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Research article

IS THE TWO-STROKE ENGINE HISTORY OR THE FUTURE OF MOTORING?

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ABSTRACT

The paper presents a condensed history of the development of the two-stroke engine. The various stages of implementation of the most significant design solutions are described chronologically to achieve the best technical and economic performance for this type of power unit. The review of selected design solutions is supplemented with illustrations and concise comments. Examples of practical engineering solutions, thanks to which previous techno-economic problems were optimized, such as insufficient lubrication efficiency of individual parts and components, significant lubricating oil consumption, ...) are presented. The work was concluded with an analytical summary and conclusions indicating the need to undertake more intensified research into developing the two-stroke engine (in particular, the possibility of using ecological propellants). Consideration of the presented research directions (suggestions) can help, among other things, to optimize power processes, i.e., to minimize the negative environmental impact of a two-stroke internal combustion engine.

KEYWORDS: two-stroke engine, automotive development, alternative power units, combustion optimization

1. Introduction

The first two-stroke internal combustion engine was constructed as early as 1860 by the French inventor of Belgian origin Étienne Lenoir. A few years later, in 1878, Scottish engineer Dugald Clerk created a model gas engine in which all operational phases occurred during one crankshaft revolution and, thus, during two piston strokes. His design became the basis for the development of gasoline two-stroke engines. Finally, German engineer Carl Benz developed the first gasoline-powered internal combustion piston engine in 1878-79. The success of the new engine was so great that in 1883 Benz founded his own automobile company, Benz & Co, to manufacture cars [1, 2].

The two-stroke engine, for most people, will be associated with older motorcycles or some passenger cars. Meanwhile, it could also be found in trucks, tractors, locomotives, and watercraft. The two-stroke engine owes so much of its popularity to the simplicity of its design solution, compact design, and lightweight. Due to fewer components, such units are cheaper to manufacture and incomparably easier to repair [3]. In addition, two-stroke engines warm up to operating temperature more quickly and have a more favorable power-to-weight ratio than 4-strokes and a power-to-engine capacity ratio [4]. Of course, two-stroke engines also have their disadvantages. These include the lack of an oil pan and the associated problem of lubricating the engine's moving parts. Lubrication in such an engine occurs by adding oil to the fuel being burned. The negative effect of such an arrangement is the oil combustion in the fuel-air mixture. This results in fatal emissions in the exhaust gas. The second major problem is the obstructed exchange of charge in the cylinder and the inaccurate combustion chamber cleaning from the exhaust gases. Since the fuel-air mixture inlet window into the cylinder and the exhaust gas outlet window must be open simultaneously for a fraction of a duty cycle, the process of emptying the cylinder of exhaust gas and filling it with new mixture overlap [5]. As a result, not all the exhaust gas will be removed from the cylinder. Moreover, some new, unburned fuel-air mixture escapes through the open exhaust port. For the reasons mentioned above, the reality of two-stroke engines could have been more optimistic. Two-stroke engines proved inefficient, burned much fuel, and emitted highly polluted exhaust [6, 7]. However, it should be noted that despite the undoubted drawbacks, two-stroke engine designs are constantly being improved, and new solutions are being sought to the problems these designs face. This article shows the successive stages of development of two-stroke engines and their ideal design solutions, up to and including the latest ones. In conclusion, the authors also indicate possible directions for further development of such engines.

2. Design solutions for two-stroke engines

Two-stroke internal combustion engines can be classified according to the degree of compression directly related to the fuel used and specific design features. This division includes engines:

- Gasoline, with a low compression ratio, was used once in some cars, motorcycles, and garden machinery.
- Medium-diesel, mainly used in agricultural tractors.
- High-compression engines used to power trucks, locomotives, or ships.

All of these engines, regardless of design, have similar advantages and disadvantages. To explain the differences between them, the construction of each of these engines will be discussed below.

2.1. Two-stroke gasoline engine

The oldest two-stroke engine is a spark-ignition gasoline engine [8]. The most common design solution for such an engine is shown in Figure 1. Such an engine has only 3 moving parts - piston, connecting rod, and crankshaft. The role of timing here is performed by a moving piston that obscures the mixture inlet window and exhaust duct at the appropriate time.

