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Slip Bearings and Lubricants in Low-Speed Heavy-Duty Spiroid Gears

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Abstract—Means of reducing the friction in slip bearings are considered, for the example of low-speed heavy-duty spiroid gears used as drives in pipeline systems.

Keywords: spiroid gear, slip bearing, lubricant, efficiency

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Low-speed heavy-duty spiroid gears are used in hoists, various technological and transport systems, and in the drives of pipe-rolling equipment [1–3]. They are used at working temperatures between –60 and +50°C, under heavy loads, and at high speeds. Consequently, their efficiency is relatively low and the wear rate of the frictional pairs is high. Such gear systems must have long life. Therefore, it is important to find means of improving their performance—for example, reducing the frictional forces in the slip bearings by the appropriate selection of the gear materials and lubricants.

We investigate the RZA-S-2000 quarter-turn gear for a pipe-rolling system (Fig. 1a) and a multiturn RZAM-S-1000 gear (Fig. 1b).

The quarter-turn gears are mounted on ball valves and disk gates. They are characterized by brief operation per cycle (no more than 200 s); the working component of the rolling system rigidly connected to the spiroid gear rotates by 90° ± 10°. The multiturn gears are used to control gate valves and similar equipment. Their working period is longer (5–60 min per cycle, 40–150 turns of the gear for 1000 or more turns of the gear's input shaft).

The characteristics of the spiroid gears considered are as follows:

	RZA-S-2000	RZAM-S-1000
Interaxial distance a_w, mm	60	40
Gear ratio i_{12}	46	11.46
Axial module of spiroid screw m_X, mm	2.750	2.774
External diameter of spiroid screw d_{a1}, mm	42	48
Internal/external diameter of spiroid gear d_{i2}/d_{e2}, mm	138/175	120/155
Maximum torque on gear's output shaft T_{2max}, N m	2000	1000
Limiting static torque on output shaft T_{2li}, N m	4000	2000
Mass m, kg	17	11

The gears (Fig. 1) include a housing *1* that contains the spiroid screw *6*; input flange (lid) *3*; adapter *4* (the output shaft for the quarter-turn gear) or a protective dome (for the multiturn gear); and a transmission consisting of the spiroid screw *6* rotating in roller bearings, and the gear *7*, rotating in slip bands. Auxiliary components include indicators, speed limiters, and structural components. The RZA-S-2000 system (Fig. 2a) is based on spiroid gear *1*, radial bearings *2*, and an end bearing *3*, while the RZAM-S-1000 system (Fig. 2b) is based on gear *1*, radial bearings *2*, and two end bearings *3*.

The following slip bearings are chosen:

1. Metal–fluoroplastic bearings manufactured from a strip consisting of a steel base (low-carbon steel) and a layer (0.20–0.35 mm) of sintered bronze powder that has been infiltrated and coated with a layer (0.01–0.04 mm) of polytetrafluoroethylene and molybdenum disulfide. The main downside of this type is high cost [4]. These bearings withstand heavy loads, operate without lubricant over a broad temperature range, and maintain a low frictional coefficient.

2. Cast-iron bearings. Such bearings operate under heavy loads, require careful installation (running-in with no load followed by gradual increase to the calculated load), and require high-quality lubricant, which largely determines the friction in the slipping pair. They are inexpensive and may be used as the bearing for the gear system's cast-iron housing (base) [5].

3. Steel slip bearings. Such bearings operate under heavy loads and at low speeds. They have high contact strength. They are inexpensive but their frictional properties do not match those of metal–fluoroplastic and cast-iron bearings [5].

4. Slip bearings with laser-induced surface nanostructure. These are improved steel bearings with a diamond-like coating (DLC).

These bearings have the greatest potential for reducing the frictional coefficient and increasing the

