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T. M. Serdiuk – Candidate of Technical Sciences, Associate Prof., Dnipropetrovsk National University of Railway Transport named after acad. V. Lazarian Dnipropetrovsk, Ukraine, serducheck-t@rambler.ru

AUTOMATED MEASUREMENT OF PARAMETERS OF TRACK CIRCUITS

Introduction

The code track circuits are the basic detectors supervising a situation of trains on railway sections – free or occupancy of blocks - sections, integrity of rails, and also carry out functions of the channel of transfer of codes automatic locomotive signal system from track-devices to the locomotive. Thus, the track circuits are a primary element directly determining safety of trains' movement [1, 2].

The investigation of spectrum of traction current is necessary to carry out in pause of code at the using of method, which is assumed to measure with the help of special device of car-laboratory "Automatics, telemechanics and communication". In given case it was carried out by the record of signal from one or two inductive coil of locomotive, which moved on the railway section. In result we able us a possibility to determine as the parameters of code current, flowing in rails and spectrum composition of return traction current, as the parameters of track circuits.

To improve method of automated measurement parameters of track circuits and harmonics of return traction current it is necessary to elaborate mathematic model of traction net. It is allowed to take into account different sources of electromagnetic influences. Most perspective from other method is automated measurement method on the base of car-laboratory because it will allow us to proceed from scheduled preventive maintenance to repair on a status of object and to reduce number or staff and to raise safety of movement of trains.

So, the development of automated method of measurement parameters of track circuits and harmonics of return traction current from car-laboratory is an actual. To solve of this task it is necessary to develop of mathematic model of track circuit, which was worked in mode of occupancy by train (mode of automatic locomotive signalling (ALS)), to improve the formula of electromotive force (EMF) of inductive coils of locomotive, to create algorithms of determining of the track circuit serviceability and parameters of code current.

Mathematic model of track circuit in mode of ALS

It is known, that the principle of work of automatic locomotive signalling system and automatic block systems is based on the transfer of the codes to the locomotive and receiving apparatuses of track circuit. It is used 50 Hz frequency of code current at the d. c. electrical traction, 25 and 75 Hz – at the a. c. electrical traction [3 – 5].

The equipment of car-laboratory uses for the definition parameters of code current in rails during measurement travel two times in year usually. The experimental data can be given with the help of special elaborated measuring system [6, 7], based in the car-laboratory for the control of parameters of code current. So there is a continuous communication between track and locomotive devices in the ALS system. The coils are situated before first wheel pair of locomotive and connect inductively with the current in rails, by the means of a magnetic field, series and towards each other (fig. 1). Magnetic field is formed around of rails by the alternating code current. Thus, there is a separate channel of communication within the limits of each track circuit.

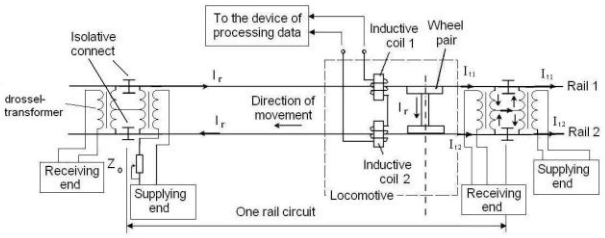

Fig. 1. Structure scheme of data transferring canal to the locomotive

For the definition of parameters of track circuit we used the equivalent scheme, given on the fig. 2. This scheme includes supplying end, rail lines and receiving end, each from which are four-poles accordingly. Four-poles of supplying and receiving end include intermediate and protective apparatuses, and four-pole of rail lines consist of only rails, connected with the help of electrical connections.

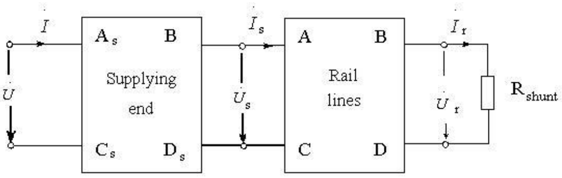

Fig. 2. Equivalent scheme of rail circuits at the present train shunt on the receiving end

According with the theory of four-poles write system of equation of voltage and current in the begin of rail circuit:

$$\begin{cases} \dot{U}_s = A_{\text{sh}} \cdot \dot{U}_r + B_{\text{sh}} \cdot \dot{I}_r \\ \dot{I}_s = C_{\text{sh}} \cdot \dot{U}_r + D_{\text{sh}} \cdot \dot{I}_r \end{cases}, \tag{1}$$

where $\dot{U}_s$, $\dot{I}_s$ – voltage and current in the begin of rail circuits (supplying end), $\dot{U}_r$, $\dot{I}_r$ – voltage and current in the end of rail circuits (in the point of putting train shunt), $A_{\text{sh}}, B_{\text{sh}}$, C_{sh}, D_{sh} – coefficients of rails four-poles in the regime of automatic locomotive signalling.

