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WAYS TO IMPROVE THE RELIABILITY AND DURABILITY OF AUTOMOTIVE DIESEL ENGINES

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The study focuses on abrasive wear caused by dust particles in the air, fuel, and lubrication systems of diesel engines. The mechanisms of wear formation and development in each system were analyzed, as well as their impact on the durability of cylinder-piston assemblies, plunger pairs, injectors, and bearing units.

It was found that abrasive particles in the intake air are the main cause of cylinder and piston wear. To minimize these effects, improvements to air-cleaning systems were proposed through the use of multistage filters with increased efficiency and optimized geometry. In the fuel supply system, the presence of fine solid particles was shown to cause accelerated wear of precision components such as plunger pairs and injectors, emphasizing the need for highly efficient fuel filtration elements. In the lubrication system, oil contamination and additive degradation were identified as major contributors to accelerated wear of piston rings and crankshaft bearings. The use of high-quality lubricants and continuous monitoring of oil pressure were recommended as diagnostic tools for predicting component wear and the need for overhaul.

The analysis revealed significant potential for improving the reliability and service life of diesel engines by optimizing filtration systems, maintaining stable thermal conditions, and ensuring proper maintenance of cooling systems. The findings indicate that enhancing filtration, lubrication, and diagnostic systems in an integrated manner can substantially extend the durability of automotive and tractor diesel engines.

Additionally, the study provides a scientific basis for developing advanced maintenance and monitoring strategies aimed at preventing premature failures in internal combustion engines. The results can be applied to the design of adaptive diagnostic systems and the modernization of maintenance procedures for agricultural, construction, and transport machinery. The proposed approach contributes to reducing operational costs, improving environmental performance, and extending the sustainable operation period of diesel engines in various industries.

This scientific paper presents the findings of the initiative research project № 0122U002187, carried out as part of ongoing investigations into improving the reliability and durability of diesel engines.

Key words: *diesel fuel equipment, plunger pairs, hydraulic density, discharge valve, injector nozzles, fuel filtration, filter element.*

Eq. 1. Fig. 28. Table. 2. Ref. 17.

1. Problem formulation

Let's consider different ways to increase the reliability and durability of automotive and tractor diesel engines. The reliability and durability of the engine largely depends on the quality of maintenance. Convenient and accessible location of units and components requiring periodic maintenance improves its quality. The problem of increasing the reliability of automobile and tractor engines is one of the main problems of our century.

The main task of reliability theory is to predict accidents and find ways to reduce them. Analysis of wear and tear of engines as a whole and systems separately makes it possible to identify the causes of premature failure of parts and components and theoretically substantiate ways to increase reliability and determine the service life of engines. The search for the main ways to increase the service life of diesel engines leads to the following thoughts.

Among the units of tractors and automobiles, the most quickly worn out and the least reliable and durable unit is the engine. Typically, the service life of automotive and tractor engines is determined by the wear of piston rings, piston grooves, cylinders, bearings and crankshaft journals, valves and other parts.The parts wear unevenly. For most parts and joints, this process can be characterized by a curve of total wear growth (Fig. 1) [1]. Section A corresponds to the period of running-in of the joint, section B to the period of normal operation, section C to the period of forced wear.

According to the classification proposed by Professor V.I. Kazartsev, section A + B is called the period of natural wear, and section B is called the period of emergency wear, equal to the time from the beginning of forced wear until the moment the coupling stops working. Observations have shown that the majority of failures are due to operational reasons.

Many years of experience in operating and repairing YaMZ engines shows that a significant portion of the main engine parts submitted for repair have a large unused resource. Fig. 2. [2] shows a graph of the probabilistic characteristics of the resource of the YaMZ -236 engines on KrAZ-256B vehicles before the first major overhaul, obtained as a result of processing the operational data. It is evident from the figure that the average resource before the first major overhaul was L_{avg} = 158 thousand km, and 80% gamma resource $L\gamma$ = 105 thousand km. When brought to reference conditions (first category of operation), we obtain L_{avg} = 300 thousand km, L_{γ} = 200 thousand km.

The following factors influence wear in descending order: the efficiency of engine protection from dust, the temperature state of the engine, unsteady speed and load conditions, etc. Failures associated with the destruction of parts occur mainly as a result of large forces at high speed and load conditions, as well as sharply changing unsteady engine operating conditions.

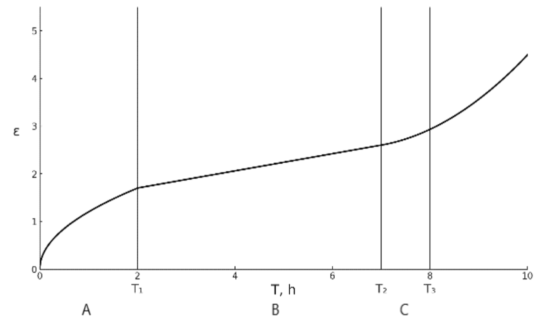


Fig. 1. Wear increase curve:
ε – wear, µm; T – time; A, B, C – sections

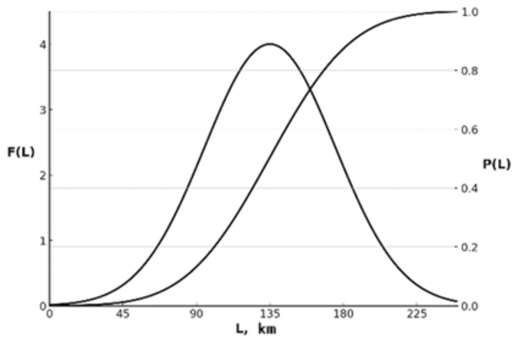


Fig. 2. Resource characteristic probability graph

YaMZ-236 engines before the first major overhaul under the conditions of the third category of operation on KrAZ-256B vehicles: P(L) is the probability of operation without major overhauls; F(L) is the distribution density of major overhauls; δ is the parameter of the normal distribution law.

The main ways to further improve the reliability of automotive and tractor engines are:

a) further improvement of air, oil and fuel purification systems;

b) improvement of fuel supply and combustion processes in the engine cylinder;

c) use of a cooling system with an all-season liquid such as "Tosol";

d) intermediate air cooling (for turbocharged diesel engines);

d) improvement of control and automation systems;

e) improvement of the culture of technical operation and quality of repairs, introduction of technical diagnostics.

Increasing the service life of automobile and tractor engines will reduce the number of major repairs, decrease the downtime of automobiles and tractors, increase their productivity, and reduce operating costs.

2. Analysis of recent research and publications

Air supply system. One of the effective and cost-effective ways to increase the durability and technical level of automobile and tractor engines is to improve the cleaning of air entering the cylinders.

The dust content of the air that enters the engine during operation of cars and tractors can vary from 0,0003 to 1,4 g/m^3 and depends on many factors: time of year, type of road and type of soil, weather, wind direction, traffic intensity, vehicle load capacity, type of tires, hood shape, air intake height, etc.

About 80% of the weight content of dust particles entering the engine air cleaner are up to 30 microns in size. The main components of dust are silicon oxides, aluminum, iron, etc. The most common in dust is quartz, the content of which ranges from 50 to 95%.

