AN EVALUATION OF THE EFFICIENCY OF THE SYSTEM USED FOR AUTOMATIC CHANGE OF THE IC ENGINES COMPRESSION RATIO

Dragoljub Radonjić [1]

UDC: 621.432:621.513

INTRODUCTION

The movement of a vehicle at the required speed with various vehicle resistance values is what conditions the ICE running, as a drive unit, within distinctly variable modes of operation. Therefore, numerous parameters of an engine's duty cycle have to be altered depending on the mode of operation, that is, load and number of revolutions, for the purpose of achieving optimal output values. The first engine systems, demanding that steering itself should have a function of the mode of operation, represented, by all means, fuel systems and the ones intended for the mixture formation along with the ignition systems. Owing to the development of the electronic engine control system and engine construction technology, the application of an increasing number of variable systems was possible: variable valve timing, variable suction system geometry [13], variable compression ratio (Figure 1). Although we have been acquainted with the ideas and constructive solutions related to these systems for a long time, it is nowadays that their realization and serial application have proved justified.

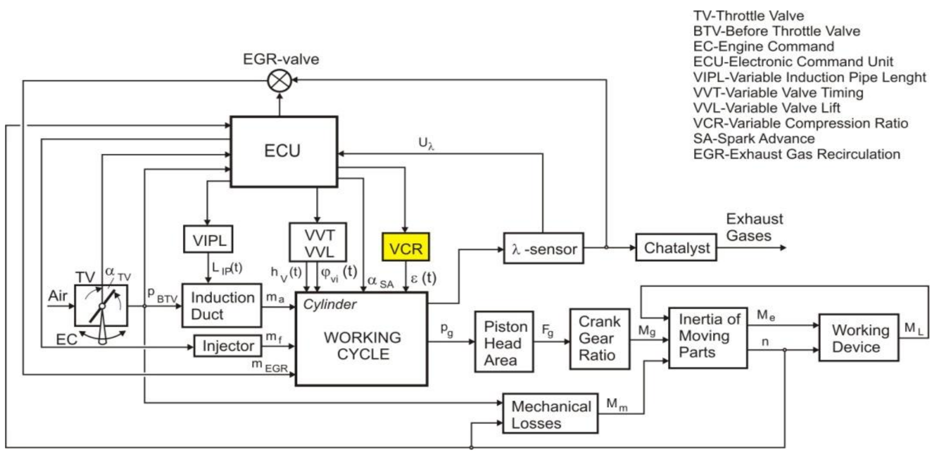


Figure 1.

The research and development of the variable compression ratio engines have become topical for the past few years because they provide us with significant possibilities as

[1] Corresponding author e-mail: drago@kg.ac.rs, University of Kragujevac-Faculty of Mechanical Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia

regards legal regulations referring to emissions and fuel consumption economy along with a significant decrease in the engine dimensions in the case of an application of engine charge. The compression ratio, as a constructive parameter, influences the output engine parameters which, first of all, entail economy (a degree of efficiency) and effectiveness (specific engine running). A diagram given in Figure 2, displays dependence of the compression ratio and indicated mean effective pressure of the spark ignition engine on the compression ratio. As it can be seen from the diagram itself, the compression ratio is limited by the appearance of diesel knock under the full load and the approximate value varying round 10. Therefore, the same value was the maximum projected value when it comes to the spark ignition engine with the constant value of the compression ratio. The engine running under the full load followed by the high values of the compression ratio (>11÷12) is unfavourable, according to the diagram presented in Figure 3, because the required decrease of the ignition advance angle invalidates the gain acquired from the higher compression ratio.

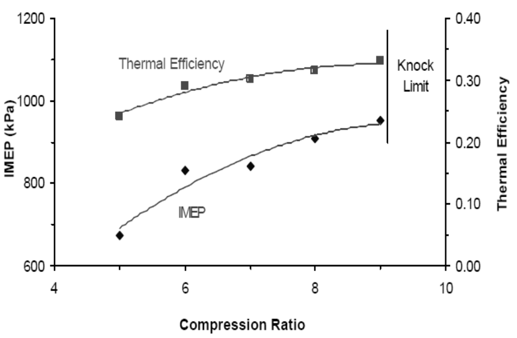


Figure 2 [1].

