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THE BEHAVIOUR OF STEEL TRIBOELEMENTS UNDER VARIOUS TESTING CONDITIONS

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Abstract: *The paper presents experimental results on testing two grease grades under severe regimes characterised by low (-10…-20°C), normal (20…25°C) and high (80…100°C) temperatures, a normal load range of 0.3…1.5 kN and different relative sliding ratios of 0, 16.3 and 33.6%, respectively. This testing methodology could be used for selecting grease grade acceptable for actual applications reducing the risk probability of failure. For the tested greases, there were measured the actual loading forces and friction moments (the triboelements in contact - roller/roller, test duration - 240 minutes, the running distance for each sample being approximately 28,000 m). There were done 3D diagrams for evaluating the most favoyrable regimes, taking into account the normal load and relative sliding ratio.*

Keywords: *Grease lubrication, friction coefficient, rolling-sliding, low and high temperatures.*

1. INTRODUCTION

The increasing demands for functioning conditions, including high speeds and temperatures require research on their behaviour in lubrication. Two of most important parameters for machine reliability, namely, efficiency and durability, are influenced by the quality of mineral or synthetic greases, having the function of protecting moving elements and reducing friction and wear processes. Experimental researches on greases are relatively numerous and related to structural processes occurring when testing or in actual exploita-tion, the possibilities of increasing their durability by additives, without negative effects on triboelements, on preventing failure and on delaying the emergence of unwanted processes and products.

2. THE TESTING MACHINE

The testing machine (figure 1) was designed taking into account the concept of tribosystem and tribomodel [2], [3], [4] and includes an Amsler device in open circuit. The original design [5], [6], [7] allows making tests with many variables. It has a thermally insulated box allowing having different environmental working temperatures: either low or high, as requested by the research. The atmosphere composition may be varied and controlled.

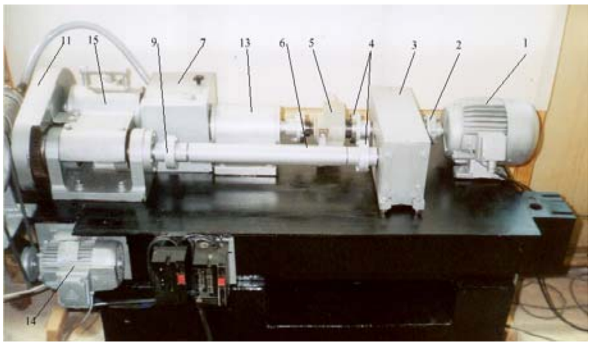


Figure 1. The testing machine. 1-engine; 2, 4 and 9-rigid couplings; 3-reducing gear; 5-torque transducer; 6-shafts; 7-thermally insulated box; 11-belt transmission; 14-system for grease circulating; 15- gear transmission.

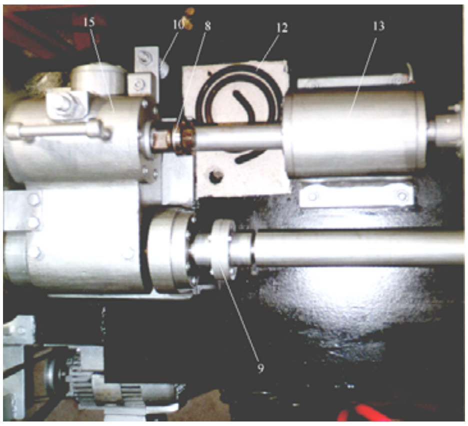


Figure 2. The working zone 8-up-roller; 10-limiting spring; 12-heating system; 13-ball bearings.

Different rolling sliding regimes may be achieved by changing the pair of rollers. Angular speed may be continuously changed, and it may be kept constant with an accuracy of ±5%.

Monitoring system includes a force transducer C9A, a torque and speed transducer (T30FN200), temperature gauges (type K, NiCr-NiAl), a dynamic acquisition system DMCplus (Hottinger-Baldwin®) and a PC.

