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The simulation model of sliding contact with three degrees of freedom and distributed parameters of the transition layer

Igor Plohov, Alexander Ilyin, Oksana Kozyreva, Igor Savraev
Pskov State University, Faculty of Electromechanics.
Address: pl.Lenina, 2, Pskov, 180000, Russia

Abstract. **The development of theoretical approaches to determining mechanical characteristics of sliding contacts by the creation of a simulation model of a sliding contact with three degrees of freedom and distributed parameters of the transition layer is considered. This model enables to obtain dynamic and integral characteristics of the sliding contact on design parameters given and characteristics of materials of contact pairs.**

Keywords: **sliding electrical contact, computation model, contact interaction, current device with sliding collecting.**

I INTRODUCTION

Many electromechanical systems have a current device with sliding collecting (CDSC) containing a single or a group of sliding contacts (SC). In the simplest case SC consists of two contact details pressed together which are moving relatively. The most common CDSC is a brush-contact device of an electrical machine, which consists of solid brushes installed in fixed brush holders and pressed against the surface of the rotating current collector (CC).

The work of CDSC is accompanied by mechanical vibrations of brushes arising from their interaction with a contact surface of CC. Surface irregularities the mathematical model of which is given in [19, 27] cause dynamic forces which modulate the contact pressure within a wide range. These forces can reach values which cause a breach of the contact resulting in short dead times [16, 19]. For high-speed CDSC (such as turbogenerators) mechanical factors are a major cause of sparking and an increased wear of contact pairs and can also cause "round light" which results in a long-term failure of a current device with sliding collecting.

So far it has not been a consensus regarding adequate modeling main features and characteristics of a sliding electrical contact. It is connected with a great variety and with the complexity of physical processes of electrofrictional interaction [2-25, 28-32]. Despite much research in this area a mathematical model of SC which must meet practical requirements has not been developed yet. The rational choice of design parameters and materials of contact pairs [26] is made mainly experimentally which results in considerable time and cost consumption.

The subject of this research is the development of theoretical approaches to the determination of mechanical characteristics of SC by creating a distributed nonlinear dynamic model for receiving dynamic and integral characteristics of SC on the design parameters given and characteristics of materials of contacting pairs [19]. The modeling of dynamics of contacting with account of nonlinear distributed parameters in the transition layer will let predict the behaviour of the SC under various modes and search optimal design solutions at the design stage. This modeling will reduce the share of long-term expensive tests at the stage of designing SC and improve the quality of the development of CDSC.

II SIMULATION MODEL

The simplest design of CDSC is shown in Fig. 1. The brush 1 placed in the guides brush holder 2 is pressed by the force F to the surface of the rotating current collector 3.

The dynamic model of SC shown in Fig. 2 has three degrees of freedom, unilateral mechanical connections and distributed nonlinear parameters of the contact layer [19]. The brush having mass m_b can perform radial oscillations Y (t) along the axis Y, tangential oscillations X (t) along the axis X and rotary oscillations φ(t) in the direction of the angle

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φ. The brush body is considered to be absolutely rigid and the mass to be distributed evenly. The center of the mass of the brush is the point A which moves dynamicly relatively the fixed coordinate system XOY. The structure of the dynamic model for axial oscillations is similar.

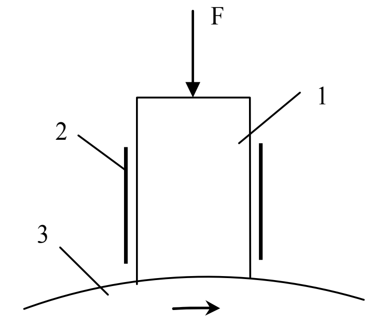

Fig. 1. Current device with sliding collecting.

