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INVESTIGATION OF FRICTION LOSS IN INTERNAL COMBUSTION ENGINE OF EXPERIMENTAL MICROGEOMETRY PISTON BEARING SURFACE

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Abstract

The piston is the most mechanically and thermally loaded engine component. The energy required to overcome the mechanical losses in the combustion engine is approx. 10% of the energy supplied to the engine in a fuel. The main node piston-pin-piston rings are most responsible for the formation of mechanical losses. It is advisable to reduce friction losses in the piston-cylinder group lead to an increase in the overall efficiency of the engine and thus reduce the fuel consumption. The way of achieving these objectives is modification of microgeometry of the piston-bearing surface, which cooperates with the cylinder wall. The geometry of the gap between the piston skirt and the cylinder liner greatly affects the friction loss inside combustion engine. A way to reduce the area covered by the oil film is the application of a stepped profile of the piston skirt. The stepwise profile can be obtained covering the cylindrical or tapered piston-bearing surface with a thin layer graphite. Covering the piston bearing surface with a thin layer of graphite one can get an extremely advantageous tribological properties of the piston assembly which means the expected parameters of oil film and reduction friction loss. In this article, the results of research on experimental pistons on friction loss in combustion engine are presented.

Keywords: *combustion engine, friction, lubrication, piston, microgeometry bearing surface*

1. Introduction

One of the main field of intense engine development is fuel consumption reduction, which is directly connected with reduction of carbon dioxide emission. Carbon dioxide is found as a main cause of so-called greenhouse effect. The most popular approach to fuel consumption reduction is a trend called as downsizing, which combines many technical solutions like gasoline direct injection and supercharging [5]. It can be explained that downsizing consist in decrease of engine displacement with maintaining power of larger engine. As a result, engine in average driving conditions operates with higher mean effective pressure. What is more important with higher efficiency, which leads to the reduction of fuel consumption. Higher level of effective mean pressure cause increase of mechanical load in the engine elements, particularly elements of crank mechanism.

Main kinematic pair of crank mechanism is formed by piston and cylinder liner. In an aspects of coupling with cylinder the bearing surface of the piston is the most significant. This friction pair is essential for total friction losses of the combustion engine. Many researches in the field of piston bearing surface friction were carried out [6, 7, 13].

The primary function of piston bearing surface is to carry the normal force to the cylinder liner surface. Normal force has significant importance for friction and wear of piston and cylinder liner and its high value results mainly from high pressure inside supercharged engine combustion chamber.

Because of reverses of direction of normal force vector sense, which occur repeatedly during engine cycle, the piston moves laterally in the cylinder in perpendicular direction to the cylinder axis [13]. In consequence of lateral movement, the piston hits the cylinder liner, especially when it moves from counter pressure side to the pressure side of the cylinder during the beginning of the power stroke. These hits cause measurable elastic deformation of the piston and cylinder liner [3, 5], which increase load of piston bearing surface and are one of the main sources of engine noise [13].

Engine manufacturers often decide to apply special layer on the piston-bearing surface, and for supercharged engines, it applies almost for all modern designs. Layers, which usually contain graphite dissolved in the polyamide-imide resign (PAI), are created by the serigraphy and are harden in high temperature. The Grafal 255 is an example of commonly used layer, which contains circa 35% of graphite without any antifriction additives. New developed layer types incorporate molybdenum disulphide (Evo Glide type) and another chemical compounds which modify friction.

The influence of piston bearing surface layer type on the coupled elements wear and friction losses is the subject of intense researches [1, 2, 4]. The results unequivocally prove positive role of commonly used layers in piston seizing and cylinder wear reduction in regular operation conditions of the engine. As a consequence of tribological researches, which were carried out outside the engine, a possibility of significant friction reduction by coating the aluminum alloy with mentioned layers was pointed. In actual engine operating conditions total friction losses depend first of all on fluid friction conditions that is why application of additional layers do not result in high friction losses reduction.

