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SIMULATION STUDY OF A TRACK CIRCUIT TO DETERMINE THE TRAFFIC PARAMETERS OF A RAILWAY VEHICLE

BADANIA SYMULACYJNE OBWODU TOROWEGO DO WYZNACZANIA PARAMETRÓW RUCHU POJAZDU SZYNOWEGO

Abstract

The article is about a range of issues concerning the possible use of track circuits, consisting of rail lines and impedance bonds for continuously monitoring traffic parameters of a rail vehicle moving within a separated track section. The solution to this problem may be useful in many applications and various types of rail traffic control systems that use track circuits as a source of information about the track block occupancy. One possible application may be in automatic railway crossing signalling systems (ARCS) for approach sections. In that application, the carried out measurement of the position and speed of a rail vehicle allows to determine a pre-warning time for the railway crossing.

Keywords: electric transmission line, track circuit, location of a railway vehicle on a track, constant-time automatic railway crossing signalling devices

Streszczenie

Tematem niniejszego artykułu są zagadnienia dotyczące możliwości wykorzystania obwodu torowego, zbudowanego z wykorzystaniem toków szynowych i dławików torowych, do ciągłego wyznaczania parametrów ruchu pojazdu szynowego przemieszczającego się po tym, wydzielonym odcinku torowym. Rozwiązanie tego problemu może być przydatne w wielu aplikacjach wykorzystujących obwody torowe jako źródło informacji o niezajętości odcinka w różnego rodzaju systemach sterowania ruchem kolejowym. Jedną z takich aplikacji może być możliwość zastosowania obwodu torowego w urządzeniach samoczynnej sygnalizacji przejazdowej jako odcinka zbliżania. Na odcinku tym wykonywany pomiar położenia i parametrów ruchu pojazdu szynowego może pozwolić na określenie czasu dojazdu pojazdu szynowego do przejazdu kolejowego.

Słowa kluczowe: elektryczna linia długa, obwody torowe, lokalizacja taboru szynowego na odcinku toru, stałoczasowa sygnalizacja przejazdowa

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1. Introduction

The article presents the first phase of simulation studies in which the preliminary analysis is presented in order to choose the frequency of the measurement signal powering the track circuit and a suitable configuration of the insulated track block. The measurement itself, which uses high-frequency sinusoidal signals for monitoring the rail vehicle, can be realized by low sampling rates (e.g. for a signal of 1050 Hz, the sampling rate could be 120 Hz).

Further stages of research will present the creation of an equivalent circuit, mathematical model of track circuit, and subsequently the simulation studies considering the possible variation of some parameters of the equivalent circuit caused by train passage taken into consideration, and finally, preliminary conclusions and findings.

An important issue of the study will be the analysis of the operational safety of such track circuits in this application. The classic approach to this problem requires the use of redundant structures of system, and in this case, the redundant measurement channels and data processing will be used.

This paper will conclude with indications for further research directions and possible modifications of the measuring system applied to track circuits.

2. Track circuits in RTC systems

In modern railway traffic control (RTC), automated equipment play a very important role. One of the main elements providing the information about track occupancy of a track block is the track circuit.

The insulated track block [13] is a track block section where two rails are insulated from each other and from the adjacent ones (not being part of an insulated section) and are a part of a track circuit. Sleepers and ballast should have maximum resistance to best isolate the two rails from each other and from the earth.

The track-circuit [13] is an electric circuit consisting of a transmitter and a receiver connected by rails, which are part of the railway track. The track circuit allows to control the occupancy of a particular block section of a rail track, i.e. the presence of a rail vehicle on it, and enables to check faults in the rails. In some cases, additional information on the speed and direction of a passing train is required. An example of a track circuit of a 1000 m length is shown in Fig. 1.

