Investigation of the Characteristics of the Transient Electrical Resistance of Contacts in the Designs of Radio Electronic Devices in the Conditions of the Formation of Contact Radio Interference

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***Abstract*–The article discusses the characteristics of the total transient electrical resistance of the contact. The coefficients of the influence of the active and reactive components on the contact impedance are estimated. The dependences of the active and reactive components of the total electrical resistance of the contact on various factors are shown. The studies of the behavior of contact resistances of structural elements carried out in this work make it possible to predict the level of contact interference to radio reception in the future. This is due to the expansion of the spectrum of re-emitted electromagnetic radiation, which occurs due to the irradiation of structural elements with standard devices emitting electromagnetic waves.**

Keywords*– *contact connections, electrophysical parameters, contact interference

I. Introduction

The quality of structural elements made with the use of mechanical joints, various contact joints, detachable joints of structural elements and components of electronic equipment, the corresponding requirements are imposed: high reliability, sufficient strength and rigidity, a high degree of wear resistance, high resistance to climatic factors, the required resistance to thermal influences, the required coefficient of friction, the constancy and thermal stability of the contact force, as well as the presence of a certain force when disconnected. The contact connection of structural elements under vibration and shock loads, as well as corrosion processes occurring on moving objects operating in real conditions, is a source of the formation of broadband contact radio interference caused by the presence of nonlinear effects and dynamic instability of its electrical properties, characteristics and parameters. Such contact radio interference arrives at the input of radio receivers, creating significant problems in the organization of radio communications and degrading and violating the electromagnetic compatibility (EMC) of onboard radio electronic equipment (EM).

Taking into account the above, the most stringent and specific requirements are imposed on contact connections located at mobile radio communication facilities. Evaluation of characteristics and quality indicators in relation to the electromagnetic compatibility of such compounds is an urgent and important problem that requires a theoretical solution and development of practical recommendations. This problem can be solved by a detailed analysis of the dynamic instability of the electrical parameters of contact joints under the influence of mechanical and climatic factors and the development of appropriate mathematical models on its basis, which can be used for practical assessments of the quality of mechanical joints, for the functioning of on-board radio-electronic equipment according to EMC criteria.

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II. Metod and Results

At present, an urgent task is to accurately determine the value of the total resistance of an electrical contact when various factors influence it. This need arises, for example, in the calculation and prediction of contact radio interference arising from the presence of imperfect mechanical contacts with variable resistance.

The contact resistance Z*c*, which determines the voltage drop at the junction of two touching conductors, generally consists of two components [1]:

$$z_c = z_s + z_t = R_c + jX_c \qquad (1)$$

Where: Z*s* - is the resistance of the surface film; Z*t* - transitions resistance.

The first component Z*s* is determined by the resistance of the surface oxide films that cover the contacting conductors and prevent the flow of current through the contact gap. The second component Z*t* is formed due to the contraction of streamlines to separate points (α-spots) of contact of two contacting surfaces, as well as due to the formation of resistance of microprotrusions conducting electric current [2].

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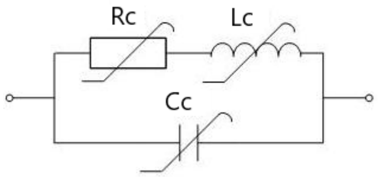

Fig. 1. Non-linear parametric equivalent circuit of the impedance of the alternating contact.

The active component of the contact resistance *Rc* determines the amount of heat generated at the contact junction when the current passes. The reactive component is due to the inductance and capacitance of the transition zone of the variable contact *Z*.

Inductive resistance is caused by the difference in the energies of the magnetic field (W_1-W_2) at the edges of the contacting elements and at the contact bridge due to the contraction of the streamlines to the α-spots of conduction. The L_C value can be calculated by the formula

$$L_C = \frac{2(W_1 - W_2)}{i_C^2} \qquad (2)$$

Where: i_C - the current through the contact jumper.

Due to the roughness of the surfaces of the contacting conductors, their contact does not occur over the entire area, but only in individual areas with purely metallic or quasi-metallic conductivity. Thus, regions with increased capacitance are formed near the conductive sections. The capacity of the transition zone is also determined by the configuration of the contact surfaces, the cleanliness of their processing and the degree of clamping force. In the general case, the capacity of the transition zone can be found by the formula

$$C_C = \varepsilon_o \int_s \frac{dS}{d} \qquad (3)$$

Where: ε_o - is the dielectric constant of the medium; *d* - is the distance between the contact surfaces; *S* - is the area of contacting surfaces.

According to the results of recent studies, contact conductance is also explained by the presence of such phenomena as cold emission, thermal emission, gas discharge, electrochemical and thermopower.

