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MATHEMATIC MODEL OF TRACTION NET FOR THE INVESTIGATION OF PROPAGATION OF HARMONICS IN RAIL LINES

Introduction

The rail circuits (RC) are the basic detectors supervising a situation of a train, free of blocks - sections, integrity of rail strings, and also carry out functions of the channel of transfer of codes automatic locomotive signal (ALS) system from track- devices to the locomotive. Thus, the rail circuits are a primary element directly determining safety of trains' movement. Simultaneously, the rail lines are included into structure traction net and pass return traction current to substations. Accordingly on work of rail circuits act set of destabilizing factors, including electromagnetic influence of the traction electrosupply system.

Therefore, it is necessary to spend complex researches of electromagnetic processes in RC, called by simultaneous course of an alarm current of automatic lockout, ALS and return traction current. The purpose is definition of stability of their work in conditions of influence of traction electrosupply system and also scientific basis of a method of the automated measurement of influence in rail lines from car - laboratory and definition of probable sources on railways with the small intensity of movement.

The main attention is given to a question of propagation of traction current harmonics on length feeder zone and definition of their influence on code current by frequency 50 Hz flowing in rail lines.

Characteristics of influence

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, telemechenics and communication". In given case it was carried out by the record of signal from one inductive coil of locomotive, which moved on the railway section of d. c. traction. In result we abble possibility to determine as the parameters of code current, flowing in rails, as the spectrum composition of return traction current [1].

As have shown researches, in a number of cases: at a feed of rectifiers traction substations by an asymmetrical and sine not wave three-phase voltage, malfunction of diodes in one of branches, reduction of coefficient of a filtration of substation's filters, commutation switching deals with to change of a mode of locomotive drive, in traction current there are harmonics multiple 50 Hz.

By the experimental researches the harmonics by frequency 50, 75, 100, 150 Hz were fixed on railway sites with electric traction of d. c. current and code rail circuits 50 Hz in a pause of a code. The harmonics, which frequency coincides with code carrying frequency of an signal current, is most dangerous among specified. The interference's amplitude by 50 Hz was 50 % from the minimal level of a locomotive signalling current in rails [2].

Knowing the law of distribution of harmonics by frequency 50, 75, 100 Hz on length feeder zone, it is possible to estimate the degree of influence of harmonics in a code current of each rail circuit within the limits of given feeder zone. Besides at performance of the automated measurements of amplitude of harmonics from car - laboratory it is possible to define the reason of occurrence, and, hence, kind of malfunction of the equipment of traction substations and rolling-stock with the purpose of exception of their influence on work of rail circuits and reduction of number of failures. The measurement can be done in process of movement of locomotive.

Mathematic model

The equivalent circuit of a traction net is shown in fig. 1 for an estimation of a degree of influence of traction current harmonics on work of rail circuits. It is offered to submit the traction net by a contour a over head system - rails. There is one way railway section, where two rail is substituted one wire, strings of an one-acceptable site are replaced by one line and are submitted by a contour a rail - ground. The contact network in an equivalent circuit also is submitted by one wire. So traction electrosupply system is submitted as six-poles, where Z_c – the resistance of over-head system, with the taking into account of the mutual induction between rails and catenary's wire; Z_r – the resistance of rails with the taking into account of the mutual induction between rails and catenary's wire; Z_{iz} – the resistance of catenary, taking into consideration of grounding of different railway construction on the rails (supports of over-head system, commutation apparatuses, sectionalization posts, discharger and etc.); Z_b – the resistance of ballasts, which consists of resistances of rail – rail connection – sleeper – ballast – ground work – ground; $\dot{U}_{cr1}$, $\dot{U}_{cr2}$ - voltage between catenary and rails, $\dot{U}_{r1}$, $\dot{U}_{r2}$ - voltage between rails and ground, $\dot{U}_{c1}$, $\dot{U}_{c2}$ - voltage between catenary and ground, $\dot{I}_{c1}$, $\dot{I}_{c2}$ - current in the catenary, $\dot{I}_{r1}$, $\dot{I}_{r2}$ - current in the rails in the input and output of lines accordingly [3].

With the use of the theory multipoles [4, 5] the systems of the equations were made. The result of decision is mathematical dependences of voltage and currents in a catenary and rails in a place of connection feeders of traction substations and near an electric locomotive.

