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Influence of filter elements on the operation of tribomechanical systems

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Annotation

Oil filter is a part of a gasoline or diesel engine lubrication system designed to clean the engine oil.
Depending on where it is installed, the oil filtration system, they are divided into three types:
- through-flow filter, which passes through all the oil that the pump feeds into the engine. A pressure regulating by-pass valve is installed upstream of the filter to protect the gaskets with oil seals. If the filter element is too dirty, the valve directs oil flow past the filter, preventing oil starvation of the bearings. Keeps engine from failing due to lack of lubrication;
- a partial-flow filter is mounted parallel to the main oil line and cleans only a portion of the oil that enters the engine. Gradually the whole volume of oil passes through the filter element, giving a fairly high cleaning efficiency. However, this method does not provide absolute protection of parts from chips and other abrasives;
- the combination filter combines a full-flow and a partial-flow cleaning principle. It consists of two filter elements, one mounted parallel to the oil line and the other cut into it. This ensures maximum cleaning efficiency and long filter life. The filter elements are divided into two types according to their efficiency in removing fine impurities: coarse filters, which remove coarse impurities, and fine filters, which remove fine impurities. According to the design of the housing and the possibility of replacing the filter element, filters are divided into multiple (collapsible) and disposable (non-collapsible). Modern engines may use filters in the form of a cartridge, which is inserted into a special compartment.

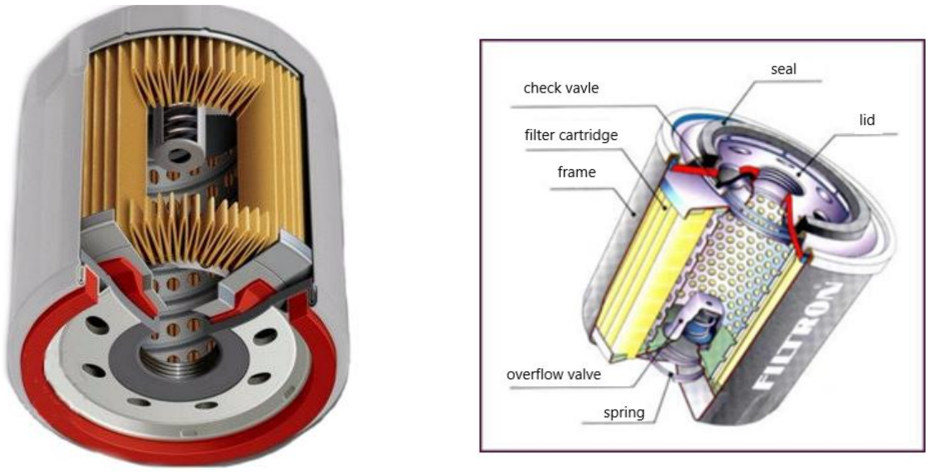
During operation, the oil is first routed to the filter and then through the oil channels to the interacting parts in the engine. This principle is used on all standard passenger cars. A settling filter (gravity filter) is a tank with a filter element and a settling tank in which impurities are deposited by gravity. The centrifugal filter operates similarly to the gravity filter, only dirt settles in it under the action of centrifugal force resulting from the rotation of the body.

Key words: filter, oil, thickness of lubricating layer, friction coefficient.

Introduction

The popular design of the oil filter includes a metal housing in which a corrugated porous paper filter element is installed and a spring-loaded bypass (overflow) valve.

A backflow (overflow) valve is installed at the inlet of the housing to prevent oil leakage after the engine is stopped. This allows oil to be stored in the oil passages and ensures nominal pressure immediately after the engine is started. The tightness of the housing connection to the oil channel is ensured by a rubber gasket. The oil, which is supplied by the oil pump, passes through a paper filter and is sent to the engine channel. If the filter is dirty or the oil is very viscous and does not flow well through the filter element, excess pressure opens the bypass valve which directly starts the oil in the engine.



