GENERALIZED METHODS OF ESTIMATIONS OF LUBRICANTS' INFLUENCE ON THE TRIBOTECHNICAL CHARACTERISTICS OF FRICTION PAIR "STEEL-STEEL" ON THE FOUR-BALL MACHINE

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Abstract: This article is devoted to the development of generalized methods of estimations of lubricants influence on the tribotechnical characteristics of friction pair "steel-steel" and its usage for selection of the best lubricating material out of set of materials "Litol-24"produced by different manufacturers.

1. INTRODUCTION

To the main raw materials for manufacture plastic lubricants of various purpose serve:

1. mineral oils of various viscosity and a degree of clearing;
2. hydrocarbonic thickeners (petrolatums, cherezins, paraffins);
3. soaps of the fat acids allocated from natural fats, and natural fats of an animal and a phytogenesis;
4. soaps of synthetic fat acids;
5. various products of chemical synthesis (silicon-organic liquids, complex ethers, dyes, etc.).

Besides the additives improving their separate properties or some of different properties (multipurpose), and also inhibitors of oxidation are entered into plastic lubricants (PL), inhibitors of corrosion and other components.

In this connection plastic lubricants have the complex chemical compound defining their operational properties.

During the production process of any lubricant *S*, its manufacturer follows the requirements of the state standard. As any lubricant can be produced by a different manufacturer, that is why in a number of cases, it is necessary to compare the influence of different grades of lubricant *S* on tribotechnical characteristics of friction pair. Thus, the Department of Machine Science and machine Components of Saint-Petersburg State Polytechnic University carried out estimation of the influence of different grades of lubricant "Litol-24" on the tribotechnical characteristics of friction pair "steel-steel".

Complexity of chemical compound PL is one of the major factors influencing distinction of properties of same products at different manufacturers.

2. RESEARCH METHODOLOGY

The research of the influence of the lubricating materials from the set $\{Sm_i \mid 1, 2, ..., p\}$ (*S* – name of the lubricant material, m_i – grade of the lubricating material *S*, *p* – quantity of grades (manufacturers) of the lubricating material *S*) on tribotechnical characteristics of the friction pair "steel-steel" is carried on the basis of grades numbering scheme according to the following algorithm:

1. Wearing test of the lubricant *S* of the manufacturer "*p*" is carried out on the friction test machine CH_SH_M 3,2 (GOST 9490-88).
2. Microhardness measurement of the sample friction surfaces is conducted using microhardness-meter PMT-3 (GOST 9450-76).
3. Two best lubricants from *p* are selected and then tear index test is carried out (GOST 9490-88).
4. Selection of the best lubricating material in the examined set is performed.

Friction pair elements, which are used in the wearing tests and tear index tests, are balls of the bearings GOST 3722. These balls are made of material "steel SHKH15", with diameter d_m = (12,70 +/– 0,01)mm. Normal ball loading at wearing tests is *P* = 196 N. Time for one test operation is Δt = (60,00 =/– 0,50) min.

Length $l_j(m_i)$ and width $h_j(m_i)$ of the wear spot # *j* (*j* = 1, 2, 3), which was formed at lubricant Sm_i tests, were measured with the microscope "Prima-expert". The diameter of wear spot # *j* corresponding to Sm_i is defined as follows:

$$d_j(m_i) = \frac{l_j(m_i) + h_j(m_i)}{2}. \qquad (1)$$

Mean diameter of the wear spot for lubricating materialSm_i is calculated by the following formula:

$$D_{И}(m_i) = \frac{1}{3} \cdot \sum_{j=1}^{3} \frac{l_j(m_i) + h_j(m_i)}{2}. \qquad (2)$$

Initial data, measurement and calculation results are given in Table 1.

