EXPRESS METHOD FOR THE TESTING OF TRIBOTECHNICAL PROPERTIES OF LUBRICANTS

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Abstract

The paper presents the results of experimental study of the tribotechnical properties of lubricants on a unit that simulates the geometric, kinematic and force similarity of well drilling conditions. Bearings with different radial clearances and the same chemical-thermal treatment were investigated. Data registration was carried out on cathode, loop oscilloscopes and electronic recorders. The load on the bearing, the moment of rolling resistance on the journal, and the angular speed of rotation of the outer race were recorded. The temperature was registered using artificial and semi-artificial thermocouples. A strobotachometer was used to determine the portable speed of the rolling bodies. The external appearance of all rolling elements was investigated, metallographic analysis of thin surface layers of all rolling elements was carried out, mathematical processing of test results was carried out. It is shown that for the express assessment of the tribotechnical properties of lubricants, the amplitude value of the oscillation of the rolling resistance moment can be used.

Keywords:

Friction;
Lubrication;
Tribotechnical Properties;
Drilling.

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1. Introduction

The issues related to friction and lubrication have been studied for a long time [1-12], but still, the final inspection of the lubricant is carried out on a four-ball machine, which fixes the braking force, i.e. is studied the process statics. Modern triboengineering requires dynamic control.

The study of the wear on the full-scale sample of retaining drill bit bearing [13], which differs from the serial radial bearing by the chute depth, showed that such bearings could be used for rapid evaluation of the tribotechnical properties of lubricants in dynamics.

2. Experiment

The studies of full-scale sample wear were carried out on the installation, simulating the geometric, kinematic and force conditions similar to real drilling conditions.

The bearings having different radial clearance ($\delta = 0.05 \div 0.5$ mm) and the same chemical and thermal treatment were examined.

The recordings made on the cathode, loop oscillograph and electronic data recorders were as follows:

- bearing loads (up to 30 kN);
- rolling resistance on the cone pin, Nm;

- outer race rotation speed (up to 200 s⁻¹);
- temperatures by the use of artificial and semi-artificial thermocouples.

Strobotachometer determined the drive speed of the rolling elements.

After the test there was made:

- visual examination of the appearance of all rolling elements;
- metallographic analysis of thin surface layers of all rolling elements;
- statistical analysis of the test results.

The results of mathematical processing of the full factorial experiment with technical petroleum jelly:

The regression equation of rolling resistance moment (an average constant value):

$$y_1 = -0.095 + 0.00071x_1 + 2.8x_2 + 0.0055x_3,$$

where y_1 – rolling resistance on the cone pin, Nm; x_1 – load, N; x_2 – clearance, mm; x_3 – outer race rotation speed, s⁻¹.

$$R = 0.94; \Theta = 24.6.$$

Partial correlation coefficients:

$$r_{y_1x_1} = 0.9; r_{y_1x_2} = 0.76; r_{y_1x_3} = 0.6;$$

$$\Theta = 16; \Theta = 5.4; \Theta = 29.$$

Partial elasticity coefficients, where

$$y_1 = 16; \bar{x}_1 = 2 \cdot 10^4; \bar{x}_2 = 0.292; \bar{x}_3 = 58.8;$$

$$\Theta_{y_1x_1} = 79\%; \Theta_{y_1x_2} = 51\%; \Theta_{y_1x_3} = 20\%.$$

The regression equation for fluctuations of rolling resistance moment as regard to its average value (i.e. its fluctuations amplitude)

$$y_2 = -0.00436 + 0.000075x_1 + 0.5.8x_2 + 0.0082x_3,$$

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$$R = 0.97, \Theta = 47.$$

Partial correlation coefficients:

$$r_{y_2x_1} = 0.59; r_{y_2x_2} = 0.6; r_{y_2x_3} = 0.9;$$

$$\Theta = 2.7; \Theta = 2.8; \Theta = 40.$$

Partial elasticity coefficients, where

$$\bar{y}_2 = 7.6; \bar{x}_1 = 2 \cdot 10^4; \bar{x}_2 = 0.292; \bar{x}_3 = 58.8;$$

$$\partial_{y_1x_1} = 20\%; \partial_{y_1x_2} = 22\%; \partial_{y_1x_3} = 64\%.$$

