Experimental Evaluation Of Efficiency Of Grease Modified By Products Of Plasma Recondensation

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Abstract*: Literature review has revealed that operation lifetime of roller bearings is a factor determining reliability of automotive machinery. In order to increase the lifetime of roller bearings, it is proposed to modify their grease. This method can be applied during machinery operation and does not require for additional chemical–thermal and mechanical treatment of bearings involving complicated and expensive equipment. A modified grease was experimentally developed on the basis of Lithol-24, Russian standard GOST 21150-87 with nanosized metal particles obtained by plasma recondensation. Comparative tribological experiments of commercial grease and nanosized grease demonstrated efficiency of the latter. The acquired experimental results demonstrated that gamma-percentile life of the bearings operating with the developed grease was by 2.4–2.8 times higher than that of the bearings operating with the commercial grease.

Index Terms*: operation lifetime, roller bearings, greasing composition, metal nanoparticles.

I. INTRODUCTION

Mechanization at agro-industrial sector is based on energy intensive and highly efficient automotive machinery. In order to take into account peculiarities of agricultural production, it is necessary to provide high reliability of all units and systems of technical objects.

At present 20–30% of total scope of works are accounted for the transportation operations in agro-industrial complex. Reliability of automobiles depends significantly on operability of chassis units. Analysis of reliability performances of KamAZ vehicles revealed that 16–22% of total failures were due to chassis. One of the main reasons of poor reliability of this system is low lifetime of roller bearings of wheel hubs [1] which can result in both increase in operation costs and decrease in transportation safety. These bearings are expensive and nonrepairable items. High cost of hub bearings together with low operation lifetime make it necessary to improve their performances which can provide significant decrease in operation costs and prime costs of agricultural products.

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Therefore, it is necessary to develop an efficient grease and to carry out integrated tests in order to evaluate its influence on lifetime of roller bearings of automotive machinery.

II. METHODS

In order to obtain the required result, experimental greases were preliminary tested; the most efficient components were selected and grease compositions were optimized; under laboratory conditions the obtained grease and commercial analog were tested; bench and full-scale tests were carried out. Analysis of the existing production technologies of efficient grease modifiers [2–11] revealed the method of plasma recondensation applied for production of metal powders in nanodisperse form. The method is comprised of vaporization of coarse powder or rod of a required metal (raw material) in plasma flow at the temperature up to 8000 K and condensation of the vapor to particles of required size (RF Patent № 2068400). An advantage of this method is the possibility of doping of the nanosized particles of metals and alloys with various elements during their production. The following powder classes were produced by plasma recondensation: pure powders (Cu, Zn, Ni, Fe, Ti, Al, BN, Mo, MoS2); binary powders (Cu–Zn, Cu–Ni, Cu–Sn, Cu–Pb, Al–Pb); doped powders (Cu–Zn–P, Cu–Zn–S, Cu–Ni–P, Cu–Ni–S, Cu–Sn–P, Cu–Sn–S, Cu–Pb–P, Cu–Pb–S); composite powders (Cu–Al2O3, Cu–BN, Cu–MoS2, Cu–ZnO2). The particles of the considered powders are nearly spherical, their sizes are 10…30 nm, specific surface area is 100…150 m2/g. On the basis of the presented list of components, the manufacturers of greases can modify them, adapt the greases to temperatures, loads and speeds of various friction units of technical objects. Experimental greases in this work were based on Lithol-24, Russian standard GOST 21150-87, and powders of the following metals and alloys: Ni, Fe, Zn, Cu–Sn, Al–Pb, Cu–Pb, Fe–Ni, Fe–Zn. The components were selected on the basis of published data and previous experimental results [2–12]. The experimental greases were prepared by intensive mechanical agitation of powders in basic grease.

Preliminary tests, complete factorial experiment, and comparative tests of the considered greases were performed using an MI-1M friction machine (Fig. 1).

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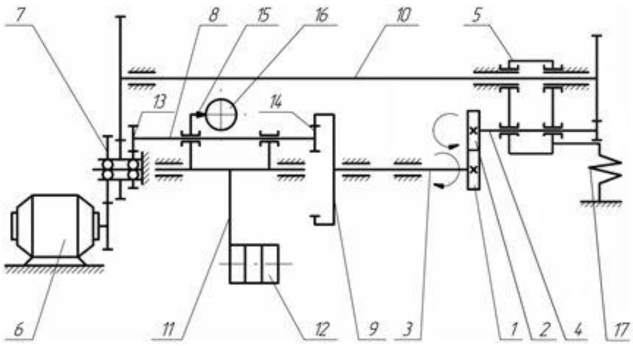

Fig. 1. Kinematic flowchart of MI-1M friction machine: 1 – bottom roller; 2 – top roller; 3 – shaft spindle; 4 – carriage spindle; 5 – carriage housing; 6 – electric motor; 7 – gear cluster; 8, 10 – shafts; 9 – internal gear; 11 – pendulum; 12 – loads; 13, 14 – gears; 15 – marker; 16 – plotting paper; 17 – loading device.

