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ASSORTMENT OF SOLID LUBRICATION COATINGS USING A MOLYBDENUM DISULFIDE BASE AND THE FIELD OF THEIR APPLICATION

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Foreign Technology Division
Wright-Patterson Air Force Base, Ohio

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The properties of 5 solid lubricating coatings: VNII-NP-209 (org. Si compds. + MOS_2 in buoac), VNII-NP-212 (urea-HCHO resin + MOS_2 in a mixt. of etoh, xylene and solvent naphtha), VNII-NP-213 (org. Si compds. + MOS_2 in buoac), VNII-NP-229 (Na_2SiO_3 + MOS_2 in distd. H_2O), and VNII-NP-230 (epoxy resin + MOS_2 in a mixt. of buoac, phme, and et cellosolve) were detd. on friction testing machines. Best results (max. life 740 to 860 min, friction path 18,000-21,000 m, and friction coeff. (0.031-0.035) were obtained for VNII-NP-212 and VNII-NP-230. These lubricants were tested by using gear wheels, gear type couplings, gear racks, screws and nuts, click devices, ball joints, pivot bearings, and rope drums. [AT1127389]

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Solid Lubricant						
Acetate						
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Molybdenum Disulfide						
Organosilicon Compound						
Test Method						
Bearing Lubricant						
Machinery Lubricant/(U)VNII-NP-209 - Solid Lubricant						
(U)VNII-NP-212 Solid Lubricant						
(U)VNII-NP-213 Solid Lubricant						
(U)VNII-NP-229 Solid Lubricant						
(U)VNII-NP-230 Solid Lubricant						

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ASSORTMENT OF SOLID LUBRICATION COATINGS USING A MOLYBDENUM DISULFIDE BASE AND THE FIELD OF THEIR APPLICATION

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Z. S. Rubtsova and V. A. Listov

Tests using friction machines have shown that solid lubrication coatings should be used only in those cases where it is impossible to use fluid or plastic lubrication materials. It is most advisable to use them in sliding friction units. However, they may also prove to be suitable for roller bearings and journal bearings (for example, with a low rotation speed), and for immobile threaded connections, reduction gears with tooth meshing, and worm gears.

The assortment of solid lubrications developed by VNII NP (All-union Sci...tific Research Institute of the Petroleum Refining Industry) is presented in Table 1.

Coatings with molybdenum disulfide and the silicone film-forming material K-55 have been designated VNII NP-209 and VNII NP-213. The coating using the urea-formaldehyde film-forming material K-411-02 is designated VNII NP-212. That using an inorganic film-forming material (sodium silicate) is designated VNII NP-229, and the coating with epoxy film-forming material EP 0.96 is VNII NP-230. The coatings VNII NP-209 and VNII NP-213 differ only in the ratio of the molybdenum disulfide and film-forming material. In the coating VNII NP-209, K = 1, and in the coating VNII NP-213, K = 0.5.

It was established that the coatings VNII NP-212 and VNII NP-230 with organic film-forming materials, as well as coatings with silicone and inorganic film-

TABLE 1. ASSORTMENT OF SOLID LUBRICATION COATINGS

Coatings	Technical Specifications	Film-forming material	Solvent	K	Field of Application
VNII NP-209	TU 45-61	K-55	Butyl acetate	1	High temperature and high vacuum of a closed space
VNII NP-213	TU 119-62	K-55	Butyl acetate	0.5	High temperature and high vacuum without a closed space
VNII NP-212	TU 88-61	K-411-02	A mixture of ethyl alcohol, xylene and naphthal solvent	0.5	For friction units operating in atmospheric conditions with a high working time
VNII NP-229	MRTU 38-1-170-65	Na_2SiO_3	Distilled water	0.5	For increasing the wear resistance of cutting tools
VNII NP-230	VTU 146-63	EP-096	Mixture of butyl acetate, toluene and ethyl Cellosolve	0.5	Subject to radiation

forming materials, may be used at high temperatures and in a vacuum.

