ATLANTIS PRESS
Atlantis Highlights in Material Sciences and Technology (AHMST), volume 1
International Symposium "Engineering and Earth Sciences: Applied and Fundamental Research" (ISEES 2019)

Development of a Technology for Field Testing of Lubricants and Additives

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***Abstract* – A preparation for field tribological tests of lubricants and additives in a real diesel engine was carried out. A diesel generator based on a TMZ-450D single-cylinder air-cooled engine and its are described. In this connection, a specific task of the work is the study of the wear of parts in the cylinder-piston group of a complete diesel engine. In the statement of such a problem, a number of fundamental questions were solved regarding the compatibility of additive packages with the basic composition of lubricating oil and the final cost of the antiwear product added to the lubricating oil. The work demonstrates the specificity of the preparation for the tests and the technology of their implementation. Additionally, the technology of measuring parts in the cylinder-piston group, i.e. pistons, piston rings and cylinder lining. The study demonstrates the results of tribological field tests of lubricants tested in diesel engine TMZ-450D. The engine has a single-cylinder vertical layout and is designed for installation on light-duty vehicles, small-sized equipment, drives for mobile power plants, and as a stationary auxiliary marine engine. The implementation of the studied antiwear lubricant additive allowed reducing the overall wear rate of the cylinder-piston group of the diesel engine by 5-7%.**

Keywords – antiwear additive; cylinder-piston group; friction; magnetite; molybdenum diselenide; unsaturated fatty acid.

I. INTRODUCTION

The study is aimed at antiwear testing of lubricants in pure form and as a composition of lubricating oil and antiwear additive [1] in a real engine.

In this connection, a specific task of the work is the study of the wear of parts in the cylinder-piston group of a complete diesel engine.

In the statement of such a problem, a number of fundamental questions were solved regarding the compatibility of additive packages with the basic composition of lubricating oil [2] and the final cost of the antiwear product added to the lubricating oil.

The parts of the cylinder-piston group (CPG) are:

- piston compression ring;
- engine piston;
- cylinder lining.

The technology of anti-wear test of the CPG implies the following actions:

1. disassembling the cylinder-piston group of the diesel engine into its components;
2. measuring the actual dimensions of the parts by micrometric methods;
3. assembling the cylinder-piston group and installing it on the diesel engine;
4. testing the anti-wear properties of pure lubricating oil;
5. removing from the diesel engine and disassembly of the cylinder-piston group into components according to item 1;
6. measuring the actual dimensions of the parts by micrometric methods according to item 2;
7. installing new piston-cylinder group on the diesel engine consisting of a piston, piston rings and a cylinder liner;
8. testing anti-wear properties of the lubricating tribological composition “lubricating oil anti-wear additive [1]”;
9. removing of the CPG from the diesel engine tested as per item 8;
10. measuring the actual dimensions of the parts of the CPG by micrometric methods according to item 2.

II. Methods and Materials

In order to save time, a small TMZ-450D diesel engine [3] served as a test diesel engine for measuring the actual dimensions of the CPG part surfaces.

The engine has a single-cylinder vertical layout and is designed for installation on light-duty vehicles, small-sized equipment, drives for mobile power plants, and as a stationary auxiliary marine engine. Technical parameters of the TMZ-450D diesel engine are shown in Table 1.

The layout of the testbed “diesel + alternating current generator set” is shown in Figure 1 [4].

On frame 1 there was mounted a single-cylinder diesel 8, generator set 6, rechargeable battery 5 with the capacity of 55 Ah, fuel tank 3 with the capacity of 10 liters and measuring instruments 4 (ammeter and voltmeter), and a panel of starting and control units. On the right side of the engine, air cleaner 2 of the power supply system and starter 7 with a capacity of up to 1.5 kW were mounted.

