa (roughly the surface of the United States of America, or 26 times the surface of Germany). This dry desert stretches from the Atlantic Ocean to the Red Sea, forming a trapezium with a length of east-west side of about 1,500-2,000 km and north-south with a base length of 4,500-5,500 km. Most of the wilderness is rocky (Hamada) with gravel (Serir), the sandy beach (Erg) occupying a smaller area.

The name Sahara comes from the Arabic language - "Sahara" which in tuareg dialect means "the sand desert". Another hypothesis is that the origin of the expression would be "sahraa" or "es-sah-ra" which means sterile, sterile. The Romans called the southern province of Carthage "Desert" (i.e., land uninhabited, abandoned). In the Middle Ages it was simply called the Great Desert and in the nineteenth century it was called the Sahara. Arabs call Sahara "Bahr bela ma" which would mean "Great without water".

The Sahara desert occupies almost entirely North Africa, extending 5630 km from west to east, from the Atlantic Ocean to the Red Sea and 1930 km from north to south, from the Atlas Mountains and the Mediterranean Sea up to in the area of savannah in the Sudan region.

In a narrow sense, it stretches to the east only to the Valley of the Nile; the desert from the East of the Nile to the Red Sea is known as the Arabian Desert.

Sahara occupies large parts of the states:

Morocco, Algeria, Tunisia, Libya, Egypt, Mauritania, Mali, Niger, Chad, Sudan and a small part of Senegal and Burkina Faso.

The climate is desert-tropical, with high average temperatures (38°C), particularly hot and dry; the dominant wind all year round is the Pasat wind, a dry wind that brings rain. The wind and high temperature variations from day to night have led to the formation of the desert. In the winter, during the night the air temperature drops to -10 degrees, while the summer can reach during the day 58 degrees Celsius. Precipitation is reduced (20-200 mm/year) and very high daily diurnal heat (30°C in air and 70°C on the ground). The average January temperature is +10°C and July 35°C. Lack of permanent watercourses, the hydrographic network is represented by winds (drought channels) that fill with water during occasional rains.

The Sahara desert is a very energetic potential (especially the day in the warmer months of the year).

Here, daytime temperatures of the soil often reach 70 [°C] (343 [°K]), which would allow a Stirling engine to produce a Carnot energy yield of about 20-25%, that is, a third or even half of the maximum efficiency with which these types of engines work normally.

The soil/air temperature difference of 30-400 m/min decreases the yield, but using the temperature difference between the surface soil and the depth of about 500, a satisfactory yield can be obtained.

An effective fitting of such high-powered Stirling engine to drive a high-frequency alternating current electric power generator could donate much more energy to the desert area during the day than solar systems (whether sand, gravel or rock) from which the engine is warm, overheating that will be done as well as in modern solar plants, through mirrors focused on that area; in this way the place that has to be a hot source will remain hot during the day (not influenced by the heat absorbed by the engine) and additionally not only will the hot zone be maintained but it will become even hotter, fact which will increase Carnot's engine output from 15-20% to much higher values, the higher the sand temperature will be.

This method allows you to get electricity (electric) on a daily basis in any season, so not only in the summer and it can also be practiced anywhere, leaving no need for a desert area.

By cogeneration, from a pre-existing energy source, usually an industrial process, with the help of an installation, in addition to the mechanical or electrical power delivered, heat is provided for heating. Normally the primary heat source is the entry for the Stirling engine heater and as such will have a higher temperature than the heat source for the heating application made up of the engine exhaust.

The power produced by the Stirling engine is often used in agriculture in various processes, resulting in biomass waste that in turn can be used as motor fuel to avoid the cost of transporting and storing waste. The process is generally abundant in energy resources being economically advantageous.

WhisperGen, based in Christchurch/New Zealand, has developed an AC Micro Combined Heat and Power co-generation based on the Stirling cycle. These micro-plants are methane-fueled heating systems that also supply electricity to the grid. WhisperGen announced in 2004 that it will produce 80000 homes of this type for UK housing. A batch of 20 plants started the test in Germany in 2006.

In nuclear power plants there is the possibility of using Stirling machines for power generation. By replacing the Stirling engine turbines, the complexity of the construction can be reduced, a higher yield can be achieved and radioactive waste can be reduced. Certain uranium enrichment reactors use liquid sodium as a cooling agent. If the thermal energy is still used in a steam plant, water/sodium heat exchangers are needed which increases the degree of danger due to the possibility of violent reaction of sodium with water in case of direct contact. Using the Stirling engine causes the water to be removed from the cycle.