When deciding the problem of which part the coating should be deposited on, the following consideration is used. In operation, the maximum section of the part surface which is coated with a lubricant should be used. For example, in a friction unit consisting of two rollers, the coating should be deposited on the rotating roller; in the guide - slide block pair, one must coat the guide [1]. It is also necessary to take into account the depositing convenience. It is difficult to create a uniform coating on internal cylindrical surfaces; therefore, in the sleeve - piston pair, the coating is deposited on the piston. Thus, the part to be coated is selected individually in each separate case, since the operating efficiency of the friction pair depends on this selection.

In order to provide the longest lifetime, t coatings are deposited on surfaces which have been subjected to a preliminary processing which is the optimum one for the given metal [2, 3]. The coating thickness with organic, silicone and fluororganic film-forming materials should be around 20 microns, and with an inorganic film-forming material it should be around 8 - 10 microns. The clearances between the friction surfaces should be provided for with consideration of the coating thickness. In particular, for piston - cylinder type pairs, the clearance should be no less than 40 microns. If, because of structural considerat. . it is impossible to fulfill this condition, the coatings are deposited in a thinner layer. In this case, the durability of the coating is somewha. reduced [3].

Tests of Solid Lubrication Coatings Using Friction Machines

When selecting the coating, it is necessary to consider not only the field of application, but also the durability of the coating, its dependence on the load N, the sliding speed v, and the nature of the metal [3].

The data presented in Tables 2 - 5 were obtained on the MI machine [1] for coatings deposited only on rotating rollers.

For a steel - steel friction pair, the coatings VNII NP-212 and VNII NP-230 have a maximum durability (740 - 860 minutes, friction path L = 18,000 - 21,000 m) with a low coefficient of friction μ (0.031 - 0.035) (Table 2). With a decrease of the load by a factor of 5.7, the durability of the coatings and, consequently, the friction path are increased by almost a factor of 10. The coefficient of friction increases simultaneously (Table 3).

The increase of the sliding speed with a high load, evidently because of the temperature increase in the contact zone, leads to a reduction of the friction path. One may make an indirect determination of the temperature increase on the basis of the reduction of the friction coefficient from 0.031 to 0.025 (which is explained by the softening of the film-forming material) with a simultaneous decrease of the sliding speed from 0.42 to 0.92 m/sec (Table 4).

TABLE 2. OPERATING EFFICIENCY OF THE COATINGS (v = 0.42 m/sec, N = 160 kgf; pair EI-347 — EI-347)

Coating	τ, min	L, m	μ	No. of tests
VNII NP-230	730 ± 40	18,300 ± 1,000	0.035	24
VNII NP-212	860 ± 20	21,600 ± 500	0.031	36
VNII NP-209	100 ± 13	2,600 ± 300	0.040	27
VNII NP-213	100 ± 13	2,600 ± 300	0.040	27
VNII NP-229	75 ± 13	1,900 ± 300	0.105	51

TABLE 3. OPERATING EFFICIENCY OF THE COATING VNII NP-230 AS A FUNCTION OF THE LOAD (v = 0.42 m/sec, pair EI-474 — EI-474)

Load, kgf	τ, in min	L, m	μ
160	310	7,780	0.028
70	1,730	43,420	0.031
28	2,810	70,530	0.107

TABLE 4. OPERATING EFFICIENCY OF COATING VNII NP-212 AS A FUNCTION OF THE SLIDING SPEED (N = 160 kgf, pair EI-347 — EI-347)

Sliding speed, m/sec	τ, in min	L, m	μ
0.42	860	21,600	0.031
0.59	560	19,700	0.034
0.66	440	17,700	0.028
0.76	290	13,800	0.028
0.92	280	15,500	0.025

The tests on the MI machine showed that the coating VNII NP-229 which has a minimum operating efficiency at 200 - 350° C is not inferior to the better coatings VNII NP-212 and VNII NP-230 (Table 5).

In the friction process, on the ITK instruments [4, 5], the coating constantly comes into contact with a new section of the belt, and the antifriction products are continuously carried away from the friction zone. If the belt is not ground after each test, a molybdenum disulfide film forms on it and the durability of the coating increases by a factor of 5 - 10. On the MI machine molybdenum disulfide also is transferred from the rotating roller to the stationary roller. When a VNII NP-209 coating is deposited on both rollers, the durability of the coating approximately doubles.

