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Track circuits adjusting calculation method under current influence traction interference and electromagnetic compatibility

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Abstract. The problem of railway transport electromagnetic compatibility automation systems in recent years has been aggravated by the use of power frequency converters in electric transport drives, which significantly increase the efficiency of traction characteristics of 3-phase electric engine. However, estimate relevant harmonic levels in the frequency range used in track circuits of railway automation and telemechanic systems. The paper provides theoretical justification for practical measurements of interference. It is shown, that the interference coefficients monotonically increase in the following cases: 1) increase in the value of the harmonic frequency; 2) increase in the propagation constant, taking into account the supports resistance of the contact network; 3) increase in the circuits track length. Operating frequencies of tonal track circuits up to 800 Hz, the interference increase rate in given length of the rail circuit slows down. The increase in interference coefficients depending on the mentioned factors is explained by the fact that with current part growth of the harmonic flows from the traction substation through the earth increases and thereby creates currents asymmetry of the track circuits.

1. Introduction

Recent years electromagnetic compatibility problem has become aggravated on Ukrainian railway network. One of the problem influence factors is use of power frequency converters in electric vehicles. These converters significantly increase traction characteristics efficiency of the 3-phase "dual power" electrical engine. However, these converters are one of sources of strong electromagnetic interference.

To change the power of electric drives traction the method of smooth sliding traction current frequency regulation in the range from infra-low frequencies to 50 Hz is used. Experience shows that with this method of power regulation a wide spectrum of harmonic components with relatively large amplitude is induced in the current traction. The induced harmonic oscillations amplitude can be comparable in level with the information tonal frequencies signals of the track circuits.

As a result, phase-sensitive track circuits receivers at frequencies of 25 Hz and 50 Hz can falsely record condition that violates railway automation safety and telemechanic system. Hence, it is advisable to create diagnostic devices in the track circuits or on-board devices of an electric locomotive, which



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will monitor the dangerous level of induced harmonics and exclude their effect on the track circuits. The current situation with interference forces developers to use more stringent requirements for the limit levels of harmonics and permissible values of the parameters of information signals. In this regard, it seems relevant to assess the levels of harmonics in the range of operating frequencies, which are used in the track circuits of railway automation and telemechanic systems. This is also important for the development of protective equipment against interference caused by the influence of current electric locomotive traction. As result, this leads to an adjustment of the calculating track circuits method. As result confirmed experimental studies theoretically obtained results which will be presented in the next article.

2. Problem Formulation

The well-known International Electrotechnical Commission decision No.77 of 1976 defines electromagnetic compatibility as the ability of devices to function correctly in a given electromagnetic environment without introducing excessive disturbances into this environment. It was also noted that the problem of higher harmonics is one of the most important problem of electricity quality components and electromagnetic compatibility.

Presence in the traction network dangerous interference higher harmonics track circuits at information frequencies creates an interfering effect on the operation of the track circuits of the railway automation system and the safety of train traffic.

The purpose of the Paper. In current article discussed methodology for calculating harmonics and compares them with the amplitudes of permissible levels in the current electric locomotive total traction.

3. Purpose and objectives

The purpose of research is to improve the methodology for calculating track circuits, taking into account the dangerous and interfering electromagnetic influence of the current traction. In the process of improving the methodology, various factors were taken into account. The schemes and track circuits configurations and reverse traction current sewerage schemes were analyzed. Additionally, other factors of signaling systems malfunctioning on certain sections of the railway during the operation of new types of rolling stock were considered.

4. Research results

It is known, that the biggest current reverse traction influence is exposed to the track circuits, to which traction substation suction feeder is connected. Figure 1 shows a diagram of the section between the electric locomotive and the traction substation with the designation of currents, voltages, conductivities, ground leakage currents and other elements that ensure the flow of traction currents. In particular, I_K is current in the contact drive and in the electric locomotive circuit; I_0, I_R, I_L – are currents at the point of connection of the feeder to the rail circuit, to the right and to the left of the traction substation; I_1, I_2 – currents, etc. Other parameters of the equivalent circuit: g_0 – supports conductivity connected to one rail; U_1, U_2 – rail-to-ground voltage, U_0, U_e – potentials at the point of drainage of electric locomotive currents and at the point of connection to the substation feeder; Z_p – rail resistance; Z_L, Z_R – input resistance of rails at the point of connection of an electric locomotive or electrical substation, respectively; M_{12} – rail mutual induction; M_{KP} – mutual induction between the electric locomotive and each rail; g_1, g_2 – rail-to-ground conductivity, respectively.

