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SOME EFFECTS OF APPLYING A NEW TYPE OF PISTONS FOR SU12-U DIESEL ENGINE

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Abstract

In the task of research and development of internal combustion engines, the strong emphasis is placed on reducing emissions of harmful substances in exhaust gases, which include carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx), particulate matter (PM, PN); while maintaining a high engine performance and, above all, adequate: power, fuel consumption, noise. One of the possibilities to reduce emissions of HC and engine working noise is to reduce the clearance between the piston and the cylinder liner. This is possible only, when the permanent deformations of the piston are reduced, which result from rapid piston temperature changes (thermal shocks). The newly developed composite aluminum alloy is characterized by high strength parameters and low dimensional hysteresis during repeated heating and cooling. The S12-U engine pistons are made of this material, and they had a slightly larger nominal diameter than the standard pistons. They were then mounted in the engine. The engine was tested on a test stand with the modern, accurate measuring equipment. Test results show, that the HC and CO content in the exhaust gas has been reduced, exhaust gas blowby to the crankcase declined, smoke emission was reduced and engine lubricating oil consumption was also reduced. Analysis of test results indicates that this has been achieved, mainly by reducing the clearances between the piston and the cylinder. The article provides detailed test results, mainly in the form of charts, on which one can compare the results, achieved by the engine with new material pistons with results of the same engine, but with the standard pistons.

Keywords: *internal combustion engines, compression ignition engines, exhaust emissions, combustion engine pistons, piston materials, testing of combustion engines.*

1. Introduction

The S12-U engine is a highly loaded diesel (CI) with a nominal power of 650 kW, designed to power heavy military vehicles and heavy construction machinery [5, 7]. While in combat, the problem of exhaust emissions is not relevant, in the conditions of peace it should be taken into consideration, as it is in relation to other internal combustion engines. Since the 50 s of the twentieth century, a decisive factor for the development of internal combustion engines, first those that were used in transport, and also those of the other applications, was to reduce the toxic exhaust emissions [6, 12, 19]. The laws were introduced, restricting the presence in exhaust gases of such components, as carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx), particulate matter (PM, PN). Currently, it is believed also to reduce emissions of carbon dioxide (CO_2) and other harmful substances, not yet covered by existing regulations [7, 8, 9].

One of the harmful exhaust gases, on whose emission the design of assemblies: piston-piston rings -cylinder liner has a decisive influence, and mainly clearances, which occur in such assemblies, are hydrocarbons (HC) [18, 19, 20].

In addition, the clearances in this assembly to a large extent determine the engine noise and blowby of exhaust gases into the crankcase. The value of clearances in the assembly: piston-cylinder liner mostly depends on materials of assembly components, and also on their heat treatment in manufacturing process.

Moreover, with regard to the pistons, their deformation, during engine operation have a big impact, mainly caused by material hysteresis during the rapid pistons heating and cooling, and also caused by complex distribution of stresses in the pistons [20, 21, 22]. Mostly pistons are made of aluminum alloy, whose thermal expansion coefficient is about twice higher than that of iron-base alloys, which are used for cylinder liners. While the use of pistons made of iron or steel is being piloted, but due to the difficult manufacturing technology and much greater weight than pistons made of aluminum alloy, they are not yet widely used. Is therefore important to improve the quality of aluminum alloys used on pistons. Mostly about increasing the strength properties, reduced hysteresis caused by rapid heating and cooling of pistons, increased resistance to seizure. Such a material turned out to be a composite silumin, wherein, compared to a standard silumin were introduced new elements: molybdenum and tungsten, and copper and nickel content was increased. These elements form intermetallic compounds, which fall within the crystal lattice and cause hardening. As a result, a material was obtained, which, after the specific heat treatment, is characterized by higher strength parameters and very low hysteresis. As a result, we could reduce the clearances in a piston-cylinder liner assembly [.

Conducted research of S12-U engine on an engine dynamometer cell showed that the emissions of hydrocarbons and carbon monoxide decreased, as well as a reduction in smoke opacity and blowby of exhaust gases to the crankcase, compared to the engine equipped with the standard pistons. The paper presents the object of study and the conditions and methodology of conducting research. Presented are also the findings of research in the form of emissions dependence graphs, in terms of external characteristics (maximum torque at a given speed) and the characteristics of the load (changes in engine load at a constant speed) [1, 2, 3, 4].

