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REASONS FOR WEAR OF PLUNGER PAIRS AND INCREASING THEIR DURABILITY DUE TO THE USE OF BIOFUEL

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Increasing the resource of various equipment units and assemblies has always been a priority task that allows not only to extend the service life of the equipment but also to avoid costs associated with its repair and downtime. The relevance of this work lies in the fact that a significant part of the equipment used for agricultural production is equipped with diesel engines. The fuel system of these engines is the most complex, expensive, and responsible unit. The reliability of its operation determines the power, economic, and environmental performance of the equipment that uses diesel engines. An analysis of tractor engine failures revealed that 30-50% of all failures are due to the fuel equipment. This is due to the low reliability of diesel engine fuel equipment under operating conditions. Therefore, manufacturers of precision parts aim to increase the resource of these parts.

The goal is formulated to establish the relationship between the causes of wear and the impact on the resource using biodiesel fuel and to set the main research tasks that require establishing a cause-and-effect relationship between different types of wear and the resource of plunger pairs. The object of research is the surfaces of plunger pairs in the environment of biodiesel fuel. The main research methods based on chemotology, tribology, physico-chemical, and operational properties of fuel and lubricants, elements of reliability theory are considered. Factors affecting the wear resistance of plunger pairs are examined, including fuel contamination with mechanical particles, increased water content in the fuel, and the impact of elastic deformations during the installation of new plunger pairs in the high-pressure pump. The two main factors affecting the wear of plunger pairs are highlighted, one of which cannot be influenced by operational measures, while the other can be changed by using alternative fuel. A scientific hypothesis within this topic is formulated. The results of the initiative research work 0122U002187 are presented in this scientific paper.

Key words: *diesel, fuel equipment, plunger pairs, reliability, resource, biodiesel fuel.*
Fig. 2. Ref. 23.

1. Problem formulation

The fuel system of a modern diesel engine is the most complex, expensive, and responsible unit, performing the following functions:

- reliable storage of a certain amount of diesel fuel;
- protection from atmospheric contamination;
- ensuring efficient fuel filtration;
- uninterrupted fuel supply during engine operation;
- uniform fuel dosing to each cylinder depending on engine load;
- timely fuel injection into the cylinders;
- fuel distribution in the combustion chamber [1, 2, 3, 4].

Currently, manufacturers aim to increase the reliability of the fuel equipment (FE) of tractor and combine engines to 10-12 thousand hours and to reduce maintenance costs by increasing the operating intervals of the pump adjustments to 3000 hours and injectors to 2000 hours [5]. According to GOST 23.1.125-84, the resource of pumps and injectors should be at least 6000 hours, and of nozzles – 3000 hours. However, under operating conditions, the reliability of fuel equipment and its components remains very low. In particular, the resource of new precision parts is: for plunger pairs – 700-3000 hours; for delivery valves – 1400-2000 hours; for injector nozzles – 800-1600 hours [6, 7, 8].

Maintenance and repair costs of FE amount to about 30% of the total tractor costs. In tractor engines, up to 27% of failures are due to the cylinder-piston group (CPG) and crank mechanism (CM), 30-50% – to the FE, of which up to 50% – to injectors, and 25-35% – to plunger pairs and delivery valves [1, 8, 9, 10].

2. Analysis of recent research and publications

Among the numerous factors affecting the wear resistance of plunger pairs, the following can be distinguished:

- contamination of fuel with mechanical particles;
- water content in the fuel;
- temperature of the fuel entering the high-pressure fuel pump (HPFP);
- elastic deformation of parts.

Contamination of fuel with mechanical particles. As is known, fuel gets contaminated at all stages of its life cycle: from production at refineries, transportation to oil depots, during storage, refuelling, and use [11, 12, 13, 14]. During the transportation of diesel fuel to the storage site, the amount of mechanical impurities in it increases from 0.0005 to 0.00630%, i.e., more than 100 times. Moreover, diesel fuel contains a large number of abrasive particles of significant sizes [15, 16, 17]. During diesel operation, when the air dust content is 1- 25 g/m³, the number of contaminants in the fuel by the time it is used up exceeds their amount at refuelling by 2-3 times. In some cases, one litter of fuel drained from the fuel tank operating in particularly dusty conditions may contain over 25 grams of contaminants [16, 18]. The amount of contaminant particles in the fuel tanks of cars and tractors directly depends on the dustiness of the area and the time of year and can reach 200-300 grams per ton of fuel [10].

Tractors perform various agricultural tasks during which air dustiness varies significantly. During ploughing, it is 0.05 – 1.1 g/m³; during sowing, 0.8 – 2.5 g/m³; during cultivation, 0.9 – 1.2 g/m³; during harrowing, 0.125 – 1.03 g/m³; during transport operations, up to 2.1 g/m³; during land levelling, up to 3.1 g/m³. The dustiness of the air at the level of the fill neck of the MTZ-80 tractor tank during sowing is 0.04 – 1.78 g/m³ [8, 10, 15].

