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TIME-FREQUENCY METHOD OF DETECTION OF RETURN TRACTION CURRENTS ON TRACK CIRCUIT IN ELECTROTRACTIVE SYSTEM OF SERBIAN RAILWAYS

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Key words: *Return traction currents, track circuit, method, detection*

Abstract: *The results of perennial explorations impact of return traction current on track circuit in electro-tractive system of Serbian Railways has accomplished the new method of detection which enable the safely define of impact of traction current on track circuit. A new method of detection of electromagnetic compatibility traction current and track circuit applied of signaling devices of railways electro-tractive systems using the Short Time Fourier Transformation (STFT) is presented. This particular kind of signal analysis makes the determination of changes of the spectral power density of a signal in function of possible time. In this paper the results of joint time-frequency analysis of the potential of track circuit in the field of return traction currents stray generated by tram-line are presented. Presented results unambiguously show the possibility of accurate identification of source of return traction currents and its interference on the underground metal construction.*

INTRODUCTION

Track circuit is the fundamental method of train detection [1]. The first track circuit, based on a DC technology, has been invented at the end of nineteenth. Over the years, the continuous technological development has enabled to realize track circuits in an increasingly performing way by using AC technology and modulations, but the basic principle for train detection is still the same.

An alternative approach is the Axle Counter system, which uses a “check-in/check-out” logic. By comparing the result for the axles counted in a block section with the result for those counted out, it is possible to know the status of the track section (free or occupied).

Track circuits contributes also for the vehicle’s speed control, since the electrical signals used for train detection can be exchanged between wayside and on-board for the transmission of speed commands. This can be realized through a modulation of the track signal and is known as “coded track circuits”. Perhaps, no single invention in the history of the development of railway transportation has contributed more towards safety and dispatch in that field than the track circuit.

Alternative current (AC) electrical railway system applied in Serbian Railways (25 kV, 50Hz) is a single-phase asymmetric consumer of electrical energy that can significantly affect to sensitive track circuit applied of signaling devices by return traction current. The return traction current distributing in the subway system is a complex problem about electric current field, which is connected with tunnel structure, tunnel space geometry size and relative position between the locomotives. The return traction current distributing model is simplified mainly from two aspects: (1) the space problem simplification for the plane problem; (2) the current electric field problem simplified for the circuit problem of distribution parameters. In the study of return traction current distributing model, when faced with the situation that multi-locomotive and several power supply substations is concerned, common method is to simplify it to single train with single substation (unilateral power supply).

Overall, a variety of methods is used to analyze return traction current distribution, including: resistive type network model [2], finite cell model [3], Π type finite cell model [4], earth return circuit model [5], lumped parameter model [6], equivalent semi-cylinder layer model [7], hemispherical electrode model based on electric field [8], longitudinal sectioning model (A transversal equivalent circuit is developed based on a 3-D soil modeling for each section) [9], model based on the Tableau method [10]. The resistive-type model is shown in Fig. 1.