2. The object of research and research test stand

The study was conducted on a test stand, on the S12-U engine. The view of the engine is shown in Fig. 1.

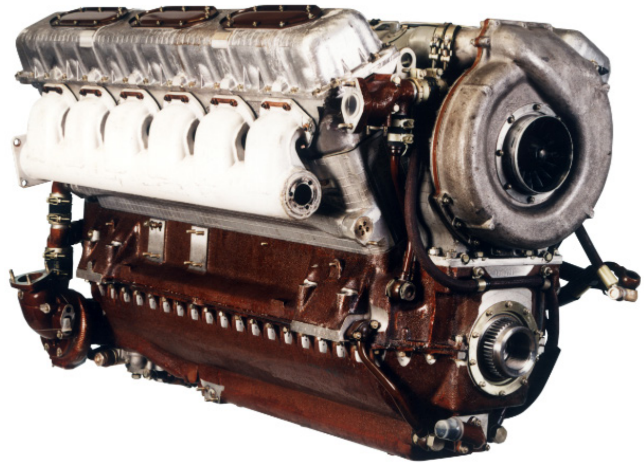

Fig. 1. View of S12-U tested engine

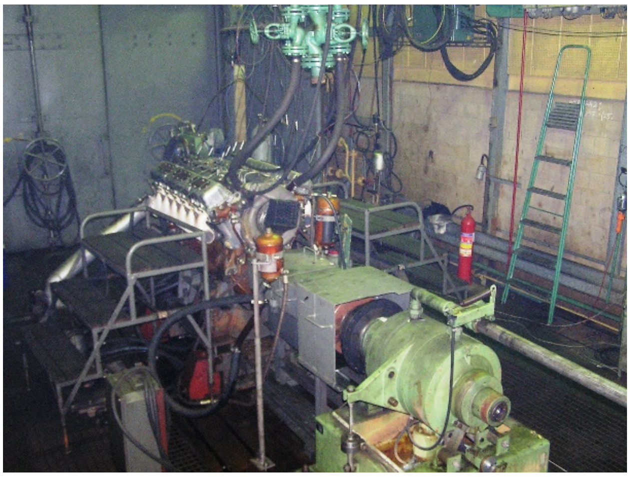

Fig. 2. S12-U engine at test stand

This engine is of a twelve cylinder, in a 60° twin bank V setup, compression ignition (CI), the direct-injection type, inline injection pump, twin supercharged, liquid-cooled, cylinder diameter of 150 mm, stroke of 180 mm (left bank)/186.7 mm (right bank), engine swept volume 38.88 dm^3, the rated power of 625 kW at a speed of 2000 rpm and maximum torque of 3363 Nm at a speed of 1300 to 1400 rpm.

Research was conducted in two stages. In the first step, research was conducted on engine equipped with standard pistons, and in a second step on engine equipped with pistons made with new material. The engine was fuelled by municipal diesel oil class Super. Lubricating engine oil category CF4 grade 20W50 was used.

Dynamometer test stand was equipped with Schenck eddy current engine brake, AVL weighing device for measuring the fuel consumption, exhaust emissions were determined by Oliver Multigas and Motorscan Leader 800 analysers, oil consumption was determined by AVL weighing device, exhaust crankcase blowby was measured using a special laboratory gas flowmeter. The engine head was equipped with piezoelectric transducer system, which registered the course of the pressure in the combustion chamber [13, 14, 15, 16]. In addition to registration of the characteristic pressures and temperatures required for the test documentation, the standard test stand equipment was used, holding a legalization certificate. The view of test stand is shown in Fig. 2.

The engine external characteristics, was determined at engine speeds: 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 1950, 2000 rpm, with a maximum dosing of fuel for a given speed.
The load characteristics were determined for speed 1200-2000 rpm, every 100 rpm, by changing the load on the engine every 100 kW.

At each measuring point, the engine must work steadily for at least 5 minutes, followed by at least two measurements.

The results of measurements were printed out in the form of protocols.

3. Results of the new pistons tests

Research has been conducted in two steps: the first step comprised engine test with standard pistons, and therefore those, which hitherto have been used in the S12-U engines.
The second step was devoted to tests on the engine fitted with the new pistons, made of a new composite material.

