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Automated measurement of rail circuits parameters and harmonics of return tractive current to improve safety of movement

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ABSTRACT
A method of automated measurement of rail circuits parameters and harmonics of return traction current has been elaborated. The mathematical model of traction network is proposed and allowed us to involve the action of different sources of electromagnetic interference on the operation of rail circuits. The results of modelling allowed establishing that the rail circuits are exposed to a dangerous influence of return traction current near a locomotive and substation

KEYWORDS: rail circuits, code current, harmonics, traction current, automated measurement

1. Introduction

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

It is important to control parameters not only of code currents and rail circuits, because a significant number of failures in rail circuits is caused by the presence of harmonics and impulse influences of return traction current (especially on the railways electrified by the alternating current).

The investigation of traction current spectrum should be carried out in a pause of code, using a method, which should measure with the help of a special device of laboratory coach „Automatics, telemechanics and communication". In the given case it was carried out by recording the signal from one inductive coil of a locomotive, which moved on the railway section of d. c. traction. As a result we could determine the parameters of code current, flowing in rails, as the composition of return traction current spectrum [1].

To improve the method of automated parameters measurement of rail circuits and harmonics of return traction current it is necessary to elaborate a mathematical model of the traction network. It is possible to take into account different sources of electromagnetic influences. An automated measurement method based on the laboratory coach is most promising in the other method because it will allow us to proceed from scheduled preventive maintenance to repair on a status of object and to reduce the number of staff and to raise the safety of trains movement.

So, the development of an automated method of parameters measurement of rail circuits and harmonics of return traction current is actual.

2. Method of measurement

It is proposed to use the following method for the definition of composition of return traction current spectrum. As it is known, an automatic locomotive signal system consists of a receiving coil, filters, amplifier, decoder and others. The receiving coil is connected inductively with the traction and code currents by means of a magnetic field, which is formed by the alternating current around rails. The structure scheme of transferring canal is given in fig. 1. So, we have a separate connection canal and can record the signal from one locomotive coil (before filter). Thus, we have a possibility to determine the parameters of code current, flowing in rails, as the composition of return traction current spectrum [1].

The electromotive force induced in the ALS coil is equal

$$E(t) = -\frac{W \cdot d\Phi}{dt} = -\frac{\mu \cdot \mu_0 \cdot I_m}{2 \cdot \pi} \cdot \frac{\pi \cdot d^2}{4 \cdot R} \quad (1)$$

where W - number of winds of the coil, Φ - magnetic flow, T×m2; μ - magnetic permeability of the environment (steel of the core), H/m; μ_0 - magnetic constant, H/m; d – side of the square core of ALS coils, m2; R - distance from the coil up to the head of a rail, m; I_m - amplitude of current in rail, A.

The results of electromotive force calculation have given a good coincidence with the experimental data. Relative errors did not exceed ± 3.5%.

This idea was realized as a special microprocessor device based on a PC type computer. It was used to define parameters of code current and the composition of return traction current spectrum. It is described in detail in [1, 2].

It is necessary to take into account that this system can be used to record signals from the locomotive coils, other detectors included in the rail circuit scheme or feeder of return traction current. It allows us to define the spectrum of interferences and possible causes of its appearance (for example, disrepair of substation's rectifiers, filters, bad insulation of track ballast and others).

3. Mathematical model

The equivalent circuit of a traction network is shown in fig. 2 for an estimation of a degree of influence of traction current harmonics on the work of rail circuits. It is suggested to represent the traction network by a contour of overhead system - rails. There is one way railway section, where two rails are substituted by one wire, strings of acceptable sites are replaced by one line and are represented by a rail – ground contour. The contact network in an equivalent circuit is also represented by one wire. So the traction supply system is presented as six poles, where Z_c – the resistance of overhead system, taking into account the mutual induction between rails and catenary's wire; Z_r – the resistance of rails taking into account the mutual induction between rails and catenary's wire; Z_{iz} – the resistance of catenary, taking into consideration the grounding of different railway structures on the rails (supports of overhead system, commutation apparatuses, sectioning 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, respectively.

