Andriy Marchenko
National Technical University "Kharkiv Polytechnic Institute"
2, st. Kyrpychova, Kharkiv, 61002, Ukraine

Volodymyr Shpakovskyy
North-Eastern Scientific Centre of the National Academy of Sciences of Ukraine and the Ministry of Education and Science of Ukraine
8, st. Bagaleya, Kharkiv, 61002, Ukraine, shpakcorundum70@gmail.com

Volodymyr Volikov
North-Eastern Scientific Centre of the National Academy of Sciences of Ukraine and the Ministry of Education and Science of Ukraine
8, st. Bagaleya, Kharkiv, 61002, Ukraine
https://orcid.org/0000-0002-4107-6277

CORDUNUM PISTONS INCREASE DIESEL ENGINE ECONOMY AND RELIABILITY

Abstract
Taking into account the oil resources depletion the requirements to fuel consumption of internal combustion engines are now increasing as well as to their reliability and durability. With the continual increase in the number of internal combustion engines in operation, along with the problem of parts of the cylinder piston group wearing out has caused exhaust from such engines to be one of the main source of harmful pollutant emissions in cities. Therefore, environmental requirements have in turn increased dramatically. The engine resource and its efficiency largely depend on the process of fuel combustion in the combustion chamber. Experimental studies aimed to improve the working process on diesel engines by piston insulation have shown an effective decrease in fuel consumption by reducing heat loss and more complete fuel combustion. When oxide ceramic coatings were used on the piston and cylinder head, the maximum power increased and the specific fuel consumption decreased. However ceramic coatings are not widely used due to their peeling. We have developed a technology for the galvanic plasma treatment of pistons, which made it possible to obtain on the pistons surface made of aluminum alloys a ceramic corundum layer with high adhesion to the base metal that does not peel and has electret properties. In 1993, pistons with a corundum surface layer were installed in a shunting diesel locomotive and life-time running tests were conducted. Such pistons increased wear resistance, reduced the wear of cylinder liners, increased the strength of the annular jumpers, and were not prone to burnouts and scuffing. They provided an increase in the resource of the cylinder-piston group of the diesel engine by more than 125 thousand engine hours. The paper provides an analysis of the effect of corundum pistons thermal insulation on significant increasing the, engine power and fuel consumption reduction. Basing on experimental bench studies of a gasoline engine, a tractor diesel engine and long-term operational life tests of diesel engines, an attempt had been made to explain the reasons for the improvement in the engines' efficiency.

Keywords
Diesel, engine, locomotive, piston, corundum, layer

Introduction

There is a fleet of approximately 1000 diesel shunting ChME-3 currently in service in Ukraine. The problem of improving the efficiency and economy of this fleet's performance is important in the context of the annual reduction of the fleet of shunting locomotives. Replacing worn-out power units with imported ones requires considerable financial expenditures. Every year the fleet of shunting diesel locomotives decreases, and the volume of shunting operations increases. To maintain the performance characteristics of shunting diesel locomotives at the proper level, it is necessary to frequently repair of diesel engines with replacement the cylinder-piston group parts. Currently the reduction of repair and operation cost of shunting diesel locomotives is one of the important problems faced by Ukrainian Railways. They are trying to solve this problem by replacing the existing K6S310DR diesel engines with Caterpillar diesel engines, however it is rather expensive. Another more economical solution is to refurbish the engines of the current fleet. To limit the heat loss of the working fluid through the walls of the combustion chamber, heat insulating overlays, heat rings, screens are used as well as cermets or ceramic coatings which have high heat resistance, hardness and wear resistance and do not require changes in the design of parts. It lets to reduce the impact of thermal loads on the life cycle and reliability of the

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engine. Several companies have tried using ceramics in engines/The Japanese company Kyoto Ceramic [1] had manufactured almost entirely ceramic engine made of sintered silicon oxide. Such ceramics were used to make the cylinders, pistons, firing bottom of cylinder head, pusher, rocker arm, bar tips and plugs of piston fingers. Cummins Engine Co (USA) [2] has developed the turbocharged diesel engine with ceramic outer cylinder insulation, ceramic piston plate, ceramic cylinder head bottom, ceramic plate on the exhaust valve plate, ceramic insert in the exhaust duct. However, ceramic parts break when the bolts are pulled, when they fall, or when the heat is uneven. The use of cermets to isolate parts has also been investigated by Fiat [1]. In order to improve the efficiency of the internal combustion engines. For the first time, partially-dynamic thermal insulation of the combustion chamber was used. The modification of the working surfaces of pistons was made using aluminum alloys to form heat-insulating corundum layer with electret properties. A rational thickness of the heat insulating layer was established, which reduced the heat flow to the piston, increased the temperature of the gas near the upper dead point, led to more complete and faster combustion of fuel, increased power, reduced fuel consumption and emissions of harmful gases and increased the resource of engine. The repairs of on-line diesel engines K6S310DR in CHME-3 type locomotives with pistons that had undergone galvanoplasma surface treatment with the formation of a corundum layer is much cheaper. It helps to solve the problem of diesel engines performance characteristics improvement in shunting locomotives of the CHME-3 type after repairs. The purpose of the publication is to inform about the benefits of the proposed piston corundum technology for internal combustion engines.

