Mathematical model of the sensor for controlling the condition of the track section with an adaptive receiver at the free condition of the controlled section

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Abstract. One of the promising areas of improvement of sensors for monitoring the condition of track sections is the development of controlling sensors, which are less dependent on changes in ballast resistance, longitudinal asymmetry and standard value of shunt sensitivity, such a direction is the development of adaptive track circuits [1-5]. The article proposes a control sensor with an adaptive receiver, principle of operation of which is that monitoring the state of the track section depends on the parameters of adjacent monitoring sensors, included in the common controlled zone CZ.

Mathematical model and analytical expressions have been developed taking into account the resistance of the rails and the resistance of the insulation being carried out [6]. Proposed the coefficients of a rail fourpole with one of the choke-transformer, powered with one side. The calculated expressions of the fourpole and the criteria for the sensitivity of the rail circuit when one line is broken are presented and derived, and also the minimum transmission resistance [6].

Key words: rail line, rail circuit, four-pole, transmission resistance, rail circuit sensitivity criterion, rail circuit modes.

1. Introduction
Currently, to improve reliability of the functioning of sensors for controlling the condition of track sections in the systems of interval train traffic control, research is underway to create innovative control sensors. The development of adaptive track circuits is based on the principle of operation, which is based on the comparison of current and reference voltages, which will allow you to monitor the condition of the rail lines even with an intensive decrease in insulation resistance and significantly increases the reliability of monitoring the state of track sections [7, 8].

The research of such a control sensor is to establish the suitability of a given sensor for monitoring the free and serviceability of the rail line, identify new functionality capabilities, define limiting parameter (maximum RL length, minimum insulation resistance, permissible longitudinal asymmetry of insulation resistance, etc. [11]), at which it is possible to perform the declared functions, determination of the optimal parameters of devices. For carry all this research first of all it is necessary to determine coefficients rail quadrupole in all operating modes of the sensor control. The article reviewed the questions of determining these coefficients on the basis of which, can carried out further research of control sensors with adaptive receiver.

2. Method for determining analytical equations of a rail line of control sensors with an adaptive receiver
Unlike typical track circuits with insulating joints [9, 10] at considering track circuits without insulating joints with an adaptive receiver it is necessary to take into account the influence of adjacent
rail lines on each other, difference in primary parameters of rail lines - wave impedance of rail lines and wave propagation coefficients due to different conditions of ballast on these lines, longitudinal asymmetry and the presence of mobile units in adjacent areas. In connection with this factor, the models of control sensors differ significantly from the known models of rail circuits with insulating joints.

In addition, the very principle of operation of control sensors with an adaptive receiver consists is that the monitoring of the condition of the track section is carried out taking into account the condition and parameters of other rail lines.

Based on the aforesaid scheme substitution control sensor with an adaptive receiver, must be considered taking into account the above factors.

Basic mathematical expressions for conduct research, determination of optimal parameters, analysis, synthesis and calculation of control sensors with an adaptive receiver are the coefficients of rail four-pole in the normal, shunt and control modes of operation of control sensors.

For calculate the coefficients of the controlling sensor the condition of the track section with an adaptive receiver in normal mode, we represent the RC3 rail circuit of length L3, shown in Figure 1 in the form of a general substitution scheme with considering influence of adjacent rail lines and the availability on them trains.

![Figure 1. General substitution scheme of the controlling sensor condition of the track section with adaptive receiver, with considering the influence of adjacent rail lines](image1)

In this scheme, we replace adjacent rail lines with superimposed shunts Rsh2, Rsh4 their input resistances Zie2, Zie4, then scheme Figure 1. converted to the scheme Figure 2.

