Tribotechnical test results at friction machine SMT-1M when treating oil lubricant with ultrasound

Arkady Simdyankin[1], Ivan Uspenskiy[2],Vassily Pashchenko, Andrey Starunskiy
FSBEI HE "Ryazan SATU Named after P.A. Kostychev"[1,2,3,4]
Road-transport Faculty, Vehicle Technical Maintenance Department
Kostychev st., 1
Ryazan, Russia
e-mail[1,2]: seun2006@mail.ru, yuival@rambler.ru, university@rgatu.ru

Abstract
The article presents the results of tribotechnical tests with friction pairs (brass-steel and cast iron-steel) as for their running and wear resistance when treating oil lubricant with ultrasound. We have found out 4.3 ... 12.3 % (synthetic oil) increase of pre-score resistance of jaws made of brass and cast iron, 12.5 ... 25.0 % (semi-synthetic oil) increase and 13.4 ... 15.3 % (synthetic oil) and 25.0 ... 28.1% (semi-synthetic oil) friction coefficient lowering respectively. We have determined peculiarities of the residual viscosity effect of oil lubricant when treating it with ultrasound and can't be detected by viscometer.

Key words: *friction, viscosity, lubricant, ultrasound*

JEL Classification: *Q55 Technological Innovation*

1. Introduction

The development of technologies to improve efficiency and service life of components and assemblies of machines and equipment is currently the most urgent task [1]. In this regard, one can consider treating liquid oil lubricant with ultrasound during the operation of various units and arrangements in order to reduce the friction coefficient, and thus increase their resource as a perspective method [3, 4]. Unfortunately, there is no unique theory of ultrasound waves influence mechanism on the surface of the lubricant and the friction units. To get the optimum ultrasound influence on the lubricant it is necessary to ground modes of operation and the source location.

The aim of the research was to test the effects of ultrasound on the lubricant to determine the behavior of different friction pairs including the cases with plastic non-ferrous metals.

2. Data and Methods

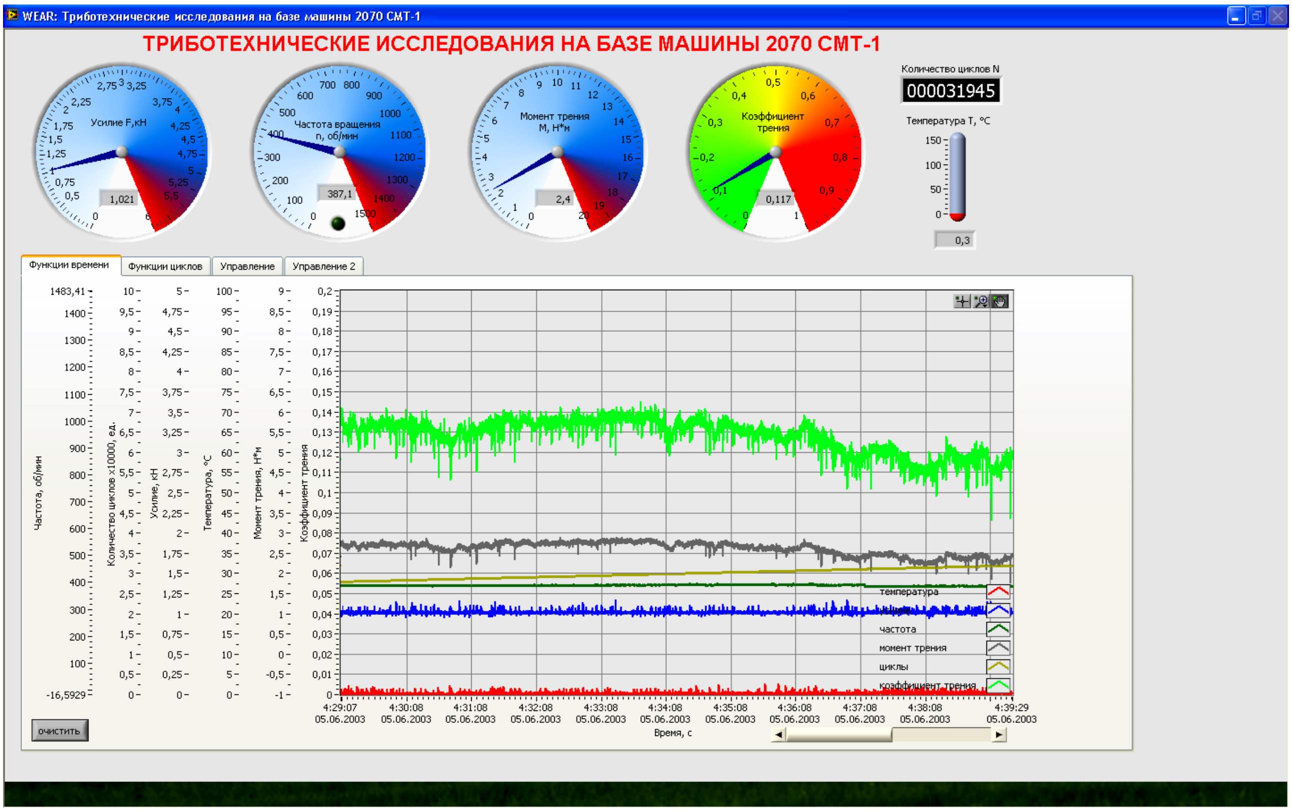
We have had the friction pairs tribotechnical tests of the type "roller-jaw" at the friction machine SMT-1M in accordance with the requirements of GOST 23.224-84 and RD 10.003-2009 for the following modes:

- the rate of rotation of the lower axle (roller) 3 ... 1500 min^{-1} with error measurement of 3 %;
- the pair friction torque up to 20 N · m with 1 % meter accuracy in static loading;
- load (force) on samples of up to 5 kN with 1 % meter accuracy in static loading;
- the temperature directly beside the nip samples up to 155 ° C with error measurement of 1,5 %.

The information from the meters of the axle rotation rate, the effort, torque and temperature goes through the multifunction data acquisition board to a computer in the form of graphs showing change of effort, torque and coefficient of friction, temperature, rotation rate dependence on time or number of cycles (the path traveled by the sample). The computer software lets you analyze the information in an «on-line» mode (Figure 1).

The essence of the rapid test method "A" group GOST 23.224-86 is to determine the ratio of the intensities of the investigated friction pairs wear at optimum load when minimal friction coefficients.

Figure 1: Operating window for tribotechnical investigations at machine SMT-1M



We have got standard samples as friction pairs for tribotechnical tests. We have had friction pairs of a movable (lower) sample (roller) made of alloy tool steel X12F1 GOST 5950-2000; a fixed (top) sample (jaw) made of gray cast iron SCh-20 GOST 1412-85 and brass LMcSKA 58-2-2-1-1 GOST 28873-90. We have pre-treated the samples so that the surface of their mutual fit when installed on the friction machine is not less than 90 % of nominal contact surface.

We have had samples tests with “roller“ constant linear speed providing the desired speed of a friction pair sliding at a fixed lubrication system at three stages: grinding, wearing-in and long break-in wear tests. The friction pairs got the effort prescribed by the test. We have used in the experiment oil lubricants of the following brands: FORMULA SAE 5W-30 (synthetic) and Mobil Super 2000 SAE 10W-40 (semi-synthetic). The lubrication mode has been boundary friction with a single lubrication in the crankcase of the test chamber.

According to experiment conditions we have treated oil with ultrasound having 17 kHz frequency during the tribotechnical tests of samples. Ultrasonic vibrations went through the actuating device (high-frequency transmitter model T25.4), located directly in the oil in the test chamber of the friction machine (Figure 2).

We have managed the frequency and power of ultrasonic vibrations changes manually via the control unit connected to the battery voltage of 12 V. We have carried out pre-grinding of friction pairs at a predetermined "roller" speed and a minimum load on the "jaw" lasting 40 minutes.

We have had the running-in ability test of friction pairs at a predetermined "roller" speed. This gradually increases the load on the "jaw" and determines the maximum pre-score load $P_{\text{мп}}$, when samples grasping happened. After that the unloading of the friction pairs and determining the optimum load $P_{\text{оп}}$, for the minimal friction coefficient f_{min} happened. The test results with running-in enable to construct *f(P)* function and determine f_{min} ($P_{\text{оп}}$) (Fig. 3).

Figure 2: General view of the test chamber with a control unit with ultrasonic vibrations (1 – test camera; 2 - high-frequency projector; 3 - control unit with ultrasonic vibrations)

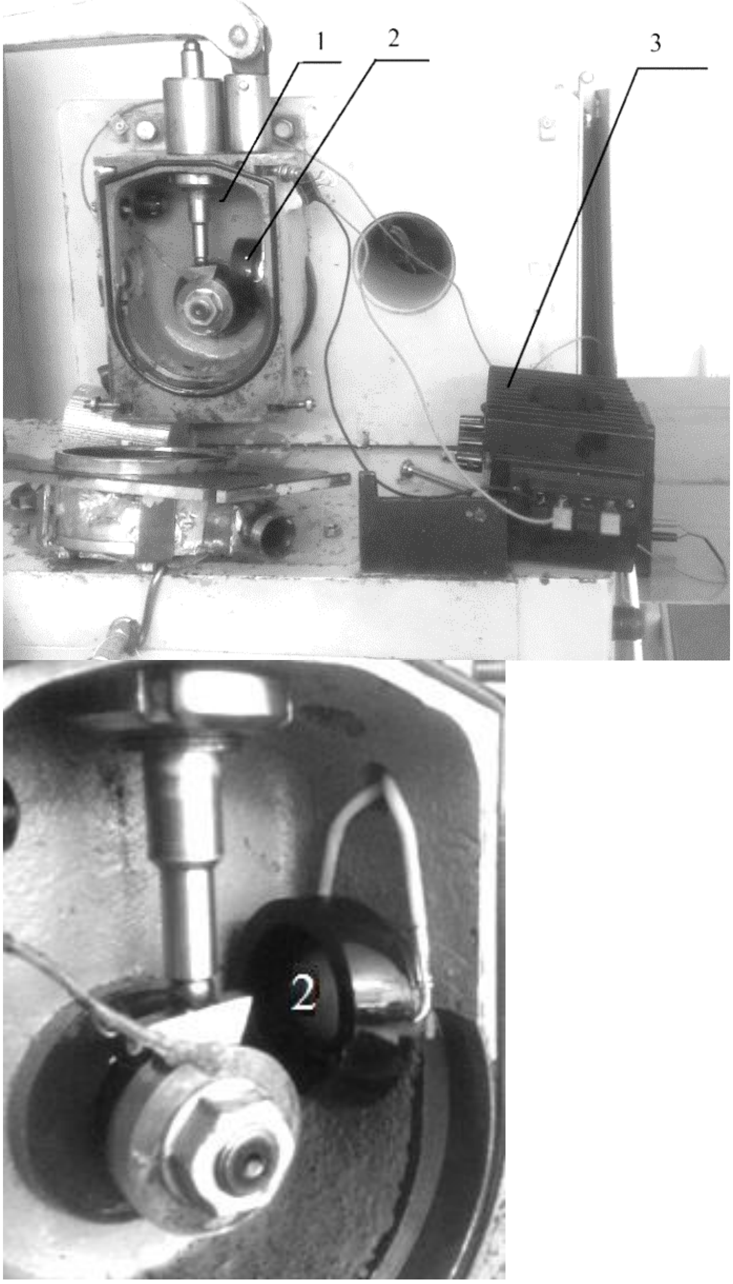
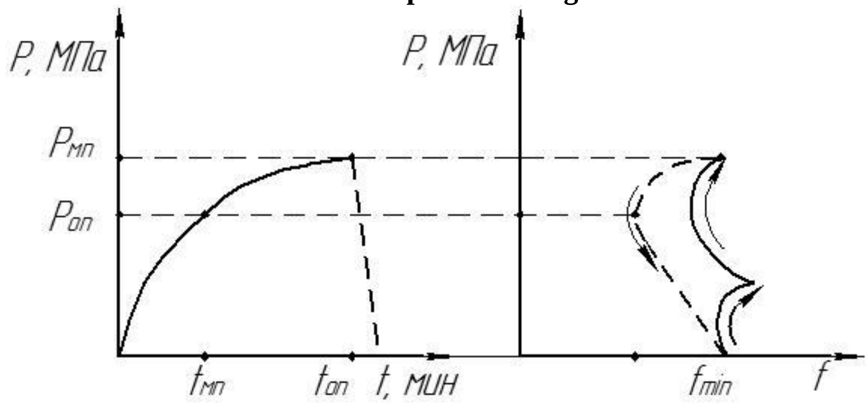


Figure 3: The evaluation function of friction pairs running-in



The results of the tribotechnical tests of running-in when oil treating with ultrasound of 17 kHz frequency as compared with samples tests without ultrasound are presented in the form of characteristic curves of friction moment and coefficient dependence on the force applied for brass LMcSKA (Figure 4) and iron (Figure 5).