Abrasive dust entering the engine through the intake tract with air causes the greatest wear of the cylinders in the upper part, upper compression rings and grooves in the piston. Therefore, further improvement of air cleaners, i.e. increasing the efficiency of air cleaning from dust and ensuring their reliable operation, is of paramount importance for reducing abrasive wear of engines.

The most important parameters of air cleaners are: duration of operation before reaching the maximum permissible resistance; resistance to the flow of air sucked in by the engine; specific volume, which characterizes the compactness of the design; specific dust capacity, which indicates the perfection of the design.

The engines of KrAZ-256B trucks use a two-stage air cleaner, which is equipped with a replaceable dry two-stage filter element with an inertial grid, through which all the air entering the engine intake manifolds passes.

The air purification coefficient from dust by such an air cleaner reaches 99% and practically does not depend on air consumption. At the same time, the first stage has a purification coefficient of 80%, which significantly facilitates the work of the cardboard filter element, ensuring its service life on the car of about 15-20 thousand km before the first maintenance and 30-40 thousand km before replacement.

Fig. 3. [3] shows the dependence of the air cleaner resistance on the duration of operation. As can be seen from Fig. 3, two-stage air cleaners used on YaMZ engines have greater efficiency compared to other air cleaners and, accordingly, a longer service life.

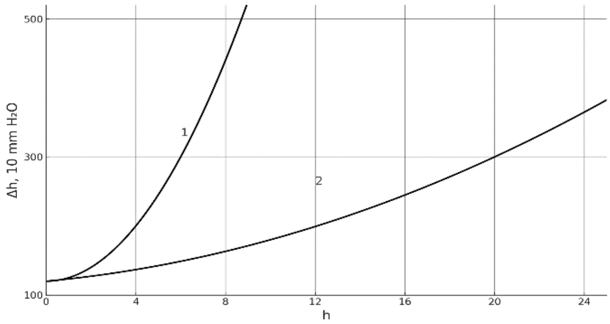


Fig. 3. Dependence of the air purifier resistance on the duration of operation during dustiness on the stand (air dustiness S = 0.4 g/m3, air flow rate 80% of the maximum): 1 – inertial-oil air cleaner; 2 – two-stage air cleaner with a paper filter element in the second stage

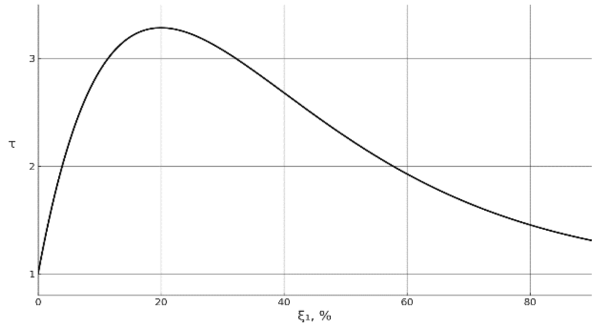


Fig. 4. Dependence of the relative operating time τ of a two-stage air purifier on the dust transmission coefficient of the first stage ε

Depending on the environment and operating conditions of vehicles and tractors, the cleaning coefficient of air purifiers $\eta_0 = \left(1 - \frac{\gamma_2}{\gamma_1}\right)$($\gamma_1$ and γ_2 are the dust content of the air at the inlet and outlet of the air purifier, respectively) fluctuates around 99, reaching 99,5-99,7% at best [4].

Research has shown that to ensure the longest service life of a two-stage air purifier, the dust transmission coefficient of the first stage ε1 should be within 8-15% (Fig. 4) [4]. A further reduction in the coefficient ε1 does not lead to an increase in the service life τ of air purifiers.

The hydraulic resistance of the air cleaning system also affects the service life of the air supply system. It is known that with an increase in the resistance of the air cleaner Δh, the cylinder filling factor ηv decreases, and, consequently, the effective and economic performance of the engine deteriorates.

The YaMZ-236B engines use air cleaners with ejector dust extraction, which are installed in the engine exhaust system. The ejector installed in the engine exhaust system increases the exhaust back pressure in the maximum power mode by 150 mm H_2O (Fig. 5) [5].

It should be noted that for turbocharged engines, an increase in the resistance of the intake and exhaust tracts leads to a deterioration in the efficiency of the turbocharger, which is why it is preferable to install air cleaners that operate without ejector devices on such engines.

The results of the studies show that when using two-stage air cleaners with cardboard filter elements, the wear rate of the cylinder-piston group of engine parts is significantly lower than when using inertial-oil air cleaners. The duration of the element's operation before resistance Δhpr appears depends on the number of corrugations i or the distance between adjacent corrugations along the inner diameter (Fig. 6.) [5].

A semi-empirical dependence of the bench duration of filter operation in hours on the parameters of the first stage of purification and the coefficient of performance was obtained [6]:

$$\tau_{mw} = \frac{35{,}75F\Delta H\left(1+0{,}023\varepsilon_1\right)\left[1-17{,}4\left(v-0{,}036\right)\right]\left[1-0{,}445\left(3{,}1-l\right)\right]}{Q_{en}\left[\left(1+q\right)\varepsilon_1-\varepsilon_0\right]\gamma_{cn}}\cdot 10^{-5} \qquad (1)$$

where F – area of cardboard CFE, m^2; ΔH – working resistance reserve, Ma; ε_1 – first stage skip coefficient, %; V – air filtration speed through cardboard, m/s; l – distance between cardboard corrugations along the inner diameter of the cardboard, mm; Q_{eng} - engine air consumption, m^3/h; q – suction coefficient; ε_0 – filter transmission coefficient, %; γ_{cn} – dust content of air at the filter inlet, g/m^3.

Analysis of this equation shows that an increase in the filter operating time can be achieved by increasing the area of the cardboard and the distance between the cardboard corrugations in the CFE, decreasing the pass coefficient of the first stage of the filter, and reducing the initial resistance of the filter by introducing suction from the first stage.

For some automobile and tractor diesel engines, particularly reliable three-stage air cleaners are produced, in which the first stage is made in the form of a mono- or multi-cyclone, the second and third are sequentially connected paper filter elements.

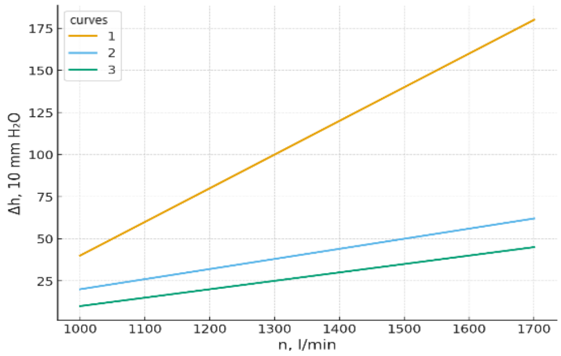


Fig. 5: Hydraulic resistance of the exhaust elements of the tractor diesel engine YaMZ- 236B:
1 – ejector; 2 – exhaust tract; 3 – spark arrester

