ANALYSIS OF ELECTROMAGNETIC COMPATIBILITY OF TRACK CIRCUITS AND TRACTION POWER SUPPLY

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ABSTRACT

The issues of electromagnetic compatibility of traction power supply devices with track circuits are considered in case ice phenomena on the contact wire. The calculated ratios for determining the value of the bias currents of the choke-transformers in the electric arc, which arises from the formation of ice on the contact wire, as well as the reasons for false occupation of track circuits at the station are analyzed.

Keywords: *electromagnetic compatibility, track circuit, electric arc, asymmetry coefficient, traction current, contact wire, resistivity of rails.*

Background. *On sections of railways with AC electric traction, there are cases of false occupation of track circuits when icing of the contact wire. As a rule, they take place at stations and very rarely on hauls.*

False occupation occurs because of the influence of traction current on the equipment of track circuits and manifests itself when the train approaches the station input signal, when suddenly the permissive signal of the entrance traffic light overlaps the prohibitory indication before the train enters the destination route established for it. As a result, the driver can pass the prohibitive indication of the entrance traffic light, which is qualified by an event associated with violation of safety rules for movement and operation of the railway transport.

Objective. *The objective of the authors is to analyze electromagnetic compatibility of track circuits and traction power supply.*

Methods. *The authors use general scientific and engineering methods, comparative analysis, mathematical apparatus.*

Results. *We will conduct a detailed analysis of the causes of such failures in the operation of the signaling devices in the period of glacial phenomena on the contact wire. Pic. 1 shows the scheme of traction power supply of an electric locomotive including a traction substation TS, track circuits 1TC-3TC with choke-transformers ChT, to the secondary windings of which the equipment of the feeding end EFE of the track circuit and the equipment of the relay end ERE are connected. Pic. 1 also shows the scheme of current collection of an electric locomotive with electric locomotive traction equipment (ELTE) and traction currents i_T, i_{T1}, i_{T2}, flowing through the contact wire and along the rails, and $i_T = i_{T1}+i_{T2}$.*

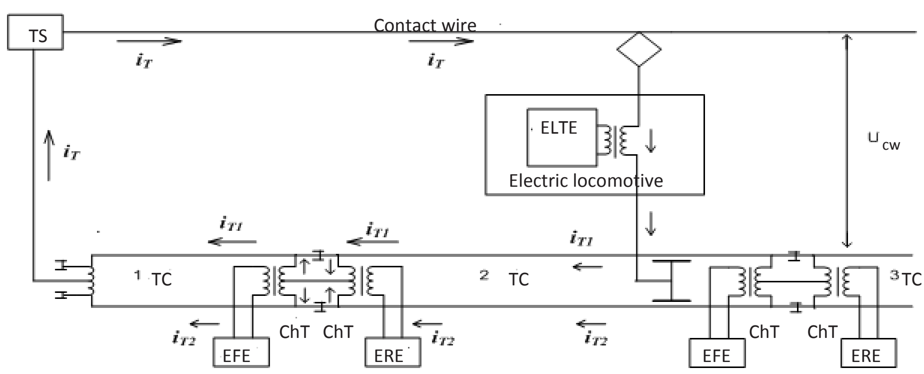
In the formation of ice on the contact wire between the pantograph slide of the electric locomotive and the contact wire, an electric arc arises [1]. To analyze the conditions for appearance of the arc, an electric circuit for replacing the traction power supply of an electric locomotive in the form shown in Pic. 2 can be used, where L is the equivalent inductance of the transformer of the traction substation TS and the electric locomotive transformer. Resistance of the contact wire and rails of the reverse traction network can be considered as an active value of r, since their inductance is many times less than the value L. The switch S will simulate the process of the electric locomotive entering the area with ice on the contact wire and, therefore, the transient process that causes the ignition of the electric arc, the voltage at which is denoted by U.

Pic. 3 shows an approximate piecewise linear approximation of the electric arc characteristic. As long as the voltage between the graphite insert of the current collector of the electric locomotive and the contact wire does not reach the value U_1, the arc does not burn and the electric circuit with the cut-off switch S (Pic. 2) is broken. When the arc voltage rises to U_1, the arc is ignited and the voltage U_2 is set on it. The decrease in voltage from the value U_1 to U_2 does not occur immediately, however, at a low frequency of the source U_{cw} equal to 50 Hz and with a simplified consideration of the problem without taking into account the inertia of the arc, this time can be neglected and it is assumed that immediately after ignition of the arc, the voltage U_2 is set on it. The voltage on the arc U_2 remains unchanged, until the moment when the current in the circuit passes through zero and the arc goes out. If the timing of the arc ignition is selected as the time reference point, the transient process in the electrical circuit of the scheme (Pic. 2) will be characterized by the following parameters:

$$U_{cw} = U_c \cdot \sin(\omega t+\alpha_v)-U_2, \quad (1)$$

where $\alpha_v = \arcsin(\frac{U_1}{U_c})$.

