Solid lubricant mass contact transfer technology usage for vacuum ball bearings longevity increasing

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Abstract. A contact mass transfer technological method of solid lubricant deposition on components of vacuum ball bearings is presented. Physics-mathematical model of process contact mass transfer is being considered. The experimental results of ball bearings covered with solid lubricant longevity in vacuum are presented. It is shown that solid lubricant of contact mass transfer method deposition is prospective for ball bearing longevity increasing.

1. Introduction
In practice of engineer all greater application is found by the knots of dry friction, the elements of that are made from "dry" construction materials, or on them hard lubricating coverages (HLC) as that apply different organic and inorganic compounds or thin metallic coverages are inflicted [1]. These coverages, dividing the surfaces of friction, facilitate and accelerate the wear process, diminish the coefficient of friction and eliminate possibility of grasping and jamming of surfaces at a friction. The results based on the use of method of process contact mass transfer (CMT) worked out in Bauman Moscow State Technical University (BMSTU) are presented below [2]. As a method while is small studied, then the task of researches was determination, both technological modes of his realization and longevity of coverage during his work in a vacuum.

2. Theoretical bases
Technological basis of process is the shock causing of HLC on the working (friction) surfaces of knots of mechanism prepared to work in a controlled environment, including, in a vacuum. A shock instrument for realization of process of preparation of surfaces is choose metallic marbles, by a radius, submerged in the powder prepared from the ground up material of the future of HLC, with the size of particles $10^{-40} \mu m$. Chart of "direct" cooperation of instrument and object with force $P$ at causing of hard lubricating coverages with the initial radius of particles shown in figure 1.

![Figure 1](image)

**Figure 1.** Chart of "direct" shock cooperation of instrument with an object.

Pin pressures in the zone of hitting are determined analytically for the case of "direct" blow of shock body at the wall of working chamber can be written:
\[ p_{\text{max}} = \sigma_{\text{max}} = \frac{3}{2\pi ab} P \]  

where \( a, b \) are sizes of semi-axes of elliptic ground of contact.

Experiments and theoretical calculations were created not only for "direct" but also for "sloping" shock co-operating of instrument with an object under different corners. It was shown that pin pressures \( p_{\text{max}} \) depending on the parameters of process forming of HLC: of the masses and initial velocities of shock bodies \( (M_i, V_i) \), mechanical properties of the inflicted material and shock bodies \( (E_M, E_r, v_M, v_r) \), geometrical sizes of the inflicted material \( (d, V_M, r) \) can exceed tensile of material of future friction pair strength, that it talks about plastic introduction of microparticless of HLC in material of the formed friction pair. Experiments on causing of HLC were produced on the stand scheme shown in figure 2.

**Figure 2.** Chart of stand for causing of HLC on the rings of ball-bearings:
1 – working technological chamber; 2 – working bodies (marbles); 3 – inflicted material (HLC as powder); 5 – rings of ball-bearings, subject to causing of HLC. Mark indexes: \( A \) – amplitude; \( W \) – pulsatance of vibrations of corps of stand.

The different technological stages were prospected CMT, at that the modes of treatment, value of energy, effort, pin tensions, were determined, that allowed to define the basic technological stages. Calculations were produced for the different sizes of amplitudes of vibration at frequency of \( v = 25 \text{ Hz} \) and 70 %-filling with of working oscillation technological chamber material of HLC and processed wares. Were set forth idea about the modes of causing of HLC:

1. Without tearing away mode of oscillation of single mass (shock bodies, wares, inflicted material) at amplitude \( A^i \leq A_i = 0,4 \text{ mm} \);
2. Distribution of mass of HLC, at amplitudes \( A_i < A^{\text{II}} \leq A_2 \), where \( A_2 = 1,3 \text{ mm} \);
3. Working technological influence at amplitudes \( A_2 < A^{\text{III}} \leq A_4 \), where \( A_4 = 6 \text{ mm} \);
4. Exit on the maximum value of destruction of shock bodies at amplitudes: \( A_3 < A^{\text{IV}} \);
5. Optimal variant of values of amplitudes at frequency of \( v = 25 \text{ Hz} \) are in limits: from 2 to 3 mm. The key phases of process of causing of HLC were thus distinguished:
   – acquisition by the marble of kinetic energy of rebound from the wall of vibrating chamber;
   – hitting of two marbles through the particle of material of HLC;
   – hitting of marble with the immobile surface of working wall.

