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Forming and Overlapping Microreliefs in Sliding Contact Simulation Model

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***Abstract.** Sliding contacts are widely used in electrical machines despite the trend towards non-contact methods of the electrical current transfer. In some cases, using of brush-contact devices is indispensable due to low cost and continuity of operations. One of methods to improve reliability of sliding contact is simulation modeling. This approach can significantly reduce the amount of expensive practical experiments in the study of different contact pairs characteristics.*

The paper introduces and describes a few new algorithms for simulation model of sliding contact which allow to improve precision and take into account more physical processes occurring in contact transient layer.

***Keywords:** sliding electrical contact, simulation model, microrelief.*

I. INTRODUCTION

Sliding electrical contacts are widely used in industry. Operating modes and application environment of the contacts vary from micromachines to large turbo-generators.

For selecting the best brushes and brush holders for specific instance usually engineering calculations or experiments are used. The full-scale experiments are often very time-consuming and expensive. Modeling of processes in sliding electrical contacts helps to do better choice and cut the cost.

Most of the developed sliding contact models use different approaches and have restricted application [1–7]. The simulation modeling lets to describe complex physical phenomena taking place in transient layer of sliding electrical contact. The most comprehensive description of simulation model introduced in [8–10].

Based on this model two computer programs was created. The first one allows calculating and plotting volt-ampere characteristics of the sliding contact [8]. The second program shows thermal spikes and distribution diagrams of temperature and electrical current density in the transient layer [11].

However, for some time past, new submodels for the simulation model were suggested and several algorithms were enhanced. These developments are described in the article.

II. MODELS AND ALGORITHMS

Discrete contact element

Each contact surface is described as a system of the surface discrete elements (DSE). The surface discrete elements are located in the rectangular array of size $N_{br}^{(x)}$ to $N_{br}^{(y)}$ for the static brush contact and $N_r^{(x)}$ to $N_r^{(y)}$ for the moving rotor contact. The upper indexes (x) and (y) are used for the tangential and axial directions of the contacts. DSE has length Δx and width Δy . For simplicity, we assume $\Delta x = \Delta y$. The area of the element is $\Delta S = \Delta x^2$.

The Fig. 1 shows the discrete contact element (DCE) that has formed by the two lying opposite and interacting surface elements.

Each surface element presents a hemisphere of radius $\Delta x/2$ based on a Δx square face of a rectangular parallelepiped with the height $h - \Delta x/2 + \Delta h/2$, where h is the height of the surface element from the center line, Δh is the distance between two neighbor layers of the contact body. The hemispheres of interacting DSE overlap on the distance δ depending on its heights and applied load. The oxide film of the contact element has thickness $f_{br} + f_r - \delta$, where f_{br} and f_r are the oxide film thicknesses of the brush and the rotor contacts. If the value of $f_{br} + f_r - \delta$ is less than zero then the contact element does not have the oxide film and it conducts the current directly. The initial distance between the centre lines H_0 is calculated by approaching the contact surfaces without load.

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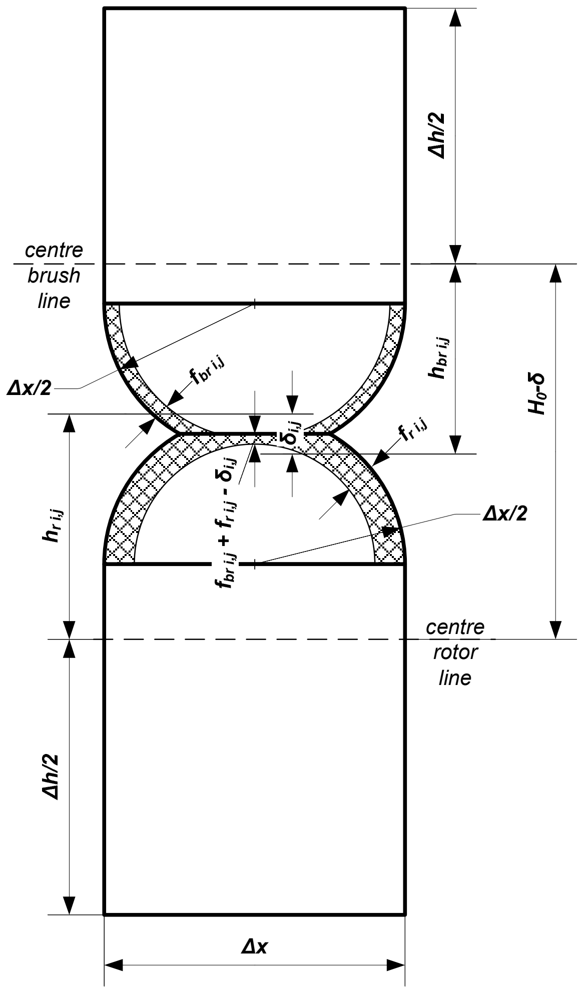