![Figure 2. Substitution scheme of the controlling sensor condition of the track section with adaptive receiver with the connection of the input resistances of adjacent rail lines](image2)
where

\[ Z_{i2} = \frac{Z_{ie2}}{Z_{i4}} \left[ \frac{B_{2sh} + R_{sh} + A_{2sh}}{C_{2sh} + R_{sh} + A_{2sh}} \right] \]

\[ A_{2sh} = c y_{2sh} l_{2sh} \]

\[ B_{2sh} = Z_{w2sh} s h y_{2sh} l_{2sh} \]

\[ C_{2sh} = \frac{1}{Z_{w2sh}} s h y_{2sh} l_{2sh} \]

\[ D_{2sh} = c y_{2sh} l_{2sh} \]

\[ Z_{i2} = \frac{Z_{ie2}}{Z_{i4}} \left[ \frac{c y_{2sh} l_{2sh} + R_{sh} + Z_{w2sh} s h y_{2sh} l_{2sh}}{Z_{w2sh} s h y_{2sh} l_{2sh} + R_{sh} + c y_{2sh} l_{2sh}} \right] \]

\[ Z_{i4} = \frac{Z_{ie4}}{Z_{i2}} \left[ \frac{D_{4sh} + R_{sh} + B_{4sh}}{C_{4sh} + R_{sh} + A_{4sh}} \right] \]

\[ A_{4sh} = c y_{4sh} l_{4sh} \]

\[ B_{4sh} = Z_{w4sh} s h y_{4sh} l_{4sh} \]

\[ C_{4sh} = \frac{1}{Z_{w4sh}} s h y_{4sh} l_{4sh} \]

\[ D_{4sh} = c y_{4sh} l_{4sh} \]

\[ Z_{i4} = \frac{Z_{ie4}}{Z_{i2}} \left[ \frac{c y_{4sh} l_{4sh} + R_{sh} + Z_{w4sh} s h y_{4sh} l_{4sh}}{Z_{w4sh} s h y_{4sh} l_{4sh} + R_{sh} + c y_{4sh} l_{4sh}} \right] \]

We transform the scheme in Figure 2 into the scheme Figure 3, replacing the left half of the scheme on its input impedance \( Z_{i3l} \).

\[ Z_{i3l} = \frac{A_{3l}}{Z_{ie3}} + B_{3l} \]

\[ C_{3l} \]

\[ D_{3l} \]

Figure 3. Converted substitution scheme of the controlling sensor condition track section with adaptive receiver

where

\[ Z_{i3l} = \frac{A_{3l} Z_{i2} + Z_{ie3} + B_{3l}}{C_{3l} Z_{i2} + Z_{ie3} + D_{3l}} \]
For conclusion the equations of coefficients a rail four-pole of the controlling sensor with adaptive receiver, we present a scheme Figure 3 in the form of the main scheme, shown in Figure 4.

**Figure 4.** Main substitution scheme of the track section condition controlling sensor with adaptive receiver

Thus, a scheme is obtained with cascade-connected is three four-pole, where the coefficients of the main rail four-pole RL3p are determined through their cascade connection:

\[
\begin{bmatrix}
A_{3n} & B_{3n} \\
C_{3n} & D_{3n}
\end{bmatrix} = \begin{bmatrix}
1 & 0 \\
0 & 1
\end{bmatrix} \cdot \begin{bmatrix}
A_{32} & B_{32} \\
C_{32} & D_{32}
\end{bmatrix} \cdot \begin{bmatrix}
1 & 0 \\
0 & 1
\end{bmatrix}
\]

(15)

After multiplying the coefficients of the matrix, we get:

\[
A_{3p} = chy_{32}l_{32} + \frac{Z_{w32} * shy_{32}l_{32}}{Z_{ie4} + \frac{ch y_{32}l_{32}}{c_{4sh} * Z_{w4sh} + Z_{w4sh} * sh y_{32}l_{32}} + \frac{Z_{w31} * shy_{31}l_{31}}{Z_{ie3} + \frac{ch y_{31}l_{31}}{c_{4sh} * Z_{w4sh} + Z_{w4sh} * sh y_{31}l_{31}}}}
\]

(16)

\[
B_{3p} = Z_{w32} * shy_{32}l_{32};
\]