Methodology for combustion chamber thermal insulation efficiency study

To solve the problem of fuel consumption and emission of harmful gases reduction, the results of previous studies on the use of ceramic coatings and heat insulating linings on engine pistons were analyzed. Experimental studies on workflow improvement in diesel engines equipped with pistons with a ceramic coating of 0.2–0.9 mm thickness demonstrated the effective fuel consumption decreasing by 6–8 g/(kW·h). For the 1ChN18/22 diesel engine the decreasing was 7–9 g/(kW·h) [3]. For 1ChN18/20 diesel engine with an aluminum piston coated with aluminum oxide with a thickness of (0.25-0.3)mm at optimum ignition timing angle ϕ=14-14,5°in nominal mode, the effective fuel consumption decreased by 2.7 g/(kW·h), for diesel engine 2ChN 21/21, with n = 1200 min^{-1} and ϕ=36-38 °, the decreasing was 5.44 g/(kW·h). Aluminum oxide coating with a thickness of (0.2–0.25)mm on the piston of a low-speed diesel engine 1ChN24/36 with volumetric mixture formation caused a decrease in the effective fuel consumption for loads less than 45% of effective power by 2.5–13 g/(kW·h) [4]. When using oxide ceramic coatings with a thickness of about 0.06 mm, obtained by anodic microarc oxidation on a piston and cylinder head, the maximum power of a two-stroke internal combustion engine was increased by 6% and the specific fuel consumption was decreased by 3.2% [5]. However, thermal insulation coatings were not widely used due to their peeling, which led to engine seizure. The use of insulating pads [6,7] led to the complexity of the design of the pistons, weight gain and reduced the reliability of the piston. Experimental study by G.Woschni et al.[8] of heat transfer in internal combustion engines using a piston with a head covered with a layer of ceramics "Nimonic-80A" with a thermal conductivity of 2 W/m·K was carried out for a single-cylinder diesel engine with an undivided combustion chamber having the diameter and piston stroke of 125 and 140 mm, respectively, with turns of 2,200 min^{-1} . It was concluded that the use of thermal insulation of the combustion chamber surface in the piston leads to an increase in fuel consumption. Making such a conclusion for heat insulation thicknesses from 2mm to 20mm, Woschni, nevertheless, showed that with small thicknesses of heat insulation there is a decreasing in fuel consumption and an increasing in engine efficiency. However, studies with the thickness of the heat-shielding layer less than 1mm had not been carried out [8]. During the development of the adiabatic engine by Professor N.F. Razleitsev the idea was proposed that the temperature of the wall should change during the cycle in accordance with the change in the temperature of the gas in the combustion chamber, that was later proved by British scientists. As a result of studies of thermal insulation materials for adiabatic engines by H. Valland,G.K. Wyspianski , F.J. Wallaces et al., University of Bath, UK [6,7] it was concluded that in order to obtain the most favorable thermodynamic indices, the duty cycle of the engine must be purely adiabatic, i.e. the temperature of the combustion chamber walls should change following the changing the gas temperature throughout the cycle. In the process of organizing the combustion of fuel in the cylinder of a diesel engine, a complex heat exchange process takes place, with a variable temperature field on the parts of combustion chamber surface. Calculations of piston thermal insulation, which were carried out taking into account the thermal inertia of zirconium $3.5x10^6$kg $/s^4$·K at n turns 3000 min^{-1}, showed the amplitude of the temperature change was 100^0C.Based on the analysis of these and other research results, a general conclusion was made: a purely adiabatic mode of engine operation cannot be achieved with any real construction of the combustion chamber walls. In addition, a significant increasing in efficiency (up to 10%) may be obtained with partial thermal insulation of the combustion chamber [8]. Attempts to create adiabatic engines failed and further work in this direction was ceased. It was pointed out on the positive effect of the hot surfaces of the combustion chamber on the performance of the diesel engine and that there are optimal temperatures for the parts of the combustion chamber that provide obtaining the most beneficial workflow for the cycle. Studies carried out by A. Pischiuger [9],O.V. Leonov and E.P. Kamzolov. [10], V.F. Ermakov [11] had shown that for combustion chambers with film and volume-film mixing and working on diesel fuels the temperature of the combustion chamber surfaces should be in the range of 320-380^{0}C. With such temperatures of the combustion chamber walls the specific fuel consumption for a diesel engine is Ch10.5/13 with the smallest vortex chamber [12]. The greatest effect in efficiency improvement was reached by the piston coating with the aluminum alloy, which consists of aluminum oxide, with a thickness of (0.2 - 0.5)mm [4]. Such a heat-insulating ceramic surface can be obtained by microarc oxidizing the surface of a aluminium alloy made piston. The establishing of optimal temperatures can be achieved by changing the thermal resistance of the surface through the thickness of the heat insulating layer change. It can ensure a decrease of heat flow from the gas to the parts of the combustion chamber, but also from parts to the fresh charge. It is known that in order to obtain the most favorable thermodynamic indicators, the duty cycle of the engine must be purely adiabatic, i.e. the temperature of the walls of the combustion chamber should change following the change in gas temperature throughout the cycle [13]. However, this is an ideal case and it is not yet possible to achieve it .As a result of a series of simulation and experimental studies for engines of various types, a rational thickness (0.12-0.16)mm of a ceramic corundum layer was determined at which the growth of the full fluctuation of the piston firing surface temperature occurs. In this case, the maximum instantaneous temperature of the cycle increases from 320°C to (380-390)°C and the minimum instantaneous temperature of the cycle decreases from 315°C to 305°C. The depth of penetration of the temperature wave into the body of the piston decreases and the rate of change of the temperature of the piston surface increases. The calculated values of the temperature change on the piston firing surface during the cycle are shown in Fig.1.