3. TESTING METHODOLOGY

Tests were done on roller-roller tribotester (figure 3 presenting a roller), roller dimensions being given in Table 1, thus obtaining different relative sliding ratios (pure rolling and rolling sliding ratios of 16.3% and 33.6%), defines as:

$$\xi = \frac{2(v_1 - v_2)}{v_1 + v_2} \cdot 100[\%] \qquad (1)$$

where v_1 and v_2 are the peripheral speeds of the rollers in contact. The tested rollers were made of the same steel grade OLC45 according to Romanian standard STAS 880-88 (grade similar to 1045 SAE steel grade, AISI 1045), having the composition: 0.43…0.50%C, 0.60…0.90% Mn, 0.15…0.30% Si, max. 0.04% P and max. 0.05% S, in two variants: tempered state, having a roughness parameter *Ra*=3.2 µm and thermally treated and grinded at *Ra*=1.6 µm.

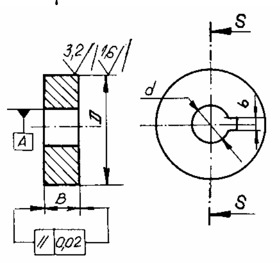


Figure 3. The roller

Table 1. Triboelements dimensional characteristics

ξ* [%]	Roller	*D*	*B*	*d*	*b*
		[mm]			
0	1	59.5	12	$22^{+0.02}_{0}$	$6^{+0.078}_{+0.030}$
	2	42.5	10	$22^{+0.02}_{0}$	$6^{+0.078}_{+0.030}$
16.3	1	55.40	12	$22^{+0.02}_{+0}$	$6^{+0.078}_{+0.030}$
	2	46.56	10	$22^{+0.02}_{+0}$	$6^{+0,078}_{+0,030}$
33.6	1	51	10	$22^{+0.02}_{+0}$	$6^{+0.078}_{+0.030}$
	2	51	12	$22^{+0.02}_{+0}$	$6^{+0.078}_{+0.030}$

* The relative sliding ratios are obtained combing machine kinematics and rollers' diameters.

For the tested greases there were measured the values of normal loafing, the friction moment and there was kept constant different temperatures of the box environment, for three rolling-sliding regimes: pure rolling, rolling-sliding with ξ=16.3% and ξ=33.6%, respectively. Test duration was of 240 minutes, corresponding to a friction distance of approximately 28,000 m. The friction coefficient was calculated with the following relationship:

$$\mu = \frac{2M_f}{Q \cdot D} \qquad (2)$$

where M_f - the resistant moment (it could also be named friction torque) [N.m], *Q* – normal load (as normal force), [N], *D* - the diameter of the driving roller, [m].

4. RESULTS

Diagrams of the friction moment vs. time pointed out a slight increase of the friction moment when starting the tests, during first 15…20 minutes (there were few exceptions), this tendency being more visible when testing at elevated temperatures (figures 4, 5 and 6) and may be explained by the high temperatures in contact until the running regime is stabilized.

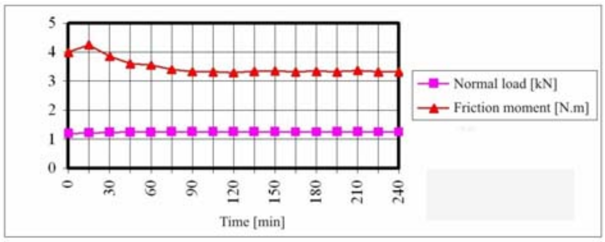


Figure 4. Friction moment and normal load vs. time; testing conditions: ξ=0%, *T*=100°C; n_1=750 rev/min; *Q*=1.1kN; grease grade UM170LiCaPb2M

