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SIMULATION AND ANALYSIS OF AN INTERNAL COMBUSTION ENGINE WITH VARIABLE COMPRESSION RATIO

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ABSTRACT

One of the disadvantages of gasoline engines to diesel engines is their low efficiency.However, due to less pollution of gasoline engines, extensive activities are done in order to increase their efficiency. One of the methods considered in this context is the use of Variable Compression Ratio (VCR).

The aim of this study is to collect and introduce the existing technologies presented for VCR engines.Also, one of the newest and most useful of these projects (MCE-5) that has been designed by one of the research companies in European, and is currently at the experimental stage, simulated and analyzed in this paper and its performance is discussed in terms of the stress distribution.Stress analysis has been done using the commercial software package ABAQUS ™.Obtained stress distribution in maximum cylinder pressure indicates good performance of the proposed system.Using the resulting stress distribution, the proposals to reduce the destructive stresses can be proposed, as an example has been observed and a solution is proposed to amend it.

KEYWORDS: Variable Compression Ratio (VCR); internal combustion engine simulation; stress analysis

INTRODUCTION

One of the important fields of work that is now being considered in the context of the engine is engines with Variable Compression Ratio[1] (VCR).The basic idea of this type of engine was introduced at the 1980, and to date, several samples are made and considered.However, so far no VCR engines are made in bulk and for commercial use due to the relatively high cost of this type of engine.However, it is predicted that, with proposing the new plans that their construction costs are lower, also due to the ascending energy costs in the world, these engines are economical, and in the future they are massively used.

To find out more on the benefits of the VCR, there is need to create different relationships between gasoline engines theory, which are also called spark ignition engines, and their practical applications.To this end, we examine the cycle of expansion and compression.In a four-stroke cycle internal combustion engine, the air-fuel mixture is drawn into the cylinder, and then is compressed by the piston. Then, the air-fuel mixture is ignited by an electric spark.The energy released of fuel is converted to heat, which increases the gas temperature, and subsequently it also increases the pressure.The pressure of gases ultimately is transformed as the work done by the piston during the expansion work.Volume ratio between the beginning and the end of expansion is the main factor determining the efficiency of the engines, and a higher ratio means better efficiency.Engine experts call this ratio generally "compression ratio".

Between the engine with a compression ratio of 1 to 7, and another engine with a compression ratio of 1 to 10, the difference in efficiency is about 10%.Between the compression ratio of 1 to 10 and 1 to 14, a difference is about 7%, but the high compression ratio of 1 to 17, increasing the compression ratio has no effect on efficiency.

In theory, to get the best performance possible, gasoline engines must have a fixed compression ratio of 1 to 17.In practice, high compression ratios are not effective.Under high loads, pressure and temperature in the combustion chamber is too high, and the gas mixture is ignited spontaneously.To stop the impacts under high loads, for example when there is a high speed or traveled slope, new engine compression ratio is approximately 1 to 10.However, this decrease in density has a negative effect on performance and consumption.In fact, the engines work under high loads in some cases.In fact, cars are used usually in the low load.During driving in the city or highways,

[1]Variable compression ratio

or even on intercity roads at a constant speed, the accelerator pedal is pressed only slightly to the bottom.For this reason, increasing the compression ratio of 1 to 14 or 1 to 15 is possible without causing impact.

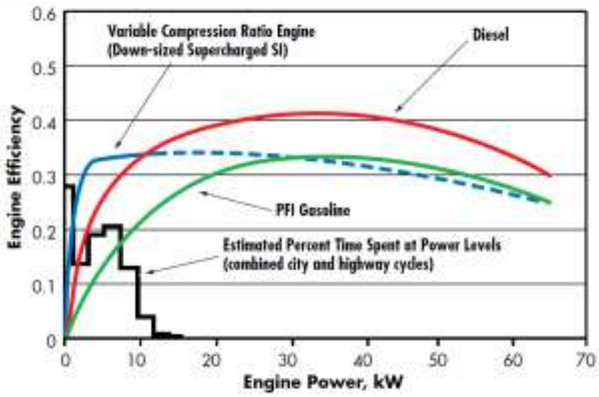

Figure 1- Comparison of the efficiency of internal combustion engines [1]

In Figure 1, the comparison between the efficiency of internal combustion engines, petrol and diesel are shown.Diesel engines due to the higher compression ratio compared with gasoline engines have more efficiency.However, due to lower-emission gasoline engines, this type of engine has attracted more attention.The use of variable compression ratio is a new strategy which proposed to increase the efficiency of gasoline engines.