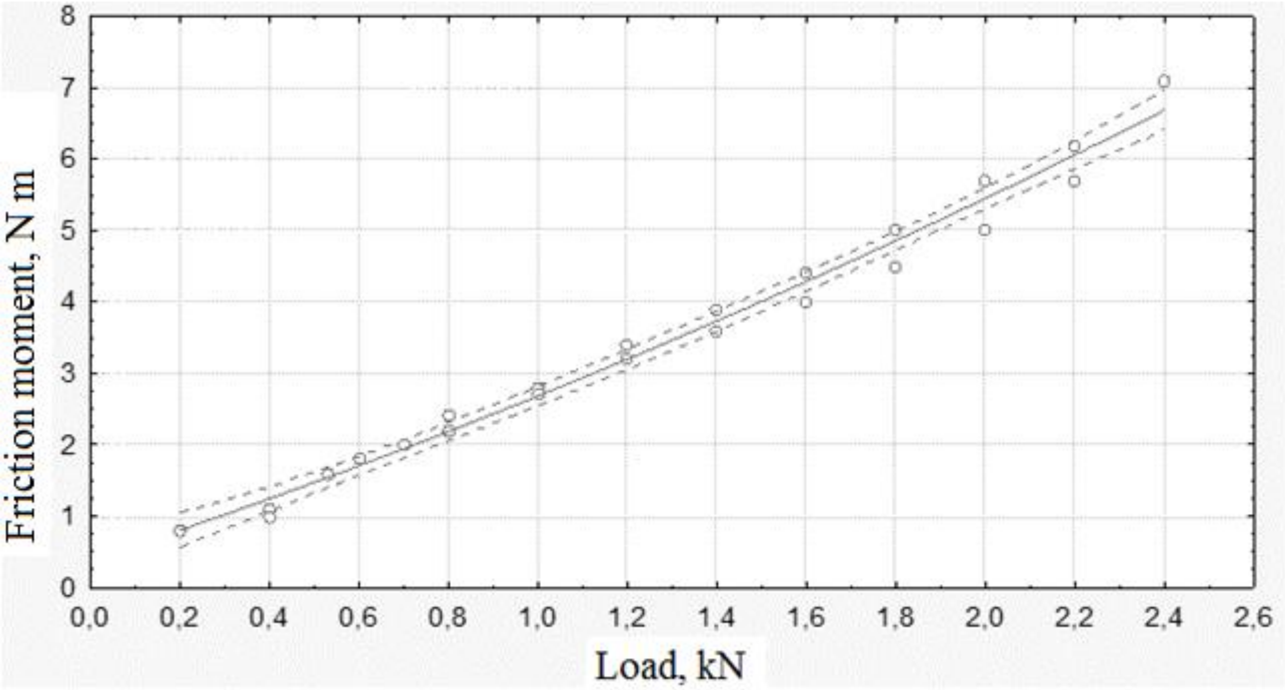
We have had long-term tests of friction pairs wear at a predetermined "roller" speed and optimal load P_{on}, obtained as a result of the running-in. The wear test lasted 8 hours at a roller speed n = 380 min^{-1}. After long wear tests movable and stationary samples are washed in an ultrasonic bath GB-5000B, dried and weighed on the analytical balance of the company "Sartorius" having precision measure to 0,00001g. We recorded the data about initial weight of the samples before and after the tests in the test report.

We have determined the intensity of moving and stationary friction pairs wear according to the following formula:

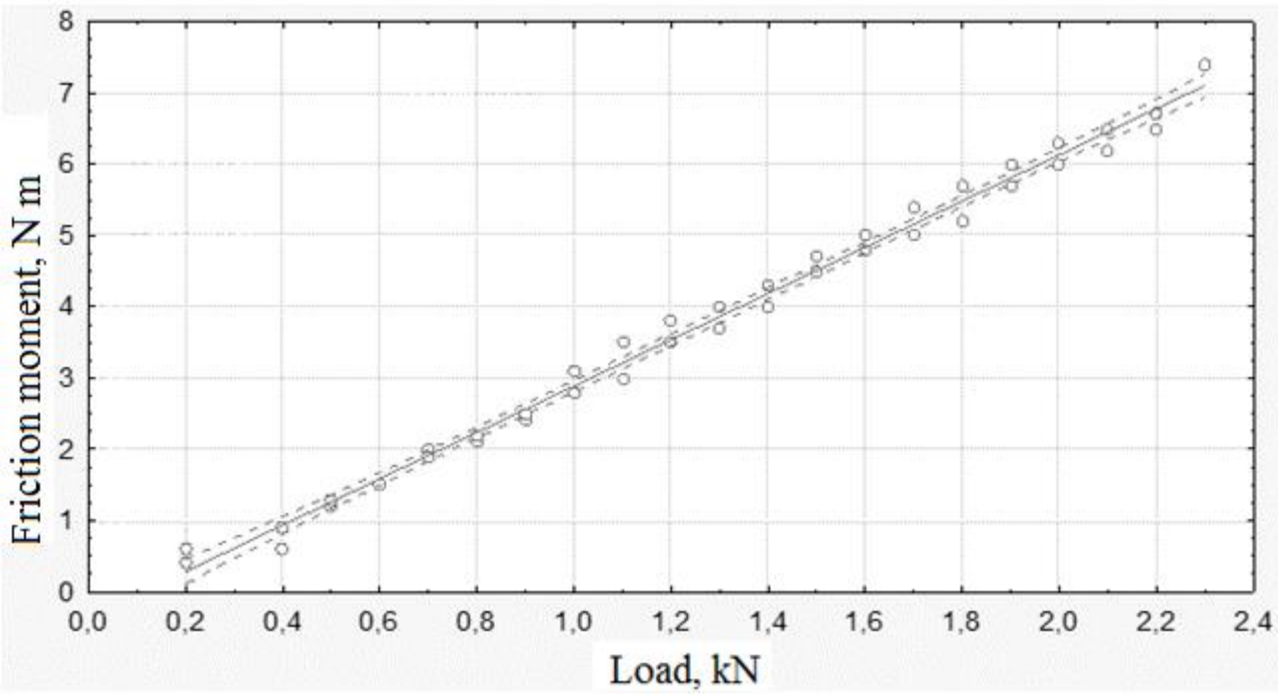
$$I = \frac{W}{N \cdot l}, \qquad (1)$$

where W - linear sample wear, m; l - linear dimension of the friction surface of the conjugate of the sample in the sliding direction, m; N - number of cycles when sample friction surface goes way *l*.

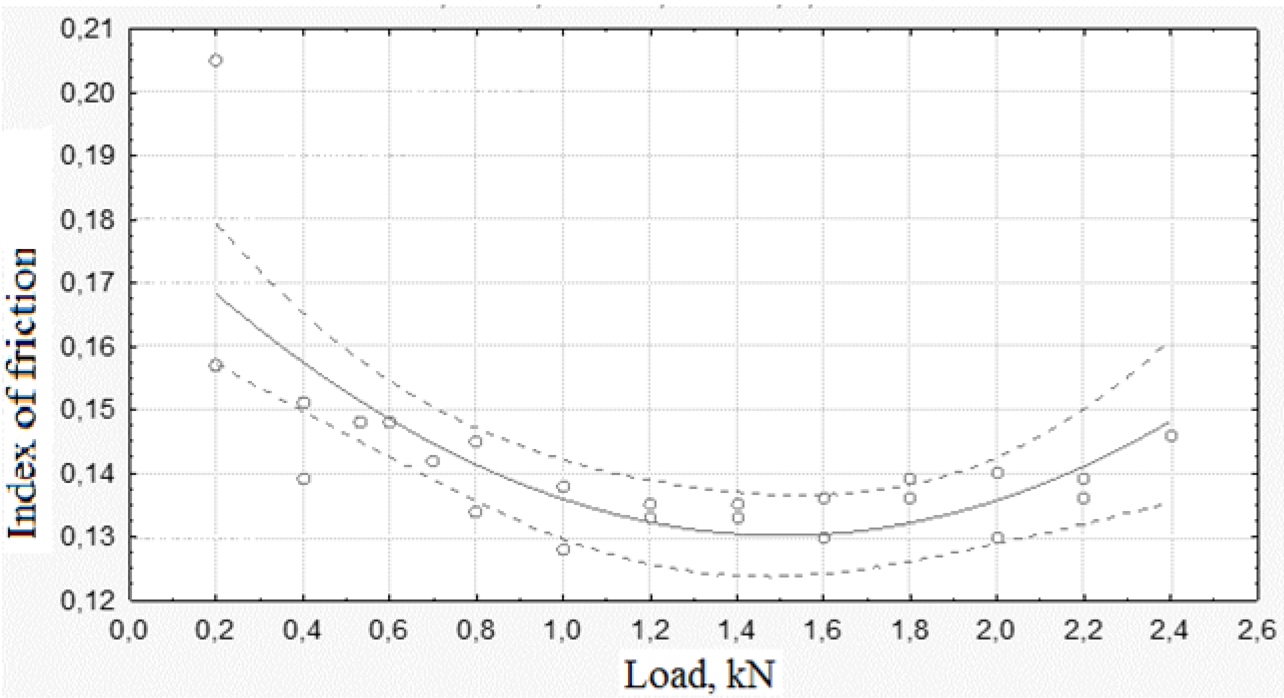
Figure 4: Results of running-in tests for brass-steel samples a), c) brass-steel + synthetic oil (without ultrasound); b), d) brass-steel + synthetic oil (with ultrasound); e), g) brass-steel semi-synthetics + oil (without ultrasound); f), h) brass-steel + oil semisynthetics (with ultrasound)


Friction moment, N m
0
1
2
3
4
5
6
7
8
0,0
0,2
0,4
0,6
0,8
1,0
1,2
1,4
1,6
1,8
2,0
2,2
2,4
2,6
Load, kN

a)

