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THE NUMERICAL INVESTIGATION OF THE WEAR AND HEATING OF ENGINE PISTON AND CYLINDER FOR THE CASE OF TRIBOLOGICAL INSERTS APPLICATION

Ivan GRUJIC[1], Zeljko DJURIC[2], Nadica STOJANOVIC[1,*]

[1]Faculty of Engineering, University of Kragujevac, 6 SestreJanjic STR., 34000 Kragujevac, Serbia

[2]University of Banja Luka, Faculty of Mechanical Engineering, Bulevar vojvode Stepe Stepanovica 71, 78000 Banja Luka, Republic of Srpska

*Corresponding author: nadica.stojanovic@kg.ac.rs

Abstract: *The IC engine cold start represents the most critical moment from the aspect of mechanical loads of piston and cylinder. The reason for this is non-existence of lubrication or just boundary lubrication between piston and cylinder, which later after IC engine cold start passes to hydrodynamic lubrication, what reduces friction significantly. In the paper it was conducted the numerical investigation of the influence of the shape of tribological inserts, made from magnesium alloy, on the temperature increment and wear of piston and cylinder, for the case of IC engine cold start without lubrication. As the input data are defined pressure of the piston on the cylinder as well as the piston speed, which were calculated on the basis of the experimental data. It was found that the shape of the tribological inserts have significant influence on the heating of piston and cylinder.*

Keywords: *IC engine cold start, lubrication, numerical investigation, tribological inserts, magnesium alloy.*

1. INTRODUCTION

The IC engine cold start is critical because during the cold start it is not established yet a hydrodynamical lubrication. According to some engineers, the piston and cylinder of the IC engine, in the moment of cold start wears, as in the case when vehicle passes 10 km in normal working conditions.

Approximately the 40% of loses due to the friction in IC engine, happens exactly because the friction between pistons and cylinder liner [1, 2]. As the consequences of friction in the IC engine, appears several undesired phenomena's and that:

- decrease in engine economy,
- wear of sliding surfaces,
- additional heating of the parts, which generates internal stresses and deformations of the parts, reduces the resistance of the parts and affects the quality of lubrication.

Five tribological pairs with significantly different wear characteristics can be observed in the piston-cylinder assembly of the engine, Fig. 1:

1. piston rings - cylinder,
2. piston rings – piston ring grooves in the piston,

3. piston – cylinder,
4. piston pin – piston, and
5. piston pin – rod bush bearing.

In order to reduce friction between piston and cylinder liner, one of the solutions is the use of the tribological inserts. Tribological inserts are usually performed in the form of tribological pads (continual or nodular discrete pads), which are constructed as the part of the piston, or as the part of the cylinder liner.

According to some researches, the use of the tribological inserts contributes to the friction coefficient decrement, compare to the case when the tribological inserts are not applied [3]. Some of the materials which are used for the tribological inserts are the graphite and molybdenum disulfide [4]. The use of tribological inserts for the piston skirt with different concentrations of graphite and molybdenum disulfide, it was found that the lowest coefficient of friction occurs in the case of the use of piston with a skirt coating which contains 4% graphite and 26% molybdenum disulfide. Some of the researchers have investigated the possibility of use of the thin-layer piston ring coatings, in order to reduce the friction between the piston rings and the cylinder [5]. They have found that with the application of thin-layer coatings on piston rings (graphite-based coating), it is possible to reduce the friction between the piston group and the cylinder by about 20% compared to the case when the same piston rings are used without coatings. This further contribute to the increased engine efficiency as well as to the increased engine economy. In similar research it was achieved the friction reduction up to 14% [6].

The influence of thin-layer piston ring coatings on the reduction of friction between the piston rings and the cylinder is also the subject of current research. In [8], it is stated that by applying thin-layer coatings of piston rings (graphite-based coating), it is possible to reduce the friction between the piston group and the cylinder by about 20% compared to the case when the same piston rings are used without coatings, which reduces fuel consumption by about 1.5%. In [9], it was established that by applying thin-layer coatings on compression piston rings, it is possible to reduce friction by about 14% compared to the case when the same piston rings are used without coatings.

The aim of this paper is to investigate the influence of the shape of the tribological inserts, on the heating of the pistons and cylinder which as consequence have the wear of the piston and cylinder. As the material for the tribological inserts, a magnesium alloy was chosen. The reason for the use of the magnesium alloy are a good lubrication characteristics of the magnesium.

2. EXPERIMENTAL RESEARCH

In order to investigate the heating and the wear of engine elements, first it was conducted a experimental investigation. The aim of the experimental investigation it was to determine the normal force, which pushes the piston to the cylinder. The forces which act in the piston mechanism can be seen on the Figure 1.

