Rubric 2: SCIENTIFIC AND PRACTICAL DEVELOPMENTS
Field "Electrical Engineering"

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IMPROVING CURRENT COLLECTION IN THE TRANSPORT SYSTEM OF THE TYPE "HYPERLOOP"

Background: the vehicle moved in the pipe with rarefied air with at high speed provides high productivity, safety, sustainability, comfort and independence from the atmospheric phenomena.

Aim: improvement of current collection at the speed range of 500-700 km/h.

Method: the method of decreasing the wear of the contact insert by using disulfide solid grease.

Results: the solution of magnetohydrodynamics equations for the grease layer allowed us to define the optimal grease layer thickness.

Conclusion: the use of this grease is advisable in an alternating current. In this case the wear of the contact insert, the degree of sparking and the electromagnetic noise are decreased.

Keywords: rarefied air, tube, perforation, sliding current collector, wear, disulfide solid grease, magnetohydrodynamics.

Рубрика 2. НАУЧНЫЕ И ПРАКТИЧЕСКИЕ РАЗРАБОТКИ
Направление «Электротехника»

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УЛУЧШЕНИЕ ТОКОСЪЕМА В ТРАНСПОРТНОЙ СИСТЕМЕ ТИПА "HYPERLOOP"

Обоснование: Транспортное средство, перемещаемое в трубе с разреженным воздухом с высокой скоростью, обеспечивает высокую производительность, безопасность, экологическую чистоту, комфортность и независимость от атмосферных явлений.

Цель: улучшение токосъема в скоростном диапазоне 500-700 км/ч

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Метод: Разработан метод уменьшения износа контактной вставки на основе использования дисульфидной твердой смазки.

Результаты: решение уравнений магнитогидродинамики для смазочного слоя позволило выявить оптимальное значение толщины смазочного слоя.

Заключение: использование данной смазки целесообразно на переменном токе при этом уменьшается износ контактной вставки, снижаются степень искрения и уровень электромагнитных помех.

Ключевые слова: разреженный воздух, труба, перфорирование, скользящий токосъем, износ, дисульфидная твердая смазка, магнитогидродинамика.

INTRODUCTION

Currently, the revival of interest towards transport systems in which passenger capsules travel at speeds of ~ 1000 km/h [1] is observed. To reduce front resistance of the capsule, it envisaged to created technical vacuum in the tube, which necessitates application of a large number of pumps, and leads to the problems associated with maintaining vacuum in the tube. As researches by the Department of Electrical and Heat Engineering at PGUPS showed, there exists an original technical solution to this problem, which is about creating rarefied air medium in the tube (pressure is supposed to 2-3 times less than the atmosphere). For partial compensation for emerging front aerodynamic resistance, it envisaged to use a perforated shell of the front part of the capsule with forced pumping out of the oncoming air through holes in the shell, with subsequent withdrawal of the air to the space behind the rear part of the capsule [2].

It needs pointing out that this solution envisages more modest speeds of the capsule, that is ~ 600 – 700 km/h.

The reduction of speed allows the use of traditional sliding current collector in these transport systems, which has a positive effect on the weight and dimensions of the capsule.

In connection with the aforesaid there is a problem of maintaining appropriate quality of the current collector system, in particular reducing wear of the elements of contact pairs. Currently, there are many ways to reduce wear. One of them is through application of solid greases, for instance, based on molybdenum disulfide MoS_2 [3].

In application of molybdenum disulfide grease in electrical sliding contacts (SC), it is necessary to take into account not only physical and chemical, but also electrical features of the sliding contact. The authors have developed and studied a method of administering solid grease on the basis of molybdenum disulfide with the help of additional insert that is installed on the current collector before the current insert.

Consideration of a number of rheological models of solid grease [4] allowed us to conclude that flowing of MoS_2 grease under the current insert, as the current passes, can be described by magnetohydrodynamic equations for

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viscous fluidity. When MoS_2 is heated to 70–90 °C the molybdenum disulfide crystals acquire fluidity and viscosity in the directions parallel to its layers, and the optimal location of crystals on the surface of friction pairs is ensured by the applied external electrical field [5].

With certain gaps, between the insert and contact wire the emergence of repulsive force is possible, which tends to detach the insert from the contact wire and increase transition resistance of the sliding contact.