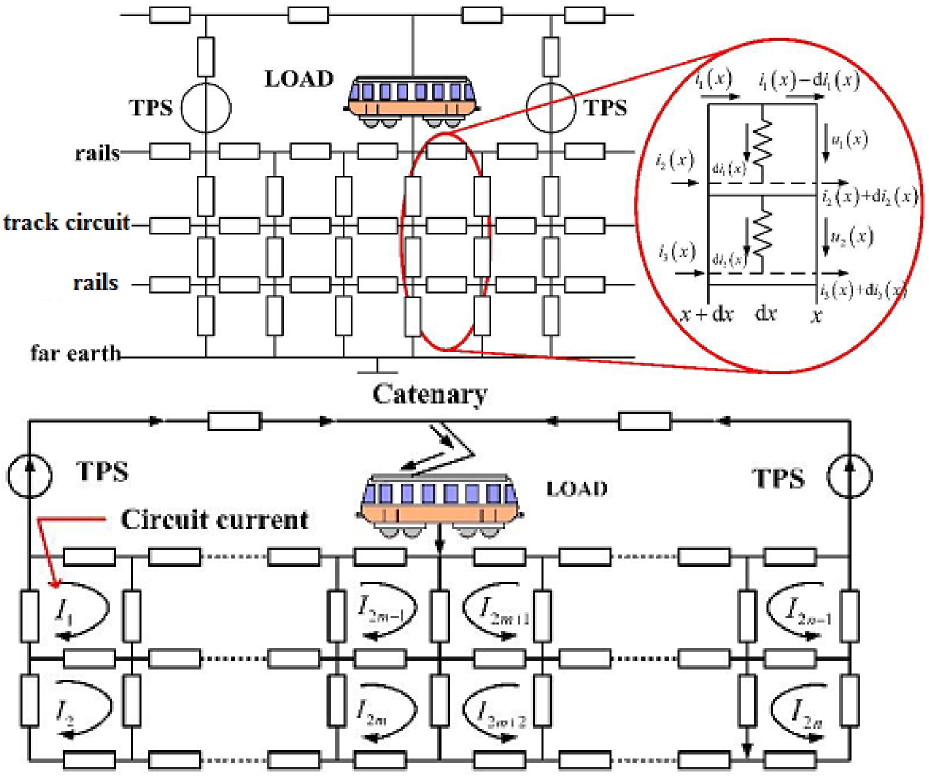


Fig. 1 Resistive-type network model (a) Continuous stray current distributing model; (b) Discrete stray current distributing model

In the model, the locomotive is often simplified as an ideal current source, the static model is referred to as the fixed locomotive traction current in time domain, the dynamic model is referred to as the locomotive position changing with distance and time. In terms of model solution method, methods like algebraic computation, numerical solving method, and software simulation is included in view of the complexity of different models.

Traditional return traction current distributing model is mainly based on the resistor network to analyze the return traction current static distribution, in which the actual ac traction system is abstracted to resistor network model. Traditional return traction current has been applied to many existing return traction current monitoring system [11, 12]. As aforementioned, many simplification methods are used for the traditional model to make the solution easier, and the model expression is more straightforward. However, due to the simplification, the engineering environment of the traditional model is relatively ideal, not considering the distribution of return traction current in special cases such as soil resistivity changing, pipe coating damage, and rail insulation damage etc. [13].

Different from the simplified analysis of the theoretical model, the simulation analysis is an effective tool to analyze the return traction current distributing under complicated environment. Many scholars used these methods to do a lot of study. Return traction current simulation analysis has a variety of ways, such as the finite element method (FEM), MatLab simulation, CDEGS (current distribution, electromagnetic field, grounding and soil structure analysis) simulation, etc. [13].

The finite element method (FEM) offers the possibility to model return traction current interference on 3D structures. The technological difficulty of return traction current distributing FEM simulation is to simplify the actual subway ac traction reflux system effectively, on the basis of guaranteeing system characteristics. Meanwhile, the boundary condition for the actual FEM calculation on the 3D structure is particularly important. Nevertheless, the FEM is limited in the size of models that can be handled.

Return traction current distributing simulation in Simulink is based resistor network and has the characteristics of discretization. However, as discussed above, it can be seen that the influencing factor analyzed by the MatLab simulation is more simplified, which is far from the actual operation conditions, [14].

Different simulation methods have different characteristics, but all can analyze the return traction current distribution under the track circuit applied of signaling devices. Compared with the mathematical model of return traction current, the parameters are more complex, thus the safety hazard of return traction current can be evaluated through of a variety of methods. Many scholars have carried on the simulation research to the performance of the CDEGS (current distribution, electromagnetic field, grounding and soil structure analysis. But the performance of CDEGS is still unsatisfactory in actual engineering operation, which is closely related to the structure of CDEGS. Through the existing analytical methods and simulation methods, the optimization of the SCCM remains to be further studied to improve the drainage efficiency of SCCM in actual engineering operation.

