Estimation of Energy Levels of Contacts and Tribological Properties of Materials of Friction Pairs

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Abstract

Estimation of the energy levels of contacts of microprotrusions of friction pairs "shoe-disk" was carried out on a friction and wear machine SMTs-2. In this case, the block was made of ordinary Kh12MF steel, and the disk was diffusion-coated with a Ni-Cu alloy and reinforced by surface plastic deformation. Experimental studies carried out on four test cycles made it possible to obtain profiles of profilograms and use them to establish the types of contacts (ohmic, neutral and blocking) for the samples and their duration of action. Investigation of the tribotechnical properties of the "shoe-disk" friction pairs made it possible to determine: surface temperature, dynamic coefficient of friction and wear of the samples. At the same time, the influence of diffusion metallization and surface plastic deformation on the relative wear resistance and roughness of samples made of Kh12MF steel was established. The physical substantiation of the obtained parameters is given.

Keywords: friction and wear machine, “shoe-disk” friction pair, sample №1 and 2, profilograms, test cycles, operational parameters.

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Sürtünmə cütü materiallarının triboloji xüsusiyyətlərinin və kontaktlarının enerji səviyyələrinin qiymətləndirilməsi

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Xülasə

"Disk-kündəli" sürtünmə cütü mikroçıxıntılarının kontakt enerji səviyyələrinin qiymətləndirilməsi СМЦ -2 sürtünmə və yeyilmə maşınında həyata keçirilib. Bu zaman kündə adi Х12МФ poladdan hazırlanmış, disk isə Ni-Cu ərintisi ilə diffuziya şəklində örtülmüş və səthi plastik deformasiya ilə gücləndirilmişdir. Dörd sınaq tsiklində aparılan eksperimental tədqiqatlar, profiloqram profillər əldə etməyə və onlarda nümunələr üçün kontakt növlərini (omik, neytral və bloklayıcı) qurmağa və onların fəaliyyət müddətini müəyyən etməyə imkan verdi. Disk-kündəli sürtünmə cütünün tribotexniki xüsusiyyətlərinin tədqiqatı: səthi temperatur, sürtünmə və yeyilmə nümunələrinin dinamik əmsalını müəyyən etməyə şərait yaradır. Eyni zamanda, diffuziya metallaşmanın və səth plastik deformasiyasının Х12МФ poladından hazırlanmış nümunələrin nisbi yeyilmə dözümlülüyünə və kələkötürlüyünə təsiri müəyyən edilib.

Açar sözlər: sürtünmə və yeyilmə maşını, "disk-kündəli" sürtünmə cütü, 1 və 2 nömrəli nümunə, profiloqram, sınaq tsikli, istismar parametrləri.

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Оценка энергетических уровней контактов и трибологических свойств материалов пар трения

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Аннотация

Оценка энергетических уровней контактов микровыступов пар трения «колодочка - диск» выполнялась на машине трения и износа СМЦ-2. Колодочка изготовлена из обычной стали Х12МФ, а диск – с диффузионным покрытием сплавом Ni-Cu и усилен поверхностно-пластической деформацией. Проведенные экспериментальные исследования на четырех циклах испытаний позволили получить профили профилограмм и по ним установить для образцов типы контактов (омический, нейтральный и блокирующий) и время их действия. Исследование триботехнических свойств пар трения «колодочка - диск» позволило определить поверхностную температуру, динамический коэффициент трения и износ образцов. Установлено влияние диффузионной металлизации и поверхностного пластического деформирования на относительную износостойкость и шероховатость образцов из стали Х12МФ.

Ключевые слова: машина трения и износа, пара трения «колодочка - диск», образцы №1 и 2, профилограммы, циклы испытаний, эксплуатационные параметры.

Introduction

Among the methods of diffusion metallization, the most effective method for increasing the durability of tools and parts is the method of applying coatings from an environment of low-melting liquid metal solutions. This technology, which consists in holding the product in a bath with a low-melting metal melt, in which the coating element or elements are dissolved, makes it possible to obtain coatings simultaneously for batches of products, on tools of the most complex configuration, in the presence of sharp edges, small holes, deep cavities, and also combine the metallization process with heat treatment. In this case, the resulting coatings are characterized by uniformity in thickness, stability of the composition, high quality and improved tribological properties.