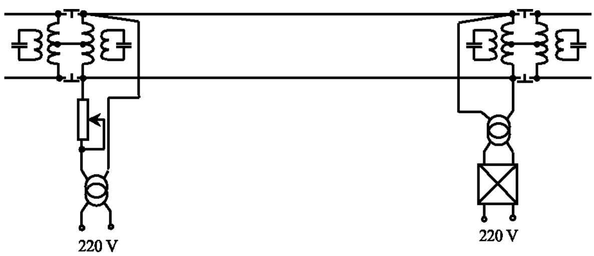

Fig. 1. Electrical diagram of a classic 50 Hz rail track circuit

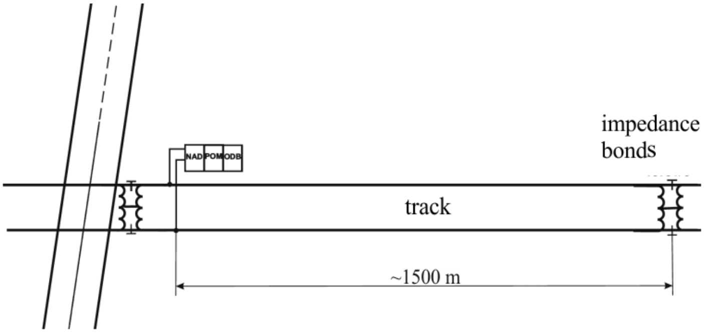

Fig. 2. Track circuit of the proposed solution for constant–time AOCR

3. Impedance bond as part of a high-frequency track circuit

Impedance bond is an important element of the track circuit. Its regulation determines the correct operation of the track circuit. A suitable connection of two chokes at the end of the track circuit allows the traction current to bypass insulated joints that divide the railway track into insulated block segments for AC signals. The impedance bond must have a very low resistance for the propulsion current (DC) and big enough impedance for the AC signal current. The impedance bond equivalent circuit is shown in Figure 3.

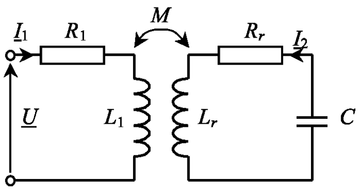

Fig. 3. The impedance bond equivalent circuit with coupled resonant circuit

The input impedance of choke is given by (1) [4, 14]:

$$Z_{dl} = \frac{U}{I_1} = \left[Z_1 + \frac{(\omega \cdot M)^2}{Z_2} \right] \tag{1}$$

where:

$Z_1 = R_1 + j\omega L_1$

$Z_2 = R_r + j\omega L_r - \frac{1}{j\omega C}$

R_1, L_1 – resistance and inductance of the primary winding,

R_r, L_r, C – resistance, inductance and capacitance of the resonant circuit.

When the secondary circuit is tuned to the resonance, i.e. when the condition (2) is met:

$$\omega L_r = \frac{1}{\omega C} \tag{2}$$

then:

$$Z_{dl} \approx R_1 + j\omega L_1 + \frac{\omega^2 \cdot L_1 \cdot L_r}{R_r} \approx R_1 + \frac{L_1}{C \cdot R_r} + j\omega L_1 \tag{3}$$

After substituting typical impedance bond parameter values, it gives (4):

$$Z_{dl} \approx 0.0006 + 0.00137f^2 + j0.014 \cdot f \tag{4}$$

where:

f – signal frequency used for measurement.

For higher frequencies, e.g. 1000 Hz, the choke impedance in resonance is very high (assuming some simplifications). If calculated, it is about 1 kΩ and is approximately purely resistive:

$$Z_{dl} \approx 1371 + 14j \approx 1371\ \Omega \tag{5}$$

4. Elementary components of the track block regarded as a transmission line

The insulated block of railway track in Fig. 2 can be regarded as a transmission line of the schematic shown in Fig. 4 [14].

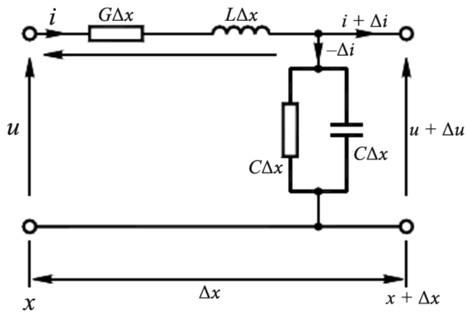

Fig. 4. Schematic representation of the elementary component of a transmission line (Δx = 1 m)

Electrical parameter determination, for a track gauge of 1435 mm with rail S-60 and steel St70P, at a temperature of 20°C, when the variability with respect to frequency is taken into account, has been carried out partly by field-calculations and partly taken from measured data.