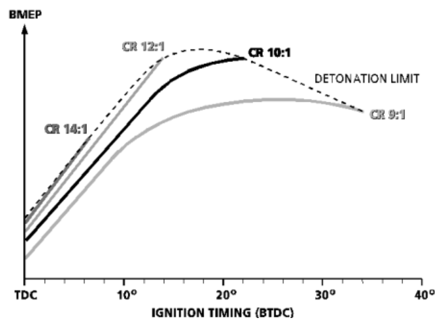


Figure 3 [7].

Since the possibility for the appearance of detonation decreases under lower loads, it is the application of the variable compression ratio engines that enables the use of high values of the compression ratios under low loads and vice versa (Figure 4). With this aim in view, various systems used for the automatic alteration of the compression ratio have been designed, the analysis of which is to be given in the following chapters.

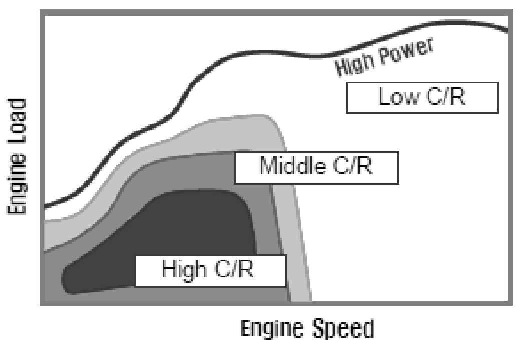


Figure 4 [2].

THE ESTIMATION METHODS OF THE ENGINE COMPRESSION RATIO

The compression ratio, defined as the ratio of the maximum to the minimum cylinder swept volume during the cycle, is known as the geometric compression ratio in literature. What is obtained by using this particular definition along with the designations presented in Figure 5 is the expression necessary for its defining:

$$\varepsilon = 1 + \frac{S}{S_c} \tag{1}$$

where are:

$S = S_{TDC} - S_{BDC}$	-piston stroke,
S_{TDC}	-position of the top dead center,
S_{BDC}	- position of the bottom dead center,
$S_c = S_{VC} - S_{TDC} - h$	-piston stroke corresponding to the compression volume,
S_{vc}	-position of the cylinder head,
h	-distance from piston crown to piston pin axis.

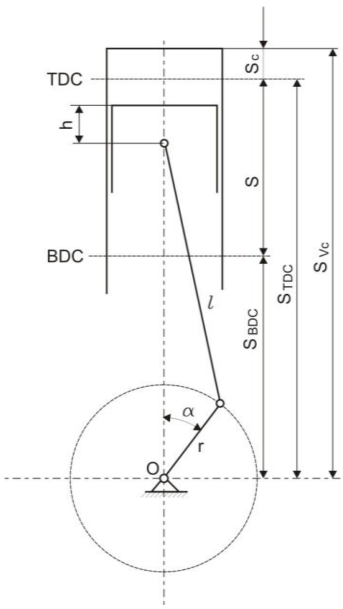


Figure 5.

The effective (actual) compression ratio value can be defined in the most accurate manner based on the ratios between various kinds of pressure occurring within the maximum, that is, minimum cylinder swept volume. In addition, the appropriate pressure values can be obtained from the simulated or experimentally recorded flow pressure during one cycle, fired or motored.

Four methods for defining the compression ratio based on the familiar flow pressure are given in literature. The first three methods are based on the polytropic compression occurring during the cycle and they give good results as regards the cycles with the lower compression ratio values. The higher compression ratios require the use of the fourth method which takes into consideration the exchange of heat and influence of crevice, along with one form of the combustion law when it comes to the fired cycles.