The methodology for track circuits asymmetry assessing considered in current paper is supplemented by calculations of the tonal spectrum harmonics. Additions of methodology were made taking into consideration resistance of the R65 rails and the voltage drop at these frequencies on the steel elements of the rail line (rail connectors, choke jumpers, etc.).

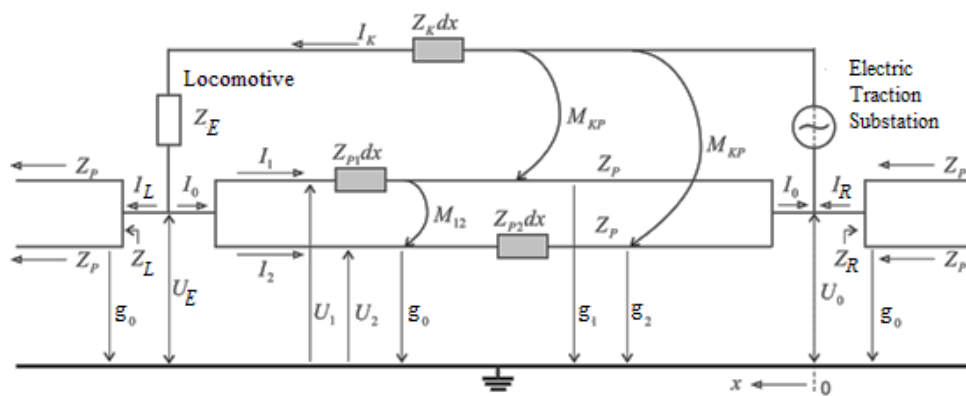


Figure 1. The equivalent circuit of the section between the electric locomotive and the traction substation.

Note that the equations given in [1] cover the main effects of the traction current and its harmonics on the equipment in the normal operation of track circuits under various climatic factors, but without taking into account the steel elements of the rail line. The equations take into account the interactions of three distributed circuits connected by mutual inductance: ‘first rail-to-ground’, ‘second rail-to-ground’ and ‘contact wire-to-ground’. In this case, each "rail-to-ground" circuit has a conductivity g_1 or g_2 and a specific impedance of the rails Z_p to a current with a harmonic frequency. Both circuits are connected by mutual inductance M_{12} and have a conductivity g_{12} along the surface of the sleepers. The ‘contact wire-ground’ circuit is connected to the rails by mutual inductance M_{KP} . The value of the current in the contact wire depends on the load of the electric locomotive and little depends on rail circuit parameters, therefore, in the calculations, the current I_K was set to a constant value.

The technique of calculating the asymmetry algebraically by equations is rather complicated and time consuming. Practical experience shows that the greatest asymmetry of the traction current harmonics in rail circuit is observed in winter when one of the track rails is used to ground the supports of the contact network with the difference $g_1 - g_2 \approx g_0$. Therefore, without significant loss of accuracy, the conductivity of one rail can be neglected. In practical calculations, it is possible to take the "rail-to-ground" conductivity equal to g_0 . Measurement statistics have shown that the value of g_0 remains very stable throughout the year. To further simplify, the calculations of two-strand track circuits, we assume that the load resistance is significantly less than the input resistance of the rail line. Therefore, it is possible to solve the problem of distribution of current in a rail line with a short circuit at the ends of the circuit (Figure 1).

It has been established that the critical insulation resistance R_{iKP} of a rail line, as shown by calculations of the control mode of tonal track circuits (which lengths are in the range from 0.25 to 1.5 km), can reach up to 1.8 Ohm·km. This value approaches the value of the insulation resistance of the rail line in winter conditions at the junction point of the contact network support and the rails. Below will be given levels assessment of harmonic currents affecting the track receivers of tone track circuits in the control mode.

From the calculated equivalent circuit (Figure 1) can be seen that the components of the current I_K , which flows in the contact wire between the electric locomotive and the substation, also flow through the grounding of the rail lines, which located to the left of the electric locomotive (I_L) and to the right of the traction substation (I_R).