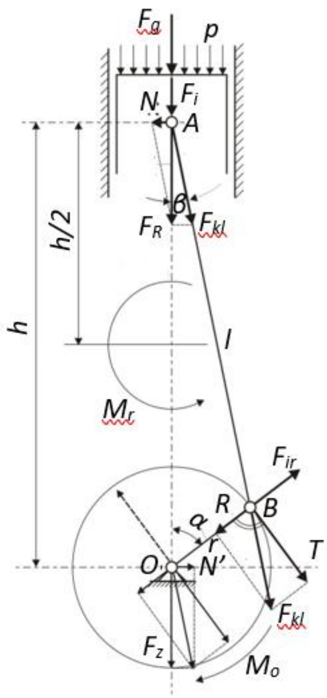


Figure 1. The dynamic scheme of the piston mechanism

The Normal force N can be calculated according to the equation (1).

$$N = F_R \cdot tg\beta \, . \tag{1}$$

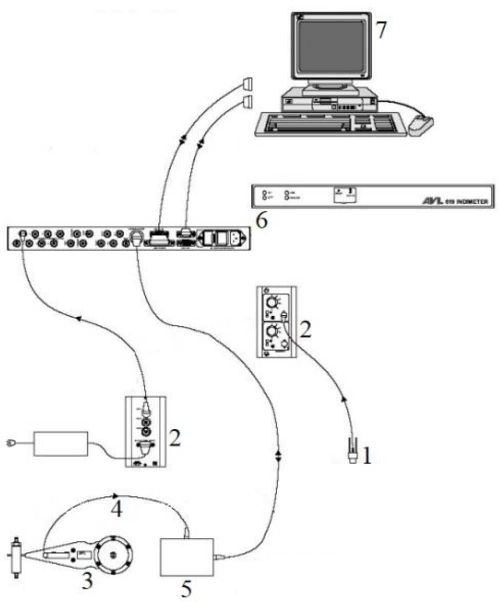
The F_R represents the resulting force which can be calculated according to the equation (2).

$$F_R = \pm F_g \pm F_{io} \tag{2}$$

The F_{io} represents the inertial force which is calculating from the piston motion law. However, it is not important from the aspect of the experimental work, so it will not be further considered. The force important from the aspect of the experimental work is the gas force F_g , which can be calculated by equation (3).

$$F_g = \left(p_g - p_o\right) \cdot A_k \tag{3}$$

The p_o is the pressure under the piston, and it is approximately equal to atmospheric pressure. While the A_k is the piston surface. The value which demanded the experimental work is the gases pressure p_g , which is determined experimentally. The scheme of the experimental installation is given on the Figure 2.



1 – pressure sensor AVL QC32D, 2 – signal amplifier KISTLER 5007, 3 – angle encoder, 4 – optical transmitter, 5 – signal multiplier AVL 365CC, 6 – acquisition system AVL Indimeter 619, 7 – computer with acquisition software AVL IndiCom 1.2

Figure 4. The experimental installation

After the conducted experimental work, all parameters necessary to calculate normal force were known, so the next step was the numerical analysis.

3. NUMERICAL INVESTIGATION

In order to conduct the numerical analysis, first was created a 3D model, Figure 3.

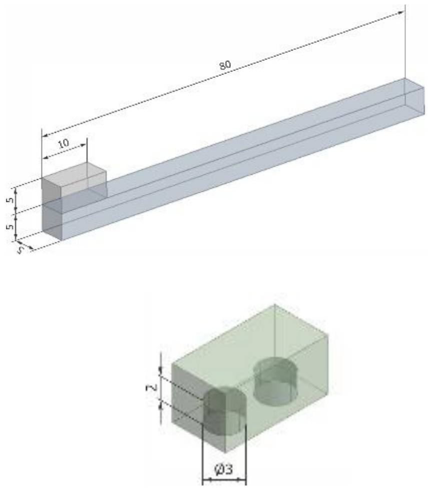


Figure 3. 3D model

The shapes of tribological inserts which were tested are circular, rectangular and rhomboids. On the Figure 3 is shown the example of the circular shape tribological inserts.

The created 3D model was created as a slice of the piston and cylinder. In order to simplify the model and to use a flat object, the slice of the 3d model was created in the boundaries of 7 degrees, Figure 4.

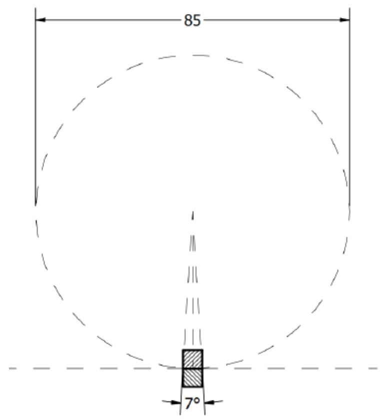


Figure 4. 3D model simplification

After this, as the boundary conditions were calculated the pressure with which normal force acts on the piston, according to the surface value of the piston slice. Besides the pressure, also it was calculated the piston movement. Values of the boundary conditions are shown on the graph (Figure 5).