TABLE I. MAIN TECHNICAL SPECIFICATIONS OF TMZ-450D ENGINE

Parameter name	Unit of measurement	Value
Diesel type	-	Four stroke, direct injection
Number of cylinders	-	1
Cylinder bore	mm	85
Stroke	mm	80
Displacement	cm^3	454
Compression ratio	-	19±1
Injection advance angle	deg.	25-32
Rated power	kW (hp)	8.0 (11.0)
Maximum torque	N · m (kgf·m)	22 (2.2)
Crankshaft speed at rated power	rpm	3600±50
Crankshaft speed at maximum torque	rpm	2700±100
Minimum crankshaft speed at idle	rpm	1000±100
Maximum rotational speed of crankshaft at idle	rpm	3800±200
Specific effective fuel consumption at rated operation	g/(kW·h)	280
Relative burning oil consumption as percentage of fuel consumption	%	6
Oil pressure in system at oil temperature (80-95°C)	MPa (kgf / cm^2)	0.2 (2.0)/ 0.08-0.1(0.8-1.0)
Response pressure of lubrication system reducing valve	MPa (kgf / cm^2)	0.6 (6.0)

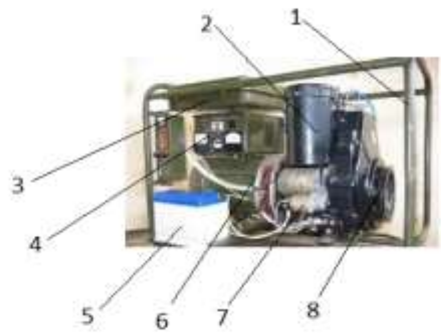

Fig. 1. Layout of the testbed diesel generator with a single-cylinder air-cooled TMZ-450D diesel engine and location of its main elements

The power take-off to the rotor of the generator was no less than 7-7.5 kW of the total engine power, which loaded it at about 85-90% of the installed total power. This simulated the main mode of loading of a small-sized diesel in the conditions of a ship cruise.

The field tests involved two objects of research playing the role of lubricants in the diesel engine:

1. circulating marine oil M-16GTsS with a viscosity of up to 16.5 mm^2/min;

2. lubricating composition of oil M-16GTsS with anti-wear additive [1] with volume concentration of 1.0%, because recently, the range of well-known lamellar solid lubricants (graphite, disulfides, molybdenum and tungsten disilicides)—according to the analysis of some literature sources—should be extended with molybdenum diselenide [5, 6, 7, 8]. In this case, the difference in compositions and the complexity of the optimal separation of solid minerals to the desired size for the normal course of the tribological reaction of restoring the microrelief of the working surface [9-11] makes layered modifiers more attractive as an antiwear additive to lubricating oils.

III. Results

At the end of each test sequence of the CPG parts of the single-cylinder TMZ-450D diesel engine for wear under the conditions of a particular lubricant composition, the surfaces of the parts were measured to determine the actual degree of wear. After 500 hours of CPG testing, the measurement of the surfaces was carried out in the following ways:

- the inner surfaces of cylinder liners d^1 and d_2 (Fig. 2), on three levels (1, 2 and 3) in two mutually perpendicular planes I and II. When measuring the surfaces, an inside micrometer caliper NI 75-100 of accuracy class 1 according to GOST 868-82 was used with a scale value of 0.01 mm and a measurement limit from 75 to 100 mm;
- the external surfaces of piston D^1 and D_2 (Figure 3), on four levels (1, 2, 3 and 4) in two mutually perpendicular planes I and II. When measuring the surfaces, an micrometer MK-100 of accuracy class 1 according to GOST 6507-90 was used with a scale value of 0.01 mm and a measurement limit from 75 to 100 mm;
- the outer surfaces of the piston rings (radial thickness *s* and axial height *h* according to Figure 4), in 8 places around the ring starting and ending with the edges of the lock. Additionally, when the ring was tangentially compressed by the loading system, when it was placed on the edge of the working profile, the lock pressure was determined to the standard clearance prescribed by the engine manufacturer (Figure 5).