The density of current distributions for the electromagnetic field is shown in Fig. 5 and 6.

The field-calculated resistance [1], approximated by the formula (6) as a function of the frequency, is shown in Fig. 7 [13, 15]:

$$R = 0.0533 \cdot \sqrt{f} \cdot 1e - 3\ \Omega/\text{m} \tag{6}$$

The distribution of flux density B in the rail is shown in Fig. 8 and 9.

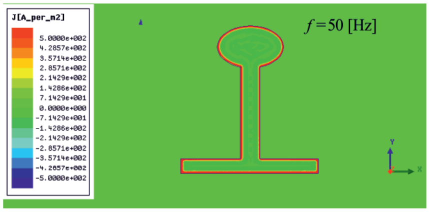

Fig. 5. Current density distribution in the rail's cross section for f = 50 Hz

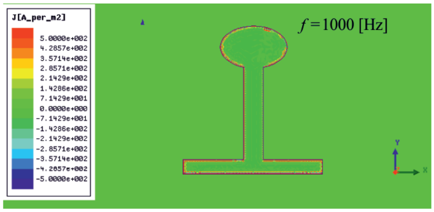

Fig. 6. Current density distribution in the rail's cross section for f = 1000 Hz

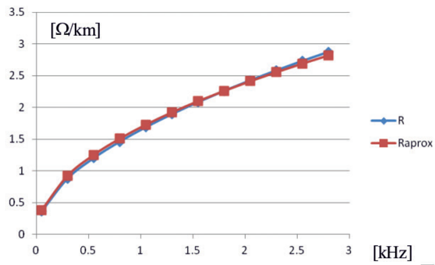

Fig. 7. Field-calculated resistance and its approximation with respect to the frequency

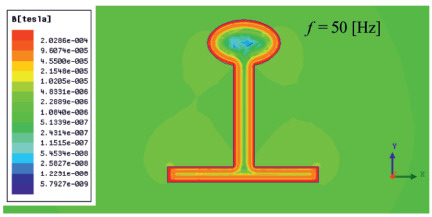

Fig. 8. Distribution of flux density B for f = 50 Hz

Fig. 9. Distribution of flux density B for f = 1000 Hz

The field-calculated inductance [1], approximated by the formula (7) as a function of frequency, is shown in Fig. 10.

$$L = 1.183567 + 8 / \sqrt{f} \cdot 1e - 6 \text{ H/m} \tag{7}$$

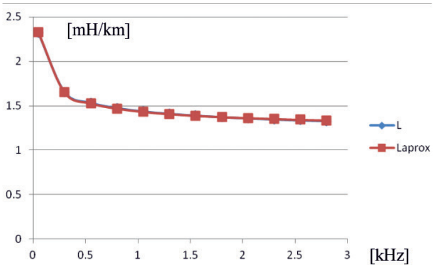

Fig. 10. Field-calculated inductance and its approximation with respect to the frequency

The capacity per unit length was measured by ORE and is within a range of 40–80 nF/km. For further calculations, the average value of 60 pF/m has been assumed:

$$C = 60e - 12 \text{ F/m} \tag{8}$$

The conductivity per unit length, between the rails, depends on the conductivity of the ballast (and weather conditions). It is within a wide range from 0.01 S km up to 0.2 S km. A large span of the train running speed on approach sections requires a solid new subgrade; therefore, it results in small elementary conductivity. For further calculations, the following interval was assumed:

$$G = [0.01 \div 0.1] \cdot 1e - 3 \text{ S/m} \tag{9}$$

Thus the resulting wave parameters of the transmission line, i.e. characteristic impedance Z_f and the propagation constant γ, are calculated from the formulas (10) and (11) [4, 14]:

$$Z_f = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{10}$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{11}$$

and their dependence on frequency for three values of $G = \{0.01, 0.05, 0.1\}$ mS/m is plotted in Fig. 11 and 12.

