**Mathematical Model and Algorithm for Determining the Shunt Zone by Train**

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**Abstract.** The article considers the development of a mathematical model of an adaptive continuous track circuit, and provides a method for determining the maximum bypass zone when removing a train from a track circuit. Based on the proposed method and the provided calculation algorithm, it is possible to conduct research and determine the optimal parameters of adaptive continuous track circuits. Based on which it is possible to take technical measures to reduce the length of the release of the track circuit by a train.

**Key words:** track circuits, continuous track circuits, shunt, four-terminal network, transmission resistance

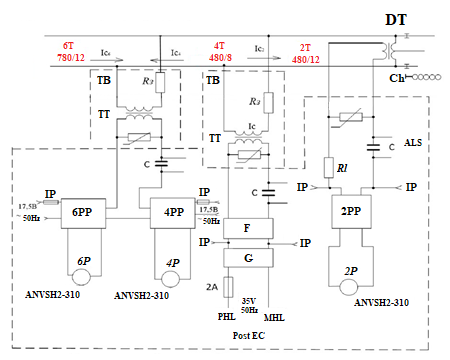
**INTRODUCTION**

The development and expansion of society leads to an increase in the development of industry and agriculture, which is based on the introduction of a new development method, so such aspects of industrial development as industry 4.0 are currently being considered, and in agriculture, bioengineering, robotics and automation [1]. To ensure sustainable development, reliable and safe use of logistics, provision of quality service in the field of transportation is required. Thus, one of the development trends of the present society is globalization and its expansion, creation and application with the integration of modern world technologies [2, 3]. To do this, we will consider three technologies with global integration, such as telecommunications, information technology and transport. For the subsequent development of the transport sector, it is necessary to develop a set of tasks for the creation of intelligent transport systems, which affects the process of integration of global technologies [4].

In modern development in many countries of the world comes the understanding of the importance of solving the problems of development of transport complexes on a global scale. First of all, ensuring the efficiency and increasing the safety of transportation, as well as preserving the environment, etc [5]. One of the main elements in the system of regulation of interval movement of trains on railway transport are track circuits, which are used in many countries of the world [6]. They act as a telemechanical communication channel, i.e., they provide the transmission of information to the locomotive and signals, check the integrity of the rail lines for breaks, as a sensor they determine the location of the moving unit and control the vacancy of sections in automatic mode. There are several types of track circuits [7, 8]. This study examines a sensor for an interval control system based on tone track circuits without insulating joints [9, 11]. The use of such chains for high-speed and high-speed movement, as they are used in various climatic conditions and increased electromagnetic component, various characteristics at stations and sections [12]. At present, scientists around the world are developing various methods to improve the reliability of tone rail circuits without iso-joints. A study of the literature shows that the first sources in the development of tonal track circuits were considered in the 1970s by A.M. Bryleev [13]. In the future, all works, in most studies, mathematical modeling was performed partially and this is explained by the implementation of labor-intensive engineering calculations, which led to a slowdown in the development of tonal track circuits. With the development of computer technology and artificial intelligence, it becomes relevant to solve complex problems of analysis and synthesis of tonal track circuits [9, 14, 15, 16].

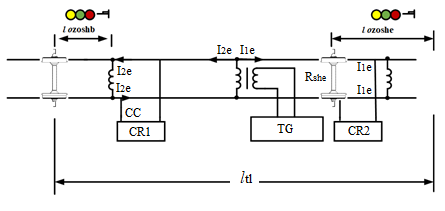
**RESEARCH METHODOLOGY**

The tone track circuits used on railways have a connection of the track receiver to the track circuit [3, 6, 9] as shown in Fig. 1. [10].



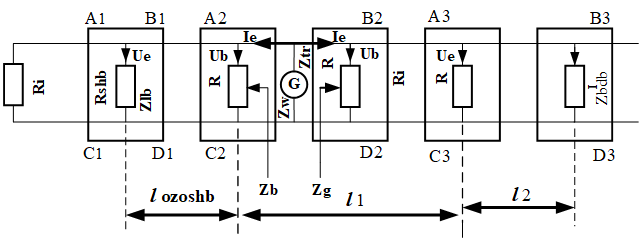
**FIGURE 1.** The tone track circuits

Where in normal mode the relay ANVSh (track receiver PP) is excited not at the moment of release of the feeder end of the tone track circuit without joints by the train, as shown in Figure 2, but when the moving unit is removed by some distance lVDShN, called the output zone of additional shunting [10], which, depending on various factors, can fluctuate from 20 to 100 meters, which leads to shunting of the adjacent track circuit (Fig. 2) [8, 14].



