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Particular mechanism for continuously varying the compression ratio for an internal combustion engine

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Abstract. Variable compression ratio (VCR) is a technology to adjust the compression ratio of an internal combustion engine while the engine is in operation. The paper proposes the presentation of a particular mechanism allowing the position of the top dead centre to be changed, while the position of the bottom dead centre remains fixed. The kinematics of the mechanism is studied and its trajectories are graphically represented for different positions of operation.

1. Why continuously variable compression ratio for an internal combustion engine?

An important feature of car engines is the wide variety of operating conditions. Among these, the partial load regimes play an essential role because the operation of these regimes is crucial for the engine's economy. Unfortunately, in these operating conditions the thermal efficiency is much lower compared to the one recorded at full load. In conclusion, constructive solutions that work especially in the area of these regimes should be sought, in order to determine an increase in thermal efficiency.

In the case of spark ignition engines, the quantitative load control by closing the intake channel determines not only pumping losses but also the reduction of the real compression ratio (\(\varepsilon_p\)). Because of the fixed (invariant in operation) value of the geometric compression ratio (\(\varepsilon_v\)), the lower mass of fresh load resulting from the decrease in the load level will occupy the same volume at the end of the compression stroke, so that the mixture will be more less compressed than the situation recorded at full load.

This is the main disadvantage of spark ignition engines. As a result, it becomes economical to increase the geometric compression ratio (\(\varepsilon_v\)) with the decrease of the load level, in this way the value or the real compression ratio (\(\varepsilon_p\)) being restored. In this direction, the variable compression ratio engine could be a very good alternative and its implementation is perfectly valid, taking into account existing technologies [1-3].

At the present there is a wide variety of technical solutions for obtaining the variable compression ratio that are known and presented in the literature. The present article aims to study the kinematic of a particular mechanism, conceived and designed by the authors, which allows continuous modification of the compression ratio by interposing a planar mechanism between the connecting rod and the crankshaft of the classic engine mechanism.

The value of the geometric compression ratio can be changed either by the volume of the combustion chamber or by the total volume of the cylinder, hence the displacement. The mechanism
proposed for the study changes the volume of the combustion chamber by modification the position of the top dead centre (TDC), while the position of the bottom dead centre (BDC) remains fixed.

2. Analysis of plane mechanisms
Analysis of plane mechanisms has evolved over time. Thus in practices are known several methods of analysis of plane mechanisms (positional, kinematic, kinetostatic or dynamic), respectively the graphical methods, graphoanalitics and analytical each of them having advantages and disadvantages.

Graphical and graphoanalitics methods (vector equations method, projected instantaneous centre of rotation, similarity, respectively polygon method forces, etc.), have the advantage that are very easily to use, requires a relative low workload, but the accuracy of results is not always the one, because the measurement error in the graphic plane.

Analytical methods (polygonal contour method) involve writing equations contour projections and their successively derivation, respectively the equations of equilibrium, resulting linear equations systems who need to be solved for as many positions of leadership element. The workload is very high, requiring solving equation systems using programs written in different programming languages, but the accuracy of results is high. This method has the disadvantage that requires knowledge of a programming language.

With the development of CAD software (Computer Aided Design) software companies have developed software packages specific field of engineering. Thus, for modelling and simulating mechanical systems are known several applications such as Mecaplan, Simulation Mechanical, Adams, SAM, Watts & Roberts, etc. some of them doing calculations by finite element method [4].

Further in the following paragraphs will be present the modelling, analysis and simulation of mechanism with SAM 7.1 software.

3. SAM 7.1. software
SAM (Synthesis and Analysis of Mechanisms) is an interactive PC-software package for the design, analysis (motion and force) and optimization of arbitrary planar mechanisms. Mechanisms can either be generated via the design wizards or they can be assembled from basic components including beams, sliders, gears, belts, springs, dampers and friction elements. SAM integrates pre-processing, numerical analysis and post processing, such as animation and xy-plots, in an easy to-use environment offering pull-down menus, mouse support and help facilities.

The mathematical foundation of the analysis kernel, which is inspired by the well-known finite element approach, offers a large number of features and overcomes many of the problems of traditional mechanism programs. Open loop, closed loop, multiple loop and even complex planetary mechanisms can equally well be analyzed due to the finite element formulation. Even the most complex mechanisms, including planetary gear trains, can be modelled within minutes [5].

4. Presentation of the constructive solution of the studied mechanism
The new concept of the mechanism proposed by the authors implies the existence of some kinematic bonds between the connecting rod and the crankshaft, which allow continuous modification of the compression ratio of the engine (Figure 1). The mechanism is a quadrilateral plan and consists of the AM, MB and O₂B elements and the corresponding joints. AP is the connecting rod and O₁M the crankshaft arm.

Modification of the compression ratio is made by the modification by an actuator (mechanical or hydraulic) of the vertical position of the O₂ joint marked in figure 1. This causes the TDC position to change, while the position of the BDC remains fixed. The lengths of the articulated elements of the mechanism were determined by successive tests and correlated with the basic dimensions of the engine mechanism.

