Научно-практический электронный журнал
Оригинальные исследования (ОРИС), *ISSN 2222-0402*
www.ores.su
original-research.ru

УДК 621.43

ПРИМЕНЕНИЕ ИННОВАЦИОННОГО РЕСУРСОСБЕРЕГАЮЩЕГО ТРИБОТЕХНИЧЕСКОГО СОСТАВА В ТЕПЛОВОМ ДВИГАТЕЛЕ ПРОМЫШЛЕННОГО НАЗНАЧЕНИЯ

Лашина Екатерина Николаевна
Старший преподаватель кафедры иностранных языков Санкт-Петербургского государственного университета промышленных технологий и дизайна
Высшая школа технологии и энергетики
Санкт-Петербург, ул. Ивана Черных, 4
E-mail: lashinapiter@gmail.com

Липатов Максим Сергеевич
Старший преподаватель кафедры теплосиловых установок и тепловых двигателей
аспирант
Санкт-Петербургского государственного университета промышленных технологий и дизайна
Высшая школа технологии и энергетики
Санкт-Петербург, ул. Ивана Черных, 4
E-mail: 110lms@mail.ru

Аннотация

В статье рассмотрены способы решения проблемы износа деталей тепловых двигателей промышленного назначения. Проанализировано влияние триботехнического состава (ТС) «СУПРОТЕК» на поверхности деталей двигателя на примере дизельной генераторной установки с двигателем Cummins KTA50G-3 1227 кВт ООО «НГ-Энерго».

Ключевые слова: энергетика, износ, ресурсосбережение, триботехника, триботехнический состав, восстановление ресурса.

APPLICATION OF INNOVATIVE RESOURCE SAVING TRIBOTECHNICAL COMPOSITION IN AN INDUSTRIAL HEAT ENGINE

Ekaterina N. Lashina
Senior Lecturer of the Department of Foreign Languages
St. Petersburg State University of Industrial Technology and Design. Higher School of Technology and Energy
St. Petersburg, Ivan Chernykh Street, 4.
E- mail: lashinapiter@gmail.com

Maxim S. Lipatov
Senior Lecturer of the Department of Heat Power Installations and Heat Engines, PhD student
St. Petersburg State University of Industrial Technology and Design
Higher School of Technology and Energy, St. Petersburg, Ivan Chernykh Street, 4
E- mail: 110lms@mail.ru

ABSTRACT

The ways to solve the problem of wear of parts of industrial heat engines are considered in the article. The influence of the tribotechnical composition (TC) "SUPROTEC" on the surface of engine parts is analyzed on the example of a diesel generating unit with a Cummins KTA50G-3 1227 kW engine, "NG-Energo" OOO.

Keywords: power engineering, wear, resource saving, tribotechnics, tribotechnical composition, resource recovery.

During the operation of industrial equipment, its reliability decreases due to wear of parts, corrosion, fatigue and aging of the material. According to world statistics, about 10% of the gross domestic product of individual countries is spent on eliminating the consequences of equipment wear (repairs, downtime during decommissioning, manufacturing of spare parts and assemblies, damage from accidents, etc.) [1]. The unproductive expenditure of such large resources affects the economy of any country in the most unfavorable way, slowing down its development.

The experience of technically developed countries shows two key directions for increasing the resource of industrial equipment and, in particular, heat engines. The first direction is the strengthening of parts of various units. The second one is repair work with the restoration of worn-out parts for secondary use. It is the solution of these two directions that makes it possible to improve the reliability, increase the resource of equipment and, as a result, reduce the costs of eliminating the consequences of its wear.

The strength properties of parts depend on the physical and mechanical characteristics of the material from which they are made, and the wear rate depends on the operating conditions. The wear of the engine and parts of the fuel equipment after a long operating time in a series of malfunctions is mentioned as one of the major aspects. The main problem is usually associated with a decrease in compression due to wear of the piston group. Other important signs of engine wear are increased oil consumption and crankcase fumes pressure (more than 10 mm of water column) [2].

The search for ways to solve the problem of wear of parts of heat engines led, first of all, to the desire to minimize the area of rubbing surfaces, to reduce the power consumption for the drive of auxiliary mechanisms, to use lubricating oils with low viscosity and certain additives [3].

Many leading companies that design and produce engines are exploring ways to improve cylinder bore finishes and to lighten reciprocating moving parts. The latter leads to a decrease in inertial forces, which makes it possible to reduce the diameter of the rod journals and, accordingly, reduce friction losses in the slide bearings.