Given accepted simplifications of rail circuit of length l , the boundary conditions can be expressed as follows:

$$I_K = I_0 + I_R \text{ at } x = 0 ; \tag{1}$$

$$I_K = I_e + I_L \text{ at } x=l, \quad I_R = \frac{U_0}{Z_R}, \quad I_L = \frac{U_1}{Z_L}; \quad (2)$$

where: Z_R and Z_L are the input impedances of the rail circuit with respect to the ground, to the right of the substation and to the left of the locomotive respectively.

The differential equations of the design circuit ('Helmholtz-type' scheme) with respect to the currents I_1 and I_2 are omitted. The integration constants in the known replacement equations, expressed through the value of the current I_K , after the transformations will be determined by the formulas:

$$A_1 = \frac{I_K}{P} \left(1 - 2 \frac{Z_{KP}}{Z_P + Z_M} \right) \left(\sinh(\gamma_0 l) + \frac{z_0}{Z_L} + \frac{z_0}{Z_R} \cosh(\gamma_0 l) \right), \quad (3)$$

$$B_1 = \frac{I_K}{P} \left(1 - 2 \frac{Z_{KP}}{Z_P + Z_M} \right) \left(\cosh(\gamma_0 l) - 1 + \frac{z_0}{Z_R} \sinh(\gamma_0 l) \right), \quad (4)$$

where: $\gamma_0 = \sqrt{g_0 Z_P}$ – signal propagation constant, $z_0 = \sqrt{\frac{Z_P}{g_0}}$ – characteristic impedance.

$$\begin{aligned} P = & \sinh(\gamma_0 l) + 2 \left(\frac{Z_P - Z_M}{Z_P + Z_M} \right) \cdot \left(\frac{\cosh(\gamma_0 l) - 1}{\gamma_0 l} \right) + \\ & + \left[\cosh(\gamma_0 l) + \left(\frac{Z_P - Z_M}{Z_P + Z_M} \right) \cdot \left(\frac{\sinh(\gamma_0 l)}{\gamma_0 l} \right) \right] \times \left[\frac{z_0 + z_0}{Z_L + Z_R} \right] + \\ & + \frac{z_0^2}{Z_L Z_R} \sinh(\gamma_0 l). \end{aligned} \quad (5)$$

The input impedance of a circuit Z_R , which has a length l_R , with the signal propagation constant of the supports γ_{0R} to the right of the substation is expressed by the equation:

$$Z_R = z_0 \frac{\cosh(\gamma_{0R} l_R) + \left(\frac{Z_P - Z_M}{Z_P + Z_M} \right) \cdot \left(\frac{\sinh(\gamma_{0R} l_R)}{\gamma_{0R} l_R} \right)}{\sinh(\gamma_{0R} l_R) + 2 \left(\frac{Z_P - Z_M}{Z_P + Z_M} \right) \cdot \left(\frac{\cosh(\gamma_{0R} l_R) - 1}{\gamma_{0R} l_R} \right)} \quad (6)$$

The input impedance to the left of the electric locomotive Z_L is expressed by the same equation, but taking into account the corresponding left circuit length and supports conductivity.

The asymmetry coefficient of the rail line according to the rails resistance for given harmonic at $x=l$ in the tonal track circuits between the substation and the electric locomotive, in the final form, is determined by formula:

$$K_o = \frac{1}{2P} \left(1 - 2 \frac{Z_{kp}}{Z_P + Z_m} \right) \left[\sinh(\gamma_0 l) - 2 \frac{\cosh(\gamma_0 l) - 1}{\gamma_0 l} + \frac{z_0}{Z_R} \left(1 - \frac{\sinh(\gamma_0 l)}{\gamma_0 l} \right) + \frac{z_0}{Z_L} \left(\cosh(\gamma_0 l) - 2 \frac{\sinh(\gamma_0 l)}{\gamma_0 l} \right) \right], \quad (7)$$

the coefficient of asymmetry of the rail line near the traction substation at $x=0$:

$$K_n = \frac{1}{2P} \left(1 - 2 \frac{Z_k}{Z_p + Z_m} \right) \left[\frac{\sinh(\gamma_0 l) - 2 \frac{\cosh(\gamma_0 l) - 1}{\gamma_0 l} + \frac{z_0}{Z_R} \left(1 - \frac{\sinh(\gamma_0 l)}{\gamma_0 l} \right) + \frac{z_0}{Z_R} \left(\cosh(\gamma_0 l) - 2 \frac{\sinh(\gamma_0 l)}{\gamma_0 l} \right) \right]. \quad (8)$$