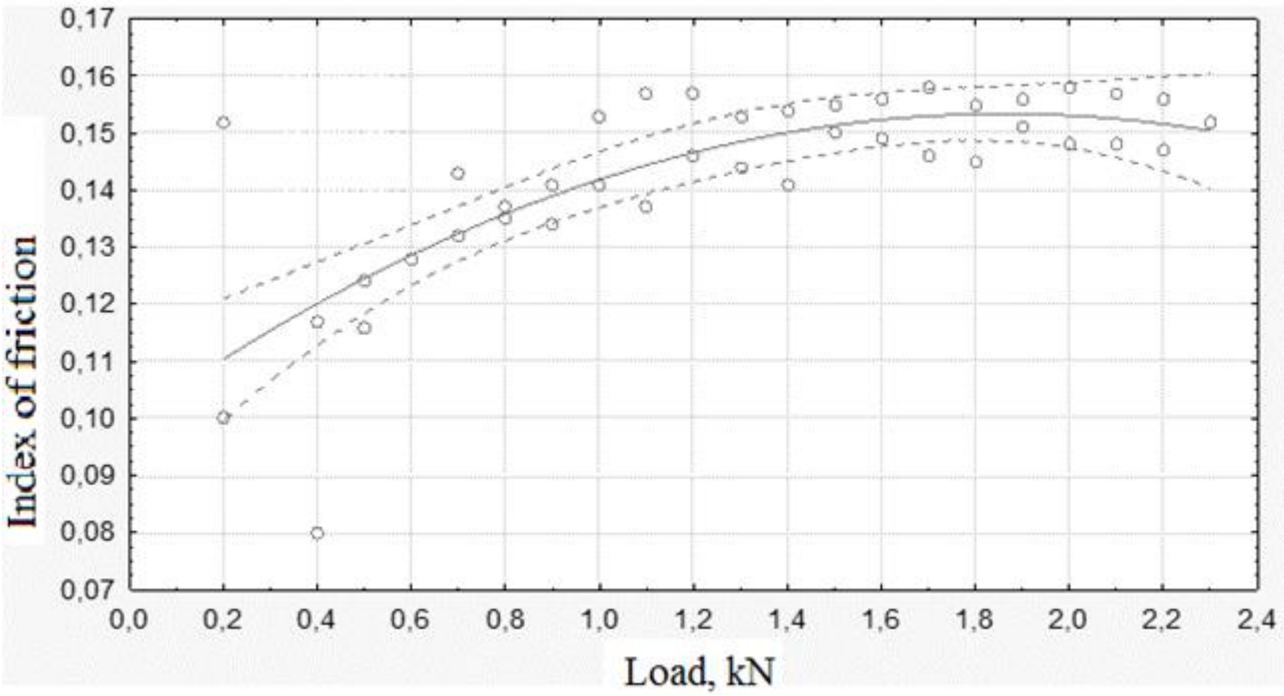

Friction moment, N m
0
1
2
3
4
5
6
7
8
0,0
0,2
0,4
0,6
0,8
1,0
1,2
1,4
1,6
1,8
2,0
2,2
2,4
Load, kN

b)



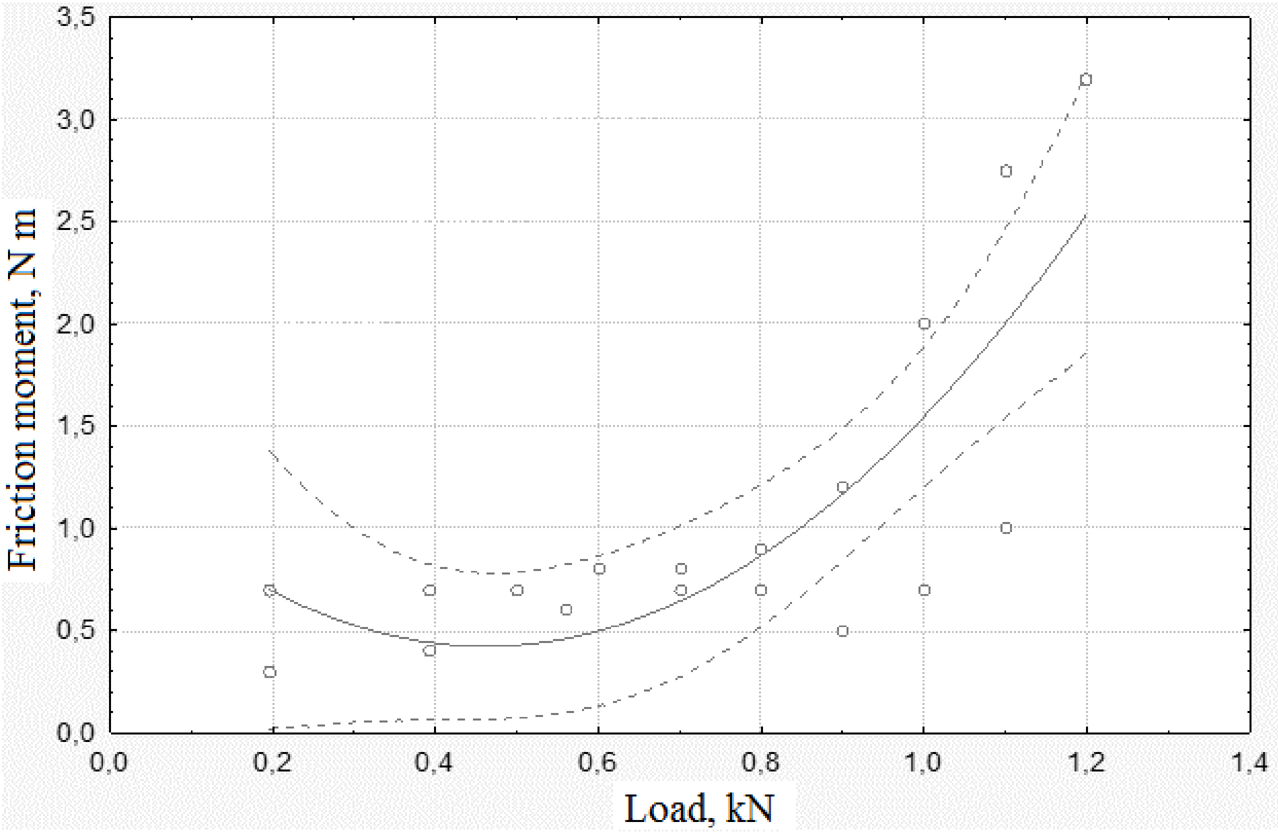
0,21
0,20
0,19
0,18
0,17
0,16
0,15
0,14
0,13
0,12
Index of friction
0,0 0,2 0,4 0,6 0,8 1,0 1,2 1,4 1,6 1,8 2,0 2,2 2,4 2,6
Load, kN

c)



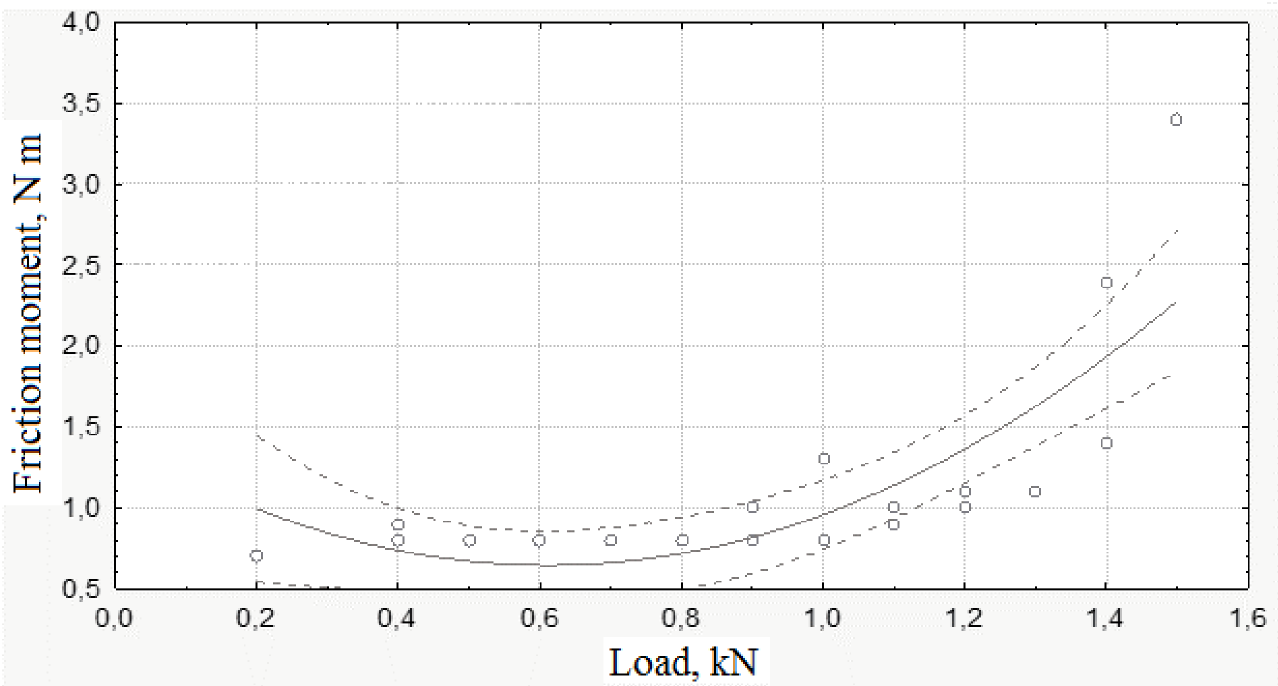
0,17
0,16
0,15
0,14
0,13
0,12
0,11
0,10
0,09
0,08
0,07
Index of friction
0,0 0,2 0,4 0,6 0,8 1,0 1,2 1,4 1,6 1,8 2,0 2,2 2,4
Load, kN

d)



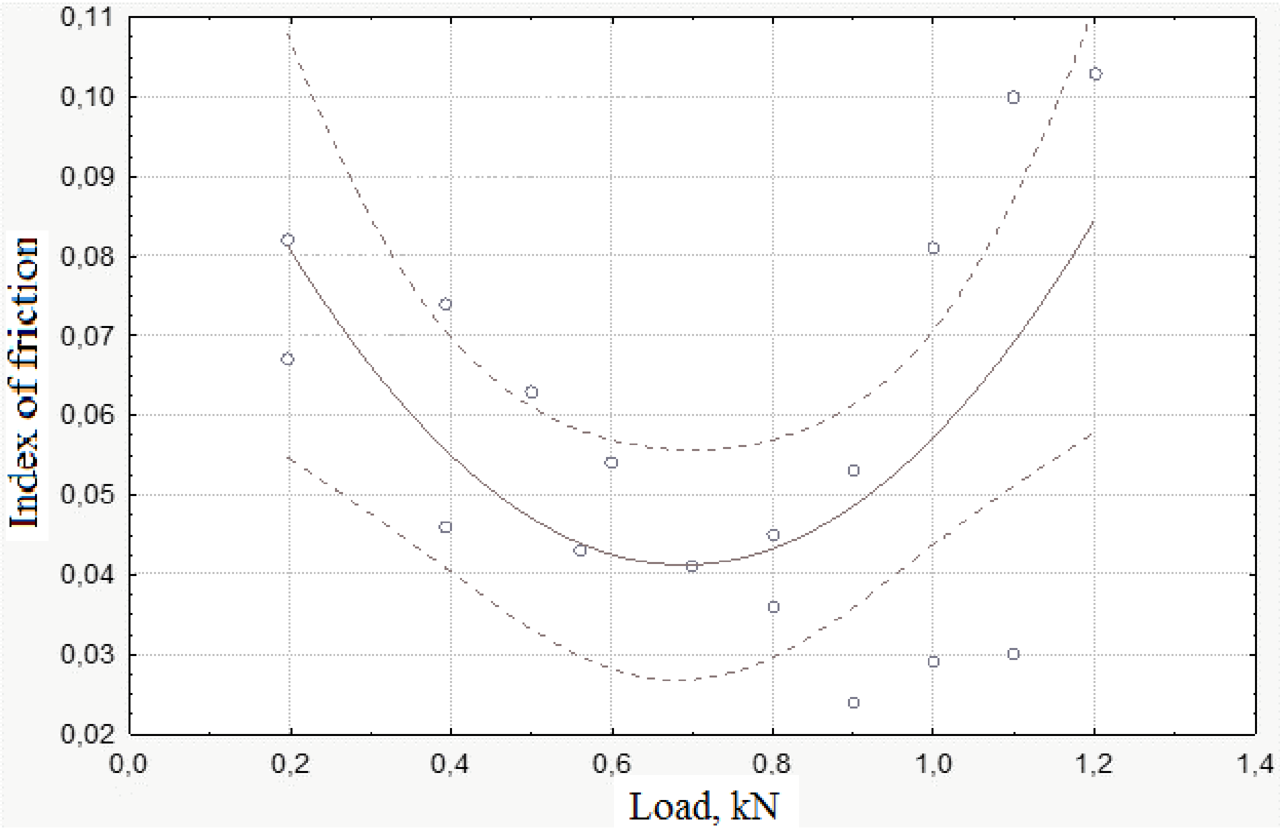
Friction moment, N m
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,0
0,2
0,4
0,6
0,8
1,0
1,2
1,4
Load, kN

e)

