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Improvement of technical service of track circuits

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***Abstract*—The automated method of measuring the time and amplitude parameters of code current and parameters of track circuits (input impedance of the track circuit, a characteristic impedance, a propagation constant) were elaborated. The mathematic model of track circuits' channel of transferring code current was improved and considered in this paper. The algorithms of definition of parameters of track circuit are offered.**

***Keywords*—track circuit, measurement, code current parameters, track circuit parameters, automatic locomotive signaling system, electromotive force of ALS coils, traction current, harmonics**

I. Introduction

There are six Railways in the Ukrzaliznytsia. The Pridnyprovska Railway has railway sections at the 3 kV d.c. traction (93.3 %) and autonomous (diesel) traction (6.7 %). It was founded since 1873 year. The length is 3275 km. The Pivdenna (Southern) Railways has railway section at the 25 kV a.c. and at the 3 kV d. c. traction (33.5 %) and autonomous traction (64.5 %). Their length is 3000 km. It was founded from 1868. The Pivdenno-Zakhidna (Southen-West) Railway was founded since 1870. Their length is 4668 km. There are railways at the 25 kV a.c. traction (35%) and autonomous traction (65 %). The Lviv Railway has 4521 km and it was building in 1861. It is more oldest from all Railways of Ukrzaliznytsia. It has all kinds of traction system. The 3207 km (71 %) from all length of Lviv Railway is equipped by the electric traction. There were electrified 469 km of railway lines at the 25 kV a.c. traction with shielding and powering wires. The Odessa Railway has near 4000 km. There are sections at the 25 kV a.c. traction (1708 km or 41 % from all) 3 kV d.c. traction (1.6 km) and diesel traction (2492 km or 59 %). Since 1997 it was electrified 63 km of lines by the a. c. 25 kV 50 Hz. Since 2015 the Donetsk Railway has 1616.7 km instead 2861.8 km and 639 km (40 %) is electrified by the d.c. traction from it predominantly.

It was electrified 1571 km of railways: 1184 km at te a.c. traction (Lviv, Pivdenno-Zakhidna, Pivdenna, Odesaa Railways) and 387 km at the d.c. traction (Donetsk, Pivdenna, Lviv Railways) since 1997 year and to presents. So 47 % of railways (10500 km from total length 22300 km) is electrified by the a. c. traction of 25 kV 50 Hz (5500 km) and by the d. c. 3 kV (5000 km). Last time (1991 – 2018 years) the electrification of railways was carried out by the a. c. 25 kV 50 Hz.

The automatic locomotive signaling (ALS) system and automatic block systems use to transfer of the codes to the locomotive and receiving apparatuses of track circuit and to regulate traffic of trains on the railway sections. To transmit codes by the ALS canals (rail lines) it is applied signals at the 50 Hz frequency for railways with d. c. electrical traction and signals at the 25 and 75 Hz for a. c. electrical or autonomous traction. TCs are a primary element, which control the trains' movement safety. They test integrity of rails [1] – [7].

Also there are code and tonal track circuits to control traffic of trains on railways of Ukraine. It was equipped 5200 km without isolative connection (known also as "velvet track") since 2010. It is meant to applied of tonal track circuits TTC3 at the 420, 480, 580, 720, 780 Hz and at the modulation 8 and 12 Hz frequencies, for example [1], [2], [4].

As above mentioned rail lines use as special channels to transfer o the codes to the receiving apparatuses of TC and ALS system and as wires to the return traction current to the substation [4]. Traction current has widely spectrum of harmonics and pulses. These natures are very different: equipment of traction substation, locomotive's motors, commutation apparatuses, operation system of locomotive based on the thyristors or IGBT transistors, atmospheric phenomena (lightning discharges), stray current from nearbody TC and others.

So the question deals with the diagnostics of TC and research of spectrum composition of return traction current with the help special measurement equipment is actual. Now the control of TC parameters is carried out manually with the help of C-438 testers and "measurement shunt" ($R_{sh} = 0{,}06$ Ohm) or with the help of special diagnostics system "Control" based on the car-laboratory „Automatics, telemechanics and communication”. In last case we determine amplitude of code current in the begging and in the end of TC, which cannot be more than 25 A and less then 2A at the d.c. traction, 1.4 A at the a.c. traction and 1.2 A at the diesel traction. Also we defined duration of first pause in circle of codes, which is not permissible from 0.12 to 0.18 s [4] – [6]. Other parameters of TC are not determined with the help of car-laboratory.