The primary barrier preventing the penetration of mechanical particles into the HPFP and injector nozzles is fuel filters for rough and fine cleaning. It has been established [5, 10, 15] that fuel filters on automotive and tractor diesels, after a certain period of operation in dusty conditions, do not sufficiently ensure fuel cleaning from mechanical impurities. The size of abrasive particles can reach 10×10^{-6} m regardless of the fuel level in the tank and the design of the filtering elements. According to GOST 14146-88, the service life of paper filter elements is 1500 engine hours. In conditions of increased fuel contamination in agriculture, to ensure the regulated fuel cleanliness, these terms need to be shortened. However, in a number of farms, we can observe an excess of filter element service life beyond acceptable limits, which leads to a sharp increase in the number and size of impurity particles in the fuel passing through the filter [15].

Water content in the fuel. Another type of diesel fuel contamination that affects the wear of precision parts of the fuel equipment is water content. Hydrocarbon fuel of all types has reverse hygroscopicity, i.e., under certain conditions, it dissolves atmospheric moisture, and when these conditions change, it releases it in the form of microdroplets. The solubility of water is primarily influenced by air temperature, humidity, and pressure (Fig. 1) [8, 10, 11].

An analysis of the water content in diesel fuel in the tank showed that the amount of free water in the fuel (excluding dissolved water) exceeds the amount of water during refuelling by 2 – 12 times. The average content of free water in tractor fuel systems is 0.059%, while the maximum permissible water content is 0.013%. Sediment from coarse and fine filter housings may contain up to 18% water [19]. Studies aimed at assessing the impact of water in the fuel have shown that during cyclic operation, an increase in emulsified water content above 0.5% leads to a significant increase in plunger pair wear. This is explained by the fact that engine stops contribute to predominant corrosion wear [10, 15, 20].

The impact of elastic deformations on plunger pair wear. Due to the small clearances in new precision FE parts, which are $0.4...3\times10^{-6}$ m, and their operating conditions, which involve high speeds and pressures, very high requirements are imposed on the surface roughness, geometric shape, and physical-mechanical characteristics [1, 6, 21].

A constantly acting factor that negatively affects the resource is the change in geometric dimensions due to elastic deformation that occurs during the installation of plunger pairs in the pump housing.

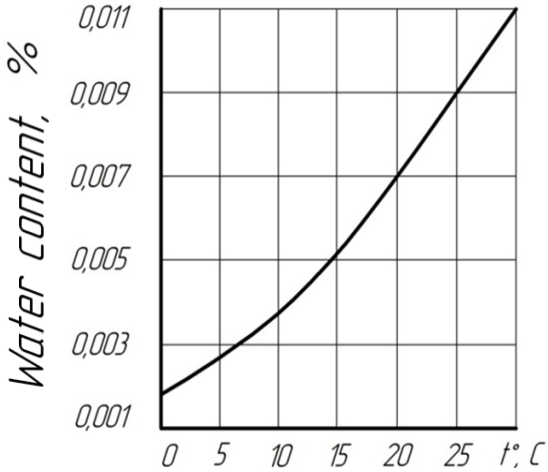

Fig. 1. The dependence of water solubility in petroleum products on temperature

In the new pump, deformation appears already during the tightening of the fitting with a torque of 30 N·m. At a tightening torque of 120 N·m, due to the action of the radial component of the elastic deformation of the plunger sleeve, the clearance in the cross-section opposite the windows will decrease, and at $0.4...3\times10^{-6}$ m below the windows, it will increase (Fig. 2). These deformations lead to the sudden failure of the fuel equipment due to the sticking or jamming of the plunger in the sleeve, which occurs because of the misalignment of the geometric axes of the sleeve and the plunger, as the mounting forces cause the compressor part of the sleeve to bend. Increasing the mounting torque of the pump fitting to 140-150 Nm can accelerate the wear of the plunger pairs of in-line fuel pumps by 20% compared to parts assembled with a torque of 100- 120 N·m [6, 8, 12, 21].

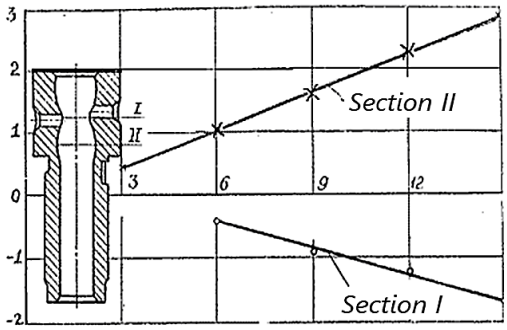

Fig. 2. Change in the clearance value in the plunger pair depending on the tightening forces

The study of the wear process of precision parts and the improvement of the reliability of tractor diesel fuel equipment is the subject of research by many scientists, such as V.V. Antipov, K.A. Achkasov, N.I. Bakhtiyarov, P.A. Vlasov, N.I. Gurevich, B.P. Zagorodsky, I.B. Kostetsky, P.M. Krivenko, I.M. Lishevsky, M.M. Tashpulatov, B.M. Fainleib, and others.

