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Influence of Polytron^{TMC} Composition on the Tribological State of the System of materials “40Ch - Transmission Oil - HCh15” when Simulating Friction Modes and Lubrication Conditions

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Abstract. In this work, definitive tribological tests were carried out on the material system “40Ch - gear oil - HCh15” to assess the nature of the action of the additional composition POLYTRON^{MTC} for its adaptability to high-speed, power loading conditions and the ability to form reliable lubricating formations in conditions of insufficient lubrication. Physical modeling of the manifestation of friction in the upper boundary of boundary lubrication with a friction coefficient of $0.12 \leq \mu_g \leq 0.2$, as well as semi-dry and dry friction was performed. It was established that high contact pressures in the range from 4.2 MPa to 8.6 MPa at the beginning of running-in created features of resistance to the flow of oil components into the zones of the contour areas of friction interaction, which determined to a greater extent mechanical metal connections when sliding with a sufficiently high coefficient of friction $\mu c = 0.3$-0.7. In this case, the conditional point contact at sliding speeds determined the number of oil molecules that were directed to the diffuser contact zone, i.e. behind the ball along the friction path on the surface of the rotating disk. A fundamental difference in the manifestation of POLYTRON^{MTC} was revealed when it is added to Opet Fullgear FRM 75W-80, CastrolSyntraxUniversal 80W-90 oils, which have a synthetic base, and Castrol ATF MultiVehicle 75W-80 oil, which has a mineral base. Graphic patterns of changes in friction and wear characteristics have been constructed for the model conjugation “moving disk-fixed ball”.

Keywords: transmission oil, dynamic coefficient of friction, temperature, pressure, test time, ball, disk, lubricant formations

Introduction

Oils used in machine units and mechanisms are often subjected to heavy loads, especially during cyclic start-stop operation, which leads to high temperatures and pressures. This leads to unacceptable damage to the working surfaces and, accordingly, to catastrophic failures. The reduction in thermomechanical stress in the contact interaction zones of the surfaces of parts that operate when changing lubrication modes is determined by a number of factors. One of them is the recommended use of additive compositions (AC) in transmission oils for the lubrication of industrial engineering parts, for example, gear transmissions of automobiles and tractors. The list of such ACs is quite wide, and each of the proposed compositions differs in the content and direction of manifestation of the implemented mechanisms for reducing friction and wear [1-4]. Nanoparticles have become a new type of composition due to their size, shape and other properties. A significant number of researchers have noted that the addition of nanoparticles, such as MoS_2 and SiO_2 nanoadditives to lubricant compositions, effectively reduces wear and friction [3, 5, 6].

Recommendations from DC manufacturers do not fully take into account the possible features of the manifestation of their tribological action when changing loading and lubrication modes in standard mechanisms of mechanical engineering objects, for example, in the same gears. Indicators of lubricity and tribological characteristics of oils are determined using standard methods [9]. At the same time, the contact geometry and simulated conditions do not always correspond to the operational geometry of the contact of real friction pairs. Based on the establishment of patterns of changes in the characteristics of the tribological state of known systems of structural metals that operate in extreme loading and lubrication modes from the used DCs, it seems to be a relevant scientific and technical task considered in tribology. In this case, the emphasis should be on determining the ability of DC to significantly improve the antifriction and antiwear properties of lubricants, which can be obtained using conventional manufacturing technology.

Process fluid POLYTRON^{MTC} is one of the representatives of DC [7]. MTC (Metal Treatment Concentrate) is a petroleum-based metal treatment concentrate, which is recommended to be added to transmission oils for lubrication systems of units and mechanisms [8]. As a result of micrometallurgical processes occurring at the peaks of irregularities, the thinnest layers of the base metal are transformed into a new type of metal, which is much harder and has significantly greater wear resistance. This secondary layer protects the main softer metal from wear [7]. With this mechanism, a certain role will be played by base oil molecules, which, depending on their origin, have different structures and polarities. Based on the above, contact pressure and the structure of the base oil seem to be the main factors in the manifestation of the active action of Polytron^{MTC}. An advertising demonstration of the lubrication capabilities of the above-mentioned

POLYTRON^{MTC} DC comes down to setting up an experiment on a friction pair “rotating disk - stationary cylindrical roller”, which contact through the tested lubricant compositions when the disk is partially immersed in them [10]. In this case, the rotational resistance is determined using a dial ammeter, and loading is carried out with a torque wrench-loader, which does not make it possible to obtain a more detailed and objective picture of the manifestation of the lubrication effect behind the classical friction coefficient when changing the rotation speed. This is especially important to know and understand when it comes to high contact loads when changing lubrication modes. This approach is used by a number of researchers, for example in [11], the mechanism of tribofilm formation and destruction was carefully monitored by monitoring the friction coefficient throughout the test. Tribological tests carried out with limited amounts of lubricant showed a direct relationship between the amount of lubricant and the time it takes for the tribofilm to break down, with tests with less amount of lubricant showing shorter life. In [12], the authors evaluate the severe operating conditions of sliding surfaces in some modes in which self-organization processes on friction surfaces are ineffective. This negatively affects the continuity and resistance of the resulting lubricating formations to destruction, and it is under such conditions that the lubrication effects need to be improved. In work [13], the authors carried out definitive tribological tests of the material systems “CuCrNiZrTi- 85W90 – 40Ch”, “CuCrNiZrTi- 85W90 - KCh50” to assess the nature of the manifestation of the action of DC ABRO GT-409 and POLYTRON^{MTC} in them on adaptability to loading and lubrication modes, the manifestation of parameters of adhesive properties when modeling shear on small-sized samples. It has been established that a more significant influence on the reduction in the parameters of adhesive properties is exerted by the POLYTRON^{MTS} components, which cause the formation of secondary lubricating formations with denser structures at the adhesion boundary with metal surfaces and reduced resistance to movement within the formed cohesive bonds between them. The claimed uniqueness of enhancing the lubricating effect of ordinary lubricants and the formation of secondary wear-resistant structures on metal surfaces [7, 8, 10] when using POLYTRON^{MTS} predetermines the need for further more applied tribological tests. This will make it possible to supplement recommendations for its use based on the characteristics of operating modes and operating conditions of specific friction pairs of mechanisms and machine units.