Magnetohydrodynamic equations for grease layer

Let us consider a plane problem of liquid viscous fluidity (imitation of grease layer) in the transverse electromagnetic field in semi-infinite space (Fig. 1).

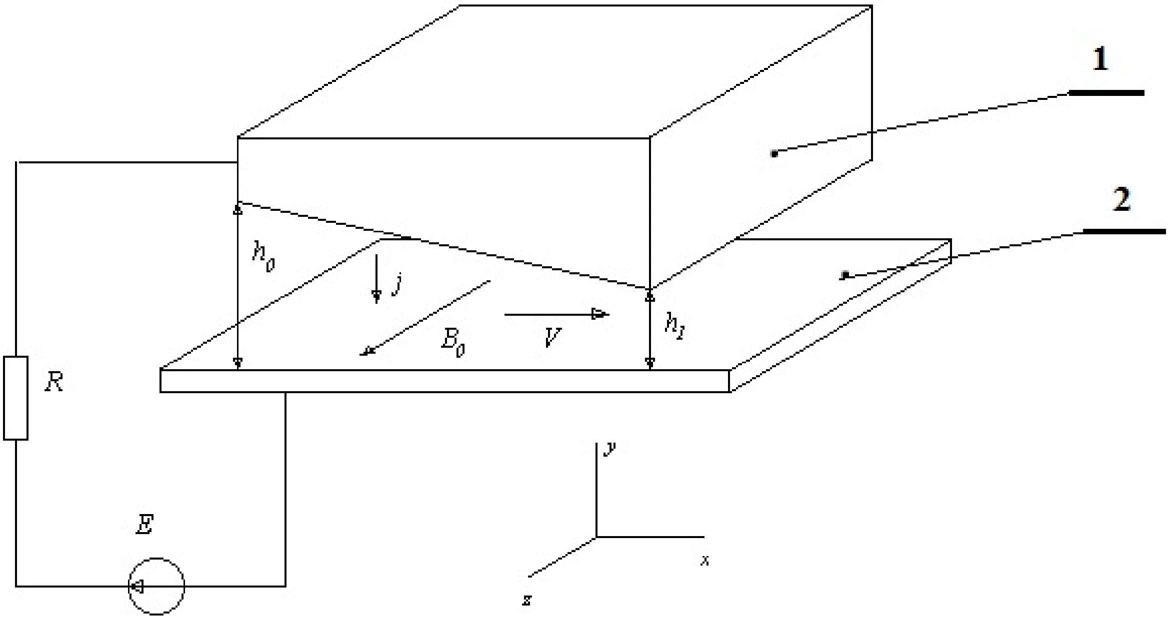

Fig. 1. Calculation of Magnetohydrodynamic model of grease:
1 – current insert,
2 – contact wire,
E – electrodynamic force source,
R – power supply circuit resistance.

The general equation of movement of grease in the electrodynamic field is as follows [6]:

$$\rho\{\frac{\partial \mathbf{V}}{\partial t} + (\mathbf{V}\cdot\nabla)\cdot\mathbf{V}\} = -\nabla\mathbf{p} + \eta\nabla^2\mathbf{V} + \mu(\mathbf{j}\times\mathbf{H}),$$

where ρ – grease density, *V* – grease flow velocity (contact insert movement velocity), *p* – pressure between contact insert and contact wire, η - dynamic

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viscosity of grease, j – current density in the contact, H – magnetic field strength in the area of contact.

If we consider a stationary plane-parallel problem, the equation of this liquid grease motion will be as follows:

$$-\nabla\mathbf{p}+\eta\nabla^2\mathbf{V}+\mu(\mathbf{j}\times\mathbf{H})=0$$

The equations for the plane boundary layer of the equation of magnetic hydrodynamics will be like:

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}=0,$$

$$0=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\frac{\partial^2 u}{\partial y^2}-\frac{\sigma}{\rho}\mu^2 uH_0^2,$$

here u – longitudinal constituent of the velocity vector, ν - magnetic layer viscosity, σ - specific conductivity of grease, μ - absolute magnetic permeability of grease, H_0 - magnetic field strength in the area of sliding contact.

The last motion equation can be put down as:

$$0=-\frac{\partial p}{\partial x}+\mu\frac{\partial^2 u}{\partial y^2}-j_y B_0, \tag{1}$$

where j_y – current density in the contact, B – magnetic induction in sliding contact.

