Secure Systems Design and Technology Development. Veliko Tarnovo, Bulgaria
Proceedings of the International Scientific Conference, 2026. Volume II, 145-150

Multifactorial Study of the Influence of an Anamegator on Oil on the Change in the Tribotechnical Parameters of the Friction Pair

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***Abstract*— The addition of an anamegator to the oil directly affects the change in the tribotechnical parameters of the friction pair by changing its operating environment. The article presents a multivariate study of the influence of the addition of an anamegator to the lubricating medium on the change in the tribotechnical parameters of a friction pair. The main objective is to evaluate the effect of the additive on friction and wear processes under different operating conditions, expressed by the change in roughness. Some of the main factors affecting the operation of friction surfaces are considered, such as load, sliding speed, temperature and concentration of the anamegator in the oil. The experimental methodology is described, including laboratory tests using a specific tribological bench and measuring the mass of the samples. The article analyses the results obtained by statistical methods for multivariate analysis, and it is found that the addition of an anamegator has a significant impact on improving lubrication performance and reducing wear under certain operating modes. The optimal values of the studied factors and the possibilities for practical application of the results are discussed.**

Keywords*— tribology, anamegator, multivariate analysis, experiment planning.

I. Introduction

Tribological processes related to friction, wear and lubrication of contact surfaces play a key role in the reliability, efficiency and durability of machines and mechanisms [1]. In the conditions of modern engineering, there is a growing interest in the development and application of various additives to lubricants aimed at improving their performance characteristics [2]. Among these additives, special attention is paid to the so-called. anamegators, which affect the structure and properties of the lubricating film and the interaction between friction surfaces [3]-[4].

Additives to lubricating oils can significantly alter the mechanism of friction and wear by forming protective layers, reducing adhesion interactions, and improving heat dissipation [5]-[6]. In this context, the study of the effect of different concentrations of additives under a variety of operating conditions is an important scientific and practical task. It is particularly important to analyse the influence of parameters such as load, sliding speed and temperature, which determine the friction mode and, accordingly, the degree of wear.

Modern approaches in tribology include the use of experimental methods combined with statistical tools to analyse the results. Multivariate analysis and experiment planning allow for the simultaneous study of the influence of several variables and their interaction on baseline indicators [7]. This allows for more accurate modelling of real working conditions and determining optimal parameters to minimize wear.

One of the important indicators for assessing the condition of friction surfaces is roughness, which reflects changes in microgeometry as a result of tribological processes. A decrease in roughness is usually associated with an improvement in lubrication mode and lower

Online ISSN 3044-7771
https://doi.org/10.68302/std2026.vol2.184

friction coefficient values [8]. Therefore, the analysis of this parameter provides valuable information about the effectiveness of the additives used.

This article aims to investigate the effect of adding an anamegator to lubricating oil on the tribotechnical performance of a friction pair by applying a multifactorial experimental approach. The main factors determining the operating mode are considered and their interaction on the change in the mass of samples is evaluated. The results of the study are aimed at determining optimal working conditions and expanding the possibilities for practical application of additives in industrial systems.

II. Method of work

For this article, laboratory accelerated tests of reciprocating motion have been carried out. Samples and counterbodies of the most commonly used materials in transport equipment were used. The experiments were carried out with a certain duration, not taking into account the pairs' operation. The prototypes are X9CrMov10 steel, GG25 cast iron and CuSu7 bronze. The friction pairs are of the steel-steel, steel-cast iron and steel-bronze type. The counterbodies are made of the steel mentioned above. The experimental setup of this article uses a standard bench for testing friction pairs in an oily medium operating on a reciprocating motion (Fig. 1).