Due to the requirement of measurement uniqueness and given the periodic character of the current and voltage distribution along the transmission line, the length of the track circuit is to be less than 1/8 of the wavelength, i.e. should not cause major phase changes over 45° within its entire length.

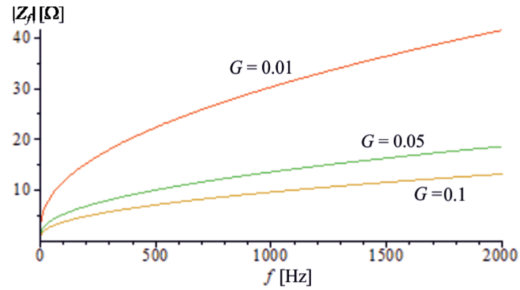

Fig. 11. Dependence of Z_f on the frequency for three values of G ={0.01, 0.05, 0.1} S/km

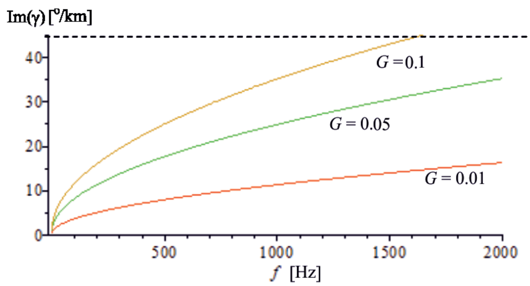

Fig. 12. Dependence of Im(γ) on the frequency for three values of G = {0.01, 0.05, 0.1} S/km

5. Configuration of track circuit for rail vehicle traffic parameters testing

Figure 13 shows the first or the last axle of a vehicle, located within an insulated block, ended with a impedance bond of impedance Z_{dl}. Measurement of the distance x, i.e. the distance of the vehicle from the AC source location, consists in the input impedance of the track measurement that depends on the x. The input impedance of the track is by definition the ratio of the phasors U_1 and I_1 i.e. $Z_{we} = U_1 / I_1$.

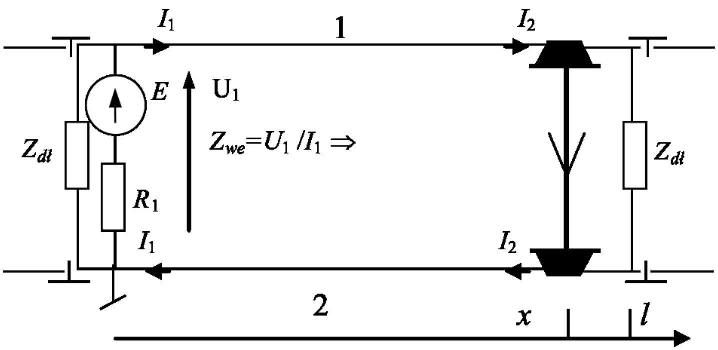

Fig. 13. System for measuring distance x of the vehicle realized by measuring the input impedance of the insulated track block

Calculation of the two parameters of input impedance of the track circuit, such as magnitude $|Z_{we}|$ and tg $\angle Z_{we}$, allows obtain the information about distance x from two sources: the measurement of magnitude and measurement of phase of Z_{we}, which is necessary for safety reasons (Duplicate Channel).

6. Simulation studies of track circuit in the application of measuring the position of a rail vehicle on a track section

It was assumed that the frequency of the supplied signal would be about 1000 Hz. For this frequency, it is possible to measure the position of the train, on an insulated track block, up to about 1000 m.

The insulated block of railway track (without a vehicle) of the length l can be regarded as an unloaded transmitting line of input impedance Z_{we0}.

The input impedance (magnitude $|Z_{we}|$ and tg $\angle Z_{we}$) depends on the length l of the insulated track block that is shorted or unloaded, and for the three values $G = \{0.01, 0.05, 0.1\}$ S/km, is shown in Figs. 14–16.

From the figures presented above, it is shown that, for $G \leq 0.1$ S/km and up to a distance of about 1000 m, it is possible to determine unequivocally both the entry into the monitored block by the rail vehicles (thanks to a clear difference between modulus and phase of Z_{weZ} and Z_{we0}) as well as tracking its position within the railway block section (thanks to $|Z_{weZ}|$ and tg $\angle Z_{weZ}$ dependence on position x of a rail vehicle).