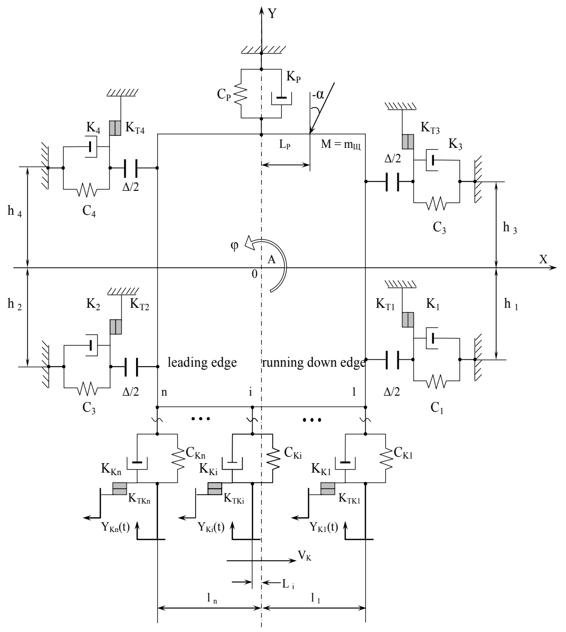

Fig. 2. Dynamic model of mechanical behaviour of a sliding contact.

The pressure spring with stiffness C_p and damping coefficient K_p affects on the brush with the force F_N, that can be applied at the angle α and at the distance L_p relatively to the radial axis of the brush. The contact area "brush - current collector" (contact layer) is described mathematically with the distributed system of boundary element (BE), each of which is defined by the rheological model of Kelvin-Voigt [1] in the radial direction and the model of Coulomb- Amontons in the tangential direction. The parameters of these models are the following: C_{Ki} is a contact stiffness of i-BE; K_{Ki} is a damping coefficient contact GE; K_{TKi} is a boundary friction coefficient ET. Similarly the contact with the rails defined by four BE of the same type is simulated. The parameters of the model are the following: C_1, .. C_4, K_1, .. K_4 are coefficients of stiffness and contact damping active elements. Mechanical connections BE are unilateral and the brush has a tangential play Δ in guides.

In accordance with the quasi-static principle of d'Alembert one can write the differential equations of the motion under the influence of kinematic disturbances Y_{Ki} (t).

For coordinate Y:

$$m_{ш}\frac{d^2Y(t)}{dt^2}+\sum_{i=1}^{n}\left\{C_{Ki}(\Delta Y_i)[Y(t)-Y_{Ki}(t)+l_i\varphi(t)]+K_{Ki}(C_{Ki})\left[\frac{dY(t)}{dt}-\frac{dY_{Ki}(t)}{dt}-l_i\frac{d\varphi(t)}{dt}\right]\right\}+$$
$$+\sum_{i=1}^{4}F_{Yi}(t)+C_pY(t)+K_p\frac{dY(t)}{dt}=-F_H(t)\cos\alpha; \tag{1}$$

for coordinate X:

$$m_{ш}\frac{d^2X(t)}{dt^2}+\sum_{i=1}^{4}\left\{C_i(\Delta X_i)[X(t)-\varphi(t)h_i]+K_i(C_i)\left[\frac{dX(t)}{dt}-h_i\frac{d\varphi(t)}{dt}\right]\right\}=$$
$$=\sum_{i=1}^{4}F_{Xi}(t)+F_H(t)\sin\alpha; \tag{2}$$

for coordinate φ:

$$J_{ш}\frac{d^2\varphi(t)}{dt^2}+\sum_{i=1}^{n}\left\{C_{Ki}(\Delta Y_i)l_i[l_i\varphi(t)+Y(t)-Y_{Ki}(t)]+K_{Ki}(C_{Ki})\left[l_i\frac{d\varphi(t)}{dt}-\frac{dY(t)}{dt}-\frac{dY_{Ki}(t)}{dt}\right]\right\}+$$
$$\sum_{i=1}^{4}\left\{C_i(\Delta X_i)h_i[X(t)-\varphi(t)h_i]+K_i(C_i)h_i\left[\frac{dX(t)}{dt}-\frac{d\varphi(t)}{dt}h_i\right]+F_{Yi}(t)l_i\right\}=$$
$$=-\frac{h}{2}\sum_{i=1}^{4}F_{Xi}(t)-F_H(t)(L_p\cos\alpha-\frac{h}{2}\sin\alpha), \tag{3}$$