(17)

\[
C_{3p} = \frac{1}{Z_{w32}} * shy_{32}l_{32} + \frac{ch y_{32}l_{32}}{ch y_{31}l_{31} * \frac{Z_{ie3}}{Z_{ie3} + \frac{Z_{ie3}}{Z_{ie3}}} + \frac{Z_{w31} * shy_{31}l_{31}}{Z_{ie3} + \frac{ch y_{31}l_{31}}{c_{4sh} * Z_{w4sh} + Z_{w4sh} * sh y_{32}l_{32}}}}
\]

(18)
where $Z_{w32}$, $Z_{w31}$ are wave resistances of the third rail line; $\gamma_{31}$ and $\gamma_{32}$ are the wave propagation constant of the third rail line.

The voltage and current at the beginning of the rail line are determined by the following expressions:

$$U_H = AU_k + BI_k;$$  \hspace{1cm} (20)

$$I_H = CU_k + DI_k.$$  \hspace{1cm} (21)

The transmission resistance of the controlling sensor condition of the track section with adaptive receiver is determined by the following expression:

$$Z_{tr} = A_{3p} \ast Z_{ie3} + B_{3p} + Z'_{ie3} \ast (C_{3p} \ast Z_{ie3} + D_{3p})$$  \hspace{1cm} (22)

Substituting into these expressions the values of the obtained equations for the coefficients of a rail four-port network, it is possible to calculate the values of voltages and currents when changing the insulation resistance of all rail lines in any combinations, thus, carry out research of the control sensor with an adaptive receiver in all modes of operation.

3. Results and discussion

A method is proposed for deriving analytical expressions for the coefficients of a rail four-pole of sensors for controlling the condition of a track section with adaptive receiver for research and design of such sensors for high-speed railway lines. Analytical expressions of these coefficients are determined on the basis of which it is possible to conduct research and determine the optimal parameters of newly created sensors for controlling the condition of track sections in the systems of interval train traffic control.

Monitoring the condition of the rail line of the adaptive jointless rail circuit should be carried out taking into account the condition and parameters of other rail lines of the control zone. In this case, it is necessary to take into account the values of the currents of the supply ends and the voltages of the receiving ends of several track circuits. In this case, the values to take into account is necessary of the currents of the supply ends and the voltages of the receiving ends of several track circuits. In view of the complexity of the algorithm for solving this problem, this problem can be solved using an electronic computer with software for monitoring condition of the track circuit.

For research carry out of a jointless rail circuit with adaptive receiver, a program was developed and some results of studies of monitoring the state of track sections depending on the input resistances at the ends of the rail circuit, changes in insulation resistance, longitudinal asymmetry and values of train shunts are shown in the following graphs:
Figure 5. Graphs of the dependence of the current of the supply end and the criterion of sensitivity to the shunt standard with the module of input resistances $Z_{in} = 0.4$ Ohm, argument $\varphi_{in} = +40^\circ$ and insulation resistance $r_i = 1$ Ohm*km.

It can be seen from the graph that the rail circuit at the standard value of the insulation resistance reliably controls the presence of a moving unit on the rail circuit, line 2 on the graph and the criterion of sensitivity to the normative shunt with $K_{sh} = 1.54$.

Figure 6. Graphs of the dependence of the supply end current and the criterion of sensitivity to the standard shunt with the input resistance module $Z_{in} = 0.1$ Ohm, the argument $\varphi_{in} = -40^\circ$ and the insulation resistance $r_i = 1$ Ohm*km.

As can be seen from the graphs, with a module of input resistances at the ends of the rail circuit of 0.1 Ohm, the current of the supply end increases almost three times, and the criterion of sensitivity to the standard shunt $K_{sh}$ has become less than one, those. with an input resistance module of 0.1 Ohm, the train on the track circuit is not detected, line 2 on the graph.
The main advantage of adaptive jointless rail chains is that they can function normally at a reduced insulation resistance is evidenced by the following graphs in Figure 7.