However, for the actual ac traction system, the results of existing models show a big difference with actual numerical value. Therefore, the purpose of calculating in the existing models is analyzing the effect of various factors on return traction current distribution qualitatively and providing guidance of traction current protection in theory.

In many cases detection of influence of return traction current is usually being carried out on the basis of the measurement of potential [15]. Simultaneous measurement of potential of track circuit and the voltage between it and expected source of return traction current [16].

The main disadvantage of this method is a direct connection of investigated track circuit and expected source of return traction current by means of the meter (in this way the source and the analyzed track circuit are physically connected by resistance of the meter) – the resistance of the layer consisted of the soil and isolation of the track circuit is comparable to resistance of the meter.

All mentioned above methods of detection of return traction current consist in the measurement and the analysis of changes of potential in the time domain. As the rule of thumb, the analyzed changes of potential have stationary characteristics. However, return traction current is an example of non-stationary signals because their mean value and the standard deviation change over time [16]. Joint time-frequency analysis makes analysis of non-stationary signals possible [17].

ANALYSIS OF CHANGES OF VOLTAGE IN JOINT TIME–FREQUENCY DOMAIN

Let us assume, track circuit A is a generator of return traction current. Measurement of the $U_A(t)$ voltage in a function of time between auxiliary electrode and the track circuit from which the leakance of return traction current takes place allow to determine them. The registered changes of voltage characterize the track circuit and are manifested in the form of frequency composition. In other words the frequency spectrum of registered voltage characterizes the track circuit. Performing of Fourier transformation of $U_A(t)$ voltage leads directly to frequency spectrum. This method of analysis is effective when voltage changes are stationary. The return traction current is not stationary signals. Their mean value and the standard deviation depend on the time of measuring. In case of non-stationary changes of voltage Fourier transform gives averaging results. Therefore the result of the analysis strongly depends on the time of measuring. It explains the luck of development of methods of return traction current analysis in the domain of time. The effective methods of non-stationary signals analysis are joint time-frequency methods. One of them is Short Time Fourier Transformation (STFT). STFT is described by the following relation:

$$\text{(1)} \qquad STFT\{U(t)\} = \int U_A(\tau)\cdot\gamma(\tau - t)\cdot\exp(-j\omega\tau)\cdot d\tau \ ,$$

where: γ - window function, t - time of window location.

Distinct from regular Fourier transform in STFT the window function is applied. Window function located in time t cuts out fragment of analyzed signal U_A(t). Then the regular Fourier transformation is performed for this fragment. Spectral power density spectrum of a signal is created and it corresponds to time *t*. In the next step the time window is moved to the next fragment of time and the new portion of analyzed signal is being cut out. By moving the time window on the time scale and repeating the process of performing Fourier transformation for cut out portions of the analyzed signal, we can obtain its spectral power density spectrum. The implementation of the window function $\gamma(t)$ makes the analyzed signal $U(t)\gamma(t)$ reaches zero beyond the window frame. This method of analysis allows determination of spectral power density in functions of time. In practice a variety of types of window function are used: rectangular, Hanning, Hamming, Blackman, Gauss [18]. However, Gauss window function is crucial in STFT:

$$\text{(2)} \qquad g(t) = \frac{1}{(\pi\cdot\sigma)^{\frac{1}{4}}}\exp\left(-\frac{t^2}{2\sigma^2}\right),$$

where: σ - parameter characterizing the width of window.