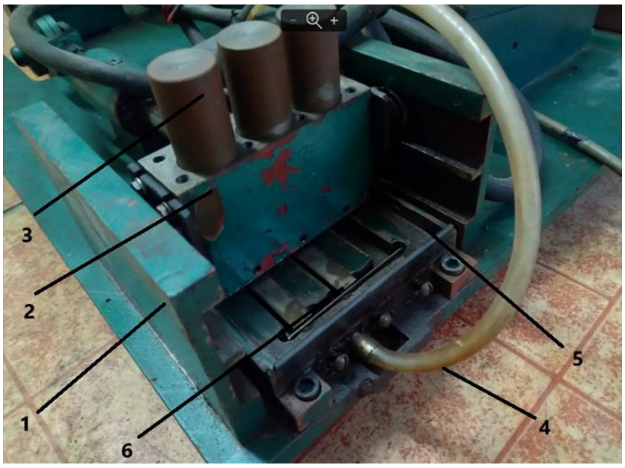

Fig. 1. General appearance of the rubbing and wear stand. 1-building; 2-body; 3-caps ; 4-Oil leak hose; 5-oil bath; 6-counterbody.

The housing 1 together with the oil bath 5 are fixed. In the bathtub are located the counterbodies 6. The body 2 bears in grooves of the hull and is movable, with which it makes a stroke of 120 mm. The load on the friction pair is carried out by turning the caps 3. Below them are springs with a known deformation curve. The springs press the cylindrical specimens onto the counterbodies 6. The grooves in the housing are the other support for the implementation of the weight. Body bearings help to significantly reduce friction in the ligaments. The whole friction process takes place in an oil bath 5. The counterbodies are fixed to the bathtub by means of fixing screws at the end.

Body 2 performs the reciprocating movement through an electric motor with a washer and arm. The reverse progressive movement is carried out by an eccentrically located hole of the washer and an arm attached to it.

The oil used is CLAAS AGRIMOT Protec10W40, covering the ACEA E9 / API CK-4 standard and according to the technical specifications of MAN M3775, DEUTZ DQC III-18LA, etc. [9]. It was preheated at a temperature of 80^0 C and added to it the Gold Ozirol MP-8 oil anamegator in a ratio of 4.8-9.2 ml/L [3], [10].

According to literature sources, the load on the pair was chosen 50 N for the purpose of comparability of the results [1]-[2], [11]-[12].

Laboratory experiments were carried out in cat. "Materials Science and Technology of Materials" at the University of Ruse "An. Kanchev" in the period March-April 2026.

The dynamics of wear of specimens and counterbodies was investigated by determining weight loss using a Sartorius TE214S scale with 210 g and an accuracy of 0.1 mg [13].

During a period of one hour of operation, the samples and counterbodies are removed from the stand, washed with acetone and subjected to measurements.

III. Results and discussion

In this article, two factors influencing the change in the tribotechnical parameters of the friction pair are studied (Table 1).

TABLE 1 FACTORS AND LEVELS OF VARIATION

Factor	Name	Level of variation		
		-1	*0*	*+1*
X1	Quantity of anamegator, ml	4,8	7,0	9,2
X2	Type of friction pair	Br-St	Ir-St	St-St

In Table 1, for easier handling of the factors, their coded values are also given. The trials were carried out according to plan B2 with nine trials. The plan is orthogonal, centred with the need to conduct experiments at nine-star points, including the centre point [14].

One of the factors X1 is the amount of the anamegator to the oil, and the other X2 is the type of friction pair. At X1, the average value is 7.0 ml/L and a level of variation of ±2.2 ml/L. At X2, the average value is the Ir-St cast iron-steel pair, and the variation is from the mild bronze-steel pair Br-St to the St-St hard steel. Steel specimens and counterbodies are hardened to a hardness of 50 HRC according to ISO 6508-1:2023 [15].

After completing 3h experiments for each of the variants, the results are processed statistically and given in the tables.

TABLE 2 ANALYSIS OF VARIANCE FOR SAMPLE MASS

Factor	SS	df	MS	F	p	% effect
X1	17.001	2	8.500	6647.147	0.00000	32.17

X2	5.757	2	2.878	2250.819	0.00000	10.89
Time	0.047	3	0.016	12.283	0.00156	0.09
X1*X2	29.993	4	7.498	5863.622	0.00000	56.76
X1*Time	0.013	6	0.002	1.677	0.23288	0.02
X2*Time	0.023	6	0.004	2.976	0.06908	0.04
Residual	0.012	9	0.001	nan	nan	0.02

In Table 2 are presents the Analysis of Variance (ANOVA) for the mass of the samples. It is noticed that all the main factors + the interaction X1×X2 actually affect the change in the mass of the samples. It was noticed that during the experiments, the confidence interval was too high. The duration does not have a significant impact on the change in the mass of the samples. All other factors are significant, with the greatest impact on wear being observed in X1*X2 with an efficiency of 56.76%. The amount of the anamegator factor X1 affects more strongly than the type of friction pair or 32.17% on the change in the mass of the samples.