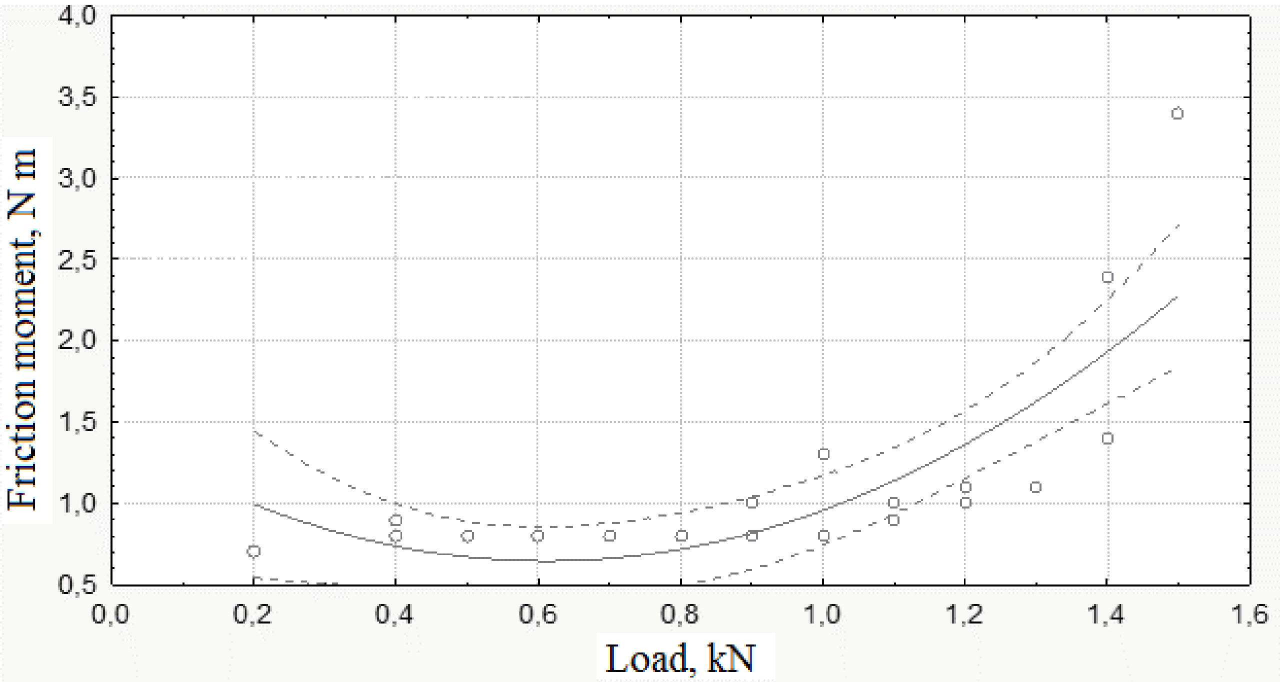


Friction moment, N m
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,2
0,4
0,6
0,8
1,0
1,2
1,4
1,6
Load, kN

f)

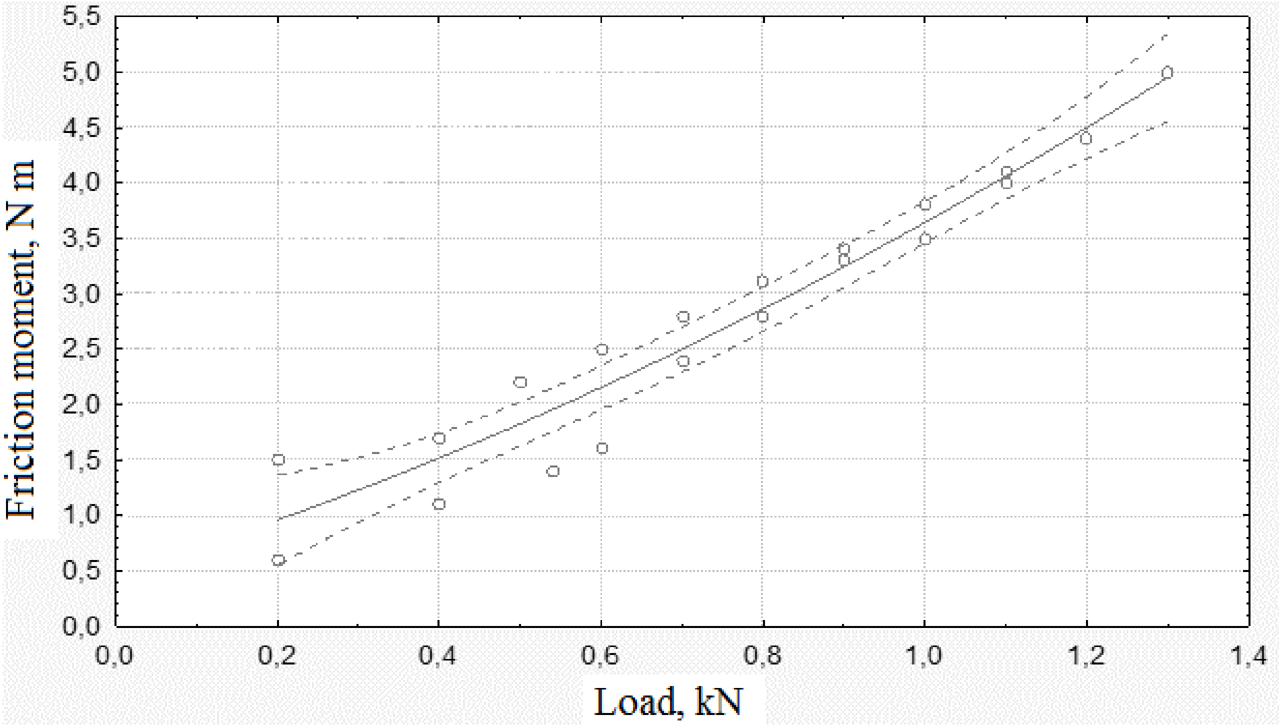


g)

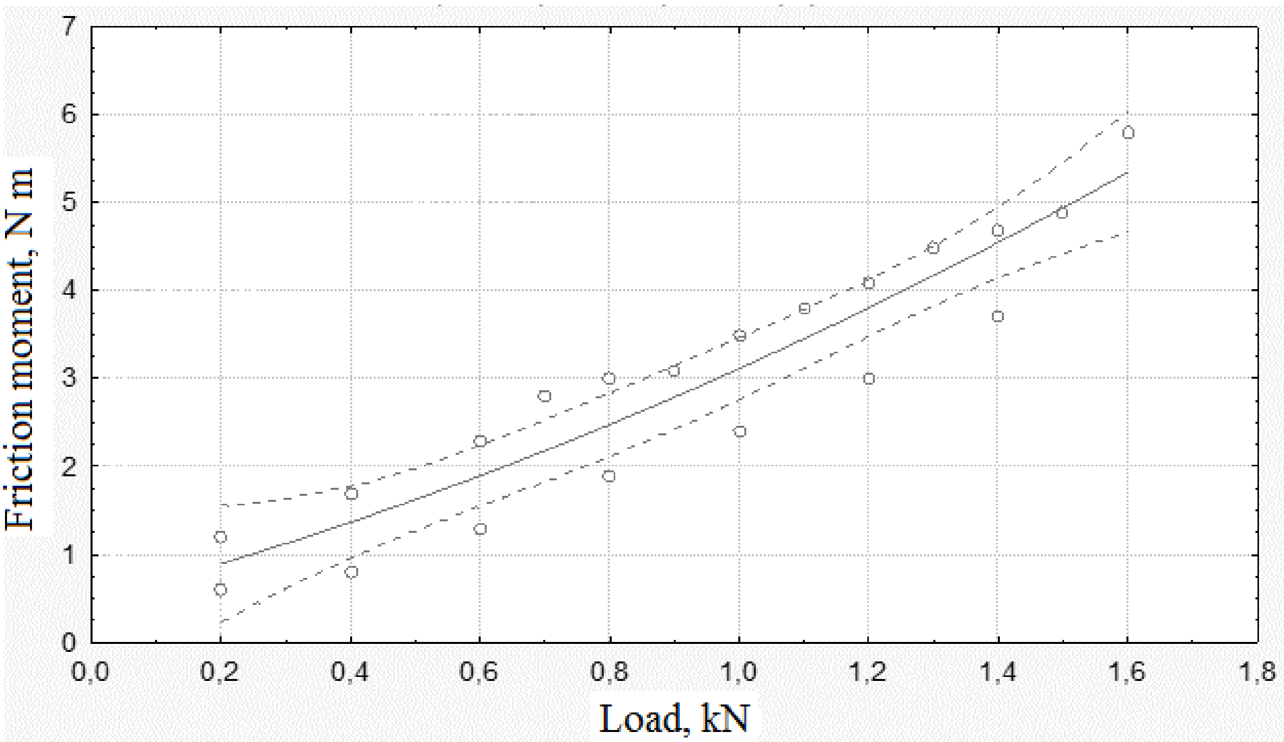


h)