Since the paper itself refers to the relative comparison of the existing systems used for the automatic compression ratio alteration for the purpose of evaluation of their efficiency, the term of the geometric compression ratio defined by the equation (1) can be used, without doubting its accuracy.

THE ANALYSIS OF THE EXISTING SYSTEMS USED FOR THE COMPRESSION RATIO ALTERATION

According to the equation (1), an alteration of the compression ratio values can be done by altering the values S and/or S_c. On the other hand, the foregoing values depend on the motion characteristics and dimensions of the piston mechanism elements, and for this reason, all of the existing solutions regarding the variable compression ratio engines are based on varying of some of these parameters. If their analysis is to be done according to that criterion, it is possible to sort out the following variants on the basis of these systems:

1. Eccentric bearings of:

   a) Main journal,
   b) Crank pin,
   c) Piston pin.

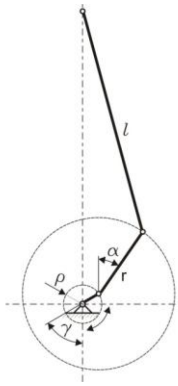
2. Variable connecting rod geometry:

   e) Multi-link rod-crank,
   f) Variation of connecting rod length (mechanical or hydraulic system).

3. Variable dimensions of the piston or combustion chamber:

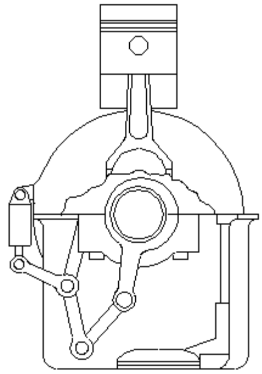
   g) Variable piston deck height,
   h) Variable combustion chamber volume,
   i) Two crankshaft phased piston engines,
   j) Moving cylinder head.

The foregoing variants are displayed in the following figures by using principle charts along with the concrete solutions which are implemented by individual producers.

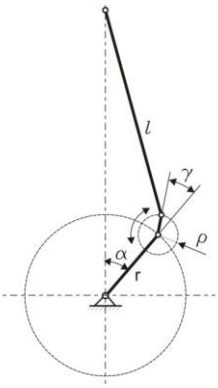


a) Eccentric bearing of main journal

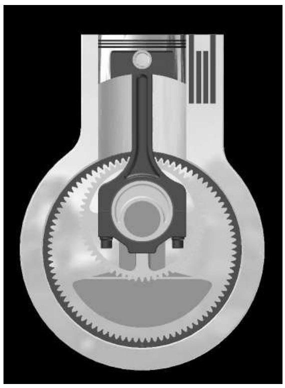
FEV Motorentechnik GmbH [4]



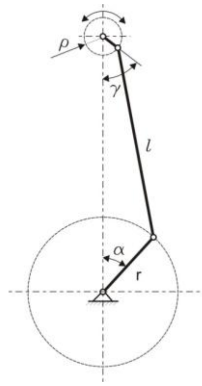
RAPAN Romanian [1]



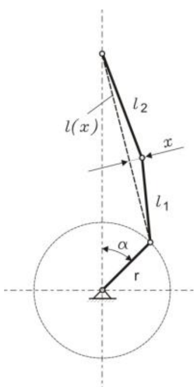
b) Eccentric bearing of crank pin



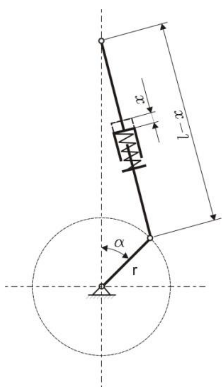
Gomecsys VCR engine [3]