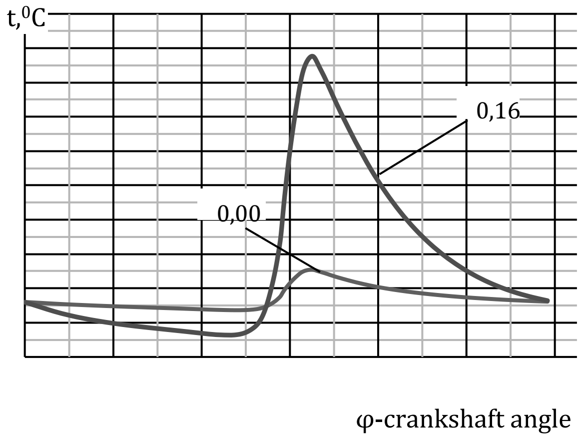

Figure 1. Temperature change on the piston firing surface during the cycle.
The figures at curves indicate the thickness of the corundum layer in mm
Source: Authors

The minimum value of the surface temperature of the standard piston was 313^{0}C, and on the corundum surface 306^{0}C. The maximum temperature on the surface of the standard piston was 325^{0}C, and on the corundum surface it was 387^{0}C, so the amplitude of temperature fluctuations was increased by 69^{0}C and was reached 81^{0}C.The calculations of the unsteady temperature state of the surface of the piston with a corundum layer were confirmed by experimental studies of the 4CHN12 / 14 engine equipped with pistons with a corundum surface layer.

Methodology of work efficiency of diesel engines with corundum pistons study.

Experimental research of the 4ChN12/14 engine were carried out on a motor stand with removal of indicator diagrams in two versions: for a diesel engine with a usual piston and for an engine with a piston having electret corundum layer on the surface in the zone of the combustion chamber. When the cylinder is filled with fresh charge, the heat flux from the wall of the combustion chamber is directed to the working fluid. The small thickness of the low heat conductive surface layer causes a decrease in its temperature to the level of the working fluid temperature. The layer temperature becomes lower than the temperature of the piston base material, the pressure drops, and the cylinder filling ratio increases. During the filling process, the surface temperature of the corundum layer of the piston decreased by 80 ° C working fluid into the wall of the combustion chamber, the layer temperature increases and becomes higher than the temperature of the piston base material [9]. The heat flux from the working fluid to the surface of the combustion chamber is reduced. The temperature of the working fluid increases and the period of delaying the auto-ignition of the fuel decreases. The pressure rise rate (dp / dφ) max during combustion for fuel supply process is higher when corundum pistons are used in almost the entire range of operating modes of the diesel engine. It may be explained by the combustion rate of the fuel increasing. The part of fuel that has fallen on the wall of the combustion chamber in the piston due to the increased temperature of the wall surface is evaporated more efficiently. The high temperature of the combustion chamber surface during combustion of the fuel and expansion of the working fluid causes the reduction the heat flux to the piston wall and, accordingly, the coefficient of relative heat loss to the wall decreasing (Fig. 2).