Distribution of grease layer is expressed as the function of coordinate x:

$$h(x)=h_0-k_x x,$$

where $k_x=(h_0-h_1)/b_{\text{вставки}}$, $b_{\text{вставки}}$ - current insert width.

If secondary effects are ignored, then equation for I–V curve of SC can be put down as

$$j_y=\sigma(E_y+uB_0),$$

$$j_x=\sigma E_x,$$

$$j_z=\sigma(E_z-uB_y).$$

Now, from the equation $\nabla\cdot\mathbf{j}=0$ and $h<<k_x$ and $j_y>>j_x$ it follows that $\frac{\partial j_y}{\partial y}\approx 0$ and j_y are essentially only function of z and x. The value B_0 is not constant, but a function of the current and the coordinate x.

The equation (1) cannot integrated analytically, and an approximate solution can be obtained only for very large or very small Hartmann numbers [7].

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$$M^2 = \frac{B_0^2 h_1^2 \sigma}{\eta}. \qquad (2)$$

For the case considered, the Hartman number has an order of 10^{-9} [6], consequently, the approximate solution can be obtained analytically. Besides, the small value of the Hartmann number suggests a simplified task solution: aggregate force field is determined by the superposition of hydrodynamic and electromagnetic field effects.

The equation (1) can be integrated using boundary conditions: $y=0$ at $u=V$ and $y=h$ at $u=0$.

$$u = \frac{1}{2\mu}\left(\frac{\partial p}{\partial x} - j_y B_0\right)(y^2 - hy) + \frac{V}{h}(h - y), \qquad (4)$$

The specific conductivity value can be determined from the dependence presented in Fig. 2 [8] for the corresponding temperature of the sliding contact elements.

The consumption of grease can be expressed through velocity integral of the grease thickness.

$$Q = \int_0^h u\,dy = -\frac{h3}{12\mu}\left(\frac{\partial p}{\partial x} - j_y B_0\right) - \frac{Vh}{2}. \qquad (5)$$

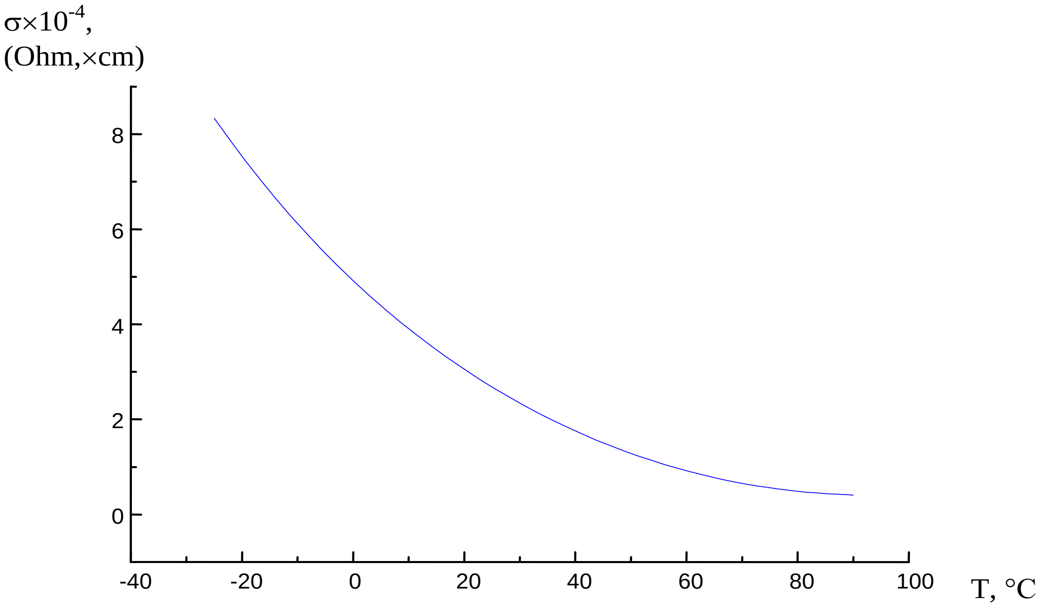

Fig. 2. Dependence of specific conductivity of MoS_2 on temperature

Using boundary conditions [9], distribution of pressure can be found:

$$p = -12\mu \int_0^x \left(\frac{Q}{h^3} - \frac{V}{2h^2}\right)dx + B_0 \int_0^x j_y\,dx. \qquad (6)$$

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On the basis of the Ohm's Law the distribution of the current density can be determined; it will be expressed through electrical field strength and flow speed. The transient voltage drop in the grease layer is determined by the following ratio:

$$\Delta U = -\int_0^h E_y dy \qquad (7)$$

Transient voltage drop in the point y=0 should equal 0.