Design of the oil filter

Analysis of recent research and publications

The influence of the degree of oil contamination by mechanical impurities on tribotechnical properties of lubricating materials is investigated by many scientists: Wenzel E.S. [1], Garkunov D.N., Dmitrichenko M.F., Mnatsakanov R.G., Mikosyanchik O.O., Bilyakovich O.M., Zhuravel D.P. [2, 3], and others. The paper [4] raises the question and analyzes the experimental data on the possibility of using synthetic porous-fiber polypropylene as a filtering material instead of the existing ones. The quality of oil filtration determines the service life of the engine. In [5] the possibility of using crystalline urea for the process of purification of waste mineral engine oils from acidic aging products was considered. Preference should be given to well-known manufacturers: Bosch; Mahle; Mann; Fram. You should also pay attention to the filters that are recommended by the car manufacturer. Visually determine the degree of contamination of the oil filter is impossible. Therefore, it is necessary to follow the manufacturer's recommendations for its replacement. Replace the filter when changing the engine oil. Depending on the oil brand and peculiarities of the car design, replacement is performed after 8-15 thousand kilometers of mileage. What happens, if the oil filter is removed. If the filter element of the lubrication system is removed, abrasive particles, especially metal filings, will get on the sliding bearing shells. This will accelerate the wear of the metal, which in turn will also enter the lubrication system. As a result, an avalanche-like process will begin, which will end with an overhaul or replacement of the engine. If the filter is not changed in time, it will get clogged and the crude oil will start circulating through the bypass valve. This will also lead to engine failure [6].

Statement of the problem

To establish the effect of contamination of engine oil during operation it is necessary to analyze the formation of the thickness of the lubricating film in tribosystems.

Basic research and presentation of scientific results

Laboratory methods of identifying wear particles. Solid particles of suspension in the filtration process can not only be trapped on the surface of the filter partition, but also penetrate into its pores. Penetration of solid particles into the pores of the partition is undesirable because it leads to a sharp increase in its resistance, which is more difficult to reduce by subsequent washing than by placing solid particles on the surface of the partition. Therefore, when separating such suspensions, it is advisable to prevent the penetration of solids into the pores of the bulkhead and retain them on its surface.

Spectral analysis of oil samples taken from the engine lubrication system by monitoring the concentration of metals and other impurities in the oil in grams per ton is widely used in engine operation. In most cases, iron and copper concentrations are monitored. Oil samples are taken 15 ... 40 minutes after the engine is stopped while the wear particles are in suspension. Frequency of sampling is set depending on the predicted intensity of wear and maintenance intensity, as a rule, at least after 200 hours of operation. If the content of wear products in the oil increases, sampling is performed more frequently.

Normal curve of the law of metal content change is shown in Fig. 1.

The 1st area - running-in period of the engine components. The graph first shows growth and then decrease of metal content at the end of running-in period up to the value characterizing normal metal content. There is an individual value of metal concentration for each engine within permissible limits, depending on the engine operation modes (the time of operation in different modes).

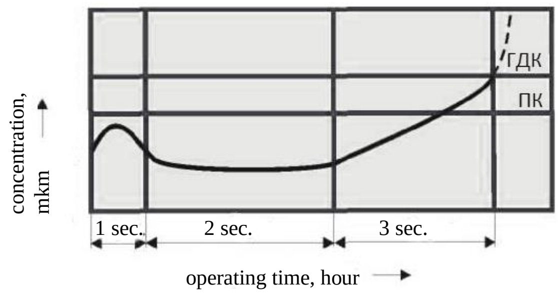


Fig.1. The normal law of change in the content of metals in the oil in the course of engine operation. PC - increased concentration, at achievement of which the engine is allowed to operate under "special control". MPC - maximum permissible concentration, reaching which the engine is to be withdrawn from operation

The 2nd area - a period of normal wear. There may be a slow growth of metal concentration as the engine runtime increases.