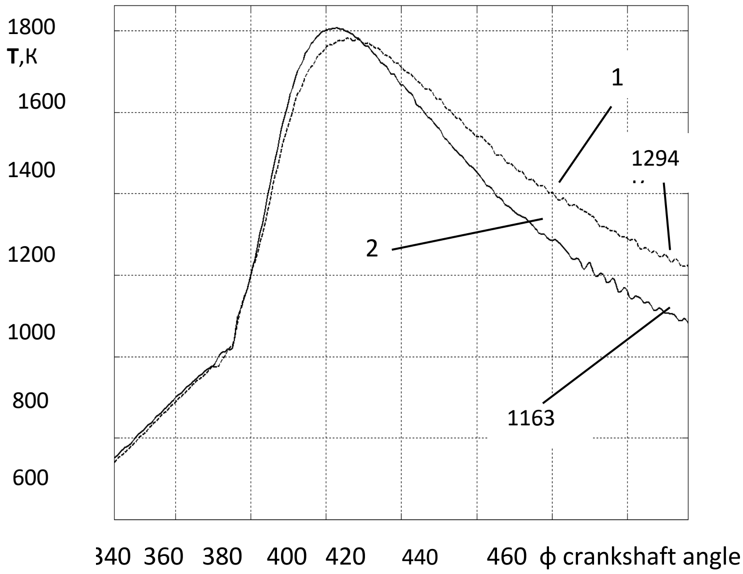

Figure 2. Gas temperature: 1 — standard pistons, 2 — experimental pistons, n = 2000 min⁻¹, pe = 0.95 MPa
Source: Author

As the thickness of the corundum layer increased, the heat flow to the piston decreased, and after the thickness of the layer 0.12mm, the heat flow decrease ceases. The rational thickness of the heat-insulating layer provided a reduction in the maximum value of the specific heat flux in the piston by 16% compared to the non-heat-insulated piston, which led to a decrease in heat loss. With the removal of load characteristics and operation of the engine with pistons with a corundum layer, the maximum cycle pressure increased by 0.5 MPa. The self-ignition process was started earlier, with less amount of injected fuel and therefore, at the first flash, the maximum value of the heat release rate decreased by 12.5%. This conditioned the soft work of the engine. The maximum value of the heat release rate in the combustion chamber with the piston having the corundum layer during the second flash increased by 8.35%. An increase the maximum value of the combustion rate in the region of the second maximum and its approximation to the top dead center improves the efficiency use of the heat of combustion use, which leads to effective power of the diesel engine increase and fuel consumption decrease. From the point of view of the conventional combustion theory, the improvement of the combustion process can be explained in the following way. The corundum layer on the piston fire surface, formed by galvanoplasmic processing, being a corundo electret with a negative surface charge of -3.9×10^{-8} Cl / cm^2, leads to the acceleration of the combustion process. That is, it is a catalyst and affects the fuel combustion process. When the fuel is injected into the electric field of the corundoelektra, electrostatic spraying takes place, which leads to earlier beginning of fuel molecules decomposition with the formation of free radicals. The appearance of a cold flame is accelerated, the time of the beginning of the process of chain self-acceleration of the reaction is reduced and the heat evolution is improved. Due to the partially dynamic heat insulation of the combustion chamber during the period of diffusion combustion, an increase in the temperature of the gas occurs. The temperature of the gas in the combustion chamber is increased by about 30 K, and on the corundum surface of the piston by about 60 K, which makes it possible to obtain a plasma with an increased concentration of ionizing action [9].The excess gas charge is basically positive, and the excess charge of corundolectret is negative. Gas molecules attraction to the corundum surface is intensified, their velocities are significantly increased, that leads to an increase in the impact of molecules on the corundum surface and the destruction of the molecule itself. There is a destruction of large molecules into small fragments. The activation energy of the beginning of the chain reaction of the decay of molecules is reduced [12]. The maximum value of the temperature of the gas in the engine with the corundum piston increases and shifts towards the upper dead center, which results the faster and more complete combustion of the fuel. It causes the engine efficiency improvement. The power of the engine increases and, accordingly, the fuel consumption decreases. It leads to the reduction of harmful gases emission. After the tests, usual pistons had a charge on the head in the thickness from 20 to 160 µm. The higher temperature of the corundum surface of the piston bottom lets to achieve the more complete combustion of fuel and significantly reduce of carbon deposits. After the tests of the engine with corundum pistons on the heads of the pistons there was no scum. This has led to a reduction in emissions of harmful gases. Comparison of mass and average operating specific emissions of solid particles of the 4ChN12/14 tractor diesel engine was carried out with standard pistons and pistons with a corundum layer Δ = 0.12 and 0.24 mm thick. Corundum layer was formed on the bottom of the piston, the side surface of the piston (up to the upper compression ring) and on the surface of the combustion chamber in the piston. As a result of the tests, a reduction in mass emissions of solid PTm particles with exhaust gases of 4ChN12/14 diesel was defined by (19-30)% [13].