The systems of equations were written using the theory multipoles [3-5]. This decision resulted in mathematical dependences of voltage and currents in a catenary and rails in a place of feeders connection of traction substations and near an electric locomotive.

The voltage in a circuit of an electric locomotive

$$\dot{U}_{cr2} = \dot{I}_{c2} \cdot \underline{Z}_{el} \quad (2)$$

The current in a catenary at the beginning of lines

$$\dot{I}_{c1}(x) = \dot{I}_{c2} + \frac{\dot{U}_{c2}}{Z_{iz}(x)} \quad (3)$$

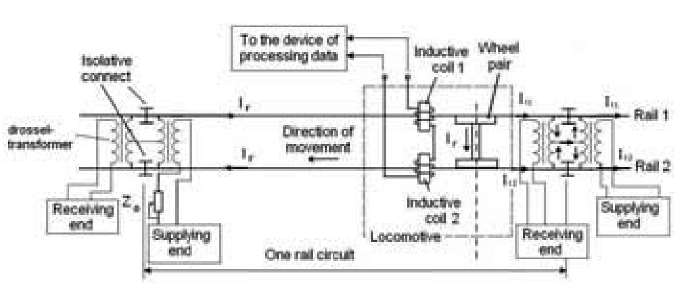

Fig.1. Structure scheme of data transferring canal to the locomotive

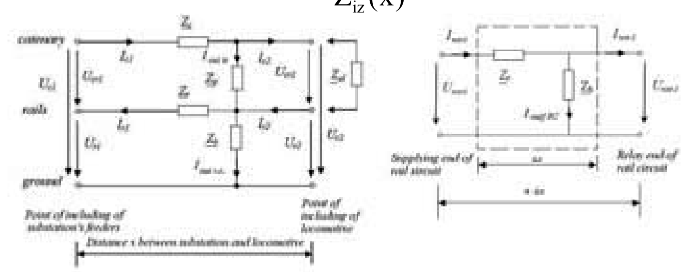

Fig.2. Equivalent scheme of one-way traction and rail network

The outflow current through insulation of supports represents a linear dependence and is described by the equation

$$\dot{I}_{out\,iz}(x) = \frac{\dot{U}_{c2}}{\underline{Z}_{iz}(x)} \quad (4)$$

Knowing the value of outflow current from the return traction current, it is possible to define the voltage of rails at the end of line (near an electric locomotive)

$$\dot{U}_{r2}(x) = \dot{I}_{out\ r.c.} \cdot \underline{Z_b(x)} \quad (5)$$

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

$$\dot{I}_{r1}(x) = \dot{I}_{c2} + \dot{I}_{out\,iz}(x) - \dot{I}_{out\ r.c.} \quad (6)$$

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

$$\dot{U}_{r1}(x) = -\dot{I}_{r1}(x) \cdot Z_r(x) + \dot{U}_{r2}(x) \quad (7)$$

The size of outflow currents from the return traction current depends on the condition of ballast. Therefore, the four poles of a rail circuit are considered separately, and the value of outflow currents from the return traction current is proportional to the outflow current from the code current, which is determined on the basis of automated measurements carried out by the laboratory coach "Automatics, telemechanics and communication" at the definition of parameters of a current locomotive signalling system in rails and serviceability of the rail circuit. The four poles of a rail line without the circuits of the supplying and relay ends are presented in 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 at the input and output, respectively, $n \cdot \Delta x$ - length of rail circuit, Δx - elementary piece, n - number of elementary pieces [5-7].

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

$$\dot{I}_{outf\ RC} = \frac{\dot{U}_{rcir2}}{\underline{Z}_b} \quad (9)$$

Outflow coefficient depends on the current $\dot{I}_{outf\ RC}$

$$K_{outf} = \left| \frac{\dot{I}_{outf\ RC}}{\dot{I}_{rcir2}} \right| \quad (10)$$

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

$$\dot{I}_{out\ r.c.} = \dot{I}_{c2} \cdot K_{outf} \quad (11)$$

As a result the potential of rails at the end of line is $\dot{U}_{r2} = \dot{I}_{out\ r.c.} \cdot \underline{Z}_b$ like (5).