The 3rd area - the period of intensive wear. This period precedes the destruction of the engine unit (or is associated with partial destruction). Intensity of concentration increase is higher, than on site 2.

The normal law of change of metal content in oil is realized only if the engine is in the process of wiping surfaces with the release into the oil of wear particles not more than 15 ... 30 μm. It is a size that most modern instruments are capable of accounting for.

One of the most common and dangerous types of wear is pitting. It is fatigue pitting of contact surfaces [7]. The beginning of the pitting process is the plastic deformation of the surface and the formation of fatigue microcracks on the friction surfaces. Up to the appearance of the first cavern of fatigue pitting the only kind of wear particles formed in oil are spherical particles of 3... 5 microns, the weight contribution of which to the total mass of particles formed during normal wear is a few percent, coinciding with the error of the spectrometer measurements.

Further wear releases large particles, which are not taken into account in the spectral analysis until significant damage occurs with the release of a large number of both large and small particles. Changes of metal content in oil during fatigue damage of parts are shown in Fig. 2.

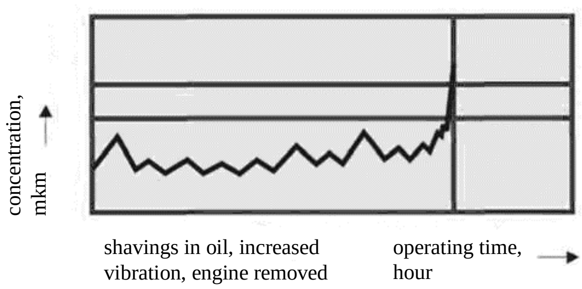


Fig. 2. Change of metal content in oil during fatigue damage of rubbing surfaces

There are technologies of spectral analysis, in which all particles in the sample are taken into account. This is achieved by dissolving wear products in an acid solution and then analyzing them on a special spectrometer.

The pherographic analysis is used to detect fatigue damage processes. As a rule, part of an oil sample is used for spectral analysis. The ferogram is examined under a microscope where the shape, size and number of particles are determined.

Laboratory examination of oils using a mesh filter element

The formation of an oil film between two parts which are in contact and move relative to each other depends on the speed of reciprocal movement. In such cases, we speak of a hydrodynamic friction regime, when the oil film is drawn into the gap between the interacting parts, separating the parts. The film is drawn into the gap more effectively (the film becomes thicker) with increasing velocity. But an increase in velocity results in an increase in the amount of heat generated by friction. The temperature of the oil rises and it becomes more fluid. This leads to a reduction in film thickness as a result of oil rarefaction. The friction coefficient depends on the roughness and accuracy of the geometry of the contacting surfaces and the presence of foreign particles in the oil (surface irregularities, foreign particles, disrupt the integrity of the film, which leads to the appearance of zones operating in semi-dry friction mode). The friction force value is proportional to the load, and it is at a constant friction coefficient. Sometimes the integrity of the oil film can be broken, and the coefficient of friction begins to grow. Then, even if the load is constant, the torque increases and conditions are created for the sliding bearings to rotate. The increased load reduces the thickness of the oil film, increasing the risk of its destruction [8]. In this case, more heat is released and leads to an increase in local temperatures in the friction zone. Oil liquefaction occurs, which leads to a further decrease in the thickness of the oil film and increases the probability of occurrence of sticking in the friction zone.

These factors have a particularly strong effect during the initial period of machine operation, during the running-in period of the parts. During this period of operation, micro-irregularities are triggered, destroying the oil film. At this moment the rubbing pairs are the most sensitive to overloading.

When performing this experimental study, the aim was to establish the mechanism of formation of the lubricating layer thickness in the contact, to determine the dynamics of wear of tribocoupling elements depending on the material of the contact surfaces, antifriction and rheological characteristics of the engine oil. At research was used the used (operating time 15 thousand km in the gasoline engine) motor synthetic oil Mobil-1 0w-40 in two states:

1) directly drained from the internal combustion engine;
2) filtered with Champion C102 filter.