The criteria for the measured dimensions to exceed the test requirements were:

1. for cylinder liner:

- noncompliance of the hole ovality in more than two measurement zones to the normative value prescribed by the engine manufacturer. The ovality in the measurement zones was determined by the following expression:

$$E = D_2 - D_1 \qquad (1)$$

where D_2 and D_1 are the measured diameters of the liner face in planes II and I, mm.

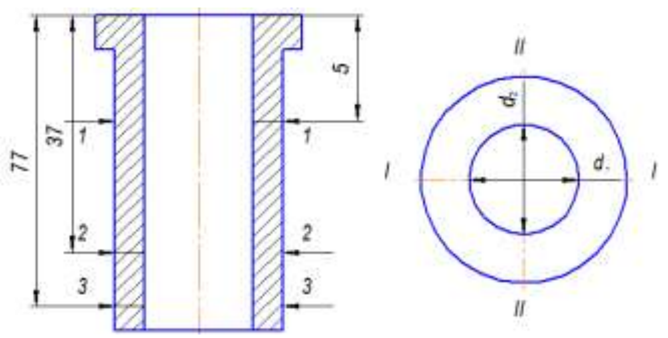

Fig. 2. Technology for measuring the friction surfaces of the cylinder liner

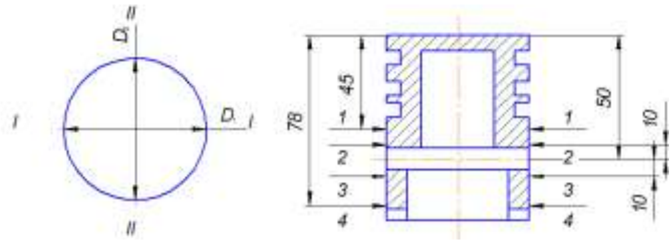

Fig. 3. Technology for measuring the friction surfaces of the piston

- noncompliance of the conicity of the hole between the measurement zones and the normative value prescribed by the engine manufacturer.

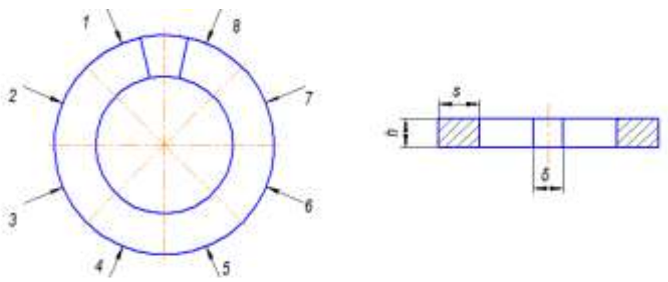

Fig. 4. Technology for measuring the friction surfaces of the piston ring

The conicity in the measurement zones was determined by the following expression:

$$K = (D_{cpi} - D_{cpi+1})/l \qquad (2)$$

where D_{cpi} is the arithmetic mean diameter in the *i*-th measurement zone between two diameters measured in planes I and II, mm; D_{cpi+1} is the same value for the consequent to the *i*-th upper or lower measurement zone, mm; l is the distance between the measurement zones described above, mm.

2. for piston:

- noncompliance of the piston skirt ovality in more than two measurement zones to the normative value prescribed by the engine manufacturer. The value of ovality after measurement was calculated by an expression similar to (1).

3. for piston ring:

- exceeding the values of thermal gaps between the side end of the ring and the side surface of the groove of the piston. The gap value equaled the difference of the axial height of the ring s and the height of the piston groove s^0. If the values of the thermal gap differed from the standard prescribed by the manufacturer in more than three places around the ring, the ring should be rejected.
- noncompliance of the tangential compression force with full gap in the compression ring lock and the gap in the lock when the ring was inserted into the nominal calibre of the liner opening.

The measurements of the surfaces of compression and oil wiper rings, cylinder liner and piston were made each time before assembling the cylinder-piston group and installing it into the engine and each time after the engine had passed 500 hours of operation after removing and disassembling the CPG.