It is important not only to reduce friction losses, but also to increase the reliability of rubbing pairs. Modern technologies open up wide opportunities: wear-resistant and anticorrosive coatings, thermomechanical surface treatment, plasma spraying of powdered hard alloys and so on [4, 5].

Another measure to reduce piston friction is to regulate the oil temperature in order to maintain its minimum viscosity, which also provides fluid friction. A noticeable reduction in frictional losses in bearings can be expected with the introduction of "gas-film lubrication" of bearings and new lubricants.

All of these methods require significant costs. An alternative to the established traditions is the implementation of the scientific and technical direction for the creation of antifriction coatings with tribotechnical materials during the operation of machines and equipment, which makes it possible to significantly increase the service life of machinery and equipment units, reduce fuel and electricity consumption by 5-20%, and operational costs [6].

A concomitant innovation direction arises, which can be called "Service without disassembly" – increasing efficiency and resource of worn-out units and assemblies without opening them by introducing tribotechnical substances into the lubricant [3].

The influence of tribotechnical substances on the wear of parts of heat engines is clearly seen on the example of the use of the TC “SUPROTEC” in a diesel generator set of diesel power plant (DPP) No. 5 with a Cummins KTA50G-3 engine (see Fig. 1).

Diesel engine Cummins KTA50G-3 is designed for installation in diesel power plants manufactured by Cummins Inc. Cummins power plants are successfully operated as the main power supply systems for facilities, they work perfectly in the most difficult natural and climatic conditions [7].

Figure 1. *Diesel engine Cummins KTA50G-3*

The method of adding tribotechnical compositions "SUPROTEC" is selected according to the principle of maximum convenience and efficiency from the following [8]:

- Filling the TC “SUPROTEC” into the unit's oil filler neck (filler hole or hatch);
- Application of the TC "SUPROTEC" concentrate on the friction surface during disassembly – assembly of the mechanism;
- Application of the TC "SUPROTEC" with an alcohol-based spray with its subsequent evaporation;
- Punching with a syringe of the TC "SUPROTEC" concentrate of bearing and other units with viscous lubricant.

Processing sequence:

- 1) initially, at the 1st step, 40 m-h before the oil change during the next maintenance add the TC "SUPROTEC promkomposit 005" to the old oil at the rate of 1 liter of engine oil in the engine crankcase:

- for an engine with operating time 0 ÷ 1000 m-h - 0.7 ml/l;
- for an engine with operating time of 1 001 ÷ 47 000 m-h - 1.4 ml/l;

- 2) at the 2nd step, when changing the oil at the next maintenance, add the TC "SUPROTEC promkomposit 005" to the new oil at the rate of 1 liter of engine oil in the engine crankcase:

- for an engine with operating time 0 ÷ 1000 m-h - 0.7 ml/l;
- for an engine with operating time of 1 001 ÷ 47 000 m-h - 1.4 ml/l;

- 3) in case of insufficient processing efficiency, it is recommended to carry out the 3rd step when changing the oil at the next maintenance, add the TC "SUPROTEC promkomposit 005" to the new oil at the rate of 1 liter of engine oil in the engine crankcase;
- 4) for long-term trouble-free operation, it is recommended to use the TC "SUPROTEC promkomposit 005" in new oil at the rate of 1 liter of engine oil in the engine crankcase:

- for engines with operating time 0 ÷ 1000 m-h - 0.28 ml/l every 1200 m-h (after two oil changes during the third change);
- for engines with an operating time of 1,001 ÷ 32,000 m-h - 0.56 ml/l every 1200 m-h (after two oil changes during the third change);
- for engines with operating time 32,001 ÷ 47,000 m-h - 0.56 ml/l every 800 m-h (after one oil change during the second change).

In the course of first two steps of processing the diesel generator set of the TC "SUPROTEC", the daily average registration of the operating parameters was organized and carried out.

For a comparative analysis of changes in the specific fuel consumption from the passport characteristics provided by the manufacturer of the Cummins KTA50G-3 engine, in the MATHCAD application, the passport data was interpolated, which made it possible to obtain the dependence of the specific fuel consumption on the load in the form of a power function:

$$b_e = 0.221 + 19.028 \cdot S^{-1.092}$$

where S – the load, kW; be – the specific fuel consumption, kg/kW.