The studies were carried out on the SMTs-2 unit, in the start-up (4.5 sec) - stop mode (3 sec). Number of cycles in the experiment was N = 1750, which corresponds to 4 hours of continuous operation of the installation, following one another, without interruption. In the friction pair was reproduced rolling mode at a relative slip of 18 %. As samples were used cylindrical rollers (d = 50 mm) made of Steel 40KH (HRC = 43) and Steel SHKH15 (HRC = 58). The maximum Hertz contact load was 570 MPa, and the volumetric temperature of the oil during the experiment was 70 °C.

The specified Mobil-1 0w-40 oil provides reliable protection for a wide range of both gasoline and diesel engine models, including turbocharged engines, intercooled charge air systems, as well as advanced direct-injection diesel (DI type) engines operating in any severity conditions.

Regularities of formation of the lubricating film thickness at start-up, depending on the use of different steel grades and used and filtered oils are shown in Fig. 3.

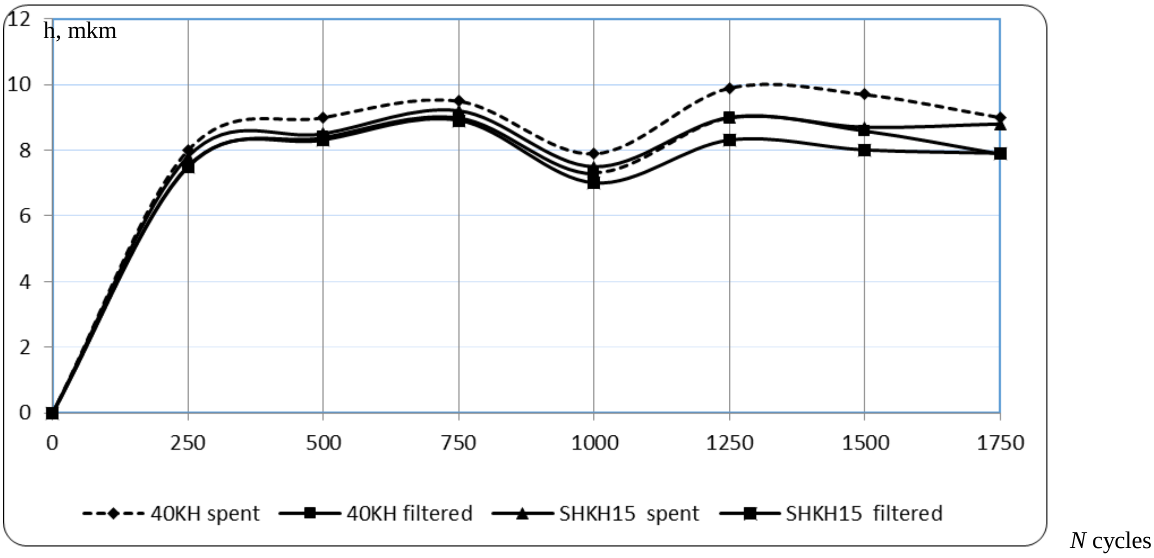


Fig. 3. Formation of the lubricating film thickness in contact with used samples of Mobil-1 0w-40 engine oil depending on the hardness of the surface material

Regardless of the hardness of the contact surfaces, it was found that during N < 100 cycles, according to the calculated parameter λ, the boundary regime of lubrication dominates, during 100 < N <150 cycles the elastohydrodynamic regime in the contact, the subsequent operating time up to N = 1750 cycles is characterized by the realization of the hydrodynamic regime in the contact. Only during the initial break-in period, which corresponds to N < 200 cycles, a high carrying capacity of the lubricating layer formed on the contact surfaces of steel 40KH is observed; during operating time 200 < N <1750 cycles a general trend is observed for the growth of the lubricating layer thickness during break-in - for the two studied steel grades this parameter averages 8.2 - 10 µm.