The durability of the coatings depends on the construction of the friction unit, the type of geometric contact, and the size of the part with the coating. The total effect of the influence of a geometric type of contact, the part size, and the absence of a rolled-on molybdenum disulfide film on the paired part leads to the fact that, despite the significant decrease of the load on the ITK instrument, the friction path on the MI machine is many times larger.

Based on the test data using friction machines, one may make a tentative judgment as to the operating efficiency of coatings based on the calculated value of the friction path. Under the real conditions of coating use, the actual friction path agrees with the calculated path only when the operational conditions of the real unit agree with the test conditions on the friction machines.

Tests of Solid Lubrication Coatings on Real Mechanisms

Coating VNII NP-209

Tests on the rod - sleeve pair with reciprocating motion. The material of both parts is stainless steel; the height of the surface irregularities is R_z - 3.2 micron; the sliding speed is 0.02 m/sec (3 cycles/sec); the operating temperature is 200° C; the vacuum is 10^{-6} torr (a change of the permanent vacuum is intolerable). The durability of the instrument operating practically without a load is 50,000 cycles; the friction path is 1,250 m.

TABLE 5. THE OPERATING EFFICIENCY OF COATINGS AS A FUNCTION OF THE TEMPERATURE*

Coating	Index	40° C	100° C	200° C	300° C	350° C
VNII NP-209	μ L, m	0,025 1 200	0,029 3 530	0,020 2 520	0,034 820	0,036 480
VNII NP-213	μ L, m	0,069 1 500	0,043 5 040	0,017 3 020	0,031 880	0,043 410
VNII NP-212	μ L, m	0,051 4 790	0,020 10 080	0,013 5 800	0,020 1 130	0,025 760
VNII NP-230	μ L, m	0,057 3 150	0,024 11 670	0,033 5 870	0,024 1 340	0,037 440
VNII NP-229	μ L, m	0,041 1 200	0,016 5 040	0,019 4 410	— 1 010	0,060 760

*The tests were conducted using the ITK instrument [4] under the guidance of K. I. Klimov.

**Commas represent decimal points.

The coating was applied to the rod. The coating was annealed beforehand in a vacuum at 600° C for 30 minutes and at 900° C for 15 minutes for the purpose of degassing. After the annealing, coatings with silicone film-forming material K-55 and the inorganic material Na_2SiO_3 remained on the parts, whereas the coatings with the organic film-forming materials E-41, EP-096, BMK-5 and K-411-02 which were tested for comparison were almost completely burned up. Evidently, the shell of the silicone or inorganic film-forming material remains on the part surface after annealing, and the molybdenum disulfide was securely held in the cells of this shell. If this assumption is made, one should expect that the durability of the coatings depends on the ratio of the film-forming materials and molybdenum disulfide (K). In order to check this, the durability of coatings using the silicone film-forming material K-55 with K equal to 0.25 - 3 was determined (Table 6).

It turns out that when K = 1 the operational capacity of the instrument parts increases by more than a factor of 2 (120,000 cycles at a speed of 3 cycles/sec) and at high speeds (17 cycles/sec) it was doubled (100,000 cycles). In the case of K $\leq$ 1, the film remained in good condition with a sliding speed of 0.02 m/sec after 100,000 reciprocating cycles. With an increase of the sliding speed up to 0.1 m/sec, the durability decreases to 8,000 cycles; the film crumbled.

TABLE 6. DURABILITY WITH A RECIPROCATING MOTION OF COATINGS WITH FILM-FORMING MATERIAL K-55 AS A FUNCTION OF K

K	Durability in cycles	L, m	No. of cycles 1 sec	Speed m/sec
0,25	100 000	500	3	0,02
0,25	8 000	200	17	0,10
0,5*	100 000	500	3	0,02
1,0**	120 000	600	3	0,02
1,0	100 000	2 500	17	0,10
2,0	50 000	250	3	0,02
3,0	5 000	25	3	0,02

*Included in the assortment as coating VNII NP-213.

**Included in the assortment as coating VNII NP-209.

***Commas represent decimal points.

When K > 1, the durability abruptly decreased and abrasive wear of the paired part began. Thus, under conditions of a vacuum as well as in the air, the optimum value of K is close to one.

Since under vacuum conditions oxidation processes are absent, the durability of the coating may be greater than in an atmosphere of air. The good condition of the coating on the parts after 120,000 cycles of operation attests to this.