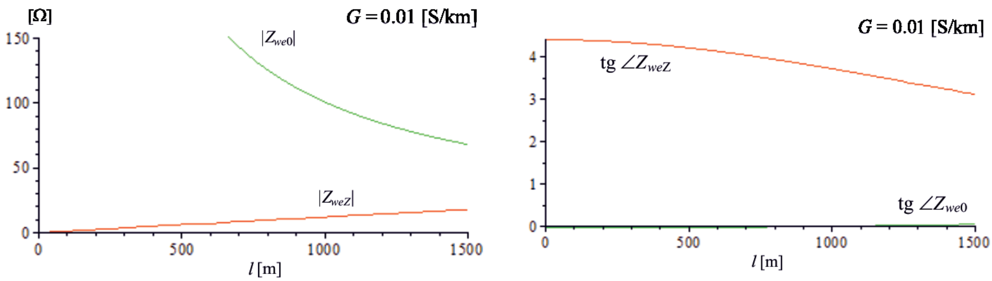

Fig. 14. The dependence of $|Z_{we}|$ and tg $\angle Z_{we}$ on track length l,where Z_{we0} and Z_{weZ} are input impedances of open and shorted track circuit for $G = 0.01$ S/km

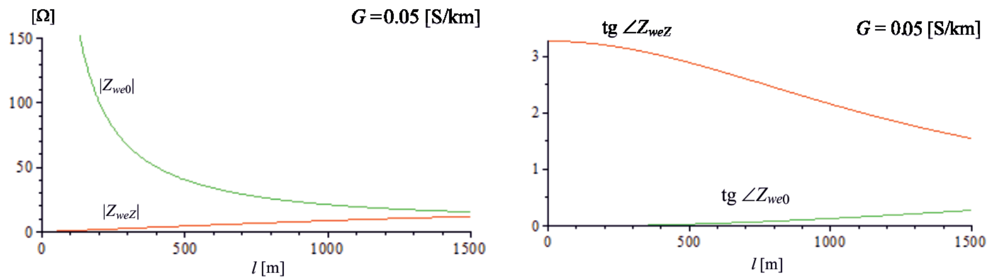

Fig. 15. The dependence of $|Z_{we}|$ and tg $\angle Z_{we}$ on track length l, where Z_{we0} and Z_{weZ} are input impedances of open and shorted track circuit for $G = 0.05$ S/km

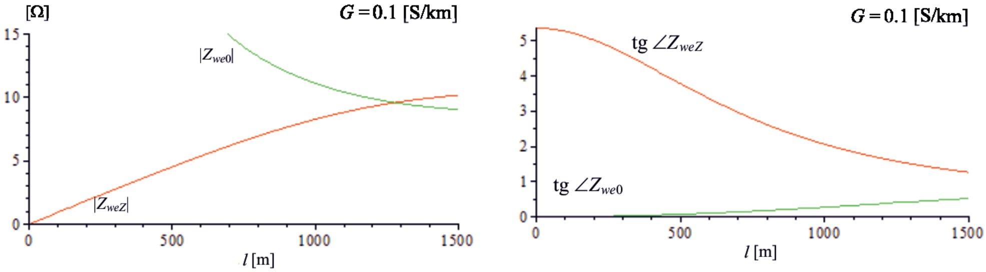

Fig. 16. The dependence of $|Z_{we}|$ and tg $\angle Z_{we}$ on track length l where Z_{we0} and Z_{weZ} are input impedances of open and shorted track circuit for $G = 0.1$ S/km

In addition, connecting an impedance bond in resonance to the end of track block does not change the input impedance of the track circuit, as it is shown in Fig. 17.