The same experiments and calculations were carried out for water, drilling mud (bentonite) and drilling mud (bentonite) +5% of oil. The calculation results were summarized in tables 1 and 2. Table 1 shows the values R_i , Θ_R , r_{y_i} , $\partial_{y_i x_i}$ for rolling resistance moment. Table 2 shows the values R_i , Θ_R , r_{y_i} , $\partial_{y_i x_i}$ for fluctuations (amplitudes) of the rolling resistance moment as regard to its average value.

From the analysis it could be concluded that at average moment of rolling resistance, the degree of load influence does not practically change and remains high regardless of the lubricant and the type of drilling fluid ($r_{y_i x_i} = 0.91 \div 0.94$ where $\Theta > 2.5$, $\partial_{y_i x_i} = 74 \div 79\%$). The influence of the radial clearance and the outer race rotation speed is variable, so far as the lubricating properties improvement, the

degree of their influence depending on the clearance (δ) and the outer race rotation speed (ω) at the time of rolling resistance becomes insignificant.

Any significant effects of oil and oil emulsion additives in the bentonite mud on the change of average time of rolling resistance have not been identified.

The change of the rolling resistance moment fluctuations as regard to its average value is greatly influenced by the lubricant quality and the speed of rotation (see fig. 1).

The effect of the radial clearance and load on the rolling resistance moment fluctuations as regard to an average value in the studied range remains practically unchanged depending on the lubricity.

The influence of the outer race rotation speed with lubricating properties' improvement on the fluctuations of rolling resistance moment as regard to its average value is significant ($r_{y_i x_i} = 0.9 \div 0.98$).

Torque fluctuations with improved lubrication are reduced; the setting traces on the side surfaces of the chute have a lesser extent.

In drilling, there are three speed modes [14]:

Table 1 The results of mathematical processing of the readings of rolling resistance moment				
Liquid, drilling mud	R_i Θ_R	r_{y_i} $\partial_{y_i x_i}$		
		Load, kN	Clearance, mm	Speed, s^{-1}
Technical petroleum jelly	0.94 24.6	0.91* 79	0.76* 51	0.61* 20
Water	0.92 37	0.94* 77	0.2 6.9	0.81* 26.5
Clay mud	0.91 16.3	0.9* 74	0.3 13	0.34 8.2
Clay mud +5% of oil	0.92 18.7	0.91* 74	0.33 13	0.41 10

* significant relationship

Table 2 The results of mathematical processing of the amplitude readings of the rolling resistance				
Liquid, drilling mud	R_i Θ_R	r_{y_i} $\partial_{y_i x_i}$		
		Load, kN	Clearance, mm	Speed, s^{-1}
Technical petroleum jelly	0.97 47	0.591* 20	0.6* 22	0.9* 64
Water	0.98 83	0.24 3.6	0.56* 10.6	0.98* 50
Clay mud	0.93 19.8	0.3 8.6	0.36 11	0.92* 40
Clay mud +5% of oil	0.92 18	0.18 5.2	0.33 10.4	0.91* 20

* significant relationship

Fig.1. Influence of the outer race rotation speed on the rolling resistance moment fluctuations

Fig.2. Hardening a) and secondary hardening b) in thin surface layers of the chute

low-speed, when the angular velocity of the cutter ($\omega < 15 \text{ s}^{-1}$); medium ($\omega = 30\div 45 \text{ s}^{-1}$), and high-speed ($\omega < 100 \text{ s}^{-1}$).

The metallographic analysis of the thin surface layers shows that at a low-speed mode there are setting traces on the chute walls, and at the bottom there can be examined some setting and hardening (see fig. 2a), and secondary hardening sites are traced (see fig. 2b). The value of temperature flashes at the bottom of the chute reached $500\div 800 \text{ }^{\circ}\text{C}$.