Tab. 1. Wear test results

No (i)	P		$d_j(m_i)$ mm	$D_{И}(m_i)$ mm	Limiting wear d_r + 0,15 mm
	N	k			
Sm_1					
1	196	20	$d_1(m_1)$, $d_2(m_1)$, $d_3(m_1)$	$D_{И}(m_1)$	0,39
...					
...	...	...	...	...	...
Sm_p					
p	196	20	$d_1(m_p)$, $d_2(m_p)$, $d_3(m_p)$	$D_{И}(m_p)$	0,39

Microhardness measurement of the sample friction surfaces is conducted according to "restored dent method" (GOST 9450-76) using microhardness-meter PMT-3. Three (3) surface areas of the sample are tested: initial surface; friction surface without mass transfer section that is typical of abrasive wear; friction surface with mass transfer sections that is typical adhesive wear. The "q" (q – quantity of the dents) dents are marked in each area of the test sample subject to established distance between their centers.

Indentor diamond point is lowered by the counterclockwise turn of the loading unit rod handle till its contact of the test sample surface during t_K = 10 ... 15 s. Then the indentor is held down during $t_{y\partial}$ = 30 s under the load. Measuring of indentor dent parameters (Fig. 1) is carried out by the microscope with 100 x magnification [1-7].

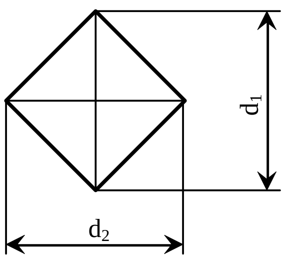

Fig. 1. Indenter dent parameters

Tab. 2. The results of microhardness measurements (i = 1, 2, ..., p, this complex symbol means the availability of p tables of reduced type)

Lubricating material · Sm_i									
	Abrasive wear			*Adhesive wear*			*Initial surface*		
k	$d_{1,k}$	$d_{2,k}$	d_k	$d_{1,k}$	$d_{2,k}$	d_k	$d_{1,k}$	$d_{2,k}$	d_k
1	$d_{1,1}$	$d_{2,1}$	d_1	$d_{1,1}$	$d_{2,1}$	d_1	$d_{1,1}$	$d_{2,1}$	d_1
...	...	...	...	...	...	...	...	...	...
q	$d_{1,q}$	$d_{2,q}$	d_q	$d_{1,q}$	$d_{2,q}$	d_q	$d_{1,q}$	$d_{2,q}$	d_q
			d			d			d
			Microhardness $HV_{a\partial}$			$HV_{a\partial z}$			HV

The results of the measurements and calculations are listed in Table 2.

The diagonal length of k (k = 1, 2, ..., q) indentor dent in the selected area is defined by the formula:

$$d_k = \frac{d_{1,k} + d_{2,k}}{2}. \qquad (3)$$

Mean length of the indentor dent diagonal in the same area:

$$d = \frac{1}{q} \cdot \sum_{k=1}^{q} \frac{d_{1,k} + d_{2,k}}{2}. \qquad (4)$$

After the measurement of obtained dents parameters and calculations using of relations (3) and (4), microhardness is defined by the formula (Glazov and Vigdorovich, 1969):

$$HV = 1854 \cdot \frac{F}{d^2}, \qquad (5)$$

where F gf – force, acting on indentor, F = 50gf = $const$, d – mean length of the indentor dent diagonal (μm), HV – microhardness value (kgf/mm^2).

By comparing the results, listed in the Tables above, the selection of the two best lubricating materials $\{Sm_a; Sm_b\}$ is carried out from the set $\{Sm_i \mid i = 1, 2, ..., p\}$.

Tear index tests of the selected lubricating materials Sm_a; and Sm_b are conducted as per GOST 9490-75.

From the load series $\{P_\alpha \mid \alpha = 1, 2, ..., 23\}$ the set of adjacent loads $\{P_\beta \mid 1 \le \beta \le 23\} = \{P_\gamma \mid \gamma = 1, 2, ..., n\}$ is selected. The elements of this set are renumbered and located in the monotone increase or monotone decrease order. The length of the tests at fixed load from the set is $\Delta t'$ = (10,0 +/– 0,2)s. The diameter of j – wear spot for lubricating material $\{Sm_i \mid i = a, b\}$ at fixed load P_γ, taking into consideration (1), is defined as follows:

$$d_j(m_i, P_\gamma) = \frac{l_j(m_i, P_\gamma) + h_j(m_i, P_\gamma)}{2}. \qquad (6)$$

