The Modeling and Analysis of the Current Density in Current Gauges and Contact System

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Transmission lines and contact assemblies adapted for conducting considerable values of constant and momentary current ratings are usually built as the set of many isolated parallel paths, in addition spaces between electric contacts are little compared with their width. Ensuring the big power-driven load capacity to a maximum is aimed at it. In these types of paths flow of the electricity through each of them is, how it could be expected, uneven. It is an effect of the occurrence of skin effect and an effect of closer acquaintance. So, we cannot increase their power-driven load capacity proportionally to the amount of transmission lines. Inductances are different, depending on the place of the path. The following calculations are supposed to explain and to depict, which from paths (in case of contact assemblies – electric contacts) will be mostly exposed at the flow of the electricity, as well as will let the resistance understand the relation of the contact effect of the material and the structure of joints.

Keywords: contact systems, current gauges, current density

1 INTRODUCTION

The figure 1 shows the parallel structure of the contact assembly which was analysed at this work. The contact assembly makes up from two "knives" and eight electric contacts structures were also being taken into consideration with one knife and with different number of electric contacts.

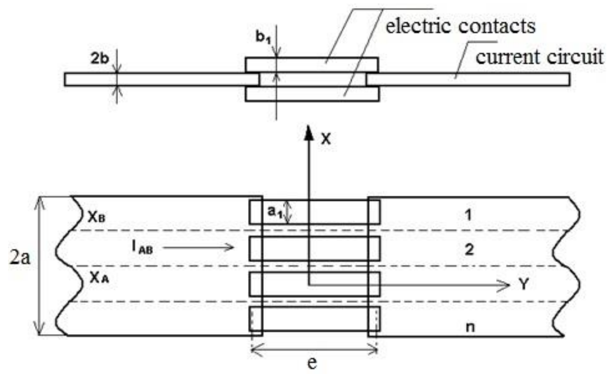

Fig. 1: Outline of arranging of electric contacts in the contact assembly, 1, 2, ... n - of electric contacts, 2a, 2b - dimensions of joints, a_1, b_1 - dimensions of electric contacts

In the figure 1 a simplified schematic diagram of the contact assembly was presented. Leading tracks have dimensions 2a x 2b and are interfacing with the contact system created from n of parallel pairs of electric contacts, about rectangular a_L x b_L diameters. For appointing the value of electricities in individual electric contacts a division of power-driven paths into n of equal, parallel strips was suggested. They established in addition, that at negligible of small contact resistance R_k and the small distance between the electric contacts, unevenness of the disintegration of the electricity in electric contact will be similar to the disintegration in power-driven paths with dimensions 2a x 2b. So the value of the current in the strip I_i is equal to the value of the electricity in the electric contact I_{1i} ($I_i = I_{1i}$). In reference to literature [1], a schedule of the δ current density was presented at a >> b (fig. 2):

$$\delta = \frac{I}{4ab} \cdot \left(1 + \chi \cdot \xi^2\right) \cdot ch\left[(1 + j) \cdot k \cdot \xi\right] \qquad (1)$$

where:

$$\xi = \frac{x}{a};\ \chi = 0{,}2 \cdot a \cdot \varpi \cdot \mu_o \cdot \gamma;\ k = \sqrt{0.7 \cdot (2\chi - 1)};$$

x- rate of the distance from the axis of the power rail (fig. 1).

Answering this equation (1) distribution curve of the current density in the copper track about rectangular diameter 120 x 10 mm^2 at the electricity I = 2000A and frequencies f = 50 Hz was shown in the figure 2. Equation (1) lets, with means of integrating in ranges from X_A to X_B, to find the coming current in zone limited by these ranges. They will correspond to these ranges zero-dimensional $\xi_A = X_A/a$ and $\xi_B = X_B/b$. From here the total value of the coming current in the AB zone is taking out:

$$I_{AB} = \sqrt{I^2{}_{aAB} + I^2{}_{pAB}} \qquad (2)$$

Nextly the parameters of parallel electric contacts were appointed. Full impedance of the electric contact is:

$$Z_{li} = \sqrt{R^2{}_l + X^2{}_{li}} \qquad (3)$$

where:
R_1- resistance equal for every electric contact.