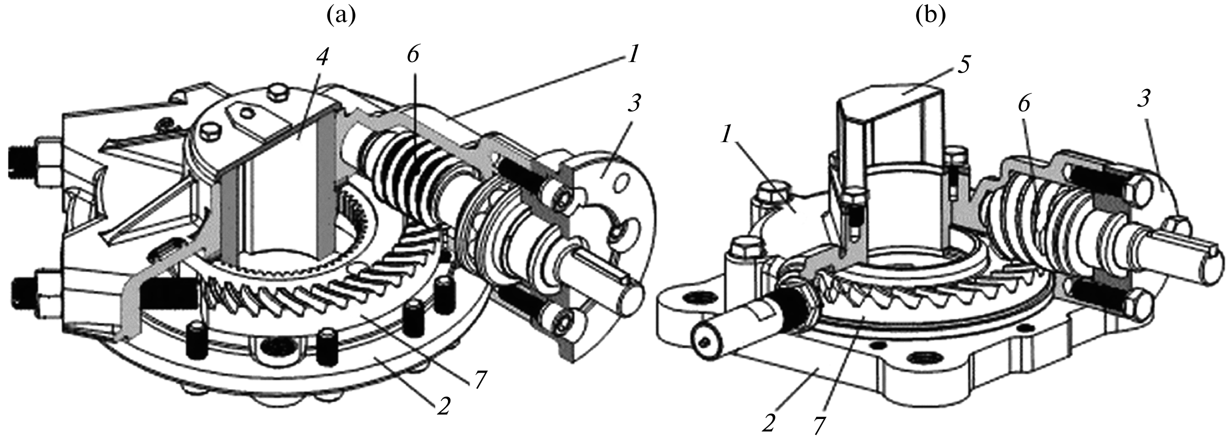

Fig. 1. Spiroid gears: (a) quarter-turn gear; (b) multiturn gear; *1*, housing; *2*, base; *3*, input flange (lid); *4*, adapter; *5*, safety valve; *6*, spiroid screw; *7*, gear.

wear resistance of the frictional pair. They are strong and inexpensive.

The diamond-like coating consists of carbon atoms with diamond atomic bonds (strong in all directions) and graphite-like bonds (strong atomic bonds within the plane but weak bonds between the planes) [6]. The diamond-like coating is applied by direct pulsed laser deposition, which differs from methods in which the surface is saturated with carbon—such as low-speed laser treatment, thermomechanical saturation, and cementation—in that carbon of different forms is present in the thermal-influence zone. The graphite is introduced in the melt under the action of laser pulses and does not dissolve completely in the melt on account of the brevity of the pulse and high cooling rate [7].

The system for direct laser deposition is shown in Fig. 3.

In producing ultradisperse graphite powder, the initial material is GK-1 graphite powder, which is ground in two stages: 1) for 40 min; 2) for 10 min with the addition of heptane. The resulting heptagraphite suspension is applied in a thickness of 10 μm to a steel 20 substrate and dried.

The laser system consists of a 50-W pulsed ytterbium optical-fiber laser (wavelength 1.065 μm). Low pressure (1 Pa) is first created in the working chamber, and then argon is introduced (101 kPa) so as to prevent oxidation on sintering. The treatment conditions are as follows: pulse length $t \approx 10{-}50$ ns; power $P_{la} = 6$ kW; density $J = 0.9 \times 10^9$ W/cm^2.

In Fig. 4, we show the surface after laser treatment. The surface luster does not fade over time. That indicates the absence of oxidation. Numerous graphite inclusions (dark spots) are also seen.

The frictional properties of the coating are investigated on a SMT-2070 system (State Standard GOST 23222–84), with lubricant. A steel disk (diameter

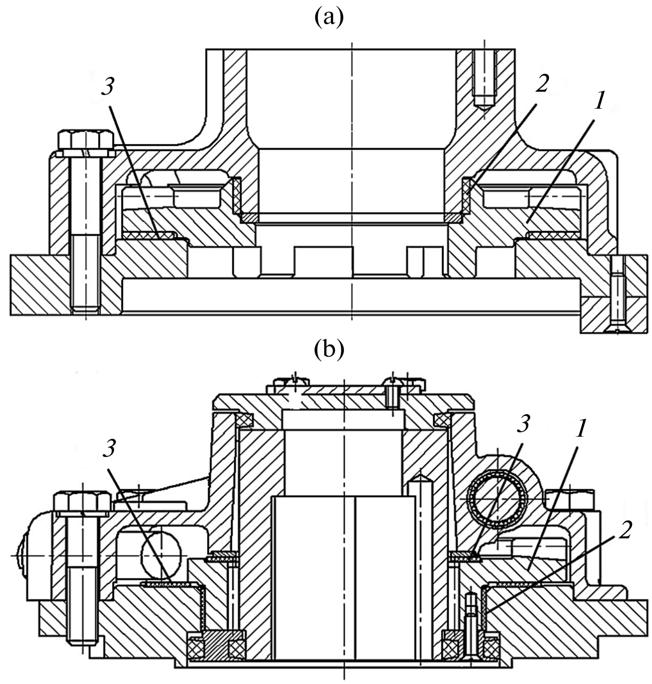

Fig. 2. Cross sections of the RZA-S-2000 (a) and RZAM-S-1000 (b) gear systems.