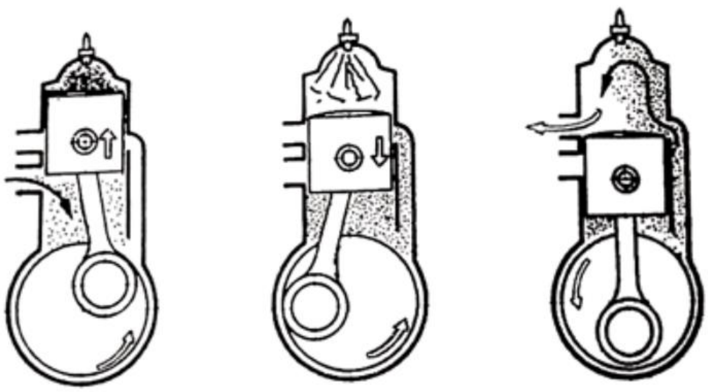

Figure 1: Diagram of a two-stroke spark-ignition internal combustion engine [9]

In practice, other design solutions are also encountered, where a special movable disc or a sheet metal one-way valve fulfills the role of the inlet valve. The latter solution is often used in small-model engines today [10]. Currently, two-stroke gasoline engines are used in gardening equipment such as trimmers, chain halves, etc.

2.2. Medium-compression two-stroke engine

The medium-diesel engine is a specific diesel-powered power unit (Figure 2). Its operating principle is identical to that of a classic two-stroke engine. However, fuel ignition, in this case, occurs spontaneously - from a glowing "pear" formed by the spun part of the cylinder head [11].

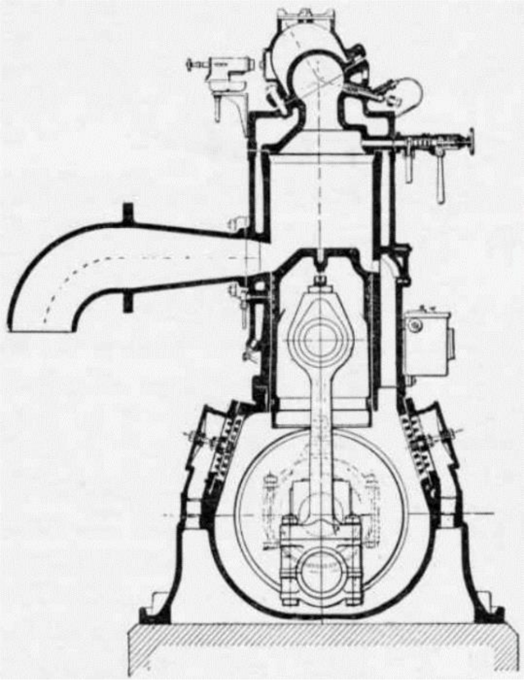

Figure 2: Schematic of a two-stroke medium-duty engine [12]

An undoubted advantage of such engines is their low sensitivity to fuel type. Literature data shows that they can run on kerosene, and various oils (diesel, cooking oil, etc.), up to and including spirit [11]. In addition, the fuel system used in the engine is provided with an uncomplicated "open" injector. As a result, these engines did not require sophisticated maintenance and were characterized by longevity. Usually, this engine with a "glow pear" is associated with Lanz Bulldog or Ursus C45 tractors.

2.3. High-pressure two-stroke engine

High-pressure two-stroke engines are most often identified with "Detroit diesel" engines. They are powered by diesel fuel and, for this reason, have a classic fuel system, the same as in four-stroke diesel engines. They also have a wet crankcase. Therefore, the air supplied to the cylinders is precompressed in an additional Roots compressor [13]. Air is provided to the cylinders, as in any two-stroke engine, through special ducts exposed by the piston during engine operation. The exhaust gases, on the other hand, escape from the cylinder through a valve located in the engine head. This valve is cam-operated - just as it is in a four-stroke engine. Construction details of a two-stroke diesel engine are shown in Figure 3. Two-stroke high-pressure engines have been used to power trucks and buses, mainly in the US.