In the process of contacting, the value of Z*c* varies widely depending on many factors: the ambient temperature, the pressure with which the contacting elements are pressed against each other, the thickness of the surface oxide film and its electrical characteristics, etc. Therefore, the exact calculation of the patterns and limits of change in the values of *Rc*, *Lc*, *Cc* when contacting structural elements of moving objects is an extremely difficult task that does not lend itself to precise mathematical definition. The currently available analytical formulas for determining the values of *Rc*, *Lc*, *Cc* are obtained for idealized conditions for switching contacts with specified geometric shapes under a number of restrictions on the state of the surface, contact pressure of contacting elements, temperature and composition of the medium. The values of the components of the contact resistance of real variable contacts *Rc*, *Lc*, *Cc* of a moving object can take any values from extremely small to infinitely large. The complete equivalent circuit of the contact resistance is shown in Fig.1. At low frequencies, in the range of operation of electrical devices, low-frequency equipment for automation and telemechanic, the contact resistance module is determined mainly by the value of its active component, especially in the case of break contacts. At very high frequencies (of the order of hundreds of MHz), the capacitance of the transition zone shunts the active and inductive resistance. In the ranges from VLF to VHF, all components of the contact resistance must be taken into account.

The total resistance of the contact junction is calculated by the formula:

$$Z_C = \frac{R_C}{(1-\omega^2 R_C C_C)^2 + \omega^2 R^2{}_C C^2{}_C} + j\frac{\omega L_C(1-\omega^2 L_C C_C) - \omega R^2{}_C C_C}{(1-\omega^2 L_C C_C)^2 + \omega^2 R^2{}_C C^2{}_C} \qquad (4)$$

The analysis of the dependence of the total contact resistance on the voltage applied to it $Zc = f(U)$ shows that the active component of the contact resistance *Rc* is most susceptible to a nonlinear dependence. In particular, the nonlinear mode of variable contact refers to the arcing stage.

An equivalent circuit of the internal resistance of the elements of a contact pair can be represented as a series connection of linear active and inductive resistances:

$$Z_e = R_e + j\omega L_e \qquad (5)$$

The total resistance of a variable contact on moving objects depends on the following factors:

- from the degree of contact pressure, degree of contamination, condition of surfaces of contacting elements, electrical conductivity of the contact zone;
- from the flowing current and applied voltage;
- from mechanical influences: random and harmonic vibration, single and multiple impact, acoustic noise;
- from temperature in the contact zone and atmospheric pressure;
- from ambient humidity (corrosion formation).

In the general case, the total electrical resistance of an alternating contact can be represented in the form of a nonlinear parametric equivalent model.

In this case, the non-linear characteristic is determined by the dependence of the active and reactive components of the resistance on the voltage applied to the contact, as well as the influence of climatic factors (corrosion formation).

The parametric characteristic is determined by the influence of mechanical external factors in time on the contact, which leads to a change in time of the active and reactive components of the impedance of the alternating contact. When calculating the active electrical contact resistance, it is necessary to take into account the pressure forces of the contacting elements, the class of surface treatment of the contacting elements (the height of the microprotrusions of the contacting surfaces in μm), the applied voltage. For a more accurate determination of the actual (effective) contact area, it is necessary to take into account the probabilistic characteristics of the contacting surfaces, namely, the probability of the distribution of microprotrusions and microdepressions relative to the average level for a given class of processing of contacting surfaces.

To determine the coefficients of influence that make up the value of the total contact resistance, we use the calculation and analytical method [3]. According to this method, the coefficient of influence of the i-th parameter has the form

$$A_i = (\frac{\partial f}{\partial q_i}) \cdot (\frac{q_i}{f}) \quad (6)$$

For a linear-fractional function, the formula for determining the influence coefficients is obtained as follows. Let the expression for the output parameter look like

$$N = \frac{Q}{H} \quad (7)$$

Where: $Q = Q$ ($q1$, $q2\ldots$, qN); $H = H$ ($q1$, $q2\ldots$, qN) are polynomials for which the exponent of the i-th parameter can be greater than one. Then, using formula (6), we find the coefficient of influence of the i-th parameter

$$A_i = (H\frac{\partial Q}{\partial q_i} - Q\frac{\partial H}{\partial q_i}) \cdot \frac{\partial q_i}{HQ} \quad (8)$$

Suppose that the exponent of the parameter qi in the numerator of relation (7) is equal to m, in the denominator - n. Then, performing differentiation and the necessary elementary transformations, we obtain

$$A_i = \frac{mQ(q_i)}{Q} - \frac{nH(q_i)}{H} \quad (9)$$

Where: $Q(q_i)$ and $H(q_i)$ are parts of polynomials that contain the parameter q_i.