3. The purpose of the article

The objective of the research is to establish the relationship between the causes of wear and the resource of plunger pairs and the impact of biodiesel fuel on wear and resource.

To achieve the goal, the following tasks were set: to analyse the cause-and-effect relationship between different types of wear and the resource of precision parts. The object of the study is the working surfaces of plunger pairs of the fuel pump operating in the environment of diesel and biodiesel fuel. The research methods are based on the main principles and laws of chemotology, tribology, physics-chemical and operational properties of fuel and lubricants, and elements of reliability theory.

4. Results of the researches

The condition of precision parts such as plungers and sleeves, delivery valve and its seat, injector needle and nozzle body is a key parameter determining the reliability of diesel engine fuel systems [6, 10, 15]. During operation, these parts undergo wear, leading to changes in fuel delivery cycle, increased unevenness in fuel delivery across cylinders, increased injection advance angle, decreased start of injection pressure, and

increased injection duration. These factors adversely affect diesel engine performance, resulting in reduced power output, worsened fuel efficiency, and increased toxicity of exhaust gases [1, 7, 10, 15].

The main types of wear in plunger pairs of fuel systems include:

1) Abrasive wear – caused by mechanical particles that may be smaller or larger than the clearance in the friction pair. When particles are smaller than the clearance, they remove microchips from the surface due to high-speed movement. If particles are larger than the clearance, they get trapped between surfaces, leading to cutting of microchips. This type of wear has been described by researchers V.V. Antipov, G.A. Tashkin, M.M. Tashpulatov.

2) Hydroabrasive wear – occurs due to the washing away of metal particles from surfaces under the hydraulic impact of fuel. This process is accelerated by abrasive particles that create surface grooving followed by flushing with fuel. This type of wear was studied by D.F. Gurevich.

3) Corrosive wear – caused by the presence of water in fuel.

4) Oxidative wear – occurs under boundary lubrication or dry friction conditions, involving the formation of an oxide film on surfaces that breaks down due to the fuel stream, exposing underlying metal layers and repeating the process [5].

5) Seizure – wear that occurs in the absence of a fuel film between parts. Molecular forces of adhesion occur at contact points, leading to destruction of the surface layer. This type of wear was investigated by B.P. Zagorodsky, V.M. Ivanov, and N.I. Bakhtiyarov.

6) Cavitation erosion – caused by the formation of vapor-gas bubbles in the fuel flow, which upon collapse create hydraulic shocks that damage the surface of the part. M.M. Ivanchenko noted that cavitation damage in the form of pits and metal tearing is often observed on precision parts of fuel systems.

According to authors [21], the percentage distribution of wear types in precision parts of fuel systems is as follows:

- abrasive wear, cutting, and scraping damage – 84%;
- wear with seizures and adhesion – 8%;
- wear with cavitation cavities and erosion – 6%;
- edge destruction, corrosion, and other types of wear – 2%.

Precision parts wear predominantly uniformly; however, certain areas experience more significant wear. These localized areas are known as local wear [20]. The plunger undergoes significant wear in the upper part, located opposite the sleeve's intake port. The wear appears as a groove-like channel extending from the upper end downward. The plunger's surface becomes cut with longitudinal scratches and acquires a matte finish.

According to research by D.F. Gurevich, plunger pairs wear under the action of abrasive particles that move with the fuel. V.V. Antipov explains that when the plunger covers the sleeve's intake port, abrasive particles enter the gap and, moving further, cut the metal from the surface of the plunger and sleeve. The helical edge of the plunger wears less, forming grooves along the plunger.

The sleeve primarily wears in the areas adjacent to the intake and overflow ports. Wear in the intake port area appears as a rectangular groove-like strip along the sleeve, while in the overflow port area, it appears as a figured strip.

Currently, there are three standards in Ukraine concerning biodiesel fuel:

- DSTU 4840:2007 Diesel fuel of enhanced quality. Technical conditions;
- Law of Ukraine No. 1391-XIV of January 14, 2000 "On alternative fuels";
- DSTU 6081:2009 Motor fuel. Methyl esters of fatty acids from oils and fats for diesel engines.

Technical requirements.