Coating VNII NP-213

Tests on air-distribution valves. Here the purpose of the coating is to protect air-distribution stopper valves against scouring. The material of the plunger and body is steel Kh17N2. The shape of the plunger is cylindrical with d = 38 mm, and the diametrical clearance between the plunger and the valve body is 60 microns. The application conditions are: the gauge pressure of the air is 6 atm, the temperature is from -60 up to 300° C, and the operational performance is 4,000 cycles. Each cycle involves turning the valve from a completely open position of the hot line to a completely open position of the cold line and back again. The turning angle of the plunger from one extreme position to the other is 90°. Consequently, during one cycle the plunger must traverse a path equal to half the length of the circumference; the total friction path equals 240 m.

With tests of the coating VNII NP-209 on the plunger surface, grooves were detected after 1,500 cycles and after 4,000 cycles scoring was detected. On the coating VNII NP-213, there was no scouring after 4,000 cycles at 280 - 300°C; in only one case was noticeable wear of the plunger detected (Table 7).

As was mentioned above, the friction path with the coating VNII NP-213 for 4,000 cycles was 240 m, whereas on the ITK instrument at the same temperature the friction path was equal to 882 m. Such a difference between the test results using a laboratory instrument and an actual unit may be explained by the fact that in the latter case the tests were not carried out to the point where the coating was completely eroded.

<u>Tests on threaded connections</u>. The coating protected the stud- nut pair against fusing together. The material is steel IKh18N9T and steel 2Kh13. The application conditions are: temperature up to 600 - 700° C, a pressure of $1 \cdot 10^{-6}$ torr, and a tightening moment of 400 kgf. cm. After remaining under the indicated conditions for 35 hours, 90 - 95 % of the threaded connections with the coating unscrewed freely.

<u>Tests on roller bearings</u>. The question of using solid lubrication coatings in roller bearings is a controversial one since, as a consequence of the low coefficient of rolling friction, these parts, as a rule, are not required to improve the antifriction properties. However, in practice, in addition to rolling friction, sliding friction also is observed in roller bearings (the friction of the ball in the recesses of the separator, etc.). Moreover, the operational conditions may be such that the use of fluid or plastic lubricants is excluded in general. Therefore, an attempt was undertaken to use coatings in roller bearings.

In radial bearings and radial thrust bearings, the clearances between the roller track and the balls are small; as a rule, they equal several microns. In thrust bearings, the clearances may change within rather large limits. From this point of view, it is simplest to use coatings on the thrust bearings. The thrust bearing 8204 (D_{ex} = 40 mm, d_{in} = 20 mm) was selected for testing. The coating was deposited on the bearing's raceway. The tests were conducted under the following conditions: temperature 300° C, rotating speed 800 rpm, linear speed 1.3 m/sec, load 193 kgf, initial contact stress 16,100 kgf/cm^2. Bearings

TABLE 7. TEST RESULTS OF COATINGS VNII NP-213 and VNII NP-209 IN AIR-DISTRIBUTION VALVES

Preliminary processing of the surface	Coating thickness, μ	No. of cycles	Character of the damage	Condition of coating
		VNII NP-213		
Pickling	20	4,000	Grooves	Remained on 50%
With a sandblaster	19	4,000	None	Remained completely
The same	18	4,000	"	The same
" "	20	4,000	Insignificant abrasion	" "
		VNII NP-209		
" "	30	1,500	Grooves	" "
" "	20	4,000	Abrasion	Not maintained
" "	30	4,000	Scouring	The same

with the coating VNII NP-213 operated for 6.5 hours under these conditions; the friction path was 58,500 m.

A radial thrust ball bearing (d_{in} = 6 mm) served as the next test object. The coating was applied to the raceway and separators; the film thickness was 5 - 6 microns; the radial load, 0.5 - 1 kgf (0.01 - 0.03 kgf/cm^2); the speed 0.03 - 0.05 m/sec (100 - 150 rpm). The instrument in which the bearing was located was heated at 350° C before operating. The tests with the solid coating VNII NP-213 were conducted in a vacuum of 10^{-6} - 10^{-7} torr at room temperature. The friction path was 10,800 - 18,000 m and no breakdown in the operation of the bearings was observed. The tests were discontinued, since the indicated lifetime of the bearings guaranteed the operation of the instrument.