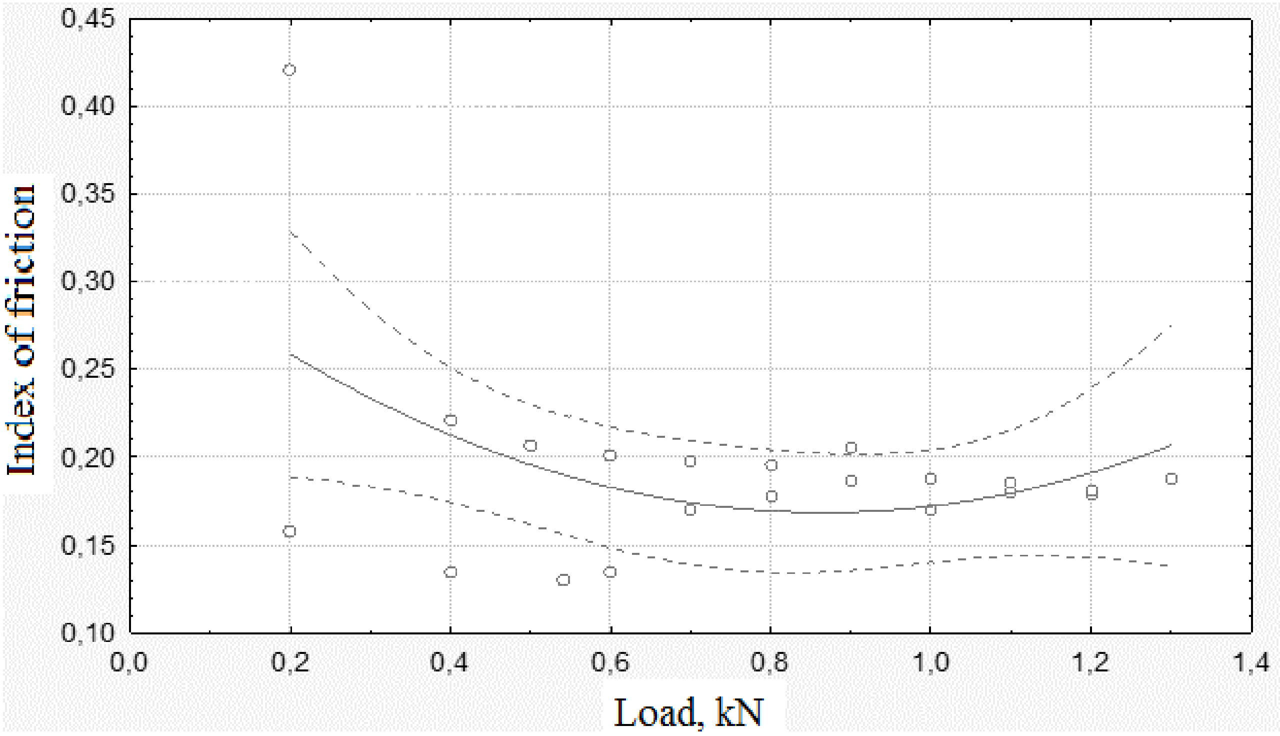
Figure 5: The results of running-in tests for cast-iron-steel samples a), c) cast-iron-steel + synthetic oil (without ultrasound); b), d) cast-iron-steel + synthetic oil (with ultrasound); e), g) cast-iron-steel + semi-synthetic oil (without ultrasound); f), h) cast-iron-steel + semi-synthetic oil (with ultrasound)



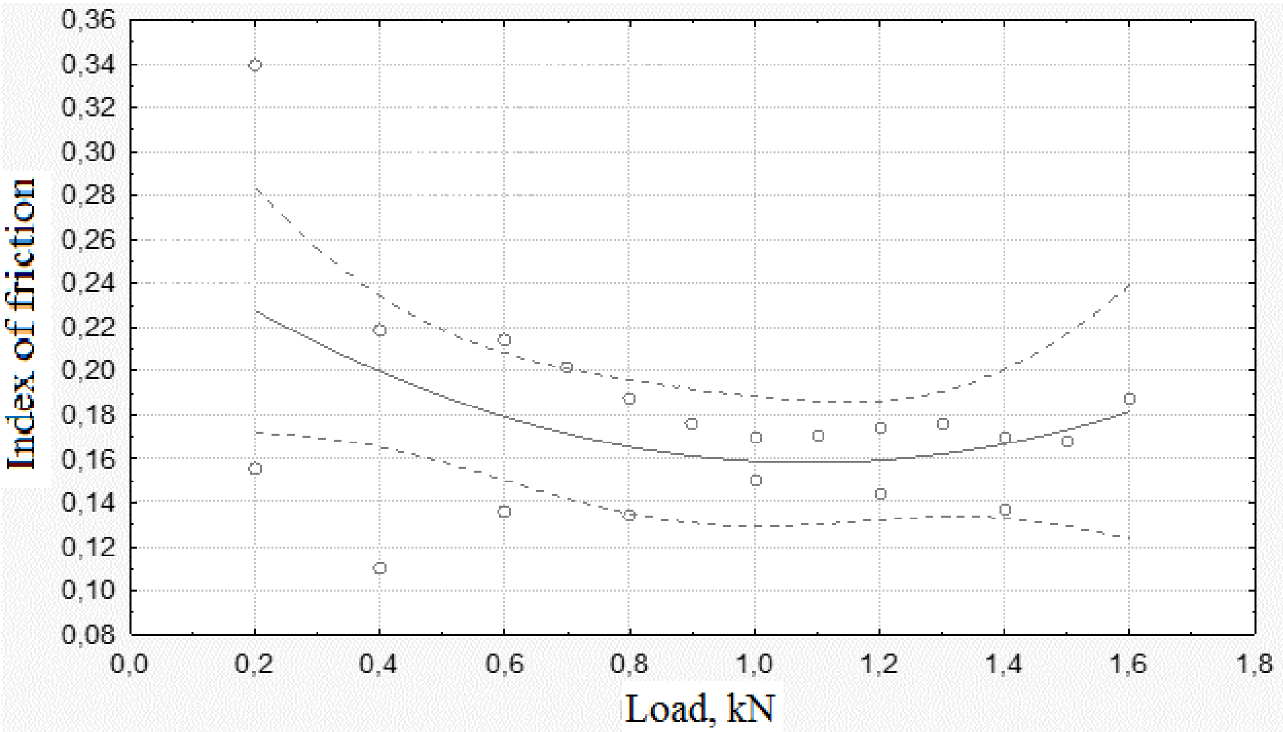
a)



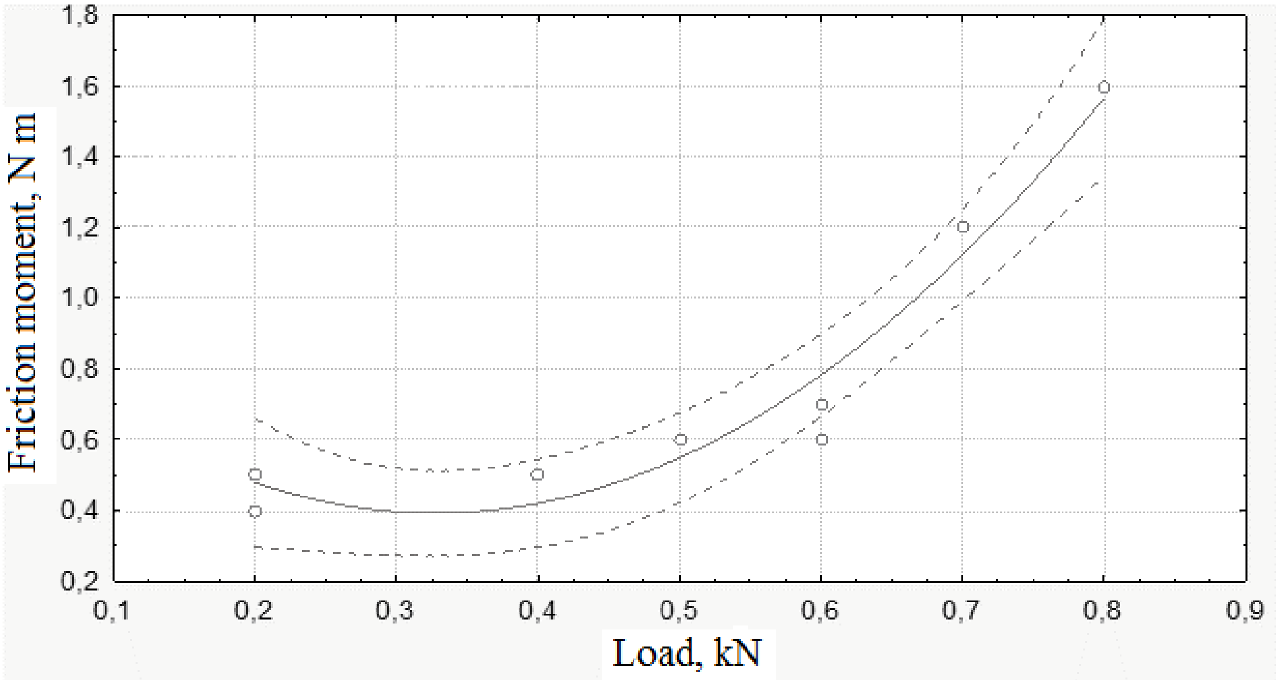
b)


Index of friction
Load, kN
0,45
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,0
0,2
0,4
0,6
0,8
1,0
1,2
1,4

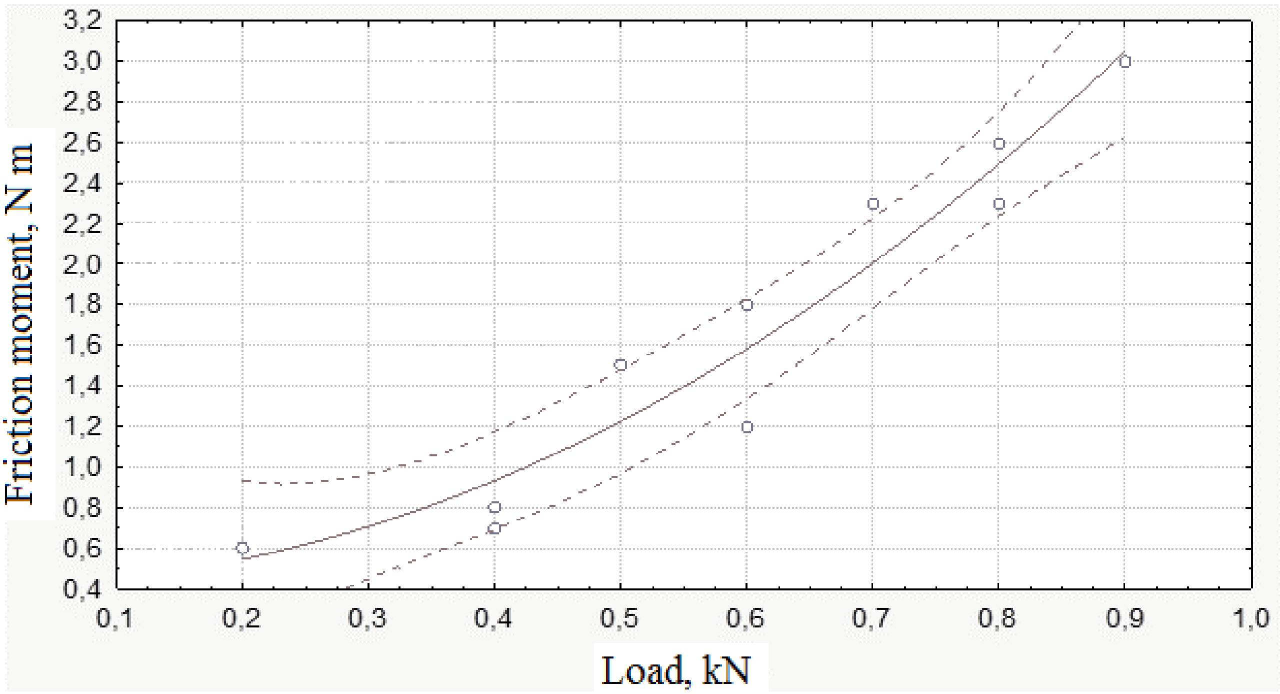
c)