Since the experiments were conducted under nonstationary operating conditions, there is a high probability of the lubricating layer breaking off at stopping, which leads to direct contact between the surfaces. Under these lubrication conditions, the formation of boundary adsorption films on the elements of the tribocoupling is of great importance.

To establish patterns in the kinetics of formation of adsorption boundary films, we measured the thickness of the lubricating film at the stop (Fig. 4).

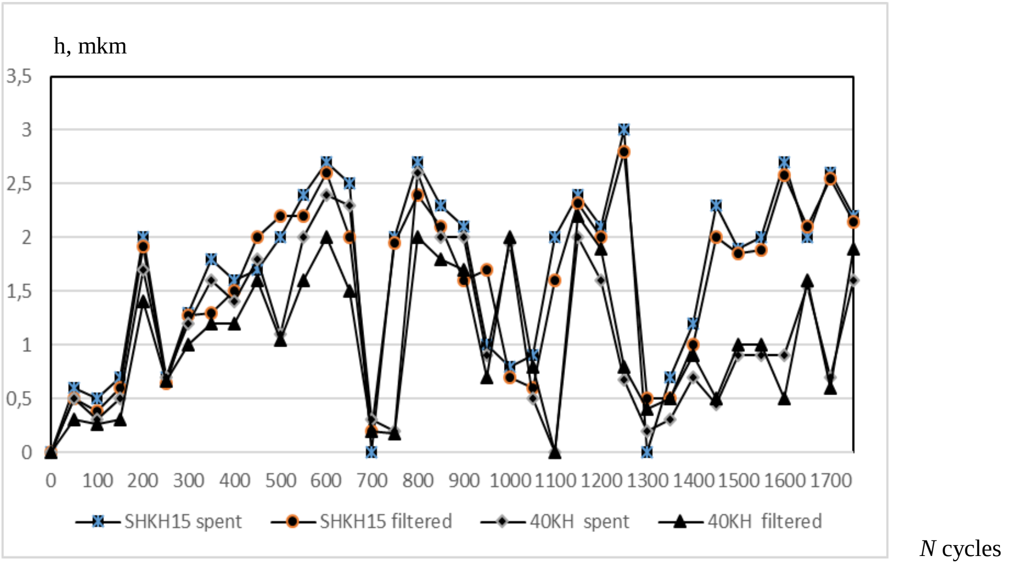


Fig. 4. Kinetics of changes in the thickness of the boundary adsorption films

For the Steels 40X and the SHKH15 after the running-in phase, which corresponds to $N < 450$ cycles, it was found that there is no sagging of the lubricating film thickness. With further operating time up to $N = 1750$ cycles, the breakdown of the lubricating film for these steel grades was only 3 %. We assume that this is associated with the ability of chromium to reach the contact surface [1], which increases the adsorption force of the interaction of the surface films of the metal in the polar-active components of the lubricant, manifested in an increase in the thickness of the non-hydrodynamic component of the lubricating film to the end of operating time, which is 1.7 μm and 2.5 μm for the Steel 40X and the SHKH15 , respectively. At the same time, a clear pattern in the formation of the boundary adsorption films is observed depending on the condition of the oils, namely: in the filtered oil sample a lower value of the studied index by 6 % compared to the used oil is observed. This can be explained by the presence of less content of mechanical impurities and fuel combustion products.