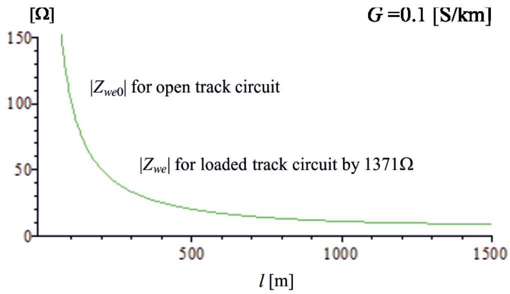

Fig. 17. Impute impedances $|Z_{we}|$ of the separated track block, for $G = 0.1$ S/km with respect to the length l, for open track circuit and loaded with resistance of 1370 Ω, are identical

Finally, if it is assumed the signal of frequency $f = 1$ kHz, then the following values for $|Z_{weZ}|$ and tg $\angle Z_{weZ}$ define unequivocally the position x of the rail vehicle within a monitored block (see Fig. 18).

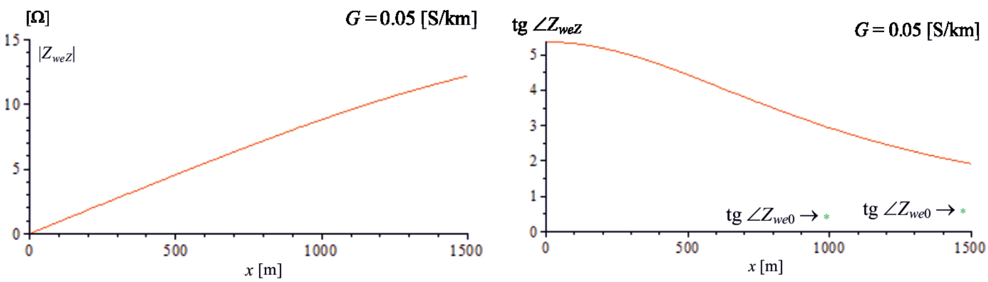

Fig. 18. Dependence of $|Z_{we}|$ and tg $\angle Z_{we}$ on distance x of the vehicle, measured from the beginning of the insulated track block (generator placement); Z_{we0} is the input impedance for open track circuit for track length of 1km and 1.5 km respectively, for $G = 0.05$ S/km

It is clear, from the above considerations, that this measurement method can be used both for electric traction and motor traction (with no traction currents and chokes) as well.

7. Possible use of the rail vehicle position and movement monitoring in automatic railway crossing signalling of an approach section

As it was explained in p. 6, the position of a rail vehicle on the track block consists in determining the two parameters: module $|Z_{we}|$ and $tg\angle Z_{we}$ of the track circuit input impedance when shorted by axle of the vehicle in distance x. These parameters depend on the length x i.e. $|Z_{weZ}|(x)$ and tg $\angle Z_{weZ}(x)$. Consequently, the module of input impedance and its argument will vary according to x (position of rail vehicle), which is shown in Figs. 14, 16 and 18.

Thus, the above presented positioning method can be used to measure the approach time of the rail vehicle to the danger zone of level crossing [3, 8, 9, 16].

Traffic safety at a level crossing is provided by an automatic signalling light with dams of road, called automatic railway crossing signalling devices (ARCS devices). These devices operate automatically, i.e. without human intervention.

Fig. 19 shows a typical layout of equipment ARCS devices on a category B level crossing of a double-track line. These are [9, 4]:

– dams of road – (1),
– acoustic indication warning drivers – (2),
– optical indication warning drivers – (3),
– track sensors, which detect entry of a rail vehicle on an approaching section – (5),
– sensors track stating occupation and leave the danger zone of a railway crossing through a railway vehicle – (6),
– optical indication warning drivers of rail vehicle, ToP – (4).