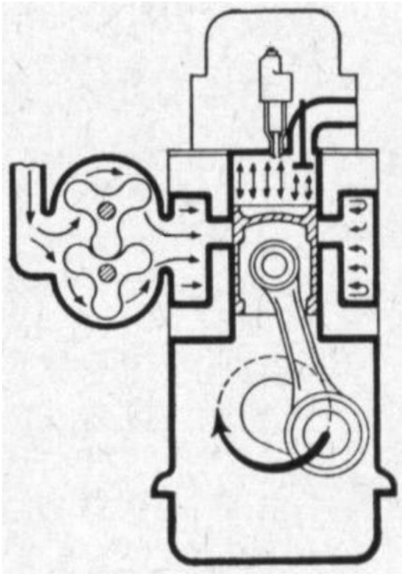

Figure 3: Diagram of a diesel two-stroke engine [14]

3. Successive stages of development of two-stroke engines

The disadvantages of two-stroke engines, mainly the emission of highly polluted exhaust, would cause an irreversible departure from this propulsion. Meanwhile, many research centers continue researching and developing their design, seeing great potential in them. Therefore, modifications to two-stroke engines that have significantly influenced the development of these units are presented and discussed below.

3.1. Resonance chamber in the exhaust duct

As already mentioned, a significant drawback of two-stroke engines was the escape of unburned fuel-air mixture during the mixture exchange in the engine cylinder. This phenomenon results from the simultaneous opening of the mixture inlet port and the exhaust gas outlet port. The solution to this problem was using a resonance chamber in the exhaust system. The effect of such a modified exhaust is that the pressure wave created by the exhaust gas flowing through the muffler reaches the resonance chamber, bounces off its rear wall, and returns to the engine. The returning pressure wave causes the unburned fuel-air mixture that escaped through the still-open exhaust port to be pushed back into the cylinder. Literature sources [9, 15] indicate that in addition to increasing the efficiency of such engines due to a reduction in the loss of the "escaping" mixture, a noticeable increase in engine compression is obtained, which translates into an improvement in the quality of the combustion process. Figure 4 shows a Vittorazi engine with a visible conical resonance chamber. Engines of this type are used to power hang gliders, paragliders, and ultralight aircraft. Similar resonance chambers are found in motorcycle engines. It should be noted, however, that the resonance chamber is only a solution with disadvantages. It works effectively only at a strictly defined engine speed. The speed of the exhaust gas flow, particularly the diameter of the exhaust port, is the reason for this condition. YAMAHA has proposed a solution to this problem. To improve the efficiency of the resonance chamber over the entire speed range, the engine used an exhaust duct with a variable cross-section. This allowed the diameter of the exhaust port to be adjusted during operation, thus regulating the moment of arrival of the wavefront pushing the escaping mixture into the cylinder. The perfect alignment of the closure through the piston of the exhaust port and the moment of appearance of the wavefront provided optimal operating conditions for the engine modified in this way [15].

Figure 4: Vittorazi Moster Factory R engine [16]

3.2. The use of a separate lubrication system and direct injection

Two-stroke engines of classic design (Figure 1) used a lubrication system through the fuel-air mixture. Such a solution required the preparation of an oil fuel mixture, usually in the ratio of 1:50. In this way, the mixture circulating in the engine simultaneously lubricated the engine's moving parts. However, most of the oil mixed with the fuel was burned. This caused unnecessary loss of oil and, more importantly, catastrophic emissions [8]. In some designs, however, I am referring to two-stroke medium-diesel engines, a "wet-sump," and a system of pressurized lubrication of critical engine points was used [12, 14]. However, these were engines of considerable size. The wet sump in a two-stroke gasoline engine was first used in 1994 in the F135 engine built by Ferrari (Figure 5). This engine also used direct fuel injection. This innovative engine generated 216 horsepower at 1374 cm^3 and had low emissions. Unfortunately, this engine did not go into mass production.