The microgeometry of the gap between bearing surface of the piston and the cylinder has a significant effect on friction losses of the internal combustion engine. It turns out that the friction losses depend more on the area covered by the oil film than the thickness of the oil film that separates the two cooperating surfaces. Several ways to reduce the oil film coverage area include most often barrel shape of the piston-bearing surface, but it can be also achieved by stepped shape of the bearing surface of the piston [8-10].

Stepped microgeometry can be obtained by the application of the H shaped graphite layers on the bearing surface of the piston. This will give the stepped profile, which is characterized by beneficial tribological properties of the cylinder-piston kinematic couple fluid friction conditions, and use of graphite can expected advantageous properties in terms of boundary friction [9, 11, 12].

The article presents the results from research of experimental pistons with stepped microgeometry bearing surface of friction losses in internal combustion engine.

2. Microgeometry of the experimental pistons

The adopted shape of the piston-bearing surface is a continuation of earlier authors' studies [8-12]. The crossbar of the H letter allows extending the area of high hydrodynamic pressure while obtaining the effect of reducing the total oil film cover area and as a consequence the total friction losses.

The bearing surface's shape modification is based on choosing the right one just to ensure the continuity of the oil film along with the smallest possible friction losses for the piston-cylinder system. Friction losses reduction will contribute to a greater mechanical efficiency of the internal combustion engine and in result lower fuel consumption.

Authors applied an H shaped layer made of the graphite and thereby obtained a stepped microgeometry of the bearing surface. Different variants of the pistons are presented in Fig. 1. The measured profile of the piston-bearing surface is shown in Fig. 2.

In order to develop a bearing surface's shape of the piston, authors defines the following factors:

- thickness of the graphite layer forming the H shape – 20 μm,
- height of the crossbar of the H shape – 1.5 and 3 mm,
- the H shape crossbar shift up or down in relation to its symmetric position.

Fig. 1. View of different piston variants

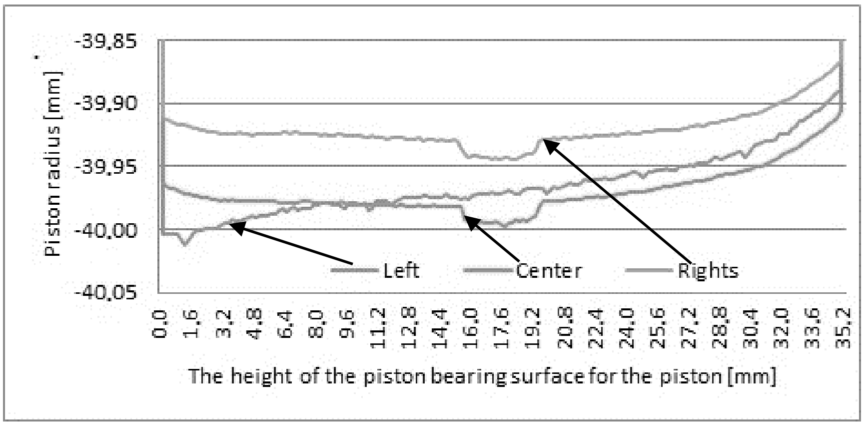

Fig. 2. The actual profile of the piston-bearing surface with the H shape graphite layer

Then to perform friction losses research in the piston-cylinder kinematic pair authors have chosen 6 variants of the H shaped layer, which are different in form and size. In Fig. 3 and 4, the profiles of piston bearing surfaces used for research are presented.