The kinematic analysis was performed in order to highlight the trajectory of the head of the connecting rod (point A in Figure 1) and implicitly of the kinematic bonds. Functional variants have been studied by modifying the horizontal and vertical distances between the O₂ and O₁ joints.
5. The cinematic study with the SAM 7.1 software

Using the constructive dimensions obtained from a preliminary analysis, the kinematic connections of the mechanism were designed through the SAM 7.1 software, simulating the movement of the mechanism and connecting rod trajectory.

The process of designing mechanisms basically can be divided into two distinct phases, namely: synthesis and analysis. After a proper specification of the demands, the first step in the design cycle consists of the synthesis phase, in which the designer attempts to find the type of mechanism and its dimensions, such that the requirements are met (as good as possible). Experience, previous designs, mechanism handbooks and the design wizards implemented in SAM can guide this creative process. Once a mechanism has been chosen, its motion and force behaviour can be analysed [5].

Next we have the results of the kinematic analysis for the case where the horizontal O₁O₂ distance ([O₁O₂] x - Figure 1) is 80 mm (figure 3) and 100 mm (Figure 4), and the vertical O₁O₂ distance ([O₁O₂] y - Figure 1) is variable (-30, -20, -10, 0 and +10 mm), in each of the two cases.
From Figures 3 and 4 one can notice the modification of the TDC position with the modification of the distance \([O_1O_2]_y\), while the BDC position remains fixed. In the case of Figure 3, with \([O_1O_2]_x = 80\) mm, the compression ratio varies between 4.04:1 and 8.73:1. In the case of Figure 4, with \([O_1O_2]_x = 100\) mm, the compression ratio varies between 3.65:1 and 8.49:1.
100 mm, the compression ratio varies between 4.63:1 and 12.06:1. Next we have the comparative results in the case of the constant holding of the relative position of \( O_2 \) joint in relation to \( O_1 \) joint, in the vertical direction, in the two variants: \([O_1O_2]_x = 80 \text{ mm}\) and \([O_1O_2]_x = 100 \text{ mm}\).

**Figure 5.** Piston stroke depending on the angle of rotation for \([O_1O_2]_y = -30 \text{ mm}\)

**Figure 6.** Piston stroke depending on the angle of rotation for \([O_1O_2]_y = -20 \text{ mm}\)
Figure 7. Piston stroke depending on the angle of rotation for \([O_1O_2]y = -10\) mm

Figure 8. Piston stroke depending on the angle of rotation for \([O_1O_2]y = 0\) mm
Figure 9. Piston stroke depending on the angle of rotation for \([O_1O_2]_y = +10 \text{ mm}\)

6. 3D modeling of the mechanism
In addition, a 3D modeling of the mechanism with the AutoDesk Inventor software was performed, during which the time depending piston displacements, speeds and accelerations were determined [6-8].

Figure 10. 3D motion simulation interface

For space considerations, only variations of the displacement, velocity and acceleration of the piston, in function of time, will be presented for the configuration of the mechanism having: \([O_1O_2]_y = -30 \text{ mm}\) and \([O_1O_2]_x = 100 \text{ mm}\).
Figure 11. Piston stroke time function for \([O_1O_2]y = -30\) mm

Figure 12. Piston velocity time function for \([O_1O_2]y = -30\) mm
7. Results and conclusions
In conclusion, for the higher performances in relation to engine economy, the \([O_1O_2]x = 100 \text{ mm}\) variant of the mechanism can be chosen because the variation of the compression ratio is higher, ranging from \(4.63:1 \div 12.06:1\), compared to \([O_1O_2]x = 80 \text{ mm}\) variant, which provides a compression ratio ranging from \(4.04:1 \div 8.73:1\).

As is shown in Figure 13, at certain points of the trajectory of the mechanism, the accelerations are very high, which is why it is necessary to thoroughly study the dynamics of the motor mechanism and implicitly the calculation of the forces that occur during operation.

References
[1] Gabor A 2012 Contribuții la determinarea răspunsului dinamic al motoarelor cu raport de comprimare variabil [Contributions in determining the dynamic response of the variable compression ratio engines], Transilvania University of Brașov, Romania, Doctoral Thesis
[2] Rațiu S and Mihon L 2008 Motoare cu ardere internă pentru autovehicule rutiere – Procese și caracteristici, [Internal combustion engines for road vehicles – Processes and Features], Publisher: Mirton, Timişoara, Romania
[3] Bosch Automotive Hand–book, 8th Edition, May 2011
[4] Miklos I Zs, Alic C I and Miklos C C 2010 Analysis of seat positioning mechanism in road vehicles Acta Technica Corvinensis – Bulletin of Engineering III(3) 27-30
[5]***http://www.artas.nl/en/downloads, SAM 7.1 - The ultimate mechanism designer, © 2014 ARTAS - Engineering Software - User Guide
[6] Cioată V G and Kiss I 2017 Dynamic analysis and parametric optimisation of the connecting rod using Autodesk Inventor, Machine Design 9(1) 29-34
[7] Cioată V G and Kiss I 2010 Computer Aided Design of the connecting rod, Machine Design 2(1) 83-86
[8] Cioată V G and Miklos I Z 2009 Computer Aided Design with Autodesk Inventor (in romanian), Publisher: Mirton, Timișoara, Romania