The state of the problem

At present, many questions concerningdiffusion metallizationfrom the medium of low-melting liquid metalsolutions are insufficientlystudied. These include issues related to the choice of the composition of the saturation medium (transport melt), the coating element, the kinetics and method of formation of coatings, as well as tasks related to the nature of the interaction of coating elements and material, with the effect of coatings on the geometry of products, and the roughness of coated surfaces.

The surface quality and contact of machine parts are considered in [1]. However, in the latter, the profiles of the microprotrusions of the friction pairs affecting their energy loading were not investigated.

In [2] dependences were obtained that describe the profiles of typical relative sections of the reference curves with the distribution of their materials along the height of the rough layer. Nothing has been said here about the types of contacts of microprotrusions of friction pairs.

The energy levels of various types of contacts of microprotrusions of friction pairs were studied in [2, 3]. However, in them, no reference was made to specific profilograms of microprotrusions of friction pairs. The problem of increasing the reliability of mates of machines, mechanisms and assemblies operating at high impulse specific loads and high sliding speeds requires the creation and improvement of existing methods of hardening the mating surfaces. In this case, at the last stage of finishing the materials, it is necessary to establish their tribological properties [4].

Formulation of the problem

This publication addresses the following issues in relation to the problem being solved: analysis of profilograms with characteristics of roughness of working surfaces of friction pairs "block-disk" after testing; comparative results of studies of tribotechnical properties of steel H12MF without and with a diffusion coating and surface plastic deformation (SPD) at various contact stresses in a friction pair.

The purpose of this work - to investigate and establish the effect on the energy levels of the “shoe-disk” contacts (the end surface is alloyeddiffusion metallization) and evaluate its tribological properties on a friction and wear machine SMTs-2. Analysis of profilograms with the characteristics of the shoe-disk friction pairs after testing. Studies of the tribotechnical properties of materials after diffusion metallization with and without PDE were carried out on a friction and wear machine SMTs-2 according to the block-disk scheme (Fig. 1).

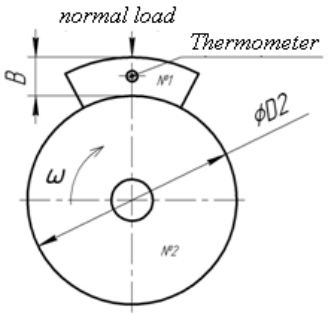

Figure 1 – Test scheme " block - disc". Sample № 1 - block (stationary), sample № 2 - disc (rotating)

The tests were carried out for 6 hours with each pair of samples under the following test conditions: normal load - 400 N, the number of revolutions of the lower sample (disk) - 300 min^{-1}, lubricating medium - I20A.

The control of the profile and roughness parameters of the samples before and after the tests was carried out on a Mahr Surf PS 1 profilometer. The tracing length was 5,6 mm, respectively, the cutoff value of the pitch was 0,8 mm. The number of base lengths (step cutoffs) was 5. Dimensional parameters were monitored with an electronic measuring instrument with a division value of 0,01 mm. The scheme for measuring the diameter of the sample "disk" (D) and the height of the block (B) is shown in Fig. 1.

The control of the weight parameters was carried out on an electronic laboratory balance Shinko AJH-420CE with a measurement division value of 0,001 g.

The energy levels of the contacts of the profilograms were considered from the point of view of the work function of electrons and ions from the surfaces of the block (W_1) and the rotating disk (W_2). If $W_2 > W_1$, then the contact was ohmic, with $W_2 = W_1$ - neutral, and when W2 <W1 - blocking. Studies at contact stresses $\sigma_к$ = 3,5 *hPa* (Fig. 2) showed the following:

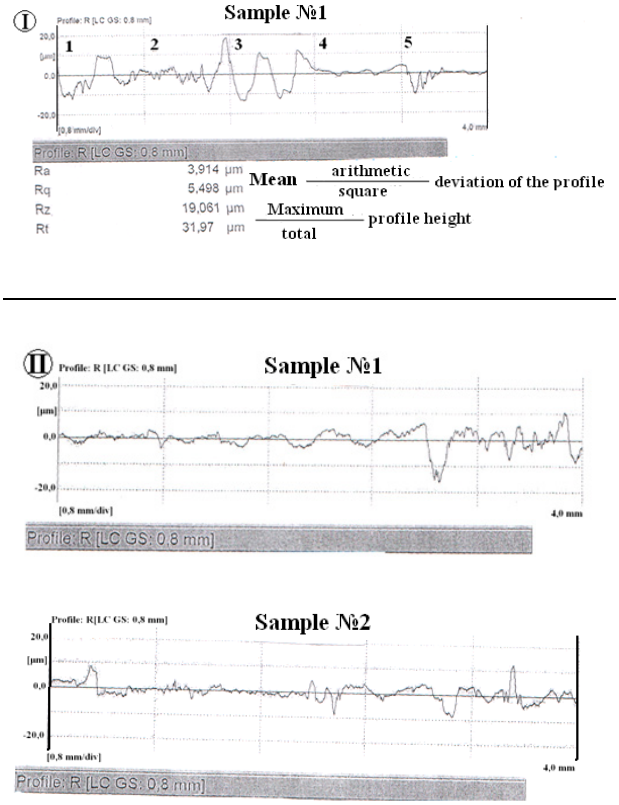

Figure 2 – Profilograms with the characteristics of the roughness of the working surfaces of the "block-disk" friction pairs after the tests on machine winding and wear SMTs-2 at contact stresses $\sigma_к$ = 3,5 hPa (cycles I and II)

Studies at contact stresses σκ = 4,5 *hPa* (Fig. 3) showed the following:

- on the III-th cycle in sample №1 in rectangles 1, 2, 3, 4 and 5 there was an alternation of the ohmic contact with the blocking contact;

- in sample №2, an alternation of ohmic contacts with blocking contacts was observed in all rectangles;

- on the IV-th cycle in the sample №1 in rectangles 1, 4 and 5 neutral contact prevailed, and in the 2 and 3 rectangles there was an alternation of ohmic contacts with blocking contacts;

- in sample №2, in rectangles 1, 2, 4 and 5, a quasi-neutral contact was observed, and in the 3rd rectangle there was a predominantly blocking contact.

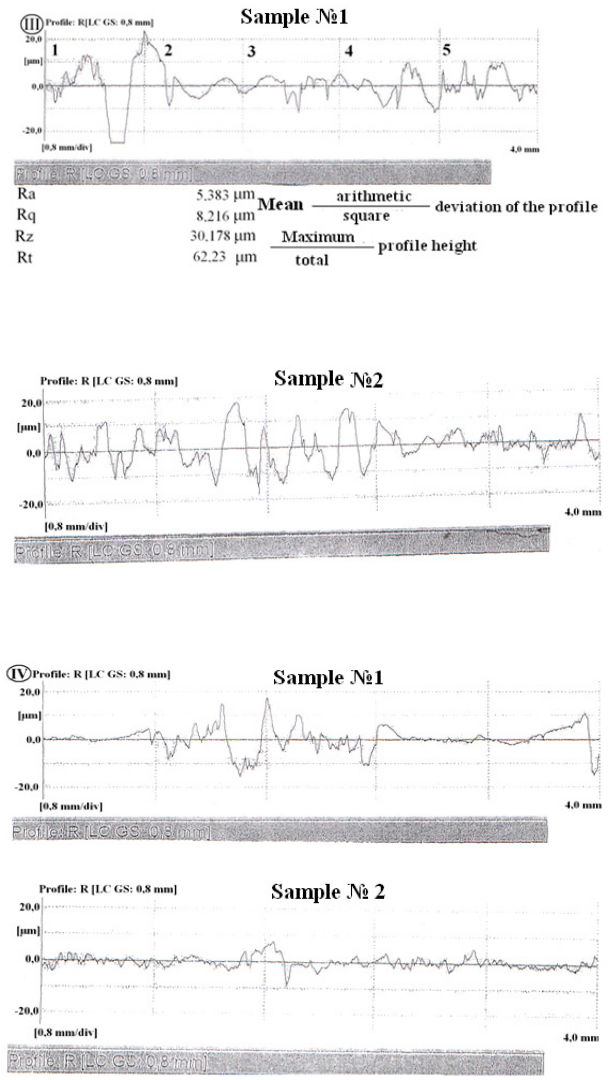

Figure 3 – Profilograms with the characteristics of the roughness of the working surfaces of the "block-disk" friction pairs after the tests on machine winding and wear SMTs-2 at contact stresses σ_k = 4,5 hPa (cycles III and IV)