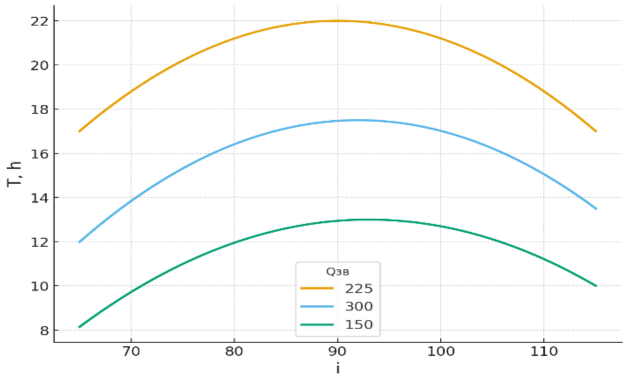


Fig. 6. The influence of the quality i of the corrugations on the service life of the T element before servicing at different air flow rates by the engine Q_{eng}(γ_1=0,5 g/m^3; Δhpr=700 mm H_2O)

Power supply system. The most important indicators of the quality of diesel fuel equipment are its durability and reliability. The achieved technical level of domestic fuel equipment does not always correspond to world achievements. Thus, the technical motor resource of serial fuel pumps does not exceed 5000 motor hours, while similar pumps of many foreign companies have a motor resource of 6000 motor hours and more. Domestic injectors are also significantly inferior to foreign ones in terms of actual service life.

Insufficient performance of fuel equipment is explained mainly by the lack of equal wear resistance of its elements. Wear resistance of units and parts of equipment is a serious problem, the solution of which requires the disclosure of the causes causing wear and breakdowns.

Insufficient reliability and durability of fuel equipment leads to increased costs for its maintenance and repair, which over the life of the engine often exceed the initial cost of the equipment by 3-4 times.

The durability of diesel fuel equipment is characterized by the service life of the main parts, the main ones being plunger pairs, injection valves and sprayers, which are manufactured according to the first precision class and have a roughness of mating surfaces of 10-12 purity class, and shape deviations within 1-2 microns.

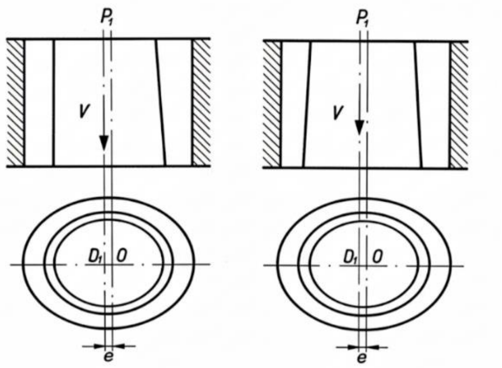
A necessary condition for the trouble-free operation of precision pairs is high stability of friction forces and wear resistance of the mating surfaces.

Plunger pair. The performance of the plunger pair is determined by the permissible value of the reduction in the cyclic fuel supply during operation. The resource of plunger pairs depends on many factors, which can be divided into two main groups. The first pear should include design and technological factors - the design of the pair, material, heat treatment and coating of the parts of the pair, the initial gap in the pair, etc.

The second group of factors reflects the operating conditions in which the pump operates. These include such indicators as fuel quality, the degree of its purification from mechanical impurities and water, the size and quantity of the contaminant that has passed through the plunger pair during operation, the speed of the plunger during operation, etc.

In this regard, the study of factors influencing the service life of precision fuel injection equipment pairs and included in both the first and second groups is of practical interest. The plunger, performing reciprocating motion, is subject to unbalanced radial forces, relative movement speeds of rubbing surfaces and hydrodynamic pressure of the liquid layer, unevenly distributed over the friction surface. The action of these factors leads to a displacement of the plunger in the bushing hole and to a redistribution of radial clearances.

In the case of placement in the bore of the sleeve of a conical plunger (Fig. 2), the largest base of which is located on the side of the upper end (Fig. 7, a) or on the side of the lower end (Fig. 7, b), the cross-section of the gap and the pressure of the liquid in the gap along the length of the mating will be variable.



a ***b***

Fig. 7. Diagram of the connection between the sleev e and the plunger

The resulting unbalanced radial forces force the conical plunger to shift in the gap and become skewed relative to the bushing axis. As the eccentricity and skew increase, the resistance to plunger movement will increase. Thus, when the alignment between the plunger and the bushing is disturbed and there are deviations from the cylindrical shape of the parts, conditions are created for their uneven wear. The plunger head is most susceptible to wear, especially the area in its upper part, located opposite the inlet window of the sleeve (Fig. 8, zone 1)

The shiny surface of the plunger becomes jagged with longitudinal grooves (in the form of ridges) as a result of wear in this area. External signs of a worn area are a matte surface shade and comb-like unevenness, clearly visible with a 10-20x magnifying glass, and with significant wear it is noticeable to the naked eye.

The plunger helical edge wears out less (Fig. 8, zone 2).The edge normally cut at an angle of 90° is rounded off due to abrasive wear. The external appearance of the worn helical edge of the plunger has grooves characteristic of abrasive wear, located along the plunger.

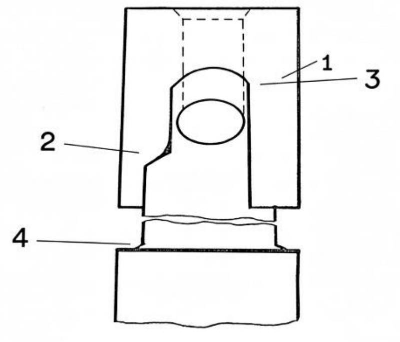


Fig. 8. Places of wear on the plunger head: 1 – zone of greatest wear opposite the inlet window of the liner; 2 – zone of the helical edge; 3 – zone of the small bridge; 4 – zone of the edge of the retaining shoulder

It is also necessary to note the minor wear of the surface of the small bridge (Fig. 8, zone 3), on which individual shallow scratches are formed, running along the plunger from the upper end to the edge of the vertical groove. Since this section of the entire finished surface of the head has the shortest length and, therefore, less resistance, then at the moment of creating high pressure in the above-plunger chamber, some of the fuel leaks along the scratches and scratches.

The edge of the plunger support shoulder also wears out (Fig. 8, zone 4). The edge, cut at an angle of 90°, is rounded due to abrasive wear, and short deep scratches are formed on its surface, running along the plunger axis along the entire circumference.

The nature and extent of wear of a plunger with two spiral closed edges is somewhat different from that considered, but the maximum wear of the plunger head is also located in the area located opposite the inlet window of the sleeve.

The inner surface of the bushing adjacent to the inlet and bypass ports wears out. Greater wear is observed at the inlet port, less at the bypass port (Fig. 9).

Wear in the intake port area covers a section in the form of a groove-shaped cavity located along the bushing. The greatest wear is concentrated near the port and, to a greater extent, above its upper edge.

As a result of uneven wear, there is no constant gap on the plunger head and the mating section of the bushing (in the area of the inlet window). The gap cross-section changes sharply along the height of the parts. If we bring it to the average value, it fluctuates within 10-15 microns.

A thorough analysis of the surfaces of worn plunger pairs showed that the wear of the plunger and bushing is of a pronounced abrasive nature and that the plunger is subject to the greatest wear in the area of small active strokes.

The technical condition of plunger pairs is assessed by dynamic density; productivity and maximum developed pressure.

The practice of operating the YAZTA fuel equipment in various climatic conditions shows that wear of plunger pairs to the condition of plunger pair 6 does not disrupt the traction and starting characteristics of the engine (Fig. 10) [6].