Eccentric bearing of piston pin

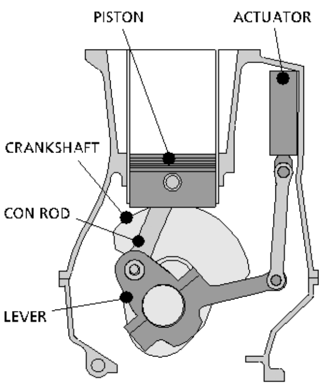


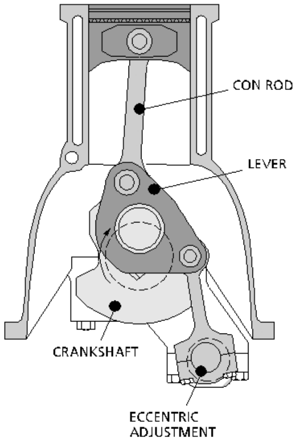
e) Multi-link rod-crank

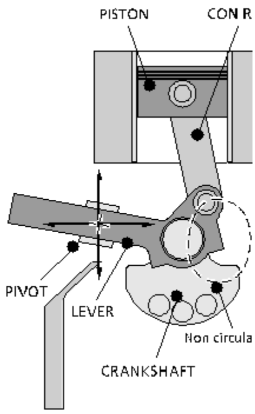


f) Variation of connecting rod length (mechanical or hydraulic system)

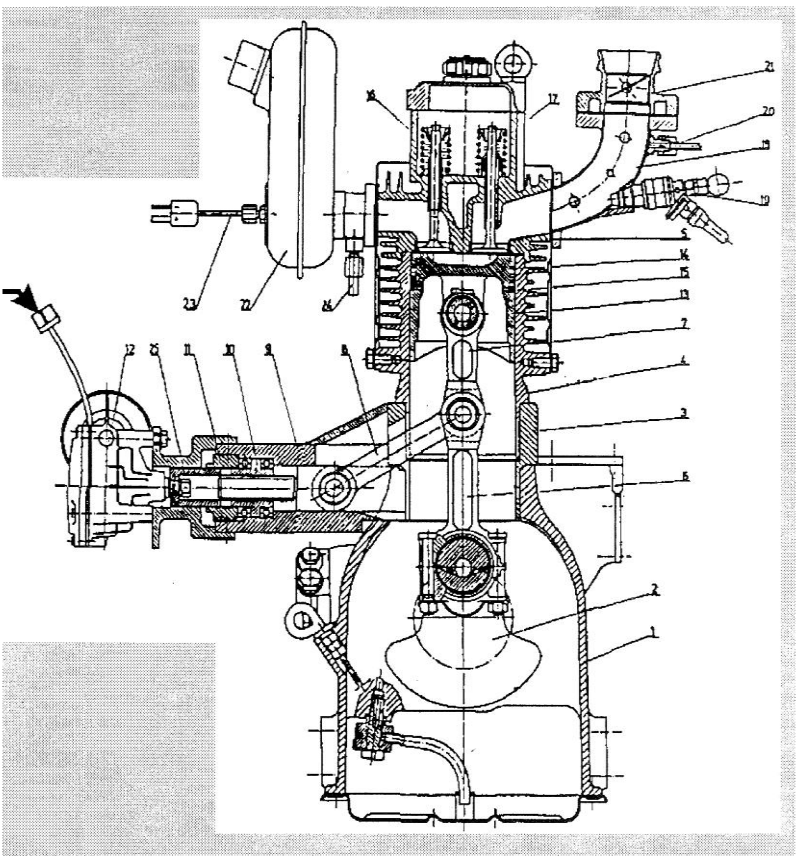
2. Variable connecting rod geometry



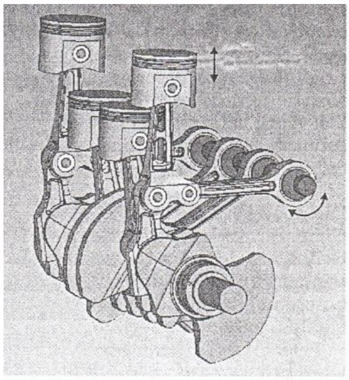




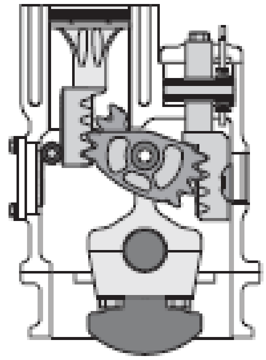
Peugeot [1] Nissan [1] Mayflower e3 [1]