The purpose of the work is to determine the effect of the POLYTRON^{MTC} composition when added to transmission oils of various viscosity classes and bases on the pattern of changes in the characteristics of the tribological state of the interface “rotating disk - transmission oil - stationary ball” during physical modeling of high-speed, force loading on lubricant formations that form on friction surfaces under various lubrication conditions.

1. Research methodology

The physical modeling of the tribological state is based on the preliminary formation of lubricating formations on the metal surfaces of small-sized samples from transmission oils of different viscosity classes with the addition of the POLYTRON^{MTS} composition with abundant lubrication of the contact zone, followed by their stepwise loading to the boundary conditions of lubrication in the absence of additional oil supply to the friction zone. This mode is considered as a type of lubricant film starvation, when the concentrated volume of lubricant is not enough to replenish layers of lubricant formations that are destroyed by friction. This approach simulates contact interaction modes when parts move relative to each other at the beginning of power flow transmission, when there is no full-fledged process of supplying lubricant to friction zones. This is especially significant when there are large contact normal pressures with a tangential component, which certainly destroy lubricant formations and the material of the working surfaces of parts. The addition of the POLYTRON^{MTC} composition in accordance with the manufacturer’s recommendations was 10% of the volume of oils for manual transmissions and 5% for automatic transmissions [7], and was aimed at the formation of lubricating formations with significantly improved anti-wear and anti-friction characteristics. To determine the nature of the influence of the POLYTRON^{MTC} composition on the tribological state of model tribocouplings, depending on the basis and viscosity of the interaction medium in a certain mode of contact interaction of friction surfaces, transmission oils were selected and used, the performance characteristics of which are given in Table 1.

Table 1. Characteristics of transmission oils

Oil name	Brief characteristics of the oil	Density ρ at 15 ^{0}C	Kinematic viscosity γ at 40 ^{0}C, mm^2/s	Kinematic viscosity γ at 100 ^{0}C, mm^2/s	Viscosity index
Castrol ATFMultiVehicle 75W-80	synthetic, for highly loaded manual transmissions of vehicles	0,87	40	7,5	159
OpetFullgear FRM 75W-80	synthetic, for manual transmissions and highly loaded vehicle gearboxes	0,857	58,2	9,8	153
CastrolSyntrax Universal 80W-90	mineral, for automatic transmissions, power steering of vehicles	0,893	168	17,0	108

Tribotechnical tests were carried out on a SMC-2 machine according to the “rotating disk - stationary ball” friction scheme in a cycle consisting of two stages, Figure 1 a. Stage No. 1 - test with abundant lubrication. Stage No. 2 – testing on pre-created lubricating formations without additional oil supply. After the first stage, the oil drained from the surface of the disk, and its excess amount was removed by soaking with felt paper. At each stage, the friction moment and temperature were recorded, and the wear rate was calculated based on the result of the integral wear of the ball at two stages. The disk rotation frequency was 300 min-1 and 1000 min-1. The normal load on the moving contact changed stepwise and was 13N, 22N, 45N, 67N, 90N, 115N, 140N, 160N, 180N. The holding time at the indicated normal loads was 2 minutes. With a sharp increase in movement resistance, as indicated by the friction machine recorder, the experiment stopped. The rotating disk was installed on the lower shaft of the friction machine, had dimensions of diameter d=50 mm, width b=12 mm and was made of steel 40X with a hardness of 42-46 HRC, Figure 1 f. A ball with a diameter of d=9.3 mm was made of steel HCh 15 , with a hardness of 55-60 HRC, was fixed by gluing a disk into the blind holes, which was fixedly mounted on the upper shaft of the friction machine, Figure 1 b-d, f. The choice of materials for small-sized samples and hardness is due to the similarity with materials that are used for the manufacture of gears, for example, for mechanisms and transmission units of cars and tractors.