Coefficients of rails four-poles in the regime of automatic locomotive signalling are equal:

$$A_{\text{sh}} = 1 + \frac{\bar{Z}}{R_{\text{sh}}},\ B_{\text{sh}} = \bar{Z},$$

$$C_{\text{sh}} = \frac{1}{R_{\text{sh}}},\ D_{\text{sh}} = 1, \tag{2}$$

where $\bar{Z} = \bar{z} \cdot l$ – resistance of rail line, Ohm, $\bar{z}$ – specific resistance of rail lines, Ohm/km, l – distance between supplying end and locomotive, km, R_{sh} – resistance of train shunt, $R_{\text{sh}} = 0,06$ Ohm.

Carrying out some mathematical transformation we can get, taking into account that voltage on the more removed end of rail circuit from generator is $\dot{U}_r = \dot{I}_r \cdot R_{\text{sh}}$

$$\begin{cases} \dot{U}_s = \left(1 + \frac{\bar{Z}}{R_{\text{sh}}}\right) \cdot \dot{I}_r \cdot R_{\text{sh}} + \bar{Z} \cdot \dot{I}_r \\ \dot{I}_s = \frac{1}{R_{\text{sh}}} \cdot \dot{I}_r \cdot R_{\text{sh}} + \dot{I}_r \end{cases},$$

$$\begin{cases} \dot{U}_s = \left(R_{\text{sh}} + \bar{Z}\right) \cdot \dot{I}_r + \bar{Z} \cdot \dot{I}_r \\ \dot{I}_s = 2\dot{I}_r \end{cases}. \tag{3}$$

So knowing value of current in the begin and end of rail circuit and voltage on the outputs of generator, which should be equal minimal voltage of way's transformer $\dot{U}_s = \dot{U}_{\min}$ and can be taken from regulative tables [4], we are allowed to define resistance of rail lines

$$\bar{Z} = \frac{\dot{U}_{\min} - \dot{I}_r \cdot R_{\text{sh}}}{2 \cdot \dot{I}_r}. \tag{4}$$

Let's determine secondary parameters of rail circuits. It is known that the coefficients of rail four-poles define with the help of secondary parameters of rail circuits [3]:

$$A = D = \text{ch}(\gamma l),\ B = \bar{Z}_v \cdot \text{sh}(\gamma l),$$

$$C = \frac{\text{sh}(\gamma l)}{\bar{Z}_v}, \tag{5}$$

where $\bar{Z}_v$ – wave resistance of rail lines, Ohm, γ – coefficient of distribution of a wave, 1/km, l – length of rail circuits, km.

We will have at the putting of train shunt on the receiving end $A = A_{sh}$, $B = B_{sh}$, $C = C_{sh}$, $D = D_{sh}$.

Then

$$\bar{Z} = \bar{Z}_v \cdot \mathrm{sh}(\gamma l),\ \frac{1}{R_{sh}} = \frac{\mathrm{sh}(\gamma l)}{\bar{Z}_v},$$

$$\mathrm{sh}(\gamma l) = \frac{\bar{Z}_v}{R_{sh}}. \quad (6)$$

And wave resistance of rail lines and coefficient of wave distribution are equal

$$\bar{Z}_v = \sqrt{\bar{Z} \cdot R_{sh}}, \quad (7)$$

$$\gamma = \frac{\mathrm{arcsh}\left(\sqrt{\bar{Z}_v R_{sh}}\right)}{l}. \quad (8)$$

The wave resistance connects with the primary parameters of rail circuits as follows [3]

$$\bar{Z}_v = \sqrt{\bar{z} \cdot R_{is}}, \quad (9)$$

where R_{is} – equivalent resistance of isolation of rail line and grounding of supports of catenary, Ohm×km.