Integrating this expression for the current density (3):

$$j_y h = \sigma \int_0^h E_y dy - \sigma B_0 \int_0^h u dy \qquad (8)$$

and, using the expression for grease consumption, we can determine the current density:

$$j_y = -\frac{\sigma}{h}(B_0 \mathrm{Q} + \Delta U)\,. \qquad (9)$$

Using the second boundary condition p=0 at x=b_{insert}.

$$0 = -12\mu \int_0^{b_{\text{вставки}}} \left(\frac{\mathrm{Q}}{h^3} - \frac{V}{2h^2}\right)dx + B_0 \int_0^{b_{\text{вставки}}} j_y dx \qquad (10)$$

Full current is determined by ratio:

$$I = \int_0^{b_{\text{вставки}}} j_y dx\,. \qquad (11)$$

Using the relation (10), consumption rate of grease can be determined:

$$\mathrm{Q} = \frac{h_0 \dfrac{h_0}{h_1} - 1}{\left(\dfrac{h_0}{h_1}\right)^2 - 1}\left[V + \frac{k \cdot B_0 \cdot I \cdot h_0}{6\mu\left(\dfrac{h_0}{h_1} - 1\right)}\right]. \qquad (12)$$

Then transient voltage drop equals

$$\Delta U = -\left(\frac{kI}{\sigma \ln \dfrac{h_0}{h_1}} + B_0 \mathrm{Q}\right). \qquad (13)$$

Distribution of current density on the surface of the insert:

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$$j_y = \frac{kI}{\ln\frac{h_0}{h_1}} \cdot \frac{1}{h}. \tag{14}$$

For convenience, the coefficient β is introduced*:*

$$\beta = \frac{kh_0 B_0 I}{6\eta V}. \tag{15}$$

Distribution of relative pressure between the insert and contact wire:

$$\overline{p}(x) = \left\{ \left[\left(\frac{h_0}{h(x)} - 1\right) - \left(\frac{h_0}{h_1} - 1\right) \frac{\left(\frac{h_0}{h(x)}\right)^2 - 1}{\left(\frac{h_0}{h_1}\right)^2 - 1} \right] + \beta \left[\frac{\ln\frac{h_0}{h(x)}}{\ln\frac{h_0}{h_1}} - \frac{\left(\frac{h_0}{h(x)}\right)^2 - 1}{\left(\frac{h_0}{h_1}\right)^2 - 1} \right] \right\}. \tag{16}$$

The bearing capacity of MHD layer in relative units is determined by pressure integral of the insert length:

$$\overline{W} = \int_0^{b_{\text{вставки}}} \overline{P} dx = \left\{ \left[\frac{h_0}{h_1} ln \frac{h_0}{h_1} - \left(\frac{h_0}{h_1} - 1\right) \frac{\left(\frac{h_0}{h_1} - 1\right)^3}{\left(\frac{h_0}{h_1}\right)^2 - 1} \right] + \beta \left[\frac{\left(\frac{h_0}{h_1} - 1\right)}{ln\frac{h_0}{h_1}} - \frac{\left(\frac{h_0}{h_1} - 1\right)^2}{\left(\frac{h_0}{h_1}\right)^2 - 1} \right] \right\}. \tag{17}$$

From the analysis of expression (17) it is possible to offer the optimal way to reduce the excessive pressure under the insert, which is about maintaining equality:

$$\frac{h_0}{h_1} = 1. \tag{18}$$

With such a combination there is no excessive pressure between the insert and contact wire. In case of upward deviation of ratio the ratio (18), the increase in the transient voltage drop is observed, and consequently in the electrical losses in the contact. The deviation to the area of low values results in a cavitation process and increases mechanical losses in the SC.

Practically, this ratio is achieved either by adjustment of pressure for disulfide insert, or variation of its contact surface.

The correctness of this hypothesis can be checked indirectly by examining such characteristics of the CS as wear of the insert or by examining the transient voltage drop in the contact.