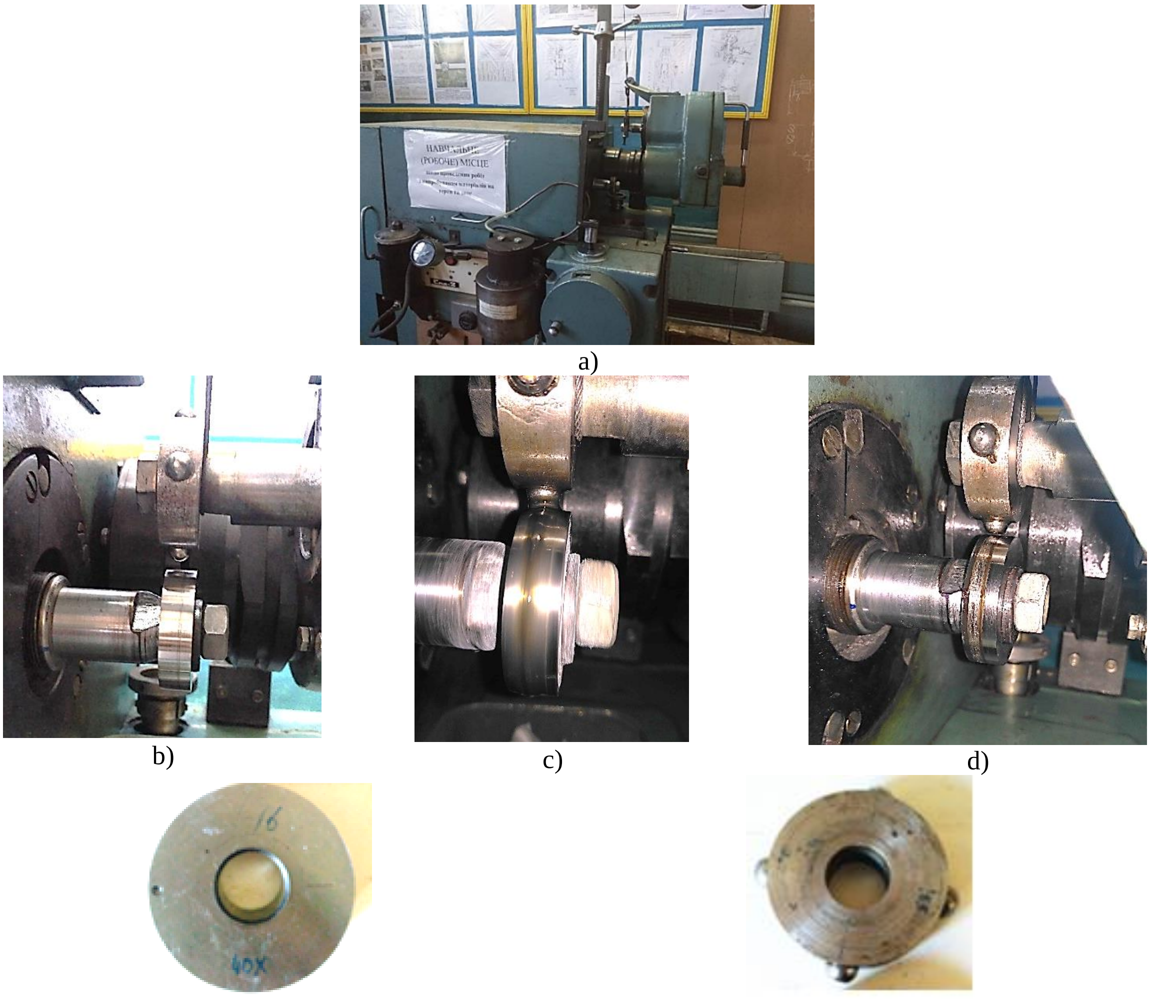


Fig. 1. Methodological support for experimental tests:
(a) – general view of the SMC-2 friction machine with additional equipment;
(b) – contact of sample surfaces without oil; (c) – contact of sample surfaces when lubricated with oil; (d) – contact of sample surfaces when the surface of a rotating disk is damaged; (e) – rotating disk;
(f) - a stationary disk with balls.

To assess the tribological state, the following characteristics were used:

- dynamic friction coefficient μ (hereinafter referred to as friction coefficient), as a criterion for changing the antifriction properties of lubricating formations and their ability to operate at maximum contact pressure conditions;

- the intensity of wear of the ball surface, as an indirect criterion of the ability of lubricating formations to resist their own destruction and counteract mechanical wear of the ball surface;

- volumetric temperature of the zone of interaction of the ball with the surface of the disk, as a criterion for assessing the general temperature state of the friction pair.

The friction coefficient was determined by the friction moment from tribograms in accordance with the load in contact and the geometric size of the roller according to expression (1), the calculation accuracy was: $\Delta\mu = 0.003$.

$$\mu = \frac{M_t}{N * r}. \qquad (1)$$

where M_t - friction moment, N m, 1 grid division of the tribogram field was 0.18 0.001 N m;

r - disk radius, m;

N – normal load, N.

The number of experiments for each of the gear oils shown in Table 1 was n=3. To evaluate the proposed characteristics using the graphic-analytical method, arithmetic mean values of the physical quantities under study were used. The wear rate of the ball surface was determined by the geometric parameters of ball wear along the friction path in accordance with expression (2). In this case, the wear rate is considered as a reduced reduction in the diameter of the ball to the plane of its wear.

$$I_S = \frac{S_1 - S_2}{2\pi r \cdot t \cdot n}. \qquad (2)$$

where S_1 - value of the area before the experiment, mm^2;

S_2 - area values after the experiment, mm^2;