The error in conducting the experiments was 0.012 or less than 0.02%. This indicates that the experiment is stable and the model explains almost everything.

TABLE 3 STATISTICS ON THE CHANGE IN THE MASS OF SAMPLES

X1	X2	Mean	Std	CV%	Min	Max
-1	-1	13.6597	0.0334	0.25	13.6364	13.7072
-1	0	12.1898	0.0723	0.59	12.1536	12.2982
-1	1	13.5556	0.0369	0.27	13.5371	13.6108
0	-1	15.0340	0.0757	0.50	14.9490	15.1191
0	0	12.2685	0.0775	0.63	12.1536	12.3237
0	1	12.4995	0.0113	0.09	12.4938	12.5165
1	-1	13.5988	0.1070	0.79	13.5371	13.7583
1	0	12.3237	0.0000	0.00	12.3237	12.3237
1	1	13.6654	0.0128	0.09	13.6590	13.6845

Table 3 shows the change in mass over the entire period of the experiment. The large change in the values of X1 and X2 is normal because different amounts of the anamegator affect different types of friction pairs. The smallest wear or minimum occurs at X2=0 or when the cast iron is rubbed. This is explained by the very structure of cast iron and its ability to absorb more of the oil with the anamegator in it. We know that the anamegator increases glide and reduces friction many times over. Its particles enter the pores of cast iron, and from there probably areas of reduced friction are obtained. On the other hand, hard steel samples and soft bronze have the opposite effect. The amount of the anamegator affects different friction pairs differently due to structural differences in their crystal structure. All CV% are between 0.00% and 0.79%. This is good because the measurements obtained are very stable, there is almost no noise, and at 0.00% there is almost perfect repeatability.

There is almost no randomness in the data because $R^2 = 0.9996$ and the model explains 99.96% of the variation. In this model, Adjusted $R^2 = 0.9986$. This shows the reality of the data presented.

The average prediction error is RMSE = 0.0190. The forecasts are extremely accurate and the error is almost zero in relation to the scale.

Residue scattering Variance = 0.0004. The pattern captures almost the entire structure and there are no hidden variations.

In the other indicator, Signal / Noise = 692.97. The signal is 692 times stronger than the noise or the pattern is very well represented.

The Shapiro residue normality test p = 0.33249 indicates that the residues are normally distributed, the model is statistically valid, and there are no regression problems.

The equation for the change in the mass of the specimens takes the form:

$$y = 13{,}142 + 0{,}162.X1 - 0{,}258.X2 + 0{,}970.X1.X2 \quad (1)$$

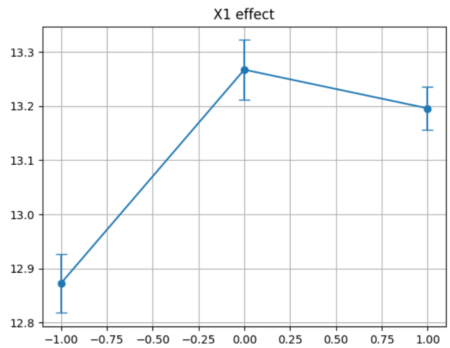

Fig. 2. The effect of X1 on the change in the mass of samples.

In Fig. 2 shows the effect of the application of the anamegator on the change in the mass of the samples during the experiment period. The maximum is clearly expressed at X1=0 and subsequently decreased. The left section of the graph shows a strongly positive effect from the growth of the anamegator to X1=0, and the right one shows a slight negative effect. Small amounts of the anamegator have a positive effect, which is best expressed at 7 ml/L. Preservation of sample mass is best in this range. An overdose is also not a very good option, due to a violation of the tribotechnical characteristic of the oil layer.

