CALCULATING OPTIMUM PARAMETERS FOR PIT LOCOMOTIVE RECEIVERS

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At the Institute of Mining of the Siberian Branch of the Academy of Sciences of the USSR an automatic control system has been developed for pit locomotive transportation with the rail network as control channel [1]. The frequencies of the monitoring and control signals lie in the range from 700 Hz to 10 kHz. Standard locomotive coils used in railroad transport are designed for fixed frequencies of 50 or 75 Hz and are unsuitable for working with a range of frequencies as used in the above system. In addition, the large size of standard locomotive coils (640 x 280 x 240) prevents their use in pit locomotives. It was thus necessary to study and choose a rational frequency range for transmitting signals via the rails and to develop a locomotive coil which can receive control signals in this frequency range, while not exceeding 350 x 100 x 100 mm in size so that it can be used on a pit locomotive.

A locomotive coil is a nonlinear multifactorial object with electrical parameters which depend on the number of turns in the winding, the width, length, and height of the core, the length of the winding, the diameter of the leads, the number of sections in the winding, the distance of the coil from the top of the rail, etc.

The method of mathematical programming requires a knowledge of the analytical equations determining the quality function. Several approximate methods of calculation are known [2, 3]. It has been found that if a rail network is fed with audio frequencies these methods are inapplicable owing to the nonlinear dependence of the emf fed to the receiver coil on the frequency of the current in the rails. The formulas given in [2, 3] assume a linear dependence of the emf on frequency, and can be used only from about 50 to 200 Hz. Let us consider the conditions for induction of an emf in a locomotive receiver coil.

The emf induced in the coil (Fig. 1) depends on the coupling \( \Phi \) and is given by

\[
E = 4\sqrt{\pi} f \Phi_{\text{max}},
\]

where \( K_f \) is the form factor of the current curve and \( f \) is the current frequency.

Let us find the coupling for a receiving coil with no core. In Fig. 1 the \( z \)-axis coincides with the axis of the conductor (rail) carrying the current. The coil, of length \( l_k \), height \( b_k \), and width \( a_k \), is located perpendicular to the \( z \)-axis at a distance \( h_k \) from it. We take the coil to be one-layer, wound with infinitely thin wire.

The coupling of an infinitesimal element of winding is

\[
d\psi_{\text{max}} = \Phi_{\text{max}} \frac{w}{l_k} dx.
\]

The current \( \Phi_{\text{max}} \) is

\[
\Phi_{\text{max}} = \int_{h_k}^{h_k+b_k} B_{\text{max}} a_k \cos \varphi \; dy,
\]

where $\phi$ is the angle between the induction vector and the normal to the plane of the elementary area, and $w$ is the number of turns.

In turn,

$$H_{\text{max}} = \frac{\sqrt{2} I}{2\pi r},$$

where $r$ is the distance from the element of winding to the axis of the current-carrying conductor.

On substitution we get

$$d \psi_{\text{max}} = \frac{2\sqrt{2} I a_k \cos \phi \cdot 10^{-7}}{r l_k} \, dx \, dy.$$

Expressing $\cos \phi$ and $r$ in terms of the local rectangular coordinates, the coupling is

$$\psi_{\text{max}} = 2 \int_0^{l_k/2} \int_{h_k}^{h_k+b_k} \frac{2\sqrt{2} \, a_k l \, w \cdot 10^{-7}}{l_k(x^2 + y^2)} \, dy \, dx.$$

Integrating (7) we get

$$\psi_{\text{max}} = \sqrt{2} \, a_k I w \cdot 10^{-7} \left\{ \ln \frac{4(h_k + b_k)^2 + l_k^2}{4h_k^2 + l_k^2} + \frac{4}{l_k} \left[ (h_k + b_k) \arctg \frac{l_k}{2(h_k + b_k)} - h_k \arctg \frac{I_k}{2h_k} \right] \right\}.$$

Putting (8) into (1), we get a formula for the emf in a one-layer coil of rectangular cross section induced by a current in a rectilinear conductor (see Fig. 1):

$$E = 4\sqrt{2} \, a_k I w \cdot 10^{-7} \left\{ \ln \frac{4(h_k + b_k)^2 + l_k^2}{4h_k^2 + l_k^2} + \frac{4}{l_k} \left[ (h_k + b_k) \arctg \frac{l_k}{2(h_k + b_k)} - h_k \arctg \frac{I_k}{2h_k} \right] \right\}.$$

If the coil is asymmetrically disposed relative to the conductor (rail), we must consider a coil with length $l_k$ as two dissimilar half-coils with lengths $l_k-x$ and $x$. In this case (9) becomes

$$E = 2 \sqrt{2} \, K_f f a_k I w \cdot 10^{-7} \left\{ \ln \frac{4(h_k + b_k)^2 + (l_k-x)^2}{h_k^2 + (l_k-x)^2} + \frac{2}{l_k-x} \left[ (h_k + b_k) \arctg \frac{l_k-x}{h_k+b_k} - h_k \arctg \frac{l_k-x}{h_k} \right] + \left( \arctan \frac{h_k+b_k}{h_k+x} + \frac{2}{x} \left[ (h_k + b_k) \arctg \frac{x}{h_k+b_k} - h_k \arctg \frac{x}{h_k} \right] \right) \right\}.$$

A real receiving coil is about 0.2 m from the rail axis; the gradient of $E$ is of order $1.2 \cdot 10^{-4}$ V/cm, and the thickness of a multilayer receiver coil with dimensions $a_k$ and $b_k$ makes a ratio

$$\frac{a_k}{b} \gg 10 \ll \frac{b_k}{b}.$$

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