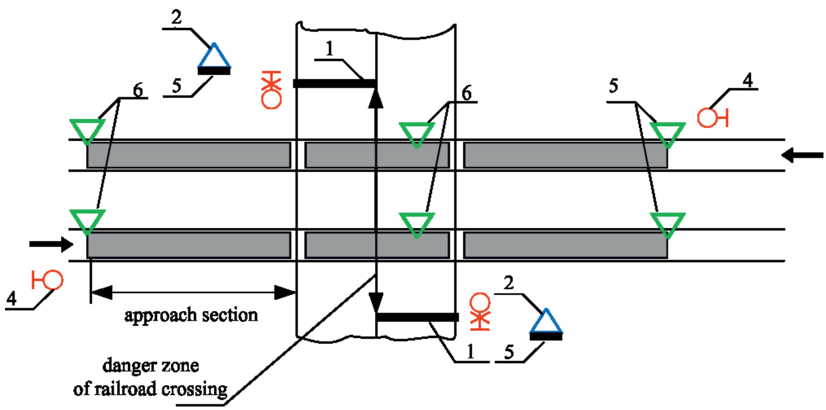

Fig. 19. Layout of automatic railway crossing signalling devices

From the point of view of ensuring the safety of road users, starting the warning process and closing the crossing must be initiated with an appropriate lead-time. This time, it is defined as the pre-warning time t_0 [6, 4]. When calculating this time, it is assumed that the rail vehicle is running at maximum permissible speed of force on the route of the railway and road vehicles leaving the danger zone passing move at the minimum speed. This t_0 time for the station's conditions, according to the decree of the Ministry of Communications [16], cannot be less than 30 s, and because of practical reasons, not more than 90 seconds. Thus, the time should be included in the range:

$$30\ \text{s} < t_0 < 90\ \text{s} \tag{12}$$

The general structure of the block diagram under consideration of automatic railway crossing devices is shown in Fig. 18 [9, 4].

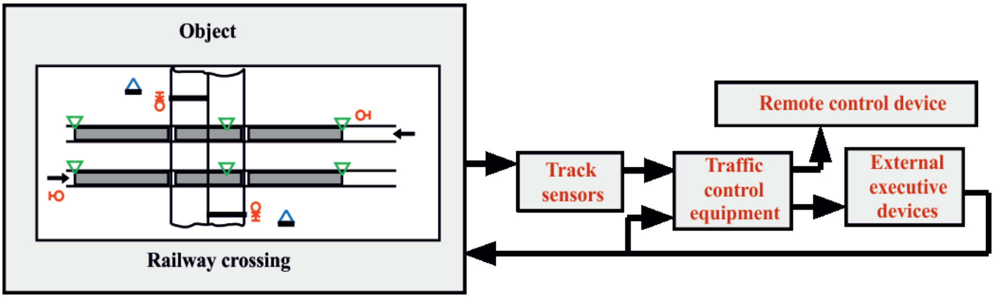

Fig. 20. The block diagram of automatic railway crossing devices

Control and measurement equipment – (traffic control equipment TCE) calculates the time of dams closing on the basis of the measured parameters $|Z_{weZ}|$ and tg $\angle Z_{weZ}$. This task can be carried out by a secure microprocessor controller of a measure-actuator device (controller of TCE) [9, 11, 12]. This is a two-channel controller of which one channel uses $|Z_{weZ}|$ and the second uses tg $\angle Z_{weZ}$ to calculate the approach time of rail vehicle to the level crossing. In case of any discrepancy between stored characteristics and measurement ones, for a given individual track, the controller interprets this situation as danger resulting in switching on warnings and closing dams, regardless of the calculated pre-warning time or distance to the railway vehicle.

8. Conclusions

This paper proposes the use of an insulated track circuit with an impedance bond, operating at a high frequency of 1000 Hz, for rail vehicle position monitoring. The simulation results of such circuit for different frequencies and different subgrade conditions acknowledge its ability to identify the position and speed of a rail vehicle according to changes of $|Z_{weZ}|$ and tg $\angle Z_{weZ,}$ up to about 1000 m. Therefore, it is possible to use this circuit to detect the rail vehicle on approach sections of the automatic level crossings and to determine the approaching time to the danger zone of railway crossings, and thus provide a constant pre-warning time and dam closing time. This solution enables constructing constant-time ARCS. For safety reasons, the measurement of the two independent parameters of a track circuit ($|Z_{weZ}|$ and tg $\angle Z_{weZ}$) are carried out, by safe two-channel control – measuring controller (controller of traffic control equipment TCE). The proposed solution may be useful for both electric and motor traction system, where the maximum allowed rail vehicle speed does not exceed 120 km/h.

Acknowledgment

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