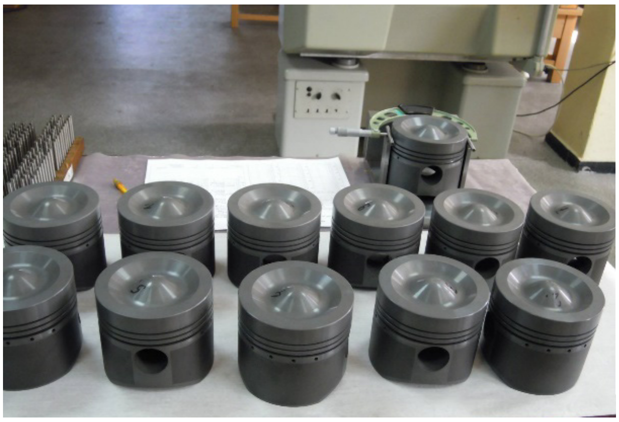

Fig. 3. The new pistons, made with new material, before S12-U engine installation

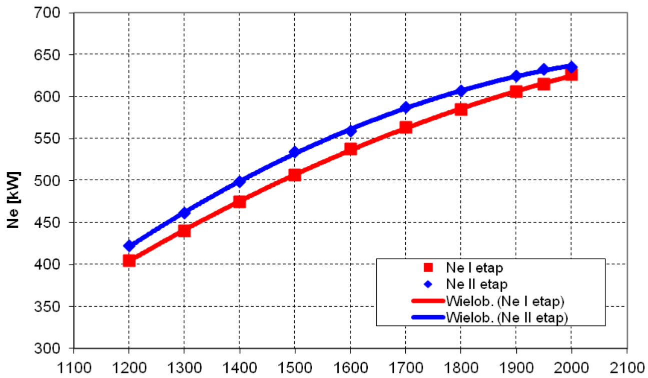

Fig. 4. Comparison of full load characteristics of S12-U engine with the standard pistons and the pistons made with new material

The pistons are on the measuring station, prior to installation in the engine. The new pistons dimensions were adjusted in relation to the standard pistons, i.e. they have a slightly larger outer diameter, allowing decreased clearance between the piston and the cylinder. As a result of the reduction piston in cylinder clearance, primarily: the decrease of unburned hydrocarbons emissions, lower particulate emissions and a reduction in exhaust blowby into the crankcase can be expected. The study was conducted under conditions of external engine characteristics (maximum load on the engine during operation, throughout the whole rev range) and the load characteristics (engine load changes in the condition of constant engine speed).

The external characteristics of an engine equipped with the standard pistons, and a modernized engine equipped with the new pistons are shown in Fig. 4.

One can notice that the power of the S12-U engine, after installing the new pistons, increased from 1.5% at the nominal engine speed to 12% in the lower speed range. Figure 5 shows the dependence on the specific fuel consumption on speed, in terms of external characteristics. Fuel consumption after installing the new pistons, as indicated by the test results, was lower, in the range of 4-7%, depending on the engine rotational speed.

Results of the measurements of concentration of hydrocarbons (HC) in the exhaust gas tests, in the conditions of external characteristics, show how the difference in HC concentration decreased between the engine with new pistons and the engine with standard pistons, with an increase in engine rotational speed (Fig. 6).

HC emissions for engine with new pistons were less than 25% at speed of 1500 rpm and dropped to 18% at nominal engine speed (comparing to the engine with the old pistons).

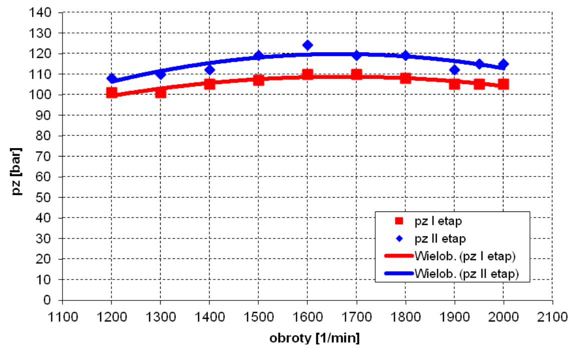

Fig. 5. Comparison of brake specific fuel consumption (bsfc) at full load of S12-U engine with the standard pistons and pistons made of a new material