Based on statistical average daily measurements, the following results were obtained:

- pattern of change in the specific fuel consumption of the diesel engine after the processing of the TC "SUPROTEC promkomposit 005" shows a tendency towards a decrease in the specific fuel consumption and a decrease in the deviation in comparison with the passport data, the number of negative deviations increased from 21.4 % to 32.2 %;
- actual reduction in specific fuel consumption, based on selective measurements, can range from 1.3% (load zone 380 ÷ 400 kW) to 5.0 % (load zone 450 ÷ 480 kW).

Measurements were made of the inner diameter of the cylinder liners, the diameter of the rod journals No. 1R and No. 2R of the crankshaft in the periods "before" and "after" processing, as well as the change in their condition was assessed.

The inner diameter of the liners was measured at 5 levels in two planes of each cylinder, provided that the temperature of the engine body at the time of measurement was equal. The measurement was carried out using an internal dial gauge NI-100-160-0.01, with a permitted accuracy of the device within any section of 1 mm in length - 0.010 mm and with permitted accuracy of the device within the entire movement of the measuring rod – 0.015 mm [9]. During the study period, the internal dial gauge was not readjusted between two measurements and was not used for other measurements. A deviation from the nominal diameter of 129.00 mm was recorded. Figure 2 shows the liner measurement diagram.

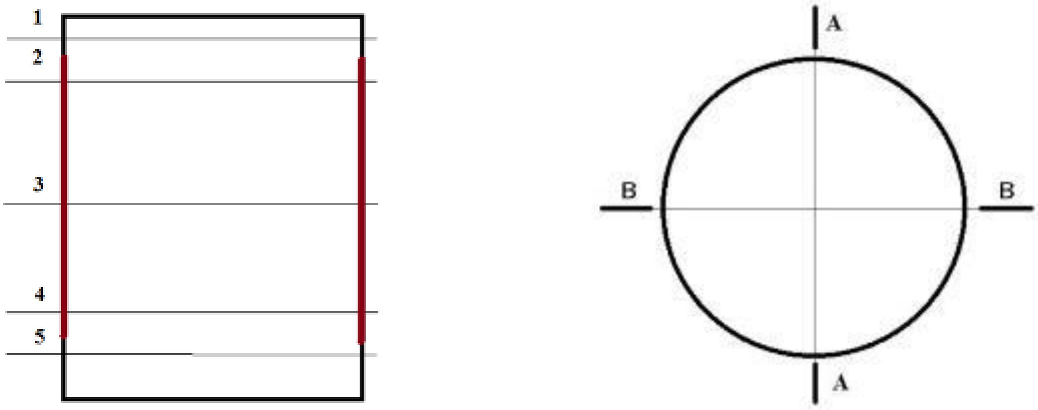


Figure 2. *Scheme of measuring the inner diameter of the sleeves*

Levels: *1 - non-operating upper zone of the cylinder; 2 - zone of operation of the first compression ring; 3 - the average level of the mirror of the compression rings; 4 - the lower level of the mirror of the compression rings; 5 - the lower level of the oil scraper ring operation mirror.*

Planes: *A-A - piston shifts; B-B - longitudinal along the crankshaft axis.*

The results of measurements of the work performed are presented in Table 1. From the analysis of the data in the table, it can be concluded that practically on all levels and planes (except for cylinder No. 2R, plane A-A, level 4), wear of the cylinder liners was not observed, on the contrary, during the period after processing relative restoration of the diameter of cylinder liners by 0.01 ÷ 0.03 mm (taking into account the measurement permitted accuracy: restoration of dimensions up to 20 microns).

Table 1. *Measurement data of the inner diameter of cylinder liners*

Level	Cylinder No. 1R						Cylinder No. 2R					
	Deviation from nominal size in planes, mm						Deviation from nominal size in planes, mm					
	A			Б			A			Б		
	Befor	After	Δ	Befor	After	Δ	Befor	After	Δ	Befor	After	Δ
1	0.35	0.33	0.02	0.32	0.29	0.03	0.32	0.3	0.02	0.33	0.32	0.02
2	0.34	0.32	0.02	0.3	0.28	0.02	0.3	0.29	0.01	0.32	0.31	0.01
3	0.28	0.28	0.00	0.29	0.28	0.01	0.25	0.25	0.00	0.28	0.28	0.00
4	0.,27	0.26	0.01	0.3	0.26	0.04	0.24	0.27	-0.03	0.29	0.27	0.02
5	0.28	0,25	0.03	0.35	0.3	0.05	0.25	0.24	0.01	0.32	0.29	0.03

The diameter of the rod journals of the cylinders No. 1R and No. 2R was measured in four planes along the central part of the neck using an MK 100-125-0.01 class A micrometer, with a measurement error of 0.006 mm. During the study period between two measurements, the micrometer was not used for other measurements.