Before the tests, the friction machine was calibrated in terms of load and friction torque.

The friction interaction of roller bearings was simulated using roller–roller coupling (Fig. 2).

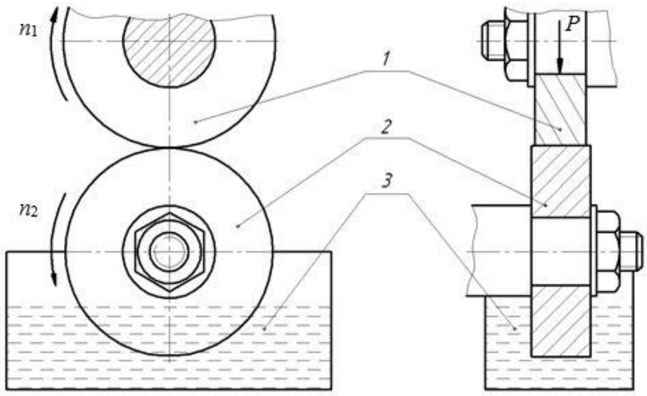

Fig. 2. Schematic view of roller–roller friction contact: 1 – top roller; 2 – bottom roller; 3 – reservoir with tested grease.

The rollers were made of steel, grade ShKh-15, Russian standard GOST 2590-88, with the following specifications: outer diameter: 50 mm, width of bottom roller: 12 mm, top roller: 10 mm, coarseness of friction surfaces Ra : 0.8 µm, hardness: 60…62 HRC.

Before the tests, the rollers were worn-in using Lithol-24 in 3 h. Lubrication was carried out by immersion of bottom roller by 1/3 diameter into lubricating trough with the capacity of 150 cm3. The wear-in was performed under the following conditions: bottom roller rpm: 500 min-1, slippage of contacting rollers: 10%, ambient temperature: 20…23°C. The load on rollers was increased from 0 to the experimental load in increments of 0.25 kN. Duration of operation at each load was 0.5 h. The load was modified by the loading device 17 (see Fig. 1). The wear-in end was determined by steady friction upon roller loading with experimental load.

The worn-in rollers were washed in petrol, Specifications TU 38.401-67-108–92, dried in air in one day, and weighed using an HR-250AZG analytical balance with the accuracy of 0.1 mg.

Then the rollers were installed in the friction machine, the considered greases were tested. Their efficiency was evaluated by roller wear rate and friction torque between them. The wear was determined by weight using the analytical balance. The friction torque was recorded automatically by the marker 15 on the plotting paper 16 using the self-recording unit of the friction machine (Fig. 1). The properties of the experimental greases were compared with those of the basic grease.

The machine was started without load. Then the rollers were loaded from 0 to the experimental load in 2–5 min. After termination of the tests, the rollers were washed in petrol, dried in air in 24 h, and weighed on the analytical balance.

During comparative tests the influence of the greases on resistance of rolling surface against fatigue flaking was additionally studied. The following roller specifications were used: outer diameter: 35 mm, width of rolling surface of top roller: 2 mm, of bottom roller: 10 mm, roughness of friction surface: Ra = 0.8 µm, and hardness: 60…62 HRC. The rollers were worn-in at the following conditions: bottom roller rpm: 220 min-1, slippage of contacting rollers: 5%, ambient temperature: 23°C. The load on rollers was increased from 0 to 0.45 kN in increments of 0.15 kN. Duration of operation at each load was 1 h.

Resistance of rolling surface against fatigue flaking was tested at bottom roller rpm of 220 min-1 and contact slippage of 5%. The rollers were loaded to 0.45 kN during 10 min. Then the load was increased by 0.25 kN and kept constant during 1 h with subsequent gradual decrease in 3 min, then the machine was stopped for examination of contacting surfaces. Then the following stage was initiated up to total duration of 1 h. The contact fatigue was determined by occurrence of pittings on roller working surfaces. Their existence was determined visually.

The bench tests were performed using a TsKB-50 facility (Fig. 3).