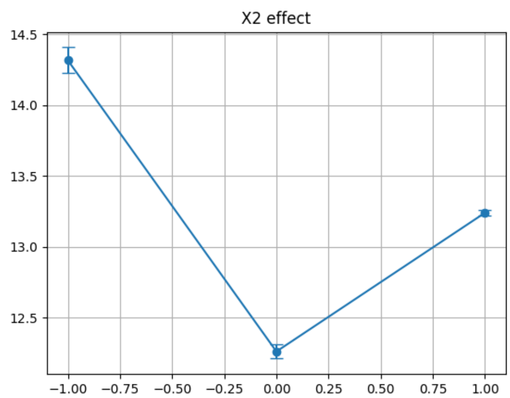

Fig. 3. Effect of X2 on the change in the mass of samples.

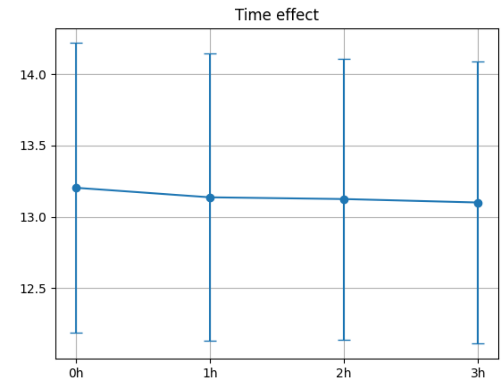

Fig. 4. Evolution of the average mass of samples.

In Fig. 3 shows the effect of the other factor X2 on the change in the mass of the samples. Here the minimum is expressed again in the zero value of the factor or in the case of a friction pair of cast iron-steel.

Figure 4 shows the dynamics of the change in the average value of the samples during the experiment. It is noticed that in the first hour the wear is the greatest, which is characteristic of the stage of operation.

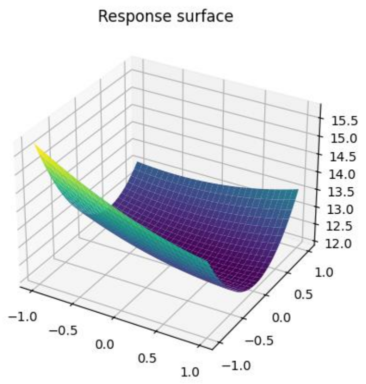

Fig. 5. 3D model of influence of factors on change in the mass of samples.

In Fig. 5 shows the three-dimensional model of influence of factors on the change in the mass of the samples. The parabola with the minimum is clearly expressed. The influence of X1 and the weaker influence of X2 is clearly expressed.

TABLE 4 ANALYSIS OF VARIANCE FOR THE MASS OF COUNTERBODIES

Factor	SS	df	MS	F	p	% effect
X1	2679.082	2	1339.5408	862071.09	0.0000	34.16
X2	2503.777	2	1251.8887	805661.94	0.0000	31.93
Time	0.034	3	0.0113	7.25	0.0089	0.00
X1*X2	2659.541	4	664.8853	427891.69	0.0000	33.91
X1*Time	0.002	6	0.0003	0.22	0.9615	0.00
X2*Time	0.006	6	0.0009	0.60	0.7231	0.00
Residual	0.014	9	0.0016	nan	nan	0.00

Table 4 shows the ANOVA analysis of the change in the mass of the counterbodies during the experiments. The X1 factor with the high F explains 34.16% of the variations. This repeats what was said above about the mass of the samples. Due to the fact that the counterbodies are made of the same material, X2 explains 31.93% of the variations. The coefficient for the time of the experiment is statistically significant at F=7.25 and p=0.008, but its effect is very small. In contrast, the interaction X1*X2 explains 33.91% of the variations. The remainder is 0.014. This indicates that the model explains almost all of the variation.

Table 5 shows the statistical data from the experiment.