For the decision of given task it is necessary to elaborate method of automated measurement TC parameters and traction current interferences. It is allowed us to take into account different sources of last. The automated measurement method on the base of car-laboratory measurement system is better from other, because it will permissible us to change scheduled preventive maintenance on the repair on a “status of object”. It allows us to decrease a quantity of staff and to increase the movement safety. The determination of spectrum of return traction current can be achieved in such way: record of signals from one or two ALS coils of locomotive or car-laboratory before filter. Also it is necessary to develop of mathematic model of track circuit and transmission channel of ALS. TC will be worked in the mode of occupancy by train automatic locomotive signaling mode) and to create algorithms of definition of the track circuit parameters. We shall use the formula of electromotive force (EMF) which induced in ALS coils of locomotive or car-laboratory [7], [8], [10] – [12].

II. Mathematic Model of Track Circuit in the ALS Regyme

The measurement system of car-laboratory applies to determine the parameters of code current. It carried out two times in year. The experimental data transmit from rail lines through the inductive coils situated before first wheel pair of locomotive to the diagnostic equipment of car-laboratory [6] – [8]. So there is a continuous communication between track and locomotive devices. The coils connect series and opportunity between themselves (Fig.1). Magnetic field is formed around of rail by the alternating code current and interferences.

The equivalent scheme of track circuits occupated by the train or measurement shunt is shown in Fig. 2. It consists of supplying end of TC, rail lines, train shunt. Each from given units can be represented as four-pole. All four-poles connect accordingly. Supplying and receiving ends include transformers, filters, protective apparatuses and relays. Four-pole of rail lines consist of rails (R50, R65 or R75), connected with the help of electrical connections.

The system of equations for voltage and current in the beginning of TC is given:

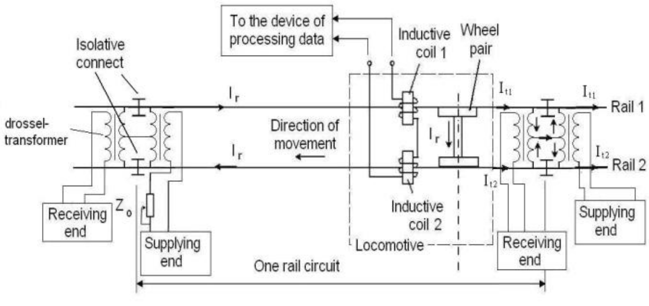

Fig. 1. Structure scheme of one track circuits occupated by the train

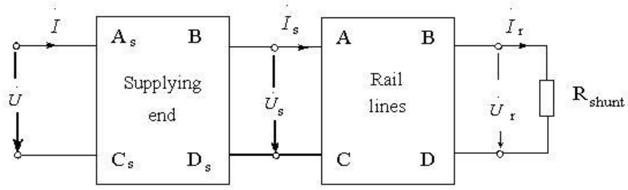

Fig. 2. Equivalent scheme of track circuits occupated by the train or measurement shunt

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

where $\dot{U}_S$, $\dot{I}_S$, $\dot{U}_r$, $\dot{I}_r$ - voltages and currents in the beginning end of track circuits (in the point of presents train), A_{sh}, B_{sh}, C_{sh}, D_{sh} - coefficients of rails four-poles in the shunt mode.

$$A_{sh} = 1 + \frac{\bar{Z}}{R_{sh}}, \; B_{sh} = \bar{Z}, \; C_{sh} = \frac{1}{R_{sh}}, \; D_{sh} = 1, \tag{2}$$

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

Let be the voltage on the generator outputs equals minimal voltage of track transformer $\dot{U}_S = \dot{U}_{\min}$ (it can be taken from regulative tables [5], [6]. So impedance of rail lines is

$$\bar{Z} = \frac{\dot{U}_{min} - \dot{I}_r \cdot R_{sh}}{2 \cdot \dot{I}_r}, \tag{3}$$

The wave impedance can be define as follows

$$\bar{Z}_v = \sqrt{\bar{z} \cdot R_{is}}, \tag{4}$$

where R_{is} - equivalent resistance of rail line isolation at the grounding of catenary supports, Ohm·km.

$$R_{is} = \frac{\bar{Z}_v^{\,2}}{\bar{z}}. \tag{5}$$

So, measuring the code current amplitude in the beginning and end of TC and taking value of generator’s voltage from regulation tables we can find primary and secondary parameters of TC.

III. THE ALGORITHMS OF DEFINITION OF CODES AND TRACK CIRCUIT PARAMETERS

The presented measuring complex is intended for fixing the signal coming from the output of the filter of the ALS system, according to the maintenance instructions [6]. The parameters of codes are diagnosed from the outputs of the inductive ALS coils. Also we record the interferences of return traction current. Thus, the above measuring complex allows analyzing not only the time and amplitude parameters of the ALS codes, but also to evaluate the effect of influence of return traction harmonics on the automation systems and reasons.