- on the I-th cycle in the sample № 1 in the rectangles 1, 2, 3, the ohmic contact prevailed, on the 4 and 5 rectangles - mainly the neutral contact;

- in sample № 2 in rectangles 1, 2, 3 there was a predominantly neutral contact, and in 4 and 5 rectangles there was an alternation of ohmic contact with a blocking contact;

- on the II-nd cycle in the sample №1 in rectangles 1, 2, 3, a neutral contact was maintained, and in rectangles 4 and 5 there was an alternation of ohmic contacts with blocking contacts;

- in sample №2, in rectangles 1, 2, 3, a neutral contact was observed, and in rectangles 4 and 5 there was an alternation of ohmic contacts with blocking contacts.

Twenty measurements of the "disk" roughness parameters with different degrees of deformation were carried out, the average values of the roughness parameters and the confidence interval of measurements after tribotechnical tests were calculated, which are presented in table 1.

As you can see from the table 1, the smallest values of the roughness parameters for the “disk” specimens subjected to diffusion metallization and surface plastic deformation were observed at contact stresses of 4,5 hPa.

Table 1 – The results of measuring the roughness parameters of a material with a diffusion metal coating

	$\sigma_к$, *hПа*	Ra, µm	Rq, µm	Rz, µm	Rt, µm
Diffusion metallized	Raw material	5,384±0,385	6,759±0,493	27,203±1,634	38,32±4,07
	0	2,176±0,240	2,930±0,306	11,258±1,155	17,74±2,01
	3,0	2,272±0,256	2,955±0,323	12,048±1,223	17,96±1,89
	3,5	2,167±0,295	2,901±0,384	11,649±1,345	17,92±2,36
	4,0	2,323±0,167	3,099±0,247	12,156±0,972	18,41±2,05
	4,5	2,000±0,205	2,689±0,283	10,931±0,961	16,68±1,84

Comparative results of studying the tribotechnical properties of steel H12MF without and with a diffusion coating and surface plastic deformation (SPD) at various contact stresses in a friction pair. There are no data in the literature on the study of the tribotechnical properties of steel Kh12MF with a diffusion coating and SPD on a friction and wear machine SMTs-2 at various contact stresses in the "shoe-disk" friction pair. The change in the temperature increment was recorded with a platinum thermocouple installed in the hole on the sample block (Fig.1).

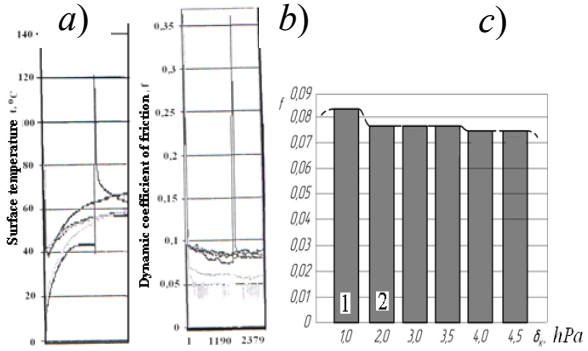

Figure 4. a, b, c – Fluctuation of surface temperature (a) and dynamic coefficient of friction (b) depending on time and function of the form f = μ (σ_k); 1, 2 - initial and subject to diffusion without (SPD of materials)

According to fig. 4a, fluctuations in the flash point are caused by the interaction of microprotrusions to which pulsed specific loads are applied. After that, the generated amount of heat is directed into the body of the rotating disk, where it causes the emergence of a surface-volume temperature with its negative gradient [5]. The fluctuation value of the dynamic coefficient of friction (Fig. 4b) is associated with a sharp increase in the friction force in the contact and a decrease in the impulse specific load due to its plastic deformation [6].

