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EFFECTIVE COMPRESSION RATIO OF COMBUSTION ENGINE AS A WAY OF INCREASING EFFICIENCY

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Abstract

The article describes the processes that take place in an engine. The main terms connected with the compression ratio are explained. Moreover, the relationship between the compression ratio and the engine efficiency is discussed. This paper is a repetition of issues connected with functioning of the engine. In this article, variables that influence the chart are described, along with some examples of the way to increase engine efficiency. This article focuses on selected methods of improving efficiency of internal combustion engines. In order to fully understand processes taking place in the combustion chamber, it is necessary to create theoretical charts of thermal cycles and, then, to compare them with actual charts obtained as a result of measurements. The structure of contemporary engines is influenced by various factors, for example preservation of natural environment or limited fuel resources. These factors are crucial for mechanical engineering and engine design. Therefore, energy consumption and environmental impact of engines are taken into consideration when researching new ways and methods of enhancing engine efficiency. One of the main aims of the researchers and engineers is to reduce the emission of carbon dioxide (CO2), carbon monoxide (CO), hydrocarbons (HC) and oxides of nitrogen (NOx) in exhaust fumes. Improved engine efficiency, lowered fuel consumption and reduced emission of toxic substances are the main advantages of internal combustion engines characterized by variable compression ratio.

Keywords: *engine, internal combustion engine, efficiency, air pollution, compression ratio*

1. Introduction

A combustion piston engine is still the most important source of power for motor vehicles and means of transport by sea. Thanks to its high efficiency and small design, such an engine overweighs other types. At present, engine designers are trying to create engines with the highest possible power. One of the assumptions allowing them to obtain higher engine power is to increase work performed in one working cycle and, consequently, to obtain higher effective pressure. In order to increase average effective pressure, the density of the charge supplied to the cylinder should be increased.

The design of modern combustion engines intended for traditional use mostly depends on such factors as environmental protection or limited fuel resources. These factors play a very important role during engine design processes. The designers are still searching for new ways of improving engines in terms of energy consumption or environmental impact.

2. Engines characterised by variable compression ratio

Terms, such as combustion space, combustion chamber (Vk), displacement volume (Vs) and total displacement volume, are necessary to explain the notion of compression ratio.

Combustion space is the volume between the cylinder, piston head and cylinder head that changes during the piston stroke. Combustion chamber can be defined as the smallest combustion space. Displacement volume is the space between the top dead centre (TDC) and the bottom dead centre (BDC) of the piston. Total displacement volume is, therefore, the sum of all displacement volumes of engine cylinders. Taking the above into consideration, compression ratio can be explained as the sum of the total displacement volume of the cylinder before the beginning of the compression process and the displacement volume of the cylinder after the completion of the process. The effective compression ratio changes largely and it is defined as the quotient of the intake manifold pressure and the engine cylinder effective pressure. From the point of view of the engine efficiency, ensuring high effective compression ratio in case of engine idling speed and partial engine load is most advisable and justified.

New engines, which are to reduce fuel consumption, emit less harmful substances and increase total efficiency, are more and more frequently designed. Scuderi introduced a new interesting concept of an engine. It is based on the assumption that intake and compression processes take place in one cylinder while the other two processes (combustion and exhaust) take place in the other. Scuderi assumes that these cylinders should differ from each other. Compressed air created in the first cylinder is transferred to the second cylinder through a passage. Ignition and exhaust of fumes take place in the second cylinder, which is bigger. Figure 1 presents the operation of the Scuderi engine.