**FIGURE 2.** Diagram of a continuous tone track circuit

To develop a mathematical model for determining the output zone of the outgoing shunt, we will present the circuit in Fig. 2 as an equivalent circuit in Fig. 3.



**FIGURE 3.** Equivalent circuit

In determining that the basic equations should be derived taking into account the analysis of the synthesis of track circuits without joints, it is necessary to take into account their specific features associated with the absence of insulation joints [15, 16]. Hence, the replacement factors of a track line without joints can be determined from Figure 3, under final conditions such as those adopted for track circuits used with insulated joints and different from the conditions adopted for continuous ones.

(1)

We also take into account the difference in voltage and current at the ends of the track circuit.

(2)

(3)

(4)

(5)

It is necessary to take into account that the ballast on each of the track circuits can change at different times of the day and have different values. Therefore, we will designate the wave propagation coefficients γ and wave resistances Zv [6] respectively through different states of the ballast:

where

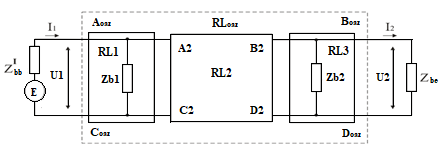
; . (6)

then

; .

where, ; ; ; ;  
; .

Let us represent A1, B1, C1, D1; A2, B2, C2, D2; A3, B3, C3, D3 as RL1, RL2 and RL3. Replacing track line 1 (RL1) and track line 2 (RL2) with input resistances, we obtain:



**FIGURE 4.** Equivalent circuit for the rail line (RL1 and RL2) with input resistances

By examining the circuit, we determine the coefficients of the rail continuous four-terminal switch RLVDZ, representing them as matrices and multiplying the three matrices between RL1, RL2 and RL3.

. (7)

After multiplying the matrices, we get:

;

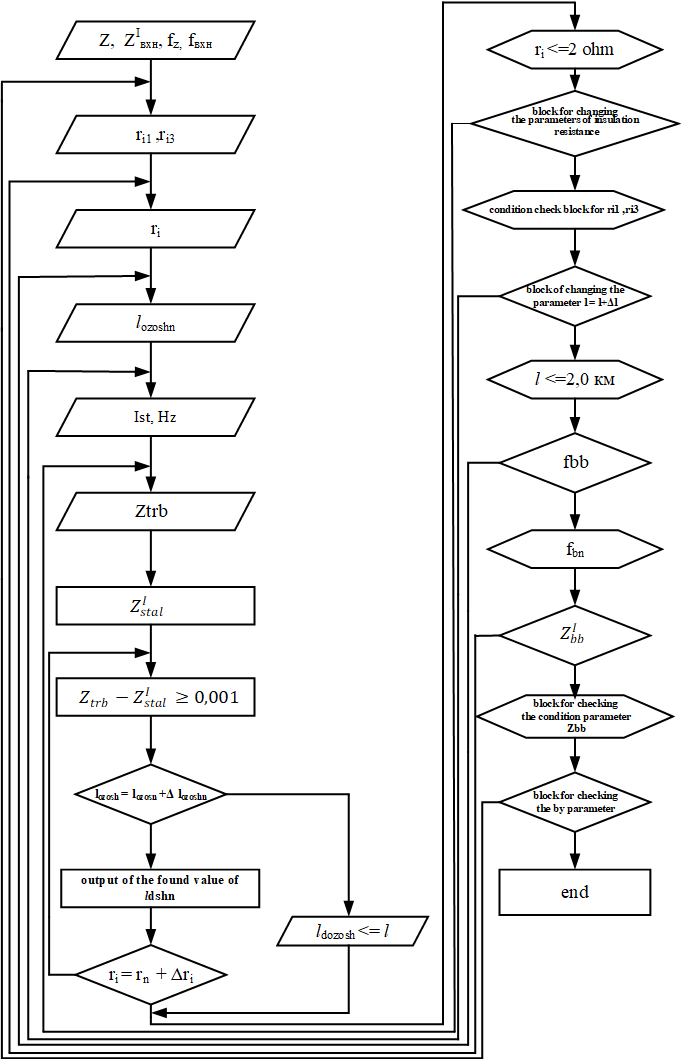
;

. (8)

where, , , , are coefficients of rail quadrupole networks obtained from the equivalent circuit.