### 3. Results of experimental researches

For the estimation of capacity of vacuum mechanisms with inflicted coverages by the process contact mass transfer next informing parameters were chosen:

1. Outgassing rate, as parameter, characterizing intensity of interchange of gases processes what be going on the surfaces of contact;
2. Moment of resistance of mechanism as parameter, characterizing expenses the energies, realized in a mechanism working in a vacuum.

The results of research of capacity of mechanisms with inflicted HLC are presented in figures 3, 4. From a diagram 2 in figure 3 completion of wear of coverage of MoS is visible attended with growth of moment of friction to 2,7 \( \text{H} \cdot \text{m} \), it is related to appearance of cohesive cooperation after 21 h of work.
A change of total moment of resistance $M$ (N·m) of two ball-bearings is in the vacuum $10^{-2}$ Pa. Points on diagrams correspond to coverages: 1 – Pb (lead); 2 – MoS; 3 – without coverage.

From the before published materials [3] we know that appearance of signs of cohesive friction is an index catastrophic wear not only the outgassing rate increases at that but also composition gassed changes with appearance of hydrogen from near surface zones of the particles pulled out at cohesive cooperation.

Megascopic outgassing rate during work of ball-bearing of covered MoS in a vacuum as compared to the coverage of Pb (lead), inflicted CMT is explained a method by the change of physical nature of dominant physical factor at a friction. So, enhance able outgassing rate of coverage of MoS in a comparatively small period of work (21,5 h) is explained by moving away of plenty (more than 100) of layers of sorbate from the ground surfaces [4]. The stable and small outgassing rate from coverage of Pb ($Q = 1,6 \cdot 10^{-5} \text{ m}^3 \cdot \text{Pa/s}$) is less, than at coverage MoS ($Q = 7 \cdot 10^{-5} \text{ m}^3 \cdot \text{Pa/s}$) talks about different physical nature of interchange of gases, what be going on in the zone of pin cooperation. As leaden coverage stably show the best results on longevity (work is more than 270 000 cycles), at the small moment of resistance (less than 0,2–0,4 Н·m) and outgassing rate of $Q = 1,6 \cdot 10^{-5} \text{ m}^3 \cdot \text{Pa/s}$, that all of it gives grounds to consider such coverage perspective.

4. Conclusions
Enhanceable outgassing rate in an initial period is explained by moving away of plenty (more than 100) of layers of sorbate from the ground surfaces. The following by it period of the stationary set work corresponds to permanent speed of wear of coverage.

It was shown that completion of wear of coverage is attended with growth of coefficient of friction and temperature, it is related to appearance of cohesive cooperation.

Appearance of signs of cohesive friction is the index of catastrophic wear at that the stream of outgassing rate increases not only but also composition gassed changes with appearance of hydrogen from the near surface zones of the particles pulled out at cohesive cooperation.

The leaden coverage shows the best work results and minimal outgassing flow, that let us consider this coverage perspective.
References
[1] Zeev N A, Kozelkin V V and Gurov A A 1991 Materials of dry friction, working in a vacuum (Moscow: Mashinostroenie)
[2] Volchkevich L I and Volchkevich I L 1994 Metronome 5–6 35–7
[3] Deulin E A, Michailov V P, Panfilov Y V and Nevshupa R A 2012 Mechanics and Physics of Precise Vacuum Mechanisms (New York: Springer)
[4] Deulin E A, Ikonnikova E I and Tkacheva E V 2013 Gerald of Bauman Moscow State Technical University 3 86–101