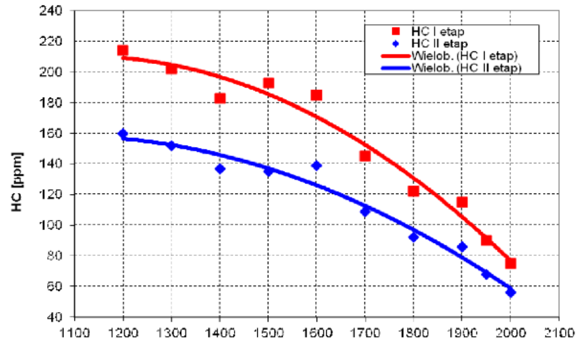

Fig. 6. Variations of HC concentrations in exhaust emission versus engine speed, at engine full load, comparing the standard pistons and pistons made of the new material

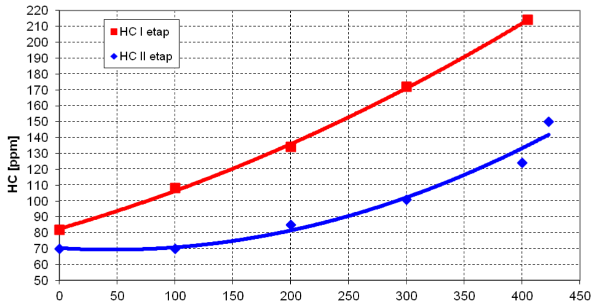

Fig. 7. Comparison of HC concentrations versus engine load for engine with standard piston and pistons made of novel material, n=1200 rpm

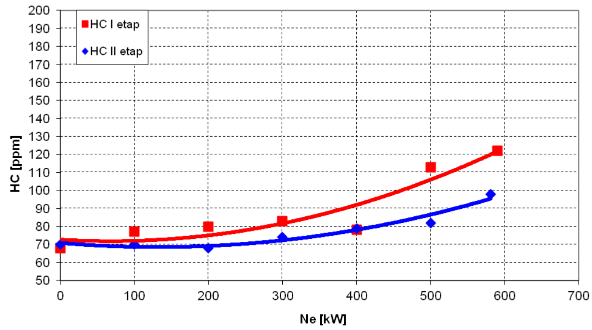

Fig. 8. Comparison of HC concentrations versus engine load for engine with standard piston and pistons made of novel material, n=1800 rpm

Fig. 7 and Fig. 8 compared the concentrations of HC emissions in the conditions of load characteristics, for the speed of 1200 rpm and 1800 rpm. By comparing these graphs it is clear, how with increasing speed, HC emission concentration decreases, which is due to a decrease in clearance between the piston and the cylinder, as a result of increase of pistons temperature.

Similar effects, as obtained in relation to the emission of HC, can be seen in relation to the exhaust gases blowby into the crankcase and for the exhaust gases opacity. Fig. 9 compares courses of exhaust gas blowby to the crankcase under the conditions of external characteristics for the standard piston engine and for the engine with pistons made of the new material.

In the entire speed range, after installing a new pistons the exhaust blowby were lower, about 30% to 45% less, which undoubtedly can be associated with a clearance reduction between the piston and the cylinder. The courses of crankcase blowby under load characteristics are similar in shape, regardless of the engine speed, wherein always the blowby are lower, for the engine with the new pistons installed. As an example, the characteristic course of blowby gases flow, under engine load characteristics conditions is shown in Fig. 10, at the engine speed of 1600 rpm.

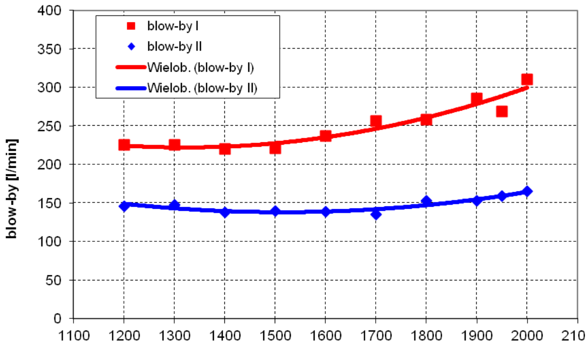

Fig. 9. Comparison of blowby to crankcase of engine with standard pistons and engine with pistons made of the novel material, the courses are versus engine speed, at the engine full load