Voltage in a circuit of an electric locomotive

$$\dot{U}_{\text{cr2}} = \dot{I}_{\text{c2}} \cdot \underline{Z}_{\text{el}} \,. \tag{1}$$

Current in a catenary in the beginning lines

$$\dot{I}_{\text{c1}}(x) = \dot{I}_{\text{c2}} + \frac{\dot{U}_{\text{c2}}}{\underline{Z}_{\text{iz}}(x)} \,. \tag{2}$$

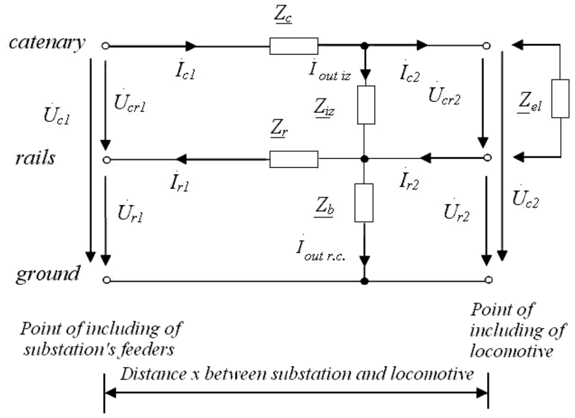

Fig. 1. Equivalent scheme of one-way traction net

The current of outflow through isolation of support represents linear dependence and is described by equation

$$\dot{I}_{out\,iz}(x) = \frac{\dot{U}_{c2}}{\underline{Z}_{\text{iz}}(x)} \,. \tag{3}$$

Knowing value of a current of outflow from return traction current, is possible is to define a voltage of a rails at the end of a line

$$\dot{U}_{r2} = \dot{I}_{out\,r.c.} \cdot \underline{Z}_b \,. \tag{4}$$

Near traction substation the return traction current is determined by the following dependence

$$\dot{I}_{r1}(x) = \dot{I}_{c2} + \dot{I}_{out\,iz}(x) - \dot{I}_{out\,r.c.} \tag{5}$$

Near an electric locomotive the potential of rails is equal

$$\dot{U}_{r2}(x) = \dot{I}_{\text{out r.c.}} \cdot Z_{\text{b}}(x) \,. \tag{6}$$

The dependence of potential of a rail in area of traction substation from coordinate between an locomotive and substation is defined as

$$\dot{U}_{\text{r1}}(x) = -\dot{I}_{r1}(x) \cdot Z_r(x) + \dot{U}_{\text{r2}}(x) \,. \tag{7}$$

The size of currents of outflow from return traction current depends on a condition of ballast. Therefore, the four-poles of a rail lines is considered separately, and value of outflow currents from return traction current is proportional outflow current of from code current, which is determined on the basis of the automated measurements carried out by the car - laboratory "Automatics, telemechanics and communication" at the definition of parameters of a current locomotive signalling system in rails and serviceability of a rail circuit. The four-poles of a rail line without the circuits of the supplying and relay ends is submitted in a fig. 2, where $\dot{U}_{rcir1}$, $\dot{U}_{rcir2}$ - voltage in the rail circuit, $\dot{I}_{rcir1}$, $\dot{I}_{rcir2}$ - signal current in the rail circuit in the input and output accordingly, $n \cdot \Delta x$ - length of rail circuit, Δx - elementary piece, n - quantity of elementary pieces [5].

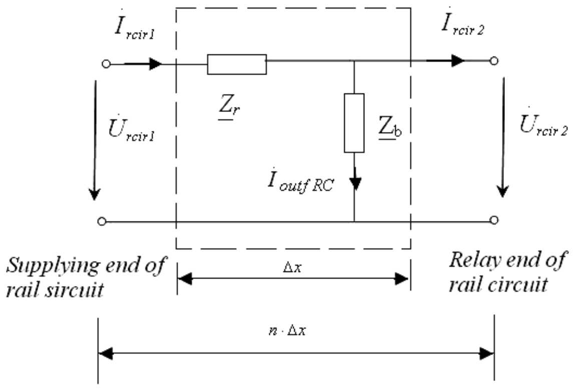

Fig. 2. Equivalent scheme of rail lines

The value of outflow current from the code current of rail circuit, submitted as a four-pole, is

$$\dot{I}_{outf\ RC} = \frac{\dot{U}_{rcir2}}{\underline{Z}_b}. \quad (8)$$

Outflow coefficient is depended on current $\dot{I}_{outf\ RC}$

$$K_{outf} = \left| \frac{\dot{I}_{outf\ RC}}{\dot{I}_{rcir2}} \right|, \quad (9)$$