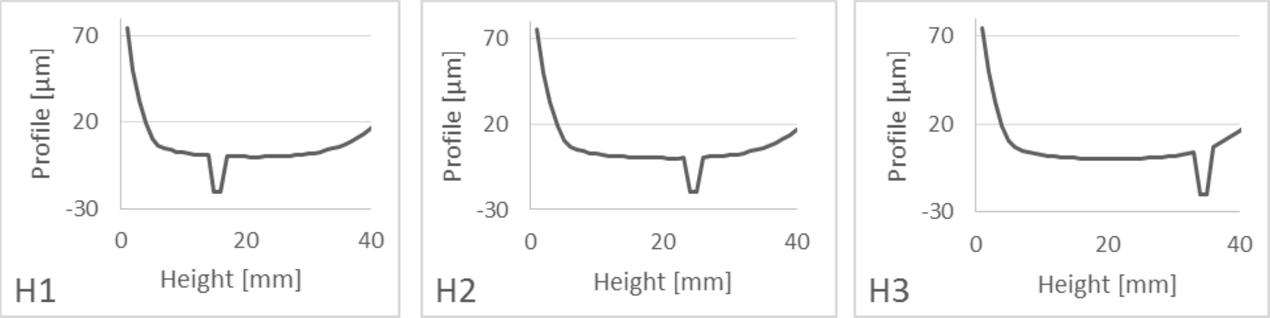

Fig. 3. H1-3 variants of the experimental piston bearing surface profile

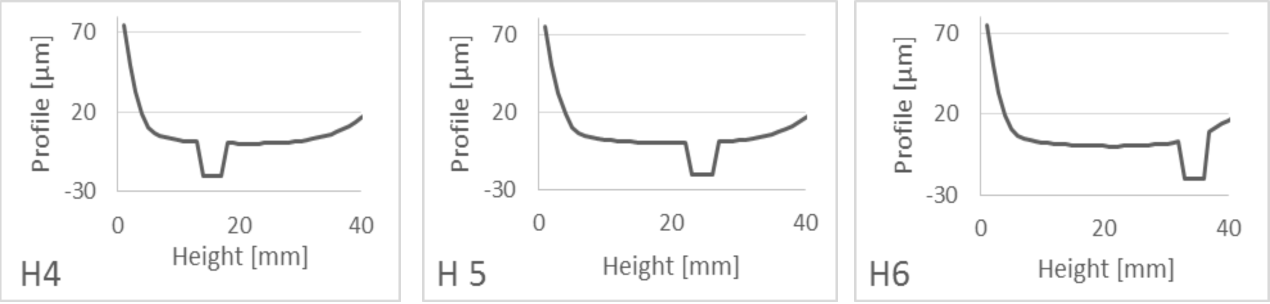

Fig. 4. H4-6 variants of the experimental piston bearing surface profile

3. Research object

The test bench of the model (Fig. 5) was built with a complete engine block FIAT 170A.046 with the crankshaft, connecting rods, pistons and engine head, in order to reproduce as closely as possible the actual working conditions of piston-engine crankshaft in the engine, while ensuring accurate measurement of torque under external drive.

Model test bench was built to measure friction loss in the piston-cylinder group composed of the modified internal combustion engine driven by electric motor from outside. The drive is transmitted through the measuring shaft, which allows accurate torque measurement with high temporal resolution. In the engine camshaft is immobilized, leaving all valves in the closed position, there is also the immobilized crankshaft-driven coolant pump and an oil pump replacing it by outer system, driven by electric motor.

A very important element of the original system is to maintain a constant oil temperature of the heat exchanger oil-cooling liquid engine, by the radiator and heater fluid and electrically powered pumps, coolant and oil.

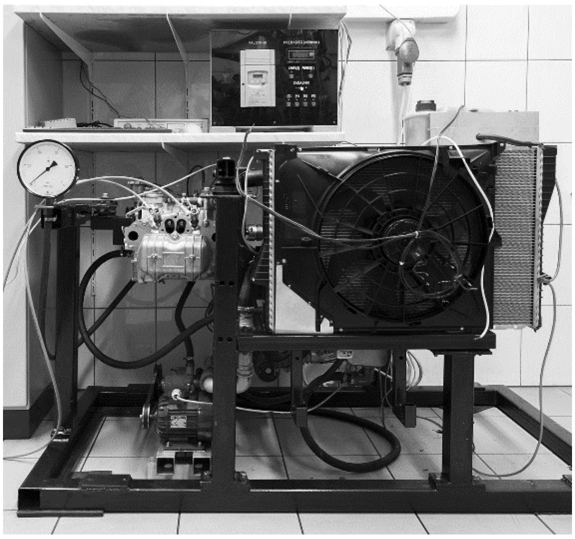

Fig. 5. The view of engine friction losses test bench

4. Research results

The approach used in construction of test bench gives opportunity to measure the torque with high accuracy and measurement frequency. The measured value of the torque due to the friction loss in the piston-crank mechanism is not significantly affected by the action of any other engine mechanism. Torque measurement is affected by the influence of thermodynamic phenomena that occur in the engine and blow-by charge to the crankcase.