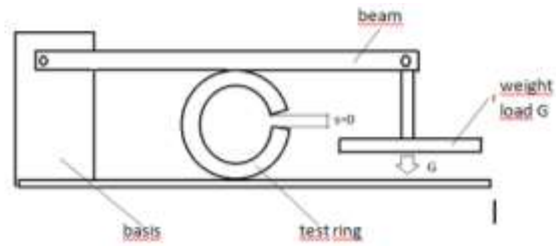

Fig. 5. Technology for measuring the tangential lock compression force of a compression or oil wiper piston ring

When measuring the gap in the ring lock a liner with the appropriate diameter was used as a calibre with the diameter of $85^{+0.02}$ mm. The gap in the lock was measured with flat probes with a measuring limit of 0.01-2 mm.

The tribological tests of pure M-16GTsS lubricant oil and tribotechnical composition “oil M-16GTsS + antiwear additive” were performed using the testbed diesel generator set based on a single-cylinder air-cooled TMZ-450D diesel engine.

The tribological antiwear tests were comprised of two stages:

1. Tests of the M-16GTsS ship lubrication oil in the amount of 600 hours of the diesel generator operation;

2. Tests of the lubricant composition “M-16GTsS oil + antiwear additive” in the amount of 600 hours of the diesel generator operation.

Each test sequence was divided into time intervals (stages) of 2.5 hours of the engine operation and another 30 minutes of diesel generator standby. Thus, each stage of the test amounted to 3 hours and the total number of stages in the anti-wear test sequence for each of the two lubricants was 200.

Each of the test working stages (150 min) began with 5 minutes of gradual increase in the rotational speed from 1000 rpm to (idle) of 3500 rpm (rated power mode). Another 145 minutes, the diesel generator was operating at the rotational speed of 3500±100 rpm, which corresponded to 80-90% of the total power output from the diesel engine to the generator.

During the 2.5-hour operation stage, the temperature and pressure of oil in the lubrication system of the TMZ-450D diesel engine were recorded by the control panel of the testbed. When the oil temperature exceeded 1000°C on the control thermometer, the diesel operation mode was changed from nominal to medium (the rotational speed of the crankshaft was decreased to 1300-1500 rpm). When the pressure of the lubricating system on the control gauge was dropping below 0.05 MPa, the engine was stopped by acting on the lever-type decompression stop system. However, there were no cases of pressure drop below 1.5 MPa during operation in the rated power mode with the crankshaft rotation speed of 3500±100 rpm. The rotational speed of the engine crankshaft was monitored by a reference ammeter mounted on the right side of the generator.

After finishing the test operation cycle of 600 hours, i.e. 200 stages of antiwear testing, the engine was stopped for disassembly of the cylinder-piston group for fault detection and visual evaluation.

The general technology of anti-wear tribotechnical testing of lubricants for a cylinder-piston group was as follows.

1. Before each of the test cycles, a new cylinder-piston part of the engine was removed from the engine's crankshaft, by disassembling the lower connecting rod head. From the demounted cylinder-piston group, the head of the block was removed together with the valve group. The demounted part of the CPG was disassembled into the following components:

- working ribbed cylinder liner;
- piston removed from the connecting rod by pressing out the piston pin;
- piston rings (two compression ones and one oil wiper) removed from the piston grooves.

2. Then a control measurement of the surface geometry of the above parts of the CPG was performed. After that the cylinder-piston group was assembled into a block with piston pin and connecting rod, piston rings were installed into the piston grooves and the piston together with the rings was pressed into the working ribbed cylinder liner. The cylinder-piston group assembly with the connecting rod was connected to the crankshaft journal. The cylinder head was fastened to the upper part of the working cylinder by assembly studs.

3. After these operations, the diesel generator was ready for operation. Fresh filtered M-16GTsS oil was poured into the engine crankcase in the amount of 1.8±0.1 liters. The diesel engine was started and the workload was applied to the generator part of the testbed. The first 5 stages of the engine operation in the amount of 12.5 working hours and 2.5 standby hours comprised the running-in period for the CPG as a part of the diesel generator.