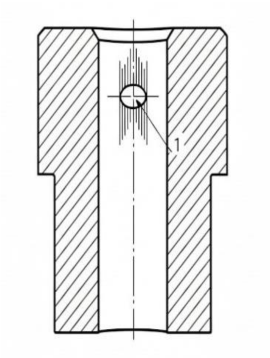


Fig. 9. Wear of the sleeve at the inlet port

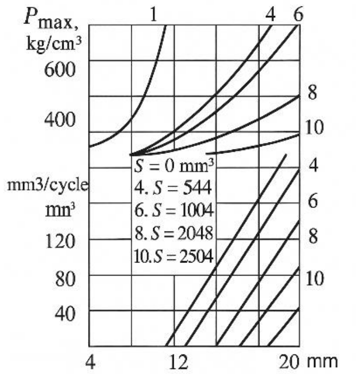


Fig. 10. Change in cyclic feed and maximum developed pressure from the rack stroke for YAZTA plunger pairs with different values of operational wear h = 80 rpm

As can be seen from Fig. 11, plunger pair N6 has a maximum starting feed of 180 mm^3/cycle with a total wear of 29 µm. This plunger pair worked on the MAZ-200 vehicle for 262 thousand km.

From this it is obvious that all plunger pairs whose dynamic indicators lie to the left of the graph than this pair belong to the group suitable for further use.

The most rational way to control the technical condition of plunger pairs during operation is to evaluate the maximum pressure they develop. Plunger pairs that do not develop a maximum pressure higher than 25 MPa at n = 80 rpm and hp = 16 mm and higher than 17 MPa at n = 250 rpm and hp = 10 mm are subject to rejection.

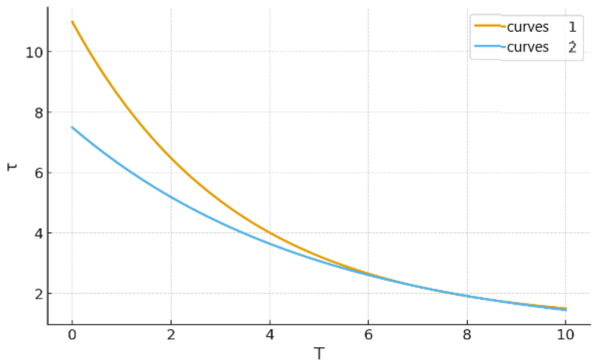


Fig. 11. Typical nature of changes in the hydraulic density of plunger pairs under normal operating conditions: 1 – with single-stage filtration; 2 – with two-stage filtration speed of 30 km/h, which corresponds to 8730 hours

One of the criteria reflecting the impact of plunger pair wear on the fuel supply characteristics is the hydraulic density of the pair. The slower it falls during operation, the lower the rate of wear of the pair and the longer its service life.

The change in hydraulic density is directly dependent on the fuel filtration scheme used (Fig. 11) [7].

Discharge valve. In the discharge valve (Fig. 12), the shut-off cone 1, the relief belt 2 and the guide tail 3 wear out. The surface of the shut-off cone wears out from the impact seating of the valve under the action of the spring, the residual fuel pressure in the fuel line, and also from the impact of abrasive particles present in the fuel.

The valve relief belt is subject to significant wear, the cylindrical shape of which is distorted and becomes conical.

At the valve seat (Fig. 13) the locking chamfer and the guide hole wear out. The reasons for wear of the locking chamfer of the seat are the same as those of the valve locking cone.

The valve seat guide hole is more damaged in the upper part, i.e. in the area of the unloading belt, and for the same reasons as the valve belt.

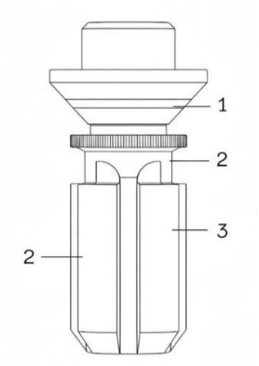


Fig. 12. Wear areas of the discharge valve: 1 – shut-off cone; 2 – unloading belt; 3 – guide tailpiece

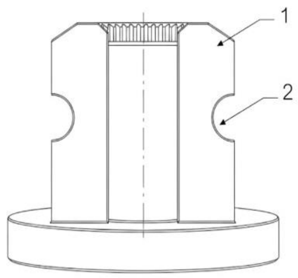


Fig. 13. Places of wear of the discharge valve seat: 1 – shut-off chamfer; 2 – guide hole

Wear of the injection valve causes: deterioration of the unloading action of the valve, which leads to a more extended injection, repeated injections, and increased unevenness of fuel supply.

It is known that the uniformity of fuel distribution across the cylinders is an extremely important indicator that determines its durability and efficiency.

Based on numerous results of operational tests of fuel equipment on MTZ-80, DT-75 and other tractors, a pattern of changes in the hydraulic density of valve pairs as the service life of the fuel equipment increases has been determined (Fig. 14) [8].

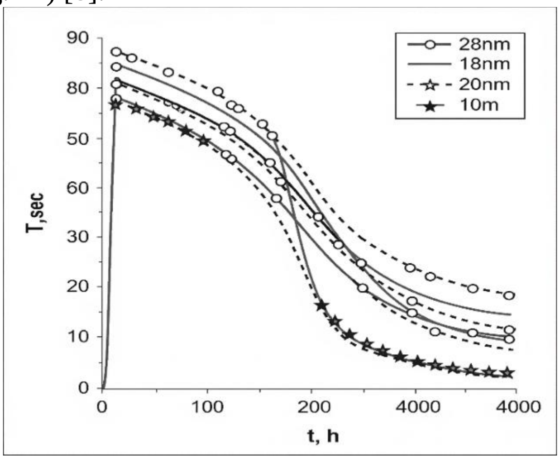


Fig. 14. Reduction in hydraulic density of the discharge valve depending on the period of operation

Analysis of Fig. 14 shows that valve pairs with 5000 engine hours of operation still have a service life; valve pairs with different initial densities along the unloading belt, or, in other words, different clearance sizes in this connection, even out and become approximately the same by the 5000 engine hours of operation.

Nozzle Sprayers. The most vulnerable part of diesel fuel equipment is the injector nozzles, which are exposed to high temperatures and chemically active combustion products in the combustion chamber.

In the spray needle (Fig. 15) the following wear out: guide part 1, cylindrical rod 2, shut-off cone 3, pin 4, spray cone 5, upper shoulder 6 and upper end of tail 7.

The presence of deep longitudinal grooves on the guide surface confirms the abrasive action of mechanical particles suspended in the fuel.

The weakest points of the needle include the shut-off cone, which takes the impact load from the injector spring and experiences the abrasive action of solid particles present in the fuel.

Increasing the reliability of the injector can be achieved by reducing the tendency of the sprayers to carbon formation. The results of the work showed that the sprayer service life significantly depends on the maximum stroke of the sprayer needle.

The greater the needle stroke, the greater the probability of gas breakthrough from the engine combustion chamber into the atomizer body and the greater the impact energy of the needle during lifting and landing. Hence, as a consequence, intensive oxidation and coke formation.

