Liquid metal sliding contacts for electric machines

A V Egorov1,3, Yu F Kaizer2,5, A V Lysyannikov2, A V Kuznetsov4, Yu N Bezborodov2, V G Shram2, N V Kuzmin4 and P A Kuznetsova2

1 Sarov State Physics Technical Institute, National Research Nuclear University MEPhI, Sarov Branch (SarPhTI), st. Dukhova, 6, Sarov, 607182, Russia
2 Siberian Federal University, Svobodny Avenu, 82/6, Krasnoyarsk, 660041, Russia
3 Volga State University of Technology, Lenin Square, 3, Yoshkar-Ola, 42400, Russia
4 Krasnoyarsk State Agrarian University, Kirenskogo, 2, Krasnoyarsk, 660049, Russia
5 E–mail: kaiser171074@mail.ru

Abstract. The electric sliding contact in the brush mechanism is one of the most unreliable components of electric machines of alternating and direct current and other electrical equipment in which the transmission of electric current is carried out using sliding contacts that require fairly frequent maintenance and can be a source of sparking. It is possible to increase the reliability and efficiency of electric machines with sliding electric contacts by replacing the dry friction mode with the liquid friction mode in the sliding electric contact. The most appropriate material for use in the construction of a liquid metal sliding contact is gallium. When replacing the sliding electrical contacts of asynchronous electric machines with a phase rotor from traditional solid to liquid metal gallium, it is possible to increase their power up to 1.4 times due to the availability of a higher thermal operating mode.

1. Introduction
The electric sliding contact in the brush mechanism is one of the most unreliable components of AC and DC electric machines and other electrical equipment. In which the transmission of electric current is carried out using sliding contacts that require fairly frequent maintenance and can be a source of sparking.

To date, a large number of scientific studies have been carried out aimed at developing solutions for diagnosing the technical condition of brushes, brush mechanisms and electric machines that use sliding contacts that implement the dry friction mode to excite the electromagnetic field [1–7]. Attempts are being made to create sliding contacts of the "graphite-graphite" type [8].

The lack of technical solutions for the creation of effective and reliable brush mechanisms and brush collector units lead to attempts to control the tribological situation in the assembly of the sliding contact [9].

The purpose of this work is to develop a general approach to the creation of sliding electrical contacts of electric rotating machines that implement the liquid friction mode, in order to increase their reliability and efficiency.

2. Materials and methods
The liquid friction mode allows you to reduce or eliminate the wear of rubbing surfaces.
During the 20th century, mercury liquid metal sliding contacts were used to reading information from the information from strain-resistant sensors used in testing heat engines and mechanical drives. Attempts to create electric machines with liquid metal sliding contacts were not made due to the high toxicity of mercury and its high resistivity.

Figure 1 shows a liquid metal sliding contact of an asynchronous electric motor with a phase rotor based on the materials [10].

![Figure 1. Liquid metal sliding contact of an asynchronous electric motor with a phase rotor: 1 - the rotor of an asynchronous electric motor with a phase rotor; 2 - the housing of an asynchronous electric motor with a phase rotor; 3 - contact rings; 4 - cavity filled with liquid metal; 5 - the housing of a contact device; 6 - rigid element; 7 - electric current supply conductors J (brushes).](image)

The rotor 1 of the electric machine 2 contains contact rings 3, a cavity 4 around which is filled with a liquid metal (for example, Gallium), which is placed in the cavity of the housing of the contact device 5, connected to the shaft 1 hermetically and movably. In the housing of the contact device 5, which is rigidly connected to the housing of the electric machine 1 by means of a rigid element 6, electric current supply conductors J (brushes) 7 are brought out, which are in constant contact with liquid metal and are electrically isolated from the housing of the contact device 5. The contact surfaces between the rotor 1 and the housings of the contact device 5 are made in the form of a movable sealed fit, for example, H7/h7 or similar.

The proposed liquid metal sliding contact of an asynchronous electric motor with a phase rotor works as follows. Electric current through the electric current supply conductors 7 is fed into the liquid metal located in the cavity 4 of the housing of the contact device 5 and enters the contact rings 3 of the rotor 1 of the electric machine 2, and then enters the windings of the electric machine (not shown in figure 1).