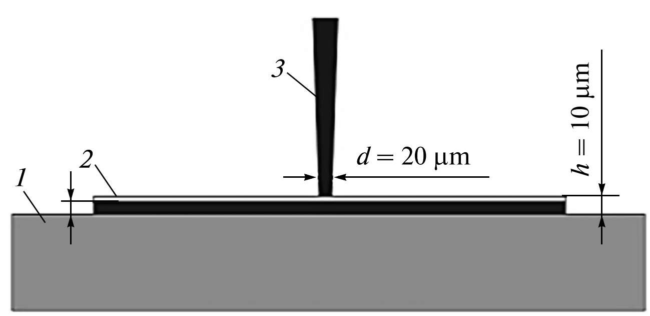

Fig. 3. Direct laser deposition: (*1*) steel substrate; (*2*) layer of ultradisperse graphite powder; (*3*) laser beam focused on the substrate.

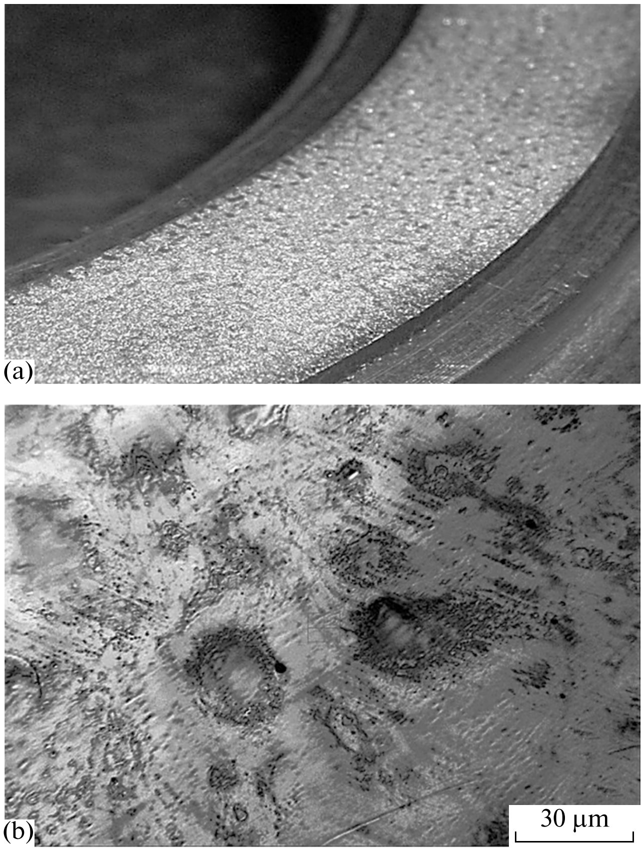

Fig. 4. Surface after laser treatment: (a) regular view; (b) at high magnification (×500).

50 mm, thickness 10 mm) and the concave inner cylindrical surface of a steel shoe are subjected to laser treatment. The load is 20 MPa; the number of load cycles is 15×10^5, with slipping friction at 150 m/min. The frictional coefficient is calculated from the parameters recorded in the tests.

The test results show that the frictional coefficient in the disk–shoe frictional pair is reduced to 0.012 by laser treatment. In the control disk–shoe pair (steel 40) after quenching and tempering, the frictional coefficient is 0.02. The reduction in the frictional coefficient may be attributed to the presence of graphite at the laser-treated surfaces.

The lubricants employed contain surfactants such as lithium soaps, which are thickeners, differ from sodium soaps in that they are compatible with the main component of the lubricant, and form transparent uniform colloidal solutions [8, 9].

To improve the performance of the lubricant, we add finely disperse graphite and molybdenum disulfide (MoS_2). Molybdenum disulfide (with a particle size of 1–100 μm) is a dry lubricant. Its lattice consists of plates, which move relative to one another in frictional pairs. That confers antiscratch properties on the lubricant and ensures that the frictional pair runs in well.

Graphite is used in plastic lubricants thickened with calcium, lithium, or sodium soaps. With a laminar crystal lattice, it is an effective antifrictional filler, which considerably improves the wear resistance and lubricant performance. The good bond of the graphite film with metal oxides is due to its structural features: the graphite molecules are weakly bound and water or oxygen molecules are always present between the graphite layers. A graphite single crystal is very strong in one plane and very weak in the perpendicular direction. Weak tangential forces lead to the appearance of slip planes, forming surfaces with very low frictional coefficient. Thus, the use of graphite lubricant or the addition of graphite results in the formation of a graphite layer at the frictional surface, boosting the antifrictional properties.

