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Evaluation Of Effectivness The Breaking-In Of Friction Pair In The Non-Stationary Work Conditions

[1]Al-quraan Tareq M.A., [2]Mnatsakanov R.G., [3]Mikosyanchik O.O., [4]Khimko M.S.,

[1]Al-Balqa Applied University, Jordan
[2]National Aviation University, Ukraine
[3]National Aviation University, Ukraine
[4]National Aviation University, Ukraine

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ABSTRACT

The method of breaking-in of contact surfaces in the non-stationary modes of friction work (start-stop mode) was presented in this work. This method gives possibility more correctly and preciously estimate the ending of breaking-in phase. The breaking-in of the friction pairs is realized due to the work of tribo-elements in the mode of real time which are loaded with the preselected stress in the condition of frequent starts-stops, the duration of which are determined by the control block. Friction moment in the contact, specific work of friction, temperature of the lubricant material, thickness of the lubricant layer are registered with the help of created computer software in concrete short equal intervals of time, and final time of breaking-in is determined in the condition of achievement the stable meanings of all parameters which are registered at maximal moment of friction in the period of start and stabilization of thickness the boundary layers of lubricant material formed on the activated surfaces in the process of friction during stop. Using basic oils without additives MC-20 (SAE - 50), I-40 (ISO VG 68) and synthetic oil PAO-8 (ISO VG 68) showed that the final term of steel breaking-in was determined by the kinetic change of tribotechnical characteristics of contact : estimation of anti-frictional characteristics of contact was done by the kinetic change of friction moment, and efficiency of lubricant and polymerized properties of lubricant material was determined by the kinetic of formation the thickness of lubricant layer. It was determined that oils MC-20, which are characterized by the highest viscosity, increasing of contact loading, independently on the temperature of the oil, decrease the term of breaking-in of contact surfaces on an average in 1,2 times. The main criterion of efficiency of anti-frictional properties is ability of oil to form the chemisorption films on the activated surface of metal. Solid films, which are characterized by the anisotropy of mechanical properties, show the low resistance to the action of alternating shear stresses. At contact loading of 570 MPa and temperature of 16^0C of oil MC-20 was fixed the acceleration of adaptation the boundary layers and formation the resinous products of organic nature of dark-brown color (polymers of friction) on the whole surface of contact, it gives possibility to decrease shear stress of lubricant layer in 2 times. With the increasing of temperature to the 70^0C the thickness of polymers decrease on the 20 %, but the shear stress of lubricant layer stays stable. For less viscous oil I-40 the analogical acceleration of breaking-in at increasing of contact loading was determined only at its volume temperature of 16^0C. At contact stress of 570 MPa and volume temperature of oils 16^0C the rheological characteristics of investigated mineral oils significantly differ from synthetic: increasing of effective viscosity in contact and shear stress of lubricant material for mineral oils is on an average 68%, but oil PAO-8 is characterized with the increasing of shear stress of lubricant material on 72%, but changes of effective viscosity at contact wasn't determined in comparison with the same parameters at 400MPa. It was determined that the main factor which influences on the rheological properties of the investigated oils is increment f the thickness the lubricant layer at start. For MC-20 this parameter doesn't depend on pressure, for I-40 decreased on 20%, and for PAO-8 decreased on the 60% at the increasing of contact loading. For oil PAO-8 increasing of pressure and temperature leads to the destabilization of tribotechnical characteristics of contact in the investigated interval of time as the result of destruction chemisorption layers due to their intensive abrasion at the frequent modes of start-stops with the increase in 4 times the gradient of share rate, and this leads to the disorientation and desorption of molecules.

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Corresponding Author: Al-quraan Tareq M.A., Al-Balqa Applied University, Jordan.

INTRODUCTION

Durability and loading ability of tribological systems of modern mechanisms and machines can be significantly increase by means of their preliminary breaking-in , as the result of which roughness, the actual contact area and, respectively, the quantity of acting stresses can be changed. However, breaking-in is not only the formation of specific layer of friction surface (Kogaev and Drozdov, 1991). and variable its physicochemical properties which are demonstrated in changes of listed above indexes, but also breaking-in is no less important in process of formation the lubricant layers that divides friction surfaces (Chumichev, 1974; Ciftan and Saibel, 1981).