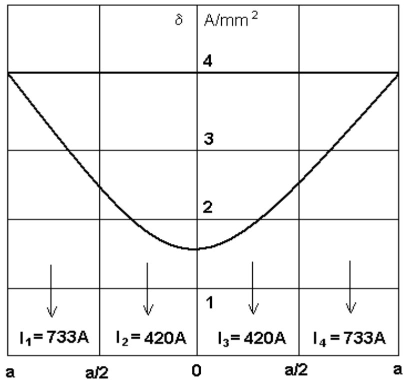

Fig. 2: Disintegration of the current density in the copper track with diameter 120 x 10 mm² at the 2000A electricity

If width of the electric contact is a1 << 2 and (fig. 1), it is possible to put it on, that resistance of the one electric contact R_1 at the alternating current will be approximately equal to the resistance at the direct current and therefore it is possible to write:

$$R_l = \frac{l}{\gamma \cdot a_l \cdot b_l} \qquad (4)$$

where:
γ - rate of the conductance of the material of the electric contact, l - length of the electric contact, a_1, b_1 - field of the sectional area of the electric contact.

According to equations (1) and (2) it is possible to enrol the equality in drops of tensions:

$$I\sqrt{R^2 + (\varpi \cdot L)^2} = I_{li}\sqrt{R^2{}_l + X^2{}_{li}} \qquad (5)$$

where:
L- inductance of the part of the power rail limited by ranges X_A and X_B and the length l, I - total of electricity running in the power rail.
That is how a reactance of single electric contact was received (5). It equals:

$$X_{li} = \sqrt{\frac{I^2}{I^2{}_{li}} \cdot \left[R^2 + (\varpi \cdot L)^2\right] - R^2{}_l} \qquad (6)$$

For finding individual X_{l1}, X_{l2}, ..., X_{ln} according to above expressions we need absolutely to know the inductance of tracks L, which approximately are determined with the following pattern:

$$L = \frac{\mu_0 l}{2\pi} \cdot \left[\ln\frac{l}{a+b} + \frac{1}{2} - \frac{\beta^4}{24} \cdot f(\varepsilon)\right] \qquad (7)$$

where:

$$\beta = 0{,}4a\sqrt{\varpi \cdot \gamma \cdot \mu_0};\ \varepsilon = \frac{a-b}{a+b};$$

$$f(\varepsilon) = (1-\varepsilon)^3 \cdot \left(1 - \frac{\varepsilon^2}{3}\right) \cdot (1 + 4\varepsilon^2 + \varepsilon^4)/(1+\varepsilon)$$

Resistance R of the power rail equals:

$$R = k_n \cdot \frac{l}{4 \cdot a \cdot b \cdot \gamma} \qquad (8)$$

where: k_n – rate of the skin effect.
To the syneresis of electricities between parallel electric contacts, apart from the R_1 resistance and the X_{Li} reactance (i = 1, 2, ..., n) also affects resistance of passing joints between electric contacts and power rails. A sum of these resistances of both joints was indicated and electric contacts with the number i through R_{ki}, and i = 1, 2, ..., n. After adding this size it is possible to present the unabridged schematic diagram of the inspected contact assembly (fig. 3).
At analysis of the syneresis of the current in joints own and mutual inductances of electric contacts were taken into consideration. If we accept, that **U** will be a comprehensive voltage drop on the entire contact assembly (fig. 3), then the electricity of single electric contact equals:

$$I_{li} = \frac{U}{R_{ki} \cdot R_l \cdot jX_{li}} = U(A_i - jB_i) \qquad (9)$$

where:

$$A_i = \frac{R_{ki} + R_l}{(R_{ki} + R_l)^2 + X^2{}_{li}}; \quad B_i = \frac{X_{li}}{(R_{ki} + R_l)^2 + X^2{}_{li}}$$