To determine the coefficients of the influence of the quantities R_c, L_c, C_c on the total contact resistance Z_k, we rewrite expression (4) so that the numerator and denominator contain polynomials

$$Z_c = \frac{R_c + j\omega L_c - j\omega^3 L^2{}_c C_c - j\omega R^2{}_c C_c}{1 + \omega^4 L^2{}_c C^2{}_c + \omega^2 R^2{}_c C^2{}_c - 2\omega_c{}^2 LC_c} \quad (10)$$

Then, using formula (9) for fractional rational functions, we obtain the following expressions for the influence coefficients:

$$A_{R_c} = \frac{R_c - 2j\omega R^2{}_c C_c}{R_c + j\omega L_c - j\omega^2 L^2{}_c C_c - j\omega R^2{}_c C_c} - \frac{2\omega^2 \mathrm{R}^2{}_\kappa C^2{}_\kappa}{1 - 2\omega^2 L_c C_c + \omega^4 L^2{}_c C^2{}_c + \omega^2 R^2{}_c C^2{}_c}; \quad (11)$$

$$A_{L_c} = \frac{j\omega L_c - 2j\omega^3 L^2{}_c C_c}{R_c + j\omega L_c - j\omega^3 L^2{}_c C_c - j\omega R^2{}_c C_c} - \frac{2\omega^4 L^2{}_c C^2{}_c - 2\omega^2 L_c C_c}{1 - 2\omega^2 L_c C_c + \omega^4 L^2{}_c C^2{}_c + \omega^2 R^2{}_c C^2{}_c}; \quad (12)$$

$$A_{C_c} = \frac{-j\omega R^2{}_c C_c - j\omega^3 L^2{}_c C_c}{R_c + j\omega L_c - j\omega^3 L^2{}_c C_c - j\omega R^2{}_c C_c} - \frac{2\omega^4 L^2{}_c C^2{}_c - 2\omega^2 L_c C_c + 2\omega^2 R^2{}_c C^2{}_c}{1 - 2\omega^2 L_c C_c + \omega^4 L^2{}_c C^2{}_c + \omega^2 R^2{}_c C^2{}_c}. \quad (13)$$

Since expressions (10) - (13) contain complex numbers, we will calculate the absolute values of their complex values. The calculation results in the range from 3 MHz to 300 MHz are shown in Table 1. It should be noted that $R_C(\omega)$, $L_C(\omega)$, $C_C(\omega)$ are functions of frequency. This means that when calculating the coefficients of influence for standard frequency ranges, it is necessary to substitute each time new values of R_c, L_c, C_c. They show that the impedance of the contact is most influenced by the active resistance, followed by the influence of the inductive component and the least influenced by the capacitive component [4,6].

Table 1. Coefficients of influence of the components of the contact resistance

Coefficients of influence of the components of the contact resistance		
A_{Rc}	A_{Lc}	A_{Cc}
0.965	0.0261	0.00233

III. Results

The dependences of the active and inductive resistance of the contact on the area of the contact surface at P = 50 N / mm^2 are shown in Fig. 2 and 3.

The dependences of the contact capacitive, active and inductive resistance on the signal frequency are shown in Fig. 4, 5 and 6.

The dependences of the active, inductive and capacitive resistances of the contacts on the contact pressure are shown in Fig. 7, 8 and 9.

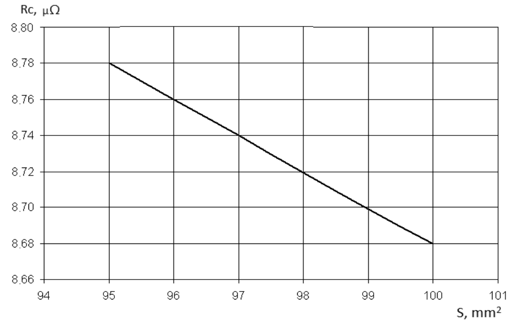

Fig. 2. Dependence of the active component of the contact resistance on the contact surface area at P = 50 N / mm^2.

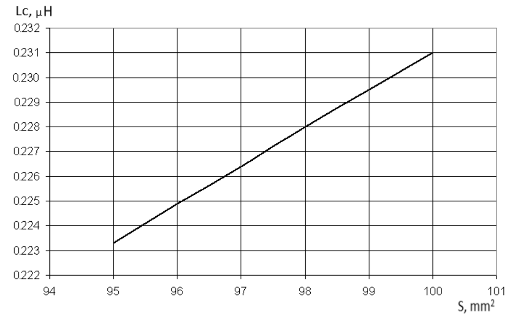

Fig. 3. Dependence of the inductive component of the contact resistance on the area of the contacting surface at P = 50 N / mm^2.