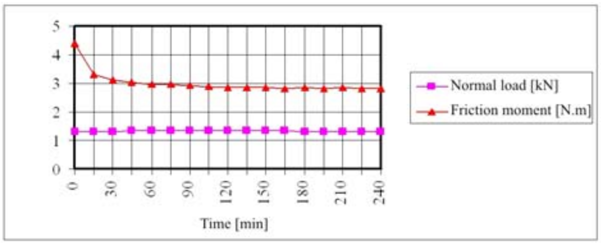


Figure 5. Friction moment and normal load vs. time; testing conditions: ξ=33.6%; *T*=90°C; n_1=600 rev/min; *Q*=1.2kN; grease grade UM185Li2EP

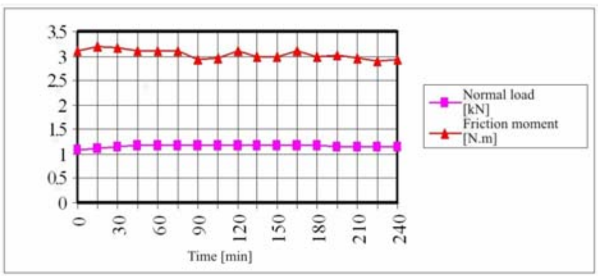


Figure 6. Friction moment and normal load vs. time, testing conditions: ξ= 33.6 %, *T*=100°C; n_1=750rev/min; *Q*=1.1kN; grease grade UM170LiCaPb2M

At the beginning of the test the triboelements thermally expand resulting a supplementary loading of the contact, and thus, an increase of the friction moment (and of the friction coefficient calculated with eq. (2)).

For the regime with ξ=0% (pure rolling) the friction coefficient decreased from initial values of μ=0.055…0.053 during the first 60 minutes of tes-ting, to μ=0.049…0.050 after 4 hours of testing. A similar behaviour was noticed under ξ>0 (sliding-rolling). For ξ=16.3%, the friction coefficient decreased from a value μ=0.067…0.063 after the first 30 minutes of testing, to μ=0.053 after 4 hours of testing; as for the tests with ξ=33.6 %, the friction coefficient decreases from an initial value of μ=0.052…0.051 after the first 30 minutes, to μ=0.046…0.047 after 4 hours of running.

For the range temperature of -10°C…-20°C there were noticed abnormal evolutions (figures 9, 10 and 11).

Figures 7 and 8 present the normal load and friction moment evolutions for the multifunctional grease grade UM170LiCaPb2M.

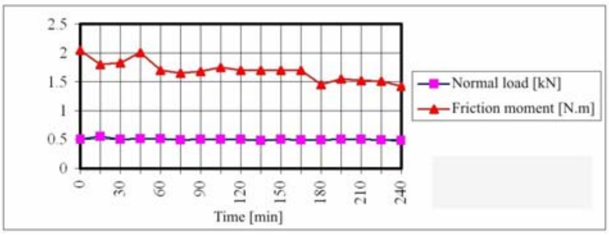


Figure 7. Friction moment and normal load vs. time, testing conditions: ξ=16.3%, T=60°C; n_1=335 rev/min; Q=0.5 kN; grease grade UM170LiCaPb2M.

Even if the normal load remains constant, the friction moments have some variations (not very high) and the friction coefficient varies in the range μ=0.054…0.076, being more than acceptable. Higher values are recorded for higher normal loads.

In nitrogen cooled environment (negative temperatures: -10ºC…-20°C), during first 20…30 minutes the tribotester has an expected evolu-tion. Under pure rolling (Figure 9) the friction coefficient is lower even if it was used a grease with lower viscosity – UM170LiCaPb2M. The colder environment keeps the grease consistency still good for generating a thin lubricating film. To the end of tests the film is probably too thin and the tribotester behaviour becomes worst, the triboelements' surfaces being very damaged (see figure 13). For ξ=33.6% (figure 10), the friction moment has only narrow variations. Even if the environment temperature is kept low, the grease film is better maintained, maybe because of the intense friction process in contact due to a greater relative sliding ratio. The rolling-sliding motion gives higher values for the friction coefficient, but constant in an acceptable range of μ=0.05…0.07.