Fig. 1. The discrete contact element

Forming microreliefs

In the process of the contacts manufacturing and operation the deformations are formed on the surface and define the microrelief: macrodeviations, waviness, roughness and subroughness. The microreliefs of two interacting rough surfaces affecting by friction and the transmission of electric current through the contact is a result of complex action of a set of mechanical, electrical, chemical and thermal factors. Whereas mechanical factors have the leading role in the formation of a waviness, deformation and fracture of microroughnesses are accompanied by electroerosion and thermoplastic processes, oxidation-reduction reaction. As a result, over time the microrelief becomes steady state having determined statistical characteristics. While the process of generating roughness is stochastic, a number of deterministic factors, which separately affect the geometric characteristics of the axial and tangential profiles, can identify the formation of waviness.

We suggest to use new algorithm to form the contact microrelief based on the Kotelnikov's sampling function [12]:

$$h_i = \sum_{k=1}^{M} \frac{\sin\left(2\pi f \frac{i}{N} - \pi k\right)}{2\pi f \frac{i}{N} - \pi k} \cdot A_k \ ,$$

where $i = 1 \ldots N$ – samples of the random process; $k = 1 \ldots M$ – process local points, heights of which depends by the vector A random values; f – upper frequency of the random process spectrum; A – vector of random values distributed by assigned probability law.

Selection of the upper frequency f and the probability distribution law for vector A allows us obtain different microreliefs with desired waviness and roughness. As far as more than one factor takes place in forming microreliefs then finite equation is:

$$h_{i,j} = \sum_{n=1}^{C} \sum_{k=1}^{M_n^{(x)}} \sum_{m=1}^{M_n^{(y)}} \left[\frac{\sin\left(2\pi f_n^{(x)} \frac{i}{N^{(x)}} - \pi k\right)}{2\pi f_n^{(x)} \frac{i}{N^{(x)}} - \pi k} \times \right. \\ \left. \times \frac{\sin\left(2\pi f_n^{(y)} \frac{j}{N^{(y)}} - \pi m\right)}{2\pi f_n^{(y)} \frac{j}{N^{(y)}} - \pi m} A_{n,k,m} \right] + R_{i,j} \ , \quad (1)$$

where $i = 1 \ldots N^{(x)}$ и $j = 1 \ldots N^{(y)}$ – samples of the random process by X and Y axis; $n = 1 \ldots C$ – factors take place in the microrelief formation; $k = 1 \ldots M_n^{(x)}$ and $m = 1 \ldots M_n^{(y)}$ – process local points for n -th factor; $f_n^{(x)}$ и $f_n^{(y)}$ – upper frequency for n -th factor; A_n – matrix of random values distributed by assigned law with size $M_n^{(x)} \times M_n^{(y)}$ for n -th factor; R – matrix of random values with size $N^{(x)} \times N^{(y)}$ used for the roughness formation.

Analysis and comparing results of performed computational experiments with the real sliding contacts allows us select optimal distribution law for matrixes A_n and R . It is normal probability distribution with zero mathematical expectation and standard deviation proportional to mean-square values for each factor waviness and roughness.

The Fig. 2 shows example of the realistic contact microrelief formed by three factors modeled in Mathcad.