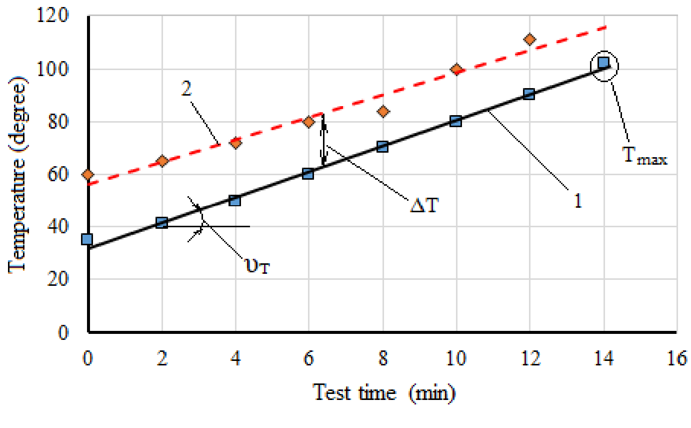
t – hour of the experiment, min;

r – disk diameter, m;

n – rotation frequency of the friction machine shaft, min^{-1}.

To determine the degree of ball wear when testing oils, prints of the ball wear area on a horizontal surface were used. In this case, the areas of the prints before and after the experiments were taken into account. To carry out this operation, the method of pressing the ball through tracing paper onto the surface of graph paper was used. Based on the results of determining the areas of indentations under corresponding normal loads, normal contact pressures were calculated. At the same time, under loads of 11N-45N, the standard deviation of the contact pressure was σ_p=1.2 MPa, that is, 8% of the average design pressures. At loads of 67N-180N, the standard deviation of the contact pressure was σ_p=3.9 MPa, i.e. 11% of calculated average pressures. Within the specified deviations, the wear area of the ball changed with each stepwise increase in the normal load. Thus, it was possible to estimate the contact pressure in the friction zone. The temperature state of the contact was determined in a non-contact manner using a Wintact WT319B infrared pyrometer with a measurement temperature of up to 600 °C and was assessed by the average values of the following indicators, Figure 2:

- rate of temperature increase υ_T, ^{0}C min^{-1};
- temperature at the end of the heavy lubrication experiment T_{max}, ^{0}C;
- relative temperature difference according to lubrication conditions ΔT, ^{0}C.



1 - tests with abundant lubrication; 2 - tests on formed lubricating formations without additional oil supply

Fig. 2. - Indicators for assessing the temperature state of the contact

Since the patterns of changes in the temperature state obeyed linear patterns, their graphical form was not given, and only the indicated indicators were considered.

2. Results and discussion

As a result of processing the obtained tribograms using Microsoft Excel Worksheet and Paint applications, graphical patterns of changes in the dynamic coefficient of friction (Figures 3-5) and the wear rate of ball samples depending on the viscosity of the transmission oil (Figure 6) were constructed using arithmetic average values.

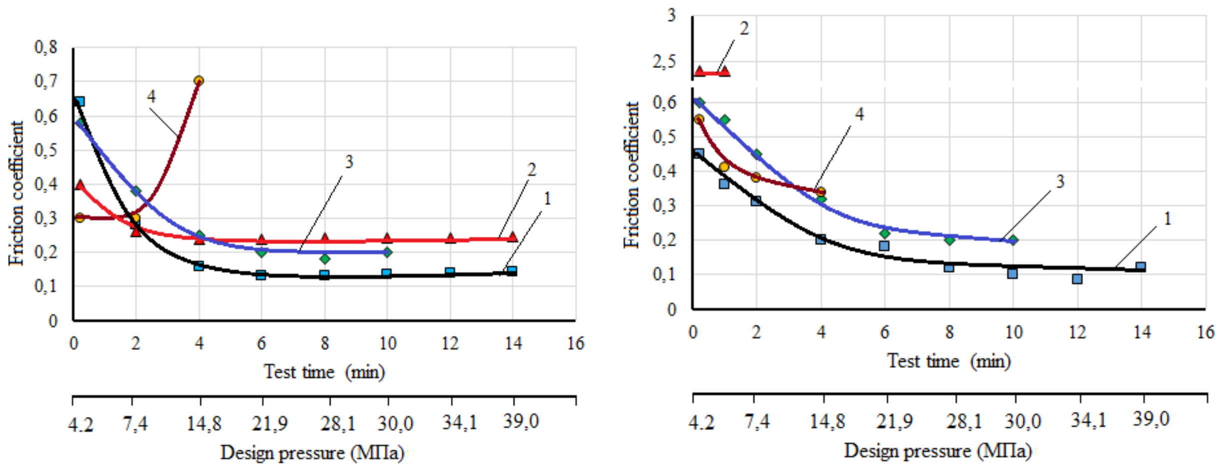
In general, based on the simulated lubrication conditions and test conditions for load and sliding speed, the following was determined. Firstly, there is a manifestation of boundary friction according to lubrication conditions in the upper limit limit (0.01-0.08) ≤ μ_g ≤ (0.1-0.15) and semi-dry friction. High contact pressures from 4.2 MPa to 8.6 MPa created conditions of resistance to the flow of oil components into the contour areas of friction interaction, which largely determined the mechanical metal connections during sliding with a fairly high coefficient of friction of 0.3-0.7. In this case, the conditional point contact at sliding speed determined the number of oil molecules that were directed to the diffuser contact zone, that is, behind the ball along the friction path.