where h is the height of the brush; Y (t), X (t), φ (t) are radial, tangential and angular values of the motion of the brush in the coordinate system given; l_i, h_i are shoulders of BE of the contact layer and guides; F_{Yi}, F_{Xi} are the friction forces in the BE of contact layer and in the guides:

$$F_{Yi}(t)=\left\{C_i(\Delta X_i)[X(t)-\varphi(t)h_i]+K_i(C_i)\left[\frac{dX(t)}{dt}-\frac{d\varphi(t)}{dt}h_i\right]\right\}K_{Ti}\,\mathrm{sign}\frac{d\Delta Y_i(t)}{dt};$$
$$F_{Xi}(t)=\left\{C_{Ki}(\Delta Y_i)[Y(t)-Y_{Ki}(t)+\varphi(t)l_i]+K_{Ki}(C_{Ki})\left[\frac{dY(t)}{dt}-\frac{dY_{Ki}(t)}{dt}+\frac{d\varphi(t)}{dt}l_i\right]\right\}K_{TKi}, \tag{4}$$

where ΔYi, ΔXi is a radial and tangential value of the convergence of interacting zones of microreliefs in i-BE:

$$\Delta Y_i = Y(t) - Y_{Ki}(t) + l_i\varphi(t), \quad \Delta X_i = X(t) - h_i\varphi(t). \tag{5}$$

After making the transition to the operator form we obtain after transformations the coordinates Y, X, φ respectively:

$$Y(p)=\frac{1}{pm_{ш}}\left\{\begin{aligned}&\sum_{i=1}^{n}\left[\frac{1}{p}C_{Ki}(\Delta Y_i)(Y_{Ki}(p)-Y(p)-l_i\varphi(p))+K_{Ki}(C_{Ki})(Y_{Ki}(p)-Y(p)-l_i\varphi(p))\right]+\\&+\sum_{i=1}^{4}\left[\frac{1}{p}F_{Yi}(p)\right]-\frac{1}{p}C_pY(p)-K_pY(p)-\frac{1}{p}F_H(p)\cos\alpha\end{aligned}\right\} \tag{6}$$

$$X(p)=\frac{1}{m_{ш}p}\left\{\begin{aligned}&\sum_{i=1}^{n}\left[\frac{1}{p}C_i(\Delta X_i)(\varphi(p)h_i-X(p))+K_i(C_i)(\varphi(p)h_i-X(p))\right]+\\&+\frac{1}{p}F_H(p)\sin\alpha-\sum_{l=1}^{n}\frac{1}{p}F_{Xi}(p)\end{aligned}\right\} \tag{7}$$

$$\varphi(p)=\frac{1}{J_{щ}p}\left\{\begin{aligned}&\sum_{i=1}^{n}\left[\begin{aligned}&\frac{1}{p}C_{Ki}(\Delta Y_i)l_i\left(Y_{Ki}(p)-Y(p)-\varphi(p)l_i\right)+\\&+K_{Ki}(C_{Ki})l_i\left(Y_{Ki}(p)h_i-Y(p)-\varphi(p)l_i\right)\end{aligned}\right]+\\&+\sum_{i=1}^{4}\left[\begin{aligned}&C_i(\Delta X_i)h_i\frac{1}{p}\left(\varphi(p)h_i-X(p)\right)+\\&+K_i(C_i)h_i\left(\varphi(p)h_i-X(p)\right)+\frac{1}{p}F_{Yi}(p)l_i\end{aligned}\right]-\\&-\sum_{i=1}^{n}\frac{1}{p}F_{Xi}(p)\frac{h}{2}-\frac{1}{p}F_H(p)(L_p\cos\alpha+\frac{h}{2}\sin\alpha)\end{aligned}\right\} \qquad (8)$$

According to the equations of motion, we will construct a generalized block diagram of the dynamic model (Fig. 3). According to the scheme the program was developed that allowed to study the influence of various factors on three coordinate oscillations of the brush. The study of tangential distributions of the contact instability, the contact pressure and the specific contact stiffness have been carried out.