Applying the STFT for Gauss peak, which is determined in time domain, we can transfer its analysis to the joint time-frequency analysis. Time and frequency resolution of such analysis depends on the range of cut out portion of the signal that is described by parameter σ. The relation between time σ_t and frequency σ_ω resolution is described by:

$$\text{(3)} \qquad \sigma_t^2\cdot\sigma_\omega^2 = \frac{\sigma^2}{2}\,\frac{1}{2\cdot\sigma^2} = \frac{1}{4}\ .$$

The increase of σ is tantamount to the increase of the range of time window. It causes the increase of σ_t, thereby the deterioration of resolution of analyzed voltage in time domain and simultaneous improvement of resolution in frequency domain. Inversely: deterioration of time resolution entails (bring about, involve) improvement of time resolution.

EXPERIMENTAL

The test experiment was performed with the setup presented in Figure 2. The aim was to detect several sources of electric field in the ground. The measurements were performed in the electric field generated simultaneously by two controlled sources of return traction current on track circuit, i.e. alternating-current (AC) generators (Agilent Ltd, Santa Clara, CA, USA). Each generator was connected to one pair of auxiliary stainless steel electrodes placed in the soil 10 m apart. The soil resistivity was 60 Vm. A voltage $U(t)$ was registered between two identical measurement electrodes R_1 and R_2 placed on the ground surface 1 m apart. Copper/saturated copper sulphate reference electrodes were used. The measurements were carried out with a 16-bit National Instruments PCI-6052E card. The sampling frequency was 10 Hz.

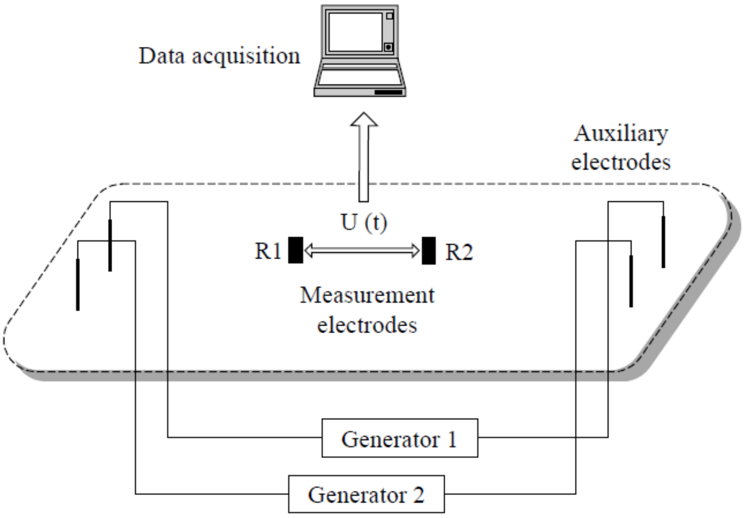


Fig. 2 Arrangement of the test experiment setup

RESULTS AND DISCUSSION

The scheme of investigated system is presented in Fig.3.