Secondly, there was an achievement of a constant friction regime by stabilizing the friction coefficient in the range of 0.12-0.22, but no stabilization of the temperature state was observed. During the experiments, the temperature constantly increased at average rates from 1.5 ^{0}C min^{-1} to 5 ^{0}C min^{-1}, and ranged from 24 ^{0}C to 120 ^{0}C. This indicated the incompleteness of the processes of adaptability of the surface structures of the sample materials and the interaction environment to an energetically favorable direction.

Thirdly, it has been determined that in some cases, a simulated contact made from the materials under study is capable of operating on the created lubricating formations without additional oil supply, but with increased resistance to movement. At the same time, the Polytron^{MTC} DC can both positively and negatively influence friction stabilization in the presence of boundary lubrication components that are concentrated and retained in the microprofiles of the contact surfaces. This indicated that the use of Polytron^{MTC} DC is compatible with all transmission oils on a basic basis, as stated by the manufacturer. However, there are peculiarities in the manifestation of the properties of DC when it is added to mineral and synthetic oils, since Polytron^{MTC} DC (hereinafter referred to as DC) appears to be a completely petroleum-based mixture [7].

2.1 Tribological state of a model tribological coupling, which was tested with synthetic gear oil Opet FullgearFRM 75W-80

The patterns of change in the friction coefficient shown in Figure 3 indicate the following.



a) b)

1 – tests with heavy lubrication, n=300 min^{-1}; 2 – tests on formed lubricating formations without additional oil supply, n=300 min-1; 3 - tests with abundant lubrication, n=1000 min^{-1}; 4 - tests on formed lubricating formations without additional oil supply, n=1000 min^{-1}

Fig. 3. - The influence of load and rotation speed on the friction coefficient of a model tribocoupling when testing OpetFullgear FRM 75W-80 oil: a – tribological contact without DC; b - tribological contact with DC

When tested under conditions of abundant lubrication, persistent lubricating layers are formed on the friction surfaces between the surfaces, which are run-in for 6 minutes without DC, and for 8 minutes with DC, reaching a constant friction coefficient μ=0.12 at a rotation speed of n=300 min^{-1} and μ=0.2 at a rotation speed of 1000 min^{-1}. That is, there was no significant effect of DC on the change in the tribological state.

When tested without additional oil supply without DC, a constant friction process is observed from 4 min. tests at rotation speed n=300 min^{-1} with reaching a constant friction coefficient μ=0.22. However, at a frequency of n=1000 min^{-1}, from the second minute there was a rapid increase in the friction coefficient to μ=0.7, and the experiments were stopped. In this case, a constant friction process took place with a friction coefficient μ=0.3. Tests with DC at a frequency of n=300 min^{-1} did not result in a friction reduction effect; there was a fairly high but stable friction coefficient μ=2.5, which caused catastrophic wear of the ball sample, and the experiments stopped in the second minute. However, an increase in frequency to n=1000 min^{-1} caused a slight decrease in friction and the ability to operate a model tribocoupling with a decrease in the friction coefficient from 0.55 to 0.32. At the fourth minute the experiments stopped. This effect is explained by the creation of current conditions for the occurrence of hydraulic lift in the contact zone.

According to the indicators of the temperature state given in Table 2, no significant changes were observed, with the exception of an increase in the rate of temperature increase by 1.4 times at a frequency of n=300 min-1 with the addition of DC.

Table 2. Temperature indicators when testing Opet Fullgear FRM 75W-80 oil

Rotation speed n, min^{-1}	without DC			with DC		
	υ_T, ^0C $хв^{-1}$	T_{max}, ^0C	ΔT, ^0C	υ_T, $^0C \cdot хв^{-1}$	T_{max}, ^0C	ΔT, ^0C
300	1,4	50	6	2	55	15
1000	5	100	20	5	60	20

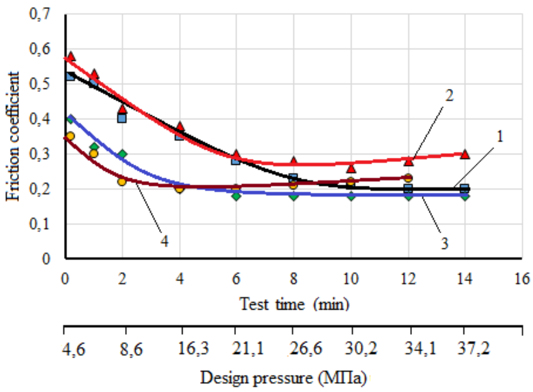
In terms of wear intensity, the values are given in Table 3, there are differences that are due to both the suspension of experiments with obvious jumps in resistance to movement on the recorder, and the manifestation of the addition of DC. Apparently, DC significantly reduces friction and wear at a frequency of n=1000 min^{-1}, but does not work at n=300 min^{-1}.