On all planes of measuring the diameter of the rod journals, with the exception of measuring the rod journal No. 2R in the plane A-A, there was no wear reduction in the diameter, but on the contrary, during the period after processing, a relative restoration of the diameter by 0.01-0.02 mm is observed (taking into account the error measurements: recovery up to 5 ÷ 15 microns).

The change in the state of the rod bearings No. 1R and No. 2R was carried out on the basis of a visual study of the upper bushings (as the most loaded) with photographing of these elements.

The study was carried out on the working area of the bushings in the places of the greatest loading, where the disappearance of a thin running-in layer of the tin coating is observed and traces of finishing machining appear. After some time, in the most loaded areas, the tin-lead coating wears out, the thickness of which is usually 15 ÷ 40 microns, and then a red-copper tint appears below the underlying electrolytic copper/nickel layer.

Figure 3 shows photos of the upper rod bearings No. 1R and No. 2R "before" and "after" processing by TC "SUPROTEC".

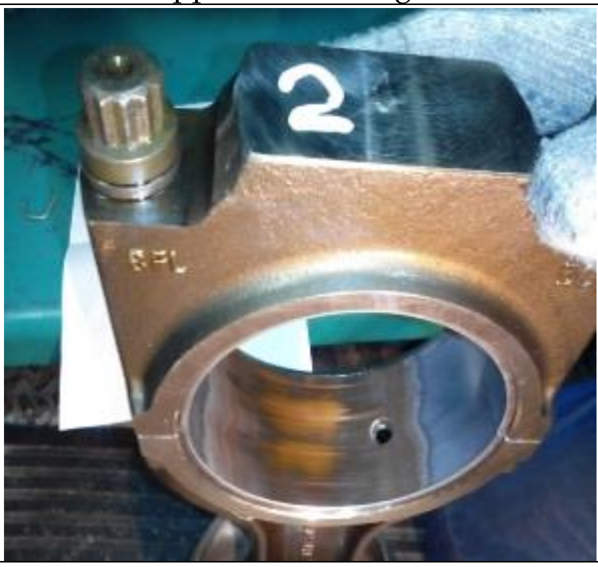
Before processing	After processing
1R upper rod bearing	
	
2R upper rod bearing	
	

Figure 3. External view of bearings of rod journals

After analyzing the photos (see Fig. 3), the following conclusions can be drawn:

• the area of the working zone of the greatest loading of the bushing did not increase, which indicates the safety of using the TC "SUPROTEC promkomposit 005" when processing according to the method of adding to engine oil as a means that does not have a negative effect on the wear of the main units and engine mating pairs;

• there was a change in the color of the working zone of the greatest loading of the insert from red-copper to greenish-bronze (this is especially evident in the photo of bushing No. 1R), which indicates the creation of a nanoscale structure (film) on this surface, which differs in properties from the original surface, which was confirmed by earlier studies on sliding bearings of turbocompressor installations.

Compression measurements for all 16 cylinders were made 3 times: before primary processing, 100 hours after primary processing, immediately before maintenance with oil change, and after secondary processing after 850 hours of operation under normal load. Compression measurement was performed with a universal CR0-40 compressor and was one of the most laborious operations for performing test processing.

The condition for this measurement was the temperature level in the engine cooling jackets, which was within + (32 ÷ 34) °C for all three measurements [10]. During the study period, the CR 0-40 compressor and the false nozzle were not used for other measurements. The measurement results are summarized graphically in Figure 4.