Analyses of the express-methodics of breaking-in of tribocoupling elements in the laboratory conditions:

There are a lot of classical methodic of breaking-in of contact surfaces, which are based on the certain choice of kinematic, loaded, temperature modes of friction pair braking-in, or the final effect of breaking-in is realized due to the choice of base lubricant material, and also by adjusting certain surface-active substances, which accelerate the stabilization of tribotechnical characteristics of contact.

The well-known method (Borodin, 1977) of breaking-in the kinematical friction pair is sliding, according to which breaking-in of kinematical pairs takes place in the surrounding of mineral oil with the additives of surfactants in the mode of start-stop for two periods, one of which is realized under 15-20% of given-by loading during 1-2 minutes, the second one is realized at given-by loading during 2-3 minutes. Nevertheless, the disadvantages of this method are: fixed duration of breaking-in periods, without reference to material type of contact surface; absence of registration the tribological parameters, thanks to the kinematics of their changes it is possible to forecast the conditions of operational characteristics in the periods of breaking-in the contact surfaces.

The methods of breaking-in the friction surfaces under loading ware observed in this work (Porokhov, 1983). According to this method, investigated samples, which are working in the condition of sliding and rolling with sliding (up to 15%), are gradually loaded within equal intervals of cycles by the load with a duration of 15 min, and the ending of breaking-in period on each link load continuously and automatically is fixed according to stabilization of friction moment, temperature of friction surface, total wear of investigated samples and temperature of lubricant material.

Cutoff term of breaking-in usually finishes with the stabilization of parameters of the friction coefficient and wear. It is necessary to mark, that only lubricant action defines favorable flowing of breaking-in (Dmytrychenko and Mnatsakanov, 2002). What is more, the process of breaking-in will proceed successfully in that case, when it finishes with the formation of supporting lubricant layer with the certain thickness and structure, optimal micro geometry of contact, and all of these provide satisfactory wear resistance of friction surfaces which are breaking-in, and, therefore, provide their durability. During breaking-in it is necessary to support needed mode of lubricant action with the help of control the thickness of lubricant layer, and this lubricant action will exclude the possibility of appearing gripping or jamming.

The role of the process of formation the lubricant layer, as main elastic hydrodynamic and boundary aspect, is less taken into account, and, certainly, represents undoubted interests for increasing the reliability and loaded property of modern mechanisms.

The aim of the work:

The aim of the work is increasing the authenticity of determining the time of breaking-in the elements of tribocoupling by the kinematics of change the tribological parameters of contact.

Materials and methods of research:

The assigned task is realized due to the mode of real time of tribological elements working, loading with the pre-chosen effort, in the condition of often start-stop, the duration of which is determined on the computer by the control block, moreover, in the determined short equal periods of time it is simultaneously fixed the friction moment in the contact, rotation frequency of contact surfaces, specific friction work and temperature of lubricant layer. And, the end time of breaking-in is determined in the condition of achievement the constant meaning of all parameters on the stop, and these parameters are registered at the maximal friction moment in the period of start and stabilization of thickness the boundary layers of lubricant material formed on the active contact surfaces in the process of friction (Mikosyanchik *et al*., 2014).