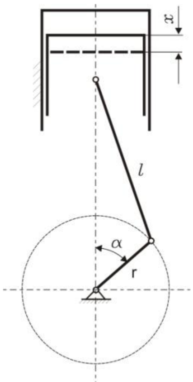
FME Kragujevac [9]



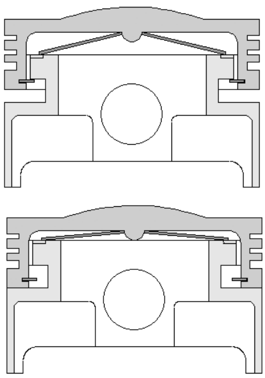
CCE RWTH Aachen [10]



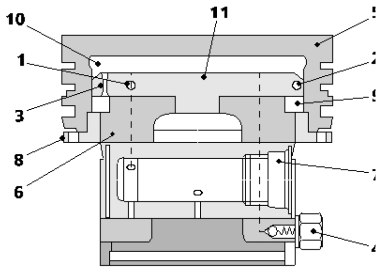
MCE-5 engine [6]



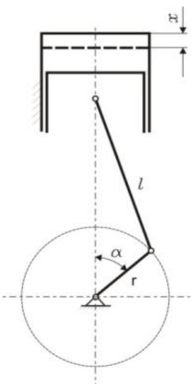
g) Variable piston deck height



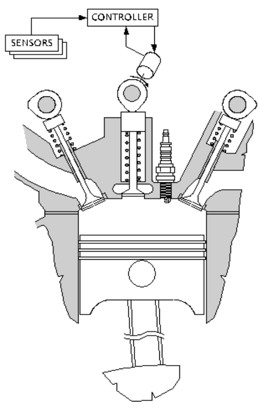
Ford VCR piston [1]



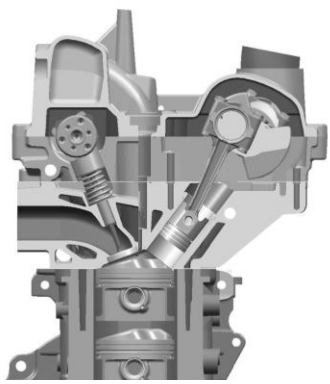
Daimler Benz VCR piston [1]



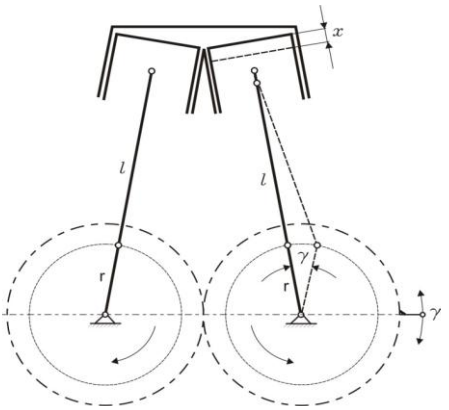
h) Variable combustion chamber volume



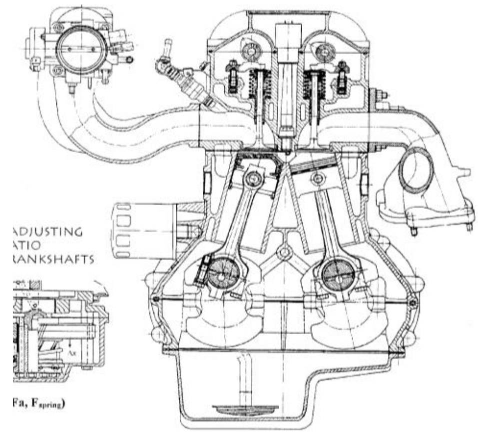
Ford VCR head [1]