Experimental studies of the 4ChN 12 / 14 engine, equipped with experienced corundum pistons, allowed to establish the results. The standard pistons after testing had a soot on the head with a thickness of 20 to 160 µm, and after testing the engine with pistons having the corundum layer on the heads of the pistons there was no soot. The higher temperature of the corundum surface of the piston bottom led to more complete combustion of the fuel and a significant reduction in carbon. Partial-dynamic thermal insulation of the piston firing surface with a corundum layer with thickness $\delta \approx$ (0.12-0.16 mm) allowed to obtain fluctuations in the temperature of the thermally insulated surface of the piston within 60–80 ° C following the changes of gas temperature. This ensured a reduction of the maximum value of the specific heat flux to the piston by 16% compared to a piston without thermal insulation. It led to the following consequences: the decreasing of heat loss and the surface temperature of the corundum piston layer by 8 ° C during the filling process compared to the temperature of the usual piston, the increasing of the maximum range of the temperature wave by 60 ° C, the decreasing of the maximum heat release rate during auto-ignition by 12.5%.The use of corundum pistons leads to decrease the mass emission of solid particles with diesel exhaust gases by 19 - 30% and CO_2 in the environment.

Results of the research

Wearing of pistons and cylinder's well in the process of operational resource tests

One of the most important indicators of internal combustion engines is its resource, which is largely determined by the wear of engine parts and especially, the piston-cylinder group. The resource of the new cylinder-piston group with standard pistons installed in the diesel engine of the ChME-3 diesel locomotive during routine maintenance is about 35-40 thousand hours. During the following maintenance repairs, the pistons and sleeves that were out of order were replaced . In February 1993, when maintenance was carried out in the Kharkiv-Sorting locomotive depot, two shunting diesel locomotives with diesel engines K6S310DR, manufactured in 11.1989, were selected for performance service tests with installation of new experimental corundum pistons and new liners. In the second diesel locomotive, new standard pistons and liners were installed. The tests were carried out for 19 years. During each routine repair (in 1994, 1997, 1999, 2002, 2005, 2008 and 2011), the dimensions of the parts of the piston-piston group — cylinder liners, upper grooves of the piston rings, and the cylindrical part of the pistons — were measured and their wear was determined. In the process of rheostat tests, fuel consumption and rheostat power were measured. Controlled diameter is a diameter located at a distance of 50 mm from the cut of the skirt. Here the most piston wear out took place. As a result of diesel locomotive operation from 03/01/1993 to 12/20/2012, the maximum wear out of the monitored part of the pistons after operating time of 125 thousand hours does not exceed 0.2 mm. On December 2011 during routine maintenance it was found that the piston sizes are within the allowable values, the width of the first annular grooves on all pistons was within tolerance, the working parts of cylinder liners had a mirror surface without longitudinal scratches and visible wear out . Figure 3 shows the wear out values of the monitored part of the pistons for experimental CHMI-3 diesel engine after operating for 125 thousand operating hours. After pistons installation with a corundum layer in the diesel engine of ChME-3, the wear out of pistons and cylinder liners was reduced (Fig. 4).

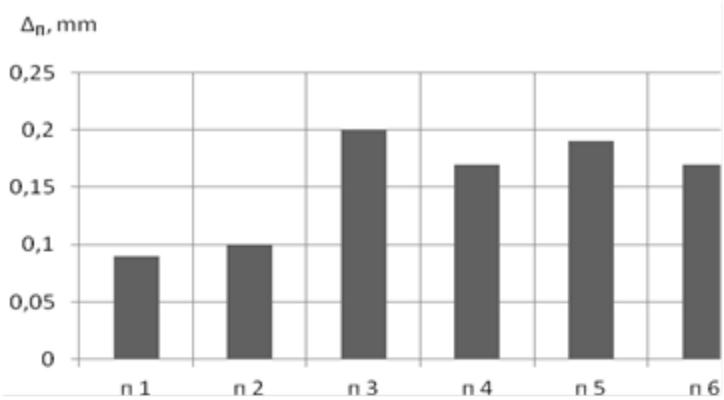

Figure 3. The wear out value of the controlled part of the pistons in the diesel engine ChME-3 after the operating time of 125 thousand hours
Source: Authors

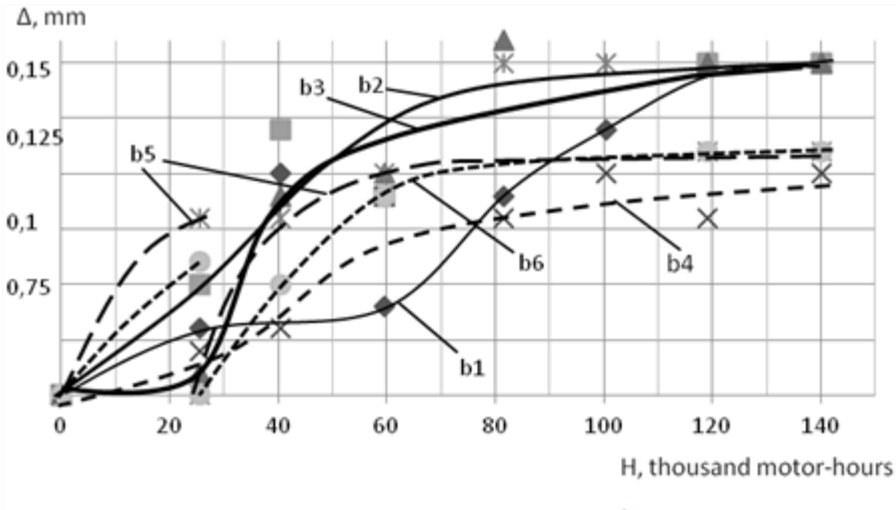

Figure 4. Wear out of diesel liners with corundum pistons during operation
b1 – b6: cylinder liners Nos.
Source: Author