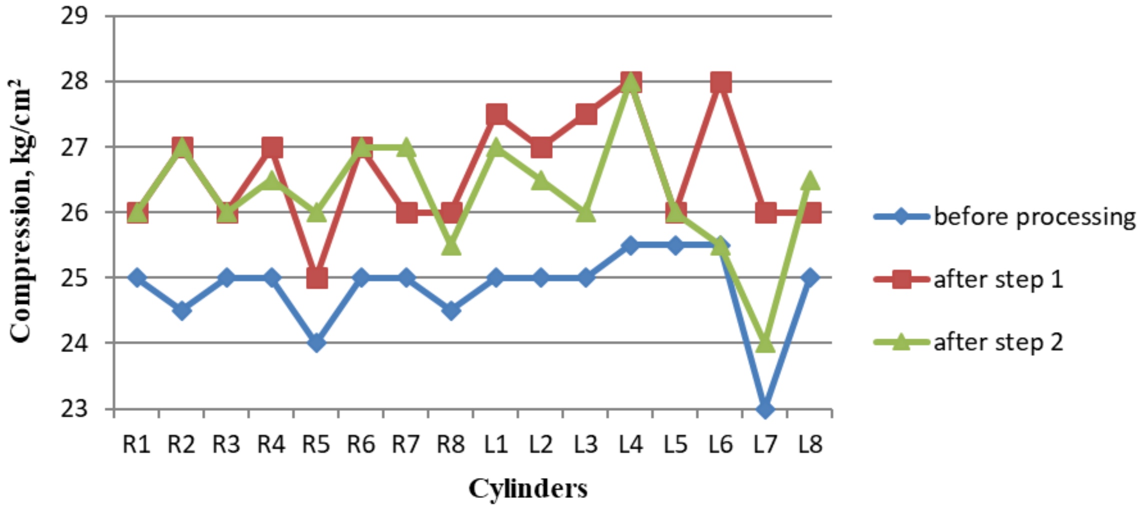


Figure 4. *Change in compression by cylinders*

The figure shows that the average compression level for all engine cylinders has increased by 1.44 kg/cm².

Due to the fact that the level of compression for a diesel engine is one of the main parameters characterizing its efficiency and reflecting the degree of service life, the increase in compression indicates significant positive changes that have occurred as a result of the processing of the TC "SUPROTEC promkomposit 005". We should note the fact that at the time of the third measurement of the compression of the tribotechnical composition itself, there was no longer in the engine oil of the engine, which indicates the aftereffect of the TC "SUPROTEC promkomposit 005", as it changes the properties of the interface surfaces directly and does not affect the performance properties of the engine oil.

The form of the surface profile (roughness) of such critical parts as the cylinder liner is one of the key parameters for all engine manufacturers, which determines the whole range of operational and resource characteristics of the engine [11].

When manufacturing, processing and running in this surface, manufacturers achieve a certain ratio of the parameters of the profile of the inner surface of the line bores, which determines the further fate of the engine under operating conditions [9]. To assess the profile of critical surfaces, manufacturers use instrumental and methodological tools specially developed for these purposes.

The surface profiles of cylinder elements No. 1R and No. 2R of the Cummins KTA 50G-3 diesel engine were measured with a Mahrsurf PS1 profilometer, which registers and evaluates surface profiles based on ISO 13565.

The registration of profiles was carried out according to the scheme of measuring the inner diameters of the line bores according to Figure 2. For the zone of operation of rings of levels 2-4, as subject to processing by the TC "SUPROTEC promkomposit 005", as well as for the purpose of collecting statistical data, measurements in these zones were made repeatedly. The purpose of registering the profiles was to analyze the change in parameters after processing, indicating a change in the surface from the point of view of the parametric ideology laid down by the manufacturer in this surface. Figure 5 shows the principal elementary sections of the profile of the inner surfaces of the cylinder liners.