In formulas (5) and (6) the coefficients and actually determine the asymmetry of the harmonic currents. The K_o coefficient refers to the track circuit that is connected to the traction substation feeder and is located between the electric locomotive and the traction substation. The K_o coefficient is expressed by the formula:

$$K_o = \frac{(I_2 - I_1)_o}{2I_k}. \quad (9)$$

The coefficient K_n characterizes the interference in the rail circuit, which is adjacent to the feeder on the opposite side of the electric locomotive. The K_n coefficient is determined by the formula:

$$K_n = \frac{(I_2 - I_1)_{oS}}{2I_k}. \quad (10)$$

In the rail circuit to the right of the electric substation, at the connection point of the suction feeder, the current difference, in its final form, is determined by the formula:

$$(I_2 - I_1)_{oS} = I_n \frac{\frac{\sinh(\gamma_{oR} l_R) - 2 \frac{Z_m}{Z_p + Z_m} \cdot \frac{\cosh(\gamma_{oR} l_R) - 1}{\gamma_{oR} l_R - 1}}{\sinh(\gamma_{oR} l_R) - 2 \frac{Z_p - Z_m}{Z_p + Z_m} \cdot \frac{\cosh(\gamma_{oR} l_R) - 1}{\gamma_{oR} l_R - 1}}}{1}. \quad (11)$$

where: I_n - total current in the track circuit to the right of the electric substation. In its final form, I_n is determined by the formula:

$$I_n = \frac{I_k}{P} \left(1 - 2 \frac{Z_k}{Z_p + Z_m} \right) \frac{z_0}{Z_R} \left(\cosh(\gamma_0 l) + \frac{z_0}{Z_R} \sinh(\gamma_0 l) \right). \quad (12)$$

5. Asymmetry calculated data analysis and interference from each harmonic of the current traction

The calculated data, which characterize the numerical harmonics values of the current traction in the normal mode, are presented in Figure 2 as the coefficients K_o and K_n . The calculations were carried out according to the methodology described in [1] for two-strand track circuits up to 1 km long. The maximum permissible value of the asymmetry coefficient of the reverse traction current in two-line track circuits of alternating current when using a choke-transformer DT-150 is 4% [9]. These coefficients represent the ratio of the half-difference of the harmonic currents at the ends of the rail circuit to the current of this harmonic in the contact wire.

Figure 2 shows the change in current I_k depending on the rail circuit length l , the harmonic frequency and the specific conductivity of the overhead contact network supports g_o . Thus, the coefficients show the proportion of the harmonic current in the overhead wire. The fraction of the current contained in the rail circuit at the maximum "rail-to-earth" insulation resistance, i.e. $g \rightarrow \min$, determines the interference in the rail circuit adjacent to the traction substation feeder on the side opposite to the electric locomotive.

Interference levels are calculated according to formulas (5)-(8) for each value of conductivity g_0 (0.25; 0.5; 1.0 Ohm·km), length of the rail circuit l (0.5; 0.8; 1.0 km) and conductivity $g_0 = 0.25 S$.

The parameters of rail lines are calculated at a temperature of 20°C and an earth conductivity $g_0 \rightarrow 95 S$. In this case, the maximum interference is observed, which is created by each harmonic.