The impact of these phenomena cannot be eliminated, but it can be assumed that their progress depends largely on microgeometry or covering coats of piston bearing surface and that allows each other comparison of these variants in the range of generated friction losses.

Measurements of friction losses were made for the presented experimental microgeometry bearing surface options of the experimental stepped piston profile and a surface of the barrel profile pistons serial used in the engine Fiat 170A.046. In a research of experimental pistons carried out five series of measurements, which were then averaged. Test series have been defined by the oil temperature of 50, 80 and 110°C. There were no refilled load, which gave a lower pressure and a force of the compressed gas. Each of these series includes ten measurement points received when the engine revolution speed was varied at 750 rpm to 3000 rpm in increments of 250 rpm. The obtained results are shown in Fig. 6-11.

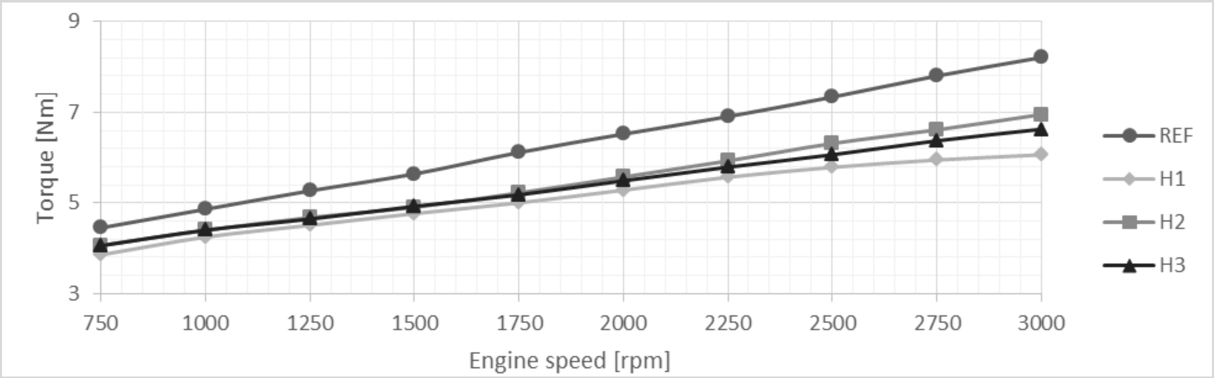

Fig. 6. Results of the variants H1-3 for oil temperature 50°C

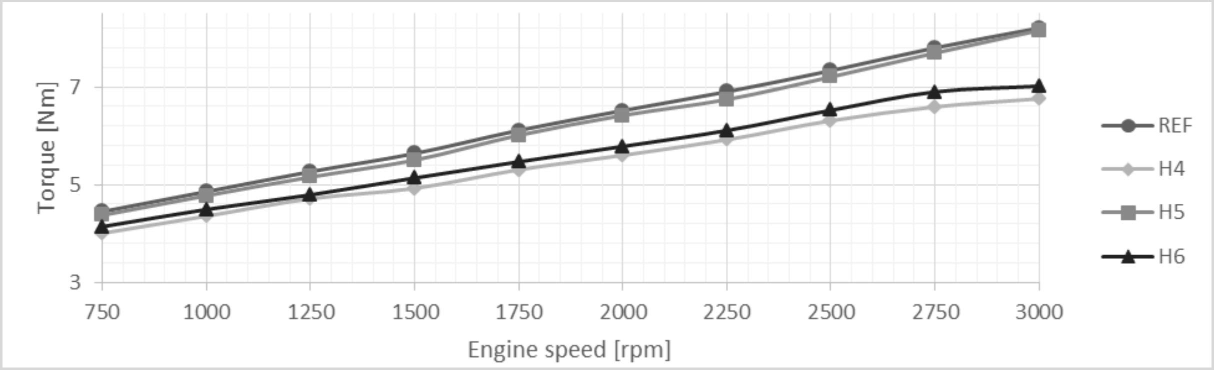

Fig. 7. Results of the variants H4-6 for oil temperature 50°C

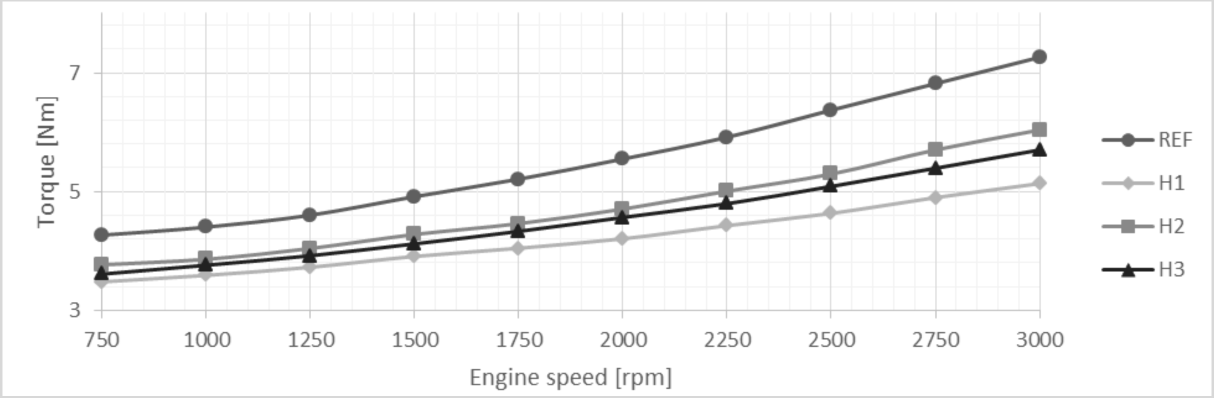