Thus, the resistance of isolation of rail line can be defined as

$$R_{is} = \frac{\bar{Z}_v^{\,2}}{\bar{z}}. \quad (10)$$

So, knowing the value of current in the begin and end of rail circuits in the results of measurements with the help of equipment, established in the car-laboratory, and taking value of generator's voltage from regulation tables we can define primary and secondary parameters of rail circuits

Electromotive force in inductive coils of locomotive

To ensure the accuracy of control a large number of defined parameters, it is necessary to analyse the processes occurring during the transmission of information to the receiving coils of a wagon laboratory. For this purpose, we developed a mathematical description of electromagnetic processes in the interaction of the current in the rails with the receiving coils. Schematic representation of the system is shown in fig. 1.

The code current I_r from generator (supplying end, as given in fig. 1) passes through the rails and interacts with the inductive coils 1 and 2 with opposite connection, spaced at l_0 from the first wheel set of a rolling stock. The induced EMF in the coils of the total is the sum of the EMF in each coil $\dot{E} = \dot{E}_1 + \dot{E}_2$.

In the simulation of electromagnetic processes let us replace the rail by equivalent circular conductor of infinite length. The sinusoidal code current $i = I_m \cdot \sin(\omega t + \varphi)$ runs to the selected positive direction coinciding with the direction of the axis z. To determine the magnetic induction and magnetic flux penetrating receptors ALS we use vector-potential of the magnetic field $\bar{A}$. The direction of this vector coincides with the direction of the current in the conductor. Vector-potential has the following relationship with the magnetic induction and magnetic flux.

$$\bar{B} = \mathrm{rot}\,\bar{A}, \quad (11)$$

where $\bar{B}$ is the magnetic induction vector, S is surface area traversed by the magnetic flux, $\bar{\Phi}$ is the magnetic flux.

$$\bar{\Phi} = \int_S \bar{B}\,d\bar{S} = \int_S \mathrm{rot}\,\bar{A}\,d\bar{S} = \oint \bar{A}\,d\bar{l}. \quad (12)$$

The magnitude and direction of the vector-potential is dependent on the current i, flowing in the conductor of $d\bar{l}$ length and from the Poisson equation is [8]

$$\bar{A} = \frac{\mu \cdot \mu_0 \cdot i \cdot d\bar{l}}{4 \cdot \pi \cdot R}, \quad (13)$$

where μ is the magnetic permeability of the medium (steel core), μ_0 is the magnetic constant, R is the distance between the radiating conductor and a point in space.

In an alternating magnetic field, taking into account the effect of the delay wave, which is essential in the transmission of the signal at high frequencies (for example in the case of tonal track circuits), we write the vector potential as

$$\overline{A} = \frac{\mu \cdot \mu_0 \cdot i\left(t - \frac{R}{v}\right) \cdot d\overline{l}}{4 \cdot \pi \cdot R}, \qquad (14)$$

where v is the wave propagation speed, m/s.

In the vector from the vector potential is as follows:

$$\dot{\overline{A}} = \frac{\mu \cdot \mu_0 \cdot I_m \cdot e^{j \cdot \omega \cdot \left(-\frac{R}{v}\right)} \cdot d\overline{l}}{4 \cdot \pi \cdot R}. \qquad (15)$$

To determine the magnetic induction vector we use a cylindrical coordinate system. We write the dependence $\overline{B}\left(\overline{A}\right)$ in complex form. In general, it has the form

$$\dot{\overline{B}} = \operatorname{rot} \dot{\overline{A}} = \overline{r}^0 \cdot \left(\frac{\partial \dot{A}_z}{r \partial \alpha} - \frac{\partial \dot{A}_\alpha}{\partial z} \right) + \\ + \overline{\alpha}^0 \cdot \left(\frac{\partial \dot{A}_r}{\partial z} - \frac{\partial \dot{A}_z}{\partial r} \right) + \\ + \overline{z}^0 \cdot \left(\frac{\partial \left(r \dot{A}_\alpha \right)}{\partial r} - \frac{\partial \dot{A}_z}{r \partial \alpha} \right). \qquad (16)$$

As the vector-potential has only z-component $\dot{A}_z$, and $\frac{\partial R}{\partial r} = \frac{r}{R} = \sin\theta$, then

$$\dot{\overline{B}} = -\overline{\alpha}^0 \cdot \frac{\partial \dot{\overline{A}}_z}{\partial r} = -\frac{\partial \dot{\overline{A}}_z}{\partial R} \cdot \frac{\partial R}{\partial r} = \\ = \frac{\mu \cdot \mu_0 \cdot I_m d\overline{l} \cdot \sin\theta}{4 \cdot \pi} \times \\ \times \left[\frac{e^{j \cdot \omega \cdot \left(\frac{R}{v}\right)}}{R^2} + \frac{j \cdot \omega \cdot e^{j \cdot \omega \cdot \left(\frac{R}{v}\right)}}{R \cdot v} \right], \qquad (17)$$

where r is projection of R to the z-surface.