3. Results

The proposed liquid-metal sliding contact of an asynchronous electric motor with a phase rotor makes it possible to avoid direct mechanical contact of the electric current supply conductors (brushes) with the contact rings of the electric machine rotor and thereby ensure the absence of mechanical wear of the contact surfaces of the electric current supply conductors (brushes) with the contact rings of the electric machine rotor, which will increase reliability and efficiency.

The existing brush mechanisms have a permissible brush operation of about 140 °C and on their basis, requirements for the permissible operating temperature of electric machines with sliding contacts are formed.

However, the permissible temperature of the insulation materials of the coatings of the conductors of electric machines allows a maximum operating temperature of 200 °C [11], and some experimental compositions of insulation materials allow an operating temperature of 275 °C.

Liquid metal sliding contacts allow working at temperatures up to the boiling point of the metals used in them.
Therefore, when using them, it is possible to increase the permissible operating temperatures of asynchronous electric motors to at least 200 °C, and to increase their specific power of an electric machine from 1 to 1.4 times.

The materials of the contact rings and contact surfaces of the sliding electrical contacts of electric machines are made of various metal materials, the minimum specific electrical conductivity of which is copper.

Table 1 shows the characteristics of metals under normal conditions having a low melting point, the characteristics of the main conductor of electric machines - copper and the material of the main types of brushes of electric machines.

| Material or product               | Melting point, °C | Resistivity, (Ohms\(\cdot\)mm\(^2\))/m |
|----------------------------------|-------------------|-----------------------------------------|
| Copper                           | 1084.5            | 0.0175                                  |
| Mercury                          | -38.9             | 0.94                                    |
| Gallium                          | 29.8              | 0.272                                   |
| Potassium                        | 63.6              | 0.066                                   |
| Sodium                           | 97.8              | 0.047                                   |
| Graphite Brushes                 | -                 | 15...40                                 |
| Carbon-graphite brushes           | -                 | 20...70                                 |
| Metal-graphite brushes            | -                 | 0.04...0.3                              |
| Electric carbon electrodes       | -                 | 0.02...0.05                             |

Under normal conditions, only mercury can exist in the liquid state, but its indicators of specific electrical conductivity and toxicity will lead to a significant complication of the design of the liquid electric sliding contact.

For the possible use of other metals, preheating of metals will be required, which can be implemented in different ways.

For example, by passing small currents through a sliding electrical contact without removing the rotor of an electric machine from a state of rest, or by using a preheating system for the cavity in which the metal is located.

The high activity of potassium and sodium in contact with atmospheric air will lead to a significant complication of the design of the liquid metal sliding electrical contact, although it will require a much smaller contact area of the liquid metal with the contact ring or the contact surface of the rotor.

Based on the above, the most appropriate material for use in the composition of liquid metal sliding electrical contacts is gallium.

In the case of replacing metal-graphite and electric-carbon electrodes with liquid metal ones made on the basis of gallium, to ensure identical performance of the sliding electric contact, an increase in the contact surface area of liquid gallium and the contact ring or contact surface will be required from 1 to 6.8 and from 5.4 to 13.6 times, respectively. Structurally, this is quite feasible in dimensions close to the dimensions of the brush assembly, since the liquid metal sliding electric contact uses the entire area of the contact ring or contact surface to transmit current.

Currently, the global production of gallium does not exceed 400 tons per year, and the accumulated capacity of gallium production is estimated at about 700 tons [12]. Thus, in the case of the beginning of widespread use of sliding liquid metal contacts made on the basis of gallium for the needs of the electrical industry, the production of gallium can cover the initial need, and then can be increased.

4. Conclusions
It is possible to increase the reliability and efficiency of electric machines with sliding electric contacts by replacing the dry friction mode with the liquid friction mode in the sliding electric contact.
The most appropriate material for use in the construction of a liquid metal sliding contact is gallium. When replacing the sliding electrical contacts of asynchronous electric machines with a phase rotor from traditional solid to liquid-metal gallium, it is possible to increase their power up to 1.4 times due to the availability of a higher thermal operating mode.

Acknowledgements
The research was supported by the Ministry of Science and Higher Education of the Russian Federation (Grant № 075-15-2021-674) and Core Facility Centre "Ecology, bio-technologies and processes for obtaining environmentally friendly energy carriers" of Volga State University of Technology, Yoshkar-Ola.

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