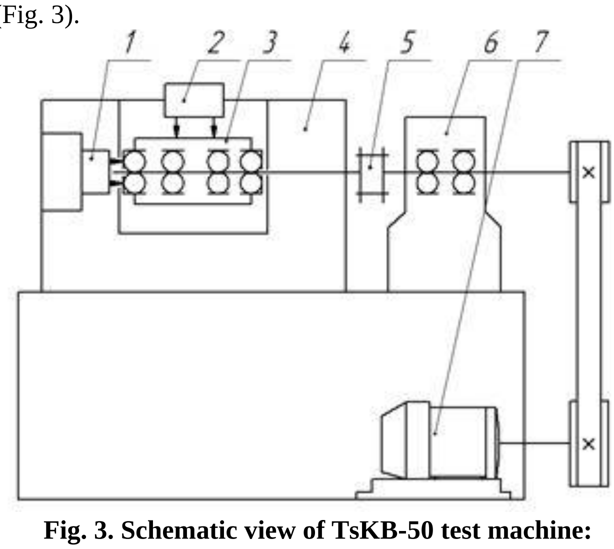

Fig. 3. Schematic view of TsKB-50 test machine: 1 – axial loading unit; 2 – radial loading unit; 3 – test equipment; 4 – block; 5 – drive coupling; 6 – drive; 7 – electric motor. This facility provides possibility of simultaneous tests of two bearings of similar size under radial, axial, or combined load (Fig. 4). The tests machine is equipped with hydrostatic loading system.

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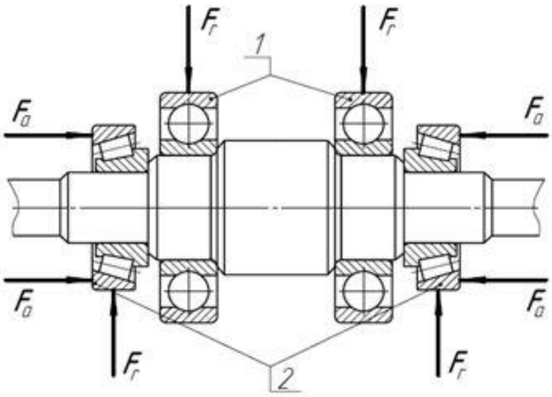

Fig. 4. Bearing loading during bench tests:
1 – loading bearings; 2 – bearings 7202.

The tests were performed with 40 roller radial thrust bearings 7202, Specifications TU 37.006.162-89, 20 bearings were sued for tests with Lithol-24, and the other 20 bearings – for tests with the developed grease.

The following test modes were applied: rpm of bearing internal ring: n = 4000 min^{-1}; radial load on the tested bearing: F_r = 4414 N; axial load: F_a = 1986 N. The duration of continuous tests was 14 h per day.

After completion of each stage of daily tests, the mass wear of bearing members was examined as well as the existence of fatigue flaking on their surfaces. With this aim radial and, partially, axial (70%) loads were released, electric motor of the test machine was deactivated, the axial load was finally released, the oil pump was deactivated, the electrics was deactivated, the accessories were unmounted, the grease was removed from the bearings. Then the bearings were washed in petrol and dried in air during 1 h, the existence of fatigue flaking on rolling surface of bearings was visually examined, and the bearings were weighed on analytical balance. The criterion of ultimate state of bearings was the occurrence of fatigue flaking on rolling surfaces. Under operation conditions, the performances of roller bearings of automotive machinery are exerted to the influence of such factors which cannot be predicted and simulated under laboratory conditions. The influence of nanocomponent grease on the lifetime of wheel hub roller bearings of KamAZ vehicles was tested during comparative tests. The tests were performed in accordance with the plan [NUT] providing observation for the *N* items during the time *T*. Failed items were neither repaired nor replaced with new ones. The tests were terminated after expiration of test time or runtime *T* for each nonfailed item. Calculation of minimum number of the observed items *N* was reduced to determination of mean-square deviation σ, arithmetic mean a_{top}, coefficient of variation *V*, and experimental reliability *H*. On the basis of *V*, ε, *H*, the number of observed items was determined:

$$N = \frac{t^2 V^2}{\varepsilon^2},$$

where t was the specified accuracy; V was the coefficient of variation; ε was the relative experimental accuracy.

At the experimental reliability of 0.90 and the coefficient of variation not higher than 15%, it was determined that the minimum number of tested roller bearings was 24 pieces.