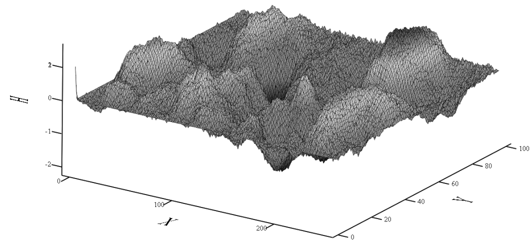

Fig. 2. The contact microrelief depending on three factors

Approaching and overlapping microreliefs

An approach algorithm is needed for searching the first touch of the contacting surfaces. On the Fig. 3 the scheme of the approach and overlap algorithms is shown, where 0_r , 0_{br} – centre lines of the contacting microreliefs; H_0 – distance between the centre lines in the radial direction without deformation.

We start the search with the initial distance

$$H_{0\,max} = R_{pbr} + R_{pr} ,$$

that equals to the sum of maximum microreliefs heights, and the minimal distance $H_{0\,min} = 0$. Then we count the number of contact points for the height $H_{0k} = \left(H_{0\,max} - H_{0\,min}\right)/2$:

$$N_{cont} = \sum_{j=1}^{N^{(y)}} \sum_{i=1}^{N^{(x)}} h_{br\,i,j} + h_{r\,i,j} - H_{0k} \geq 0 .$$

Further we use bisection method: if the number of contact points $N_{cont} > 1$, then $H_{0\,min} = H_{0k}$; else if the number of points equal zero (no contact) $N_{cont} = 0$, then $H_{0\,max} = H_{0k}$. After that, we define the next height $H_{0k} = \left(H_{0\,max} - H_{0\,min}\right)/2$. The procedure repeats until we find the height H_0, where there is only one contact point.

The overlapping algorithm uses Hertzian theory for elastic contact between two spheres. When the microreliefs is overlapping, the spheres of the opposite contact elements interact and its elastic deformation occurs. The process continues until contact load will equal to the sum of reactions (Fig. 3): δ – overlap of the microreliefs under the load; $H_0 - \delta$ – distance between the centre lines under the load; $\Delta h_{i,j} = \left(h_{br\,i,j} + h_{r\,i,j}\right) - \left(H_0 - \delta\right)$ – overlap of a contact element (if $\Delta h_{i,j} \geq 0$) or distance between surface elements (if $\Delta h_{i,j} < 0$).

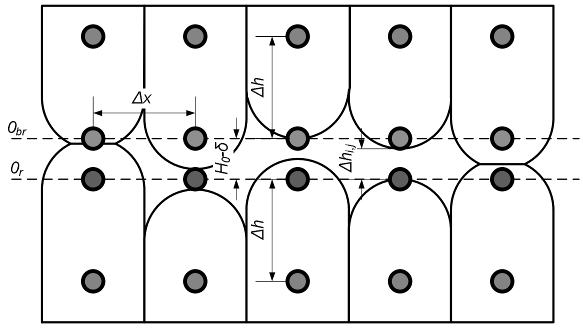

Fig. 3. The approach and overlap of two-contact microreliefs scheme

After calculating the initial distance between the microreliefs H_0, we start searching the overlap δ using an initial value based on the waviness and roughness parameters of the contact surfaces. Further, for each discrete contact element with the positive overlap $\Delta h_{i,j} > 0$ we calculate:

– relative elastic modulus

$$K_{i,j} = \left(\frac{1-\mu_{br}^2}{E_{br}} + \frac{1-\mu_r^2}{E_r} \right)^{-1} ,$$

where μ_{br} and μ_r – Poisson’s ratio, a E_{br} and E_r – elasticity modulus;

– relative radius of curvature

$$R_{i,j} = \left(\frac{1}{R_{br\,i,j}} + \frac{1}{R_{r\,i,j}} \right)^{-1} = \frac{\Delta x}{4} ,$$

where R_{br} and R_r – sphere radiuses equal to $\Delta x/2$;

– force (reaction)

$$F_{i,j} = \frac{4}{3} K_{i,j} \sqrt{\Delta h_{i,j}^{\;3} R_{i,j}} = \frac{2}{3} K_{i,j} \sqrt{\Delta h_{i,j}^{\;3} \Delta x} ;$$

– radius of contact spot

$$a_{i,j} = \sqrt{\Delta h_{i,j} R_{i,j}} = \frac{1}{2} \sqrt{\Delta h_{i,j} \Delta x} ;$$

– contact area

$$A_{i,j} = \pi a_{i,j}^2 = \frac{\pi}{4} \Delta h_{i,j} \Delta x ;$$

– average pressure

$$p_{i,j} = \frac{F_{i,j}}{A_{i,j}} .$$

After summing the reactions for all overlapping contact elements we use bisection method for the next overlap δ and repeat the calculations iteratively until the reaction will be equal to the contact load with the specified accuracy.