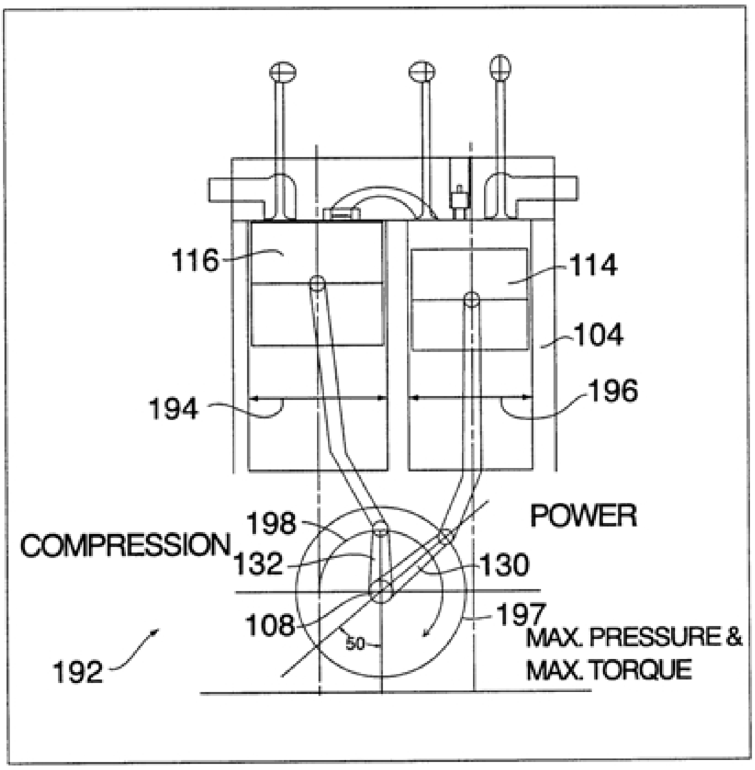

Fig. 1. Operation of the Scuderi engine

Work performed with each motion of a piston is a big advantage of this solution. It is also possible to develop this type of the engine by adding a turbocharger; this will result in the reduction of the size of the first cylinder responsible for air compression. The increased efficiency of this engine contributes to the reduction of the amount of harmful substances emitted to the environment during the combustion process. The results of the first tests showed that this engine consumes 25% less fuel and the emission of nitrogen oxides is reduced by 80%.

Another way of increasing the engine efficiency was developed by the MCE-5 DEVELOPMENT Company. The engine design is characterised by a variable compression ratio. The concept of the engine is based on the assumption that the connecting rod is linked by means of the first-class lever, which is supported on the piston valve on the one side and on the MCE-5 valve mesh on the other side. Figure 2 presents engine MCE-5.

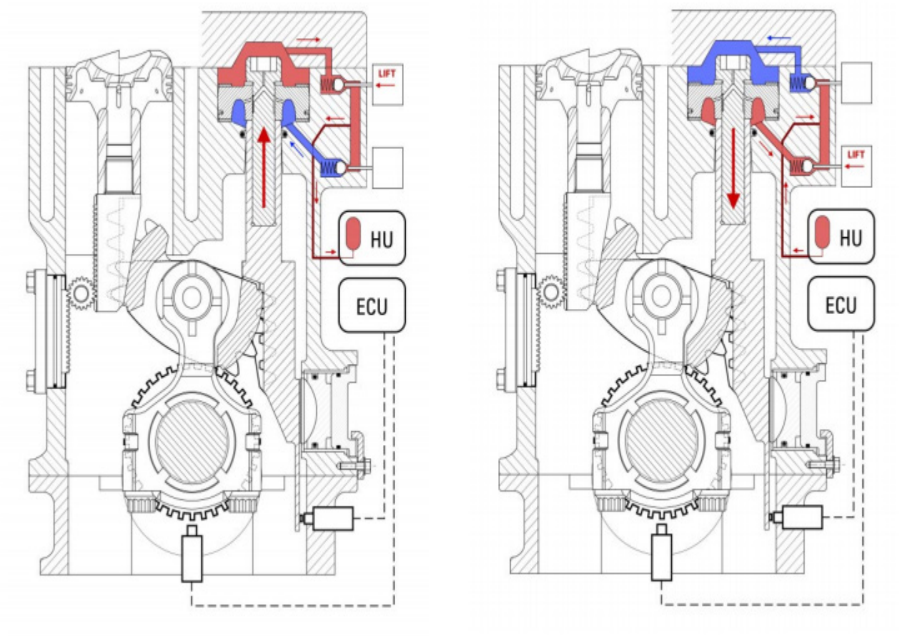

Fig. 2. MCE-5 engine

Tab. 1. Specific transmission times in terms of the number of rotations per minute