For an infinitely long conductor (the rail line), the magnetic field at a distance R from the source (where $r = R$, $\sin\theta = 1$)

$$B(t) = \frac{\mu \cdot \mu_0 \cdot I_m}{2 \cdot \pi} \times \left[\frac{\sin\left(\omega t - \frac{\omega R}{v}\right)}{R} + \right. \\ \left. + \frac{\omega}{v} \cos\left(\omega t - \frac{\omega R}{v}\right) \right]. \qquad (18)$$

In accordance with the law of electromagnetic induction electromotive force induced in the receiving coil ALS is

$$E(t) = -\frac{W_в \cdot d\Phi}{dt} = -\frac{\mu \cdot \mu_0 \cdot I_m \cdot d^2}{2 \cdot \pi} \times \\ \times \left[\frac{\cos\left(\omega t - \frac{\omega R}{v}\right) \cdot \omega}{R} - \right. \\ \left. - \frac{\sin\left(\omega t - \frac{\omega R}{v}\right) \cdot \omega^2}{v} \right]. \qquad (19)$$

where $W_в$ is the number of coil turns, d is the side of square core cross-section of the locomotive coils.

Below we show the simulation results in the electromotive force depending on the distance of the coil over the head of the rail. As well as the results of the measured voltage in the coils of locomotive signalling wagon laboratory provided by the manufacturer (fig. 3). Relative measurement error was ± 3,5 %.

Thus, we have obtained the equation of EMF induced in the coils of ALS, which takes into account the wave delay effect, which occurs in tonal rail circuits of high frequency and high-frequency noise. The resulting relationship between the current ALS and EMF can be used to determine the parameters of the code current by using the proposed hardware and software measuring complex, in which sensors are information locomotive coils.

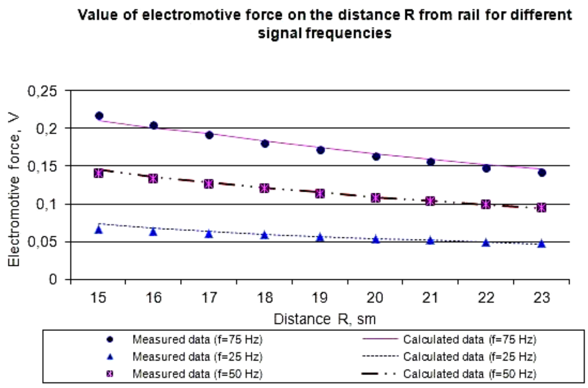

Fig. 3. Dependencies of the electromotive force at a distance R from the rail for different signal frequencies

Method of measurement. The algorithms of determining of track circuit serviceability and parameters of code current

The designed hardware and software measurement system can record the signal from the output of the filter of the ALS system, as required by the instructions for maintenance of signalling, centralization and blocking devices [1], and the outputs of the receiving coils. Signal recorded by the receiving coils of ALS, is the amount of code signals from ALS and traction current with all its harmonics, and transients that occur during operation of the locomotive. And therefore, this device allows us to analyse not only the temporal and amplitude parameters of codes of ALS, but also assess the impact of noise on the automation systems and analytically determine their cause.

It is proposed to use following method for the definition of parameters of track circuit from car-laboratory. The technique of control of the parameters of track circuits from car-laboratory includes measurements, which performed by two electromechanics. It is necessary to calibrate the apparatuses of car-laboratory on the base of real track circuit before measurement. It is important that track circuit work in mode of occupying by rolling stock. Thus it checks the conformity of results of measurement, carried out by the developed apparatuses, to data was given directly in the track circuit at the measurement of code current. Next step is the definition of original data of investigated section: or station, the name of railway section, length and type of TC, the sampling frequency settings and the quantization step, which used at the analog-to-digital conversion of the signal. Developed apparatuses is established in car-laboratory and it is described in [6, 7]. Further actions of operator-electromechanic are the observations of work of equipment. Reading the data from the inductive coils and checking of parameters of TC and code current is carrying out automatically. At the same time The monitoring of levels and spectral composition of current in rail lines are done to identify their and to remove the reasons of their appearance. According to the results of control of parameters of track circuits is created a database that allows us to automate the process of finding of TC with faults and predict their causes.