Thus, the use of solid lubrication coatings in roller bearings is entirely possible in certain cases.

Tests on gears. With the operation of gears, two kinds of friction appear simultaneously — that is, sliding friction and rolling friction. Therefore, tests of solid lubrication coatings on gears are of special interest. The tests

TABLE 8. CHARACTERISTICS OF REDUCTION GEARS

No. of pairs	Driving Wheel		Driven Wheel		σ in kgf/cm^2
	Rotation, rpm	z_1	Rotation, rpm	z_2	
I	8000	32	3340	80	468
II	3340	28	1100	80	674
III	1100	27	430	70	1045

were conducted on a reduction gear (Table 8).

The coatings were deposited only on the driven wheels which were made from steel EI-474, bronze BrAzh-94 or Duralumin V-95T; the driving wheels in all cases were made from steel EI-747. The tests were conducted for 500 hours (the required operational time) or until the appearance of wear I of the wheel pair. Each coating was tested on three reduction gears (the torque on the output shaft was ∿ 2.7 kgf · cm). The coating VNII NP-213 with a thickness of 5, 20 or 40 micron on steel wheels completely guaranteed an operational time of 500 hours. On the reduction gears with bronze or Duralumin driven wheels, the durability of all the coatings being studied (a thickness of 18 - 22 microns) was considerably less; this is seen from the following data (in hours):

Coating	BrAzh-94	Duralumin V-95T
VNII NP-230	28	12
VNII NP-213	24	10
VNII NP-212	14	10
VNII NP-209	10	6
VNII NP-229	4	-

Coating VNII NP-212

Coating VNII NP-212 has found the widest application for friction units which operate for a long time under atmospheric conditions.

Tests on cutter presses used for cutting sheet metal. One of the most important elements of cutter presses is the knife packet which is made in the form of a punch with a guide column (plunger pin) and sleeve which moves with a reciprocating motion along the column. In order to assure normal operation of the knife packet, the columns must be lubricated or they must be made of material which does not require lubrication. The use of a fluid or lubricating grease under the given conditions is not possible, because of the inadmissibility of lubrication on the metal. The coating VNII NP-212 proved to be very effective under the following conditions: specific load in the unit 240p kgf/cm^2, room temperature, translational speed 0.04 - 0.2 m/sec, duration of the operation 3,000 double strokes, sleeve path during one stroke 0.8 m. The size and material of the samples being tested are: sleeve D_{ex} = 42 mm, d_{in} = 30 mm; column D = 35 mm, 1 = 250 mm. The steel 20 was case-hardened and tempered (HR_c = 58 - 60). The tests were conducted in cycles: the cutter press operated for 15 minutes and then stopped for 15 minutes. The coating VNII NP-212 was deposited on the column. The friction coefficient of the pair varied from 0.18 to 0.24. At the start, it had a high value; then it decreased to the minimum, and toward the end of the experiment it increased to the maximum.

Tests on joints. In the operating process of a hinged connection (a spherical ring and pin), both the ring and the pin rotate inside the ring of both parts. The material is steel ShKh-15, the temperature from -60 to 80° C, the maximum turn angle of the spherical ring is $\pm$ 20°, the load varies from 0 to 10.5 T, the sliding speed is 0.03 m/sec. The coating is deposited on the external and internal surface of the spherical ring. The torque obtained with the testing was 10 kgf · cm with a load of 10.5 T. This torque value is considerably lower than the value obtained when making tests of a unit with plastic lubrication. After 200 hours of tests (a friction path of 2,000 m) no traces of scouring or wear were detected on the friction surfaces having a coating of VNII NP-212. In tests for a greater durability (350 hours), the clearances between adjoining parts increased by a factor of 2 - 3.

Tests on wire potentiometers. The shaft - sleeve is the rubbing pair; the first member is made from steel 2Kh13, and the second — from steel EI-474. The rotating speed of the shaft is 80 rpm, the linear speed is 0.03 m/sec, the temperature of the surrounding varies from -60 to 160° C, the pressure of the surrounding medium is 5 - 760 torr. The lubricant TsIATIM-221 which is being used under these conditions ensures 10,000 rotations without jamming; the required operational time of the potentiometer is 20,000 rotations. Under these conditions, the potentiometer shafts with a coating of VNII NP-212 did not jam after

20,000 rotations.