US government laboratories have developed a modern Stirling engine under the name SRG (Stirling Radioisotope Generator) for use in space exploration. It is designed to generate electricity for spacecraft leaving the solar system with a life span of several decades.

This engine employs a single discharge piston (to reduce moving parts) and high energy acoustic waves for energy transfer. The heat source is a radioactive fuel block and the residual heat is eliminated in space. This assembly produces four times more energy from the same fuel block as compared to a similar radiator (RTG) type radiator (radioisotope thermoelectric generator).

Theoretically, Stirling engines would also have the advantage of being an airplane engine. They are quieter and less polluting, yields increase with altitude (internal combustion engine output decreases with altitude), are safer in operation due to fewer components, especially mobile components and lack of ignition, produce less vibration (structure of resistance will last longer), are more reliable and safer using less explosive fuel.

Kockums, the Swedish ship builder, constructed at least 8 Gotland submarines with Stirling drives in 1980.

In the automotive industry, the use of Stirling engines to drive cars is often argued by the power / weight ratio too low and a start-up time too long.

Alongside projects from Ford and American Motor Companies at NASA, at least two Stirling engines were built.

The bigger problems lie in the long start time, the slow response to acceleration, stop and load that has not been resolved immediately. Many believe that hybrid drive would eliminate these shortcomings, but for the time being, no vehicle has been built on this basis.

The vehicles designed at NASA were called MOD I and MOD II. In the case of MOD II, a normal spark ignition engine was replaced by a 4-door Chevrolet Celebrity hatchback in 1985.

In the report published in 1986, Annex A states that consumption on both the highway and the city has decreased for the average car from 5.88 L/100 km to 4.05 L/100 km and for the high-capacity car from 9.05 L/100 km to 7.13 L/100 km.

The start time of the NASA vehicle was 30 seconds, while the Ford pilot car using an electric preheater in the hot air area managed to start in just a few seconds.

Conclusions

The most common external combustion engines were steam engines. Although initially used as a naval engine, the emergence and development of steam engines (as well as the first cam mechanism) are closely related to the emergence and development of tissue wounds (automatic tissue machines).

Today, stirring thermal combustion engines complement and even replace steam engines, but in large part those with internal combustion.

Most uses, stirling engines, have them in vehicles and road, land and marine vehicles, but also within modern energy systems.

Because the stirling engines started harder and less adapted to the car-load feature of a car, initially the stirring engines were introduced on adaptive cars, or together with an internal combustion engine (diesel or Otto) under the form of hybrid engines, or more recently with an electric motor.

Along with an internal combustion engine, the stirring engine greatly increases the efficiency of the hybrid system, because it even works with the heat dissipated by the diesel engine or Otto, that is, cooling the internal combustion engine is not done by dissipating (heat loss) but all the thermal energy (which is in the form of heat) that has to lose the internal combustion engine will be the warm source of the stirling engine and instead of losing it, it will act effectively on the stirling engine, thus greatly enhancing the efficiency of the system.

In green, sustainable, renewable, clean and friendly energy, stirling engines are mainly used in two ways:

- Like a power generator in solar farms, where all the redesigned and concentrated heat from the sun, lots of parabolic mirrors, heat concentrated on a huge boiler with water or oil, is used to heat the boiler, which is the source constantly warming the stirring engine, effectively acting it and it still rotates a very high current generator
- Or as a motor positioned in the glare of a huge parabolic mirror, acting constantly on the mirror, rotating it in all directions so that it can permanently capture as much solar energy as possible

In addition to vehicles and green energy, stirring engines are still used since their appearance in power groups, stationary or portable power generators, hospitals, military units and so on.

Today the conquest of space is done through robotization, automation, with modern, fast, autonomous spacecraft, with many capabilities, but also with stirling generators (Petrescu *et al.*, 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae).

The operation of a main mechanism of a stirling engine is basically similar to internal combustion heat engines, with the exception that all times are engines. From this point of view, the mechanical efficiency of a stirring engine has the advantage of being greatly increased compared to internal combustion engines, all times being active, provided that the heat output of the

stirling engine can be raised from the design (by using a warm source at a minimum of 900 degrees).

A stirling engine uses to operate a temperature gradient, so any difference between the ambient temperature and the source used can cause a stirring engine to work. You can use high temperatures (hot source), or low (a cold source). The working principle of an external combustion heat engine is similar to that of the refrigerator, but it is reversed.

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Ethics

This article is original. Authors declare that are not ethical issues that may arise after the publication of this manuscript.

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