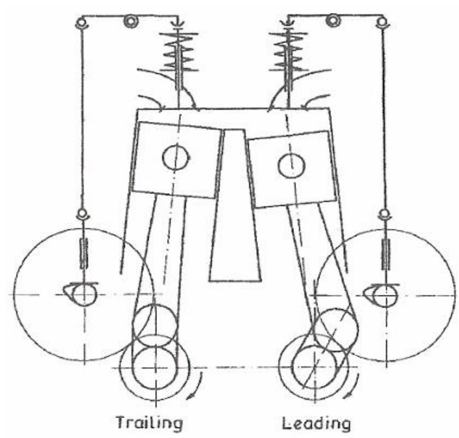
Volvo/Alvar VCR head [4]



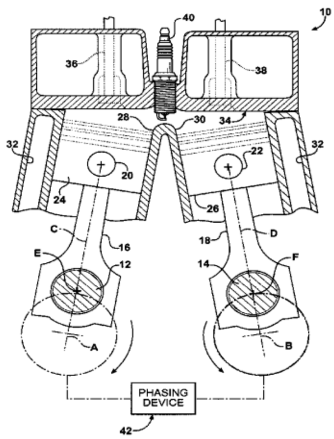
i) Two crankshaft phased piston engines



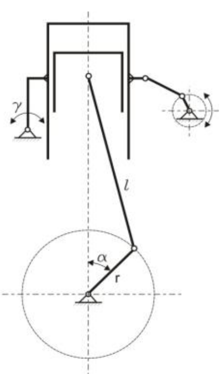
FME Kragujevac (“A”-engine) [9]



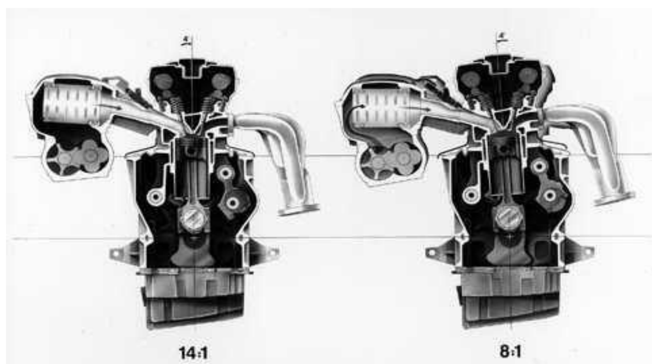
BP/Ricardo Phased pistons [5]



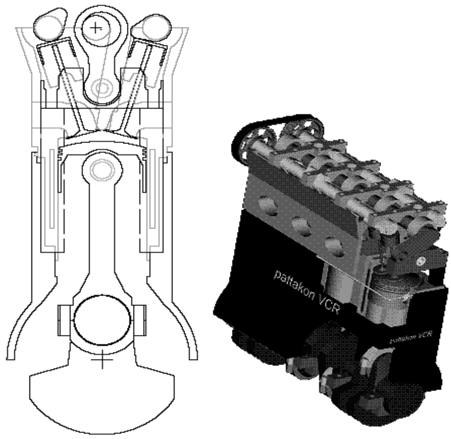
Patent No.: US 7,584,724 B2, 2009. [8]



j) Moving cylinder head



SAAB VCR engine [1]



Pattakon (Greece), Patent US 20100229834, Date: 16.09.2010. [12]

Controlling the work of these systems is done in the function of the engine mode of operation, and in the course of this process the components with the rotary (servo or step motors) or translatory motion (hydraulic actuators) are used as actuators. The specific transmission ratio mechanisms, that is, the gain stage ones are often placed between the control actuator and control object in order to implement the optimum compression ratio alteration law.

Efficiency of the work of these systems can be evaluated by using the compression ratio alteration law having the function of the control values: angle or displacement. Commencing with the equation (1) and some of the basic relations for defining the piston stroke, the appropriate mathematic models of the particular variants of the systems used for the automatic compression ratio alteration have been placed. The appropriate dependencies diagram presented in the following figures have been obtained by using the Simulink program taken from the Mathlab program package. In addition, the curves, which are appropriate for some of the variants, have been marked by the appropriate designations given in the letter forms (*a, b,... j*).