Considering the good results of the tests of the coating VNII NP-212 on the ITK laboratory instruments at 300° C, tests of the coating on the potentiometer shafts were conducted at higher temperatures. It was found that the coating VNII NP-212 at 270° C ensured the same operating efficiency of the unit (20,000 rotations) as the lubricant TsIATIM-221. The friction path of the shaft during 20,000 rotations was 900 m. Since the test conditions on the ITK instrument and in the potentiometers differed only slightly in respect to the values of the load and speed, the friction path in the actual unit practically agreed with the calculated friction path in the instrument ITK at 300° C (see Table 5).

Coating VNII NP-229

At present, stainless and heat-resistant steels, titanium and its alloys, aluminum and other metals which easily form an oxide film and therefore yield with difficulty to mechanical processing (grooves, scratches and cold hardening appear) are widely used in engineering. In order to improve the processing quality of the surface and also to increase the durability of cutting tools, the most available and inexpensive coating — that is, VNII NP-229 — was tested. The absence in the coating of easily combustible and explosive solvents considerably facilitates its industrial production and application.

The coating VNII NP-229 was tested on boring, milling, screw-tapping, cutting, reaming, chiselling, screw-die, drawing and other tools. It was established that it increases the wear resistance of the tool on the average by a factor of 1.5 - 2.

Coating VNII NP-230

This coating was designed mainly for mechanisms operating under conditions where there is radiation. In many friction units with such an operation, relatively high temperatures also act in addition to the radiation. The coating VNII NP-230 was tested under actual conditions at 350° C and also under the simultaneous influence of a high temperature (100 - 200° C) and radiation.

TABLE 9. OPERATING CONDITIONS OF COATING VNII NP-230

Friction Unit	Material	Unit Diameter, mm	Load kgf	Initial contact stress, kgf/cm^2	Temp., ^{o}C	Speed m/sec	Operating regime	Operating time
Conical and cylindrical gears	St. 40Kh	up to 90	up to 650	-	100	0.9	Reversing with pauses	106 cycles (1000 hrs)
Rack with pinion gear	IKh18N9T	-	60	-	100	up to 2500*	The same	30000 cycles (250 hrs)
Screw - nut	St/bronze	-	190	-	100	up to 2500*	" "	10000 cycles (360 hrs)
Shafts of rachet and pawl	St. 45	up to 35	insignificant	-	100	0.2	" "	The same
Spherical joints	IKh18N9T	up to 50	60	15	200	insignificant	25 min after 10 min	3 years
Spherical pivot	IKh18N9T	up to 50	190	40	100	up to 2500*	Reversing with pauses	10000 cycles (360 hrs)
Drum for a cable	St. 45	up to 200	50	2500	100	7	The same	The same
Flat guides	Cast iron	200 X 200		0.5 - 2.5	20	0.06	Reciprocating motion with pauses	50000 cycles 30 km (150 hrs)

* rpm

Tests on a rod - sleeve pair. The material of the pair is steel 30KhGSA and cast iron 41.8. The clearances are 40 micron, the motion is reciprocating, the speed is 0.06 m/sec, the specific pressure is $30 \cdot kgf/cm^2$, the temperature is from -60 to 350° C. The required operating time is 100 hours, including 8 hours at 350° C. The operating procedure is periodic. The relatively small clearances in the rod - sleeve pair allow one to deposit a coating layer on the rod with a thickness of no more than 10 - 15 microns.

The coating VNII NP-230 lasts for the required time. The friction for 100 hours was 21,600 m, and for 8 hours at 350° C it was 1,700 m.

Tests on various friction units of electric power equipment. The tests were conducted on gear transmissions, helical transmissions and rack and pinion transmissions, on sleeves and shafts, on connecting rod joints, on drums for tables and on flat guides. The material and dimensions of the parts, the load, the motion speed and the operating procedure are presented in Table 9.

For all friction pairs, the coating ensured the required operating time. In tests on the guides, the coating ensured only 100 hours of operation (friction path of 20 km) instead of the required 150 hours (friction path of 30 km).

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