Time (sec) to switch	1000 rpm	1500 rpm	2000 rpm	2500 rpm	3000 rpm	3500 rpm
18:1 to 7:1	0.240	0.160	0.108	0.084	0.078	0.067
12:1 to 8:1	0.116	0.067	0.052	0.040	0.037	0.032

The biggest advantages of the MCE-5 engine include the possibility of adjusting the compression ratio to relevant operating conditions in a given moment. It will be reflected in the increase in engine efficiency and in the reduction of fuel consumption and emission of harmful substances.

The design presented by Duke Engines is an extremely interesting way of increasing engine efficiency. This idea aims at the development of an engine where cylinders run parallel to the crankshaft. Cylinders with air inlet, plugs and exhaust fumes outlet rotate around the crankshaft. To sum up, this engine requires only 3 spark plugs and 5 cylinders in order to obtain the same number of strokes as a 6-cylinder engine.

The change in the compression ratio causes the increase in the engine efficiency, but continuous increase is not possible for design reasons. The advantages of this engine include higher compression ratio, smaller vibrations, reduced fuel demand and lighter structure.

3. Theoretical and total engine efficiency

The theoretical efficiency of spark-ignition engines according to the Otto cycle mostly depends on the compression ratio and it can be expressed by means of the Taylor's theorem:

$$\eta_t = 1 - \varepsilon^{1-k}, \tag{1}$$

where:
k – heat capacity ratio.

According to the presented formula (1) above, the theoretical change in the compression ratio from 10 to 14 increases the engine efficiency by 5%; the increase is therefore high. The increase in the engine efficiency may result in a negative phenomenon, i.e. knocking combustion, which becomes stronger as the engine load increases. Therefore, it is impossible to use such a high fixed compression ratio in the complete field of work.

The total efficiency can be defined as the use of the energy contained in fuel, so it is the efficiency of the conversion of thermal energy into mechanical energy. It can be expressed as the ratio of usable heat to the amount of heat supplied to the factor.

In order to understand precisely the processes occurring in an engine, you should acquaint yourself with the thermal cycle and thermodynamic processes taking place in a combustion chamber. Ideal cycles were created by Diesel, Otto and Sabathe. They made it possible to compare and make calculations describing the work of a given engine.

Unlike ideal cycles, actual cycles mostly result from the recording of actual pressure in the combustion chamber based on the location of the crankshaft. Otto, the author of the cycle, assumed that heat inflow and outflow take place during the isochoric process.

The efficiency of this cycle is known as a theoretical efficiency; the quotient of the theoretical work of the cycle to the amount of heat supplied to the cycle is the result of this efficiency.

The above-mentioned ideal Otto cycle was accepted by researchers as the most similar to the actual cycle of the spark-ignition piston engine.

Indicator diagrams are used to describe heat and mechanical loads of an engine. Thanks to them, various parameters of engine work can be optimized. Actual cycles are superior to ideal cycles because they take the entire load exchange process in the cylinder into account.

As a result of the comparison of the ideal Otto cycle with the actual cycle of a spark-ignition engine, the following differences can be found:

- the actual cycle has two additional charge exchange stages,
- the compression process starts at a lower pressure,
- the expansion process is also a conversion,
- the maximum pressure of the cycle is clearly decreased.

It is possible to present the relationship between:

- pressure,
- volume,
- temperature of gas.

In order to correctly calculate and create a chart of total efficiency for a spark-ignition engine working according to the Vibe cycle, it is necessary to assume that:

- compression and expansion processes are polytropic curves,
- semi-perfect gas is a thermodynamic factor conducting the work,
- the volume of the amount of the factor participating in the cycle is constant,
- in a spark ignition engine heat is supplied at constant volume and in a Diesel engine heat is supplied at constant pressure and volume,
- exhaust residue is taken into account.

At the beginning of the engine modelling process, a comparative cycle should be calculated based on the amount of supplied heat. Then, the following parameters presented in table 2 are assumed and calculated.