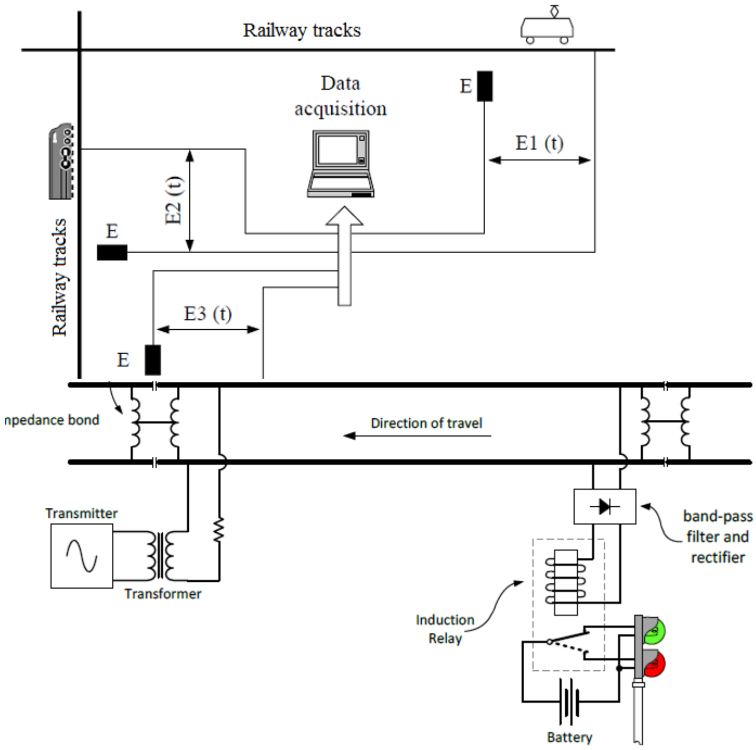


Fig. 3 Arrangement of the main experiment setup

The generator of return traction currents was electric raiway-line. The investigated track circuit is energized by an alternating electrical current with a frequency of 83.5Hz, to avoid interference from the return traction current. Three potentials were registered simultaneously with respect to the reference electrodes *E*: potential $E_1(t)$ of railway tracks, potential $E_2(t)$ of railway tracks and potential $E_3(t)$ of the track circuit. The potentials of the railway tracks were measured using portable copper/saturated copper sulphate reference electrodes, placed on the ground surface 1m from the rails. The track circuit potential was measured using so-called "permanent" copper/saturated copper sulphate electrode, buried and installed close to the track circuit. Soil resistivity was equal to 110 Vm. The measurements were carried out using 16-bit data loggers manufactured by IQ Computer Board. The sampling frequency was 8 Hz.

An analysis of the registered signals was obtained using "LabView" joint time-frequency analysis software.

Figure 4 shows an example result of the test experiment. Initially two generators were operating: generator 1, sinusoidal field 1.5 Hz output amplitude 6 V; generator 2, sinusoidal field 1.0 Hz output amplitude 3V. The former was turned off after 150 s, the latter after 290 s.

The result of the experiment performed on the track circuit in the interference area of return traction current generated by two AC powered rail transit systems is depicted in Figure 4. The spectrogram "(a)" shows the energy changes of the track circuit potential in the joint time and frequency domain. Spectrogram "(b)" – shows the energy changes of the rails potential, and Spectrogram "(c)" – shows the energy changes of the rails potential. These potentials were registered simultaneously.