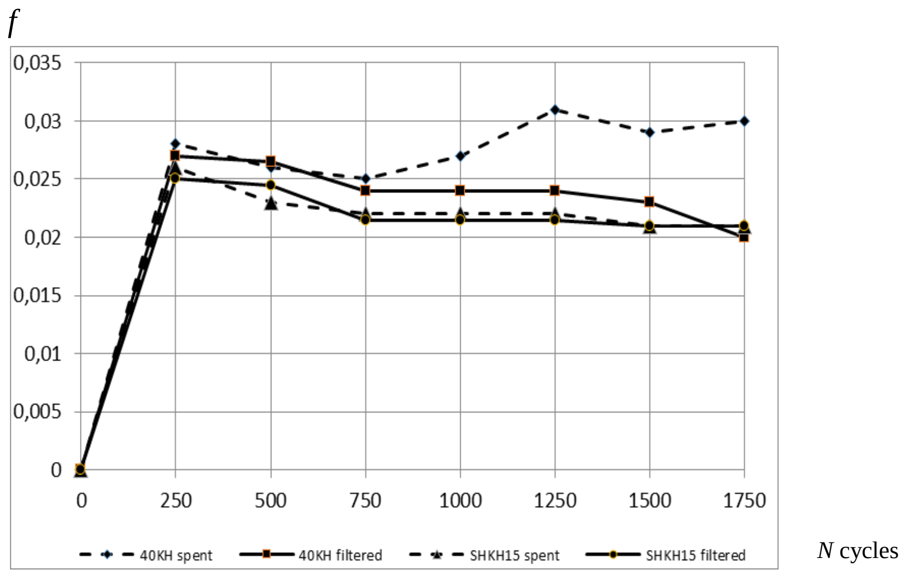


Fig. 5. Change of friction coefficient (*f*) with operating time depending on used steel grades and type of oils

When studying the friction coefficient (Fig. 5) for rollers made of the Steel 40KH in the initial period of running-in up to N < 200 cycles value of this parameter is less - 0,028, and for filtered oil 0,026 that is explained by the greatest value of a hydrodynamic component of greasing film thickness at the start-up, further at 250 < N < 950 cycles value of friction factor is established almost the same for the Steel SHKH15 and varies within 0,028-0,026; At N > 1000 the highest value of the studied parameter when using the Steel 40KH for the used oil - 0,031 - 0,029, which is associated with a smaller thickness of the non-hydrodynamic component of the lubricating film. Also the decrease of antifriction properties at the final stage of workover is determined for the samples of the Steel 40KH with use of filtered oil. This decrease is caused by the highest values of the oil film displacement stress in the contact due to the increase of the oil effective viscosity, namely, for the Steel 40X: η_{ef} = 10,19 – 10^2 Pa · s, for the SHKH15 the ratio is respectively (1 : 0,745) (fig. 5). At the same time, for the filtered oil, the improvement of antifriction properties with both steels under study is found, explained by the highest values of the non-hydrodynamic component of the lubricating layer thickness.

So, the kinetics of friction coefficient change in the contact is influenced by the rheological properties of the lubricant. In our opinion, the mechanism of this process is as follows. At initial formation of boundary adsorption films there is structure of lubricant components on the friction-activated contact surface, which leads to increase of shear stresses of oil film and correlation growth of friction coefficient. As the boundary films adapt to dynamic load conditions, the displacement stresses of adapted adsorption films decrease, which also causes increase of antifriction properties. So, at N > 1000 cycles of operating time boundary films with thickness of 2,5 microns, stable to mechanical and thermal destruction, which are characterized by the most effective antifriction properties, in comparison with another type of lubricant, are formed on the surfaces from the Steel SHKH15 using filtered oil.