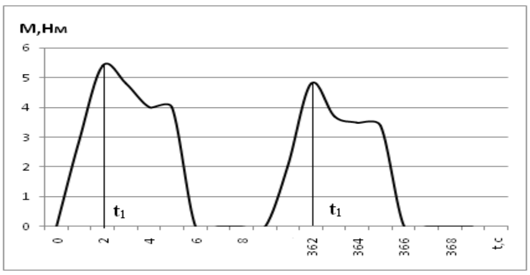
Breaking-in of the friction pair in the non-stationary work conditions is implemented as follows. According to the operational conditions the materials of tested samples, rotational speed of contact surfaces and condition of their relative movement (sliding, reverse, rolling with sliding (from 0 to 100%)), contact loading, type and temperature of lubricant material are chosen. The friction pair is loaded by the preselected effort, lubricated with the investigated lubricant material, set relative displacement of tribocoupling elements by means of programming the rotation frequency of each tested sample with the help of control block and performs friction in the mode of frequent start-stop. Over 0,01s from the work beginning, continuously, on each cycle of start-stop, the friction moment is registered with the help of strain method, the rotation frequency of each contact surface with the digital block, the temperature of lubricant material with special thermometer and the thickness of lubricant layer with the method of voltage drop during normal glow discharge (Rajko, 1974). According to the indicators of measurement the dependence of friction moment is built (pic. 1a), and this moment is rapidly increases up to maximum in the start period with the further decreasing, oscillations and stabilization in each cycle of breaking-in, rotation frequency of contact surfaces (pic. 1b), temperature of lubricant material and general thickness of lubricant layer in the period of start and the thickness of boundary layers of lubricant materials on the stop (pic. 1c). Calculation of specific friction work is carried out by means of integrating the square, which is limited by the curve of friction moment, and, respective time of breaking-in during starting, to which the certain rotation frequency of contact surfaces is corresponded, taking into account the kinetic energy of rotational details (pic. 1d). The period of finishing of breaking-in is determined by the simultaneous stabilization during 5-10 cycles of hours the maximal friction moment, specific friction work, temperature of lubricant material and general thickness of lubricant layer (hgen), which corresponds to the time t1 in the starting period of each cycle and stabilization the thickness of boundary layers habs of lubricant material which corresponds to time t2 in the middle stop term in each cycle (pic. 1).

For assessment the efficiency of breaking-in of tribocoupling elements depending on material type of friction pair and lubricant materials of different operational assignment the next condition were chosen: material of friction pair - bearing steel Standards: SAE 52100, DIN 100Cr6, 1.3505; lubricant materials – motor mineral oil without additives MC-20 (SAE - 50), distillate oil with little sulfuric oil of selective treatment I-40 (ISO VG 68) and synthetic polyalphaolefin oil PAO-8 (ISO VG 68); bulk temperature of oils are 16^0C and 70^0C; contact loading – σ_{max} =400 and 570 MPa; cycle duration – start – 4s, stop – 3,5s.

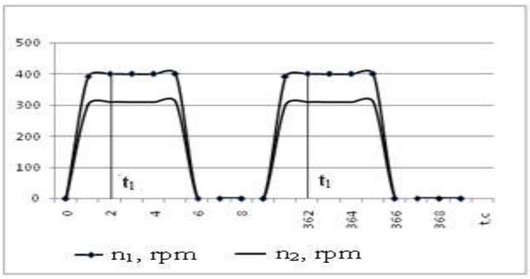
Results of researches and their discussion:

The investigated oils characterized by a decrease of main parameters of efficiency of lubricant process with the increasing of contact stress up to 570 MPa, with the bulk temperature of oils 16^0C. For mineral oils it is determined predominance of mixed mode of lubrication with the dominant influence of boundary lubricant mode, and synthetic oil PAO-8 is characterized only with boundary lubricant mode.

In the condition of many-cycle action the frequency of destruction of absorption layers for MC-20 increases on 20%, in comparison with their degree of destruction at σ_{max} 400 MPa, but adaptation time decreases at $N \geq 400$ it is formed the stable boundary later, and this fact provides effective lubrication with the domination of hydrodynamic mode (table 1). Realization of this mechanism is possible at the expense of increasing the thickness of absorption layers on the 50% and formation of chemisorption film (hres = 0,057-0,354 mcm).