Table 3. Wear rate Is of the ball sample, 10^{-10} m

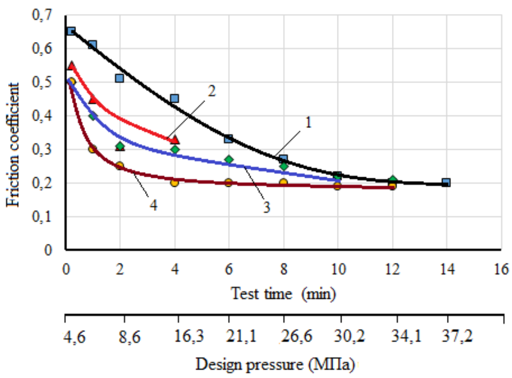
Rotation speed n, min^{-1}	without DC	with DC
300	0,4	25,3
1000	31,8	4,9

2.2 Tribological state of a model tribological coupling, which was tested with Castrol Syntrax Universal 80W-90 synthetic gear oil

The patterns of change in the friction coefficient shown in Figure 4 indicate the following.



a)



b)

1 – tests with abundant lubrication, n=300 min^{-1}; 2 – tests on formed lubricating formations without additional oil supply, n=300 min^{-1}; 3 - tests with abundant lubrication, n=1000 min^{-1}; 4 - tests on formed lubricating formations without additional oil supply, n=1000 min^{-1}

Fig. 4. - The influence of load and rotation speed on the friction coefficient of a model tribocoupling when testing CastrolSyntraxUniversal 80W-90 oil:a – tribological contact without DC; b - tribological contact with DC

When tested under heavily lubricated conditions, thinner lubricating layers are formed on the friction surfaces compared to Opet Fullgear FRM 75W-80 oil. Depending on the rotation speed and the presence of DC, the surfaces of the samples are not run in equally. In this case, the output of the tribocoupling to a constant friction coefficient, which had a value of $\mu \approx 0.2$ without DC at n=300 min^{-1}, is 10 minutes, with DC – 12 minutes. At the same time, at a rotation speed of n=1000 min^{-1} without DC, the running-in time was 4 minutes, and with DC, reaching a constant coefficient was not determined. This is explained by the viscosity-temperature properties of the tested oil, since its viscosity index is significantly lower than that of OpetFullgear FRM 75W-80 oil, Table 1 (108-153), although Castrol Syntrax Universal 80W-90 oil is higher in viscosity class. The mechanical properties of the lubricating formations that are formed in this case are not sufficient to resist the convergence of surfaces to provide boundary lubrication with a low coefficient of friction. The addition of DC delays the running-in of surfaces at low rotation speeds, and causes dispersion of oil molecules at the peaks of microprofiles at high rotation speeds , causing lubricant-depleted contact between metal surfaces. And as a consequence of what has been described, there is a greater coefficient of friction. Thus, for 4 minutes of testing tribocoupling with a DC at a rotation speed of n=1000 min^{-1}, the friction coefficient had a value of 0.3, and without a DC – 0.2, respectively.

When tested without additional oil supply without adding DC, the stable process of boundary friction was short-lived and was observed within 2 minutes. At a disk rotation frequency n=300 min^{-1}, a constant friction coefficient μ=0.27 occurred from the 6th minute of testing. At a disk rotation frequency n=1000 min^{-1}, a constant friction coefficient μ=0.2 was observed from 3 minutes of tribocoupling tests. Subsequently, the movement resistance gradually increased, and the rate of increase in the friction coefficient was 0.005 min^{-1}. The addition of DC ensured, starting from the 4th minute of the experiments, a steady process of contact interaction with a friction coefficient of μ=0.2. That is, DC created the conditions for the formation of more reliable lubricating formations capable of withstanding an increase in contact pressure in the friction zone.

According to the indicators of the temperature state given in Table 4, no significant changes were observed, with the exception of an increase in the rate of temperature growth by 1.4 times at the rotation speed of the disk sample n = 300 min^{-1} with the addition of DC. This condition was also observed for Opet Fullgear FRM 75W-80 oil.

Table 4. Temperature indicators when testing Castrol Syntrax Universal 80W-90 oil

Rotation speed n, min^{-1}	without DC			with DC		
	υ_T, ^0C хв$^{-1}$	T_{max}, ^0C	ΔT, ^0C	υ_T, ^0C хв$^{-1}$	T_{max}, ^0C	ΔT, ^0C
300	1,2	52	3	1,7	60	15
1000	5	100	25	5	80	20

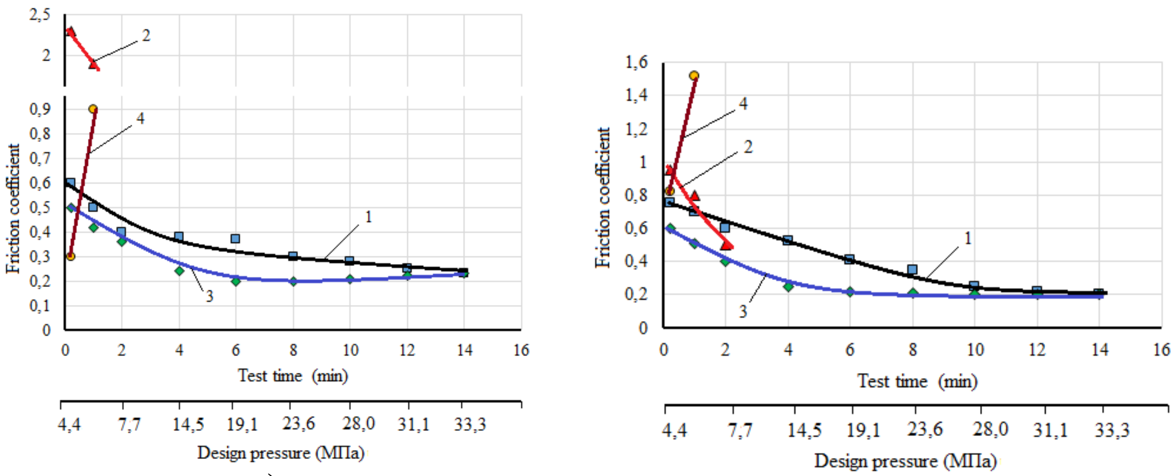
According to the wear rate of the ball sample, the value of which is given in Table 5, the addition of DC causes an increase in wear rate by 2.1 times and 3.6 times at the corresponding test frequencies. Since this test time characteristic is integral, greater wear, based on the graphical dependencies (Figure 4b), appeared in the period from the beginning of the experiments to 8 minutes of testing.