Hydraulic tightness is the main criterion for assessing the technical condition of precision pairs. The consequences of low tightness are fuel leakage in the atomizer, extended injection, deterioration in the quality of fuel fragmentation, poor cutoff - all this reduces power, causes smoke in the exhaust, intensive formation of carbon deposits on the atomizer, piston bottom and coking of piston rings.

During operation, the hydraulic density of the sprayers changes. Fig. 16 [9] shows the dependence of the sprayer hydraulic density on the operating time. As can be seen from Fig. 16, at the beginning of operation, during the first 100-300 engine hours, the hydraulic density increases by an average of 30-50% of the initial value, and the process of running-in of the surfaces of the mating parts of the sprayer occurs. After the end of the running-in process (600-800 engine hours), the hydraulic density begins to gradually fall, as wear of the locking surfaces and initial destruction of the guide surface of the needle and the mating hole of the sprayer body appear.

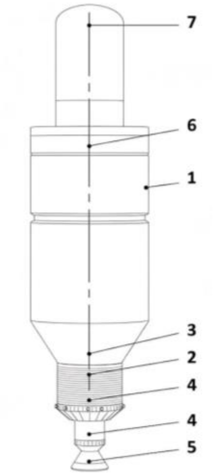


Fig. 15. Places of wear of the needle surfaces: 1 – guide surface; 2 – cylindrical rod; 3 – locking cone; 4 – cylindrical part of the pin; 5 – spray cone; 6 – upper shoulder; 7 – end face of the shank

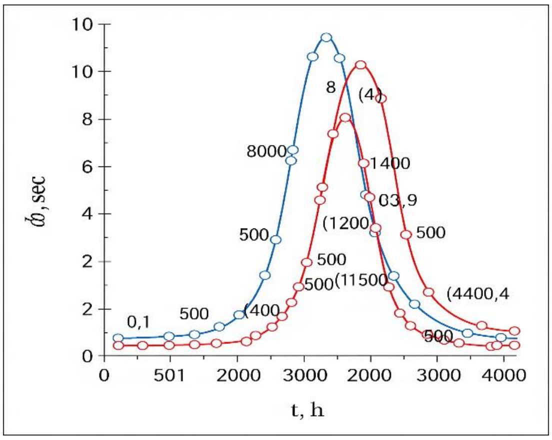


Fig. 16. Dependence of the hydraulic tightness of the injectors on the operating time (3 different injectors): t – operating time in engine hours; τ – time of pressure drop from 20 to 18 MPa

After the fuel equipment has worked for 2500-3000 engine hours, a sharp drop in hydraulic density occurs. By this time, the working surfaces of the needle and the sprayer body are significantly worn out, especially the locking surfaces of the named parts.

Based on data from [10], the injectors have a satisfactory hydraulic density indicator after 3500-4000 engine hours, and some up to 4500 engine hours.

Fuel filters. The durability of diesel fuel equipment largely depends on the quality of fuel purification. Currently, there are a large number of filters, diverse not only in design, but also in efficiency.

The design of fuel filters with radial sealing of filter elements developed by the engine plant (Fig. 17, 18, 19.) allowed to significantly increase failure-free operation of the unit. This was confirmed by operational tests of fuel filters with radial sealing, both single-stage and two-stage.

The design level of various filters is clearly shown in Fig. 17-19 and the data in Table 1.

Table 1

Design level of different filters

Filters	Fig. 17	Fig. 18	Fig. 19
Probability of failure-free operation	0,841	0,9459	0,9795

Modern diesel engines typically use two-stage fuel purification.

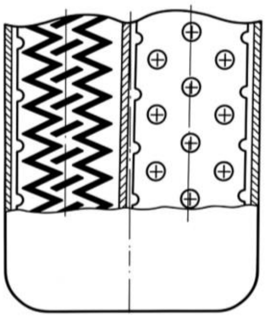


Fig. 17. Fuel filter with radial sealing of filter elements

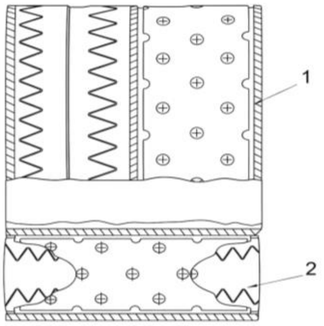


Fig. 18. Two-stage fuel filter with radial seal: 1 – first stage filter element; 2 – second stage filter element

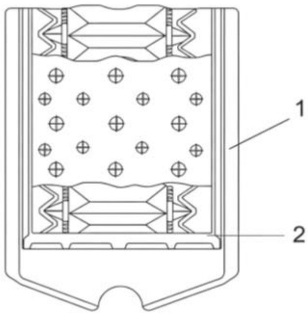


Fig. 19. Tolling filter with a two-stage filter element: 1 – filter element first stage; 2 – filter element of the second stage.

The service life of a filter element can be determined by the time of its proper operation: maintaining the permissible values of completeness and fineness of cleaning, the pressure drop on it, at which the engine power can drop to the set values.

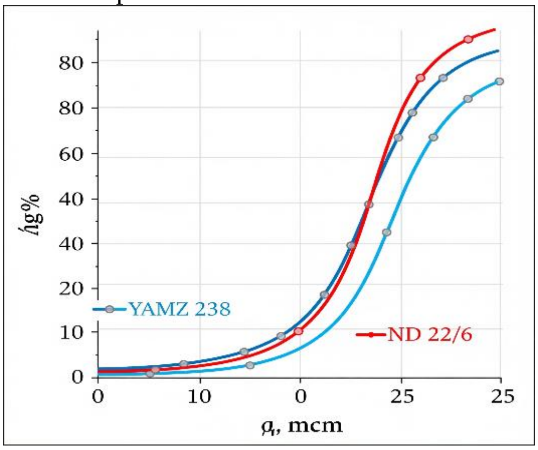


Fig. 20. Dependence of the reduction in cyclic fuel supply on the filter density

The fineness of the filter has a significant impact on the service life of the plunger pair. (Fig. 20) [11] shows the dependence of the fineness of the filter on the drop in productivity of fuel pumps, from which it is evident that with an increase in the size of the particles passed by the filter, there is an increase in the drop in the cyclic feed (i.e., an increase in the wear of the plunger pairs).

At the same time, with the improvement of the fineness of the screening, the initial resistance of the filter increases, resulting in a decrease in the service life of the filter elements. In this regard, it is advisable to select the fineness of the screening based on obtaining the maximum technical and economic efficiency from the use of filters on the engine.

Therefore, when choosing a filter, it is necessary to take into account the type of pump, as well as the conditions in which the engine will operate (plowing, transport work, dustiness of the air, etc.).

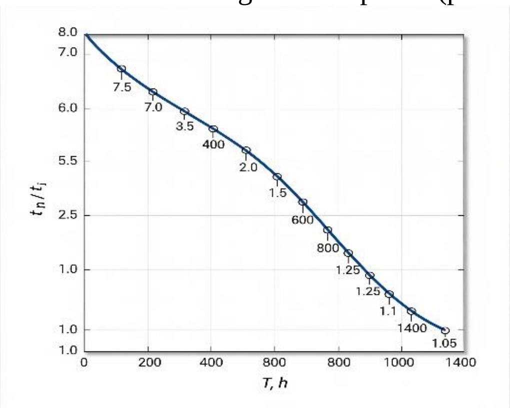


Fig. 21. Dependence of the service life of filter elements on the filterability coefficient of fuels

One of the most important characteristics of the filter element of the fine fuel filter, along with the fineness and completeness of filtration, as well as hydraulic resistance, is its service life between replacement of filter elements. This period is determined by the intensity of clogging of the pores of the filter element with pollutant particles and a decrease in its throughput.