Index of friction
Load, kN
0,36
0,34
0,32
0,30
0,28
0,26
0,24
0,22
0,20
0,18
0,16
0,14
0,12
0,10
0,08
0,0
0,2
0,4
0,6
0,8
1,0
1,2
1,4
1,6
1,8

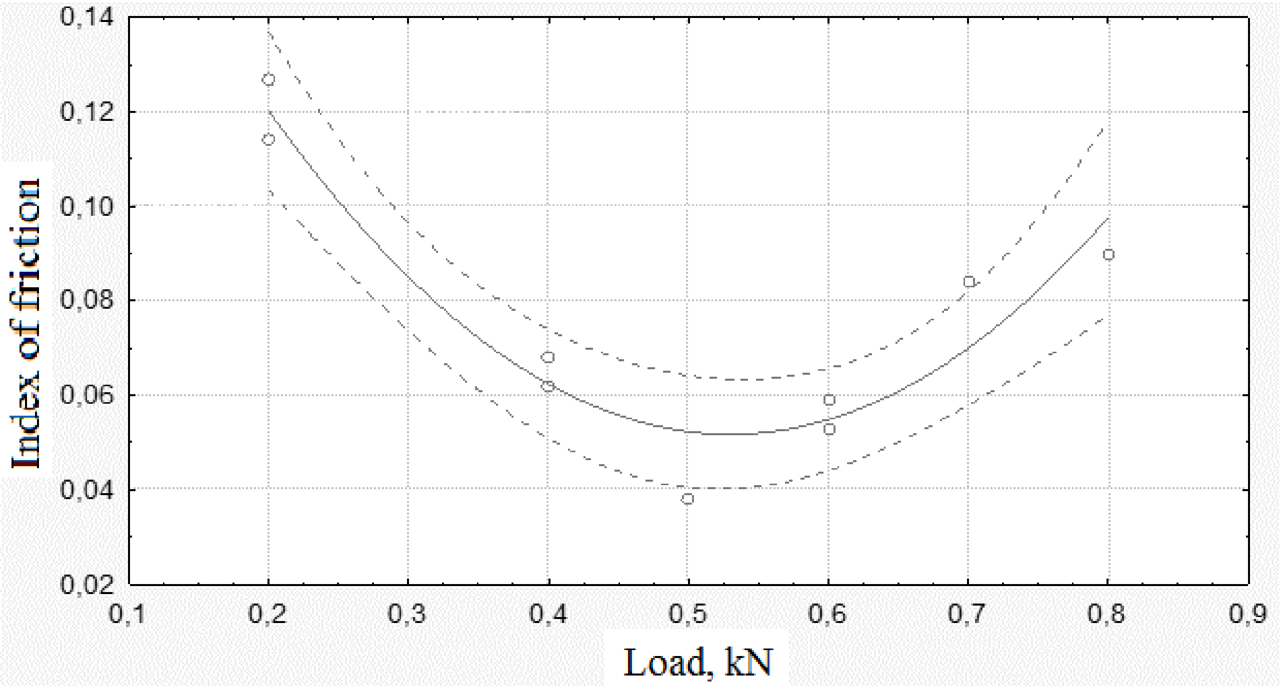
d)


Friction moment, N m
Load, kN
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9

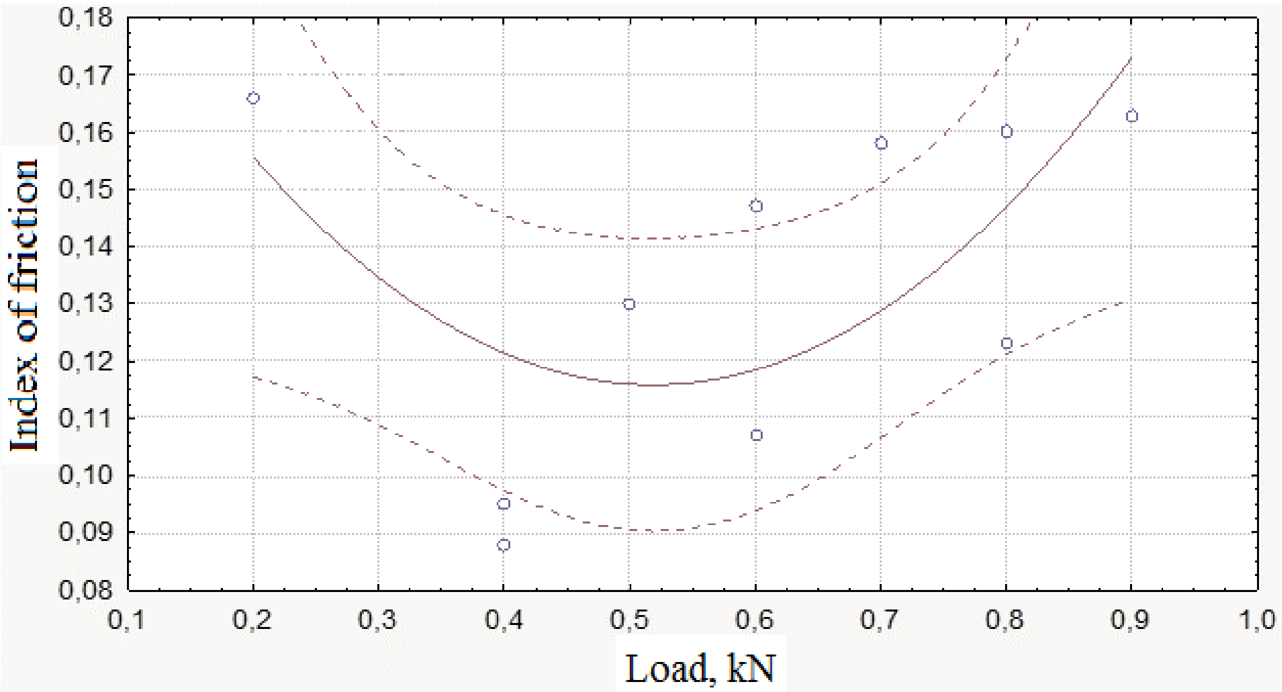
e)


Friction moment, N m
Load, kN
3,2
3,0
2,8
2,6
2,4
2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0

f)



g)



h)

We have determined the linear wear of the sample *W* according to the following formula:

$$W = \frac{\Delta G}{\gamma \cdot F_c}, \tag{2}$$

where *ΔG* - the change of the sample mass in the test kg; *γ* - density of the material, kg/$м^3$; F_c – sample contour contact area m^2.

We have determined the intensity of pairs wear as the sum of the intensities of a pair elements wear (jaws and roll).

Comparative evaluation of the wear rate was conducted in terms of wear and tear factor:

$$\Phi = \frac{I_{\Sigma}}{P_{on}}, \qquad (3)$$

where I_{Σ} - the amount of the pair elements wear rates; P_{on} - the optimal load (effort), MPa.

We have presented the results of the samples wear test in Table 1 (Oil - FORMULA SAE 5W-30) and Table 2 (Oil - Mobil Super 2000 SAE 10W-40).

Table 1: Results of wear tests (Oil - FORMULA SAE 5W-30)

Sample/ Material	Sample Mass, g		Wear,g	Load, MPa	Ultra-sound, kHz	Wear Parameters			
	before	after		$P_{оп}$		$I_{п}$	$I_{н}$	I_{Σ}	Φ
Roller / X12F1	80,575155	80,57502	0,000135	10,0	-	$1{,}34\cdot10^{-13}$	$1{,}63\cdot10^{-11}$	$1{,}65\cdot10^{-11}$	$1{,}65\cdot10^{-12}$
Jaw / LMcSKA	8,251155	8,250955	0,0002						
Roller / X12F1	80,576335	80,57621	0,000125	10,0	17,0	$1{,}19\cdot10^{-13}$	$1{,}03\cdot10^{-11}$	$1{,}04\cdot10^{-11}$	$1{,}04\cdot10^{-12}$
Jaw / LMcSKA	8,256645	8,256483	0,000162						
Roller / X12F1	80,62114	80,62086	0,00028	8,0	-	$2{,}79\cdot10^{-13}$	$1{,}66\cdot10^{-11}$	$1{,}69\cdot10^{-11}$	$2{,}11\cdot10^{-12}$
Jaw / SCh-20	8,96084	8,96067	0,00017						
Roller / X12F1	80,60957	80,60902	0,00055	8,0	17,0	$5{,}49\cdot10^{-13}$	$5{,}89\cdot10^{-12}$	$6{,}44\cdot10^{-12}$	$8{,}05\cdot10^{-13}$
Jaw / SCh-20	8,95476	8,95470	0,00006						

Table 2: Results of the durability test (oil - Mobil Super 2000 SAE 10W-40)

Sample/ Material	Sample Mass, g		Wear,g	Load, MPa	Ultra-sound, kHz	Wear Parameters			
	before	after		$P_{оп}$		$I_{п}$	$I_{н}$	I_{Σ}	Φ
Roller / X12F1	80,566283	80,56581	0,000473	7,0	-	$4{,}7\cdot10^{-13}$	$3{,}27\cdot10^{-11}$	$3{,}31\cdot10^{-11}$	$4{,}74\cdot10^{-12}$
Jaw / LMcSKA	8,230083	8,229683	0,0004						
Roller / X12F1	80,56335	80,56315	0,0002	7,0	17,0	$1{,}99\cdot10^{-13}$	$3{,}19\cdot10^{-11}$	$3{,}21\cdot10^{-11}$	$4{,}59\cdot10^{-12}$
Jaw / LMcSKA	8,22297	8,22262	0,00035						
Roller / X12F1	80,55625	80,55613	0,00012	5,0	-	$1{,}19\cdot10^{-13}$	$1{,}57\cdot10^{-11}$	$1{,}59\cdot10^{-11}$	$3{,}16\cdot10^{-12}$
Jaw / SCh-20	8,94589	8,94573	0,00016						

Roller / X12F1	80,556395	80,55625	0,000145	5,0	17,0	$1,45\cdot10^{-13}$	$1,08\cdot10^{-11}$	$1,09\cdot10^{-11}$	$2,19\cdot10^{-12}$
Jaw / SCh-20	8,94600	8,94589	0,00011						

To understand the effect of reducing the coefficient of friction when lubricant oil treatment with ultrasound we have evaluated viscosity. To study viscosity they frequently use falling-ball method. However it is difficult to apply it with contaminated oil because it is impossible to track the movement of a metal ball in it. But in experiments with falling-ball method pure oil has shown anomalous effect called the effect of residual viscosity (E.R.V.). It was found out that the fall of the ball in oil, heated to a temperature by ultrasound and heat may vary 1,5 ... 2 times.

Figures 6-8 shows the results for determining the time of a working body in oil heated to the same temperature by ultrasound and heat [2].

