THEORETICAL BASIS OF SLIDING CONTACT USED AT THE TRANSFORMERS WITH CONTINUOUS VOLTAGE ADJUSTMENT

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REZUMAT. În rola de contact utilizată în cadrul dispozitivului colector de la transformatoarele cu reglaj continuu al tensiunii sub sarcină unde are loc o distribuţie neuniformă a curentului, rezistenţa ohmică a traseului conductor prin aceasta nu se poate calcula cu formula clasică, iar din această cauză, în circuitul închis format din spira scurtcircuitată de către rolă apare un curent de scurtcircuit, factor determinant pentru producerea unei supraîncălziri locale apreciabile, în special în zona punctelor de contact.

Cuvinte cheie: contact alunecător, pierderi, transformator, scurtcircuit

ABSTRACT. In the sliding contact which is used at the transformers with continuously adjustable voltage under load occurs an irregular distribution of current and therefore the ohmic resistance of conductor route through the sliding contact can not be calculated with the classical formula, and in this case, in the closed loop consisting of the spire which is shorted by sliding contact it is produce an short-circuit current, the determining factor for the production of a considerable local overheating, especially in the points of contact.

Keywords: sliding contact, losses, transformer, short circuit

1. INTRODUCTION

In the sliding contact, which is used at the transformers with continuously adjustable voltage under load, occurs an irregular distribution of current, are valid Kirchhoff's circuit law and Ohm's law and therefore the ohmic resistance of conductor route through the sliding contact can not be calculated with the classical formula.

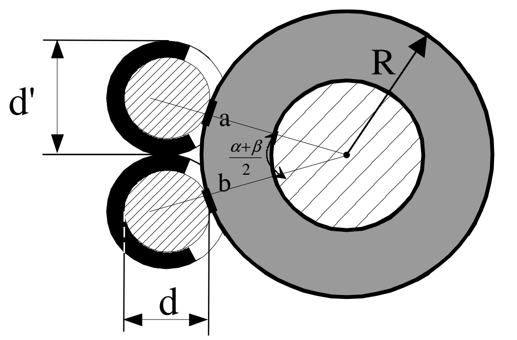

Fig. 1 A schematic representation for the contact area between the contact roller and winding turns

Theoretically, it is accepted that the roller comes into contact only with one single turns, but in reality, it comes into contact, almost always, with two adjacent turns, the corresponding position is clearly and more stable mechanically.

Because the electromotive force induced in the short-circuited turn occur directly in the design of the autotransformer therefore the short-circuit current depends, primarily, by the total resistance of the circuit, i.e. by the resistance of short-circuited turn, by the contact resistances established in the contact points between the sliding contact and the turns and by the short-circuit resistance considered between the contact points of sliding contact with the turn shorted.

Therefore, in the closed circuit formed by the turn shorted by sliding contact appears a short-circuit current produced by the induced EMF(electromotive force)in the turn by the alternating magnetic flux which crossing the ferromagnetic core of the autotransformer, causing, ultimately, a considerable local overheating, especially in the contact points.

For to visualize the distribution range of temperature it used a thermal imager Fluke Ti25 and the results are presented in Fig. 2.

Measuring the actual temperature has required compensation of apparent temperature (the amount of radiation emitted) by adjusting reflected temperature and atmospheric influence factors. Interpretation of thermographic images obtained has allow us to conclude that the temperature implicitly the current density have high values in the vicinity of the points of contact between sliding contact and coils and the field lines are concentrated in this part of the contact area.