The main aim is to reduce the fuel injection time, it is best if the entire fuel volume is in the cylinder within the TDC time. Designers search for high efficiency and reliability of the entire engine.

In case of the Otto cycle, the efficiency increases with the increase in the compression ratio and isentropic exponent, in this case the amount of supplied heat is of no importance. However, the increase in the compression ratio will be directly reflected in the increase in the total engine efficiency.

Tab. 2. Parameters of the engine

PARAMETER	EXPLANATION
p_1	filling end pressure
p_o	ambient pressure
a	pressure decrease coefficient during filling stroke
η_v	filling coefficient
ε	compression ratio
T_o	ambient temperature
p_1	charge temperature at the beginning of the compression stroke
prs	exhaust residue pressure
n_1	compression polytropic exponent
p_2	pressure at the end of compression stroke
T_2	temperature at the end of the compression stroke
L_t (kmol/kg)	theoretical air demand for combustion of 1 kg of fuel
M_t (kg/kg)	theoretical demand for air to burn 1 kg of fuel
L_p	actual amount of air required to burn 1 kg of fuel
μ_r	actual coefficient of molecular process
T_m	maximum temperature of the cycle
pm_t	maximum theoretical pressure of the cycle
p_5	pressure at the end of the expansion process
n_2	expansion polytropic exponent
T_5	temperature at the end of expansion process
p_6	average outlet pressure
p_t	average friction pressure
p_e	average usable pressure
η_m	mechanical efficiency
η_o	total efficiency

Figure 3 presents an example of the change in the compression ratio and total efficiency of a spark-ignition engine. The following formula was used to calculate the total efficiency:

$$\eta_o = \frac{8.31454 \cdot L_p \cdot p_e \cdot T_o}{Wu \cdot \eta_v \cdot p_o}, \tag{2}$$

where:

L_p – actual amount of air required to burn 1 kg of fuel,

p_e – average usable pressure,

T_o – ambient temperature,

Wu – fuel net calorific value,

η_v – filling coefficient,

p_o – ambient pressure.

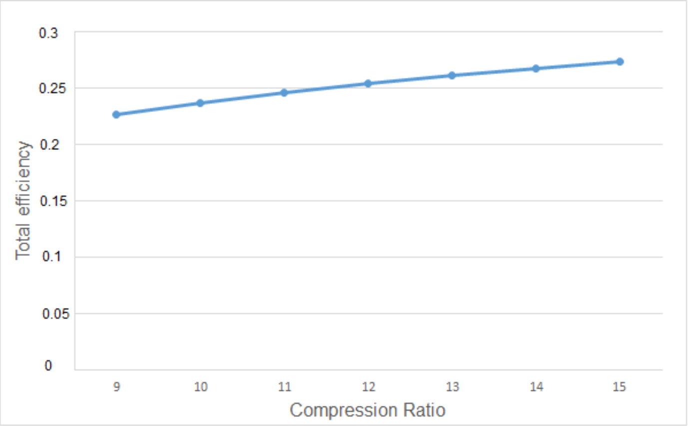

Fig. 3. Characteristics of the total efficiency as a function of compression ratio for a spark-ignition engine

According to the above charts, the increase in the theoretical efficiency and in the design efficiency is proportional in both cases.

4. Conclusions

The increase in overall efficiency in the real internal combustion engine, compared with the theoretical − Formula 1 does not cause a significant increase in efficiency as a result of increased compression ratio. However, this growth increases by up to 4% in a desired very fast. However, a higher compression ratio makes it possible to expand exhaust gases to increase their volume; as a result, the temperature of exhaust fumes changes and there is a smaller loss of thermal energy.

The development of an engine comparative cycle is the basis for making thermal calculations of the engine.

Searching for new design solutions becomes more and more expensive; it mostly results from the need to go deeper into physical phenomena taking place in an engine. There is a visible tendency to develop engines with a variable compression ratio. The designers are searching for new design solutions to increase the efficiency of engines.

Therefore, adjustment of the effective compression ratio for temporary engine operating conditions is also very a desirable. Therefore, it is looking for effectively address this problem.

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