TABLE 5 STATISTICS ON THE CHANGE IN THE MASS OF THE COUNTERBODIES

X1	X2	Mean	Std	CV%	Min	Max
-1	-1	199.3100	0.0550	0.028	199.2500	199.3800
-1	0	197.1098	0.0428	0.02	197.0722	197.1714
-1	1	201.7386	0.0000	0.00	201.7386	201.7386
0	-1	200.2687	0.0754	0.04	200.2077	200.3778
0	0	198.8774	0.0538	0.03	198.7987	198.9206
0	1	204.1710	0.0000	0.00	204.1710	204.1710
1	-1	200.0496	0.0461	0.02	199.9894	200.0858
1	0	197.9241	0.0482	0.02	197.9000	197.9964
1	1	198.2820	0.0632	0.03	198.1920	198.3366

Factor X2 has a strong nonlinear effect. The effect of X1 is clearly expressed at X1=0. Here again there is a repetition with the change in the mass of the samples.

The coefficient of variation is minimal in almost all counterbodies. This confirms that the measurements obtained are noise-free and correct.

And here there is almost no randomness in the data, because $R^2 = 0.9999$ and the model explains almost 100% of the variation. In this model, Adjusted $R^2 = 0.9997$. This again shows the reality of the data presented.

The average prediction error is RMSE = 0.0209. The forecasts are again extremely accurate and the error is almost zero in relation to the scale.

The scattering of the residues Variance = 0.0004, the same as the samples. The pattern captures almost the entire structure and there are no hidden variations.

In the other indicator, Signal / Noise = 9557.5933. The signal is 9557 times stronger than the noise or the model is excellently represented**.**

The Shapiro residue normality test p = 0.88181 again shows that the residues are normally distributed, the model is statistically valid, and there are no regression problems.

The equation of change in the mass of the counterbodies takes the form.

$$y = 198{,}88 + 0{,}41.X1 + 1{,}95.X2 - 2{,}75.X1.X2 - 0{,}85.X1^2 + 2{,}60.X2^2 \quad (2)$$

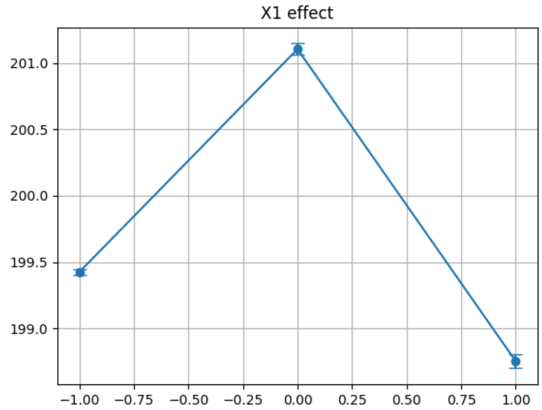

Fig. 6. The effect of X1 on the change in the mass of the counterbodies.

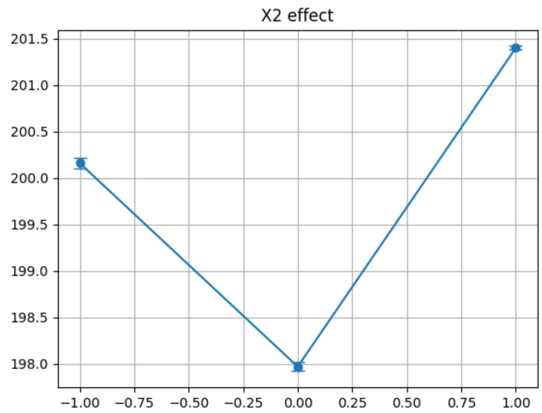

Fig. 7. Effect of X2 on the change in the mass of the counterbodies.

In Fig. 6 shows the effect of X1 on the change in the mass of the counterbodies. The factor has a strong effect and a non-linear character with an optimum in the centre. It is clearly shown that at X1=0 there is a pronounced maximum. With an increase in the supplement, the effect of an overdose is expressed by a decrease in the mass of the counterbodies.

In Fig. 7 shows the effect of the other factor X2 on the change in the mass of the counterbodies. A pronounced U shape is observed on the graph. A global maximum is observed at X2=1. The intensity of the change in the mass of the counterbodies working with cast iron is the greatest. In the case of steel counterbodies, this change is negligible, with slightly greater wear occurring in bronze counterbodies.