When a diesel engine works with standard pistons, the resource of liners is approximately 35-40 thousand hours, and due to the large wear out, they are replaced during routine repairs. Therefore, the modernization of diesel locomotive with the installation of pistons having the corundum layer allowed to increase the life cycle of the cylinder-piston group more than a three time. During the tests of the Belarus tractor diesel D240 with a corundum piston worked for 15 thousand engine hours without replacement of the cylinder-piston group. After the 36-hour motor tests of the 4ChN12/14engine with standard pistons, the cylinder liners had longitudinal scratches, and after testing the engine equipped with corundum pistons with the liner there were no scratches, they had a mirror surface. A corundum layer on the cylindrical surface of the piston, with a high hardness and fine-grained structure let the surface of the liner to be smoothed. The low friction coefficient and porosity of up to 10-12% of the corundum layer ensured in friction reduction and the reduction in of the liner surface wear out.

Research of the efficiency of the heating diesel working with corundum-electric pistons

The rheostat tests of diesel engines with new pistons and sleeves with corundum layer showed the conformity of performance characteristics to the technical conditions. During rheostat tests, the parameters of diesel locomotive engines were measured according to diesel locomotive characteristics. Comparison of the characteristics of the experimental and existing diesels with the new pistons and sleeves, after the technical repair, show that an experimental diesel engine with corundum pistons develops significantly more power than a existing. After new corundum piston installation, prior to operational tests on mode 8, the test engine developed a maximum rheostat power N equal to 1040 kW at turns 750 min^{-1}, and standard Nc = 634 kW at turns 680 min^{-1} (Fig.5).

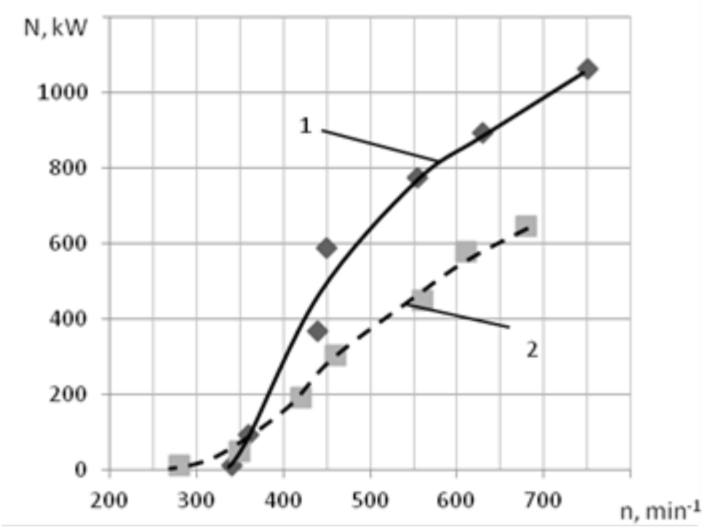

Figure 5. Characteristics of diesel locomotive engines after major overhaul and replacement of the cylinder of the piston group: 1 - diesel locomotive No. 6830 with pistons with corundum layer;
2 - diesel locomotive №6835 with standard pistons
Source: Authors

Rheostat tests of diesel engines performed at the depot Kharkov-Sorting for 20 years showed a significant reduction in diesel fuel consumption of locomotive with corundum layered pistons were installed. In the process of rheostat tests, fuel consumption was measured using the AIRT-2 device developed by the Ukrainian State Academy of Railway Transport and the RECORD Company Attorney of the State Enterprise "Kharkivstandart-Metrology" (Certificate No. 3383 dated July 09, 2008). According to the results of rheostat tests, the specific effective fuel consumption of a diesel engine with serial and corundum pistons was estimated. The specific fuel consumption of a diesel engine with pistons having a corundum layer decreased by 10% (Fig. 6).