Compression ratios of the variants designated with: *a, b, c, i, j* are expressed in the function of the angular coordinate γ, whereas the displacement x is used as an independent variable with the following variants: *e, f, g, h*. Both coordinates refer to the element displacement which causes the compression ratio alteration, meaning that the model does not take into consideration the transmission ratio of the mechanism placed between the control actuator and that particular element.

The diagrams presented in Figure 6 display the compression ratio alteration having the function of an angle γ for the cases: *a, b, c, i, j*, also, the maximum compression ratio value adopted here is: $\varepsilon_{max}=14$, the angle alteration interval: $\gamma = 0 \div 60^o$, and the relative eccentricity: $\rho/r = 0.2$. The relative eccentricity is designated with: *ro/r* in the diagrams. The following conclusions can be reached on the basis of the form of the curves given in Figure 6:

- the same compression ratio alteration law is valid for the variants *a* and *c*,

- the compression ratio alteration speed (resolution sensitivity) is the least when it comes to the variant *b*, and it is the greatest when it comes to the variant *j*, the confirmation of which is given in the diagrams presented in Figure 7, which represents the abstracts of the compression ratios of these variants.

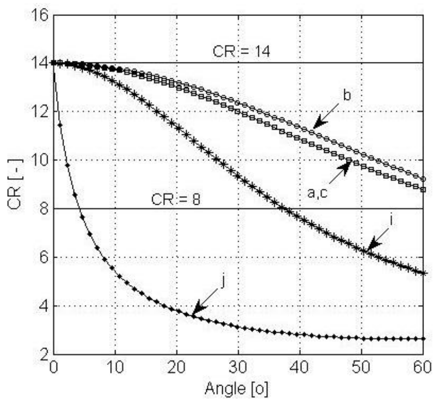


Figure 6.

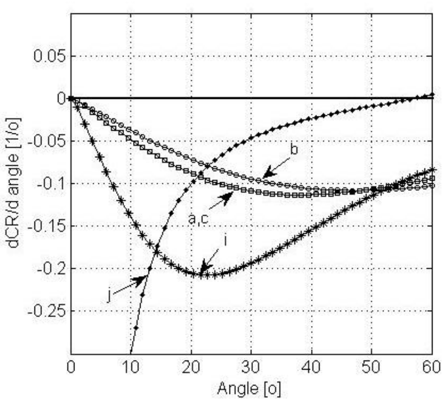


Figure 7.

An increase of system sensitivity of the variants *a*, *b*, and *c* can be realized through the increase of the relative eccentricity, which is shown by diagrams presented in Figure 8 for the variants *a* and *c*, that is, in Figure 9 for the variant *b*.

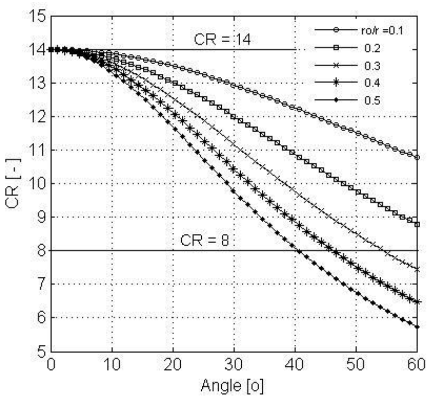


Figure 8.

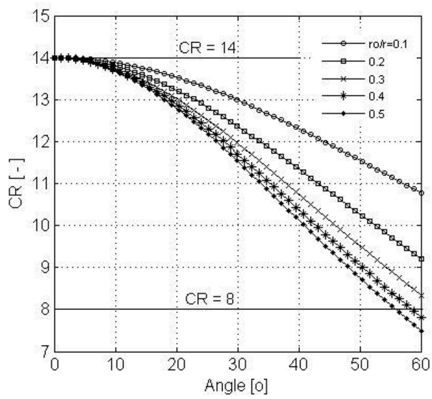


Figure 9.