Therefore, 12 KamAZ-5320 vehicles were involved in the tests of 24 wheel hub bearings of one size. During the tests the bearing units of six vehicles at the left side were filled with Lithol-24, and at the right side – with the developed grease. The bearing units of other six vehicles were filled with nanocomponent grease at the left side and with Lithol-24 at the right side.

The runtime T was set to 140 thousand kilometers. Aiming at detection of occurrence of ultimate state of the bearings, the signs of fatigue flaking on working surfaces of their rollers were visually controlled each 10 thousand kilometers.

The lifetime of bearings, which exceeded the preset limit, was estimated according to the procedure of lifetime prediction [13, 14]. The 90% lifetime of wheel hub bearings was calculated as follows:

$$L_{90} = \frac{C_{\text{act}}^{m_p} \cdot 10^6 a_p}{\beta \sum_{i=1}^{n} \alpha_i \sum_{k=1}^{m} \gamma_{i_k} \omega_{0_k} \int_0^{P'_{\max}} P'^{m_p}_{i_k} f\left(P'_{i_k}\right) dP'}, \quad (2)$$

where Cact was the actual dynamic bearing capacity, N; mp was the variable characterizing load type of these bearings; ap was the adjusting coefficient depending on loading conditions; β was the loaded mileage proportion; αi was the coefficient accounting for distribution of vehicle drive along the i-th road type; γ_{i_k} was the proportional coefficient of drive using the k-th gear along the i-th road type; ω_{0_k} was the loading rate of bearings, cycle/km; $f(P'_{i_k})$ was the distribution density of reduced load upon driving at the k-th gear under the i-th operation conditions; P´ was the reduced load on the most loaded rolling member in bearing, N.

For higher reliability of the experimental data, the procedures and appliances were selected so that to provide the best accuracy in combination with mathematical statistics for computer aided data processing and estimation of the observation results [13].

III. RESULTS AND DISCUSSION

The obtained results of preliminary laboratory tests (Figs. 5 and 6) demonstrated that the greases with Fe, Ni, and Zn were characterized by the best antifriction and wear resistant properties.

The grease composition was optimized during complete factorial experiment. The developed grease named as Cluster-S was protected by Russian patent [15].

The results of antifriction tests of Lithol-24 and the developed grease demonstrated that the average friction torque with Lithol-24 after stabilization was 7.8 N·m, it was steady during the experiment. The developed grease promoted decrease in the average friction torque to 6.6 N·m. Therefore, modification of the commercial grease by powdered Fe, Ni, Zn decreased the average friction torque in a simulated friction couple by 1.15 times in comparison with the basic commercial grease.

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Modification of Lithol-24 by powdered Fe, Ni, Zn made it possible to improve not only its antifiction properties but wear resistance as well. As a consequence, the wear of rollers during tests with the basic grease was 5.5 mg. Addition of nanosized metal particles into the commercial grease decreased the wear of rollers to 2.4 mg. Therefore, the developed grease deceases the wear of rollers by 2.3 times in comparison with Lithol-24.

Taking into consideration the causes of failure of rolling bearings [2, 16], it is important to specify the extent of influence of the considered greases on resistance of rolling surfaces against fatigue wear.

This was studied during a set of laboratory tests. The obtained results demonstrate that the developed grease promotes increase in the number of cycles before occurrence of initial pittings by 1.86 times in comparison with Lithol-24. The load causing fatigue flaking increased by 55%.

The obtained data can be attributed to modification of rolling surfaces by nanosized components during friction. Comparative laboratory tests of antifriction and wear resistant properties of the developed grease demonstrate that the applied nanosized metal particles improve these properties and increase wear resistance of surface layers of friction members in comparison with Lithol-24. High antifriction properties of modified rolling surfaces decrease tangential stresses occurring during friction. As a consequence, the amplitude of plastic microshears in contacting surfaces decreases, hence, it is exerted to plastic deformations to a greater extent [2, 16]. The obtained effect promotes increase in the number of load cycles before initiation of fatigue cracks in surface layer and segregation of weakened bulk of material from the surface with formation of cavity.

Bench tests revealed that the lifetime corresponding to 90% reliability of bearings operating with Lithol-24 was 78 h and that of bearings operating with the developed grease was 186 h, i.e. by 2.4 times higher.

No pittings were revealed during examination of rolling surfaces operating with the developed grease after termination of commercial tests. On the basis of the obtained results, it was concluded that further operation of the bearings was possible.