The potential of rails and the return traction current at the input of six poles (fig.1) is defined by the following equation

$$\dot{U}_{r1} = -\dot{I}_{r1} \cdot \underline{Z}_r, \ \dot{I}_{r1} = \frac{\dot{U}_{cr2}}{\underline{Z}_{iz}} + \dot{I}_{r2} - \dot{I}_{st.ret.c.} \quad (12)$$

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

The offered mathematical model of railways traction network with a small intensity of movement differs from the existing analogues by the consideration of resistance between all wires in the supply system. That allowed us to determine sources of electromagnetic influences more precisely by the results of measurements carried out by the laboratory coach and to take into account the influence of grounding of catenary's supports on the work of rail circuits.

4. Results of modelling

The consideration of homogeneous traction network is rather simple and convenient with the help of the suggested mathematical model. However, in reality the traction network is inhomogeneous. Its inhomogeneity is related to primary parameters of traction network and can result from breakage of electrical connections of rail circuits, various resistances of insulation of catenary or rail network, the presence of rigid points on a contact wire obtained as a result of wire repair etc.

Let's assume that an inhomogeneous traction network is defined by the variability of ballast resistance at the length of a feeder zone. As a result the outflow coefficient, which characterizes the size of outflow current through the ballast, also will be variable. The size can be obtained by measurements of rail and ballast resistance by an indirect method [2, 5].

The calculations 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 (was taken for P65 rails), ballast - 100 Ohm·km, insulation 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 [8, 9]. The feed of zone is unilateral. The substation is at 0 km. The value of electric locomotive current is 1 A at the frequency of 50 and 100 Hz. While modelling, the value of locomotive current was taken as 1 A, because it is minimal current in rail circuits which can be switched by means of a relay of 50 Hz code rail circuits. The feeder zone is 10 km long. There is one electric locomotive on the section, which leaves a traction substation.

The form of current and voltage curves will depend on the ballast resistance along the feeder zone. As a result the value of outflow coefficient can be received for each rail circuit situated in the feeder zone. It will depend on the distance.

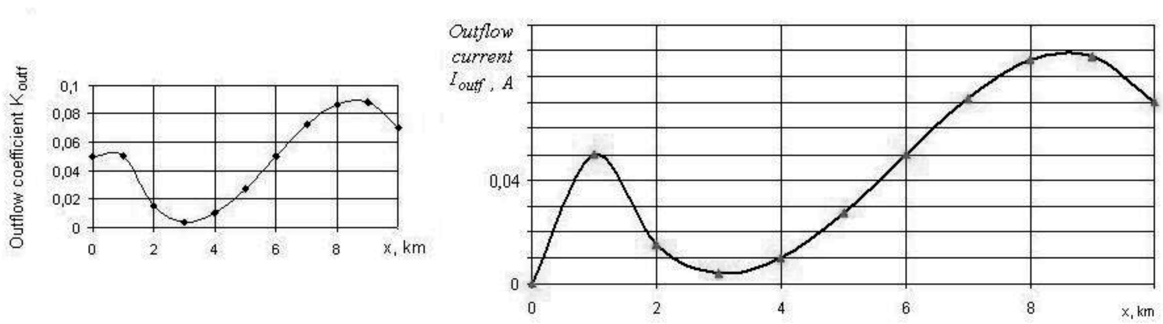

Fig.3. Dependences of outflow coefficient and current of 1 A 50 Hz on the coordinate

The character of change of outflow current through the support insulation at a constant insulation resistance (according to the task set) also will be similar to dependence for a homogeneous network. The dependence of outflow current through the support insulation will be linear. The interest in this case is represented by the dependence on outflow coefficient. The character of change looks like that shown in fig. 3. The graph of outflow current trough the ballast is also shown in fig. 3. This dependence is similar to the curve of outflow coefficient $K_{outf}(x)$. At $x = 0$ km the outflow currents through insulation and ballast are very small, the return current will be equal to the current supplied by the locomotive from the catenary.

Fig. 4 shows the dependence of propagation of 50 Hz harmonic in the catenary and rails in the points of feeders including on the distance between the locomotive and substation (coordinate x). For a 1 A 100 Hz harmonic the dependence of return traction current will be similar if we neglect the part of ballast's resistance.