Figure 6: Relationship between flat body fall in mineral oil SAE 15W40 time and temperature: 1 - oil treated with ultrasound; 2 – heated oil

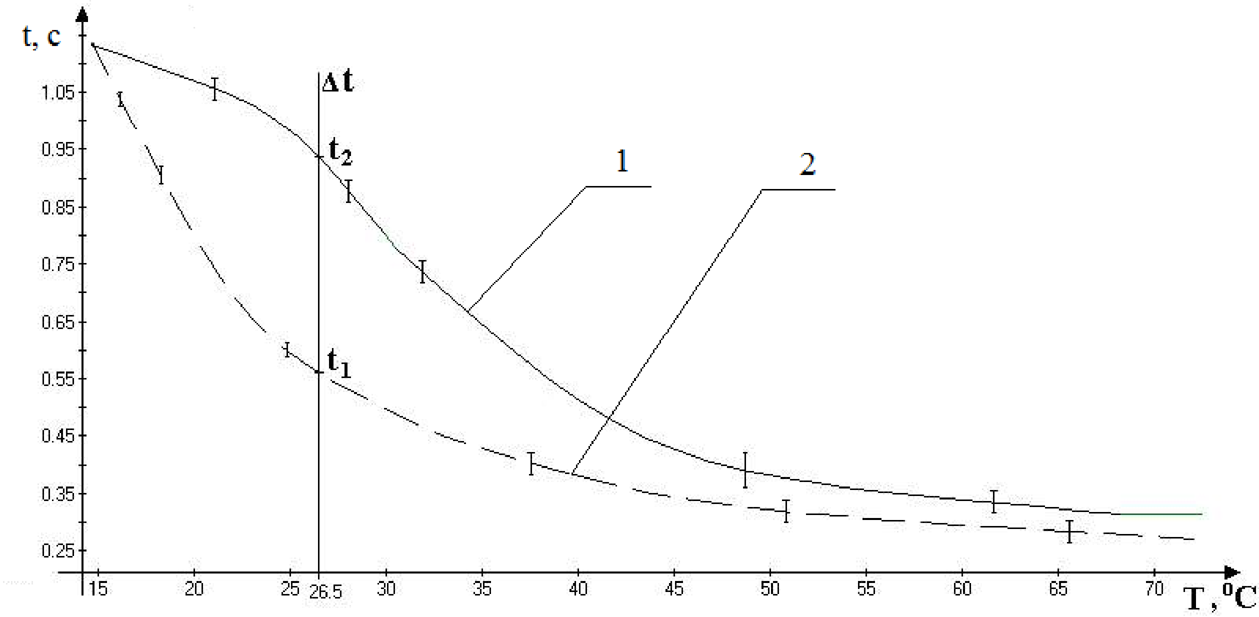
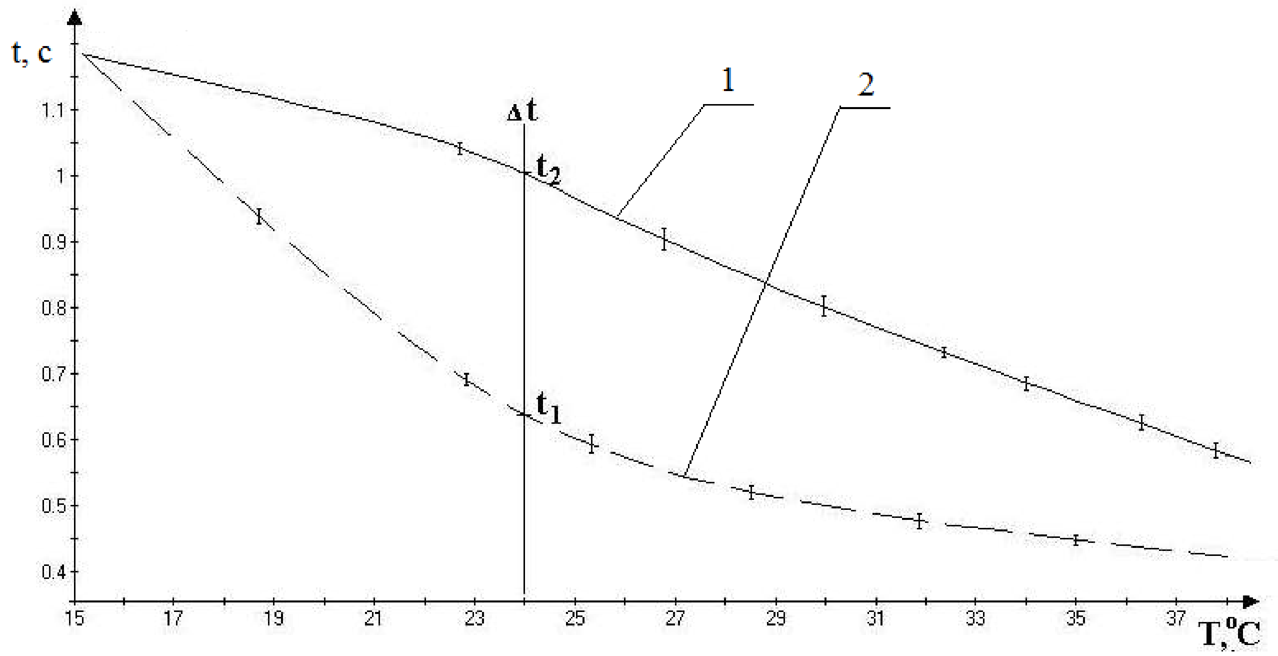


Figure 7: Relationship between the flat body fall in semi-synthetic oil SAE 10W40 and temperature: 1 - oil treated with ultrasound; 2 – heated oil



The provided graphs show that in all cases with oils heated to the same temperature by ultrasound and heat there is a time difference of the flat working body fall and, consequently, different viscosity. The oils heated by ultrasound have higher viscosity than those heated to the same temperature by heat. It can be seen in the graph (Figure 6) mineral oil 15W40 at t = $26{,}5^0$ C has maximum parameters and semi-synthetic oil 10W40 oil at t = 24^0 C has lower parameters and synthetic oil 5W40 at t = 23^0 C has the least parameters.

Figure 8: Relationship between the flat body fall in synthetic oil SAE 5W40 and temperature: 1 - oil treated with ultrasound; 2 – heated oil

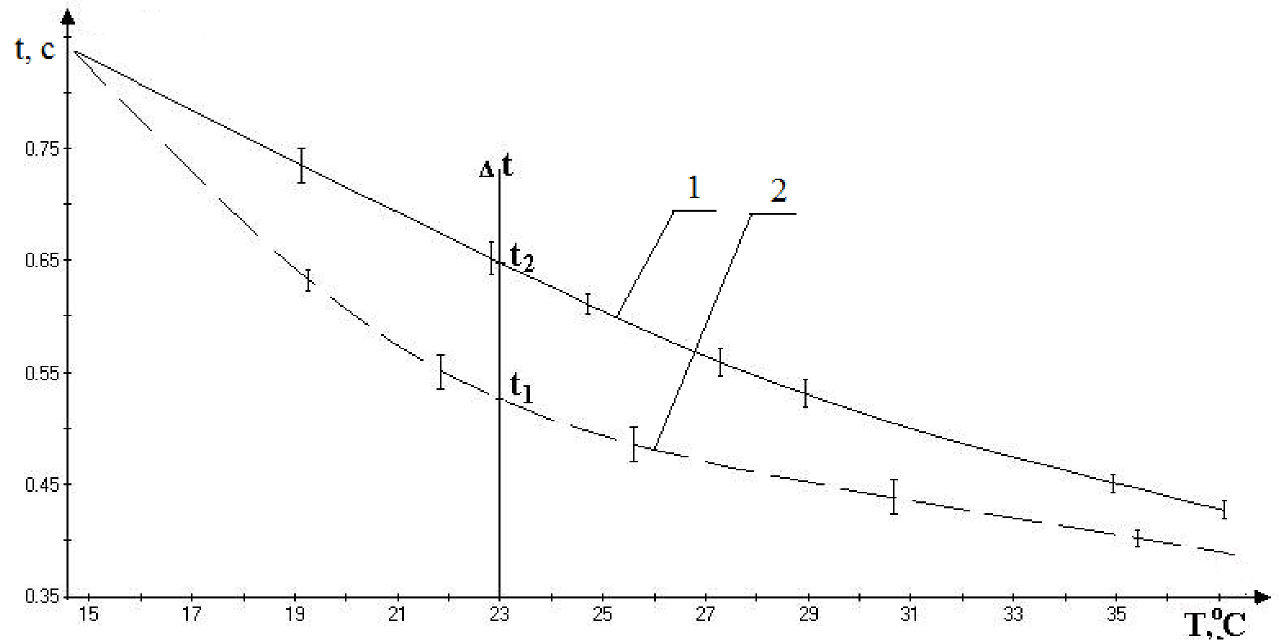
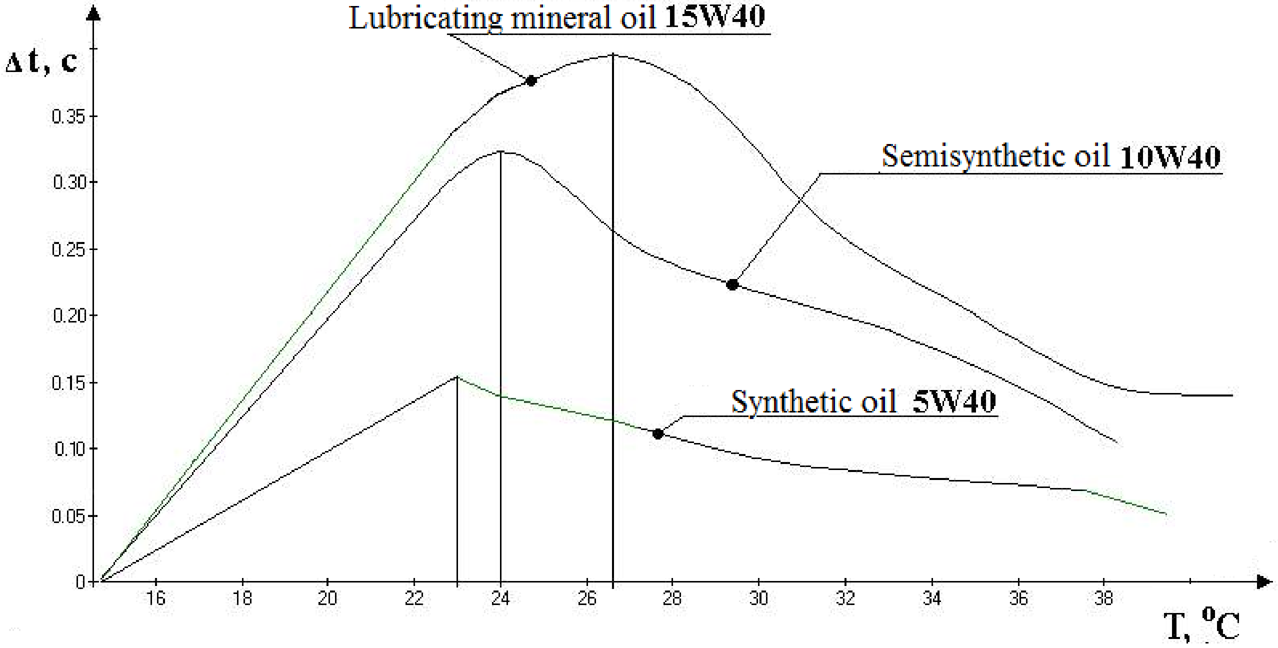


Figure 9 is a generalized graph of relationship between the flat body fall in oil, heated by ultrasound (fall time t_2) and heat (fall time t_1). For convenience we have time difference Δt, and $\Delta t = t_2 - t_1$.

Figure 9: Time difference Δt of the flat body fall in oils depending on the temperature



Figures 10 and 11 show the study results of residual viscosity effect in pure 15W40 mineral oil depending on the time delay after treating with ultrasound at different temperature.