According to the first law of Kirchoff, total electricity **I** running through the contact assembly is equal to the sum of floating electricities in individual electric contacts:

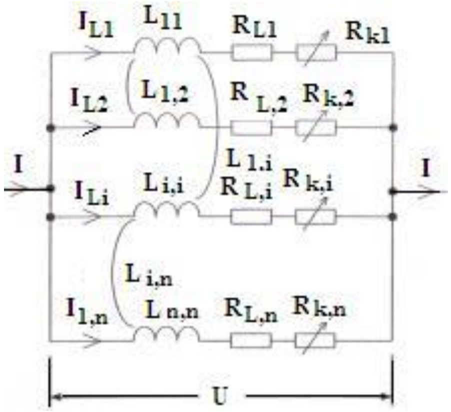

Fig. 3: Schematic diagram of the inspected contact assembly, i - total electricity, I_{L1}, I_{Li}, I_{Ln} - currents in individual zones of power rail, Li, 1, Li, i, L_n, n - inductance own and mutual, R_{L1} - resistance of the electric contact, R_{k1} - resistance of the contact assembly

Using the relation to the electricity of the single electric contact and total voltage drop on the contact assembly at the set of contact resistance R_{ki} and the calculated Z_{Li}, it is possible to calculate the impedance electricity in the electric contact. Achieved results with above method are confronted with field calculations made by using the ANSYS program.

2 RESULTS

Calculations of the disintegration of the current in the crosswise axis of the contact assembly of the flat electric contact are made for the following parameters (current rating I = 2000A, dimensions of joints 2a x 2b = 120 x 10 mm^2, the number of electric contacts 2n = 10, dimensions of electric contacts 2_{a1} x 2_{b1} = 25 x 10 mm^2, the length of electric contacts l = 145 mm, averaged value of the contact resistance $R_k = 39 \cdot 10^{-6}$ Ω. While analysing results it was stated that the R_p resistance had a fundamental influence on the unevenness of the syneresis of the current in the contact assembly. In the extreme case, when $R_p = 5$ μΩ (fig. 4) this unevenness can achieve the 21% of the current rating of the contact assembly. It is particularly dangerous since it can lead to the extreme overheating of the electric contact. In the figure 4a syneresis of the current in the contact assembly was described for the resistance of the R_p contact assembly $R_p = 5$ μΩ.

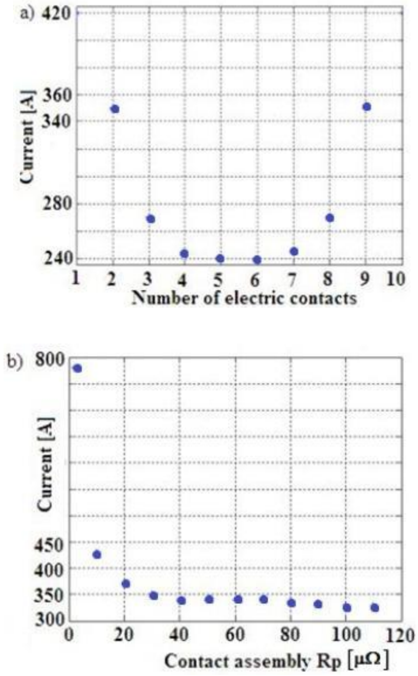

Fig. 4: a) Syneresis of the current in the flat contact assembly at R_p = 5 μΩ, b) relation of the value of the floating electricity in extreme fuse of contact assembly ad valorem of contact resistance