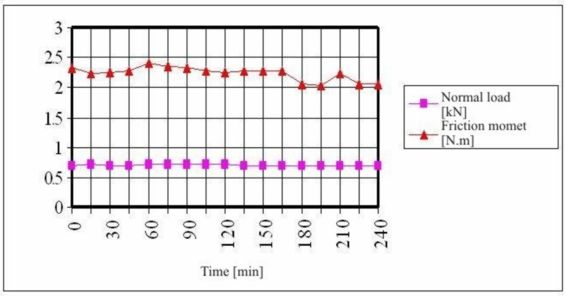


Figure 8. Friction moment and normal load vs. time, testing conditions: ξ=33.6 %, T=25°C; n_1=400 rev/min; Q=0.7 kN; grease grade UM170LiCaPb2M

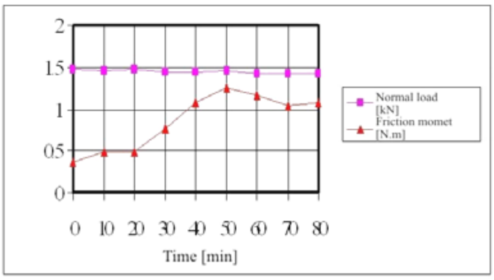


Figure 9. Friction moment and normal load vs. time, testing conditions: ξ=0%; T=-10ºC; n_1=600 rev/min; Q=1.5 kN; grease grade UM170LiCaPb2M

The regime with ξ=16.3% seemed to be the most unfavourable (see figure 11) as the values of the friction moment, thus, also those of the friction coefficient have variations with higher and non-uniform amplitudes.

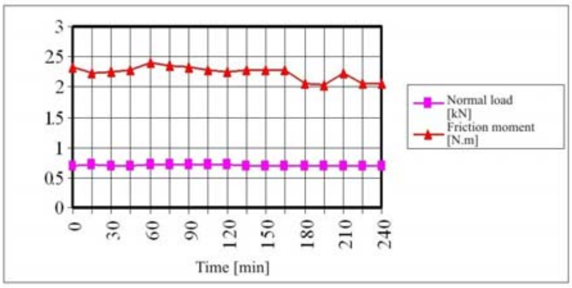
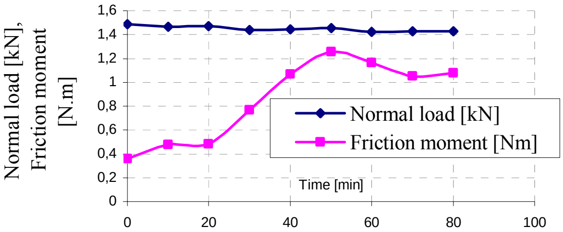


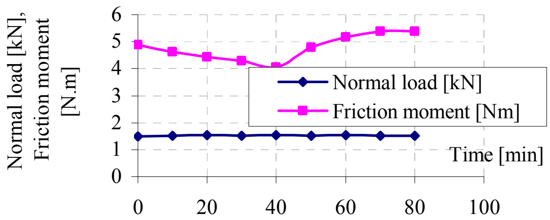
Figure 10. Friction moment and normal load vs. time, testing conditions: ξ=33.6%; T=-10^{0}C; n_1=600 rev/min; Q=1.5 kN; grease grade UM170LiCaPb2M

One may notice the correlation beetwen evolution of the friction moment and the behaviour worsening toward the end of the testing time, till severe adhesion, initiated when the friction moment riches its maximum of M_f = ~5.4 Nm. Figure 13 presents macrostructures of the roller, after being damaged.