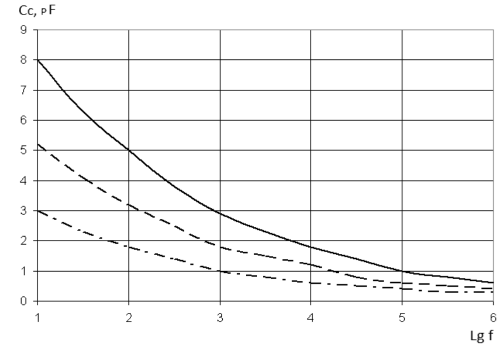

Fig. 4. Dependence of the contact capacitance on the signal frequency.

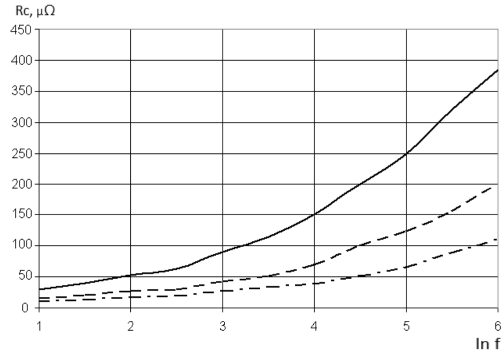

Fig. 5. Dependence of the active resistance of the contact on the signal frequency.

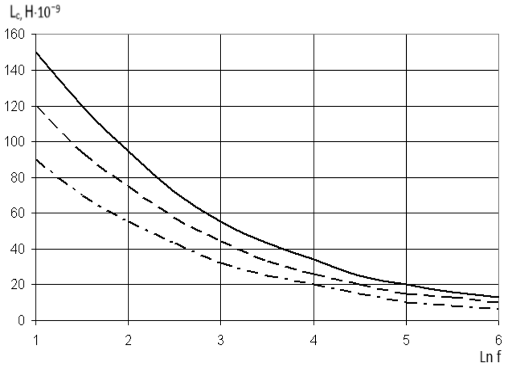

Fig.6. Dependence of the inductive resistance of the contact on the signal frequency.

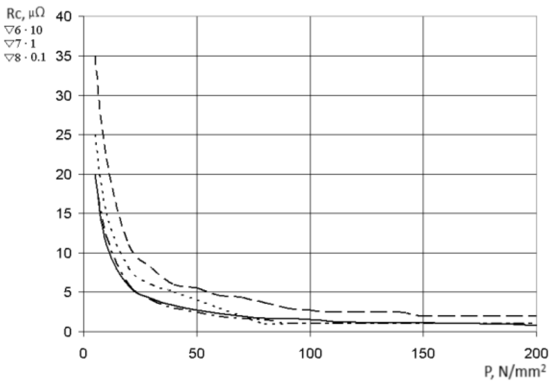

Fig.7. Dependence of the active resistance of the contact on the contact pressure.
__ ∇ - 8 Al; _ _ ∇ - 7 Al; --- ∇ - 6 Cd; _. _∇ - 6 Al

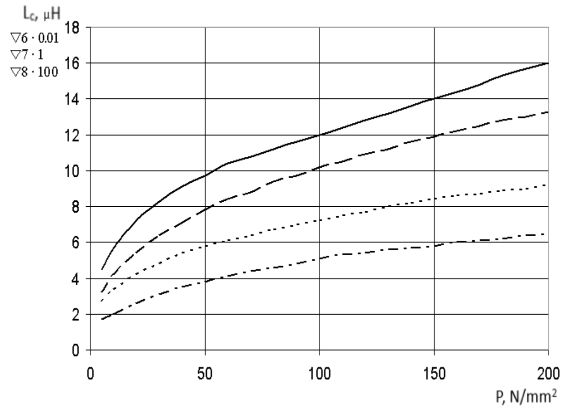

Fig.8. Dependence of the inductive resistance of the contact on the contact pressure.
__ ∇ - 6 Cd; _ _∇ - 7 Al; --- ∇ - 6 Al; _ _∇ - 8 Al

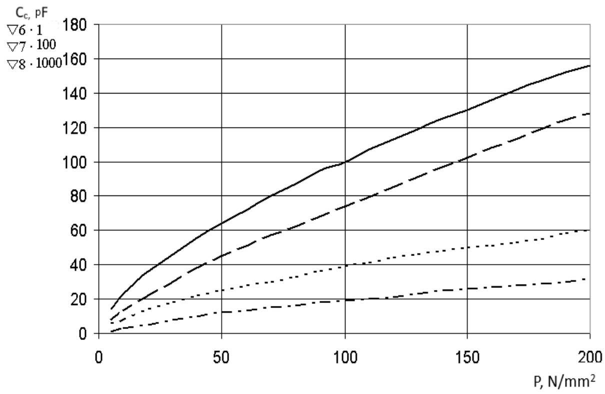

Fig. 9. Dependence of the capacitance of the contact on the contact pressure.
__ ∇ - 6 Cd; _ _∇ - 8 Al; --- ∇ - 6 Al; __ ∇ - 7 Al

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