We have developed the method for determining the parameters of the TC with the help of car-laboratory. Two operators-electricians require for monitoring the TC parameters [6]. It is necessary to calibrate the apparatuses of the car-laboratory before measurement by the comparison data from TC and on the monitor of proposed system of car-laboratory.. Special attention should be paid to the track circuits operating in shunt mode. The next important step is to determine the initial data:, the name of the railway sections and stations (specified map), the length and type of TC, the sampling frequency and quantization step settings of analog-digital converter (ADC). The measurement method and system are described more detail in [7], [8], [10], [12]. The main task of the electricians is to control the operation of equipment. Work place of electrician of car-laboratory “Automatics, telemechanics and communication” and results of measurements of code and return traction currents is given in Fig. 3.

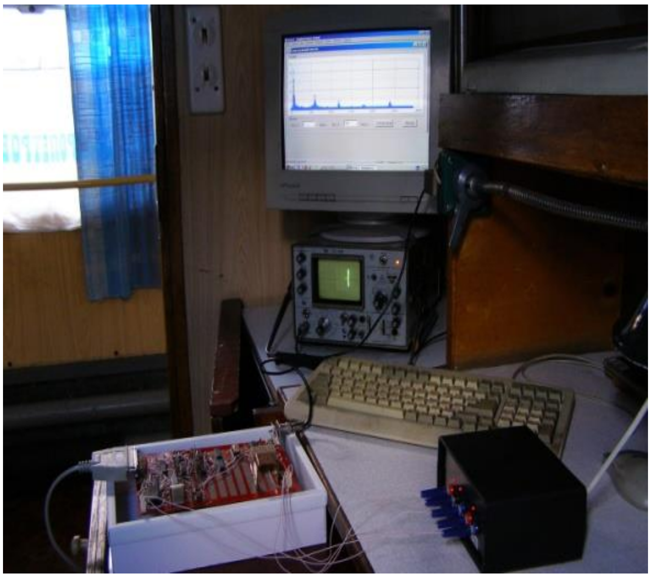

Fig. 3. Work place of electrician of car-laboratory “Automatics, telemechanics and communicaion” and results of measurements of code and return traction currents

Based on the results of monitoring the TC parameters, a database is created. That permissible to automate the process of detecting some failures of TC and predict their causes. Thus, the number of monitored TC parameters has expanded. Some of parameters (failures or some deviations in the regulations) can be determining by comparison a measuring data with the theoretical characteristics of TC. As a result, the time spent on the control parameters of TC will be reduced. The work of electrician will be facilitated. The mathematic models of traction and rail net, methods of optimization were used at the processing data [10] – [17].

At the definition of code signals types we solve such problems: measurement of the pulse and pause duration and the exception of sags and surges of a signal; determination of the code type (“green”, “yellow”, “red-yellow”) and kind of code track transmitter (KPTSH-5 or KPTSH-7); length of TC; parameters of TC (input impedance and wave coefficient); integrity of isolation connects.

The value $0.6U_{\text{n}}$ is the minimum voltage that will be recognized as a useful signal by the ALS system. The system should not identify the signals at the amplitude greater or equal to $0.6U_{\text{n}}$ and 0.2 s duration as a useful signal. The signal at the amplitude less or equal to $0.4U_{\text{n}}$ and 0.1 s should not be identify as pause of code too. The programmed timer of measurement system is used to calculate the duration of pulses and pauses. At the short-term loss of signal at the determination of the pulse duration the pause timer can start. If a signal is not appeared during 0.1 s, the pause counting continues. But as the pulse timer has not been disabled, pulse timer will carried out correction (the subtraction of the pulse duration by 0.1 s). A similar process is used to determine the pause at the appearance pulses or harmonics. Algorithm for their definition is shown in Fig. 4.