According to DSTU 6081:2009 Motor fuel. Methyl esters of fatty acids from oils and fats for diesel engines. Technical requirements, biodiesel fuel is a complex methyl ester of fatty acids (FAME) that has the characteristics of diesel fuel and is produced from vegetable or animal oils used as fuel. Mixed diesel fuel is obtained by mixing diesel and biodiesel fuels or diesel fuel and vegetable oils. The issue of using biodiesel fuel has been studied by scientists such as S.M. Devyanin, V.A. Markov, S.A. Nagornov, L.S. Orsik, G.S. Savelyev, V.G. Semenov, V.F. Fedorenko, O.M. Zazulia, and others. Their works present the results of their own research, as well as data obtained by leading global automotive and tractor manufacturing companies such as Volkswagen, Ford, Fiat, Mercedes-Benz, Porsche, Fendt, Case, John Deere, Same, Steyr, as well as foreign authors including Clark N., Gerpen J., Grigg C., Knothe G., Krahl J., Lampel H., Schumacher L., and Simon K.

Based on the reasons discussed above, the wear of plunger pairs can be divided into two factors: wear that depends on the properties of the precision parts materials and the environment in which these parts are located. Within this scientific work, we do not consider the material properties of the plunger pairs and consider the first wear factor to be constant and defined by the manufacturer of the precision parts. However, the second

factor – the wear factor that we can influence – is the use of alternative fuel, which differs from traditional fuel in terms of density and viscosity at the very least [22].

Recently, there has been significant scientific interest in the use of biodiesel fuel as an alternative fuel [23], which consists of methyl esters of fatty acids of vegetable or animal origin. Compared to diesel fuel, biodiesel fuel has higher density and viscosity, and thus, it can be assumed that its lubricating properties will also be better. Therefore, within the framework of this issue, the use of biodiesel fuel in high-pressure fuel pumps as the environment in which precision parts operate is of considerable scientific interest.

Thus, it is reasonable to propose a scientific hypothesis about improving the wear resistance of plunger pairs by using methyl esters of fatty acids as an alternative fuel for classic diesel engine designs. We believe that increasing wear resistance will be achieved by enhancing the lubricating properties of the alternative diesel fuel.

5. Conclusions

1. The reliability of fuel equipment and its components during operation remains extremely low. The key parameter of the technical condition of diesel engine fuel equipment, which affects its reliability, is primarily the condition of precision parts such as plunger pairs.
2. The main factors affecting the wear of plunger pairs have been considered, among which the main ones are: fuel contamination with mechanical impurities, increased water content in the fuel, and elastic deformations during the installation of plunger pairs in high-pressure pumps.
3. The main types of wear that plunger pairs experience during operation have been considered.
4. The use of biodiesel fuel as an alternative for changing the environment in which precision parts operate has been proposed.
5. A hypothesis has been formulated, according to which the use of biodiesel fuel will lead to improved lubricating properties of plunger pairs and, as a result, to increased wear resistance, which is a relevant scientific and technical task.

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ПРИЧИНИ ЗНОШУВАННЯ ПЛУНЖЕРНИХ ПАР ТА ПІДВИЩЕННЯ ЇХ ДОВГОВІЧНОСТІ ЗА РАХУНОК ВИКОРИСТАННЯ БІОПАЛИВА

Збільшення ресурсу вузлів і агрегатів різної техніки завжди було пріоритетним завданням, яке дозволяє не тільки подовжити термін експлуатації техніки, але й уникнути витрат, пов'язаних з її ремонтом і простоєм. Актуальність цієї роботи полягає в тому, що значна частина техніки, що використовується для виробництва сільськогосподарської продукції, оснащена дизельними двигунами. Паливна система цих двигунів є найскладнішим, найдорожчим та найвідповідальнішим агрегатом. Від надійності її роботи залежать потужність, економічні та екологічні показники техніки, що використовує дизельні двигуни. Аналіз поломок тракторних двигунів виявив, що 30-50% усіх відмов припадає на паливну апаратуру. Це пов'язано з низькою надійністю паливної апаратури дизельних двигунів в умовах експлуатації. Тому, заводи-виробники прецизійних деталей ставлять перед собою збільшення ресурсу цих деталей.

Розглянуті фактори, що впливають на зносостійкість плунжерних пар, зокрема забруднення палива механічними частинками, збільшення вмісту води в паливі та вплив пружних деформацій при монтажі нових плунжерних пар в насосі високого тиску. Виділено основні два фактори, що впливають на зношення плунжерних пар, на зміну першого із нього не можна впливати завдяки експлуатаційним заходам, а зміна іншого може бути викликана використанням альтернативного палива, що є на сьогодні, сформульовано наукову гіпотезу в розрізі даної тематики. В даній науковій праці представлені результати виконання ініціативної науково-дослідної роботи 0122U002187.

Ключові слова: *дизель, паливна аппаратура, плунжерні пари, надійність, ресурс, біодизельне паливо.*
Рис. 2. Літ. 23.

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