4. After each of the 600-hour test sequences, the diesel was stopped, and its CPG was demounted from the crankcase and disassembled into components in accordance with item 1.

5. The components of the cylinder-piston group were measured according to the technique in item 2.

6. A new cylinder-piston group with new piston, two compression rings, one oil wiper ring and working ribbed cylinder liner was assembled.

7. Together with the connecting rod and the block head, the CPG was mounted on the crankshaft of the TMZ-450D diesel engine.

8. The crankcase of the engine was rinsed with light oil to remove residual lubricating oil tested in the cycle from all friction surfaces and oil lines.

9. After pouring in the lubricant composition “oil M-16GTsS + additive”, a new 600-hour tribological test was performed.

10. At the end of the 600-hour tribological test, the engine was stopped. The cylinder-piston part was demounted and disassembled into components for measurement.

After two complete sequences of comparative tribotechnical testing of two lubricating fluids in the diesel generator with the TMZ-450D diesel engine, the wear of the CPG parts was compared with drawing the conclusions about the effectiveness of the two lubricants.

The results of the study have the accuracy of 0.01 mm and are accompanied by micrometric measurements. The following data was obtained:

- the measurements of parts of two replaceable cylinder-piston groups before the antiwear tests;
- the change of the dimensions during a test sequence in a particular object of the study;
- the measurements of the friction surfaces of the CPG parts after the test.

Also the most important characteristic of the state of the piston as a part of the cylinder-piston group of the engine was obtained, the calculated maximum thermal gap between the groove side surface and the ring taking into account the greatest deviation of the groove height from the nominal value measured after the test.

IV. Conclusion

In general, according to the test results, the following conclusions can be drawn about the condition of parts of the cylinder-piston group as a result of field testing of two lubricants:

1. The thermal gap between the groove side surface and the ring in all two test sequences did not exceed the permissible value of 0.4 mm, but in the case of using the additive [1] to the lubricating oil (sequence 1), the gap around the groove is more uniform. On the other hand, the gap in the case of the lubricant composition in some locations along the piston groove approached the nominal value. This may indicate unaccounted factors of thermal stress during the run-in phase of the CPG piston elements or warping of the piston groove when working in harsh conditions of fuel-air mixture combustion.

2. The change in the radial thickness *s* of the ring in the test sequence 1 (oil with the additive [1]) as compared to the test sequence 2 (conventional lubricating oil) is more even and lower. This primarily affected the elasticity of the ring after the tests: before the testing, the tangential elasticity of all six piston rings was 20 kN, while after the 600-hour test sequence with the additive [1], the tangential elasticity remained within 18 kN. In the case of pure circulating oil, it was already less than 16-17.2 kN, which indicates a slight loosening of the ring along its length. Moreover, application of pure M-16GTsS oil increases the operating clearance of the ring lock which is proved by checking with ring caliber with the diameter of 85 + 0.02 mm. This indicates decreased radial elasticity of the ring.

3. Deviations of the radial width (thickness *s*) and axial height *h* in both test sequences did not exceed the allowable values, but turned out to be higher in the case of pure oil without the additive. This can be explained increased antifriction and anti-wear properties of the lubricant layer in the case of the additive [1] containing molybdenum diselenide and unsaturated fatty acids, which play a role in the proper organization of molecular chains at the contact surfaces of friction parts.

4. The deviations of the ovality of the cylindrical surface of the piston and the cylinder liner (Tables 9 and 10) did not exceed the allowable values; however, in the case of the antiwear additive [1], the ovality along the connecting rod rocking plane was completely gouged and became zero. This has no appreciable effect on the mutual wear of CPG parts over the entire service life, but can create conditions for the deterioration of the piston surface thermal state.