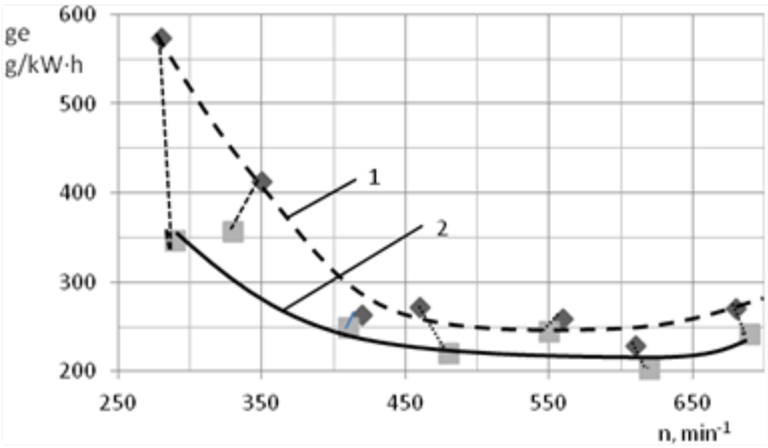

Figure 6. Specific effective diesel fuel consumption: 1 - with standard pistons; 2 - with corundum pistons
Source: Authors

The improvement of the combustion process is confirmed by the absence of carbon deposits on the bottom of the piston with a corundum layer. After testing, standard pistons had carbon deposits on a head with a thickness of 20 to 160 µm, and after testing engine with corundum pistons, there was no deposit on the piston heads. The maximum value of the rheostat (traction) efficiency of a diesel locomotive ChME-3 with pistons having the corundum layer reaches 36%, and a diesel locomotive with standard pistons 31%). In almost 5 to 8 modes, the traction efficiency of a diesel engine with pistons with a corundum layer is 5% higher. In 2011, an analysis was made for the diesel locomotive equipped with a corundum piston and diesel locomotives equipped with standard pistons operating in approximately the same conditions and with almost the same annual mileage. The fuel consumption and mileage of diesel locomotives for each month of work is taken into account by the form of TCT 5. Basing on the test data, the results of fuel consumption and mileage of the indicated locomotives for 2005–2010 years are presented in the table 1.

Table 1. Actual average annual specific fuel consumption of diesel locomotives CHME3 in kg per km of run (2005-2010 years)

No. of locomotive	2005	2006	2007	2008	2009	2010	Consumption for 35 thousand km
6830	1,9	1,96	1,91	1,90	2,22	2,13	66,56tons
4384	2,7	2,7	2,62	2,57	2,56	2,78	90,1(23,5)
5820			2,1	2,35			82,56 (16,0)
5822				2,34			81,9 (15,3)
5833			2,2	2,2			77 (10,4)
6835			3,37	3,27			114,6(48,1)
7321			4,3	4,2			145,8 (79,2)
7323			2,16	2,71			94,86 (28,3)

The values in brackets indicate fuel overrun by diesel locomotives with a run 35 thousand km
Source: Authors

During 2005 - 2006, the mileage for diesel locomotives with pistons with corundum layer and with standard pistons was almost the same, and the fuel consumption of diesel locomotives with standard pistons was more. From table 1 it is clear that the average annual fuel consumption per 1 km of diesel locomotives with standard pistons is higher than the fuel consumption of a diesel locomotive with corundum pistons. It becomes obvious that with a run of 35 thousand km the best diesel locomotive with standard pistons consumes 10.437 tons more fuel than a diesel locomotive with pistons having the corundum layer. Of course, such a comparison of fuel consumption is not entirely correct, since diesel locomotives have different operating time after technical repair and work with different loads, different downtime and distance of runs for certain operations are different and so forth. However, to some extent such an assessment allows, to some extent, to evaluate the efficiency of a diesel engine and to conclude that the installation of pistons with a corundum layer in diesel engines of shunting diesel locomotives significantly reduces fuel consumption by shunting diesel locomotives.

Discussion with the other papers

An experimental study by German scientists G. Woschni et al. of heat transfer in internal combustion engines using a piston with a head coated with a Nimonic-80A ceramic layer, ZrO2 5 mm thick allowed to conclude that it is practically impossible to obtain a reduction in fuel consumption by thermal insulation of the combustion chamber walls [8]. Making such a conclusion for thermal insulation thickness from 2 mm to 20 mm, Woschni, however, showed that with small thermal insulation thickness, fuel consumption is reduced and engine efficiency is increased. However, studies for the thickness of the heat-shielding layer less than 1 mm were not carried out [8]. As a result of studies of heat-insulating materials for adiabatic engines obtained by scientists H. Valland et al. from the University of Bath, United Kingdom [6], it was concluded that to obtain of the most favorable thermodynamic parameters, the duty cycle of the engine should be purely adiabatic, i.e. the temperature of the walls of the combustion chamber should change following a change in gas temperature throughout the cycle. Based on the analysis of these and other research results, a general conclusion was made: a purely adiabatic mode of operation of the engine cannot be achieved with any real design of the walls of the combustion chamber. However, an increase in efficiency (up to 10%) can be obtained with partial thermal insulation of the combustion chamber [6].The technology of galvanic-plasma processing developed by authors made it possible to create a ceramic corundum layer on the firing surface of the pistons of a diesel shunting diesel locomotive with an optimum thickness of (0.12-0.16) mm. Such thickness lets to obtain temperature fluctuations on the piston surface within 80-100^{0}C following a change in gas temperature during the cycle. In addition, the electret corundum layer has a negative surface charge $-3.9\bullet10^{-8}$ C / cm^2 and, being as catalyst, accelerates the process of fuel combustion. This improved the efficiency of fuel combustion heat use, increased the effective diesel power, reduces fuel consumption and reduces the emission of harmful gases. So the significant technical and economic advantages of pistons with a corundum layer use in internal combustion engines are shown in the

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paper. It allows to reduce the specific fuel consumption per unit of work and to low the level of CO_2 emissions to environment.