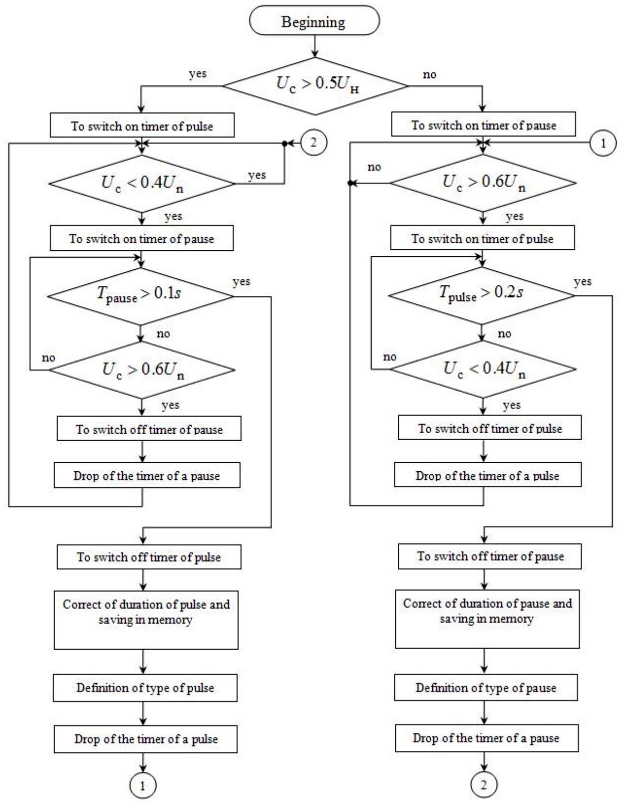

Fig. 4. Algorithm of definition the duration of pulses and pauses of code circle

All pauses and pulses were divided into certain types shown in the Table I. The sequence of pulses and pauses determines the type of code, and the duration of pulses and pauses defined the type of code track transmitter (CTT), see in Table II.

TABLE I. TYPES OF CODE PULSE AND PAUSE

Type of pause	Duration, s	Type of pulse	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 II. COMBINATION OF PULSES AND PAUSES OF CODES

Type of code track transmitter (KPTSH-5)		Type of code track transmitter (KPTSH-7)	
Code	***Combination of impulses and pauses***	***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

Automated measurement system calculates the duration of the pulses and pauses and then it determines type of CCT. It allows to protect railway section against dangerous failures on short-circuit of isolation connectors. It is known that code track transmitters are alternated for adjacent track circuit. The lengths of TCs are known before for all railway section. So system compares real length and measuring value. At the inputting the train on next TC the useful signal get down.

Algorithm for definition the TC length and failure of isolation connectors(isolating joints) is presented in Fig. 5. To validate the coordinates of isolation connector we need to check calculated length l_{TC_i} with initial date for each i -th track circuit. The error has to less the 3 % from the actual value. Data correction is needed to compute of TC length. It should be considered that the type of CTT is determined only after decoding of three code circles duration 1.6 s for KPTSH-5(8) and 1.86 s for KPTSH-7(9) each. Thus, the TC length is equal measuring value minus distance accorded to movement of locomotive during the decoding of the three code circles.

To diagnostics of the TC serviceability was elaborated follow algorithm, which is carried out on the current curve of the locomotive signaling $I(x)_{meas}$ depending on the coordinates obtained at the measurements. The code current curve $I(x)_{meas}$ is compared with calculated $I(x)$ for nominal operating conditions: the specific impedance of the rail lines Z1 = Z2 = $0{,}8e^{65j}$ Ohm / km at the welded copper connectors, the specific conductivity of insulation Y1 = Y2 = 0,5 S/km.

If we have break points of the first kind in the $I(x)_{meas}$ curve, we can done conclusion about failure of rail connectors in this place. If amplitude of ALS current $I(x)_{meas}$ is less than calculated value, it indicates that the ballast impedance is less than normal (or conductivity insulation is more than norms that is same).

The ocsillogram and spectrum of code and traction current in station TC are given in Fig. 6.

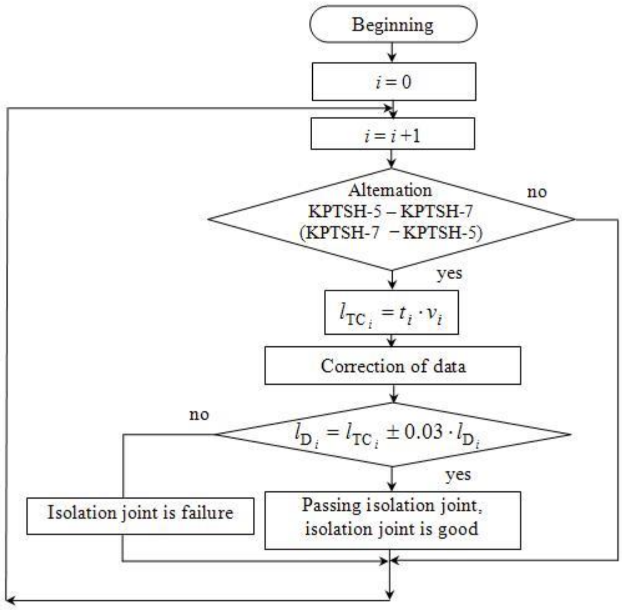

Fig. 5. Algorithm for definition of the track circuit length and serviceability of isolation connectors