5. The conicity of the cylinder face along the length of the slant height did not exceed the allowable values and in the case of anti-wear additive [1] had a significantly lower value, which indicates less distortion of the mutual geometry of CPG parts (piston and cylinder).

6. In general, the qualitative changes in the processes of friction and wear of a diesel engine can be hardly discussed when using standard oil or its anti-wear counterpart. However, the quantitative indicators demonstrate a considerable decrease in the wear rate of the CPG parts with the same operating time in the case of the anti-wear additive [1].

Acknowledgment

The research is carried out within the framework of the agreement on mutual scientific and technical cooperation between Astrakhan State Technical University and the Central Research and Design Institute of Fuel Equipment for Tractor and Stationary Engines (TsNITA, St. Petersburg), as well as under the agreement on mutual scientific and technical cooperation between Astrakhan State Technical University and Grozny State Oil Technical University named after Academician M.D. Millionshtchikov

References

[1] Patent No. 2570643 Russian Federation, IPC C10M 169/04, C10M 125/22. Antiwear additive. A.P. Perekrestov, Yu.N. Drozdov, V.A. Chanchikov, I.N. Guzhvenko, S.A. Svekolnikov; applicant and

patent owner: ASTU, applied on July 22, 2014; published on December 10, 2015, Bulletin no. 34, 5 p.

[2] L. Zhenggui, Zh. Jiarong, L. Deyou, Ch. Xin, L. Bo, Y. Fengyu, "Investigation of friction power consumption and performance of a water turbine seal based on the imbalanced rotation of nano-magnetic fluids", Advances in Mechanical Engineering, vol. 10 (4), pp. 1–9, 2018.

[3] T.V. Ta, N.H. Vu, M.A. Triet, D.M. Thien, V.T. Cang, "Assesment of Marine Propulsion System Reliability Based on Fault Tree Analysis", International Journal of Transportation Engineering and Technology, no. 2 (4), pp. 55–61, 2016.

[4] V.A. Chanchikov, I.N. Guzhvenko, S.A. Svekolnikov, E.U. Arstanaliev, M.N. Abishev, Sh.M. Medetov, "Development of a friction machine for accelerated anti-wear comparative testing of lubricants", Bulletin of Atyrau Institute of Oil and Gas, no. 1 (37), pp. 96–99, 2016.

[5] E.A. Marchenko, "On the mechanism of wear of molybdenum diselenide", Friction and wear, no. 4, no. 438–443, 2000.

[6] T.A. Lobova, "Nteraction of friction surfaces with 2H-MoS2 lubricants", Friction and wear, no. 4, pp. 391–398, 2008.

[7] E.A. Marchenko, "Application of diselenides of refractory metals to ensure stability of friction units", Bulletin of scientific and technological development, no. 5 (21), pp. 16–21, 2009.

[8] I.N. Guzhvenko, V.A. Chanchikov, S.A. Svekolnikov, O.V. Burmistrova, "Investigation of the effect of dispersity of layered friction modifiers on the antiwear properties of lubricants", News of the Samara Scientific Center of the Russian Academy of Sciences, no. 1 (2), pp. 187–192, 2016.

[9] M.A. Saidov, Kh.I. Shamsurkaev, A.F. Dorokhov, A.A. Musaev, R.S. Makhmatkhadzhieva, I.I. Kozlova, L.U. Magomadova, S.-M.S. Musaev, "Use of Nanotechnologies to Manage the Reliability of Fuel Equipment within Diesel Engines", Advances in Engineering Research, vol. 177 [International Symposium on Engineering and Earth Sciences (ISEES 2018)].

[10] A. Cebers, "Physical properties and models of magnetic fluids", Magnetohydrodynamics, no. 4 (27), pp. 381–393, 1991.

[11] M.A. Saidov, A.P. Perekrestov, "Influence of nanodispersed modifications of magnetite powders on spray nozzle efficiency of diesel engine injector", IOP Conf. Series: Earth and Environmental Science, vol. 87, pp. 082042, 2017.