Mean diameter of wear spots is similarly (2):

$$d_{И\gamma}(m_i) = \frac{1}{3} \cdot \sum_{j=1}^{3} \frac{l_j(m_i, P_\gamma) + h_j(m_i, P_\gamma)}{2}. \qquad (7)$$

According to GOST 9490-88 the limiting wear values series $d_{np\alpha} = d_{r\alpha}$ + 0,15 mm is put as one-to-one dependantizer to the load series 1. Thereby, for the set:

$$d_{np\gamma} = d_{r\gamma} + 0{,}15mm, \qquad (8)$$

where $d_{r\gamma}$ – diameter of the balls' elastic range of stress according to Herz (mm), at load P_γ, H(kgf).

Conditional load, corresponding to axial load P_γ, at lubricating material $\{Sm_i \mid i = a, b\}$ tests can be found from the following relation:

$$Q_\gamma(m_i) = P_\gamma \cdot \frac{d_{r\gamma}}{d_{И\gamma}(m_i)}. \qquad (9)$$

Tear index is calculated by the following formula:

$$И_3(m_i) = \frac{\sum_{\gamma=1}^{n} Q_\gamma(m_i)}{n}. \qquad (10)$$

Initial data, measurement and calculation results are presented in Table 3.

Tab. 3. The results of tear index tests (*i* = *a*, *b*; this record means that this table is used twice)

No (γ)	P_γ		$d_j(m_i, P_\gamma)$	$d_{И\gamma}(m_i)$	$d_{np\gamma}$	$P_\gamma \cdot d_{r\gamma}$	$Q_\gamma(m_i)$
	N	kgf					
1	P_1		$d_1(m_i, P_1)$ $d_2(m_i, P_1)$ $d_3(m_i, P_1)$	$d_{И1}(m_i)$	d_{np1}	$P_1 \cdot d_{r1}$	$Q_1(m_i)$
2	P_2		$d_1(m_i, P_2)$ $d_2(m_i, P_2)$ $d_3(m_i, P_2)$	$d_{И2}(m_i)$	d_{np2}	$P_2 \cdot d_{r2}$	$Q_2(m_i)$
...	...		...	...	...	...	...
n	P_n		$d_1(m_i, P_n)$ $d_2(m_i, P_n)$ $d_3(m_i, P_n)$	$d_{Иn}(m_i)$	d_{npn}	$P_n \cdot d_{rn}$	$Q_n(m_i)$
						Tear index	$И_3(m_i)$

By the difference $\Delta И_3 = И_3(m_a) - И_3(m_b)$ the best lubricant can be found.

3. PROCESSING OF RESEARCH RESULTS

For comparative researches it is expedient to use the plastic lubricants most widely presented in the market.

„Litol-24" was selected as tested lubricating material *S*. The grades quantity (the number of manufacturers) for the research was taqen as $p = 4$. The lubricant material grades were as follows, m_1: "*OLLRIGHT*", m_2: "*Misma Ross*", m_3: "*ARGO*" and m_4: "*BMP auto*".

After wear tests of the lubricants and calculations using equations (1) and (2) the following values of mean diameter of the wear spot were obtained:

1. $D_И(OLLRIGHT) = 0{,}50mm$;
2. $D_И(Misma \quad Ross) = 0{,}33mm$;
3. $D_И(ARGO) = 0{,}35mm$;
4. $D_И(BMP \quad auto) = 0{,}41mm$.

These data confirm distinctions of a chemical compound which can be caused not only character of productions, but also changes during ageing lubricants.

Influence test specifications of lubricants and render also properties of used metal samples.

For microhardness measurement the quantity of indentor dents in each of the tested surface area was taken as $q = 5$. After marqing and measurement of indentor dents and calculations applying (3), (4) and (5), the following values of microhardness in the initial surface area were obtained:

1. $HV(OLLRIGHT) = 181{,}03kgf \setminus mm^2$;
2. $HV(Misma \quad Ross) = 146{,}09kgf \setminus mm^2$;
3. $HV(ARGO) = 138{,}88kgf \setminus mm^2$;
4. $HV(BMP \quad auto) = 188{,}05kgf \setminus mm^2$.