Fig. 8. Results of the variants H1-3 for oil temperature 80°C

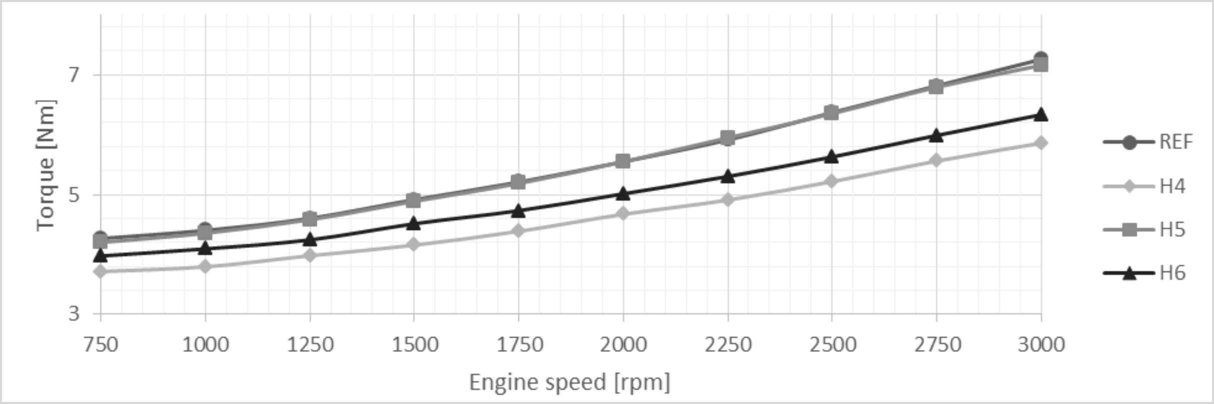

Fig. 9. Results of the variants H4-6 for oil temperature 80°C

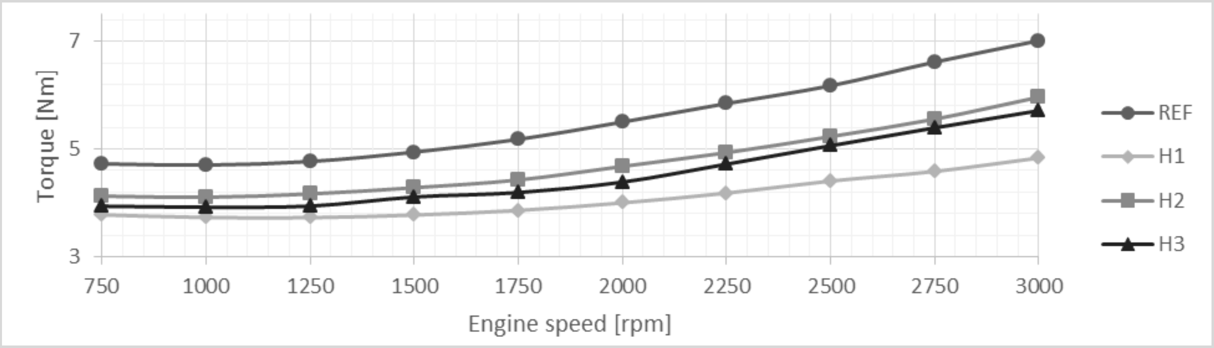

Fig. 10. Results of variants H1-3 for oil temperature 110°C

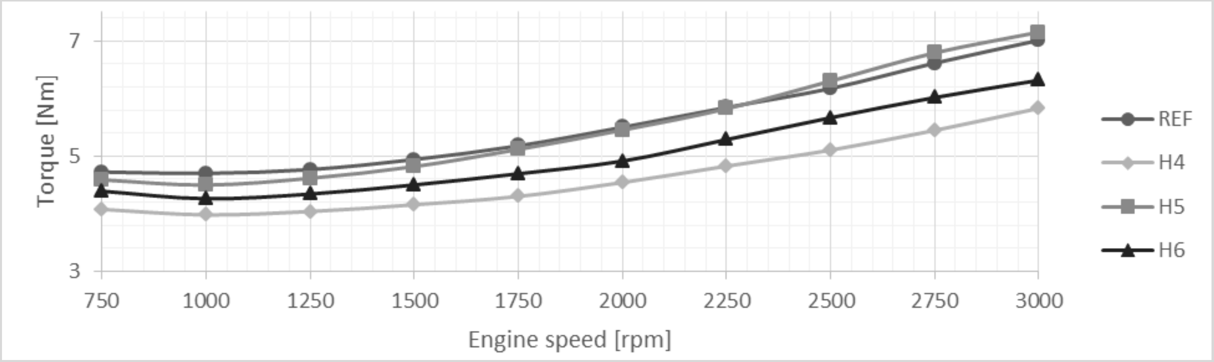

Fig. 11. Results of the variants H4-6 for oil temperature 110°C

The use of stepped microgeometry bearing surface has resulted in a significant reduction in friction losses, which is a reduction of the external drive torque up to 25% under the most beneficial engine operating conditions. It should be emphasized that the showed differences are related to the total friction losses, which in addition to losses on the piston-bearing surface, include friction loss of the rings and crankshaft. The results of the studies presented in the literature show that all of these kinematic pairs are comparable in terms of friction losses. In consequence, reduction of friction losses recorded with use of experimental pistons, which only microgeometry of the bearing surface has been changed is surprisingly large.

5. Summary

Studies in experimental bench model of the motor pistons with the stepped profile-bearing surface were made to estimate the value of the friction losses in the piston-crank mechanism and to draw the following conclusions:

- the greatest benefits of using stepped microgeometry piston bearing surface were observed when the oil temperature was highest (110°C); Properly lowered benefits were observed when the oil temperature was 80°C and the lowest was at a temperature of 50°C,
- it was showed the greatest reductions of friction losses were observed for variants of the pistons with the bar letter H shifted downwards relative to the position symmetric about 16% (H4) and 25% (H1), because this variants extended the oiled area, it ensures the generation of a continuous oil film separating the cooperating surfaces,
- in all measurement series with closed load restriction valves, friction losses have been reduced by use stepped microgeometry of the bearing surface, regardless of engine speed,
- the coolant temperature regulates temperature of engine and oil, which affects the friction losses,
- a stepped surface can be achieved by the coating of the support surface of the piston using dry lubricants like i.e. graphite,
- a layer of dry lubricants are particularly desirable under lack of continuity of oil film conditions.

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