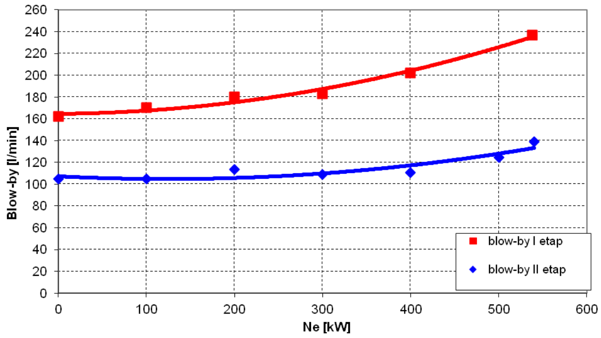

Fig. 10. Comparison of exhaust gases blowby to crankcase of SU-12 engine with the standard pistons, and the pistons made of novel material, versus engine load; at engine speed 1600 rpm

The installation of new pistons resulted in significant reduction of crankcase gases blowby, up to the 40%, comparing the pistons of the new material and the standard pistons. The characteristic is the small difference of gases blowby throughput at different engine loads (for constant engine speed). This can be attributed to the fact, that while the clearance between the piston and the cylinder decreases with increasing engine load, but at the same time the pressure in the combustion chamber increases, and in this respect, it affects the balance of the flow. Similar blowby gases waveforms also occur at other engine speeds. At rated speed, the almost constant difference remains between a blowby exhaust throughput with the engine on standard pistons and the engine on new pistons. This difference is equal to about 45%, so consumption of lubricating oil should be smaller.

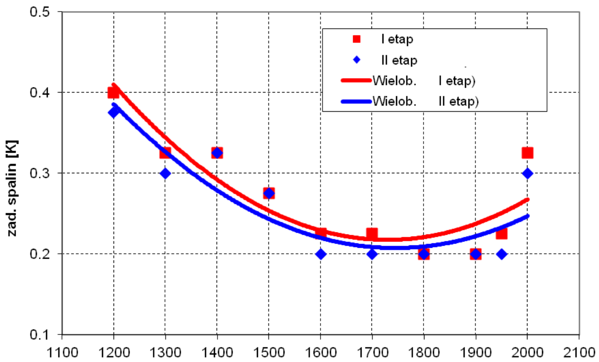

Fig. 11. Comparison of soot contents in exhaust gas of S12-U engine with the standard pistons and pistons made of novel material at full load conditions

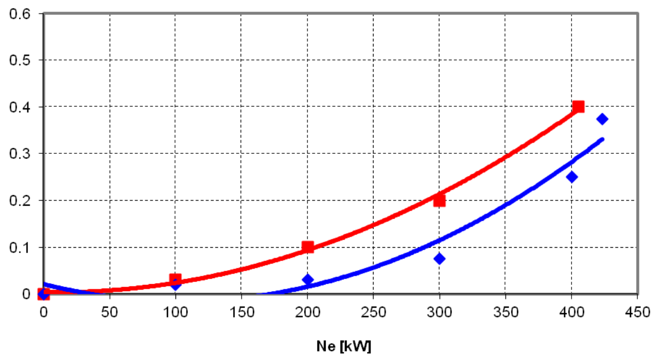

Fig. 12. Comparison of soot content in exhaust gases of S12-U engine with the standard pistons, and the pistons made of novel material at part load conditions; n=1200 rpm

The results of tests also show that after installing pistons with new material, the smoke emissions have been reduced. Fig. 11 shows, in terms of external characteristics, the curves of exhaust gas opacity for the engine, equipped with standard pistons and for the engine, equipped with pistons of the new material. In the engine whole operating range, for the engine with new pistons, the exhaust smoke emission was lower, than for the engine with standard pistons. Under certain running parameters of an S12-U engine, fitted with the new pistons, even zero emissions opacity occurred. This is clearly apparent on the load characteristics curves, in the lower range of engine rotational speeds. On the Fig. 12 is shown course of the exhaust gas smokiness at the load conditions, and at the speed of 1200 rpm.