The service life of filter elements, stipulated by ISO 4020:2001 in the amount of 1500 hours, can be ensured during operation

The dependence of the service life of filter elements on the fuel filterability coefficient is shown in Fig. 21. [12]

If we consider the reliability and durability of fuel equipment as a whole, taking into account that the distribution of its operating time before the first failure is subject to the normal law, then the dependence of the distribution of the operating time of fuel equipment on the duration of its operation is represented by the graph shown in Fig. 22. [13].

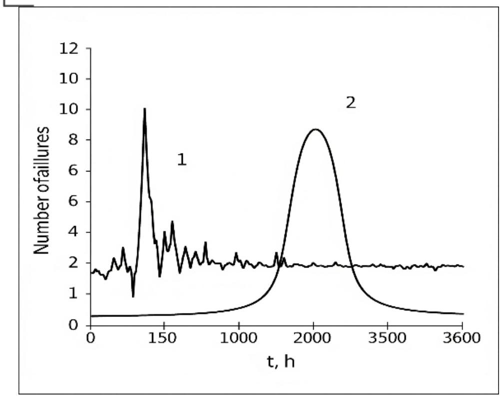


Fig. 22. Distribution of operating time of fuel equipment of SID-14 diesel engines until the first failure: 1 – experimental curve; 2 – theoretical curve

The average value of fuel equipment operating time before the first failure with a probability of 0.95 was obtained equal to 1932 engine hours, and before the first repair – 2960 engine hours. The average operating time of repaired fuel pumps before repair is approximately 2 times less than that of new ones.

The analysis of the main causes causing wear of precision fuel equipment parts is of theoretical and practical interest, since measures aimed at eliminating or significantly reducing the influence of causes contribute to increasing the durability and reliability of the fuel system as a whole, and thus the efficiency of the diesel engine.

Lubrication system. For reliable engine operation and lubrication modes that do not cause accelerated wear, normal operation of the following units is necessary: oil pump, coarse and fine oil filters, valves, instruments. Hydraulic density and mechanical reliability of its provision, as well as the condition of the oil pump drive, play a major role in the operation of the oil system.

Lubrication prevents direct contact of metals, cools rubbing surfaces and carries away abrasives and other harmful impurities. Even a short-term absence of lubrication between rubbing surfaces of parts leads to worsening of friction conditions, increased wear and sometimes to melting of bearings and seizure of parts.

The quality of lubricants is of great importance for increasing the wear resistance of parts. It is known that during engine operation, motor oil "ages" and loses its qualities. The amount of additives in it decreases, as a result, the intensity of wear of parts of the cylinder-piston group increases, especially in the zone of high temperatures. It has been established that in the absence of additives in the oil, the wear rate of piston rings increases more than 2-2,5 times.

With a decrease in additives in oil, the amount of resins and other products that quickly clog filters and oil channels. Insufficient amount of lubricant between the rubbing parts surfaces leads to a decrease in the lifting force and to a slowdown in the floating of the shaft journal. As the friction force increases, the temperature increases, the viscosity of the lubricant decreases and, consequently, the transition to liquid friction is difficult.

Timely replacement of contaminated oil, flushing of the oil system, the use of measures to eliminate the ingress of abrasive particles into the oil during refilling and preventing premature coking and contamination of surfaces can significantly increase the wear resistance of engine parts.

The trend towards dieselization of the vehicle fleet poses new problems and challenges in the field of creation and application of motor oils.

The use of turbocharging and the complication of operating conditions have significantly tightened the operating conditions of engine oil (the oil temperature in the crankcase has increased from 330-350°K to 380-400°K).

The specialists are faced with the task of creating oils with improved motor properties and ensuring a long service life for engines.

The technical condition of the bearings and crankshaft journals is characterized by the size of the oil gap between them. This gap increases as the bearings and journals wear out, and the oil leakage from the main line through the gaps between the journals and bearings also increases. As a result, the pressure in the main oil line decreases. According to YaMZ, an increase in the gap in the main bearings of the YaMZ -236 engine from 0,076 to 0,186 mm and in the connecting rod bearings from 0,056 to 0,165 mm causes a decrease in pressure in the main line from 18,5 to 5 MPa, i.e. by 2,5 times.

Similar changes in oil pressure in the lubrication system depending on the wear of the crankshaft bearings were obtained in the works carried out in the laboratory of durability and reliability of engines NAMI. This allows us to predict the wear of the crankshaft bearings and the engine service life before major repairs based on the oil pressure in the main line.

Fig. 23. [14] shows the dependences of the clearance b in the connecting rod bearings and the pressure P in the lubrication system on the operating time of the YaMZ engines. As can be seen from Fig. 23, the maximum values of the clearances of the connecting rod bearings are (210 mem), the minimum permissible values of the oil pressure in the main line at the nominal speed of the crankshaft are slightly less than 0,35 MPa, and at idle speed - less than, 0,15 MPa.

A general assessment of the condition of the lubrication system and an approximate forecast of its performance can be made on the basis of the method developed at LSHi (Fig. 24) [15].

Region A corresponds to insufficient lubrication and operation with reduced pressure when the engine hours are reached

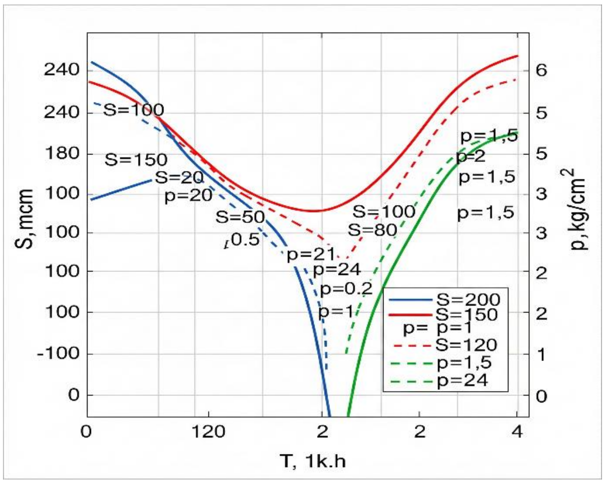


Fig. 23. Dependence of clearance S in connecting rod bearings and pressure P in the lubrication system from engine operating time (solid lines - yam3-238n, dashed lines – YAMZ- 236/238): I – clearance S: 2 and 3 – pressure P at maximum power and idle speed

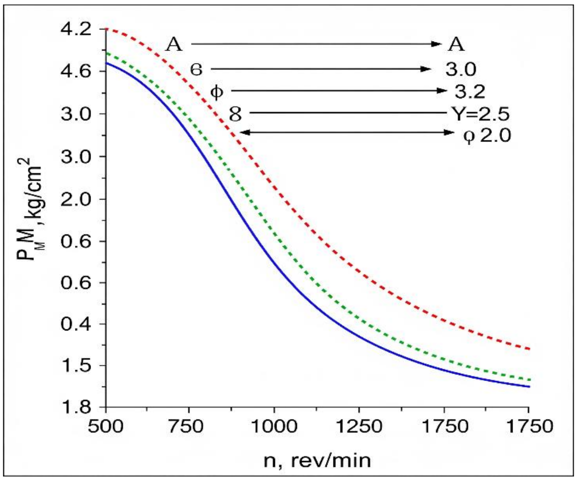


Fig. 24. For operational testing of the engine life of normal operation of the engine lubrication system

When the engine hours are worked out according to control № 2, area B corresponds to operation with insufficient lubrication supply, and area G corresponds to operation with normal oil supply.