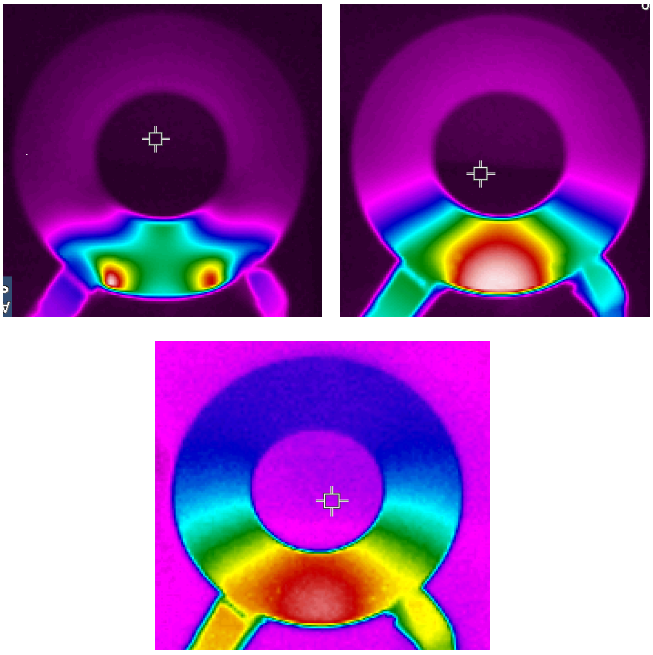

Fig.2 Distribution range of temperature in sliding contact

The calculation for the resistance of coil and the contact resistance established in the contact points between the sliding contact and the coils is exhibited widely in the literature dealing with the theory and design of electrical devices.

2. ANALYTICAL MODEL FOR ZETA POTENTIAL AT POINTS OF CONTACT OF THE SLIDING CONTACT

In as regards the calculation for short-circuit resistance R considered between the contact points of sliding contact was started from the integrating of electrokinetic field equations inside the contact roller and made the following simplifying assumptions:

❖ Sliding contact is composed of two conductors homogeneous, linear and isotropic, with different conductivities σ_1 and σ_2, materials that form two concentric zones. The thickness *g*, the roll is sufficiently small compared with the other dimensions, so that the field can be considered plane parallel

❖ contact points *a* and *b* are basically two rectangular area of width equal to the thickness and roll length and arc length R (β - α);

❖ current density $\overline{J}$ is uniformly distributed in in the rectangular contact areas *a* and *b* and is normal to the lateral surface of the roller;

❖ the autotransformer leakage magnetic field does not influence the distribution fild lines in sliding contact;

❖ operating regime is steady state mode.

To determine the electrostatic field must be aware of field (electric charge, electric fields of foreign, non-electric fields or electric currents), the nature of the environment in which the field is manifested through material constants (electric permittivity ε, conductivity σ that the resistivity ρ and magnetic permeability μ) and the geometry of the electric charges. Also, in order to calculate a field intensity of the field must be determined that densities of the field parameters of piping systems and the forces that manifest in the field.

Calculation of short-circuit resistance Rk roll contact can be made from steady relationships:

$$rot\,\overline{E} = 0 \quad \text{results} \quad \overline{E} = -grad V \tag{1}$$

$$\overline{J} = \sigma \cdot \overline{E} \tag{2}$$

$$div\,\overline{J} = 0 \tag{3}$$

of these three relationships that zeta potential meet Laplace's equation:

$$\Delta V = 0 \tag{4}$$

with appropriate boundary.

Upon learning the solution of this equation which satisfies boundary conditions imposed, could cause the current field lines:

$$\overline{J} = -\sigma \cdot grad V \tag{5}$$

Having regard symmetry of the problem, the coordinate system centered on the center the roll and the reference axis of the argument as the axis of symmetry (Fig. 3) in polar coordinate system, Laplace's equation (5) becomes:

$$\rho \frac{\partial}{\partial \rho}\left(\rho \cdot \frac{\partial V}{\partial \rho}\right) + \frac{\partial^2 V}{\partial \rho^2} = 0 \tag{6}$$

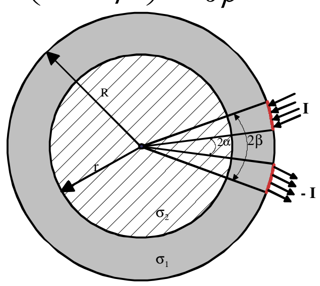

Fig. 3. Representation of sliding contact in polar coordinate system

Boundary conditions necessary for determining unambiguously the zeta potential V (ρ, φ) are the following:

➢ For $\rho = R$ (R-outer radius of the roller contact): radial component of the current density is zero throughout the roll periphery except in such areas $_a$ and $_b$ where is constant.

$$J^{(1)} = -\sigma_1 \frac{\partial V^{(1)}}{\partial \rho} = F(\varphi) \qquad (7)$$

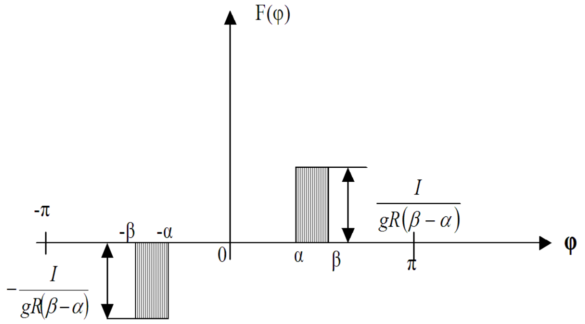

Fig. 4 Graphical representation of the function F (φ)

- For ρ = r (r - inner radius of the roller contact), i.e. the limit of separation between the two conductors. Normal component of current density is conserved as those of the stationary electric field:

$$J_\rho^{(1)} = J_\rho^{(2)} \quad , \quad \sigma_1 \frac{\partial V_\varphi}{\partial \varphi} = \sigma_2 \frac{\partial V_\varphi}{\partial \varphi} \qquad (8)$$

$$E_\kappa^{(1)} = E_\varphi^{(1)} \quad , \quad \frac{1}{\rho}\frac{\partial V_\rho^{(1)}}{\partial \varphi} = \frac{1}{\rho}\frac{\partial V_\rho^{(2)}}{\partial \varphi} \qquad (9)$$

- For $\rho = 0$ sau $\rho = \pi$ on reasons of symmetry or power lines are perpendicular to the axis of symmetry, therefore the boundary conditions needed to solve the Laplace's equations are:

$$\frac{\partial V^{(1)}}{\partial \rho} = \frac{\partial V^{(2)}}{\partial \rho} = 0 \qquad (10)$$

The general solution of Laplace's equation (6) satisfying the boundary conditions (7, 8, 9, 10) can be written as:

$$V(\rho,\varphi) = \sum_{\lambda=1}^{\infty}\left(C_\lambda \cdot \rho^\lambda + \frac{D_\lambda}{\rho^\lambda}\right)\cdot\left(A_\lambda \cdot \cos\lambda\varphi + B_\lambda \sin\lambda\varphi\right) \quad (11)$$

So, for the conductivity σ_1 general solution (11) must satisfy the boundary conditions: $A_\lambda = 0$ and $\sin\lambda\pi = 0$, hence: $\lambda = n$ and the solution domain is :

$$V^{(1)}(\rho,\varphi) = -\frac{4}{\pi}\cdot\frac{I}{\sigma_1 g(\beta-\alpha)}\cdot\sum_{n=1}^{\infty}\left(\frac{R}{\rho}\right)^n \cdot \frac{\left(1+\frac{\sigma_2}{\sigma_1}\right)\cdot\rho^{2n} + \left(1-\frac{\sigma_2}{\sigma_1}\right)\cdot r^{2n}}{\left(1+\frac{\sigma_2}{\sigma_1}\right)\cdot R^{2n} - \left(1-\frac{\sigma_2}{\sigma_1}\right)\cdot r^{2n}} \cdot \frac{1}{n^2}\sin\frac{n(\beta+\alpha)}{2}\cdot\sin\frac{n(\beta-\alpha)}{2}\cdot\sin n\varphi$$

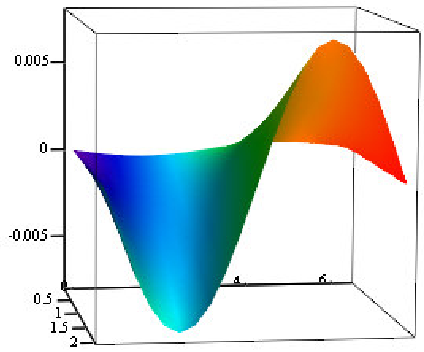

Fig. 5 Graphics potential distribution in the contact points of the roller to the conductivity σ_1