In the figure 4b the relation of the value of the floating electricity was described in extreme electric contacts of contact assembly ad valorem of contact resistance [2]. Phenomenon of increasing unevennesses of the syneresis of the current in the contact assembly (fig. 4) is outweighing, especially in contact assemblies plated with silver, being characterized by a low resistance of the passage (below 20 μΩ). Based on calculations it should be considered the possibility of creating centre electric contacts (of the ones less burdened) with the smaller diameter than the rest of the electric contacts. On the stage of manufacture it would give great material frugalities relatively. Above an analytical way bringing modelling of large-power-driven paths was presented oneself to choose from determined type of power rail. Increasing the section excessively is unjustified economically, and character of receipts can point at the value of the current rating not being located in the rail type. An outline dimension of the power-driven path and a way of arranging are also pointing to the personal touch of power rails. At present large-power-driven paths have a compact structure. Power rails are well-behaved very close one to another so that there are no places filled up with air. The warmth with ease is penetrating into the casing (if it appears) which works as a radiator. However a syneresis of the current in very arrangement of parallel tracks is becoming a problem. For appointing the syneresis of the current in large-power-driven paths field methods were used. Towards analytical methods they let among others for appointing the location of areas, about the greater concentration of cargoes and the temperature distribution. With software using this method and giving great abilities of examining the phenomenon of driving the electricity out, there is an ANSYS program. The figure 5 shows the structure of tested power-driven thorium and it's implementation in the program.

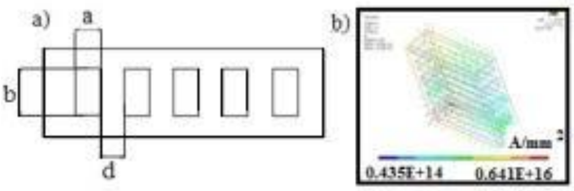

Fig. 5: Arrangement of parallel power-driven paths: a) structure a, b - cross sections, d - distance between paths, b) analysis of the syneresis of the electric charge in parallel power-driven paths a = 4 mm, b = 30 mm, length l = 1000 mm, d = 10 mm, at the flow of the electricity of burden 5kA

Based on the schedule of the electric charge in power-driven paths it was appointed by integrating average value of the electricity, in individual tracks. At the flow of the electricity with value 5 kA through, arrangement of parallel power-driven paths, we can observe uneven syneresis of the electricity. Towards the centre power-driven path (path 3) outside power-driven paths (paths 1 and 5) are burdened at about 30% with considerable value of the electricity. The unevenness of the syneresis of the electricity is a non-linear relation. Definitely larger differences of the value of the current in individual tracks are at burdening 20-100 kA a disintegration of the density of the electric charge was analysed from this scope (fig. 6).

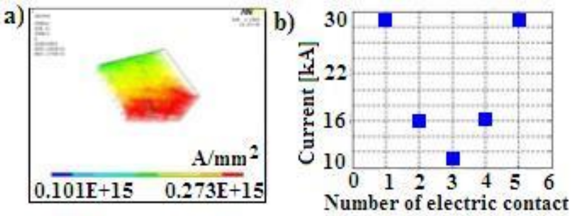

Fig. 6: a) Analysis of the syneresis of the electric charge in parallel power-driven paths a = 4 mm, b = 30 mm, length l = 1000 mm, d = 10 mm at flow 100 kA, b) analysis of the average value of the current in individual power-driven paths at the flow of the electricity about straining 100 kA

At the frequency of the electricity of 50 Hz, designing and making large-power-driven paths and power rails, in arrangements of parallel strips, with the same diameter isn't justified. Explicitly they are indicating results of calculations that with centre paths a lower electricity is floating.

3 SUMMARY

Miniaturization of devices and electrical power engineering apparatus in particular of switchgears, often makes it impossible to ensure required distances. In the heavy industry, aviation high frequencies are often exploited. Along with the increase in the frequency of the electricity an unevenness of the syneresis of the current in power-driven paths is growing. Based on calculations there should be considered the possibility of making centre paths (of the ones less burdened), with the smaller diameter than remaining. On the design phase, it is possible to take different shapes of the power rails into account. On the stage of manufacture it would give great material frugalities.

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