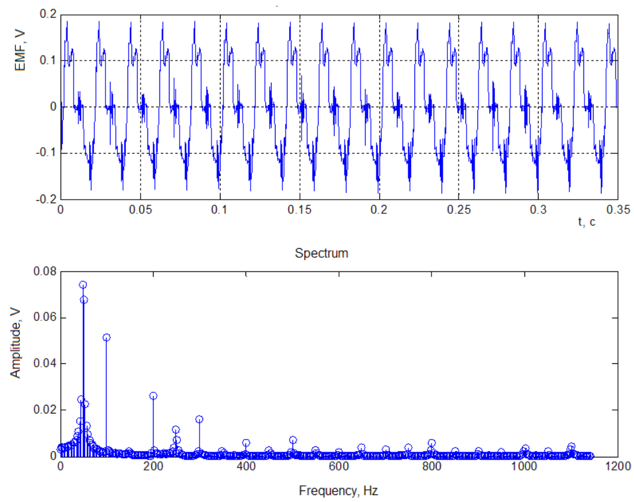

Fig. 6. Ocsillogram and spectrum of code and traction current in station TC at the d.c. traction

After measurements all data are calculated. Databases are created. They involve data, which indicates the whole number of investigated TCs; TCs ,where amplitude of code current was below was the permissible minimum (2A at the d.c. traction, 1.4 A at the a.c. traction and 1.2 A at the autonomous traction) at the beginning of TC; TCs, where the time parameters of the codes does not confirm to requirement; TCs at the underestimated the ballast impedance; TCs with the broken electrical connectors; amplitude and frequency harmonics of return traction current for each TC and perhaps causes. Proposed measurement system is allowed to observe the diagnostics results along the all length of each TC after trip.

IV. CONCLUSIONS AND ACKNOWLEDGMENTS

The level of electrification of railways of Ukrzaliznytsia was analyzed. So 47 % (10500 km from total length 22300 km) is railways by the a. c. traction of 25 kV 50 Hz

(5500 km) and d. c. 3 kV (5000 km). 47 % of railways (10500 km from total length 22300 km) is electrified by the a. c. traction of 25 kV 50 Hz (5500 km) and by the d. c. 3 kV (5000 km). Last time (1991 – 2018 years) the electrification of railways were carried out by the a. c. 25 kV 50 Hz. The railways at the a.c. traction have more widely spectrum of return traction current from the section at the d. c. traction. Thus the question deals with the diagnostics of TC and research of spectrum composition of return traction current with the help special measurement equipment is actual. That is why it is proposed to monitor the amplitude and frequency of harmonics of return traction current by the special equipment based on car-laboratory "Automatics, telemechanics and communication".

The formulas for the definition of primary and secondary parameters of track circuits (wave impedance, resistance of isolation, impedance of rail lines) were received.

The algorithms for the definition of duration of pulses and pauses of codes and deviation of their from norms, type of code, definition the TC length and failure of isolation connectors (isolating joints), parameters of track circuits were elaborated.

The scientific novelty consists in the method for definition of parameters of TC and harmonics of return traction current. This method and proposed diagnostics system allows you to determine by the electromotive force induced in the one or two ALS coils the amplitude and frequency currents flowed in ALS channel (rail lines), time parameters of code current. We are monitored the amplitude of the code current along the TC length, the duration of the pulses and pauses of codes, the code type and the CTT, coordinate, the TC length, serviceability of isolation and electrical connectors, parameters of harmonics and impulse interferences in rail net, their causes. Two operators-electricians require for monitoring the TC parameters.

Databases involve data, which indicates the whole number of investigated TCs; TCs ,where amplitude of code current was below was the permissible minimum (2A at the d.c. traction, 1.4 A at the a.c. traction and 1.2 A at the autonomous traction) at the beginning of TC; TCs, where the time parameters of the codes does not confirm to requirement; TCs at the underestimated the ballast impedance; TCs with the broken electrical connectors; amplitude and frequency harmonics of return traction current for each TC and perhaps causes. Proposed measurement system is allowed to observe the diagnostics results along the all length of each TC after trip.

The application of proposed method of control parameters of TC from car-laboratory will reduce service time and will permit to another type of TC' maintenance: the service on the "status of object". The approbation of given diagnostics apparatuses was executed on the base of car-laboratory „Automatics, telemechanics and communication" of Pridneprovsky Railway of Ukrzaliznytsia.

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