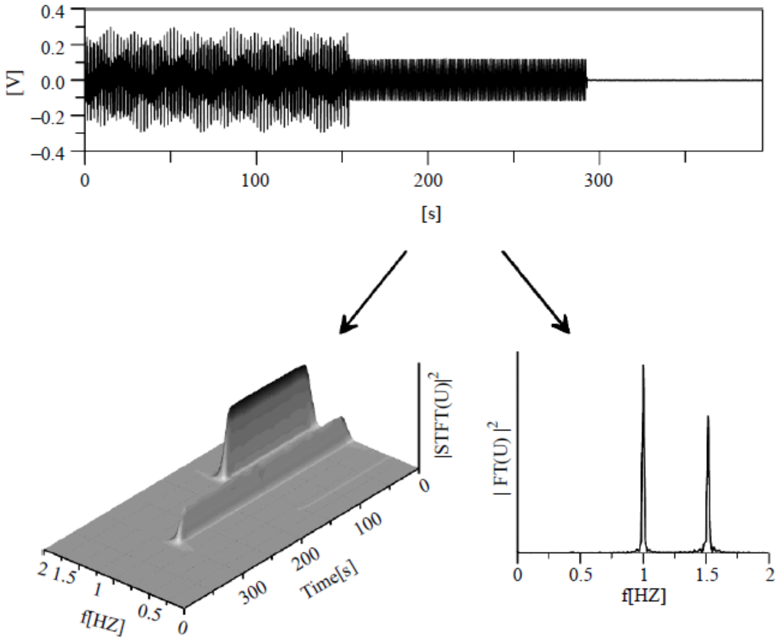
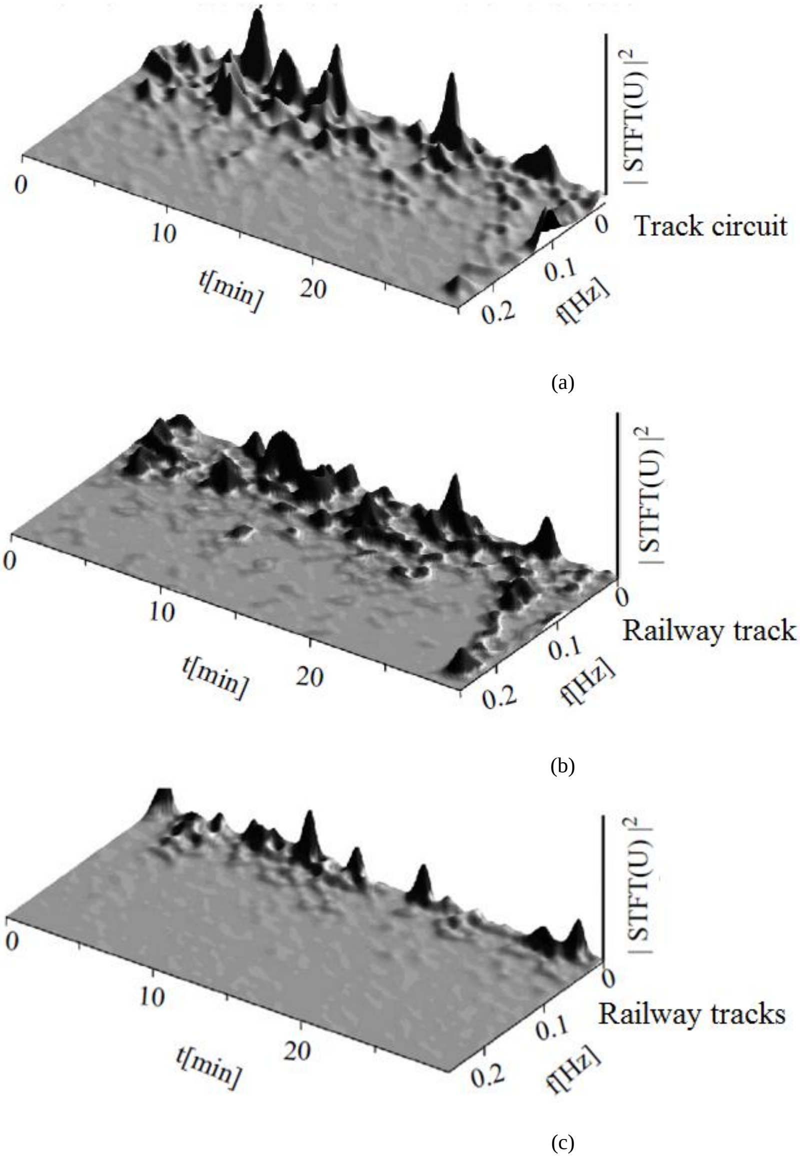


Fig. 4 Time register of voltage between measurement electrodes in the presence of two AC fields 1.5 Hz and 1.0 Hz generated in different instants of time, its classic Fourier transformation spectrum (FT) and its spectrogram (STFT)

The STFT spectrogram in Figure 4 indicates the presence of frequencies 1.0 and 1.5 Hz in the measured signal. It is also possible to compare the energies of both frequency components. It can be seen that the energy of the signal 1.5 Hz was higher than was the energy of the signal 1.0 Hz. Moreover, the periods of current generation by each source are evident in the spectrogram on the time axis.

The depicted result illustrates that the joint time-frequency analysis allows detection of the presence of several electric current sources (in this case AC generators). Thus, the STFT analysis results in complete time and frequency characterization of the electric field generated by each source. This information is inaccessible using the classic Fourier transformation, which gives an averaged result for the entire period of measurement. Moreover, the frequency spectrum FT shows higher energy of the signal 1.0 Hz than of the signal 1.5 Hz (the inverse of reality), which results from longer duration time of the former.