In fig. 4c presents the generalized results of changes in the dynamic coefficient of friction during tests on the SMTs-2 friction and wear machine. The application of diffusion Ni-Cu coatings provides a decrease in the dynamic coefficient of friction relative to the original samples (1) by 8.4% in relation to the tested ones at $\sigma_к$ = 2,5-3,5 *hPa* (Fig. 4 c). Subsequent plastic deformation leads to a further decrease in the dynamic coefficient of friction, while its minimum value is observed after processing data with contact stresses of 4,0 and 4,5 *hPa* (a decrease in the dynamic coefficient of friction by no more than 3.0% for lower contact stresses (2,5-3,5 *hPa*)). Before and after the study of the tribological properties of materials, the dimensional and weight parameters of the samples were monitored; the results of these measurements are summarized in Table 2.

According to fig. 5, we analyze the graphical dependences of the relative wear resistance (δ12589) and roughness (3456710) after diffusion metallization and surface plastic deformation of the samples.

Two graphical dependences have an intersection point A and a common point 5. Part of the first dependence 2589 and the second 4567 were under the influence of the semiconductor effect during friction.In the absence of the latter, part of the first graphical dependence has a concave curve 2-9. Straight line 7-10 intersects with point 8. In this case, straight line 7-10 may have the contours of a convex and a concave curve, depending on the plastic deformation of the samples [7, 8]. The application of diffusion Ni-Cu coatings with subsequent deformation leads to an increase in wear resistance relative to untreated surfaces of products. In this case, the relative wear resistance of samples with Ni-Cu coating is from 1,0 to 3,5 in the range of contact voltages from zero to 4.5 *hPa*.

Table 2 – Experimental data on tests of the shoe-disk friction pair

Sample number	Material H12MF	$\sigma_к$, *hPa*	Bec		Mass wear, g	Relative dimensions		Linear wear, mm
			before	after		before	after	
			tests, g					
Block №1	-	3,0	14,913	14,914	-0,001	8,99	8,99	0,00
Disk №2	dif. мет. withSPD		162,733	162,680	0,053	49,95	49,94	0,01
Block№1	without cover	3,5	14,934	14,933	0,001	8,99	8,99	0,00
Disk №2	dif. мет. withSPD		162,880	162,817	0,063	49,94	49,93	0,01
Block №1	without cover	4,0	14,781	14,783	-0,002	8,99	9,00	-0,01
Disk №2	dif. мет. withSPD		162,062	163,018	0,045	49,95	49,94	0,01
Block №1	without cover	4,5	14,786	14,788	-0,002	9,00	9,00	0,00
Disk №2	dif. мет. withSPD		162,911	162,873	0,038	49,95	49,94	0,01
Block №1	without cover	With-outSPD	14,748	14,749	-0,001	8,98	8,99	-0,01
Disk №2	dif. мет. withSPD		163,130	163,043	0,087	49,95	49,93	0,02
Block №1	without cover		14,838	14,791	0,047	8,99	8,97	0,02
Disk №2			162,472	162,338	0,134	50,05	50,02	0,03

Note: diff. met. with SPD - diffusion metallization with surface plastic deformation

The lowest relative wear resistance after plastic deformation was observed at contact stresses of 3,5*hPa*. At the same time, there was a minimum roughness (Ra = 20 μm). In the course of testing for wear resistance, it was found that due to sliding friction, there is a significant decrease in roughness by approximately the same value.

The discussion of the results

1. Having considered the energy levels of the contacts of the profilograms under four-cycle loading of the friction pair "block (1) - disc (2)" on the SMTs-2 friction and wear machine, taking into account the work function of electrons and ions (W_1, W_2) from their working surfaces, it was found that ohmic contacts ($W_2 > W_1$) work the longest, neutral contacts ($W_2 = W_1$) - less than average time, blocking contacts ($W_2 < W_1$) - the rest of the time.

2. The application of diffusion Ni-Cu coatings provide a decrease in the dynamic coefficient of friction relative to the original samples by 8.4%, and between the tested samples by only 3.0%. It should be noted that plastic deformation at contact stresses of 4,0 and 4,5 *hPa* gives a minimum decrease in the dynamic coefficient of friction.