References

1. Wenzel E.S. Improvement of the operational properties of oils and fuels: monograph / E.S. Wenzel. - Kharkiv, KhNADU, 2010 - 224 p.
2. Zhuravel D.P. Modeling the processes of changing the quantitative and qualitative indicators of motor oils during their use. Labor TDATU. Issue 2, v. 14. Melitopol, 2000, pp. 37-40.
3. Crane D.P. Investigation of the lubricating ability of oils in the interface of automotive engines. Sectoral mechanical engineering. Proceedings of TGATA. Issue 2, vol. 1. Melitopol, 1997 S. 46-48.
4. Butskiy A.V. Application of synthetic materials as filtering materials in oil filters of diesel locomotive engines. Collection of scientific works UkrDUZT, 2017., Issue. 174.S. 42-50.
5. Korchak B.A. Regeneration of used mineral motor oils. Qualifying scientific work based on the foundations of the manuscript. Dissertation for the degree of candidate of technical sciences in specialty 05.17.07 Technical technology of fuel and fuels and lubricants. National University "Lviv Polytechnic", Ministry of Education and Science of Ukraine, Lviv, 2018r.
6. What is an Oil Filter and how does it work? The principle of work and what is it for. [Electronic resource]. Access mode: https://auto.ria.com/uk/terms/maslyanyj-filtr/.
7. Zamaletdinov, II On the latest methods of studying the processes of pitting corrosion / II Zamaletdinov, EA Kolobova. - Text: direct // Technique. Technologies. Engineering. - 2017. - No. 1 (3). - S. 36-45. - Link mode: https://moluch.ru/th/8/archive/46/1655/.
8. Zakalov, A.V. Tribotechnics and increasing the reliability of machines [Text]: A.V. Zakalov. - Ternopil: TSTU, 2000 .-- 354 p.

Дмитриченко М.Ф., Савчук А.М., Туриця Ю.О., Міланенко О.А. Вплив фільтруючих елементів на роботу трибомеханічних систем.

Масляний фільтр – це деталь системи мащення бензинового або дизельного двигуна, призначена для очищення моторної оливи.

В залежності від місця монтажу, системи фільтрації оливи вони діляться на три типи:

- повнопоточний фільтр, що пропускає крізь себе всю оливу, яку насос подає в двигун. Для захисту прокладок з сальниками перед фільтром встановлюється перепускний клапан, що регулює тиск. При надмірному забрудненні фільтруючого елемента клапан направляє потік оливи повз фільтра, запобігаючи масляне голодування підшипників. Це не дає двигуну вийти з ладу через відсутність мащення.

- частковопоточний фільтр монтується паралельно головному оливопроводу і очищає лише частину оливи, що надходить у двигун. Поступово весь обсяг оливи проходить через фільтруючий елемент, що дає досить високу ефективність очищення. Однак такий спосіб не забезпечує абсолютного захисту деталей від стружки та інших абразивів.

- комбінований фільтр поєднує повнопоточний і частковопоточний принцип очищення. Він включає два фільтрувальних елементи, перший з яких встановлюється паралельно масляній магістралі, а другий врізається в неї. Це забезпечує максимальну ефективність очищення і довгий термін служби фільтрів. По ефективності видалення дрібних домішок фільтруючі елементи діляться на два види: фільтри грубого очищення, призначені для видалення великих включень; фільтри тонкого очищення, що видаляють мілкофракційні включення. По конструкції корпусу і можливості заміни фільтруючого елемента фільтри діляться на багаторазові (розбірні) і одноразові (нерозбірні). У сучасних двигунах можуть застосовуватися фільтри у вигляді картриджа, який вставляється в спеціальний відсік.

Під час роботи олива спочатку подається до фільтра, а потім по масляним каналам до взаємодіючих деталей в двигуні. Цей принцип застосовується на всіх серійних легкових автомобілях. Фільтр-відстійник (гравітаційний) представляє собою ємність з фільтруючим елементом і відстійником, в якому домішки осідають під дією гравітації. Відцентровий фільтр, що працює аналогічно гравітаційному, тільки бруд осідає в ньому під дією відцентрової сили, що виникає в результаті обертання корпусу. Процес утворення масляної плівки між двома контактуючими й рухомими відносно одна одної деталями залежить від швидкості взаємного переміщення.

При виконанні даного експериментального дослідження метою являлося встановлення механізму формування товщини мастильного шару в контакті, визначення динаміки зношування елементів трибоспряження залежно від матеріалу контактних поверхонь, антифрикційних та реологічних характеристик моторної оливи.

Ключові слова: фільтр, олива, товщина мастильного шару, коефіцієнт тертя.