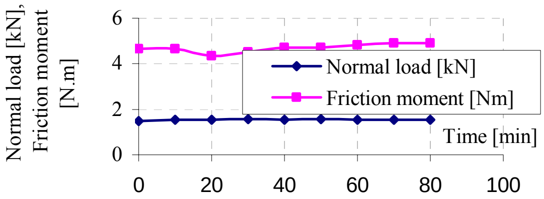
Such a behaviour is explained by the fact that friction processes are less intense and grease film is bearing less shear, thus the thermal energy generated by friction is less than that generated in rolling-sliding conditions.



a) ξ=0%



b) ξ=16.3%



c) ξ=33.6%

Figure 11. Friction moment and normal load vs. time; testing conditions: T=-10°C; n_1=600 rev/min; Q=1.5 kN; grease grade UM185Li2EP

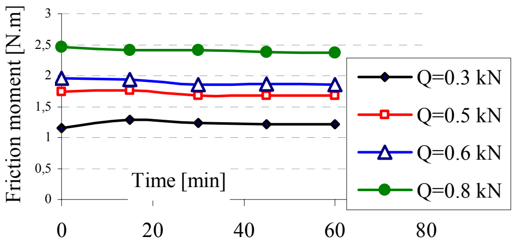


Figure 12. Influence of normal load of friction moment. Testing conditions ξ=16.3%, T=60°C, n_1=400rev/min; grease grade LiCaPb2(M)

For the tested greases it was attempt to evaluate the superimposed influence of load and relative sliding ratio on the friction coefficient. By the help of a specialised soft there were selected regression equations that “fit” better to mathematically describe the tests’ results for each grease grade, taking into account the smallest squared errors as criteria.

For grease grade UM185Li2EP, the friction coefficient could be given by the following function:

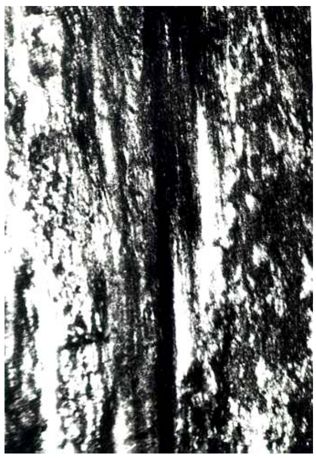
$$\mu = a + b\cdot\xi_1 + c\cdot lgQ + d\cdot\xi_1^2 + e\cdot lgQ + f\cdot\xi_1\cdot lgQ \quad (3)$$

where μ - the stable friction coefficient (average value), ξ- the relative sliding [%], Q - normal load [here in kN]. The values of the regression coefficients are given in table 2.

Analysing the 3D diagram (figure 14a) one may notice that it agrees to the tendency given by experimental research. Thus, for small loads and small relative sliding ratios, the values of friction coefficient are low, even if during the beginning of the test, there was a slight increasing tendency (not taking into account for plotting the 3D diagrams). After that the regime becomes stabilized, the friction coefficient slightly decreases (this process being noticed for the majority of done tests), its variations being in a narrow range around the average value. When the load increases, the friction coefficient has higher values (other test parameters being kept constant), even 4…5 times greater than the value obtained for the lowest tested load. The most damaging regime seems to be that of very small load combined with the greatest value for the relative sliding ratio, the friction coefficient varying in the range of μ=0.14…0.15.