The expansion of zone B compared to zone A can be used to judge the changes that have occurred in the engine, and the reduction of zone G compared to zone B can be used to judge the remaining engine life. The dashed line indicates incorrect adjustment of the system valves.

The mechanisms and parts of an engine operating under unsteady loads are in less favorable conditions (in terms of wear) compared to steady-state modes. An increase in the dynamic indicators of the cycle, a discrepancy between the performance indicators of the lubrication system and the requirements of the mode, a deterioration in the conditions for cleaning the oil, etc. lead to the fact that the wear resistance of the parts of the cylinder-piston group, the crank mechanism decreases.

For unsteady modes, the minimum value of the oil pump performance coincides in phase with the highest value of the maximum cycle pressure and the average rate of pressure increase in the engine cylinder, and the oil purification coefficient for the characteristic wear elements decreases and is greater the higher the parameters of unsteady modes.

When plain bearings operate in unsteady modes, a decrease in the thickness of the oil layer leads to an expansion of the contact zones of the shaft journals and bearings. A transition from semi-liquid friction to boundary friction with a rupture of the oil film is possible.

It has been established [16] that the wear of such parts as cylinder liners, compression and oil scraper rings, pistons, bronze bushings, etc., in non-steady-state conditions increases by 1,2-1,8 times, depending on the nature of the condition. kg/cm^2

The main advantages of centrifuges are their simple design and high operating efficiency: abrasive particles of contaminants are removed from the oil first, which significantly reduces wear on rubbing surfaces. This eliminates the need for replaceable filter elements.

The results of the studies show that of all the tested oil cleaning systems, the most effective system for reducing wear of parts by abrasive particles of oil contamination is a combined system - a full-flow fine filter in combination with a partially flow centrifuge.The use of a combined system made it possible not only to achieve minimal relative wear of parts, but also to increase the service life of the full-flow filter by 1.8 times (before replacement with a new one) (Fig. 25) [17].

Cooling system. Engine operation at excessively low or high water and oil temperature conditions reduces engine reliability and increases wear of its parts (Fig. 26) [1]. The reason for increased wear of engine parts at low thermal conditions is deterioration of their lubrication (due to insufficient supply of high-viscosity oil). At excessively high temperatures, lubrication of parts also deteriorates due to low oil viscosity.

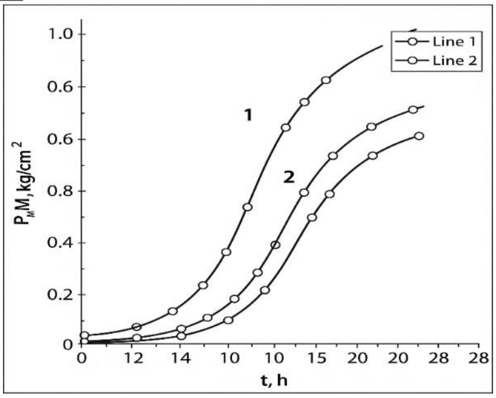


Fig. 25. Change in pressure drop in a full-flow fine oil filter: 1 – oil cleaning only with a full-flow filter; 2 – oil purification by a full-flow filter and a partial-flow jet centrifuge

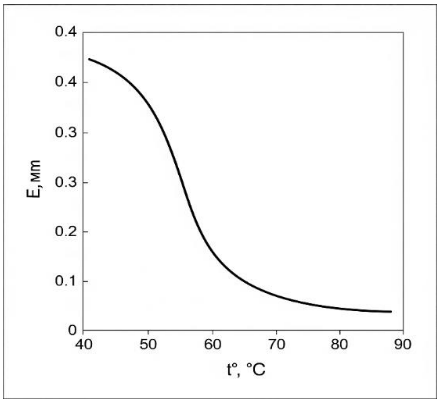


Fig. 26. Effect of cooling water temperature on engine cylinder wear

For reliable operation of engines with conventional cooling, it is necessary to stabilize their thermal conditions for water and oil close to the optimum, 80-90°C. Maintaining the temperature conditions of the engine operation close to the optimum is ensured mainly by using blinds on radiators with automatic control, reliable and effective thermostats, temperature-controlled fans, water-oil radiators, etc.

3. The purpose of the article

The aim of this study is to substantiate and develop scientific and practical measures to improve the reliability and durability of automotive and tractor diesel engines by analyzing the mechanisms of wear, identifying the most influential operational factors, and optimizing filtration, lubrication, and cooling systems.

Research objectives:

1. To analyze the main causes and patterns of wear in diesel engine components under real operating conditions.
2. To assess the impact of abrasive particles, fuel and oil contamination, and inadequate thermal regimes on engine performance and longevity.
3. To investigate the efficiency of air, fuel, and oil filtration systems and their role in reducing abrasive wear.

4. Results and discussion

On KrAZ-256B engines and others, thermostatically controlled fans with electromagnetic or hydraulic clutches are used. On YaMZ-240B diesel engines, a hydraulic clutch with proportional regulation of the fan speed depending on the engine temperature is used.

Maintaining the optimal engine temperature regime largely depends on the reliable operation of the cooling system and its individual units.

Fuel efficiency, reliability and durability of the engine largely depend on the technical condition of the cooling system.

External signs of malfunction in the cooling elements are shown in Table 2.

Table 2

External signs of malfunction in the cooling elements

External signs of malfunction	Reasons
Water boiling in the system with open blinds	Slipping or breaking of the fan belt
Water boiling without belt slippage with open blinds	Failure of the thermostat
Water boiling in the system with a working thermostat and water pump	Contamination of the cooling system with scale
Water leaking from the cooling system	Violation of the tightness of connections and damage to elements
Water boiling in the system with no circulation in the upper tank	Breakage of the impeller of the water pump

During operation of cars and tractors (especially in conditions of high temperatures and dustiness), significant contamination of the cooling system is observed with the formation of a layer of scale and mechanical impurities up to 3-4 mm thick on the cooled and heat-dissipating surfaces, which leads to an increase in the maximum temperatures of the coolant and to engine overheating. The presence of chemical and mechanical impurities in water causes corrosion and abrasive destruction of aluminum alloy parts.

The deposits of scale and mechanical impurities in the radiator are reduced heat transfer from its surfaces, increase hydraulic resistance and reduce fluid circulation in the system (Fig. 27) [1].

These deposits, when shaken, can bounce off the washed surfaces and clog the passage holes of the tubes, which makes it necessary to periodically clean the radiator and even replace it.