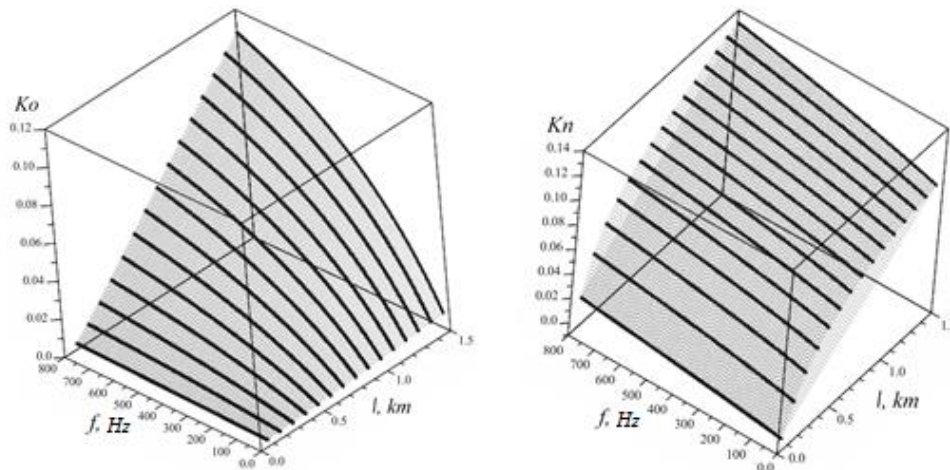


Figure 2. Variation dependences of K_o and K_n asymmetry coefficients on the frequency f and length l of the rail circuit at $g_0 = 0.25 S$

Figure 2 shows that the asymmetry coefficients increase monotonically: with an increase in the value of the harmonic frequency, with an increase in the propagation constant γ_0 , taking into account the supports of the contact network, and with an increase in the rail circuit length. At frequencies of tone track circuits up to 800 Hz, the rate of increase of the electrical interference for a given circuit length slows down. The growth of the interference coefficients depending on the above factors is explained by the fact that with an increase in γ_0 , that part of the harmonic current increases, which flows to the traction substation through the ground and creates an asymmetry of currents.

Coefficient K_o , other things being equal, is less in magnitude than coefficient K_n despite the fact that the current I_o flowing along the rails between the electric locomotive and the traction substation is greater than the current I_n entering the adjacent rail circuit from the traction substation feeder through the ground. This effect is explained by the phenomenon of current induction in the rails from the contact wire. This contributes to the equation of currents in the rail circuit.

Figure 3 shows the dependence of the change in the interference current on the frequency and length of the rail circuit for $g_0 = 0.25 S$.

It was found that on a double-track section with a symmetrical connection of the tracks to the suction feeder, the return current of electric locomotives from the substation, flowing in each of the four track

circuits adjacent to the feeder, is equal to
$$I_{Ke} = \frac{I_{mn}(\text{single track section})}{2} = \frac{I_{mn}(\text{double track section})}{4}.$$

On a single-track section, the estimated contact network current is half the current of the substation. Thus, the currents between the rail lines in each circuit remain the same, regardless of whether there is a second path of the calculated current flow in the contact wire or there is one path with the same currents. At the same time, as measurements show, it is enough to evaluate the effect of interference with two electric locomotives moving along the same path.

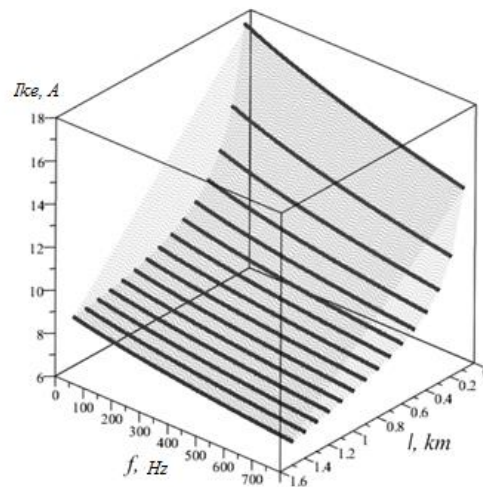


Figure 3. Dependences of the change in the interference current I_{ke} on the frequency f and length l of the rail circuit at $g_0 = 0.25 S$.

6. Conclusion

Analyzes main factors that characterize the electromagnetic influence of traction current on track circuits. In order to improve the methodology for determining the levels of hazardous interfering electromagnetic influence of the traction current, specific rail circuit diagrams, their configurations, various train situations under different conditions and operating modes of track circuits were analyzed.

The maximum permissible values of the traction current electromagnetic effect on the track circuits were determined both by theoretical calculation methods and by laboratory studies.

Experimental measurements of interference were carried out directly on railway sections, as well as in the power circuits of the rolling stock. As a basis for determining the maximum permissible levels of harmonic interference caused by reverse traction current, criteria of reliable operation of track circuits in all modes under the influence of the most unfavorable factors, according to safety conditions, were used.

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