Pic. 1.



In this case, the current of the transient for i>0 can be represented as:

$$i=\frac{U_c}{z}\cdot\begin{bmatrix}\sin(\omega t+\alpha_v-\varphi)-\\ e^{-\frac{t}{\tau}}\cdot\sin(\alpha_v-\varphi)\end{bmatrix}-\frac{U_2}{r}(1-e^{-\frac{t}{\tau}}), \qquad (2)$$

where $\phi = arctg(\omega L/r)$, $z=\sqrt{(\omega L)^2+r^2}$, $\tau = L/r$.

Pic. 4 shows the graphs of dependence of voltage U_{cw} and the current i, as well as the voltage across the arc $U = \pm U_2$. As can be seen from the graph, the steady-state current mode i in the time interval from 0 to 1 is determined by the time-varying voltage U_{cw}, which does not reach the value U_1 and is described by the equation (2). The intervals of arc extinction between currents 1–2 and 3–4 depend on the parameters of the electrical circuit and can be reduced to zero, that is, the electric arc can burn continuously. The condition for continuous combustion in this case is the relationship between the voltages at point 1 (Pic. 4) when $U_3 \geq U_1$, which in turn depends on the amplitude value U_c on the contact wire and the inductance L.

For sufficiently large values of L and U_c, the arc can burn continuously. Let's consider the conditions under which this will occur.

If, for i = 0, the voltage $U = |U_3| \geq |-U_1|$, then the arc burns without interruptions, and points 1 and 2, 3 and 4 respectively merge into one. In this case, the steady-state mode will occur when the angle α_v changes and takes a certain largest value α_c.

The voltage of the source, at which the polarity of the arc current changes, will also increase to a certain value $U > |-U_1|$.

The value of α_c can be determined from the condition that the time between the moments of ignition of the arc and the passage of the current through zero is equal to half the period ϖ. In this case we will have:

$$\frac{U_c}{z}\left[\sin(\alpha_c-\varphi+\pi)-e^{-\frac{\pi}{\omega\cdot\tau}}\cdot\sin(\alpha_c-\varphi)\right]-$$

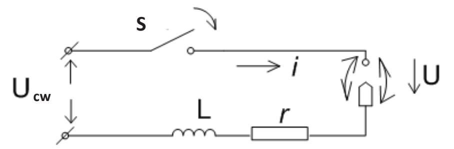
$$-\frac{U_2}{r}(1-e^{-\frac{\pi}{\omega\cdot\tau}})=0, \qquad (3)$$

hence:

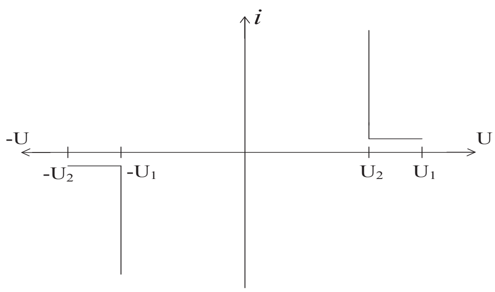
$$\alpha_c=\varphi-\arcsin\left(\frac{U_2\cdot z\cdot(1-e^{-\frac{\pi}{\omega\cdot\tau}})}{U_c\cdot r\cdot(1+e^{-\frac{\pi}{\omega\cdot\tau}})}\right). \qquad (4)$$

With the existing values of the inductance L and the voltage of the traction power grid, the arc burns continuously. However, the process of continuous combustion cannot cause a malfunction in the operation of the signaling devices, since the current i does not contain a constant component, and from the higher harmonic components of this current there is a sufficiently reliable protection based on the use of synchronous phase-sensitive receivers of the DSSh type [2], in which the track and local circuits are powered by different and independent power sources.

At the same time, it should be noted that the electric arc is accompanied by a powerful thermal process, which emits a huge amount of heat into the environment. The electric power output is on average from 50 to 100 kVA. Such energy is able to instantaneously melt ice in the vicinity of the current collector's panel and restore contact in the electric locomotive power system, that is, to extinguish the electric arc. After the extinction of the arc and the cooling of the elements of the electric locomotive's current collector, when it moves continuously, there is again run-over the ice on the contact wire and the ignition of the electric arc. Thus, during the movement of an electric locomotive, periodic switching-on and switching-off of the electric arc and the process of commutation of the alternating current with energy storage devices connected with these phenomena occur.



Pic. 2.



Pic. 3.

