ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1168450

GEOMETRIC SHAPE OF THE SUPPORT SURFACE OF THE PISTON

Antoni Iskra, Maciej Babiak, Emil Wróblewski

Poznan University of Technology
Institute of Combustion Engines and Transport
Piotrowo Street 3, 60-965 Poznan, Poland
tel.: +48 61 6652049, fax: +48 61 6652204
e-mail: emil.z.wroblewski@doctorate.put.poznan.pl

Abstract

Geometry of the slot between piston bearing surface and cylinder bore affects the friction losses of the IC engine to the far extent. It appears that these losses depend more on the area covered with oil than the thickness of oil layer separating collaborating parts. Barrel-shaped or stepwise piston bearing surface is the way to reduce the oil-covered area. The first concept has been used for years while the stepwise profile has not been applied for various reasons, although this idea providing higher load capacity of oil layer in stepwise slot was published in literature in the fifties of twentieth century. The stepwise profile can be obtained covering the cylindrical or tapered piston-bearing surface with a thin layer graphite.

This paper presents the results of simulation leading to the reduction in friction losses and abrasive wear of piston bearing surface and cylinder bore.

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 in a case of film rupture – an ignorable abrasive wear of the graphite layer and/or cylinder bore.

Keywords: *combustion engine, piston, friction losses*

1. Introduction

Over the years, combustion engine's pistons changed their geometric proportions to a greater extent, but still their essential role is to close the variable volume combustion chamber. However performing of such main functionality is accompanied by a number of adverse effects, such as [3, 5]:

- friction losses,
- forces and moments of inertia transferred to the motor suspension,
- lubricating oil consumption,
- noise emission.

These effects affect the performance of the entire engine, some of them arise from the piston and its rings properties.

Current trends in the construction of the piston are to reduce its dimensions, i.e. height of the support surface. As a result, the weight of the piston is lowered thus lower friction losses because the surface of the oil film working against the cylinder wall is much smaller [1, 6].

Also important are less visible geometric features of the pistons such as:

- taper shape,
- barrel-like shape,
- roundness,
- supporting surface roughness.

The geometry of the gap between the bearing surface of the piston and the cylinder has large effect on friction losses. The area covered by the oil film contributes to these losses more than the thickness of the oil film. A method to reduce the coverage area of the oil film is to use different bearing surface shapes of the piston stepped-like or barrel-like. Barrel-like shape is commonly used, but a stepped one was not yet applied for various reasons. The stepped shape can be obtained i.e. by the application of refining coatings of materials with good friction properties [2, 7]. One such material is a graphite, commonly used to cover the bearing surface of the piston. Currently the entire bearing surfaces of the piston are coated. Such method produces different boundary friction conditions, but it does not affect the fluid friction formation significantly in the oil film.

This article presents the results of simulation research for the reduction of frictional losses and wear of the bearing surface of the piston and the cylinder wall by covering the support surface of the piston with a layer of graphite in the H-shape. A stepped profile obtained this way is characterized by beneficial tribological properties of the kinematic piston-cylinder system under fluid friction conditions. By the use of graphite material, some benefits concerning boundary friction conditions can be also expected. The solution proposed by the authors hereby extends the scope of tasks performed by the coatings on the bearing surface of the piston.

2. Development of the piston bearing surface resulting in friction loss reduction

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 thus lower fuel consumption.

The authors assume to apply graphite H-shaped layer to the support surface of the piston. The modified shape is shown in Fig. 1.

Fig. 1. Piston with an H-shape coating layer

In order to develop a bearing surface's shape of the piston the following factors need to be determined:

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

In order to perform friction losses analysis in cylinder-piston system there were 6 different shape variants and H-shape size profiles as in Fig. 2-7 developed. The authors assumed graphite layer thickness of 20 μm with the width of the crossbar of the H-shape of 5 mm.

3. Simulation research results

The authors performed simulations using a computer software developed by Mr Iskra at the Combustion Engine Department of Poznan University of Technology [4].