Figure 10: Relationship between the flat body fall in oil time and the hold time after ultrasound treatment at 30⁰ C: 1 - oil treated with ultrasound; 2 – heated oil

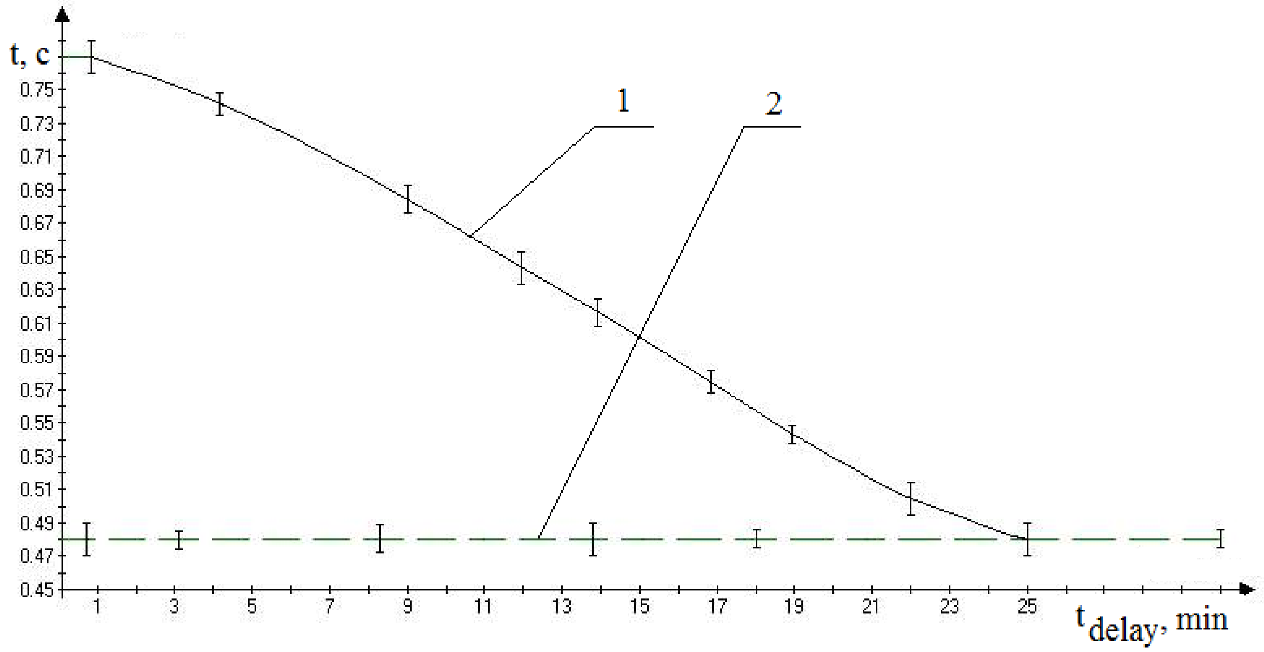
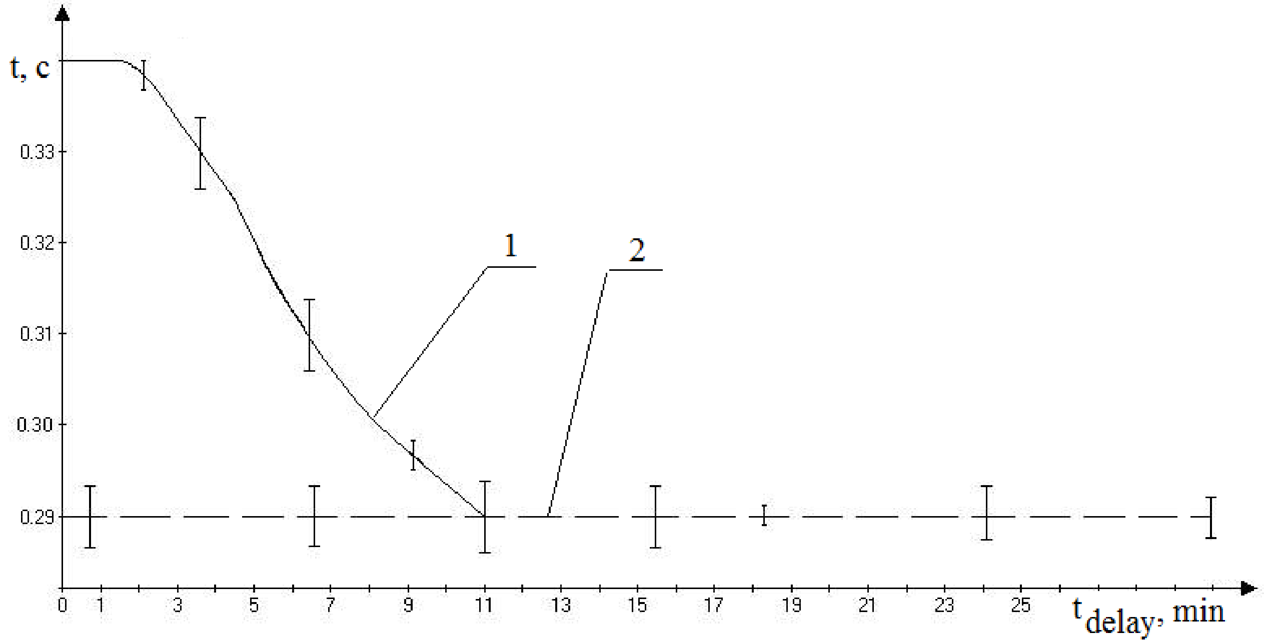
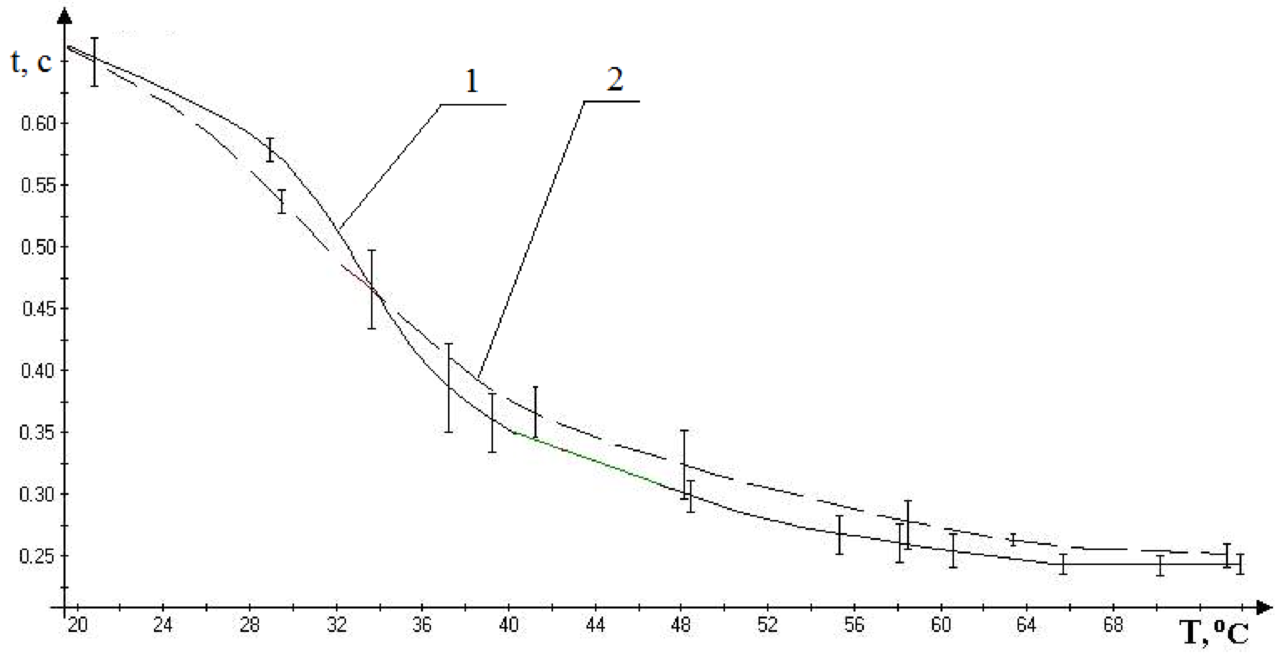


Figure 11: Relationship between the flat body fall in oil time and the hold time after ultrasound treatment at 60^0 C: 1 - oil treated with ultrasound; 2 – heated oil



It is known that NS-100 is a uniform base for mineral oil 15W40 containing no chemical additives. Figure 12 shows the results of determining of the flat body fall in NS-100-based mineral oil 15W40, warmed up to the same temperature by ultrasound and heat. The results show no significant difference for time t_2 and t_1.

Figure 12: Relationship between the flat body fall in NS-100 oil and temperature when ultrasound treatment and heat: 1 - oil treated with ultrasound; 2 – heated oil



4. Conclusion

The tribology tests have shown 4,3 ... 12,3 % (synthetic oil) and 12,5 ... 25,0 % (semi-synthetic oil) increase of pre-score resistance (brass and cast iron respectively) and 13,4 ... 15,3 %

(synthetics) and 25,0 ... 28,1 % (semi-synthetics) lowering the coefficient of friction for oils treated with ultrasound as compared with initial variants. Thus we have shown the positive effect of ultrasound on the lubricant in direct contact with a pair of friction.

We have not found out any significant differences between oils viscosity when heated or treated with ultrasound with the help of viscometer. Thus, we have discovered the features of the residual viscosity effect (E.R.V.): E.R.V. is more obviously manifested in pure mineral motor oil, less in semi-synthetic and least in synthetic oil.

1. E.R.V. remains in oil after treatment for 15…30 minutes. The higher the temperature the less time the effect lasts.
2. E.R.V. is not observed in initial homogeneous oil not containing any chemical additives.
3. E.R.V. is not observed when determining viscosity by viscometer.

The discovered features make possible to determine the mechanism of E.R.V. Probably the lubricant oil is heated when ultrasound of definite frequency and intensity depending on the initial oil content and chemical additives nature. At that one can achieve formation of stable ultrasonic waves having vivid energy maximums and minimums. Creation of waves must lead to redistribution of additives molecules in such a way that they start accumulating in areas with minimum energy, i.e. in oil treated with ultrasound. There appeared areas of additives molecules increased or decreased concentration. There are some additional links between molecules in areas with increased concentration that probably leads to E.R.V. Due to heat there are these zones changes in time and E.R.V. goes down and disappears. The impossibility of determining E.R.V. by viscometer is due the fact that when going through small section holes there is oil mixing and additives molecules spread regularly. Based on experimental and theoretical investigations we have discovered that the maximum effect of residual viscosity is achieved with specified intensity of ultrasound $I_y = 0.33$ W/cm^3, frequency ranges of $0,5 \cdot 10^5$ Hz $\leq \nu \leq 3,0 \cdot 10^5$ Hz, and temperature limits of 23^0 C $\leq t \leq 27^0$ C) depending on the oil type.

References

[1] Barinov, S., Zagorodskikh, B., & Simdyankin A. (2003). Investigation of Wear-Resistance of Detail with Heterogeneous Surface of Friction. *Friction and Wear*, 24(5), 568-572

[2] Kolosov, A. (2004). The Method and Device to Control and Forecast the Process of Internal Combustion Engine Break-In: Diss…of Cand. Of Techn. Science, Ryazan SATU Named after P.A. Kostychev

[3] Mashkov, Yu., Negrov, D., Ovchar, Z., & Zyablikov, V., (2006). Improvement of Mechanical and Tribotechnical Properties of Polymer Composition Materials with the Help of Ultrasonic Vibrations Energy. *Friction and Wear*, 27(3), 313-317

[4] Rauba, A., Petrochenko, S., & Fedorov, A. (2013). Increase of Wear-Resistance of the Working Surface of Machines Collectors of Direct Current by Shock-Acoustic Treatment Method. *Friction and Wear*, 34(1), 58-62