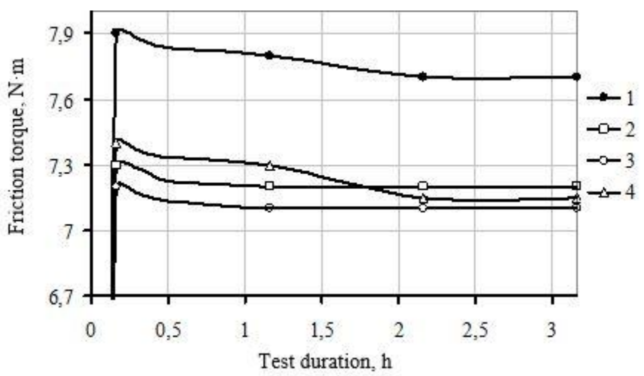

Fig. 5. Friction torque during preliminary laboratory tests of greases:

1 – Lithol-24; 2 – Lithol-24 + Fe; 3 – Lithol-24 + Ni; 4 – Lithol-24 + Zn.

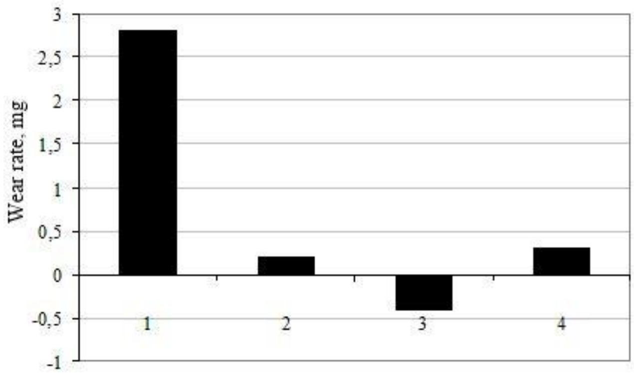

Fig. 6. Wear of rollers after preliminary laboratory tests of greases:

1 – Lithol-24; 2 – Lithol-24 + Fe; 3 – Lithol-24 + Ni; 4 – Lithol-24 + Zn.

After data processing according to the procedure in [13] it was determined that the gamma-percentile life of rollers lubricated with the developed grease increased by 2.8 times in comparison with that lubricated with Lithol-24 (Fig. 7).

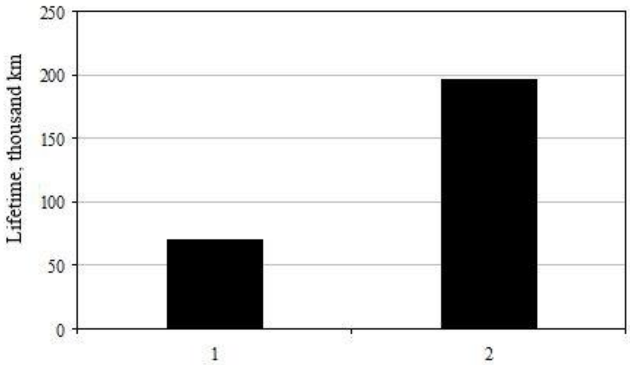

Fig. 7. Gamma-percentile life of roller bearings after full-scale tests with the greases:

1 – Lithol-24; 2 – Cluster-S.

Therefore, the results of commercial tests confirmed high efficiency of the developed grease used as an operation method aimed at improvement of lifetime of roller bearing of tractors and machinery.

IV. CONCLUSION

Analysis of performances of units and systems of KamAZ vehicles widely applied in agro-industrial sector revealed necessity to improve lifetime of roller bearings of wheel hubs. On the basis of literature overview, preliminary laboratory tests, and complete factorial experiment, the grease composition was developed aimed at improvement of lifetime of hub bearings of tractors and machinery. Comparative laboratory tests demonstrated that the developed grease in comparison with the basic Lithol-24 decreased average friction torque in simulated friction couple by 1.15 times, roller wear by 2.3 times, and increased the number of cycles and load of fatigue flaking by 1.86 and 1.55 times, respectively.

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The bench tests revealed increase in lifetime of roller bearings lubricated with the developed grease by 2.4 times. Comparative commercial tests demonstrated that the application of nanocomponent grease resulted in increase in the gamma-percentile life of wheel hub roller bearings of KamAZ-5320 vehicles by 2.8 times in comparison with that obtained with commercial grease Lithol-24.

FINAL REMARKS

The presented results make it possible to evaluate reliably the efficiency of nanosized metal particles obtained by plasma recondensation and used as modifiers of Lithol-24 grease applied upon operation of numerous bearing units of automotive machinery.

CONFLICT OF INTEREST

The authors confirm that the submitted data do not contain conflict of interest.

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