As a result, the number of parameters controlled from car-laboratory, equipped with the developed hardware and software apparatuses, expands. The method of measurement parameters track circuits is proposed in [6, 7]. It is based on the comparison a measuring data with the theoretical characteristics, corresponding normalized functioning of TC. As a result, the time spent on the control parameters of TC will be reduced, the working conditions of personnel will be facilitated l and the subjectivity in the measurement will be excluded.

In determining the types of code signals received from the track circuits, we solve such problems: measurement of the pulse duration and pause with the exception of sags and surges of a signal; selection of the type of code by the pulse duration and pauses; determining the type of the code received from the track circuit and the type of the code track transmitter; definition of amplitude and time parameters of the code signal.

To solve the first problem were taken signatures of pulses and pauses when a signal with an amplitude greater than or equal to $0,6U_n$ for at least 0,2 s is recognized as a useful signal, and the signal with an amplitude of less than or equal to $0,4U_{\text{n}}$ for at least 0.1 s – as the pause. The value $0,6U_{\text{n}}$ is the minimum value that will be recognized as a useful signal when the system is the automatic locomotive signalling. To calculate the duration of pulses and pauses the software timers are used. Algorithm for determining the duration of the pulses and pauses is shown in fig. 4.

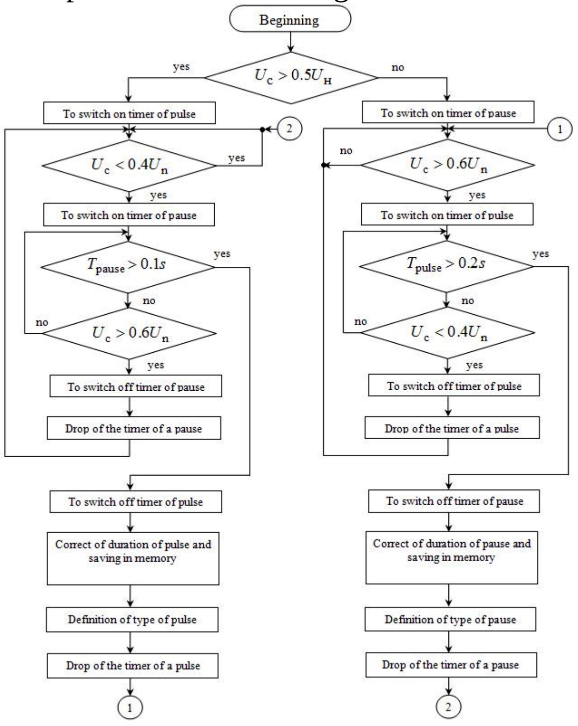

Fig. 4. Algorithm for determining the duration of the pulses and pauses

In addition to determining the duration of the pulses and pauses, also their adjustments are made, designed to prevent a momentary signal. For example, if short-term loss of signal during the determination of the pulse duration the pause timer can start. If a signal for 0,1 seconds is not recovered, the pause counting continues, but as the pulse timer has not been disabled, then after stop the pulse timer the pulse correction is carried out (the subtraction of the pulse duration by 0,1 s). A similar process is organized during the determination of the pause in the event of a pulse.

To solve the second problem and determine the type of message frame and code track transmitter (CTT) all pauses and pulses were divided into certain types listed in table 1. The sequence of pulses and pauses that make up a particular type of code, and the appropriate code for the type of CTT is shown in table 2.

Table 1

Types pulse and pause of code

Types of pause	Duration, s	Types of impulse	Duration, s
P1	0,12 ± 0,02	I1	0,22 ± 0,02
P2	0,57 ± 0,02	I2	0,3 ± 0,02
P3	0,63 ± 0,02	I3	0,35…0,38 ± 0,02
P4	0,72 ± 0,02	I4	0,6 ± 0,02
P5	0,79 ± 0,02	I5	Distorted pulse
P6	More than 0,85	I6	More than 0,75 – continuous signal
P7	Distorted pause		

Table 2

Combination of impulses and pauses of codes

Type of code track transmitter – KPTSH-5		Type of code track transmitter – KPTSH-7	
Type of code	Combination of impulses and pauses	Type of code	Combination of impulses and pauses
Red-yellow	I1-P2-I1-P2	Red-yellow	I2-P3-I2-P3
Yellow	I3-P1-I3-P4	Yellow	I3-P1-I4-P5
Green	I3-P1-I1-P1-I1-P2	Green	I3-P1-I1-P1-I1-P5

To solve the third problem, and determine compliance with the requirements of the decrypted code signal amplitude was also been developed appropriate software. Automated measurement hardware and software package calculates the duration of the pulses and pauses in the message frame and therefore can determine what type of code track transmitter is used in this track circuit. It is known that, when a stage is equipped with automatic lockhaul code system, each signalling point is an alternation of code track transmitters, which allows for protection against dangerous failures on short-circuit block joints separating the track circuits. Therefore, it is possible by changing one code track transmitter by another one to determine the location of insulation junction.