Now it is difficult to carry out measurement of return traction current in rails. So, to characterise its value we will use the parameter - potential of rails.

The maximal potential of a rail will be at the point $x = 0$ km. Further at the removal of locomotive from substation the potential of a rail will be reduced. The dependence $\dot{U}_{r2}(x)$ remains nonlinear, because the form of curve is defined by the change of ballast's resistance. The potential of rails at the end of section (near the electric locomotive) will be defined by a current supplied from catenary and ballast's resistance in the given feeder zone.

The potential of rails near the traction substation (at the beginning of investigated section), called by the course of the return traction current. At the construction of curve $\dot{U}_{r1}(x)$ is used $\dot{I}_{r1}(x)$ and $\dot{U}_{r2}(x)$, which depend on the outflow coefficient. At the growth of coordinate within limits $0 \le x \le \frac{1}{4}l$ the value $\dot{U}_{r1}(x)$ will decrease, at $\frac{1}{4} \le x \le l$ $\dot{U}_{r1}(x)$ will increase (fig.5). The parameter l is the length of feeder zone (in our case 10 km).

From these dependences give it is possible to determine the value of current and potential of rails at the known value of locomotive's current at different coordinate x at the beginning of section (near substation) or at the end. Thus we can measure the value of traction current harmonics and then calculate the values I_{r1}, I_{r2}, I_{c1}, I_{c2}, I_{outf}, U_{r1}, U_{r2} and their influence on the work of rail circuits. The results of modelling allowed establishing that the rail circuits are exposed to a dangerous influence of return traction current near a locomotive and substation.

5. Conclusion

A mathematical model allowing us to estimate the distribution of traction current harmonics with locally concentrated loading has been developed. It uses a

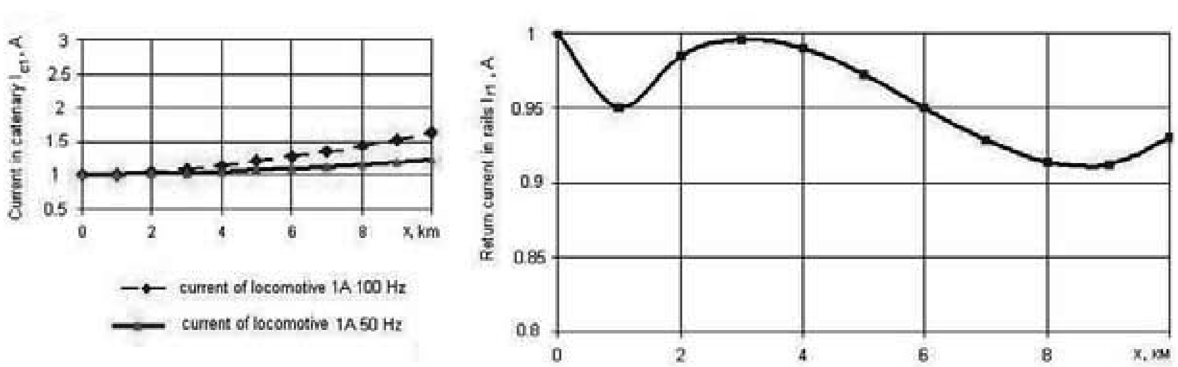

Fig.4. Dependence of harmonic 1 A 50 Hz in the catenary and rails at the points of feeders including on the distance between the locomotive and substation (coordinate x)