Adapting variable compression ratio to driving conditions permanently is one of the most important advantages VCR, which is associated with an average of 5 to 7 percent reduction in fuel consumption.As shown in Figure 1, according to the average of time that cars run on low power makes the efficiency of VCR engines is even higher than diesel engines.Taking step toward the VCR begins with a mechanical challenge.However, statement of problem is easy, but finding the solution to is difficult.This is because, the compression ratio, is controlled inevitably by the activity of member which transfer force.That is, exposed to gas pressure and inertia forces generated by moving elements.Controlling the compression ratio without causing major problems is an important problem that investigations are ongoing to solve it.

In the case of internal engine aerodynamics, fixed compression ratio, topics such as the efficiency and production of pollution, unchanged cylinder head, the shape of the combustion chamber and piston kinematics were very important, which each of these cases during the last decade have developed and improved for use in conventional engines.

If necessary, VCR engine has a complex mechanism, but its mechanical efficiency is considered as a significant advantage relative to conventional engines.

In total, the most important challenge for VCR engines is to find a plan which with least complexity possible provides the possibility of change of the compression ratio according to engine operating conditions.

MATERIALS AND METHODS

Mechanisms of VCR

In March 2000, the Saabmanufacturer unveiled its car with variable compression ratio, the car was equipped with a 1.6-liter supercharger, and it was called "SAAB Variable Compression" (SVC) [2].SVC engine had power 168 KW (228 hp) and torque305 Nm.Saab claimed that the engine can reduce fuel consumption to 30% compared to conventional engine with equivalent power.In addition, the FEV Motorentechnik Company unveiled its conceptual model on variable compression ratio, which was a 1.8-liter engine that was mounted on an Audi A6car.In this sample, the fuel consumption was reduced by 27% [3].

The two engines were compared with 6 cylinder 3-liter engines, and considered as a good source to achieve important results.

Based on observations made, it was found that, VCR engines even in comparison with Fixed Compression Radio (FCR)sophisticated engines have higher fuel consumption.

Currently, the most famous VCR engine is a SAAB SVC engine.The engine controls compression ratio using the rotation of the upper element.The advantages of this engine include the lack of change in the moving elements of the common engines.

Figure 2: SVC engine made by SAAB Company

The combustion chamber shape and SAAB SVC piston engine kinematics are an essential element of it which makes it possible to change the compression ratio (Figure 2).In this project, with rotation of crankshaft which connects the upper element of the engine to the engine body, the combustion chamber resizes.SAAB Engine has the undeniable benefits. But there is a major problem in the engine building, redesign of cylinder head, the engine body and cylinders.In conventional engines, cylinder heads, engine body and bearing rings are tightly screwed, which have been formed a rigid integrated unit.Thus, the favorable performance of moving elements in a variety of conditions, as well as vibration and noise will be guaranteed.This is more tangible in the powerful engine.Design offered by SAAB, because of rotation of two elements of the engine to each other reduces the overall stiffness of engine.In addition, the rotation of the upper element of the engine creates additional problems:The connection between the exhaust pipe and manifold, keeping the engine in a suitable pyramidal shape and sound emission limit and keeping power of the vehicle as a constant value.

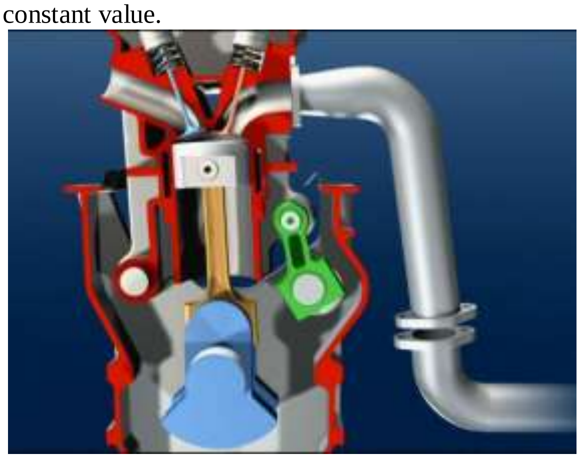

Figure 3: SVC engine problem in the motor connections

Another point worth noting is that the SAAB SVC engine does not have the ability to change the compression ratio for cylinders individually.VCR engine design proposed by the FEV Company uses a system called (CCP) control the crankshaft position to change the compression ratio of the engine.Such as SAAB SVC, the engine benefits from the moving elements as all conventional engines.The difference is that, the compression ratio is changed using placing the crankshaft bearings on the out of center holes (Figure 4).