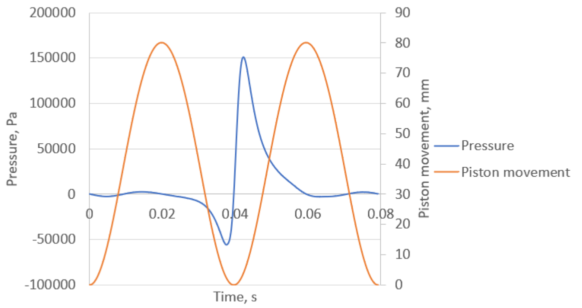


Figure 5. Values of the boundary conditions

After the boundary conditions were calculated, the boundary conditions were defined in the software. The software used for the simulation was ANSYS, Transient Structural module.

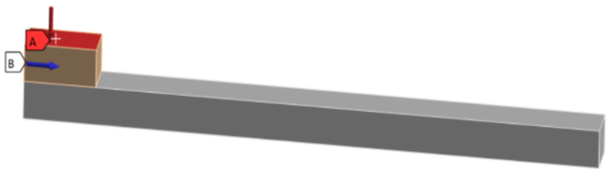


Figure 6. Boundary conditions defined in ANSYS

4. RESULTS AND DISCUSSION

One good side of the numerical investigation is because it gives the graphical representation of the results. The elements heating obtained by the numerical analysis for one case is shown on the Figure 7.

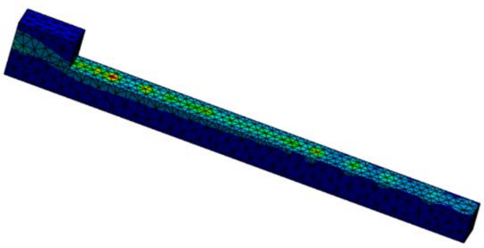


Figure 7. Heating of the piston and cylinder

As is expected, the highest heating was achieved in the case when the piston is constructed without tribological inserts. The detail results are shown on the Figure 8.

It can be seen that the best results gave a rectangular inserts, after that the circular inserts, and at the end the rhomboid inserts.

The reason for this is quite simple, and it looks in the size of the area of the tribological insert which first enters into the contact with the cylinder liner. With the increment of this area, decreases the friction what leads to the temperature decrement.

The temperature obtained by the numerical analysis is not to high. More accurately, it is under the temperature which engine parts should have in order to achieve the best efficiency.

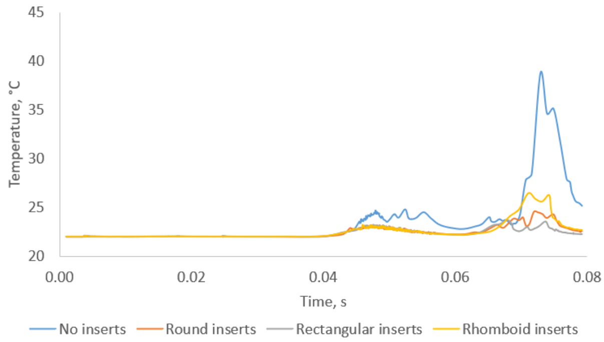


Figure 8. The temperatures obtained for different shapes of tribological inserts

However, if we take into the consideration the period of the maximal temperature achievement, we can se that the period is quite short. Which means that the temperature raise ratio is high, which in worst scenario was 288,24 °C/s. This phenomenon of sudden heating can cause material properties disturbance, which over time will affect on the parts function.

The increased temperature will lead to the material properties fading, which during time will affect on the wear of these elements. So, the aim is to maintain temperature rise ratio as lowest as possible. According to this, the use of the tribological inserts is justified, if we wish to prolong the life time of the IC engine.

5. CONCLUSION

The research in this paper was conducted from two parts and that, from the experimental one and from the numerical one. The advantage of the numerical analysis is the posibility of the results graphical representation.

From the aspect of the heating and of course furher from the aspect of the wear, the worst case is obtained for the piston without tribologic inserrts, which was expected.

The obtained temperatures are not to high, however, the temperature raise ratio is high. This means that the application of the right shape of the tribological inserts can contribute how from the aspect of the reduction of the heating of the piston and cylinder, as well as from the aspect of the reduction of the wear of these elements.

This means, that if the aim is the prolongation of the IC engine life, then the application of the tribological inserts is justified.

ORCID iDs

Ivan GRUJIC 0000-0003-0572-1205
Zeljko DJURIC 0009-0001-8573-6038
Nadica STOJANOVIC 0000-0002-4199-0587

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