(a)



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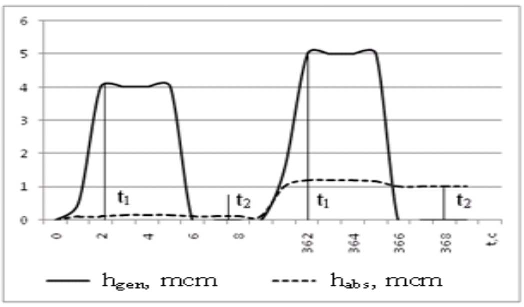

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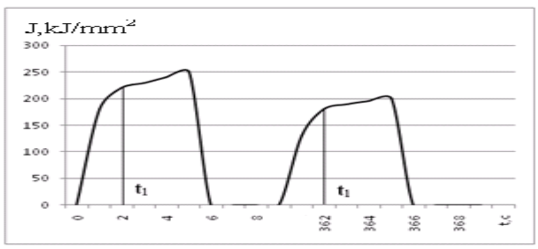


(d)

Pic. 1: Dependence of friction moment (a), rotation frequency of tasted samples in condition of rolling with sliding (b), general thickness of lubricant layer and thickness of boundary layers of lubricant material (c), specific friction work (d) on working time of tribosystem.

Less viscous mineral oil I-40 at the operating time N ≥ 440 also forms stable absorption layers, and on the 70% of area the self-generating organic films or polymers of friction are formed, the thickness of which is 0,014-0,048 mcm.

With the increasing of loading on oil PAO-8 in 60% of cycles it is observed the destruction of lubricant absorptive layers, adaptation of boundary layer takes place only in process of hours N ≥ 530, and the thickness of self-generating organic film, in comparison with the chemisorption layers, formed by the oil at σ_{max} = 400 MPa, is decreased on 70% (hres = 0,014 - 0,051 mcm).

With the increasing of oils bulk temperature up to 70^0C it is determined the decreasing of increment of thickness of the lubricant layer in the period of start for oils MC-20, I-40 and PAO-8 on 40%, 20% and 20%, respectively. For mineral oil MC-20 adaptation of absorptive layer takes place much earlier, that at temperature 16^0C, at operational time N ≤ 250, and the thickness of chemisorption layers decreases on 20% (hres = 0,061 - 0,175 mcm) (table 1).

Table 1: Change of tribotechnical characteristics in the condition of start for oil MC-20.

σ=570 MPa, t=16^0C

N	H_{abs}, mcm	h_{gen}, mcm	$\eta_{ef}\cdot 10^2$, Pa•s	λ
2	0,002	2,002	19,822	1,820
40	0,001	2,001	17,364	1,819
80	0,113	2,113	15,750	2,150
112	0,001	2,001	13,134	1,819
117	0,243	2,243	14,725	2,551
160	0,150	2,150	14,116	2,269
195	0,114	2,114	13,877	2,151
275	0,000	2,000	11,570	1,818
401	0,014	2,014	9,635	1,860
442	0,263	2,263	10,823	2,299
487	1,432	3,432	16,411	6,058
565	0,412	2,412	11,541	4,763
638	0,971	2,971	14,216	3,031

σ=570MPa,t=70^0C

N	h_{abs}, mcm	h_{gen}, mcm	$\eta_{ef}\cdot 10^2$, Pa•s	λ
2	0,171	0,871	9,012	1,500
40	0,000	0,900	9,313	1,510
80	0,002	0,902	8,916	1,509
112	0,043	0,943	8,183	1,621
117	0,094	0,994	8,626	1,789
160	0,041	0,941	6,176	1,638
195	0,001	0,901	5,613	1,510
275	0,570	1,470	8,504	3,239
401	0,282	1,182	6,049	2,030
442	0,713	1,613	8,613	3,738
487	0,041	0,941	4,816	1,638
565	0,480	1,380	9,057	2,960
638	0,332	1,232	6,304	2,522

Qualitatively other process of lubricant action is determined for oil I-40. In the non-stable mode with the increasing of temperature the destruction of absorptive layers increases in 2 times, at operation time the adaptation of boundary layers wasn't determined. It is necessary to mark, that thickness of self-generated organic film increases on 40% (h_{res} = 0,032 - 0,060 mcm), but formation of these type of films takes place only on 20% of contact area.

Analogical lubricant action is determined for synthetic oil PAO-8 – in the initial period of breaking-in, at boundary mode of lubrication, there is no adaptation of absorption layers, subsequently the thickness of chemisorption films is increased on 0,022 mcm, but formation of self-generated organic films is fixed only on the 60% of contact area of friction pair.