To determine spatial distributions in the tangential direction of the contact pressure of the specific contact stiffness and a coefficient of a relative instability (CRI) we perform the following: 1) at each step of the calculation in each BE we determine the presence of the contact as a Boolean constant as well as a specific stiffness and pressure using the value of the contact convergence member; 2) the data are being collected during the period of the calculation then they are averaged over the time and given as graphs. Moreover on the data obtained we calculate the parameters that characterize the quality of contacting on the average over the entire contact area.

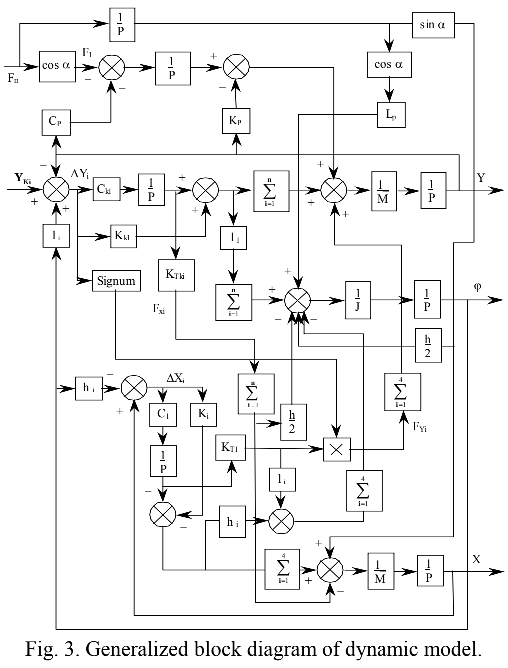

Fig. 3. Generalized block diagram of dynamic model.

Fig. 4 shows as an example the interconnected dynamic response to the standard kinematic perturbations obtained with the dynamic model.

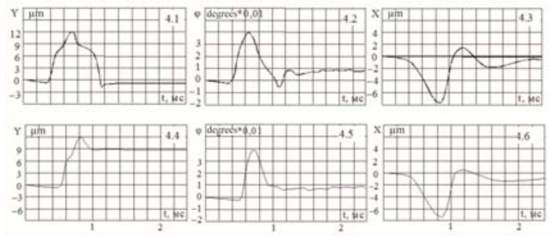

Fig. 4. Pulse response (top row) and unit-step response (bottom row) by $\alpha = 0$.

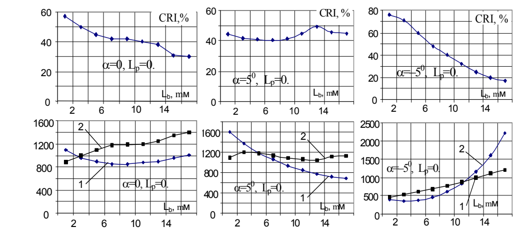

Fig. 5. Contact distributions for different values of α and Lp. the top row of the graphs is the coefficient of relative instability, %;
the bottom row of the graphs is the specific pressing N/m (curve 1), specific contact stiffness, MN/m/m/ (curve 2).

III CONCLUSION

The analysis of the arrays of these characteristics obtained under different constant conditions and for different kinematic disturbances shows that: 1) generally the distributions of a contact are nonlinear; 2) by axial pressing force application the leading edge of the brush contact is more stable than the running down edge of the brush; 3) the contact pressure on the edges of the brush is more than in the middle; 4) the distribution of the contact stiffness is shaped qualitatively inversly in the relation to the distribution of CRI; 5) the increase of the linearity distribution of the stiffness and CRI can be achieved at positive values of the angle α and arm L_p.

The analysis of the dynamic reactions shows that the loss time of the contact at the interaction of the brush with a single protrusion decreases when the pressure force is displaced or tilted in the direction of the leading edge. Practically all contact pressure is concentrated on the leading edge of the brush that works stablely while CRI of running down edge of the brush increases significantly.

Now the dynamic model of the mechanics of the electrofrictional interaction is realized by means of the system of simulation Simulink MATLAB.

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