Figure 4: The CCP design for VCR engine

The FEV engine, like Saab SVC, does not change the combustion chamber shape and piston kinematics. However, this plan has its own problems.Performance of crankshaft hydrodynamic bearings in this project in addition to their machining precision bearings is also dependent on the geometry of the hole out of the center that the need for high precision machining of these holes will be arisen.Moreover, because of the mobility of the crankshaft axis of rotation, it can't be connected directly to the power transmission system, and there is a need to redesign the interface.In the case of this project, as the SAAB SVC project, operators must change the compression ratio, should be strong enough to withstand the force of the gas pressure of the cylinders.It is not also possible to change the compression ratio in the cylinder separately in this project.

Figure 5- VCR engine made by FEV Company

Many schemes have been proposed to change the compression ratio of the engine, all of which are in the early stages, and practical problems are prevented

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from achieving them and mass production. In this context, we can mention the following:The design of ALVAR Company, that uses an additional piston for changing the volume of the combustion chamber, the model of MAY FLOWER Company whixh uses a slider mechanism to change the angular position of the crankshaft and finally, the model of Ford-Daimler-Benz engine design Company which uses the piston with mobile crown to increase or decrease the volume of the combustion chamber.

MCE-5 engine

The main mechanism of the MCE-5 engine is shown in Figure 6. [4]. In this scheme, the switching control piston, the position of the upper element of the main piston is changed and thus, combustion chamber volume changes.MCE-5 prototype model has the ability to use a compression ratio of 1 to 7 to 1 to 20 without changing the kinematics piston.Unlike most VCR engines, TDC[2] in MCE-5 engines crankshaft is always synchronized with the source position.Unlike some members VCR engines the MCE-5 volume is always remains unchanged.MCE-5 includes a number of bearings that such conventional engines are pressure lubricated.MCE- 5 is compatible with all existing cylinder heads and combustion conditions are such as common engines and have the ability to function at its maximum and minimum compression, control of it makes us possible to have variable compression ratio.

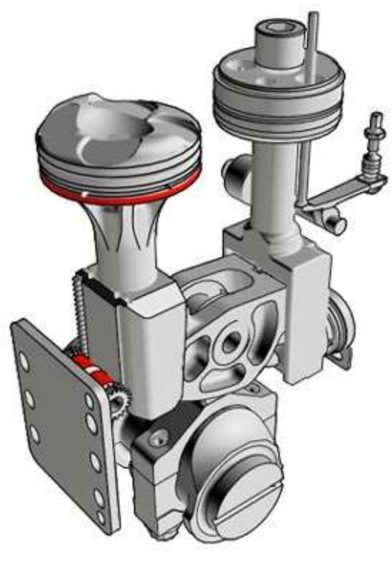

Figure 6: The MCE-5 engine

[2]**top dead centre**

Moving elements of the MCE-5 Engine are heavier than gasoline engines, but this engine significantly reduces fuel consumption and delivers high power and torque.