Table 2 gives information about the residual terms of stabilization the anti-friction and lubricate properties of contact at breaking-in of tribocoupling elements in the surrounding of mineral oil MC-20 and I-40 and synthetic oil PAO-8.

Table 2: Time for stabilization of tribotechnical characteristics of contact at breaking-in

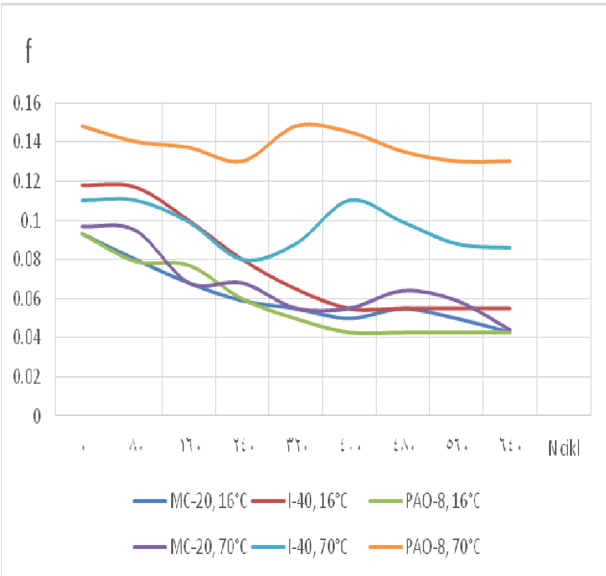
Contact stress, MPa	Oil bulb temperature, ^{0}C	Lubricant material		
		MC-20	I-40	PAO-8
400	16	470 cycles / 59min	500 cycles / 63min	350 cycles / 44min
	70	350 cycles / 44min	550 cycles / 69min	250 cycles / 31min
500	16	400 cycles / 50min	440 cycles / 55min	530 cycles / 66min
	70	250 cycles / 31min	-	-

For more viscous oil MC-20 increasing of contact loading, independently on oil temperature, decrease the time of breaking-in of contact surfaces, in average in 1,2 time. For less viscous oil I-40 analogical acceleration of breaking0in is determined only under its bulk temperature 16^0C. However, for synthetic oil PAO-8 increasing of the pressure leads to the reverse effect – operational time of breaking-in increases in 1,5 time at the oil temperature 70^0C and stabilization of tribotechnical characteristics of contact in the investigated time interval doesn't take place.

Influence of the contact loading, total speed of rolling and oil temperature on the formation and adaptation of absorption layers, fully reflects the kinematic change of rheological and anti-frictional oil characteristics.

At contact pressure of 570 MPa and oils bulk temperature 16^0C rheological characteristics of investigated mineral oils significantly change from synthetic PAO-8. If for MC-20 and I-40 increasing of effective viscosity in contact (η_{ef}) and shear stress of lubricant material (τ) is in average 68%, then PAO-8 is characterized by the increasing of τ on 72%, and changes of η_{ef} in contact didn't established, in comparison with η_{ef} and τ at σ_{max} = 400 MPa.

The main factor that influences on the rheological properties of oils is growth of thickness the lubricant layer at start with the increasing of rotation frequency. For MC-20 this parameter with the increasing of σmax up to 570 MPa doesn't change, for I-40 decreases on 20%, and for PAO-8 on 60%. In consequence of this the gradient of speed shift of oil layer increases in 2,85 times (γ) of synthetic oil, and this fact leads to the partial destruction of the molecules. Radicals, which are formed, are the source of formation the boundary film, but at the cyclic loading, as the result of frequent micro-plastic shifts and action of alternating shear stresses, increased the time of absorption layers adaptation and thickness of formed self-graduated organic films are significantly decreased. But, despite of the mentioned above processes, the boundary absorption layers leads to decreasing of shear stress of oil layer in 2 times. At operation time of N ≥ 400, at adaptation of boundary layer, was fixed the significant increasing of anti-frictional properties – the friction coefficient decreases from 0,093 to 0,043 (pic.2).