The graph shows, that up to the engine power of 160 kW, there has been no engine exhaust gas opacity, and under these conditions, at the maximum engine power there was a small increase in the

exhaust gas opacity. Similar effects can be seen, by analysing the results concerning CO emissions. After installing the new pistons in the engine, the power range, in which there were no emissions of CO, has expanded. As such example, one can present changes in CO emissions in load characteristics conditions, at a speed of 1,700 rpm (Fig. 13).
You can see, that while using standard pistons, there was no emission of CO to the engine load of 200 kW, in case of the new pistons, CO emissions started to occur, when engine power exceeded 300 kW. For synthetic evaluation of the new pistons, the engine oil consumption can be used. Oil consumption is mainly due to combustion of the engine oil on the surfaces of the cylinders and on the surfaces of the pistons. Increase in the consumption of engine lubricating oil is favoured by an increase in exhaust blowby volume to the crankcase. In studies of oil consumption on engine equipped with new pistons and engine equipped with standard pistons, the significant reduction in oil consumption for the new pistons has been shown, the reduction of about 17%. This is the average score of 5 trials.

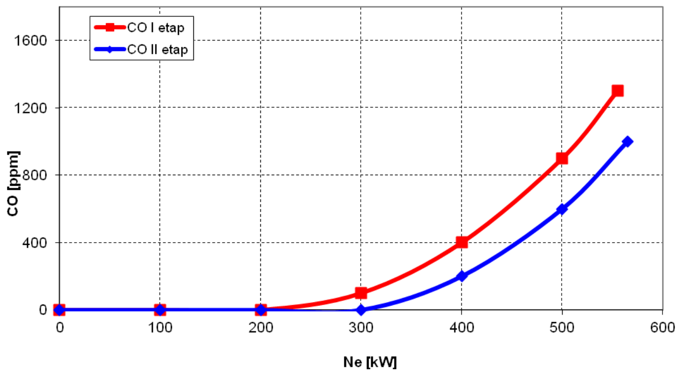

Fig. 13. Variation of CO emissions in exhaust gases of S12-U engine, with standard pistons and pistons made of novel material, at part load conditions; n=1700 rpm

Fig. 14. View of pistons made of novel material after S12-U engine testing

On pistons, after tests, do not found any alarming signs of the beginnings of seizing or damage. Pistons traces of collaboration with the cylinder bores were correct, on the upper surfaces of the piston, closing the combustion chamber gathered some carbon deposits. The carbon build up, however, was smaller, than on standard pistons.
Fig. 14 shows the appearance of the new engine pistons after the tests, including: engine running in, determination of the engine characteristics, engine emission measurements, measurements of the engine exhaust gas opacity, measurements of exhaust blowby, and measurements of the oil consumption.

Thus, the results indicate the possibility of replacing the previously used pistons with new type ones, which should lead to a reduction: fuel and oil consumption, exhaust emissions, and above all, HC, CO and PM emissions, reducing of the engine noise, reducing exhaust gases blowby into the crankcase. You can also expect prolongation of the engine life.

5. Conclusions

1. The aim of the modernization of the pistons was to reduce the clearance at a piston-cylinder liner assembly by reducing dimensional piston hysteresis during fast cyclic heating and cooling of the pistons, which would reduce the emissions of harmful substances in exhaust gases, primarily unburned hydrocarbons (HC) and carbon black content, reducing oil consumption, reduce exhaust gases blowby to the crankcase and also increase resistance to thermal shock.
2. The conducted comparative studies on engine fitted with standard pistons and engine, on which novel pistons were mounted, revealed that this objective has been achieved.

3. The results show that the engine with installed new pistons achieved: a reduction in specific fuel consumption in the range of 4%-7%, increase the nominal power of approximately 1.5% and power at lower speeds up to 12%, reduce emissions of carbon monoxide (CO) by 10-20%, reduce emissions of hydrocarbons (HC) by 18%-25%, reducing blowby to the crankcase by 30-45%, reduced exhaust gas smokiness, on lower engine loads it even disappear entirely.
4. An important achievement after the application of the new pistons is to reduce the consumption of lubricating oil by about 17%, indicating better bearing film control on the surface of the cylinder liner.
5. Most of the achieved results is due to a decrease in clearance between piston and cylinder at a piston – cylinder assembly, which is particularly well evident in the case of HC emissions, when the engine load was raised, so raised the piston temperature, which resulted in the reduction of the clearance between the piston and the cylinder liner, and HC content in the exhaust gas decreased steadily.
6. New pistons are made of the new composite silumin alloy, characterized by the introduction of new alloying elements: molybdenum and tungsten, and increased amounts of copper and nickel elements and after casting the pistons are subjected to multi-stage heat treatment. As a result, the new pistons are characterized by very high strength parameters, and low dimensional hysteresis on the fast, cyclical heating and cooling.

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