![Figure 7](image)

**Figure 7.** Graphs of the dependence of the current of the supply end and the criterion of sensitivity to the standard shunt with a module of input resistances $Z_{in} = 0.4$ Ohm, argument $\varphi_{in} = 0^\circ$ and insulation resistance $ri = 0.06$ Ohm * km.

The graph shows that even with a very low insulation resistance $ri = 0.06$ Ohm * km, a train is reliably determined on a controlled track circuit.

4. **Conclusion**

A model of a sensor control with an adaptive receiver is proposed, taking into account the influence of adjacent track circuits, and analytical expressions for the coefficients of a rail four-pole system are obtained with serviceable rail lines. Determining method for the analytical expressions for the coefficients of a rail four-pole control sensor with adaptive receiver at good condition of the rail threads.

5. **References**

[1] Aliev, R. M. & Aliev, M.M. & Tokhirov, E. T 2020 Methodology for Determining the Optimal Values of Resistance at the Ends of the Jointless Track Circuit with Considering Twofold Shunting International Journal of Emerging Trends in Engineering Research, IJETER 8 (9), 5048-5052

[2] Theeg G., Vlasenko S. 2009 Railway Signaling & Interlocking. International Compendium. Editors: A. DVV Media Group publication. Eurailpress, 448 p.

[3] Tilk I.G. 2010 New automatic and telemechanical devices for railway transport. – Yekaterinburg: UrGUPS, p. 168.

[4] Rosenberg E.N. et. al. 2008 Exclusion of the passage of the forbidden traffic light signal: new technique and technology // Automatics, communication, informatics: Popular industrial and technical journal 2, 10-11.

[5] Vasilenko, M.N. & Denisov, B.P. & Kultin, V.N. & Rastegaev, S.N. 2006 Calculation of the parameters and check of the operation of the jointless tonal rail circuits // Problematics of the transport systems. News of PGUPS, 2, 101 – 109.
[6] R. M. Aliev, E. T. Tokhirov, M. M. Aliev 2020 The Mathematical Model of the Sensor for Monitoring the State of the Track Section with Current Receivers International Journal of Recent Technology and Engineering (IJRTE) 8 (5), 5634-5637.

[7] Kulik P.D., Ivanin N.S., Udovikov A.A. 2004 Tone rail circuits in RCA systems: construction, adjustment, maintenance, troubleshooting, increase of operational reliability. - Kiev: Publishing house "Manufacture" p. 288.

[8] Lisenkov V.M., Vanshin A.E., Katkov M.V. 2010 Methods of increasing the safety of the rail circuits functioning. // Journal «Automation, communication and informatics». 4, p 8-10.

[9] Lisenkov V.M. 1999 Statistical Theory of Traffic Safety (Textbook for HEIs) of the Ministry of Railways of the Russian Federation, Russian Academy of Sciences M.: VINITI RAS, 1999, p.332

[10] Overview of existing, under construction and planned high-speed lines in the world //World Railways. 2007, 12, p. 9-15.

[11] Vasilenko M. N., Denisov B. P., Kultin V. B., Rasstegaev S. N. 2006 Calculation of parameters and check of the performance of the jointless tonal rail circuits // Izvestiya St. Petersburg State University of Railway Transport, 2, p 104-112.

[12] Hutchinson M., Marais J., Masson E., Mendizabal J., Meyer zu Horste M. 2017 Precise and reliable localization as a core of railway automation (Rail 4.0) // International Congress on High-speed Rail: technologies and long term impacts, 10, p 51-65

[13] Hintze P., Pruter F. 2018 “But that’s not the kilometer in the plan!” – the potential of georeferenced railway infrastructure data // Signal+Draht, 11, p 6–15.

[14] Senesi F., Marzilli E. 2007 ETCS European Train Control System. Development and implementation in Italy. Roma: CIFI. p. 316.

[15] Honcharov K. V. 2013 Investigation of transient processes in tonal track circuits Вісник Дніпропетровського національного університету залізничного транспорту 4 (46), p.7-11