The spectrograms “(a)” and “(b)” in Figure 5 are similar in form. It can be observed that at certain moments of the time, the signal energy for the same frequencies increases on both spectrograms. The changes in the spectral power density of the measured signals versus time are the same on the spectrograms “(a)” and “(b)”. This characteristic shape of both spectrograms correlated closely with railway traffic.



(a)

(b)

(c)

Fig. 5. STFT spectrograms of registered simultaneously ((a) Track circuit potential; (b) railway track potential; (c) railway track potential

The same time and frequency location of spectral lines on the spectrograms “(a)” and “(b)” gave unequivocal proof that the return traction generated by passing railway vehicles affected the state of the investigated track circuit.

The shape of the spectrogram “(c)” correlated with the railway traffic. It is indicated by an increase of the signal energy for very low frequencies at certain moments of time. The localizations of spectral lines on the spectrograms “(a)” and “(c)” were not the same. This means that return traction current generated by the railway line did not interact with the investigated track circuit.

The conclusion is important in respect of railway protection: in order to mitigate return traction current effects, the presented results point to the necessity of installing a drainage bond only between the track circuit and the railway tracks. A drainage bond to the railway rail would be needless.

CONCLUSION

The presented results illustrate the exemplary use and the advantages of the applied analysis method. This method allows determination if and which return traction current source(s) interact(s) with the investigated track circuit. The identical time and frequency localizations of spectral lines on the spectrograms corresponding to the track circuit and return traction current source identify conclusively the interference source.

The same time and frequency localization of peaks on spectrograms performed for voltage signals of source and investigated track circuit versus reference electrode indicates the interference of electromagnetic field generated by passing traction vehicles. The measurement of voltage changes of the source and the analyzed track circuit is carried out independently. In other existing methods the voltage between the source and the track circuit is measured. Carrying out of such measurement causes the fact that the analyzed track circuit and the source are physically connected by means of resistance of the meter. It may determine the changes of the potential of the track circuit. When the STFT spectrograms performed for voltage of structure-electrode and voltage of rail electrode differ from each other significantly (it is manifested by lack of characteristic spectral lines corresponding to time of tram passing and different shape of spectral power density spectra) it indicates the lack of interference of return traction current on track circuit.

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ВРЕМЕВО-ЧЕСТОТЕН МЕТОД ЗА ОТКРИВАНЕ НА ОБРАТНИ ТЯГОВИ ТОКОВЕ НА КОЛОВОЗ В ЕЛЕКТРОСНАБДИТЕЛНАТА СИСТЕМА НА СРЪБСКИТЕ ЖЕЛЕЗНИЦИ

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Ключови думи: *обратни тягови токове, релсова верига, метод, детектиране*

Резюме: *Резултати от въздействието на обратния тягов ток върху релсовата верига в електро-тяговата система на железниците на Сръбската република, дадоха възможност да се разработи нови метод, който позволява безопасното откриване и определяне на въздействието на тяговия ток върху релсовата верига. Представен е нов метод за откриване на ток на електромагнитна съвместимост и на релсови вериги, прилагани от сигналните устройства на електро-тяговите системи за променливотокови железопътни линии с използване на краткотрайно преобразуване на Фурие (STFT). Този специфичен вид анализ на сигнала прави определянето на промените в спектралната плътност на мощността на сигнала в зависимост от възможното време. В тази статия са представени резултатите от съвместния времево-честотен анализ на потенциала на релсовата верига в областта на отклоненията на обратните тягови токове, генерирани от трамвайната линия. Представените резултати недвусмислено показват възможността за точна идентификация на източника на възвратни тягови токове и неговата интерференция върху подземната метална конструкция.*