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Level Crossing Activation Time Prediction in Dependence on the Train Real Speed

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ABSTRACT

The analysis of accidents at level crossings showed that a significant number of them have been occurred at the automatic crossings with signalling lights and automatic half barrier crossings. One of the main causes of accidents is that road users do not obey the warning signals at crossings due to excessive waiting time because real speeds of different trains can vary greatly, while approach distance to crossings is determined for the fastest trains with maximum permissible speed. The purpose of this work is the mathematical justification of the method for the level crossing activation time prediction in dependence on the real speed of an approaching train, based on measurements of input track circuits' impedance at approach section. The investigations have been carried out by mathematical modeling of track circuits' operation modes during train movement. The relative error of the method has been determined.

KEYWORDS: telematics, transport, level crossings, waiting time

1. Introduction

Level crossings (LCs) are the places where railway and motorway meet in the same level and so they are one of the most dangerous areas for the rail and vehicle traffic. Number of traffic accidents at level crossings has decreased in recent years, but is still large (fig. 1). The analysis of accidents at level crossings showed that significant number of them has been occurred at the automatic crossings with signalling lights and automatic half barrier crossings (fig. 2). A similar situation is typical for many countries. For example, in Europe more than 300 deaths per year occur due to accidents at level crossings [1], and most of them happen at open LCs. One of the main reasons of accidents is the violation of the traffic rules by the road users and drive through closed LCs. It is often provoked by excessive waiting time for cars at a closed level crossings caused by the slow moving train. Activation of an automatic LC's system occurs when a train enters a part of a track at LC approach section, the length of which is determined by the safety requirements for the fastest trains moving at the maximum allowable speed. The real speed of different trains can vary greatly. To improve safety on the LCs various methods for monitoring of the movement of cars in the LC area as well as the speed and location of the train on the track at LC approach section were proposed [2-5].

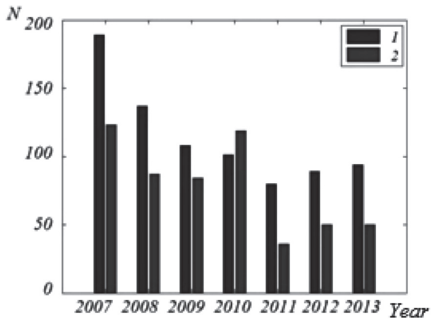

Fig. 1. The number of traffic accidents at Ukrainian level crossings (1) and the number of victims in them (2) [1]

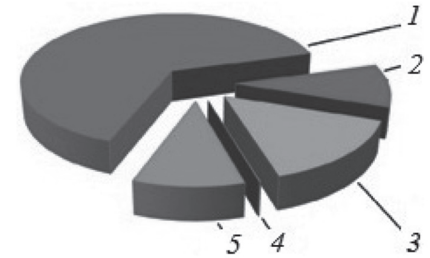

Fig. 2. Percentage of traffic accidents depending of LCs types: 1- the automatic crossings with signalling lights; 2- automatic half barrier crossings; 3 - barrier LCs operated by staff; 4 - LCs operated by staff; 5- accidents outside the LC zone [1]

Track circuits (TCs) are often used to detect the presence of the train in the LC approach section, therefore methods for monitoring the location of the train in the approach to LC area based on analysis of the TC parameters in the frequency [6] and time [7,8] domain are of practical interest. However, the problem is that the parameters of the track circuit are significantly affected by the ballast resistance, which varies in an uncontrolled manner. The purpose of this work is to improve the method of predicting a reasonable time for activating an LC's signaling system depending on the real speed of the train by correct determination the location and speed of the train in the LC approach section. To achieve the goal the problem of improving the accuracy of determining the localization of a train by measuring the parameters of a TC have been carried out. The investigations have been performed by modeling of the track circuit input impedance in depending of train location with variation of the ballast resistance.

2. Mathematical model

The equivalent circuit of an TC with absence of vehicle on it (in normal operation mode) is represented as series-connected two-poles and four-poles elements (Fig. 3 (a)) where the following notations are adopted: TTU and RTU are tuning units, respectively, at the transmitter and receiver ends of TC, RL is the rail line, $\underline{Z}_a$ and $\underline{Z}_b$ correspond to the impedance of adjacent track circuits for jointless TCs, $\underline{Z}_R$ is impedance of a receiver. The equivalent circuit of a TC with train on it includes additionally $\underline{Z}_S$ - train shunt impedance located at coordinate x that counted from TC's input terminals (fig. 3 (b)). The signal current $\dot{I}_1$ with voltage $\dot{U}_1$ and frequency 25 or 50 Hz for code TCs and 420, 480, 580, 720, 780 Hz for audio-frequency TCs is fed to the input of track circuit from the transmitter.

The matrixes in A-form for all elements of equivalent circuits (Fig. 3) were obtained as in [7]. The general matrices for track circuits that consists of series-connected elements were calculated as the product of matrixes for all elements of TCs

$$\underline{M}_0 = \prod_i \underline{M}_i \qquad (1)$$

The input impedance Z_{inp} of the track loop terminated by train's shunt was determined as

$$\underline{Z}_{inp} = \frac{\underline{M}_0(1,1)Z_s + \underline{M}_0(1,2)}{\underline{M}_0(2,1)Z_s + \underline{M}_0(2,2)} \qquad (2)$$

where $\underline{M}_0(i,j)$ is element of general matrix M_0.