Table 5. Wear rate Is of the ball sample, 10^{-10} m

Rotation speed n, min^{-1}	without DC	with DC
300	3,7	7,8
1000	3,0	10,7

2.3 Tribological state of a model tribological coupling, which was tested with synthetic gear oil CastrolATFDexronIIMultiVehicle 75W-80

The patterns of change in the friction coefficient shown in Figure 5 indicate the following.



a) b)

1 – tests with abundant lubrication, n=300 min^{-1}; 2 – tests on formed lubricating formations without additional oil supply, n=300 min^{-1}; 3 - tests with abundant lubrication, n=1000 min^{-1}; 4 - tests on formed lubricating formations without additional oil supply, n=1000 min^{-1}

Fig. 5. - The influence of load and rotation speed on the coefficient of friction of a model tribocoupling when testing Castrol ATF Dexron II Multi Vehicle 75W-80 oil:
a – tribological contact without DC; b - tribological contact with PolytronMTC DC

When tested under conditions of abundant lubrication without the addition of DC, a constant mode of boundary friction was observed briefly for 2 minutes (line 3, Figure 5a) at a rotation speed of n=1000 min^{-1}, the friction coefficient was $\mu\approx$0.2. At a rotation speed of n=300 min^{-1}, the running-in of the surfaces did not end until the end of the experiments (line 1, Figure 4 a). It is obvious in this case that the speed of contact interaction hindered the speed of reliable structuring of thin lubricant formations. At the same time, the high rate of entry of oil components into the friction zone provided lower values of the friction coefficient, which at a rotation speed of n=1000 min^{-1} was 1.5 times less than at a frequency of n=300 min^{-1}. The addition of a DC with the same features of contact interaction as without a DC led to the achievement of steady-state friction only at the 10th minute of the experiments at a rotation speed of n=300 min^{-1} and at the 6th minute at n=300 min^{-1} (lines 1 and 3 of the figure 5 b). That is, the manifestation of the time factor of the manifestation of the properties and action of the DC to form the corresponding lubricating formations is obvious. But again, it is noted that the steady state of boundary friction occurred with an increase in contact pressure with a friction coefficient of μ = 0.2.

When tested without additional oil supply without adding DC, the formed lubricating formations of the lubricant layers were not able to reduce friction, as evidenced by sharp jumps in the resistance to movement behind the recorder of the friction machine and the experiments stopped. The addition of DC caused a decrease in the initial friction coefficient by 2.5 times at a rotation speed of n=300 min^{-1}, but its large value μ=0.8-1.0 caused significant wear of the ball samples and destruction of the disk surface (Figure 1 d), and the experiments stopped. The created lubricating formations with the addition of DC did not work even at a rotation speed of n=1000 min^{-1}. At the same time, the coefficient of friction at the beginning of the tests was higher for 2.6 cuts compared to layers that were formed without adding DC, and its growth rates were almost the same. According to the temperature indicators given in Table 6, there was an increase in the temperature growth rate by 1.3 times at a disk rotation speed of n=300 min^{-1} with the addition of DC. And at a frequency of n=1000 min^{-1}, on the contrary, there was a decrease in the rate of temperature increase by 1.4 times, which correlated with a decrease in the friction coefficient. High maximum temperatures at a frequency of n=1000 min^{-1} also confirmed the destructive processes of friction surfaces and the inability of the remote control to influence this at high sliding speeds.

Table 6. Temperature indicators when testing Castrol ATF Dexron II Multi Vehicle 75W-80 oil

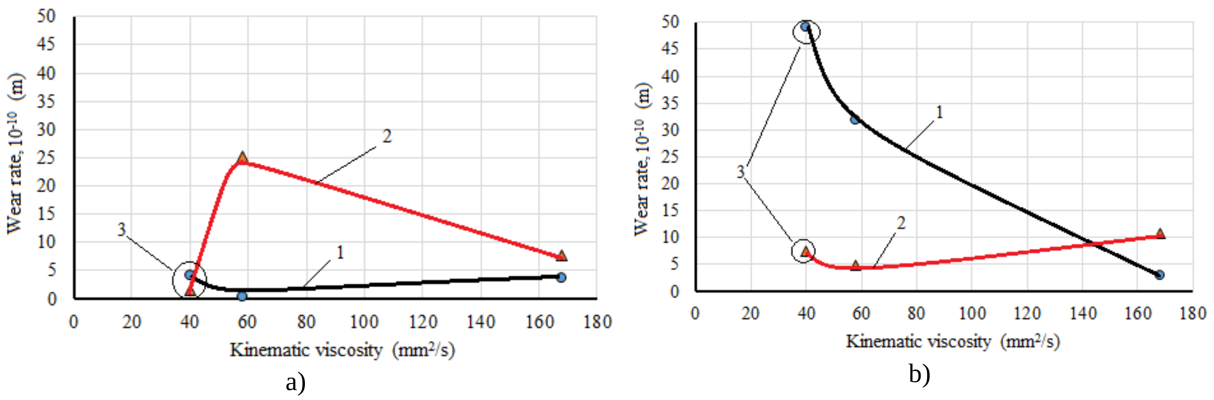
Rotation speed n, min^{-1}	Without DC			With DC		
	υ_T, ^{0}C.хв$^{-1}$	T_{max}, ^{0}C	ΔT, ^{0}C	υ_T, ^{0}C.хв$^{-1}$	T_{max}, ^{0}C	ΔT, ^{0}C
300	1,3	52	8	1,7	55	16
1000	5,5	120	32	3,8	90	20