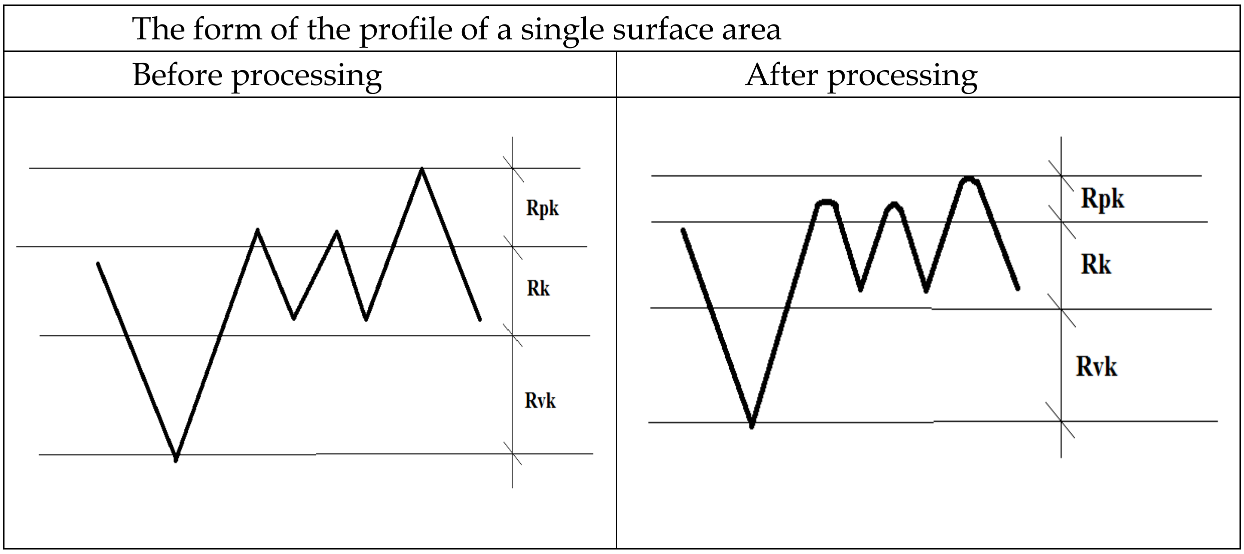


Figure 5. *Changing form of the profile of a single section of a honed surface*

Based on the results of the registration of parameters, the following conclusions were made:

• after processing, the height of the peaks of the Rk profile has significantly decreased;

• the surface was smoothed, which led to a decrease in the probability of the development of undesirable wear processes in the “ring-cylinder” pair;

• the sum of the parameters Rpk and Rk has significantly decreased, which indicates a good running-in in the engine oil of the TC "SUPROTEC promkomposit 005";

• the depth of marks Rvk slightly decreased, which ensured a higher hydraulic tightness of the “ring-cylinder” interface, and this, in turn, led to an increase in compression and an increase in efficiency.

In general, the ratio of parameters has become more consistent with the characteristics laid down by the engine manufacturer.

For an internal combustion engine (ICE) with a medium degree of wear (50 – 70 % of the resource), the main result of the use of the TC “SUPROTEC” is the restoration of the parameters of the working process, primarily due to the equalization of the compression along the cylinders.

Compression is improved as a result of partial restoration of the worn-out layer of friction surfaces of parts of the cylinder-piston group (CPG), as well as friction units: "cylinder liner – piston ring – piston groove". Restoring the compression results in improved combustion conditions and improved engine operating parameters. As a result, fuel consumption is reduced, power and throttle response increase, noise, vibration and emissions of harmful exhaust gases are reduced. In addition, the layer formed on the friction surfaces increases the engine resource and reduces friction losses. Improving the seal in the oil scraper rings reduces oil consumption for waste, and reducing fumes breakthrough into the crankcase increases the life of the lubricating oil and the life of the engine as a whole. A decrease in crankshaft bearing clearances and an increase in the hydraulic tightness of the gear pump leads to an increase in pressure and oil consumption, which improves the quality of lubrication and cooling of engine parts.

For internal combustion engines, to a significant degree of deterioration (loss of power by 20 %, increase in fuel consumption by more than 20 %, increase in oil consumption for waste by more than 5 times, significant engine smoke [10, 12], with low mileage, the oil quickly turns black) the results of using the TC "SUPROTEC" may not appear at all, even with a 2-fold increase in the concentration of the composition. In this case, it is advisable to carry out a major overhaul and then carry out processing with the TC “SUPROTEC”.

The effect of using the TC “SUPROTEC” in the Cummins KTA50G-3 engine will be as follows:

• in accelerating the engine running-in process [2], including after overhaul (due to the adaptive properties of the tribotechnical composition in the optimization of mating friction parts);

• in increasing the engine resource by 1.5 ÷ 2 times (due to a decrease in the intensity of wear of parts);

• in increasing the effective engine power (by improving the quality of fuel combustion, reducing the losses of the working fumes breakthrough into the crankcase and reducing friction losses);

• in maximum protection of the engine against wear, stress, overheating and during "cold start";

• in facilitating the "start" of the engine at low temperatures;

• in the ability not to impair the performance characteristics of rubber products;

• in reducing the fuel consumption of the engine by 3 – 5 % (due to the restoration of compression, the quality of fuel combustion improves);

• in reducing the level of noise and vibration in the engine by 5 - 10 dB (due to the alignment of the working process along the cylinders and damping with a thicker layer of oil);

• in reducing the emission of harmful emissions of engine exhaust gases for CO and CH up to 50 % (by improving the quality of fuel combustion);

• in the possibility of short-term operation in conditions of oil starvation;

• in the restoration of the functional properties of hydraulic compensators [13].