Fig. 4 shows experimental example of microreliefs overlapping [13]. As we see the overlap approximation (dashed line) has the exponential dependence on the contact load that is corresponding to the Hertzian theory solution for two spheres.

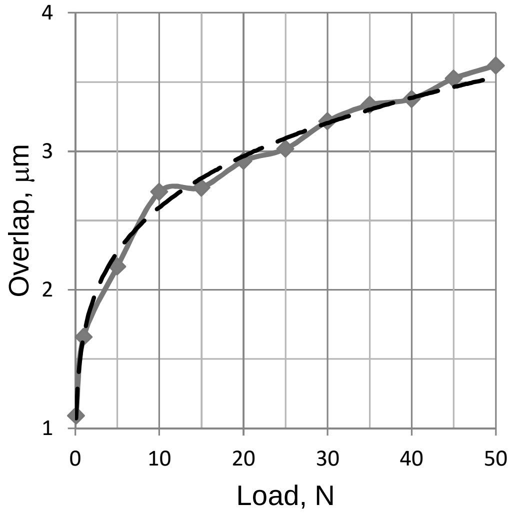

Fig. 4. Experimental results of overlapping

Contact areas

It should be noted, that the actual contact area of the sliding contact is larger than for static contacts and can be calculated as

$$A_{ск} = A_{ст}\sqrt{1+\mu^2}\ ,$$

where A_{sl} – sliding contact area, A_{st} – static contact area, μ – friction coefficient [14]. However, the difference for real slip-ring assemblies is only a few percent and can be neglected in the calculations.

The sum of all contact spots areas $A_{i,j}$ forms the bearing contact area A_b. This area is much less than the apparent contact area A_c. Usually the bearing area A_b partially is covered by insulating films. The electrical current will flow through the film only in the contact elements in which $f_{br_{i,j}} + f_{r_{i,j}} - \Delta h_{i,j} \le f_{tun}$, where f_{tun} – maximum film thickness when tunneling effect is possible. The sum of direct conductivity areas and tunneling conductivity areas forms the actual contact area A_a (Fig. 5).

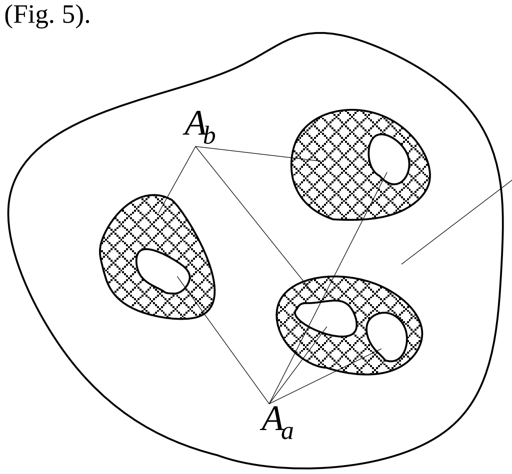

Fig. 5. The apparent, bearing and actual contact areas

III. CONCLUSION

Thus, a few new algorithms for the simulation model of sliding contact have been introduced and described in the paper.

The new models of discrete surface element and discrete contact element provide improving calculation precision of mechanical, electrical and thermal processes occurring in contact transient layer. In the work [15] these models were used for calculating time dependent thermal processes taking into account heat generation due to the friction and the electrical current, the constriction resistance, oxide films, heat flow to the neighbor elements and contact bodies.

Using equation (1) for contact microrelief generation allows take into account any external influences that form waviness and roughness of contact surfaces, such as: brush assembly design, mechanical vibrations of electrical machine parts, natural oscillation frequency of contacts [16].

Using Hertzian theory for the overlapping algorithm allows improving calculation precision of the reaction, pressure and contact spot area for interacting contact elements. As consequence, it improves calculation precision of constriction resistance, electrical and thermal processes. Also, it can be used in contact wear modeling.

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