The use of water as a coolant in a conventional cooling system leads to increased deposits of scale and contaminants on the walls and to corrosion of the walls, and in winter, in addition, to cases of block defrosting.

Therefore, on vehicles of the KrAZ family and others, a more reliable closed cooling system with an expansion tank is used (to compensate for changes in the volume of coolant).

The most favorable temperature range for engine operation is between 75-98°C. This temperature is maintained using thermostats, a hydraulic clutch for turning on the fan with automatic control, and driver-controlled blinds.

The cooling agent used in such engines is the all-season low-freezing (-40°C) liquid TOSOL-A40, which has anti-corrosion properties and is usually replaced after 1-2 years.

A loose fan belt tension causes the engine to overheat, slip, and wear out quickly. Belts that are too tight also wear out quickly. The same thing happens to the fan bearings.

Fig. 28 shows a reliability map of diesel engines installed on dump trucks (solid lines) and tractor units (dashed lines).

Little attention is paid to monitoring the condition of the cooling system during operation. Meanwhile, the cooling system has, as can be seen from the analysis, a significant impact on the wear of the cylinder-piston group parts, increasing as the deposits (scale) on the surface of the cylinder liner increase.

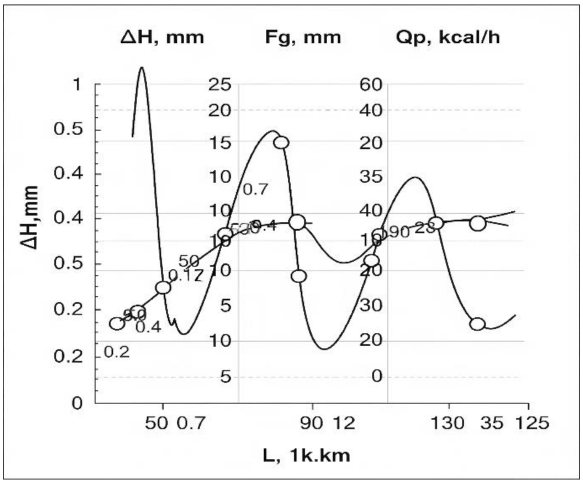


Fig. 27. Change in the thickness of the scale layer dN, the flow area of the tube F* and the heat transfer of the radiator

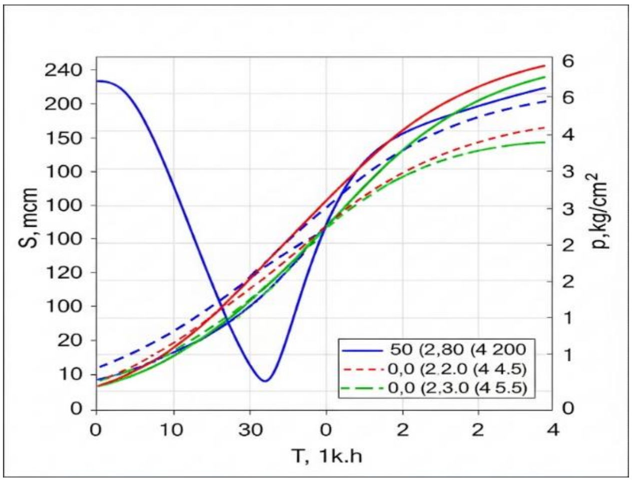


Fig. 28. Reliability map:
1 – water pump belt; 2 – generator belt

Analysis of wear and tear of diesel engine systems under operating conditions shows that there are large reserves for increasing the reliability and durability of automobile and tractor diesel engines in improving the design of systems and in improving the culture of technical operation.

And since increasing the reliability and durability of machines is currently of great national importance, theoretical and experimental research that helps identify reserves for increasing reliability and durability does not lose its relevance.

5. Conclusion

An analysis of diesel engine wear processes under real operating conditions identified the key factors affecting engine longevity, including abrasive wear, contamination of working media, and filtration system efficiency.

It was determined that the most influential factors in wear progression are the effectiveness of engine dust protection, thermal stability, and variations in load and speed conditions.

The study confirmed that most failures and resource losses are operational in nature, caused by insufficient maintenance and poor control of air-cleaning and cooling systems.

Recommendations were developed to improve the reliability and service life of diesel engines, emphasizing the modernization of filtration systems, the use of high-quality lubricants, improved maintenance culture, and diagnostic methods for assessing residual engine life.

The proposed technical and operational measures will reduce wear rates, improve operational stability, and extend the service life of automotive and tractor diesel engines.

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СПОСОБИ ПІДВИЩЕННЯ НАДІЙНОСТІ ТА ДОВГОВІЧНОСТІ АВТОМОБІЛЬНИХ ДИЗЕЛЬНИХ ДВИГУНІВ

Дослідження зосереджено на абразивному зносі, спричиненому частинками пилу в системах повітря, палива та змащення дизельних двигунів. Було проаналізовано механізми утворення та розвитку зносу в кожній системі, а також їх вплив на довговічність циліндропоршневих вузлів, плунжерних пар, форсунок та підшипникових вузлів. Було виявлено, що абразивні частинки у впускному повітрі є основною причиною зносу циліндрів та поршнів.

Щоб мінімізувати ці наслідки, було запропоновано вдосконалення систем очищення повітря шляхом використання багатоступеневих фільтрів з підвищеною ефективністю та оптимізованою геометрією. У системі подачі палива було показано, що наявність дрібних твердих частинок призводить до прискореного зносу прецизійних компонентів, таких як плунжерні пари та форсунки, що підкреслює необхідність високоефективних елементів фільтрації палива. У системі змащення забруднення маслом та деградація присадок були визначені як основні фактори, що сприяють прискореному зносу поршневих кілець та підшипників колінчастого вала. Використання високоякісних мастильних матеріалів та постійний моніторинг тиску масла були рекомендовані як діагностичні інструменти для прогнозування зносу компонентів та необхідності капітального ремонту.

Аналіз виявив значний потенціал для підвищення надійності та терміну служби дизельних двигунів шляхом оптимізації систем фільтрації, підтримки стабільних теплових умов та забезпечення належного обслуговування систем охолодження. Результати дослідження показують, що вдосконалення систем фільтрації, змащення та діагностики комплексним чином може суттєво подовжити термін служби автомобільних та тракторних дизельних двигунів.

Крім того, дослідження забезпечує наукову основу для розробки передових стратегій технічного обслуговування та моніторингу, спрямованих на запобігання передчасним відмовам двигунів внутрішнього згоряння. Результати можуть бути застосовані для проектування адаптивних діагностичних систем та модернізації процедур технічного обслуговування сільськогосподарської, будівельної та транспортної техніки. Запропонований підхід сприяє зниженню експлуатаційних витрат, покращенню екологічних показників та продовженню терміну сталої експлуатації дизельних двигунів у різних галузях промисловості.

Ця наукова стаття показує результати ініціативної науково-дослідної роботи № 0122U002187, виконаної в межах поточних досліджень, спрямованих на підвищення надійності та довговічності дизельних двигунів.

Ключові слова: паливна апаратура дизельний двигун, плунжерні пари, гідравлічна щільність, нагнітальний клапан, форсунки, фільтрація палива, фільтруючий елемент.

Ф. 1. Рис. 28. Табл. 2. Літ. 17.

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