The economic calculation (without taking into account the savings in fuel and lubricants and maintenance costs) allows us to conclude that over the entire period of operation (up to 120,000 m-h), the use of the TC "SUPROTEC promkomposit 005" in the engine oil of the Cummins KTA50G-3 diesel engine will save, from 88 to 94% of the amount for the purchase of a new engine, depending on engine operating time.

Tribotechnical compositions "SUPROTEC" and methods of their application did not have any negative impact on the wear of the main units and engine interface pairs. The area of the working zone of the greatest loading of the bushing did not increase, which indicates the safety of the use of the TC "SUPROTEC promkomposit 005". Based on the results obtained when using tribotechnical compositions "SUPROTEC" and the method of its application, the following conclusion was made: the approximate term of the service life extension will be 60,000 m-h.

The cost of extending the resource when buying a new engine at the current rate of 72.72 rubles/$ will be: W = 6 320 thousand rubles (at the rate of the Central Bank of 07/01/2021);

The costs of purchasing the TC "SUPROTEC promkomposit 005" for the entire service life (120,000 m-h) will be:

- for engines with operating time 0 ÷ 1000 m-h: Зтс = 395.2 thousand rubles;
- for engines with an operating time of 30,000 ÷ 32,000 m-h: Зтс = 619.4 thousand rubles;
- for engines with an operating time of 45,000 ÷ 47,000 m-h: Зтс = 763.8 thousand rubles;

Thus, the economic effect will be:

- for engines with operating time 0 ÷ 1,000 m-h: 5,404.8 thousand rubles;
- for engines with an operating time of 30,000 ÷ 32,000 m-h: 5,180.6 thousand rubles;
- for engines with an operating time of 45,000 ÷ 47,000 m-h: 5,036.2 thousand rubles.

The measure is low-cost and quickly pays for itself. In addition, it can be stated that the economic effect from the use of the TC “SUPROTEC” in the Cummins KTA50G-3 diesel engine is even higher since the increase in the resource will reduce the level of operating costs for the repair and maintenance of the installation.

Based on the research done, it can be concluded that the composition of “NPTK SUPROTEC” OOO showed good results when operating a Cummins KTA50G-3 diesel engine. This compound has formed a protective layer on friction surfaces at a microscopic level, which has a strong oil-holding capacity and increased microhardness.

During the course of the study, the following improvements occurred:

- a change in the color of the working zone of the greatest loading of the insert from red-copper to greenish-bronze, which indicates the creation of a nanoscale film on this surface.
- increase in the average level of compression for all cylinders by 1.44 kg/cm^2.
- reduction of the actual specific fuel consumption.

The applied technology has shown high technical and economic efficiency in all friction units of machines and equipment. With insignificant total costs of tribo- compositions (about 2% of operating costs), their regular and qualified use can improve the reliability, efficiency and safety of industrial equipment operation, as well as greatly simplify the implementation of a lot of preventive and repair work. "Service without disassembly" is relevant for machinery and equipment of all industries.

The results obtained can be recommended for use at industrial enterprises and facilities of the fuel and energy complex of St. Petersburg as an effective means for restoring (optimizing) technical characteristics and increasing the efficiency of industrial equipment.

Список литературы

1. Гаркунов Д.Н. Восстановление двигателей внутреннего сгорания без их разборки [Текст] / Д.Н. Гаркунов, В.И. Балабанов //Тяжелое машиностроение.- Москва, 2008.
2. Любимов Д.Н. Структура смазочных слоев, формируемых при трении в присутствии присадок минеральных модификаторов трения [Текст] / Д.Н. Любимов, К.Н. Долгополов и др.// Трение и износ. - 2009. - № 5 (30), - с. 516-521.
3. Гаркунов Д.Н., Мельников Э.Л., Гаврилюк В.С. «Триботехника»: 2-е издание, стереотипное. М.: МГТУ им. Н.Э. Баумана, 2013, 402 с.
4. Иванов В.И. «О роли восстановления и упрочнения деталей и инструментов для повышения эффективности деятельности предприятий АПК», Труды Госнити, 2016г., с. 139-147.