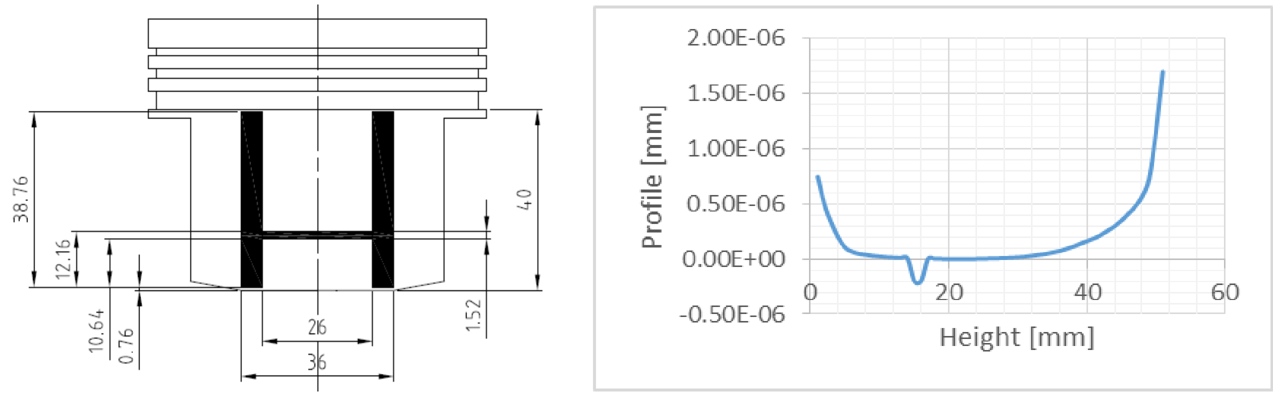

Fig. 2. Tr1 piston profile and dimensions

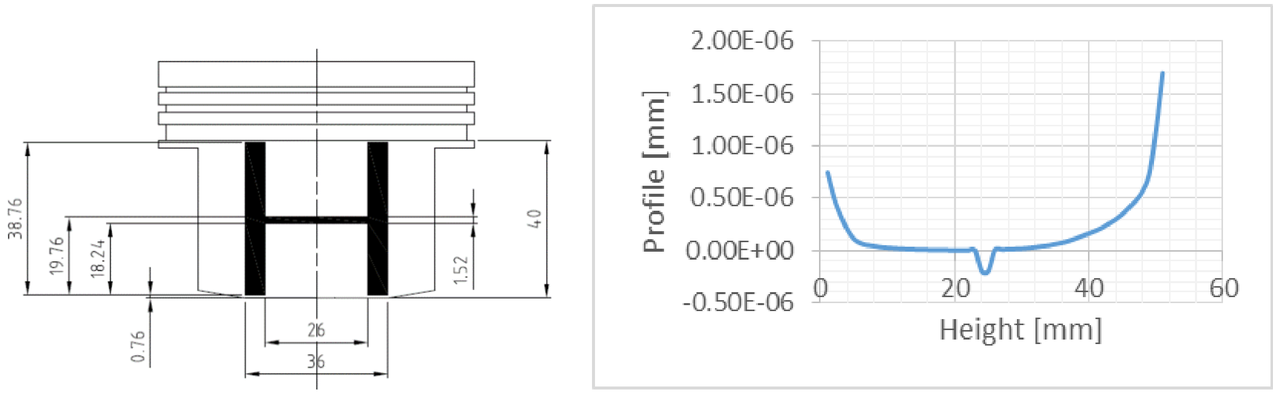

Fig. 3. Tr2 piston profile and dimensions

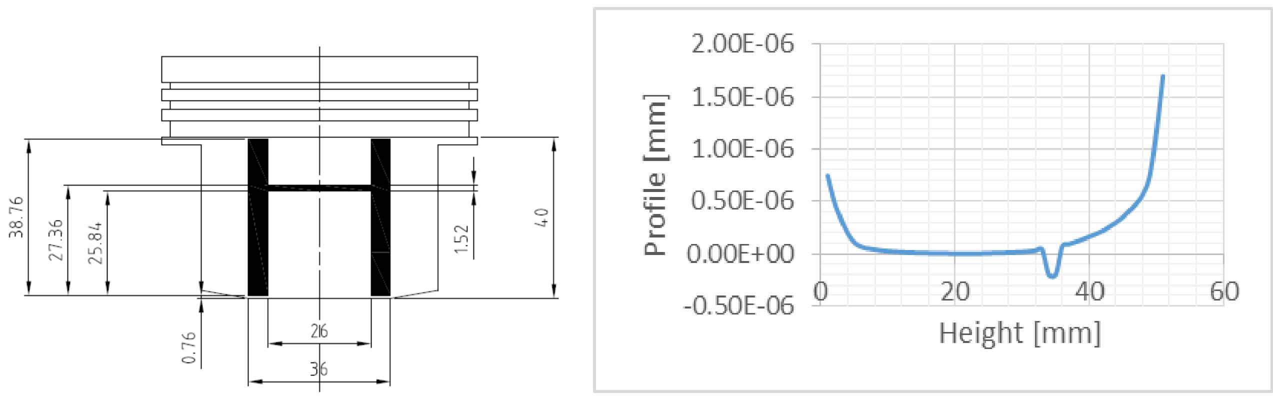

Fig. 4. Tr3 piston profile and dimensions

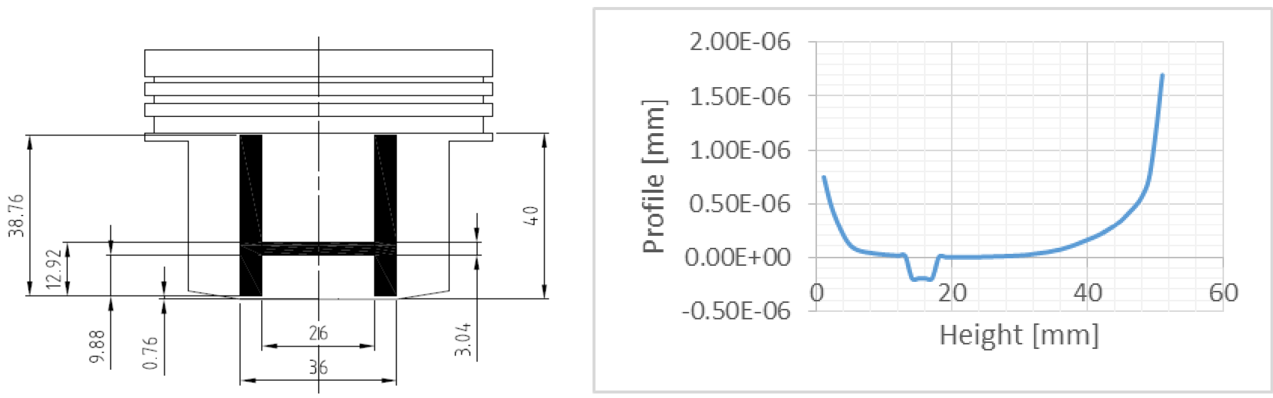

Fig. 5. Tr4 piston profile and dimensions

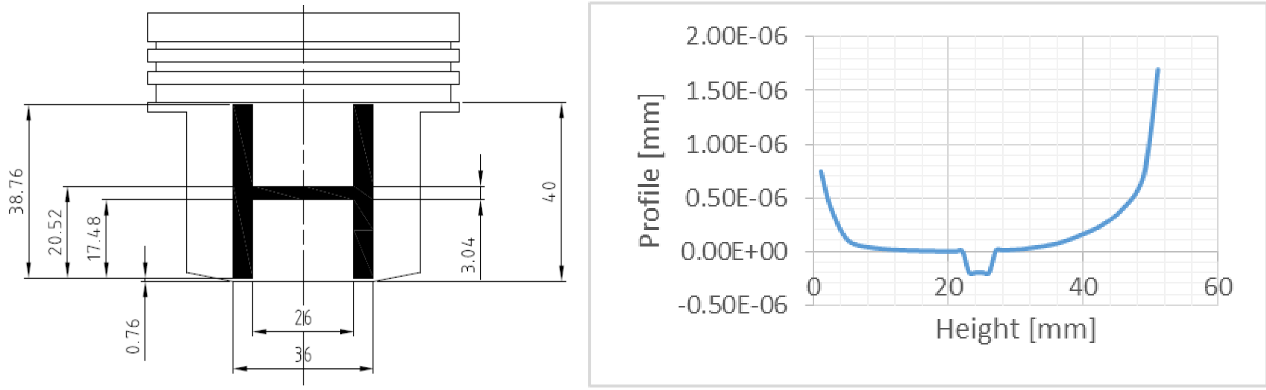

Fig. 6. Tr5 piston profile and dimensions

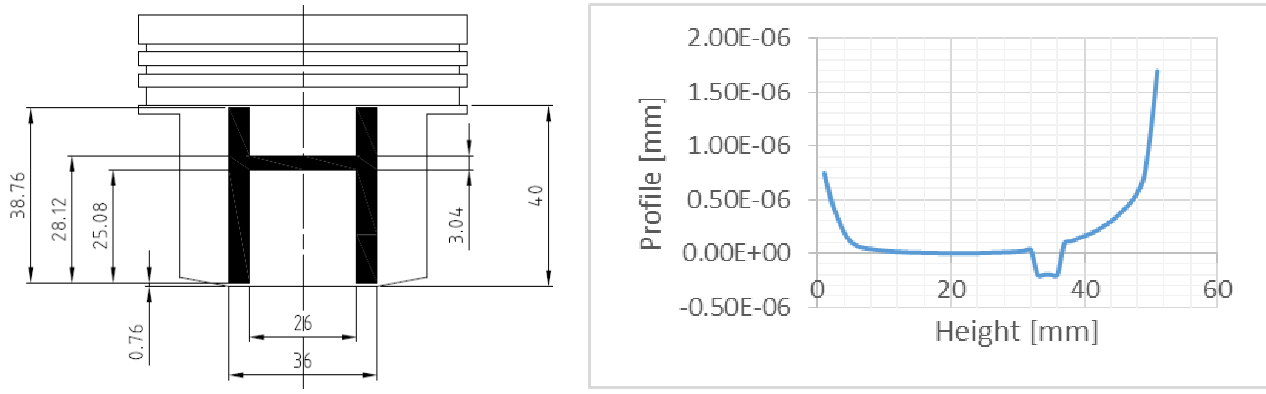

Fig. 7. Tr6 piston profile and dimensions

The calculation of oil film parameters were done using different geometry variants (Chapter 2) beginning from the stepped shape profile, and ending at barrel-like shape one. The analysis was conducted under the following conditions:

– engine revolution speed at 750-4000 rev/min,
– initial oil layer thickness at cylinder liner of 35 μm,
– lubricating oil temperature of 10°C,
– lubricating oil type of 5W30,
– pressure increase of $\varphi = 1$,
– piston rings height: 1.5; 2; 4 mm,