Impact of research results on science, economy, environment and society

Conducted scientific studies have shown the possibility of obtaining a partially-dynamic thermal insulation of the combustion chamber to increase the efficiency by using the heat of combustion of fuel. The optimum thickness of the corundum layer was determined, which allowed to obtain a change in the temperature of the walls of the combustion chamber following a change in gas temperature throughout the cycle. The increase in engine force is accompanied by an increase in mechanical and thermal loads on the parts and affects the resource and reliability, which mainly depend on the wear of the crankshaft necks, cylinder liners and piston damage. As the temperature of the piston increases, the mechanical properties of the piston material deteriorate, and the uneven temperature field in the various sections of the piston causes considerable thermal stresses and uneven deformation, which is the main reason for the shortening of the service life of the piston and piston rings. The pistons crack the edges of the combustion chambers, there is wear and tear of the ring jumper, melting of the piston head and the appearance of burrs on the cylindrical part and clutch with the cylinder sleeve. Generally, engine life and technical and economic and toxicity indicators depend on the performance of the parts of the cylinder-piston group. Therefore, the use of pistons with a corundum layer made it possible to increase the engine resource by more than 3 times. The corundum layer, being a catalyst, accelerates the process of fuel combustion. Engines with standard pistons have significantly worse combustion quality. The consequence of this is an increase in fuel consumption and a decrease in diesel power. In engines with pistons with a corundum layer, the combustion process proceeds almost in the design mode. This provides the calculated parameters for the specific fuel consumption and power during the operation of the engines. Furthermore, this positive effect becomes greater with increasing operating time of internal combustion engines. This reduces fuel consumption and reduces the emission of harmful gases. The creation of engines with a 15-20% lower fuel consumption will reduce the consumption of fuel for transport, reduce greenhouse gas emissions of CO2 into the environment and reduce operating costs due to a significant increase in the resource of the cylinder-piston group.

Summary and conclusions

Based on the inspection and measurement results within the operation period from March 1993 to December 2012, we can make the following conclusions. The use of pistons with a corundum layer permits to increase the operating life of the cylinder-piston group of a diesel engine of a ChME-3 diesel locomotive engine by more than three times. The pistons with a corundum layer and cylinder liners had worked from March 1993 to December 2011 for more than 125 thousand running hours; as for the diesel locomotive with commercial pistons, the cylinder-piston groups had been replaced three times over the same period. As a result of the analysis of previous studies on the use of ceramic coatings and heat-insulating linings on engine pistons, the technology of galvanic-plasma processing of pistons has been developed. The modification of the working surfaces of pistons made of aluminum alloys was performed with the formation of a heat-insulating corundum layer on the firing surface of the piston, which made it possible to obtain fluctuations in the temperature of the piston surface following a change in gas temperature during the cycle. For the first time, partially-dynamic thermal insulation of a combustion chamber was used to reduce heat loss during fuel combustion. The rational thickness of the ceramic corundum layer was determined, which ensures a decrease in the heat flux into the piston, an increase in the gas temperature near the upper dead center, and more complete and faster combustion of the fuel. As a result of experimental studies of a tractor diesel engine, it has been established that a diesel engine with corundum pistons reduces the mass emission of solid particles with exhaust gases by 19 - 30% and to a reduction in the smokiness of exhaust gases by 15 - 20%. As a result of 19 summer rheostatic tests, it was found that the maximum rheostatic power of a diesel locomotive with corundum pistons exceeds the power of a control diesel engine with serial pistons by more than 20%. Almost traction efficiency of a diesel engine with pistons with a corundum layer was increased by 5% in comparison to a diesel engine with standard pistons. The specific effective fuel consumption of a diesel engine with pistons with a corundum layer decreased by 10%. The installation of pistons with a corundum layer in a diesel shunting diesel engine allowed to reduce the average annual fuel consumption by 25-30%.On December 25, 2012, the Technical Council for the Main Directorate of the Locomotive Economy resolved: “Given the positive results of testing corundum-coated pistons, the Technical Council considers it advisable to recommend corundum-coated pistons to railways for widespread implementation when the locomotives carry out technical repairs and overhauls”. In accordance with this decision, 42 shunting diesel locomotives have already been modernized.

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