**RESULT**

To develop the algorithm, it is necessary to determine , the resistance ratio during normal operation of the tone track circuit, and , which determines the presence of a shunt in the transmission resistance in the adjacent circuit.

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**FIGURE 5.** Block diagram of the algorithm for determining the length of the bypass exit zone

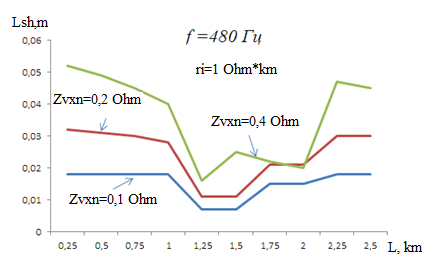
where

 ; (9)

 (10)

An algorithm has been developed for making decisions and determining the maximum bypass zone when moving a train away from the track circuit.

Based on the above developed algorithm and program for determining the optimal shunting zones of the track receiver when a train approaches a tone track circuit that does not have iso-joints.



**FIGURE 6.** Graphs of the dependence of the length of the additional bypass zone on the approach of the train at a signal current frequency of 480 Hz, different modules of input resistance Zvxn

**CONCLUSION**

A mathematical model of a continuous track circuit has been developed, and a method for determining the maximum shunt zone when a train moves away from a block section has been given. Special attention in modeling and derivation of analytical expressions is given in the development of optimal linkage of sensor operation for automation systems. Implementation of the device in relation to microprocessor control systems. The developed analytical expressions completely describe the operation of tone track circuits without iso-joints. Based on the proposed calculation method, it is possible to conduct research into the optimal parameters of continuous track circuits. Based on which it is possible to take technical measures to reduce the length of the shunt application after the train has passed the section and overlapped the adjacent section of the track, thereby completely freeing the train from the track circuit. In conditions of changing climate conditions and ballast pollution, operation and evaluation of ballast insulation resistance under the influence of train shunt is difficult. It is possible if there is a reliable algorithm for predicting the insulation resistance value and if the prediction method is not possible, use an indirect control method, which will be discussed later.

**FUTURE SCOPE**

The constructed theory of continuous track circuits and analytical solution provide a number of opportunities to conduct a research and make a contribution to the technological development:

The next steps of research can be directed at the generalization of the offered model and its implementation in the new generation of microprocessor control systems, providing real-time diagnostics, predictive upkeep and adaptive signal control in the railway network.

One sniff of potential is employment of machine learning algorithms to predict ballast insulation resistance in different environmental conditions and different operational conditions. This would be a considerable safety benefit and lower the false positives in the circuit behavior.

Indirect control algorithms were formulated to address several issues including the following:

Where direct measuring or predicting of insulation resistance is impossible, strategies to be used indirectly must be formalized. Stronger algorithms can be studied on the basis of track signals response pattern or past performance statistics in future studies.

Madness testing and field testing at various conditions- extreme weather, different train speeds, different track compositions, etc can be used to demonstrate soundness of the model and also optimize circuit parameters with respect to reliability and safety.

Further investigations will allow perfecting the determination of the upper shunt zone and creating new methods of reducing shunt length. This would enhance the accuracy of the block occupancy detection and upsurge the rail lines throughput.

The work can be aimed in standardizing the suggested practices to be adopted by the railway authorities. Field trials and pilot implementations will help in exploration of both operative advantages and sacrifices.

As the IoT and cyber-physical systems will be introduced to railways, the model can be further extended to take advantage of distributed sensor networks and cloud-based monitoring systems to make decisions in advance.

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