Pic. 2: Changes of friction coefficient at breaking-in of contact surfaces in non-stationary mode at σ_{max} 570 MPa.

For mineral oils at polycyclic mode of loading, in our opinion, another mechanism of formation the self-generated organic film is realized. Inactive hydrocarbons of paraffin, naphthenic and aromatic types, getting into electrical field of friction surfaces, acquired certain dipole moment, which accelerates the modification of metal surfaces as the result of formation on them pitch similar products of organic origin of dark-brown color (Chernozhykov *et al*., 1978).

There was determined intensification of self-generated organic film formation with the increasing the content of aromatic compounds (Heinicke, 1987), and according to the investigations of other authors (Klaman, 1988) increasing of thickness of self-generated organic film with increasing of molecular weight of paraffin type was fixed. MC-20 by its fractional composition, unlike of I-40, consists of paraffin fraction with bigger molecular weight of carbohydrates, on 10% increased the content of aromatic compounds and on 4% pitches similar compounds (Losikov, 1966). At σ_{max} 570 MPa, 16^0C was determined the increasing of thickness of self-generated organic films of mineral oils on 70%, which is associated with more intensive activation of metal friction surface with the increasing of loading. It is necessary to mark, that formation of chemisorption films of oil I-40 takes place on the 70% of friction surface, due to carbohydrate composition of oil fraction and less η_{ef} in contact.

Solid films, which are characterized by the anisotropy of mechanical properties, demonstrate the low resistance to the action of alternating tangent stresses – shear stress of oil layer at operational time decreases in 2 times, and provides significant decreasing of friction coefficient (f), as adaptation of boundary layers was determined decreasing of friction coefficient for MC-20 from 0,093 to 0,043, and for I-40 from 0,118 to 0,0055 (pic.2).

Less viscous oil I-40 and PAO-8 in condition of dynamic loading didn't show the effective lubricant action at temperature 70^0C – during the whole experiment didn't determine the adaptation of absorption layers: thickness of self-generated organic films increased on 40%, but formation of chemisorption layers which are stable to the action of alternating shear stresses, takes place on the 20% of contact surface for I-40 and on 60% of surface for PAO-8

Work (Menter, 1951) observes the non-stable lubrication at boundary friction, which are connected with the destruction of film and explained by its melting with the increasing of temperature. But, critical temperature of oils molecules disorientation of boundary layers I-40 and PAO-8 is 140^0C (Klaman, 1988; Kyliev,1985), and presence of chromium in steel bearing steel Standards: SAE 52100, DIN 100Cr6, 1.3505, from which the pair of friction is made, increases the critical temperature of decomposition (Menter, 1951; Fote *et al*., 1977). We think, that destruction of chemisorption layers takes place as the result of intensive abrasion in the modes of frequent start-stop, moreover, as a result of significant increasing of speed shear gradient with the increasing of temperature (γ increased in 2,5 times for I-40 and in 4 times for PAO-8), which lead to the disorientation and desorption of molecules.

The determined experimental meanings of shear stress of oil layer for oil I-40 and PAO-8, likely, is explained by the deformation of lubricant film as a result of jamming between contact friction surfaces at sliding. Analogical results of deformation of the boundary layer were presented in the work (Bowden and Tabor, 1950).

As follows, at absorption of boundary layer the chemisorptions layers are destroyed, as the result of which effective lubricant action of oils I-40 and PAO-8 in condition of dynamic loading at σ_{max} 570 MPa, t = 70^0C didn't provide; the boundary layer of lubrication is dominated and characterized by the high meaning of friction coefficient during the whole experiment, and this fact makes impossible to determine the end term of breaking-in of contact surfaces.

Conclusion:

Represented method of breaking-in of contact surfaces in non-stationary conditions of work gives possibility for more significantly and accurately estimation of the breaking-in ending phase by the kinetic change of main tribotechnical characteristics of contact at simultaneous estimation of physic-mechanical properties of material surface layers of contact surfaces by the kinetic change of specific friction work, anti-frictional characteristics of contact by the kinetic change of friction moment and lubricant and polymerization properties of lubricant material by the kinetic formation of thickness the lubricant layer.

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