It is known that when sinusoidal voltage is switched on in an electrical circuit containing inductance L and the active resistance r (Pic. 2), a transient process is formed at which the current i will contain the forced i_f and the free component i_{fr}:

$$i = i_f + i_{fr}. \qquad (5)$$

At the same time i_f is determined from the expression:

$$i_f=\frac{U_c}{z}\sin(\omega t+\psi-\varphi), \qquad (6)$$

where $z=\sqrt{(\omega L)^2+r^2}$, $tg\varphi=\frac{\omega L}{r}$.

And the free current component i_{fr} can be calculated by the expression:

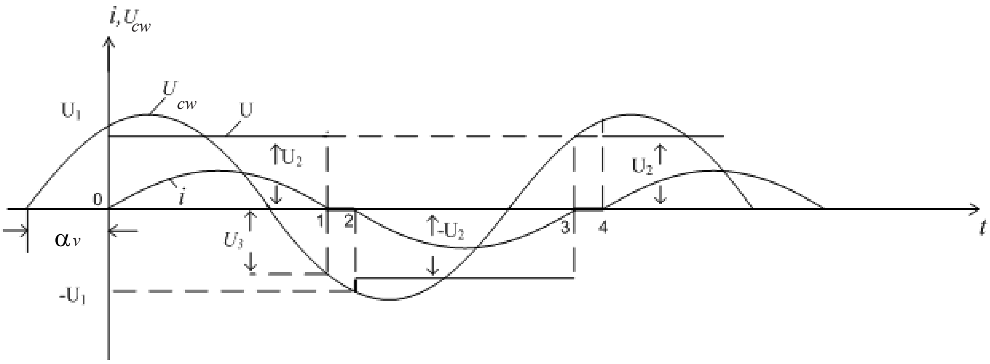
$$i_{fr}=-\frac{U_c}{z}\cdot\sin(\psi-\varphi)\cdot e^{-\frac{t}{\tau}}, \qquad (7)$$

where $\tau = L/r$, ψ – current value of the sinusoidal current phase.

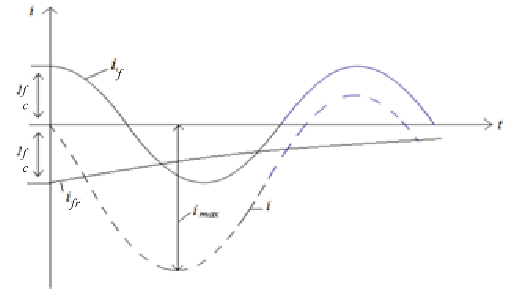
Given that the process of commutation of an electrical circuit occurs periodically with a certain period T, which in turn depends on a number of factors such as the thickness of the ice on the contact wire, the speed of the electric locomotive, the current consumed by the electric locomotive, etc., then in the alternating traction current of the electric locomotive a certain average value of the constant component of the current is formed:

$$I_{av}=\frac{1}{T}\int_0^T i_{fr}(t)dt. \qquad (8)$$

The average value I_{av} is a direct current that flows in the reverse traction network on a par with the variable traction current i_T. This current I_{av} passes through the traction windings of the choke-transformers ChT (see Pic. 1) and, in the presence of asymmetry in the track circuit, magnetizes the magnetic system of the choke-transformer, which



Pic. 4.



Pic. 5.

does not have an air gap [3, 4]. In this case, the working point of the ChT electromagnetic system shifts, and the system enters saturation, that is, the induction ceases to change under the influence of the signal current of the track circuit, which also flows through the winding of the choke-transformer, but has a frequency different from the frequency of the traction current. As a result of the process, the choke-transformer does not direct the EMF from the signal current to the additional winding where the track circuit equipment is connected, and the voltage on the track relays drops to the relay armature release voltage [5]. This leads to a false occupation of the track circuit. It should also be noted that the maximum value i_{max} of the transient current can be twice the amplitude of the forced current I^f_c (Pic. 5).

Conclusion. *In the currently operated track circuits with AC traction, the asymmetry of the track circuit is estimated from the variable traction current flowing through the traction winding of the choke-transformer. The established norms for asymmetry in variable traction current ensure stable operation of track circuits under operating conditions in the absence of ice on the contact wire. Icing of the contact wire leads to a change in the composition of the traction current, which appears along with alternating current of 50 Hz and direct current. And the asymmetry with respect to direct current can have completely different values in comparison with the controlled values on alternating current. This is because, for example, with longitudinal asymmetry of the track circuit, the specific resistance of the rails at a frequency of 50 Hz is 6–8 times higher than the resistivity at direct current. It should also be noted that it is not possible to control the asymmetry in direct current by the measuring instruments used in operation, and the procedure for measuring the asymmetry in direct current is not provided for in the schedule of technological maintenance of track circuits.*

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