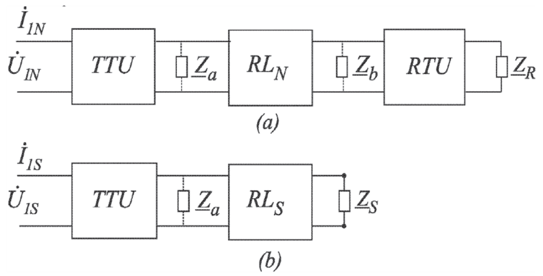

Fig. 3. Equivalent circuit of TC with absence of vehicle on it (normal operation mode) (a) and with train on it (shunt operation mode) (b) [own study]

3. Results

Modulus of input impedance $Abs(Z_{inp})$ for code and audio-frequencies track circuits with length from 0 to 300 m depending on train coordinate x are shown in Fig. 4.

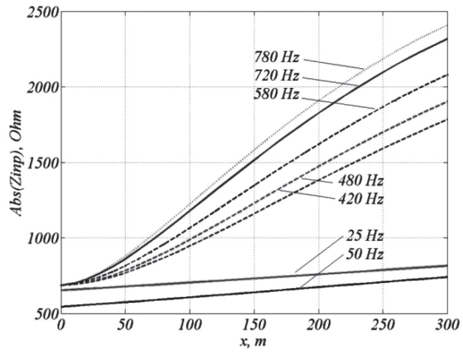

Fig. 4. Dependencies of modulus of TC's input impedance on train coordinate for different signal frequencies [own study]

Monotonous dependencies of TCs' modulus of input impedance $Abs(Z_{inp})$ from train coordinate x allow us to use them for determining train coordinate by measured values of input impedance of track circuit. The resolving ability of this method, that characterized by the rate of TC's input impedance changing with coordinate x is increased with frequency (Fig. 4).

The relative change of TC's input impedance Z_{inp} with variation of ballast resistance r_b were calculated to evaluate ballast resistance affect on accuracy of the method as follows

$$\underline{Z}_r(x) = \frac{\left(\underline{Z}_{inp}(\mathrm{x}, r_{b2}) - \underline{Z}_{inp}(\mathrm{x}, r_{b1})\right)}{\underline{Z}_{inp}(r_{b1})} \qquad (3)$$

where r_{b1}=0,8 Ohm/km is the minimum value of the ballast resistance, allowed by the safe operation conditions of the track circuits, r_{b2}=50 Ohm/km is the maximum value, ballast resistance above which the increase in its value practically does not affect the parameters of the TC. Module of relative change of

TC's input impedance depending on signal current frequency and train coordinate is shown in fig. 5.

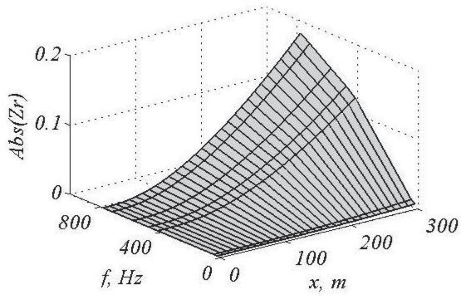

Fig. 5. Dependence of the module of relative change of TC's input impedance on the frequency and coordinate [own study]

According to this dependence, the relative error of the method has values acceptable for practical use (<1 %) only for signal frequencies of 25 and 50 Hz and for short track circuits (<300 m). As the frequency of the signal current or track circuit length increases, the relative error significantly increases also.

Therefore, the practical application of the method of determining the coordinate of a train on the basis of the measured TC's input impedance is possible only after obtaining additional information on the current ballast resistance value and intelligent processing of the measurement results [9]. For this purpose the general dependencies between input voltage and current at TC's feeding terminals and parameters of track circuits for various operation modes of TC were considered as follows

$$\bar{V}_{1N} = \left|\dot{U}_{1N} \;\; \dot{I}_{1N}\right| = F_N\left(rb, f_s, L_{TC}\right); \quad (4)$$

$$\bar{V}_{1S} = \left|\dot{U}_{1S} \;\; \dot{I}_{1S}\right| = F_S\left(x, r_b, f_s\right); \quad (5)$$

$$\bar{V}_{1B} = \left|\dot{U}_{1B} \;\; \dot{I}_{1B}\right| = F_B\left(x_B, r_b, f_s\right); \quad (6)$$

In these expressions L_{TC} is the length of TC, f_s is a signal current frequency, x_B is coordinate of broken rail; index N corresponds to normal operation mode of TC, index S –shunt operation mode and index B – a mode with a broken rail.

The intelligent data processing system at the first stage determines TC operation mode (normal or shunt) by the measured values of the input electric vector V_1. If the track circuit operates in normal mode the system determine ballast resistance r_b by using dependence between r_b and input vector V_{1S} in accordance to known dependence (5). Based on the assumption that the coordinate of the train when it moves within track circuit changes much faster than the value of the ballast resistance r_b we can assume that r_b practically does not change during this time. Therefore we can assume that ballast resistance value in shunt operation mode is equal to the value r_b measured just before the train has entered the track circuit. As a result we can use obtained value r_b to improve accuracy of determination of the train coordinate based on measured TC input voltage and current in shunt operation mode.

For track circuit mode when the rail is broken (TC failure mode), the voltage and current at the input terminals of the track circuit change their values abruptly and then the electrical values of the input signal change slightly due to fluctuations in the ballast resistance. This mode can be mistaken for an emergency stop of a train on a track circuit. In both these cases the intelligent data processing system forms a warning signal transmitted to the control centre.

4. Conclusion

To improve the method of predicting a reasonable time for activating an level crossing signaling system depending on the real speed of the train the problem of increasing accuracy of determining the localization of a train by measuring the parameters of a track circuit have been carried out. The investigations have been performed by modeling of the track circuit input impedance in depending of train location with variation of the ballast resistance. For practical application of the method the intelligent data processing system have been proposed.

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