The microhardness values in the abrasive wear area:

1. $HV_{аб}(OLLRIGHT) = 153{,}85kgf \setminus mm^2$;
2. $HV_{аб}(Misma \quad Ross) = 126{,}04kgf \setminus mm^2$;
3. $HV_{аб}(ARGO) = 95{,}36kgf \setminus mm^2$;
4. $HV_{аб}(BMP \quad auto) = 151{,}21kgf \setminus mm^2$.

The microhardness values in the adhesive wear area:

1. $HV_{адг}(OLLRIGHT) = 138{,}91kgf \setminus mm^2$;
2. $HV_{адг}(Misma \quad Ross) = \varnothing$; (The sign $\varnothing$ (empty set) means the absence of adhesive wear area.)
3. $HV_{адг}(ARGO) = \varnothing$;
4. $HV_{адг}(BMP \quad auto) = 174{,}40kgf \setminus mm^2$.

Fluctuations of microhardness are caused by anisotropy of mechanical properties of metal samples and character of adsorption of surface-active substances on a surface of friction. Influence can render and the maintenance polarly active products of oxidation of components PL.

Considering the values of wear spot mean diameter and microhardness values (the absence of adhesive wear areas) the following lubricating materials were selected for tear index tests – Sm_2: *Litol* – 24(*Misma Ross*) and Sm_3: *Litol* – 24(*ARGO*). From the load series 1 the set of employment $\{P_\gamma \mid \gamma = 1, 2, ..., 6\} = \{32$ *kgf*, 40 *kgf*, 50 *kgf*, 63 *kgf*, 80 *kgf*, 100 *kgf*, $\}$ was chosen. Its elements were arranged in the monotone increase order.

After tear index tests of these lubricating materials and taking into consideration the formulas (6), (7), (8), (9) and (10) the following values of tear index were received:

1. $И_3(Misma \quad Ross) = 323N$;
2. $И_3(ARGO) = 343N$.

Material: *Litol* – 24(*Misma Ross*) has less tear index than material. The difference is the following: $\Delta И_3 = И_3(m_3) - И_3(m_2)$ = 343 N – 323 N = 20 N.

Thus, in case of lubricating material change from lubricant: *Litol* – 24(*ARGO*) to lubricant Sm_2: *Litol* – 24(*Misma Ross*) the tear index decrease, by 5 – 6%.

It is possible to assume, that in lubricant Litol - 24 (ARGO) contains more anti-adhesion polarly-active components, than in plastic lubricant Litol - 24 (Misma Ross). It can be caused both production, and process of ageing during storage of a product.

As products of ageing there can be such polarly-active components as:

1. Fat acids;
2. Spirits;
3. Complex ethers;

The given products are formed and change properties of plastic lubricants.

4. CONCLUSIONS

1. The developed generalized methods allow us to estimate the influence of any liquid or semisolid lubricating material of different grades on tribotechnical characteristics of friction pair "steel-steel" and choose the best lubricating materials.

2. The lubricating material Sm_2: *Litol* – 24 (*Misma Ross*) has the best anti-wear properties, mean diameter of wear spot – 0,33mm.
3. Anti-adhesion properties lubricant *Litol - 24 (ARGO)* has shown the best.
4. In communication with complexity of a chemical compound of the given lubricants there is a distinction anti-adhesion properties and character of influence of surface-active substances on a surface of friction of examinees of samples.
5. Differs and the bearing ability of the lubricant layer expressed in occurrence of zones of adhesive deterioration in case of use of one lubricants and absence of given zones at use of others.
6. In communication with complexity of a chemical compound of the given lubricants there is a distinction of anti-wearing properties and character of influence of surface-active substances on a surface of friction of examinees of samples.
7. Differs and the bearing ability of the lubricant layer expressed in occurrence of zones of adhesive deterioration in case of use of one lubricants and absence of given zones at use of others.
8. Following the executed analysis of microhardness measurements in the three areas it was established that:
   - initial surface has the highest microhardness;
   - microhardness of the worn area with abrasive type of wear is 15 – 20% lower than microhardness of the initial surface;
   - microhardness of the adhesive wear areas differs in extensive limits between the microhardness of the above mentioned areas.

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