Kinematics of a Variable Compression Ratio Engine

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Abstract: - This article presents one of the actual solutions of VCR engines and its characteristics, the task being to study the kinematics of the concept for a mass-produced engine in terms of functionalities, reliability and durability while presenting reasonable production costs. Changing the geometry of the crank rod linkage in an internal combustion engine leads to changes in the system kinematics and modifies the stresses which occur in such a system. For this reason, when designing an engine with variable compression ratio, kinematics and then, a dynamic calculation must be done to determine the new strength of different components. The article presents an analyze of the kinematics of system for a variable compression ratio engine with a rotating block.

Key-Words: - Variable compression ratio VCR, engine, fuel-efficient

1 Introduction
Designing high performance vehicles that are fuel efficient and clean is difficult since we also want them to remain inexpensive. It is useless venture to produce low fuel consumption vehicles that do not sale well because they are too expensive. It is therefore necessary to find simple, low cost and effective solutions, and that is the whole strategy of the Variable Compression Ratio (VCR) engine producers. Far from being a revolution, VCR engines are a major evolution of conventional engines [1].

2 Kinematics of a system with rotating cylinder block
The engine implement VC by an innovative and interesting method - slidable cylinder head and cylinder. As can be seen in the picture below, the SVC engine has a cylinder head with integrated cylinders - which is known as monohead. The monohead is pivoted at the crankcase and its slope can be adjusted slightly up to 4 degrees, in relation to the engine block, pistons, crankcase etc. by means of a hydraulic actuator, therefore the volume of the combustion chamber , when piston is in compressed position, can be varied. SVC is cleverer than any previous patents for variable compression ratio engines because involves no additional moving parts at the combustion chamber or any reciprocating components, so in theory is simple, durable and free of leakage. The monohead is self-contained, that means it has its own cooling system. Cooling passages across the head and the cylinder wall. There is a rubber sealing between the monohead and engine block. The VC allows the Saab engine to run on very high supercharging pressure - 2.8 bar. So high that today's turbochargers cannot provide. Therefore it employs supercharger instead. At other speed, the VC is adjustable continuously according to needs - depends on revs, load, temperature, fuel used etc., all decided by engine management system. Therefore power and fuel consumption can be optimized at any conditions. The prototype is an inline 5-cylinder with 4-valve head with a displacement of 1598 cm³. Compression ratio can be varied between 8:1 and 14:1. With the supercharger, it output a maximum 225 hp and a torque of 305 Nm, with a very low fuel consumption. Saab claims it saves 30% compare with equally powerful conventional engines. In terms of specific output, it achieve 150 hp per litre. At the same time, the emissions of carbon dioxide are reduced proportionately to the fuel consumption, while the CO, HC and NOx emissions enable the SVC engine to fulfill the EU4 emission regulations. The engine management system detect the fuel grade and decide the most appropriate compression ratio to be used [1]. The mechanics of a such engine is computed using [4],[5],[6].
Let’s suppose the engine in the initial position. The kinematic calculation for this position is made with classical methods. If the engine rotates with an angle $\alpha$, then two sets of data changes in the formulas that describe the system kinematics: first the eccentricity of the rod-crank system and second, the position of the upper and lower dead point. This modification can damage the engine and therefore requires a precise calculus.

For any movement of the cylinder block the eccentricity will increase. If the initially eccentricity is zero, by rotating the cylinder block in either part, the eccentricity will increase, causing the modification of the compression ratio. The zero point to start the cycle becomes in this case point of $\alpha$ angle. The OC distance remains constant during the rotation, the axis $C_x_1$ becomes, after the rotation with an $\alpha$ angle, the axis $B_x_1'$.

The figure 2 shows the cylinder block rotation with an $\alpha$ angle and the figure 3 shows a sketch that allows the calculation of the new eccentricity, after the rotation. The eccentricity $e$ becomes $e'$ and we can write [2]:

$$e' = BD = R + e - OD = R + e - R \cos \alpha = e + R(1 - \cos \alpha) > e$$

If the cylinder block rotation is directly counterclockwise, the mathematic relations remain the same, with the observation that the angle $\alpha$ from previous formulas changes with angle $-\alpha$. 
Let us now deal with the calculation of the compression ratio for an engine with variable compression ratio, depending on the cylinder block rotation. To calculate the compression ratio when we know the eccentricity, we analyze Fig.5.

\[
\sin \beta_1 = \frac{e}{r+l}; \quad \sin \beta_2 = \frac{e}{l-r};
\]

The monocylinder stroke in this case is:

\[
s = D_{\text{max}} - D_{\text{min}}
\]

and the compression ratio:

\[
\frac{1}{\varepsilon} = \frac{s_o}{D_{\text{max}} - D_{\text{min}} + s_o};
\]

If the engine block is rotated with an angle \( \alpha \), the eccentricity becomes \( e' \) and the formulas for the piston displacement are:

\[
D'_{\text{max}} = \sqrt{(r + l)^2 - e'^2}; \quad D'_{\text{min}} = \sqrt{(l - r)^2 - e'^2};
\]

and the angles made with the piston axis are:

\[
\sin \beta'_{1} = \frac{e'}{r+l}; \quad \sin \beta'_{2} = \frac{e'}{l-r};
\]

The monocylinder stroke changes:

\[
s' = D'_{\text{max}} - D'_{\text{min}}
\]

and the compression ratio:

\[
\frac{1}{\varepsilon'} = \frac{s'_o}{s'_o + s''_o};
\]

The \( s_o \) becomes:

\[
D' = s'_o = s_o + D_{\text{max}} - D'_{\text{max}}
\]

so the compression ratio is:

\[
\frac{1}{\varepsilon''} = \frac{s_o + D_{\text{max}} - D'_{\text{max}}}{s_o + D_{\text{max}} - D'_{\text{min}}};
\]

Fig.6 presents the extreme positions of the rod-crank system for a rotated cylinder block.
There is a very small variation of the compression ratio for neighboring positions of the initial position. For a better view of the variation for small angles, a chart was made; with a range of variation of 10 degrees for the rotation angle (initially it was 120 degrees). The following chart was obtained:

So for a variation of 10 degrees of cylinder block rotation, a variation of 0.05% in compression ratio is obtained.

3 Conclusion

The modification of the engine block position leads to the geometry changing of the crank rod mechanism and in the end, to stress changes in the crank rod system. Consequently, the design of such an engine, involves a kinematic and dynamic calculation for the components of the engine to see if there will be new stresses that will result from the rotation of the engine block.

ACKNOWLEDGEMENT

1. This paper is supported by the Sectoral Operational Programme Human Resources Development (SOPHRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/88/1.5/S/5932.

2. This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/89/1.5/S/59323.

3. This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/6/1.5/S/6.

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