At high-speed mode, there are setting on the chute walls; setting, hardening and secondary hardening (fig. 3b) at the bottom of the chute. The value of temperature flashes at the bottom of the chute reached $1000\div 1200 \text{ }^{\circ}\text{C}$. In this zone there is a block painting (fig. 3b), surface descaling, deep surface cracks are formed, as well as internal cracks without exposure (looks alike pitting (see fig. 3a).

With the mode change, the speed and especially the load, the portable speed of the rolling elements changes. It is either less than the calculated one and then we can assume that the rolling bodies are

Fig.3. The appearance of the chute looks alike pitting (a), secondary hardening and block painting (b)

«welded» to the cone pits, or higher, then the rolling bodies are «welded» to the outer race. All this is confirmed by the metallographic analysis of thin surface layers of rolling elements.

Conclusion

The experiments show that high-quality lubricants used in mechanical engineering at contact loads (up to 0.5 GPA) are not suitable for such contact loads as in drilling (up to 5 GPA). The quality of these lubricants is manifested only in friction between the rolling elements and the walls of the chute.

The experiments show that for high – quality lubricants, the average value of the rolling resistance moment at loads of not more than 0.5 GPA differs by 5-10 %, while the moment fluctuations as regard to its average value differ by 2-3 times.

Consequently, the amplitude value of the rolling resistance moment fluctuation can be used for express - evaluation of tribotechnical characteristics of lubricants.

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Экспресс метод оценки триботехнических свойств смазок

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Реферат

В работе представлены результаты экспериментов по исследованию триботехнических свойств смазок на установке, моделирующей геометрическое, кинематическое и силовое подобие условий бурения скважин. Исследовались подшипники с различным радиальным зазором и одинаковой химико-термической обработкой. Регистрация данных проводилась на катодный, шлейфовый осциллографы и электронные самописцы. Регистрировались нагрузки на подшипник, момент сопротивления качению на цапфе, угловая скорость вращения внешней обоймы, температура с помощью искусственных и полусинтетических термпар. Строботаксометром определялась переносная скорость тел качения. Исследовался внешний вид всех элементов качения, проводился металлографический анализ тонких поверхностных слоёв всех элементов качения, проводилась математическая обработка результатов испытаний. Показано, что для экспресс-оценки триботехнических свойств смазок можно использовать амплитудное значение колебания момента сопротивления качению.

Ключевые слова: трение; смазка; триботехнические свойства; бурение.

Sürtkü yağların tribotekniki xassələrinin qiymətləndirilməsi üsulu

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Xülasə

Məqalədə sürtkü yağlarının tribotekniki xassələrinin tədqiqi məqsədi ilə quyuların qazılması şəraitlərinin həndəsi, kinematik və güc oxşarlığını modelləşdirən qurğuda aparılan eksperimentlərin nəticələri təqdim edilmişdir. Müxtəlif radial boşluqları olan və eyni kimyəvi-termiki emaldan keçmiş podşipniklər tədqiq olunmuşdur. Məlumatların (verilənlərin) qeydiyyatı katod, şleyf oscilloqrafları və elektron özüyazanla aparılmışdır. Podşipnikə verilən yüklər, sapfada rəqsin müqavimət anı, xarici kəmərin bucaq fırlanma sürəti, süni və yarısünü termocüt vasitəsilə temperatur qeydə alınmışdı. Strobotaxometrle rəqs edən cisimlərin keçirici sürəti müəyyənləşdirilmişdi. Bütün rəqs edən elementlərin xarici görünüşünün tədqiqi, elementlərin incə səth təbəqələrinin metalografik təhlili və sınaq nəticələrinin riyazi emalı aparılmışdır. Göstərilmişdir ki, sürtkü yağlarının tribotekniki xassələrinin ekspress-qiymətləndirilməsi üçün rəqsin müqavimət anının dalğalanmasının amplitud göstəricisini istifadə etmək olar.

Açar sözlər: müqavimət; sürtkü yağı; tribotekniki xassələr; qazma.