Figure 7: The MCE-5 engine elements

MCE-5 engine moving elements

It should always be in the minds of that, "How can create a balance between the loss of vibration and the engine power.In the case o MCE-5f motor, cycle efficiency is more important.And its results include high torque, high power and fuel efficiency. However, in conventional engines, piston friction losses are not created only by shear stress in the oil, and are due to motion of the piston and cylinder.But the axial load is transferred by connecting rod to the sides.Unlike conventional engines, the top element of the MCE-5piston is not subjected to radial stress. And as a result, reduces friction losses and wear of the cylinder, despite the great sweep, MCE-5 mass is not comparable to diesel engines, and doesn't increase the friction losses. Also, common spark ignition engine compression ratio produces the greater inertia.For example, if the MCE-5, which has a 200 horsepower power, is compared with a diesel engine that has 160 horsepower power, you can see that, both of them have the same inertia force.However, one of the advantages of piston guidance in the MCE-5 is not limiting the range of motion of the piston and the radial stress removal. MCE-5 piston guide prevents the quick kick of piston. In conventional engines, a quick kick in the piston occurs when the piston moves from one side of the cylinder to the other side of the cylinder. These rapid impacts occur during the 720 degree cycle, 6 times.Biggest piston impact occurs at the beginning of the expansion phase.The angle of bar is changed after the vertical position.When the piston is placed under gas pressure, parameters such as position change its angle, and there is also the possibility of a collapse of the piston and cylinder.Piston stroke causes noise and friction. The cause of abrasion is in the cylinder and cavitation is in the outside of it, as well as fuel consumption also increases.There is this problem in MCE-5, the piston in them is always in contact with one side of the cylinder, and depends on the compression ratio.At the low compression ratio, piston is on one side of the cylinder, and at the higher the compression ratio, the cylinder is in contact with the other side. There is no change in the exposure of them during one cycle to another cycle. So there is not a lot piston stroke.When, there is no piston stroke, there is no friction between the grooves and rings, and contact in the cylinders is improved.When there is no piston stroke and piston radial, friction in the cylinders is also reduced and minimized,which in turn, reduces the angular strain in engine life.Lack of parameters such as, radial stress of piston, piston strokes and reduced wear and strain on the cylinder is associated with ring-shaped tensions,and thus, reduces resident friction losses.Now, we investigate different elements of the engine.MCE-5Engine is a comprehensive engine which combines Innovative Elements (which transfer the power from piston to the crankshaft), and uniqueincentives (which control the compression ratio of the engine).Main components of the MCE5 VCR engine block are shown in Figure 8.

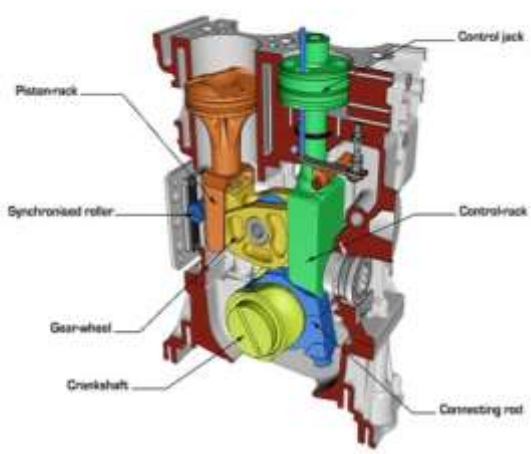

Figure 8: The MCE-5 engine elements

RESULTS AND DISCUSSION

Stress analysis in the main elements of the MCE-5 engine by using ABAQUS software

The model used in finite element analysis is shown in Figure 9. Element 3 in order to make easy the calculations is considered as a rigid object and all degrees of freedom are constrained.

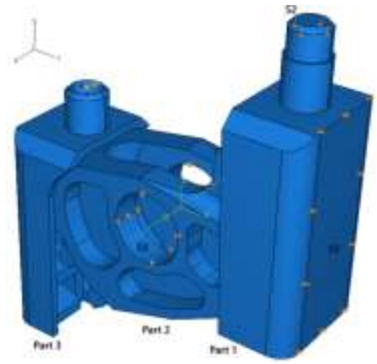

Figure 9: Components used in the stress analysis of MCE-5 engine

S1 surface motion is constrained in the directions of 1 and 3, and the S1 surface motion is in a way which only can be rotated around the axis plotted in Fig.The system situation in the most critical mode is considered, when the maximum pressure is applied on the element 1 from the piston, and the piston force is applied through the surface S2 to the Finite element model.

Figure 10: Applying load of the piston

In order to avoid the instability of the solution, due to a collision between surfaces, the solution is done in two stages.In the first phase, the boundary condition of shift for -0.001 mm on the direction 2 is applied and the contact surfaces of elements 1 and 2 will be involved.In the second stage, the displacement boundary condition is removed, and the force calculated of piston is applied on the S2 level as pressure boundary condition (Fig. 10).To mesh elements, the size of the side of 5 mm is used, and at the contact between the element of 2 and 3, the size of sides of 1 mm is used.Type of element for elements 1 and 2 is selected as C3D4 four-sided element 3 and for element 3, C3D8 hexagonal is considered.Element 3 is modeled because little movement during the piston's movement using rigid elements (Figure 11).