Graphite is distributed uniformly over the lubricant volume. As it is consumed in the frictional zone, its concentration is slowly replenished from outside. To accelerate this process, we use a surfactant that has a large binding energy with metal, which selectively absorbs carbon particles so that a high graphite content in the contact layer reduces the frictional coefficient. A suitable surfactant is nitrated oil, a corrosion inhibitor that is based on auto oil such as Avtol [10]. (In such applications, its viscosity and other properties are of no great significance.) It is possible to use spent oil; this may even be preferable, since it will include acidic groups formed as a result of friction.

In contrast to the classic process, in which the nitrating agent is nitric acid in the presence of sulfuric acid, we simply use concentrated nitric acid without modification, so that nitrating is accompanied by partial oxidation of the hydrocarbons.

Thus, under the action of concentrated nitric acid, oxidative nitrating occurs. Both nitroalkanes and oxynitroalkanes may be formed. This inhibitor is inexpensive. A thin and strong film with excellent antifrictional properties is formed on the surface treated by this agent. We believe that the corrosion inhibitor may replace the expensive molybdenum disulfide currently employed.

The table presents eight lubricant compositions employed in the tests.

In the tests, we use slip bearings made of different materials and lubricants of different composition. The test system is based on an open power flux. The torque created by the motor is transmitted to the input of the gear system attached to the support. Then, the torque is transmitted through a stepup gear to the braking shoe. The torque at the input shaft is measured by means of a torque sensor; that at the output shaft is measured by a clock-type dynamometer.

Lubricant compositions in tests

Lubricant	Main component	Relevant standard	Composition
1	Fiol Ultra T	TU 0254-003-5238210–04	Semisynthetic lubricant
2	LITA	TU 0254-009-80388604–2008	Lithium petroleum lubricant; 10% fine-grain graphite; 5% MoS_2
3	Tomflon M360	TU 0254-017-1235252–04	Semisynthetic lubricant (PTFE), 15% fine-grain graphite
4	Tsiatim 201	GOST 6267–74	Lithium petroleum lubricant; 10% fine-grain graphite; 5% MoS_2
5	Tomflon M360	TU 0254-017-1235252–04	PTFE, 10% fine-grain graphite; 5% MoS_2
6	Tsiatim 201	GOST 6267–74	Lithium petroleum lubricant; 3% corrosion inhibitor; 10% fine-grain graphite
7			Lithium petroleum lubricant; 3% corrosion inhibitor; 10% fine-grain graphite; 2.5% MoS_2
8			Lithium petroleum lubricant; 3% corrosion inhibitor; 10% fine-grain graphite; 5% MoS_2

Repeated brief load pulses are applied; the temperature of the gear system, the state of the working surfaces is periodically monitored; the efficiency of the gear system is measured. For each load, at least three measurements are made; mean values are employed in the graphs.

To compare the operation of the slip bearings, we consider the RZA-S-2000 quarter-turn gear system. In Fig. 5, we show the dependence of the efficiency on the torque *m* at the output shaft when the left (a) or right (b) surfaces of the screw turns are driven, for slip bearings made of metal–fluoroplastic strip (*1*), cast iron (*2*), and steel (*3*), and bearings with laser-induced surface nanostructure (*4*).

The efficiency is greatest when using metal–fluoroplastic slip bearings and bearings with laser-induced surface nanostructure; the difference between these two cases is slight (around 2%). Therefore, since the bearings with laser-induced surface nanostructure are less expensive (by about 30%), they may be recommended in the given operating conditions.

To assess the influence of the lubricant composition on the efficiency of the gear system, we consider the RZAM-S-1000 multiturn gear system. The test results are shown in Fig. 6. (The numbering of the curves corresponds to the numbers of the lubricant compositions in the table.)

All the lubricants employed exhibit satisfactory antiwear and antiscratch properties at standard loads. The most effective are those based on Tomflon M360 and Tsiatim 201. Lubricants based on Tsiatim 201 are less expensive. The use of composition 6 in the table somewhat increases the efficiency of the gear system. Compositions 7 and 8 have little influence on the efficiency, and therefore MoS_2 may be omitted, with corresponding financial savings.