From physical considerations for the domain with the conductivity σ_2, the solution to equation (6) in the area $V^{(2)}(\rho,\varphi)$ is:

$$V^{(2)}(\rho,\varphi) = -\frac{8}{\pi}\cdot\frac{I}{\sigma_1 g(\beta-\alpha)}\cdot\sum_{n=1}^{\infty}\cdot\frac{(\rho R)^n}{\left(1+\frac{\sigma_2}{\sigma_1}\right)\cdot R^{2n} - \left(1-\frac{\sigma_2}{\sigma_1}\right)\cdot r^{2n}} \cdot \frac{1}{n^2}\sin\frac{n(\beta+\alpha)}{2}\cdot\sin\frac{n(\beta-\alpha)}{2}\cdot\sin n\varphi \qquad (14)$$

3. THE MATHEMATICAL MODEL OF SHORT-CIRCUIT RESISTANCE R_K

Mind knowing Laplace equation solution (6) for zeta potential, given by expressions (13) and (14) in the two areas, we can calculated the short-circuit resistance of the sliding contact with the expression:

$$R_k = \left|\frac{V_a - V_b}{I}\right| \qquad (15)$$

where V_a and V_b are zeta potential of areas *a* and *b,* the potential areas where current enters and exits I:

$$V_a = V^{(1)}\left(R, \frac{\alpha+\beta}{2}\right), V_b = V^{(1)}\left(R, -\frac{\alpha+\beta}{2}\right)$$

The angle $\frac{\alpha+\beta}{2}$ is determined by the diameter of winding *d*, the thickness of the insulation of the insulated diameter *d'* and the outer radius of the roller *R*, as shown in fig.3

Finally, we obtain the following mathematical model for calculating short-circuit resistance:

$$R_k = \frac{8}{\pi\,\sigma_1 g(\beta-\alpha)} \sum_{n=1}^{\infty} \frac{1}{n^2} \cdot \frac{1 + \dfrac{1-\dfrac{\sigma_2}{\sigma_1}}{1+\dfrac{\sigma_2}{\sigma_1}} \cdot \left(\dfrac{r}{R}\right)^{2n}}{1 - \dfrac{1-\dfrac{\sigma_2}{\sigma_1}}{1+\dfrac{\sigma_2}{\sigma_1}} \cdot \left(\dfrac{r}{R}\right)^{2n}} \cdot \sin^2\left[\frac{n(\alpha+\beta)}{2}\right] \cdot \sin\frac{n(\beta-\alpha)}{2}$$

In case we have homogeneous roll, made from a single material R_k expression becomes:

$$R_k = \frac{2}{\pi\,\sigma\, g\,(\beta-\alpha)}\left[(3\beta+\alpha)\cdot \ln(3\beta-\alpha) - (3\alpha+\beta)\cdot \ln(3\alpha+\beta) - 2\cdot(\beta-\alpha)\cdot \ln(\beta-\alpha)\right]$$

4. CONCLUSIONS

Value of short-circuit current established by the roll depend on the the total resistance of the circuit, i.e. by the resistance of short-circuited turn, by the contact resistances established in the contact points between the sliding contact and the turns and by the short-circuit resistance considered between the contact points of sliding contact with the turn shorted.

The practical importance of the Rk expression consist in the opportunity given to study the effect of varying ratio $\frac{\sigma_2}{\sigma_1}$ or $\frac{r}{R}$ on the value of the short circuit resistance R_k, thus obtaining valuable information about the choice of materials and dimensions roller contact.

The influence of material conductivity it is made the core of sliding contact is, if analyzed, making it possible to use restricted formulas (see last mathematical expression for R_k). The influence of the central core of thesliding contact becomes important when the ratio , where is the need to use complex calculation formulas (see general mathematical expression for R_k).

The applicability of resulting formulas is limited because it is not known,with precision, the surface contact between turns and sliding contact, this size can be determined approximately from the measured contact resistance, adopting some simplifying assumptions.

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