Using outflow coefficient, we can give outflow current from the return traction current

$$\dot{I}_{out\,r.c.} = \dot{I}_{c2} \cdot K_{outf}. \quad (10)$$

In result potential of rails in the end of line is

$$\dot{U}_{r2} = \dot{I}_{out\,r.c.} \cdot \underline{Z}_b. \quad (11)$$

Potential of rails and return traction current in the input of sex-poles (fig.1) is defined with the help of following equation

$$\dot{U}_{r1} = -\dot{I}_{r1} \cdot \underline{Z}_r, \quad (12)$$

$$\dot{I}_{r1} = \frac{\dot{U}_{cr2}}{\underline{Z}_{iz}} + \dot{I}_{r2} - \dot{I}_{st.ret.c.} \quad (13)$$

It is necessary to notice, that the factors of outflow are defined separately for each rail circuit within the limits of researched feeder zone. In case of homogenous of traction net outflow coefficient will be identical on all its length.

The offered mathematical model of traction net of railways with the small intensity of movement differs from existing analogs by the account resistance between all wires in the electrosupply system. That is allowed us more precisely to determine sources of electromagnetic influences by results of measure carried out by the car - laboratory and to take into account influence of grounding of catenary's supports on work of rail circuits.

Result of modeling

The account of homogeneous traction net is rather simple and convenient with the help of the offered mathematical model. However the traction net is inhomogeneous in reality. Its inhomogeneous is dependence on primary parameters of traction net and can be called by breakage of electrical connections of rail circuits, various resistance of isolation of catenary or rail net, presence of rigid points on a contact wire received as a result of wire repair etc.

Let's in inhomogeneous traction net is defined by dissimilarity of ballast resistance on length of a feeder zone. In result outflow coefficient, which characterizes size of currents of outflow through ballast, also will be variable. The size can be received by measurements of resistance of a rail and ballast by an indirect method [5].

The calculation were executed at the following initial data: resistance of rails - $0{,}11 + j \cdot 2 \cdot \pi \cdot f \cdot 8.021 \cdot 10^{-4}$ Ohm/km (were accepted at rails P65), ballast - 100 Ohm·km, isolation of support 105 and 106 Ohm·km and catenary - $0{,}159 + j \cdot 2 \cdot \pi \cdot f \cdot 9.772 \cdot 10^{-4}$ Ohm/km. A feed of railway section is unilateral. The substation is on 0 km. The value current of an electric locomotive is 1 A by frequency 50 and 100 Hz. At the modelling value locomotive current was accepted 1 A, because it is minimal current in rail circuits which can be switch of way relay of code rail circuits 50 Hz. Length of feeder zone is 10 km. There is one electric locomotive on the section, which leaves traction substation.

The form of a curve current and voltage in many respects will depend on size of ballast resistance on length of feeder zone. In result the value of outflow coefficient can be received and each member will depend on current coordinate.

The character of change of outflow current through isolation of support at the constant isolation resistance (according to the put task) also will be similar to dependence for a homogeneous net. The dependence of outflow current of through the support isolation will be linear. The interest in this case is represented by the dependence on outflow coefficient. The character of change looks like, given on a fig. 3.

The diagram of outflow current trough the ballast is shown on fig. 4. It looks like as dependence of outflow coefficient from coordinate. At the $x = 0$ km the outflow currents through isolation and ballast are very small, the return current will be equal to a current supplied by locomotive from the catenary.

On a fig. 5 is given the dependence of harmonic of 50 Hz in the points of including of feeders on distance between locomotive and substation. For a harmonic 1 A 100 Hz the dependence will be similar if we neglect by the image part of ballast's resistance.