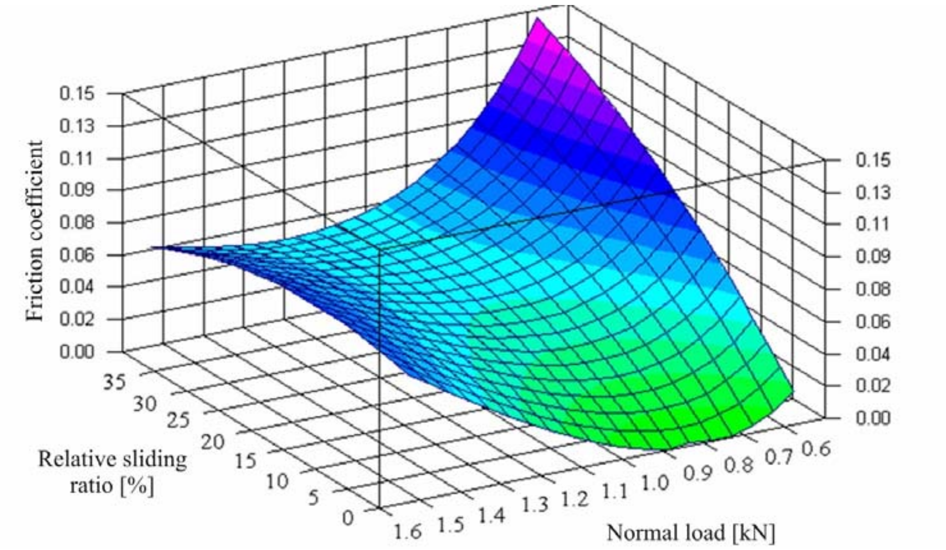
b) Severely worn roller: ξ=16.3%; T=-10°C; n_1=600 rev/min; Q=1.5kN

c) Initial structure for steel grade OLC 45, thermally treated.

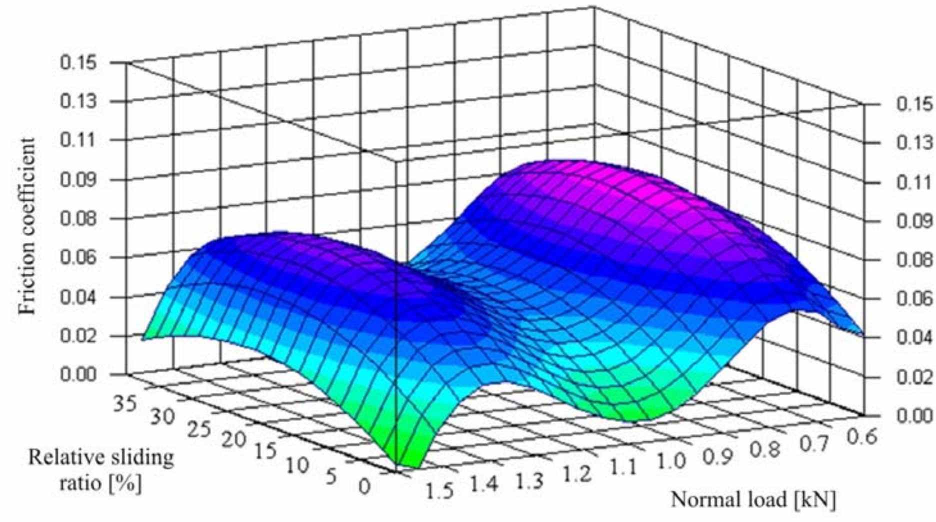


a) Severely worn roller: ξ=16.3%; T=-16.3°C; n_1=750 rev/min; Q=1.5kN

Figure 13. Macrostructures of the rollers (magnification 50:1)



a) for the grease grade UM185Li2EP



b) for the grease grade UM170LiCaPb2(M)

Figure 14. Friction coefficient as a function of relative sliding rate and normal load

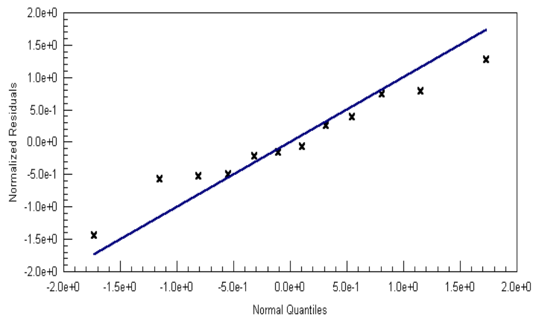
The most favourable regime was that with high loads, the values of friction coefficient varying in a narrow range for the two different rolling-sliding regimes and it could be explained by a rapid flattening of the surface asperities for both triboelements, the stabilized regime beginning earlier as compared to tests done under smaller normal load.