In Fig. 8 shows the dynamics of change in the average value of the mass of the counterbodies during the experiment. A uniform process of wear of the counterbodies is noticeable. The intervals are very wide and overlap strongly. This shows that the differences between the times are almost indistinguishable. The effect is negligible and has negligible impact on the wear process.

In Fig. 9 shows the three-dimensional model of influence of factors on the change in the mass of the counterbodies. The peak is clearly expressed in yellow, after which the values decrease. Conversely, the minimum is expressed in a blue-purple color. The system does not react linearly, but a combination of factors is taken into account.

The wear of the specimens, the counterbodies and the pair as a whole can be given with the formula:

$$I = m_i - m_f \tag{3}$$

where m_i is the initial value of the mass, g;

m_f – the final value of the mass, g.

According to the formula given in this way, the wear of the specimens, the counterbodies and the pair is determined. The result is presented in Table 6.

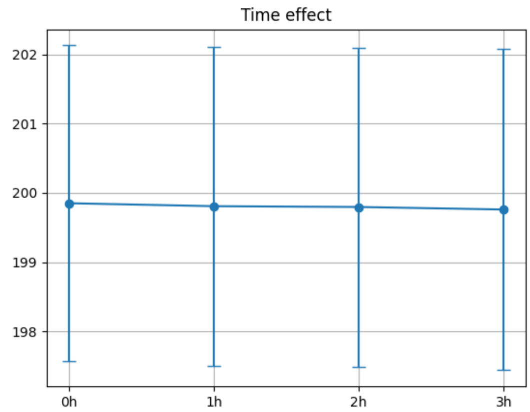

Fig. 8. Evolution of the average mass of counterbodies.

The above for the factor X1 is also confirmed by the results in Table 6. The lowest wear rate shall be obtained for specimens and counterbodies operating at a factor of X1=0, followed by X1=1.

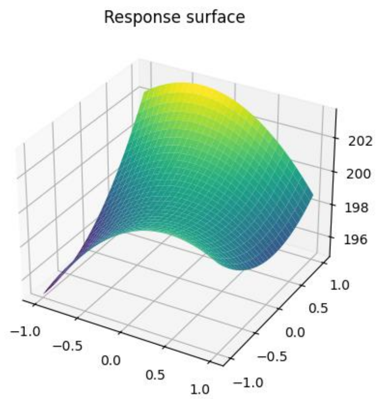

Fig. 9. 3D model of influence of factors on change in the mass of counterbodies.

TABLE 6 SIZE AND WEAR RATE OF THE PAIR

X1	X2	I_S, g	I_{CONTRA}, g	I_C, g	V, mg/s
-1	-1	0,070875	0,05103	0,121905	0,0112875
-1	0	0,144585	0,099225	0,24381	0,022575
-1	1	0,07371	0	0,07371	0,006825
0	-1	0,1701	0,1701	0,3402	0,0315
0	0	0,1701	0,121905	0,292005	0,0270375
0	1	0,02268	0	0,02268	0,0021
1	-1	0,22113	0,09639	0,31752	0,0294
1	0	0	0,09639	0,09639	0,008925
1	1	0,025515	0,144585	0,1701	0,01575

IV. CONCLUSIONS

Based on the analysed results and statistical data, the following main conclusions can be drawn:

The addition of an anamegator has a significant impact on improving lubrication performance and reducing wear. The greatest influence on wear is the interaction between the amount of anamegator (X1) and the type of friction pair (X2), which explains 56.76% of the variation in samples.

Small amounts of the anamegator have a positive effect, with the best results for maintaining the mass of specimens being observed at a concentration of 7 ml/L (zero level of factor X1). An overdose (over 7 ml/L) leads to a slight negative effect due to a violation of the characteristics of the oil layer.

The lowest wear is recorded in the friction pair of cast iron and steel (Ir-St). This is due to the porous structure of cast iron, which allows better absorption of oil with the anamegator and the creation of zones of reduced friction.

In the case of specimens, wear is most intense during the first hour of operation, which corresponds to the stage of surface operation. With counterbodies, the wear process proceeds more evenly.

The mathematical models used are extremely accurate, with a coefficient of determination R2 above 0.999, which means that they explain almost 100% of the variations in the experimental data.

ACKNOWLEDGMENTS

The author/s would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

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