The maximal potential of a rail will be in a point $x = 0$ km/

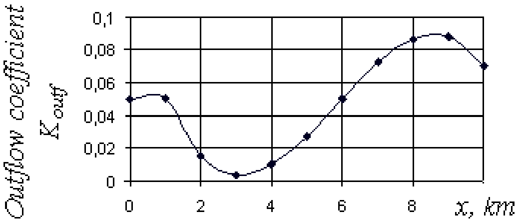

Fig. 3. Dependence of outflow coefficient on coordinate

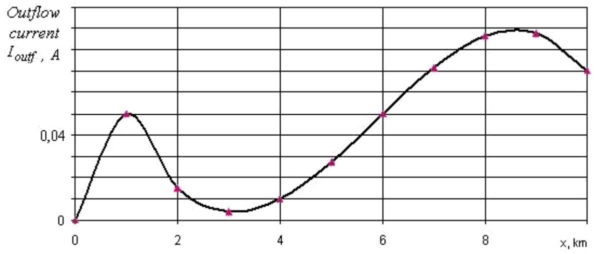

Fig. 4. Dependence of outflow current of 1 A 50 Hz from on coordinate

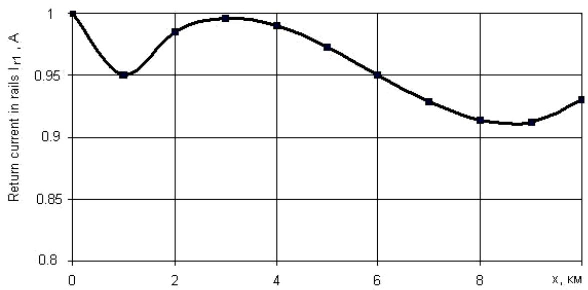

Fig. 5. Dependence of return traction current of 1 A 50 Hz on distance between locomotive and substation

Further at the removal of locomotive from substation potential of a rail will be reduced. The dependence $\dot{U}_{r2}(x)$ remains nonlinear, because the form of a curve is defined by the change of ballast's resistance. The potential of rails at the end of section (near an electric locomotive) will be defined by a current supplied from catenary and ballast's resistance on given feeder zone.

The potential of rails near traction substation (in the beginning of investigated section), called by course by the return traction current. The dependence is submitted in a fig. 6 for harmonics of the rectifier by frequency 50 and 100 Hz at the greatest possible amplitudes of a current.

At the building of curve $\dot{U}_{r1}(x)$ is used $\dot{I}_{r1}(x)$ и $\dot{U}_{r2}(x)$, which is depended on outflow coefficient. At the growth of coordinate in limits $0 \le x \le \frac{1}{4} l$ the value $\dot{U}_{r1}(x)$ will be decrease, at the $\frac{l}{4} \le x \le l$ $\dot{U}_{r1}(x)$ will be increase (fig.6).

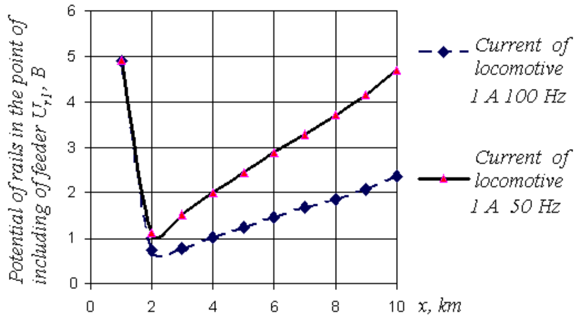

Fig. 6. Dependence of rails' potential on distance between locomotive and substation

Conclusion

The sources of influences acting on transfer of code currents and work of rail circuits are determined. The harmonics by frequency 50, 75, 100, 150 Hz were fixed on railway sections with the electric traction of d. c. in return current. Most dangerous among mentioned above is 50 Hz harmonic, as coincides by frequency of a code current. In a number of cases the amplitude of a 50 Hz harmonic achieved 50 % from the minimal level of a code current in rails, at which the way relay can switch. The most probable reason of its occurrence is bad work of substation's rectifiers.

The mathematical model allowing us to estimate distribution of harmonics of traction current with locally concentrated loading is developed. It uses convenient at the investigation of railway section with the small intensity of work. It differs from existent by the account resistance between all wires of traction electrosupply system. It has enabled more precisely to determine sources of electromagnetic influences and to take into account action of grounding of catenary's supports on work of RC. The value of outflow currents is established by the automated indirect measurements on the basis of car - laboratory.

The results of modeling of distribution of harmonics by amplitude 1 A frequency 50 and 100 Hz on length of inhomogeneous railway section with a unilateral feed at various resistance of isolation and wires of traction net have shown, that when there is one electric locomotive on a section and a feed of its unilateral, current in a contact network in the points of feeders including will change with the increase of coordinate similarly to a current in a homogeneous net, because neither current of an electric locomotive, nor power failure on an electric locomotive, nor isolation resistance according to the given conditions do not depend on resistance of a ballast.

The increase of a current in a contact network is observed at the rise of harmonic's frequency and equal amplitudes, as the resistance of an electric locomotive and catenary have inductive character and directly proportionally to frequency of current. If resistance of isolation of catenary's supports is more than 105 Ohm·km, the value of a current supplied from traction substation is remained constant on length of feeder zone.

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Ключові слова: тяговий струм, рейкові кола, фідерна зона, завади, гармоніки.

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