5. Лялякин В.П. «Восстановление деталей - важный резерв экономии ресурсов», Вестник ОрелГАУ 2(11), с. 95-97.
6. Балабанов В.И., Дунаев А.В., Ладиков В.В., Подчуфаров С.Н., Рыжов В.Г. «Безразборное восстановление работоспособности изношенных узлов и агрегатов. Итоги 25-летнего развития» Журнал ТРУДЫ ГОСНИТИ (ISSN: 2587-6864). Изд.: Федеральный научный агроинженерный центр ВИМ (Москва), 2015г., с. 80-90.
7. Гладышев Н.Н., Короткова Т.Ю. Автономные источники тепловой и электрической энергии малой мощности: учебное пособие/ СПбГТУРП. СПб., 2010, – 323 с: ил. 129.
8. Официальный сайт ООО «НПТК «Супротек» - https://suprotec.ru
9. Дунаев А.В. Экспресс-оценка остаточного ресурса цилиндропоршневой группы двигателей внутреннего сгорания [Текст] // Горный информационно-аналитический бюллетень. – 2009, - с. 411-419.
10. Васильев А.В. «Особенности акустического наддува автомобильных двигателей внутреннего сгорания с использованием активных генераторов звука»; Журнал NOISE THEORY AND PRACTICE (eISSN: 2412-8627), 2017 г., с. 16-24.
11. В.В. Елецов «Восстановление и упрочнение деталей машин»: электронное учебное пособие – Тольятти: Изд-во ТГУ, 2015, – 335 с.
12. Новиков В.И. «Роль трибологии в предотвращении всемирной экологической катастрофы. Трибология – машиностроению» Труды 10-й юбилейной Всероссийской научно-технической конференции с участием иностранных специалистов 19-21 ноября 2014 г. М:. ИМАШ РАН, - с. 91.
13. Функциональные присадки смазочных масел. Интернет-ресурс http://mydocx.ru/2-116253.html

References

1. Garkunov D.N. Restoration of internal combustion engines without disassembling them [Text] / D.N. Garkunov, V.I. Balabanov // Heavy mechanical engineering. - Moscow, 2008.
2. Lyubimov D.N. The structure of lubricating layers formed during friction in the presence of additives of mineral friction modifiers [Text] / D.N. Lyubimov, K.N. Dolgopolov et al. // Friction and wear. - 2009. - No. 5 (30), – pp. 516-521.
3. Garkunov D.N., Melnikov E.L., Gavrilyuk V.S. "Tribotechnics": 2nd edition, stereotyped. M.: MGTU im. N.E. Bauman, 2013, 402 p.
4. Ivanov V.I. "On the role of restoration and hardening of parts and tools to improve the efficiency of agricultural enterprises", Proceedings of Gosniti, 2016, pp. 139-147.
5. Lyalakin V.P. "Reconstruction of parts is an important reserve for saving resources", Vestnik OrelGAU 2 (11), pp. 95-97.
6. Balabanov V.I., Dunaev A.V., Ladikov V.V., Podchufarov S.N., Ryzhov V.G. “CIP recovery of worn out components and assemblies. Results of 25-year development”; TRUDY GOSNITI journal (ISSN: 2587-6864). Publisher: Federal Scientific Agroengineering Center VIM (Moscow), 2015, pp. 80-90.
7. Gladyshev N.N., Korotkova T.Yu. Autonomous sources of thermal and electrical energy of low power: textbook / SPbGTURP. SPb., 2010, - 323 p: ill. 129.
8. The official website of OOO "NPTK "Suprotec"- https://suprotec.
9. Dunaev A.V. Express-assessment of the residual life of the cylinder-piston group of internal combustion engines [Text] // Mining information and analytical bulletin. – 2009, - pp. 411-419.

10. Vasiliev A.V. "Features of acoustic pressurization of automobile internal combustion engines using active sound generators"; NOISE THEORY AND PRACTICE Magazine (eISSN: 2412-8627), 2017, pp. 16-24.
11. V.V. Eletsov "Restoration and hardening of machine parts": electronic textbook - Togliatti: Publishing house of TSU, 2015, - 335 p.
12. Novikov V.I. “The role of tribology in preventing a global ecological catastrophe. Tribology for mechanical engineering” Proceedings of the 10th Anniversary All-Russian Scientific and Technical Conference with the participation of foreign specialists November 19-21, 2014 M.: IMASH RAS, – p. 91
13. Functional additives for lubricating oils. Internet resource http://mydocx.ru/2-116253.html