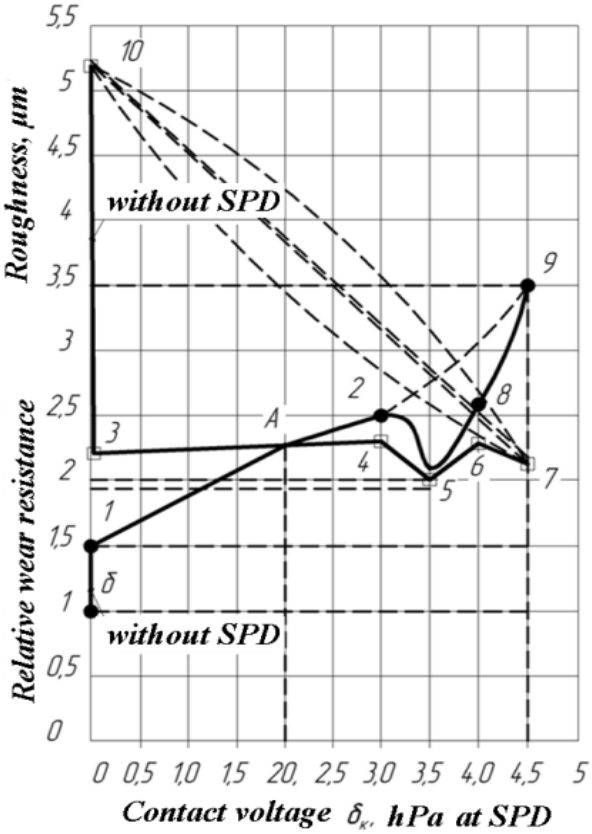

Figure 5 – Influence of diffusion metallization and surface plastic deformation on the relative wear resistance and roughness of samples from steel Kh12MF; —●— - wear resistance; —▭— - Ra after tests, μm

3. The application of diffusion Ni-Cu coatings, as well as subsequent deformation, leads to an increase in wear resistance relative to the untreated surfaces of the products. In this case, the relative wear resistance of samples with Ni-Cu coating is 1,5, plastic deformation leads to a further increase in the wear resistance of the samples, and the greatest wear resistance was observed at a contact stress of 4,5 *hPa* and amounted to 3,56. The lowest wear resistance after plastic deformation was 2,15 and was observed at contact stresses of 3,5 *hPa*.

4. In the process of testing for wear resistance it was found that due to sliding friction there is a significant decrease in roughness (from 3.5 to 1.5) Ra, μm.

Conclusion

The determination of the main tribological properties of various pairs of friction, taking into account the medium in laboratory conditions, was carried out on a friction and wear machine SMTs-2.

REFERENCES

1. **Demkin N.B.** Surface quality and contact of machine parts / N.B. Demkin, E.V. Ryzhov / M.: *Mechanical Engineering*, 1981. 241 p. *(in Russian)*
2. **Janahmadov A.Kh., Volchenko D.A., Volchenko N.A.** [and others]. Design and verification calculation of frictional units of tape-shoe brakes of drawworks / Standard. Baku: "*Apostroff*", 2016. 312 p. *(in Russian)*
3. **Janahmadov A.Kh., Volchenko D.A., Volchenko N.A.** [and others] Tribology: friction, wear, lubrication // Baku: "*Apostrof-A",* 2019. 640 p. *(in Russian)*
4. **Chichinadze A.V.** Fundamentals of tribology / - M.: Mashinostroenie, 2001. 664 p. *(in Russian)*
5. **Volchenko A.I., Javadov M.Y., Volchenko N.A.** [and others]. The relationship of external and internal electrothermomechanical friction in frictional units (in English) // *Herald of the Azerbaijan Engineering Academy*, vol.12, № 4, 2020. Pp. 27-39. *(in Russian)*
6. Metallurgy and heat treatment of steel / Edited by M. L. Bershtein and A. G. Rakhshtadt / *Handbook,* Volume 1. Moscow: Metallurgy, 1983. 352 p. *(in Russian)*
7. **Svaruk M.P.** Fracture mechanics and strength of materials: in 4 volumes. Vol. 2. Factors of stress intensity in bodies with cracks. - Kiev: *Nauk. Dumka*, 1988. Pp. 63-75. *(in Ukraine)*
8. **Shlykov Y.P.** Contact thermal resistance / Y.P. Shlykov, E.A. Ganin, S.N. Tsarevsky / M.: *Energiya,* 1987. 328 p. *(in Russian)*

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