For validation of the coordinates of the insulation junction we need to check for compliance with the calculated length l_{TC_i} of the i-th track circuit with an error of 3 % to the actual value. Coincidence of the real and the measured length matches the TC working condition of isolating joints, different – is faulty. Data correction means specification of the measured TC length in mind that the type of CTT is determined only after deciphering code of three parcels from one type of CTT. Therefore, the length of the track circuit is subtracted the measured distance traveled by the train during the decoding of the three code packages. Algorithm for computing the length of RC and definition isolating joints fault is shown in fig. 5.

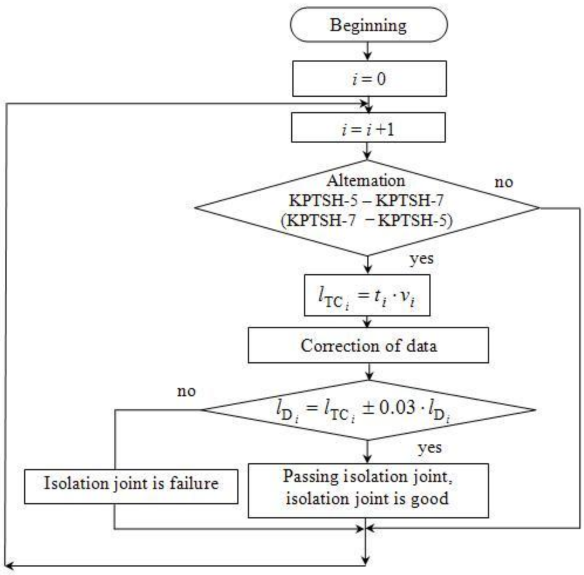

Fig. 5. Algorithm for determining the length of the track circuit and serviceability of block joints

Algorithm for checking the status of the track circuit involves determining the state of the track circuit and it is carried out on the current curve of the locomotive signalling $I(x)_{\text{meas}}$ depending on the coordinates obtained from the measurements. Evaluation is done by comparing the measured code current curve $I(x)_{\text{meas}}$ of ALS with calculated $I(x)$ at nominal operating conditions of the track circuit (for example, the resistance of the rails $Z1 = Z2 = 0,8e^{65j}$ Ohm/km with welded copper connectors, the frequency of the current signal of 50 Hz, the conductivity of insulation $Y1 = Y2 = 0,5$ S/km) and given its length. Appearance of break points of the first kind in the current curve $I(x)_{\text{meas}}$ of locomotive signalling indicates an open rail connectors at this point. Underestimated the value of ALS current $I(x)_{\text{meas}}$ compared with the calculated value indicates an undervalued ballast resistance.

After measurements are made on this stretch data are processed. As a result, databases are created that allow you to view the results of measuring the current of locomotive signalling along the length of each track circuit studied (its amplitude and timing), the shape of the ALS current curve and other parameters determined during the measurement of the trip. It also creates a database, which indicates the number of track circuits, which revealed the following variations: the amplitude at the beginning of the TC is below the minimum value, the length of time parameters of the code does not conform underestimated the resistance of the ballast, open electrical connectors.

Conclusions and acknowledgments

As a result, the develop hardware-software apparatuses allows you to define by the EMF induced in the two receiving coils separately, the following quantities: the magnitude of the code current for the entire length of the track circuit, the duration of the pulses and pauses for all parcels of code, determine the type of code signal and the type of code track transmitter, coordinate, the length of the TC, serviceability of insulating junctions and electrical connectors. The results of measurements of EMF induced in each of the receiving coils apart, the spectral composition of the noise occurring in the traction network, and harmonic amplitude and impulse noise, the causes of noise in the rail network can be revealed.

The test of offered measuring apparatuses were executed on the Pridneprovsky railway.

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Ключові слова: рейкове коло, параметри кодового струму, параметри рейкового кола, електрорушійна сила.

Ключевые слова: рельсовая цепь, параметры кодового тока, параметры рельсовой цепи, электродвижущая сила.

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