– piston height: 40 mm.

Please note that the simulation was based on the theory of hydrodynamic lubrication and it does not take into account factors like i.e. tribological properties of materials working under boundary friction conditions. The simulations were aimed at defining the characteristics of a stepped profile under fluid friction conditions that prevail most of the time in the internal combustion engine.

The results of simulations are summarized in Tab. 1-3. Obtained values are:

– Nr [W] – friction losses for piston bearing and cylinder surfaces,
– Nc [W] – total friction losses for piston and piston rings system.

Figures 8 and 9 show simulation results for friction losses of the barrel-like shape and stepped-like shape (H-shape) of bearing surfaces.

Research shows that not all variants have brought the expected reduction in friction losses for the piston-cylinder system in relation to reference pistons. In most cases, however, friction losses reduction can be obtained. For further analysis, there were two H-shapes chosen with different crossbar thicknesses between the slats. Fig. 10-11 show the greatest reduction in friction loss for piston – cylinder system in relation to reference pistons.

Tab. 1. Friction losses – Nr and Nc values. Pistons with barrel-like bearing surface shape

n [rev/min]	Nr [W]	Nc [W]
750	5.09	17
1000	8.21	28
1500	15.35	53
2000	24.68	84
2500	34.08	120
3000	46.47	163
3500	61.21	212
4000	77.44	266
Average	34.07	117.88

Tab. 2. Friction losses – Nr values for each of 6 H-shapes

n [rev/min]	Tr1	Tr2	Tr3	Tr4	Tr5	Tr6
750	7.02	5.19	6.66	7.13	5.64	6.29
1000	10.56	7.38	10.54	10.72	8.03	9.99
1500	18.09	12.66	19.85	18.07	13.55	18.95
2000	25.18	19.1	30.59	26.37	20.56	29.44
2500	33.08	26.65	43.17	35.27	27.19	42.34
3000	43.84	36.53	59.44	46.04	36.36	56.54
3500	56.64	46.41	74.9	58.36	46.89	72.42
4000	70.97	57.5	93.56	73.62	58.87	90.01
Average	33.17	26.43	42.34	34.45	27.14	40.75