According to the wear rate of the ball sample, the value of which is given in Table 7, the addition of DC causes a decrease in the wear rate at rotation speed n=300 min^{-1} by 2.6 times. This is explained by the intensification of the formation of lubricating formations with a shorter time to reach a stable friction mode, and, accordingly, their ability to resist destruction of the metal surfaces of the samples. At a frequency of n = 1000 min^{-1}, there is also a decrease in wear intensity, which is 6.5 times. However, such a decrease does not lead to normal mechanochemical wear, but causes pathological destruction of surfaces, Figure 2 d.

Table 7. Wear rate Is of the ball sample, 10^{-10} m

Rotation speed n, min^{-1}	without DC	with DC
300	4,2	1,61
1000	49,1	7,5

A generalization of the identified trends in the influence of the viscosity class of transmission oil (in accordance with Table 1, kinematic viscosity at 40 0C is taken as an argument), its basis, the addition of DC, the speed mode of contact interaction and lubrication conditions on the wear rate of the ball sample in the form of graphical patterns is shown in Figure 6.



1 – without DC; 2 – with DC; 3 – viscosity of mineral-based oil

Fig. 6. - The influence of the kinematic viscosity of the transmission oil on the change in the wear rate of the ball sample according to the test conditions and modes:
(a) – at disk rotation frequency n=300 min^{-1}; (b) - at disk rotation frequency n=1000 min^{-1}

The constructed graphical dependencies indicate the following. There is a fundamental difference in the manifestation of DC when it is added to oils on mineral and synthetic bases. Firstly, for mineral oil, regardless of the sliding speed, the formation of lubricating formations takes place, causing the intended reduction in wear rate at a rotation speed of n = 300 min^{-1} (item 3, Fig. 6a), and its significant reduction at a rotation speed of n = 1000 min^{-1} (item 3, fig. 6b).

Secondly, for synthetic oils at low sliding speeds and a range of kinematic viscosity, for example from 58 mm^2/s to 168 mm^2/s (Table 1), the addition of DC has a negative effect on wear. At the same time, it is possible to achieve equality of wear intensity with a further increase in viscosity, i.e. more than 168 mm^2/s. And since the graphical dependence is tied to a temperature of 40 ^0C, it is predicted that the viscosity can be increased by regulating the volumetric temperature of the tribological contact. The opposite picture develops at high sliding speeds. At a rotation speed of n=1000 min^{-1} (item 3, Fig. 6b), the addition of DC generally has a positive effect on the formation of wear-resistant lubricating formations from oil components on both mineral and synthetic bases, but in a reduced range of kinematic viscosity, that is from 40 mm^2/s to 58 mm^2/s. Starting from a viscosity of $\nu \approx 58$ mm^2/s, the strength and composition of lubricating formations change, and DC begins to have a weak negative effect on wear when added to synthetic oils. In the range of kinematic viscosity from 140 mm^2/s to 150 mm^2/s, the wear rate of the ball sample is conditionally equal both with and without the addition of DC. Those. wear occurs through the same mechanisms, which are based on the resistance to destruction of cohesive bonds of oil molecules with the active metal centers of the sample materials under the influence of tangential shear deformations. At the same time, a further increase in viscosity of more than 150 mm^2/s causes a change in the strength of the designated adhesive bonds: with DC they decrease due to the energetic imbalance of molecular-mechanical submicrosystems of lubricating formations due to the presence of unrelated hydrocarbons; without DC they increase due to the physical density of the base hydrocarbon compounds.

Conclusions

The results obtained in the work revealed the features of the manifestation of friction and wear of the material system “40X – (transmission olive + POLYTRON^{MTS}) - HCh15” when modeling the destruction of boundary oil formations in the range of contact loads from 4 MPa to 40 MPa at rotation speeds of 300 min-1 and 1000 min-1 1, which reproduces the operating conditions of gears when lubrication conditions are violated.

It has been established that, based on the totality of the obtained tribotechnical characteristics, improvement of the lubrication effect of the considered transmission oils under the influence of POLYTRON^{MTS} is possible under certain restrictions determined by the speed, load conditions and base oil base.

New information about the obtained patterns of changes in the coefficient of friction, wear intensity, and the temperature state of the studied tribological contact expands information about the possible consequences of using POLYTRONMTS. At the same time, it seems possible to compare the results of tribological tests with real load operating conditions of parts, for example gears, and consider questions about the recommended use of POLYTRON^{MTS}.

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