The characters of the compression ratio alteration, having the function of the relative displacement *x/r* when it comes to the variants: *e, f, g, h,* are shown by means of diagrams in Figure 10. As it can be noticed from the diagrams, the same compression ratio alteration law is valid for the variants: *f, g, h,* while the variant *e* displays an influence of a relation: l_1/l.

Characteristics of these systems regarding the compression ratio alteration speed are shown in Figure 11, owing to the appropriate abstracts from the compression ratio according to the relative displacement: *dCR/d(x/r)*.

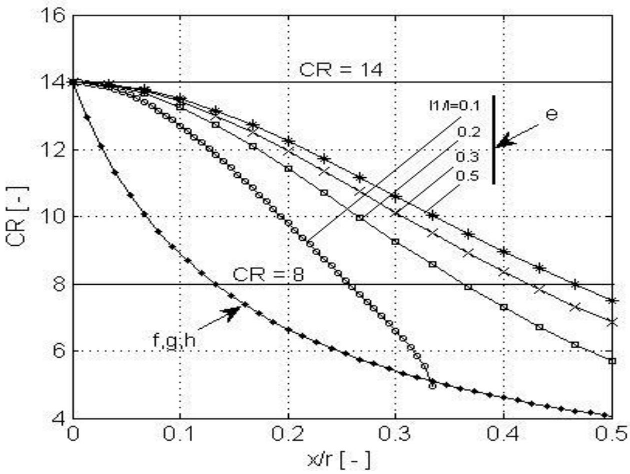


Figure 10.

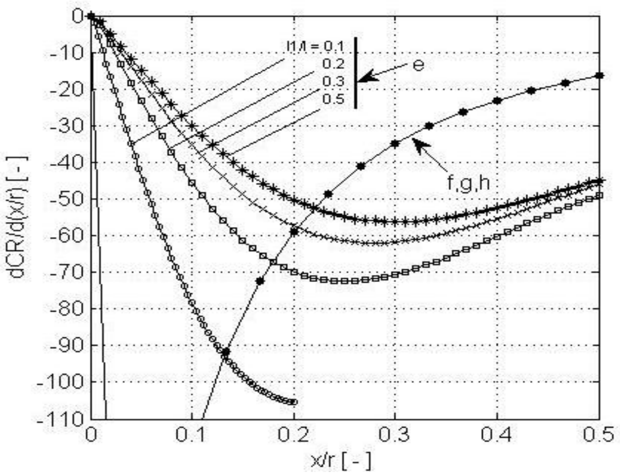


Figure 11.

CONCLUSIONS

The variable compression ratio engines provide significant possibilities regarding the improvement of characteristics of economy and toxicity along with a decrease in the engine dimensions followed by the application of engine charge. When it comes to all of the displayed systems, the compression ratio alteration, having the function of the engine mode of operation, is being performed by altering the dimensions or position of bearings of the piston mechanism elements (crankshaft, connecting rod, piston), that is, by altering the combustion chamber volume (moving cylinder head, phase piston delay). An application of these systems to motors represents a process of making a construction complex to a significant degree and increase of the production cost; also, it often represents a decrease of performance reliability of particular elements, the cause of which is an altered construction along with increased load.

The analysis of these systems' characteristics by means of the Simulink simulation models enables us to establish influential parameters regarding the compression ratio alteration law and evaluation of their efficiency as regards the alteration speed, that is, sensitivity to the control value. According to this criterion, the most efficient systems are: *f, g, h, j* where the compression ratio alters according to the hyperbola law, owing to the fact that they operate with the constant piston stroke *S*, and that compression ratio alterations are done by altering the value S_c (see the equation (1)).

A particularly interesting solution is, by all means, the variant *j*, which possesses the best characteristics according to the above mentioned criteria, and this fact explains why it has been realized with the engine S-5. The compression ratio alteration from 14 to 8 is done for the turning angle of the engine block from 4.2^o. A significant decrease in the engine dimensions is realized in the case of the application of charge to this particular engine.

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