Tab. 3. Friction losses – Nc values for each of 6 H-shapes

n [rev/min]	Tr1	Tr2	Tr3	Tr4	Tr5	Tr6
750	19	17	19	19	18	18
1000	30	27	30	30	27	29
1500	56	50	57	55	51	56
2000	85	79	90	86	80	89
2500	119	113	129	121	113	129
3000	161	154	176	163	153	174
3500	208	197	226	209	198	223
4000	259	246	282	262	247	278
Average	117.13	110.38	126.13	118.13	110.88	124.50

As a result of the simulation, Tr2 and Tr5 variants showed the greatest friction losses reduction in the piston-cylinder system. It can be also observed that reduction in friction loss is more intense for higher crankshaft revolution speeds. The importance of this observation should not be undervalued as increasing of the revolution speed results in faster heating of engine components and lubricating oil hence reducing its viscosity that may lead to the occurrence of boundary friction conditions. This may also have a positive effect on reducing friction losses under the assumption that the boundary friction will not occur at the bearing surface and the cylinder liner.

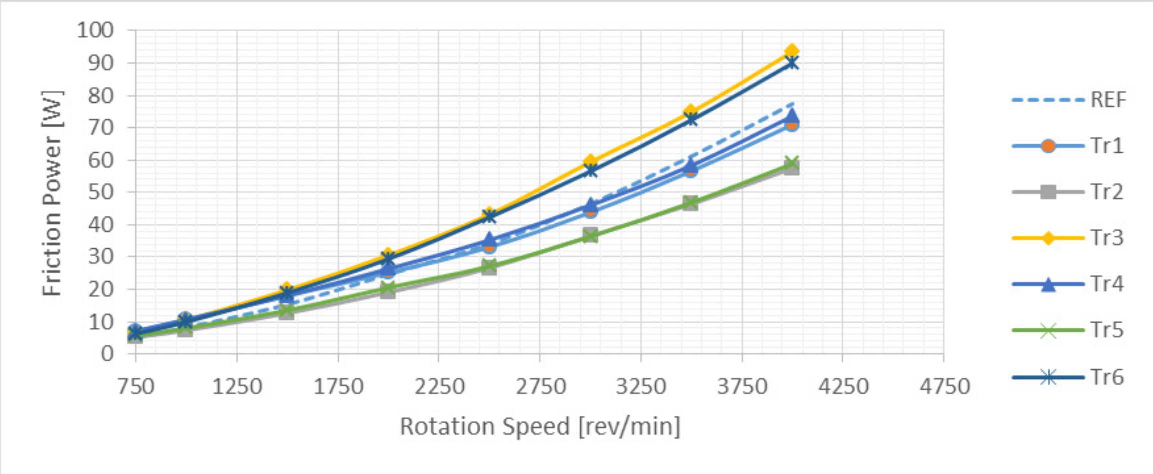

Fig. 8. Friction losses – Nr values, all pistons

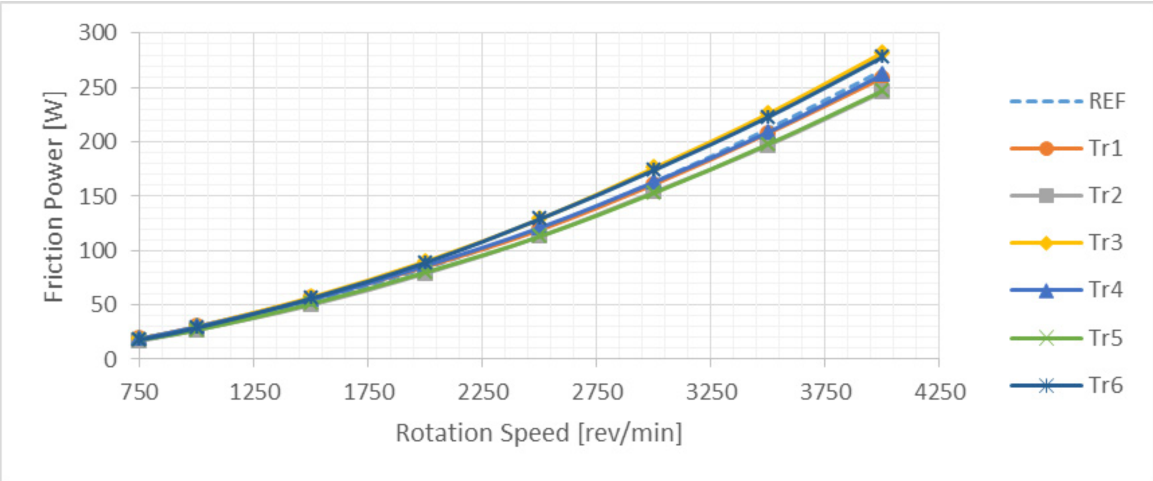

Fig. 9. Friction losses – Nc values, all pistons

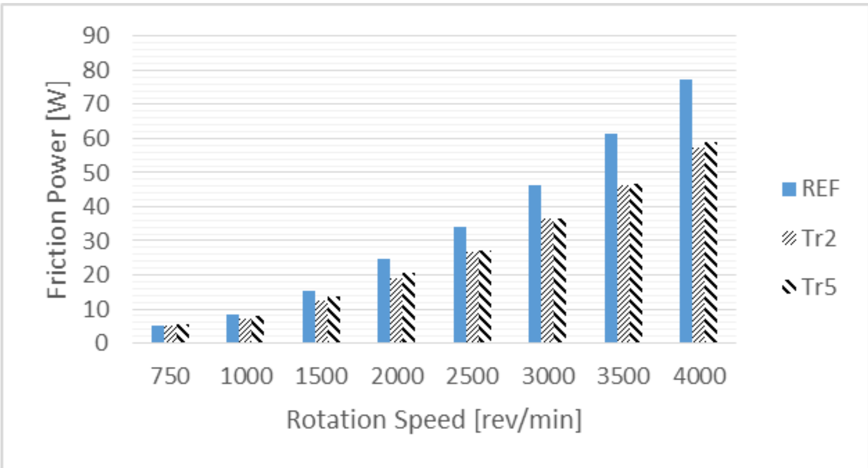

Fig. 10. Friction losses – Nr values for Tr2 and Tr5 pistons

Summary

The results from the research allow concluding that:

– the application of the H-shape bearing surface of the piston allows to reduce friction loss by about 6% in relation to the barrel-like shape,

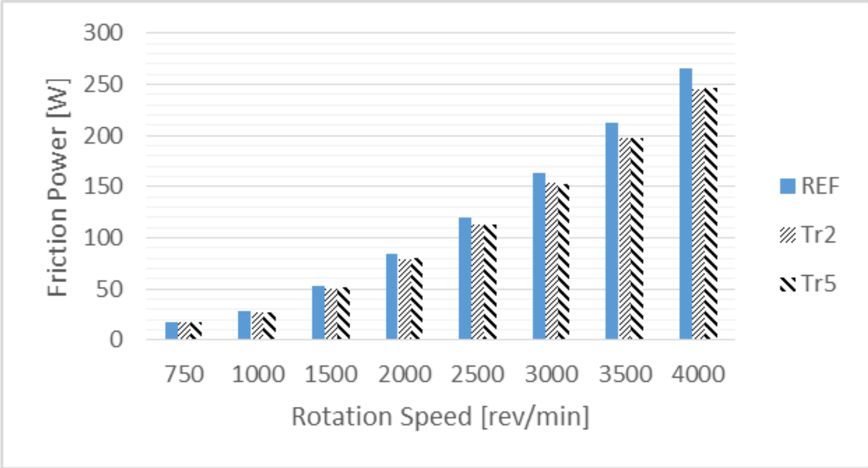

Fig. 11. Friction losses – Nc values for Tr2 and Tr5 pistons

- a stepped surface can be achieved by the coating of the support surface of the piston using lubricants like i.e. graphite,
- layers of lubricants are particularly desirable under lack of continuity of oil film conditions,
- replacement of the barrel-like shape surface with a stepped one can result in reducing fuel consumption.

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