Frictional tests using lubricants of different composition and slip bearings made of different materials show that it is expedient to use corrosion inhibitor as

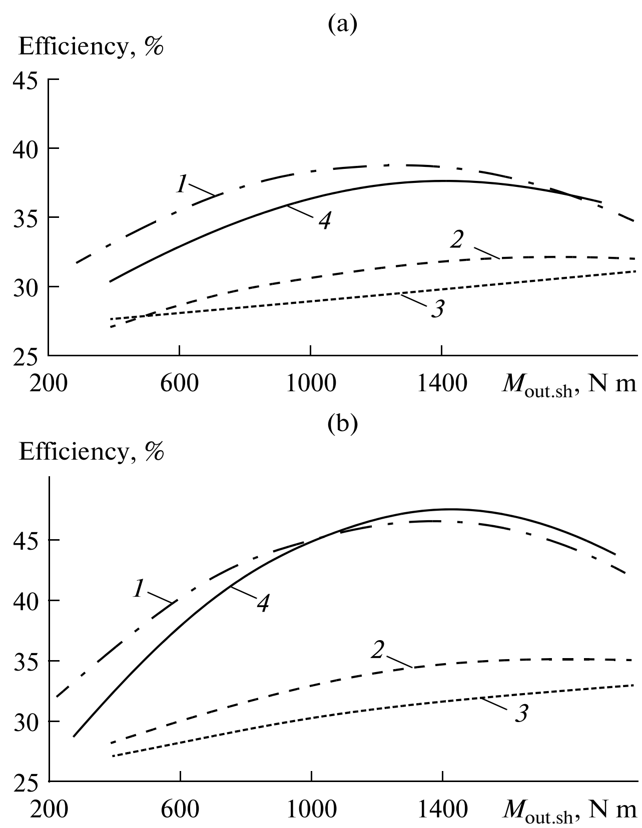

Fig. 5. Dependence of the efficiency of the gear system on the torque *M* at the output shaft when the left (a) and right (b) surfaces of the screw turns are driven, for different slip bearings.

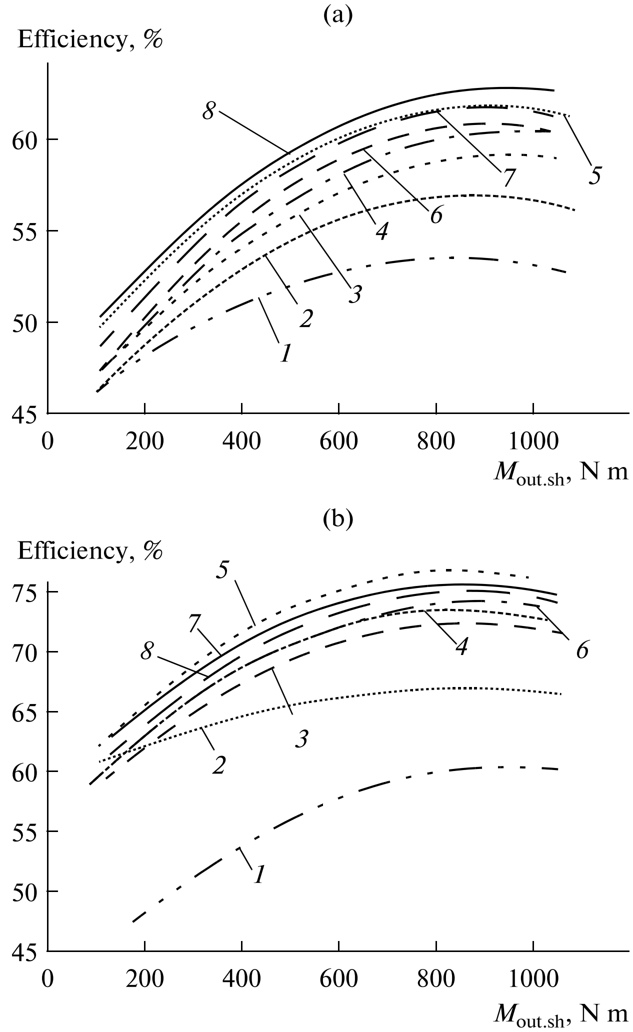

Fig. 6. Dependence of the efficiency of the gear system on the torque *M* at the output shaft when the left (a) and right (b) surfaces of the screw turns are driven, for different lubricants.

an additive in the lubricant and to use direct laser deposition at the contact surfaces.

These conclusions also apply to other frictional pairs and require further study in different operating conditions.

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