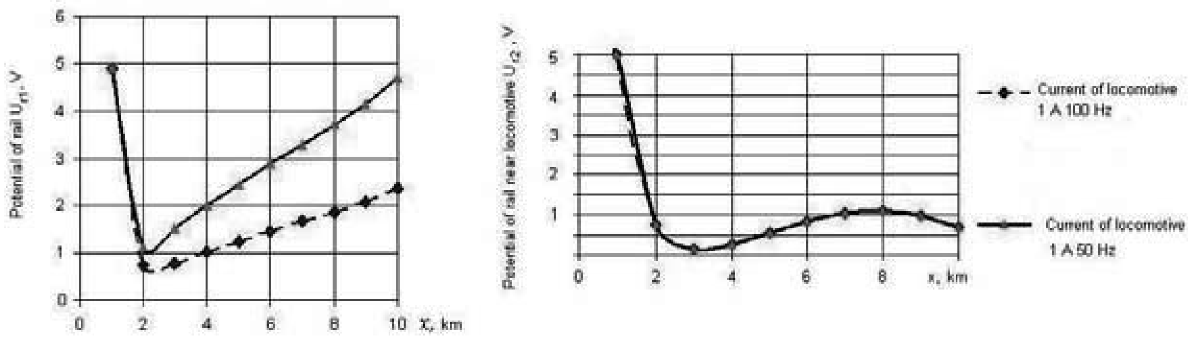

Fig.4. Potential of rails near the substation (beginning of section) U_{r1} **and locomotive (end of section)** U_{r2} **vs. coordinate x**

convenient (?) at the investigation of railway section with a small intensity of work. It differs from the existing situation by the resistance between all wires of traction supply system. It has enabled more precise determination of sources of electromagnetic influences and taking into account the effect of catenary's supports grounding on the operation of RC. The value of outflow currents has been established by the automated indirect measurements using a laboratory coach.

The sources of influences acting on the transfer of code currents and work of rail circuits are determined. The harmonics of frequency 50, 75, 100, and 150 Hz were fixed on railway sections with the d. c. electric traction in return current. Among the mentioned above the 50 – 100 Hz harmonics are most dangerous, as coinciding with the frequency of the 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 track relay can switch. The most probable reason of its occurrence is improper operation of substation's rectifiers.

The results of modelling the distribution of 1 A amplitude harmonics of 50 and 100 Hz frequency on the length of inhomogeneous railway section with a unilateral feed at various resistances of insulation and wires of traction network are shown. There is one electric locomotive on a section and its supply is unilateral. The current in a catenary at the points of feeders including will change with the increase in the coordinate similarly to the current in a homogeneous network, because neither the current of an electric locomotive, nor a power failure in an electric locomotive, nor the isolation resistance according to the given conditions depend on the ballast resistance.

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

Bibliography

[1] SERDYUK T., GAVRILYUK V., "Research of electromagnetic influence of traction current and its harmonics on the rail circuits" in 17th Int. Wroclaw Symp. and Technical Exhibition on Electromagnetic Compatibility. Wroclaw, Poland, June 2004, pp.260-263.

[2] SERDYUK T. GAVRILYUK V., "Automating system to control of parameters of code current in rails ", Journal of Dniepropetrovsk national university of railway transport named acad. V. Lasaryana, Dniepropetrovsk, Ukraine, no. 3, 2004, pp. 15-20.

[3] SERDYUK T., GAVRILYUK V., "Interaction of electrosupply traction system of direct current with the rail circuits", Information-operating system on railway transport, p.108-112, no. 4, 2007.

[4] Adonc G. T., Multipoles (Theory and methods of calculation). Yerevan, Armenia, 1965.

[5] SERDYUK T., GAVRILYUK V.., "Experimental investigation influences in rail circuits". Journal of Dniepropetrovsk national university of railway transport named acad. V. Lasaryana. Dniepropetrovsk, Ukraine, pp. 15-18, no. 9, 2005.

[6] SERDYUK T., GAVRILYUK V., "Distribution of harmonics of return traction current on feeder zone and evaluation of its influence on the work of rail circuits" 18th International Wroclaw Symposium and Exhibition on Electromagnetic Compatibility EMC'06. Wroclaw, Poland, p.467 – 470, 2006.

[7] SERDYUK T., GAVRILYUK V., "Rail circuits in the condition of electromagnetic influence of traction net" 18th International Wroclaw Symposium and Exhibition on Electromagnetic Compatibility EMC'06. Wroclaw, Poland, p.482-485, 2006.

[8] KOTLYARENKO N. F. and all, Way's block and autoregulation, Moscow, Russia: Transport, 1983.

[9] KOTELNIKOV A. V., NAUMOV A.V., SLOBODYANYUK L. P., Rail circuits in the conditions of influence of grounding devices. Moscow, Russia: Transport, 1990.