For the grease grade UM170LiCaPb2(M) the regression equation of the friction coefficient as a function of relative sliding ratio and normal load is:

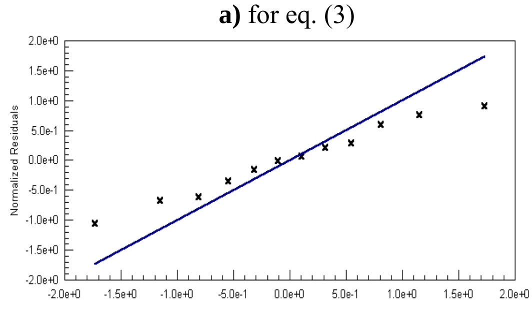
$$\mu = a + b \cdot \xi + c \cdot \xi^2 + d \cdot lgQ + e \cdot lgQ^2 + + f \cdot lgQ^3 + g \cdot lgQ^4 + h \cdot lgQ^5 \quad (4)$$

where μ - the friction coefficient, ξ - the relative sliding ratio [%], Q – the normal load [here in kN]; the values of regression coefficients are given in table 2.

The error diagrams (figure 15) reveals a spread of measured values both above and under the average line, in a narrow range, meaning that the regression equations are acceptable.



a) for eq. (3)



b) for eq. (4)

Figure 15. Error diagrams

Table 2. Values of the regression coefficients

Variable	Value	Standard error	t-ratio	Probability (t)
Values of the regression coefficients for eq. (3)				
a	0.007014	0.00799	0.877865	0.41378
b	0.002632	0.000705	3.733244	0.0097
c	0.079677	0.023538	3.385068	0.01477
d	-3.73E-05	1.73E-05	-2.15401	0.07469
e	0.184837	0.054365	3.399943	0.0145
f	-0.00366	0.001055	-3.47342	0.01325
Values of the regression coefficients for eq. (4)				
a	0.010305	0.020316	0.507207	0.63869
b	0.003064	0.001791	1.710755	0.1623
c	-6.27E-05	4.43E-05	-1.415226	0.22992
d	0.030178	0.100702	0.299674	0.77935
e	0.676152	0.508113	1.330712	0.25407
f	-0.21541	0.905049 6	-0.226629	0.83182
g	-4.03068	3.048167	-1.322329	0.2566
h	-3.647003	4.043756	-0.901885	0.41811

Taking into account the average values of the friction coefficient for the done tests, a 3D diagram was drawn (Figure 14b) that has a different aspect as compared to that in figure 14a, obtained for grease grade UM185Li2EP.

When testing at elevated temperatures (90…100°C), viscosity of grease grade UM170LiCaPb2(M) rapidly decreased (thus, it could be qualified as of poorer quality as compared to UM185Li2EP), due to an intermittent film generation or even the intermittent absence of this one, the regime could be qualified as mixt. From this 3D representation one may notice a more reduced influence of the relative sliding ratio on the friction coefficient as compared to the normal loading influence, that one being much higher. Greater values of friction coefficient are obtained for loads in the range 0.65…0.7 kN and 1.2…1.3 kN, respectively.

One may notice that the values of the friction coefficient are still in a range acceptable for lubricated contact between triboelements made of steel**.**

5. CONCLUSIONS

Using a certain grease grade as lubricant in tribo-systems functioning in severe or/and extreme conditions, has to be done after testing several grades under nearly similar parameters as those in actual applications and then recommending the better.

3D diagrams may be used for selecting functioning conditions to be in the range of acceptable friction coefficient, to avoid regimes with higher probability of damaging the triboelements, because they could bring together the cumulative influence of two or more influencing factors.

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