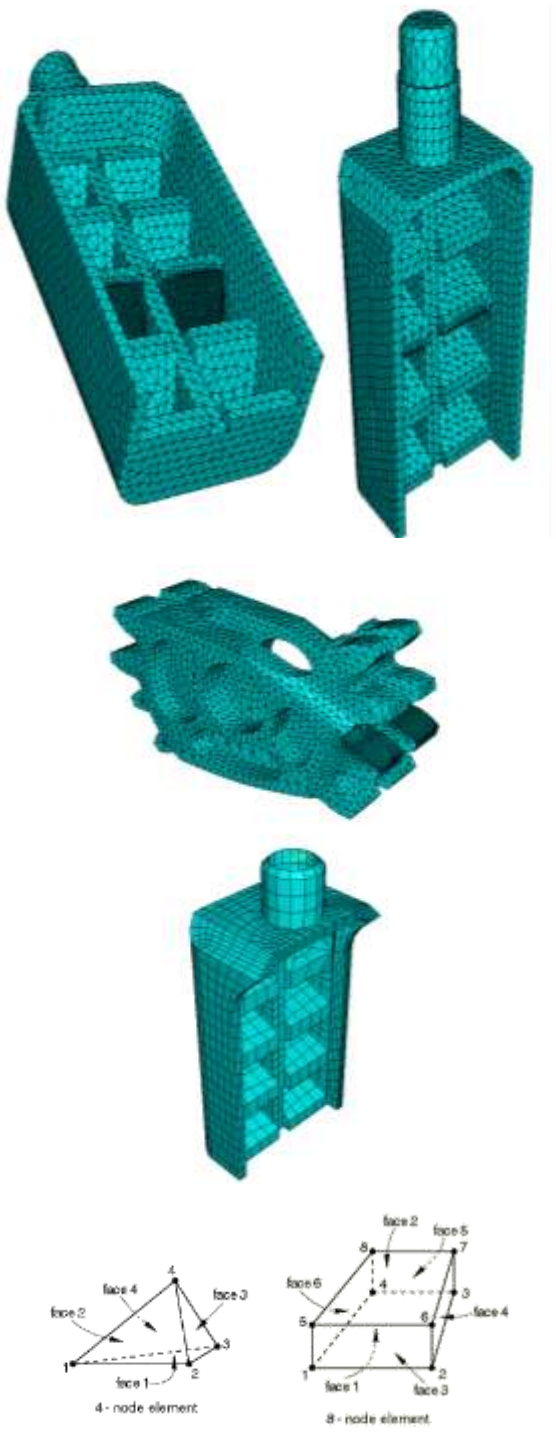

Figure 11: Elements of parts

*T*he time of 0.1 s is considered for each of the solutions steps and static solution with variable time steps is selected between $1*10^{-6}$ to 0.1 and 0.001s is considered as the initial value.Stress distribution (von Mises stress) in the system is shown in Figure 12.The maximum stress in pieces is calculated as 875 MPa.Of course, stress to 3,000 MPa is created on both sides of the gears involved in gear surfaces that this is cut.

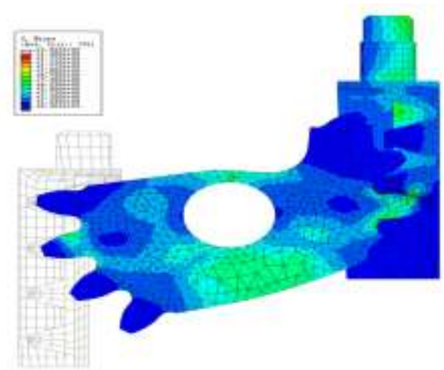

Figure 12: Distribution of stress

CONCLUSION

The size of the MCE-5 VCR 1.5 and 4-cylinder engine includes a combination of compact engines' dimensions (length and width) and diesel engines (Height). Furthermore, VCR 1.5 liters engine can be used in all cars, the same as similar conventional engine is used, and in addition to producing a high torque (160 KW and 300 Nm), it has low fuel consumption as well.Because of these features, MCE-5 technology offers solutions for application of VCR engines with high power andefficient fuel in a wide range of cars.When we talk about final costs of MCE-5 technology, remembering the fact is very important that, MCE-5 is not a perfect engine, but only is a VCR engine block.However, certain parts of it are in accordance with the specific requirements of the VCR and the power and torque, but other engine components technically remain unchanged (cylinder head, pipes, peripheral devices).

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