Figure 5: Ferrari F134 engine [16]

In 2017, however, an engine manufactured by Rotax went into series production. The Rotax 850 E-TEC engine (Figure 6) is designed to power snowmobiles. This engine has a classic design with piston-obscured ports, an adjustable exhaust port diameter, direct fuel injection, and a system for injecting an additional portion of fuel at the throttle in the highest rpm position. This system improves the engine's response to "gas". In addition, the engine uses a lubrication system unprecedented in such engines. The crankshaft system is lubricated by pressure through internal channels in the crankshaft. In contrast, the cylinder is lubricated through a specially designed injector system that introduces oil only into strategic areas of the engine requiring lubrification. Such a lubrication system makes it possible to reduce the amount of oil burned by as much as 80%, thus significantly reducing the number of pollutants emitted with exhaust gases.

Figure 6: Rotax 850 E-TEC engine [18]

3.3. Application of supercharging

As an example of a turbocharged, two-stroke gasoline engine, the 850 E-TEC TURBO unit was launched in 2020 by Rotax. This two-cylinder engine, with a capacity of 850 cm^3 and a weight of 40 kg, generated 165 hp at 8000 rpm. According to the designers, the main task of the turbocharger here is to maintain constant engine power regardless of the altitude at which the engine operates. In contrast, a classic naturally aspirated engine is characterized by decreased generated power due to diluting air.

4. Development prospects of two-stroke engines

In the current era, with the energy crisis and the general trend toward sustainable production, it is reasonable to assume that internal combustion two-stroke engines may be of interest to researchers and manufacturers. Such units are characterized by several advantages, which include:

- fewer components, making them cheaper to produce and more accessible to service,
- The possibility of using a resonance chamber, fuel injection, pressure lubrication system, and turbocharging, making such engines less harmful to the environment,
- the possibility of building multi-fuel engines, which in the current era of the fuel crisis, is a not inconsiderable feature.

Given the past year's events, the underrated design is the mid-engine. Especially since it shows minor sensitivity to the fuel type and quality, one can be convinced that this same design will be dynamically developed soon. The authors believe that the possibility of feeding such engines with a mixture of diesel and cooking oil will be studied first, or the suitability as the fuel of various cooking oils will be investigated. Noteworthy is the fact that switching completely to fuel in the form of one of the food oils will achieve the effect of changing agricultural production from animal husbandry to the production of oil crops, which is less harmful to the environment. This will support domestic producers and reduce the need for oil - a largely imported raw material. It should not be expected that two-stroke medium-diesel engines will be used in passenger cars since their start-up is time-consuming and quite cumbersome. However, objectively it can be said that there is still great potential in this design, which is worth developing.

5. Conclusions

Based on a comparative analysis of the development of the two-stroke engine design to achieve the best technical and economic indicators, the need for intensive research aimed at its more comprehensive application was justified. Today, the evolution of this drive unit (despite the apparent design expansion) is still cheaper to produce than the four-stroke engine. In a period of global crisis, this is one of the factors predicting significant economic benefits from attempts to develop and intensify research into the implementation of new design solutions, e.g., in a hybrid, multi-fuel direction such as a two-stroke mid-engine. Furthermore, looking at existing trends in alternative energy sources, it is predicted that a hydrogen-powered two-stroke engine will soon be developed.

Formula 1 is already planning to use fuel units powered by innovative synthetic fuel in its vehicles. Likely, the next step in the evolution of the two-stroke engine (before the use of hydrogen) will be to move away from liquid hydrocarbon power. But before that happens, an important issue is to adapt this engine to burn a wide range of cooking oils. Looking at the idea more broadly, one can see that prospects are opening up for an increase in the production of oilseed crops (not only in Poland), thus transforming some livestock farms into agricultural areas. In global environmental terms (according to the FAO), current livestock farming generates about 14.5% of greenhouse gas emissions (including contributing indirectly to the contamination of land and surface water). Making this a reality boils down to achieving so-called "fuel security", which, especially now (during a European armed conflict), is crucial to calming the global economy.

In the end, it is possible to formulate a thesis that if the leading innovators (Rotax, Mercedes-Benz, Ferrari, ...) had directed their approach to the complete minimization of emissions of the two-stroke power unit at the expense of the highest technical performance, a multitude of new and inspiring (ecological) design solutions would have been created. Thus, despite the simple design of the two-stroke engine in its original form - the chapter in question remains open and inspires enthusiasts of this design.

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