In order to undertake the experiment on finding optimal working conditions for molybdenum disulfide, a bench was created on the basis of an induction machine with a phase rotor AK-52 (AD) with a capacity of 4.5 kW. Here the contact wire was imitated by a contact ring, the current insert – by MG-

4 conductive brushes (contact area of the brush S_b=1.6 cm^2, pressure on the brush p_b=400 g/cm^2), disulfide insert – by an additional brush of molybdenum disulfide. The pressure on the additional brush varied in the following levels: $p_{(D)}$ = 100 g/cm^2, 250 g/cm^2, 400 g/cm^2. The contact area of the additional brush was $S_{(D)}$ = 0.4 cm^2, 0.8 cm^2, 1.2 cm^2. This was 25%, 50% and 75% of the contact surface of the conductive brush. The experiment was repeated three times. The values of wear were determined by an arrow indicator followed by specification by weighing on an analytical scale. At realisation of the given experiment within twenty hours the mathematical model of deterioration in relative units is received:

$$I_h = 0.026 + 0.0086\cdot \underline{S}_{(\text{Д})} + 0.0114\cdot \underline{p}^2_{(\text{Д})} + 0.015\cdot \underline{S}^2_{(\text{Д})}\,. \qquad (19)$$

The graphical interpretation of the polynomial obtained is given in Fig. 3.

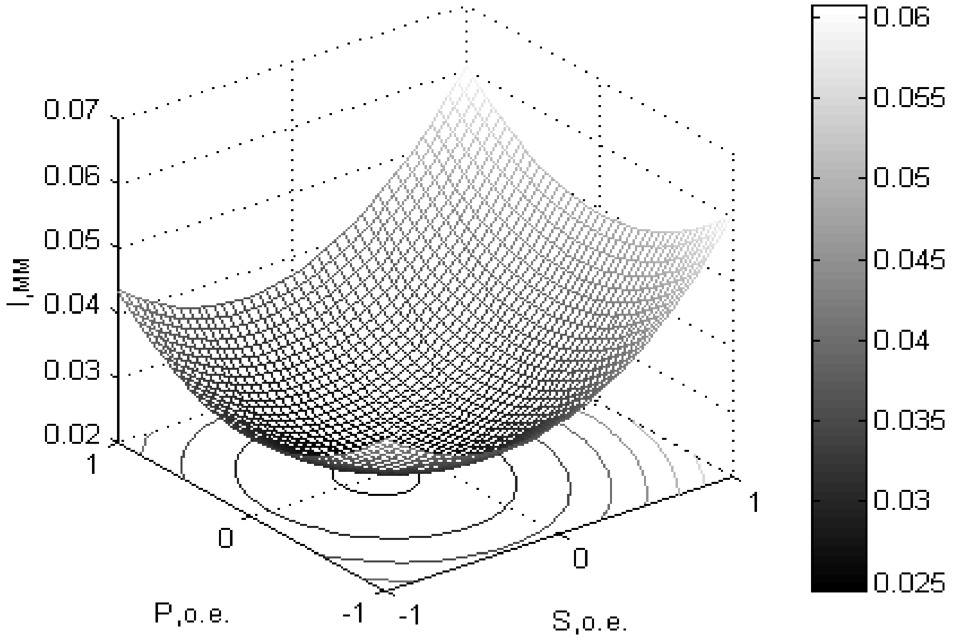

Fig. 3. Graphical interpretation of the polynomial of the MG-4 brush wear

The minimal value of the brush wear is observed in the point, where MHD force equalled 0. For the system in question, this makes $S_{(D)}(min)$=0,9 cm^2, $p_{(D)}(min)$=150 g/cm^2.

Summarising, it should be noted that the use of molybdenum disulfide on the given grease of AD with the optimal combination of pressure on the additional brush and its contact area, allows reduction of the wear of the working brushes by 1.7–2 times [10-15].

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Conclusions

Using solid molybdenum disulfide grease considerably decreases wear of the current inserts, and large contribution to the effect observed is made by electrical field, that orients the crystal in a direction that the friction becomes Magnetohydrodynamic.

Solving the MHD equations for grease layer enables determination of an optimal value of the grease thickness. Theoretical solution of the problem coincides well with the experimental data. For the certain contact pair, the combinations of pressure and contacting area of additional brush have been determined; additional brush imitated disulfide insert, that ensures an optimal value of the grease layer.

The authors make it expressly clear that:

1. No conflict of interests has taken or may take place;
2. The present article does not contain any researches with people as the objects involved.

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