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# Methodology for Determining the Optimal Values of Resistanceat the Ends of the Jointless Track Circuit with Considering TwofoldShunting

**Ravshan Aliev[1], Marat Aliev[2], Ezozbek Tokhirov[3]**
[1]Tashkent State Transport University, Tashkent, Uzbekistan, silara@mail.ru
[2]Tashkent State Transport University, Tashkent, Uzbekistan
[3]Tashkent State Transport University, Tashkent, Uzbekistan, etokhirov@yahoo.com

## ABSTRACT

The main criterion for the functioning of jointless rail circuits with a current receiver is to ensure the reliability of their work and ensure the safety of train traffic. In jointless rail circuits with current information retrieval when two trains are on the relay end, a critical situation may arise when the track receiver can trigger from the second train when the first train is on the controlled section. To determine the critical distance and optimal values at the ends of the rail circuit, the article presents equivalent circuits and derives the shunt sensitivity equations, determines the critical distance of the minimum shunt sensitivity and the equation for determining the optimal resistances at the ends of a jointless rail circuit with a current receiver.

**Key words:** tonal track circuits; track receiver; substitution schemes, input resistances, quadrupole coefficients, receiver current, transmission resistance, shunt sensitivity.

## 1. INTRODUCTION

Investigations of track circuits [7] can be performed under operating conditions – linear investigations, on laboratory mock-ups – laboratory investigations using a computer. The most effective research method is a computer method [11]. It allows you to conduct a comprehensive analysis of the track circuit, identify adverse conditions, optimize the method of monitoring the state of the rail line. To carry out such studies, a mathematical model of the rail line [8], [17] should be compiled, which would make it possible to establish the relationship between currents and voltages at the ends of the rail line for various parameters of the rail line and input resistances at the ends. The final stage of the study is a comparative analysis of the calculation results and linear tests.

Known substitutionscheme [3], [4], [8], [15] of the rail line allow you to analyze the operation of the TC with the receiver, which has a fixed value of switching voltages. For each of the main operating modes, the most unfavorable values (from the point of view of performing these modes) of insulation resistance $r_i$, voltage of the power supply $U_{ps}$, coordinates of the location of the train (shunt) $X_{sh}$, and damage to the rail line $X_c$ were taken as the calculated ones. If, under the most adverse conditions, reliable control of the state of the rail line is achieved, then, under other conditions, it will also be performed.

## 2. METHODS

In jointlesstrack circuits with current removal, the possible range of resistance changes at the ends of the track circuit is of great interest, in which the shunt and control modes are provided taking into account the specific features of the operation of jointlesstrack circuits.

When calculating the optimal values of the resistance at the ends and the maximum lengths in jointlesstrack circuits with current removal [9] from the condition of the shunt mode, it is necessary to take into account the presence of the second train on the adjacent track circuit $R_{sh1}$(Figure 2), and in normal operation, the presence of the outgoing train from the supply end of the track circuit$R_{sh}$(Figure 1).

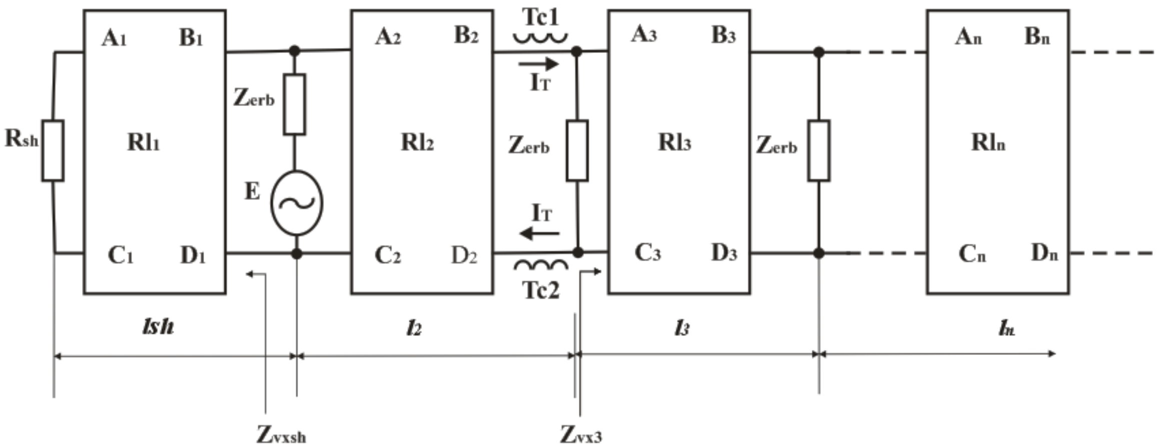

**Figure 1:**Substitution schemeof a continuous rail circuit with a current receiver in normal mode

In this scheme:

*$l_2$* isinvestigated the track circuit length;

*lsh* isdistance to the outgoing train;

$RL_1$,$RL_2$,$RL_3$ ……RLnarequadripolestrack circuits;

$R_{sh}$ isoutgoing train resistance;

$Z_{ebr}$ isreverse input resistance of the supply end of the track circuit;

Tc1 and Tc2 are receiving coils;

$Z_{vxsh}$ is input resistance of the adjacent track circuitfrom the side of the outgoing train:

$$Z_{vxsh} = \frac{z_{v2} sh\gamma_1 l_{sh}}{ch\gamma_1 l_{sh}}$$

$Z_{vx3}$ isadjacent rail input impedance;

$A_1$ ,$B_1$ ,$C_1$ ,$D_1$ ………….. $A_n$ ,$B_n$ ,$C_n$ ,$D_n$ arequadripole rail coefficients.

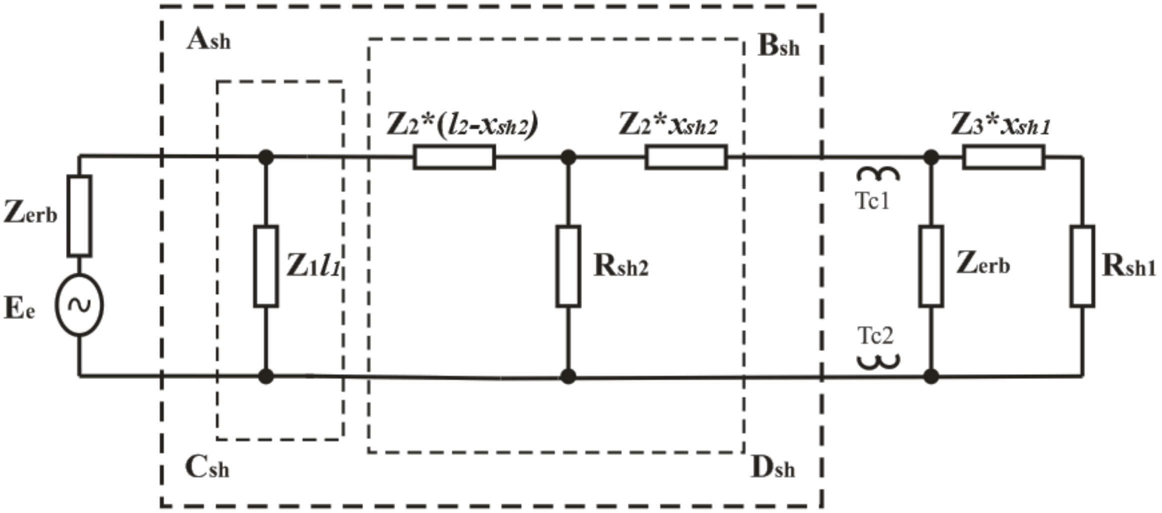

**Figure 2:**Shuntlesstrack circuitsubstitution schemewith current receiver

In this scheme:

$R_{sh2}$is resistance of the train shunt, the train entered the controlled area;

$R_{sh1}$ is resistance of a train shunt, a train located on an adjacent rail circuit;

$z_1$ is the resistance of the rail loop of the section where the retreating train is located;

$l_1$ is the distance to the receding train;

$x_{sh2}$ is distance from the relay end to the train located in the controlled area;

$x_{sh1}$ is distance from the relay end to the train located on the adjacent rail chain;

Given these features for the shunt mode, the equation of the shunt sensitivity Rsh2 can be represented as follows:

$$R_{sh2} = \frac{Z_{ebr} * z_2 * x_2 + z_2^2 * (l_2 - x_{sh2}) *}{N \frac{z_v}{z_v + Z_{ebr}} [A_n * Z_{ebr} + B_n + Z_{ebr} * (C_n * Z_{ebr} + D_n)] -} \rightarrow$$

$$\rightarrow \frac{\rightarrow * x_{sh2} * \left(1 + \frac{Z_{ebr}}{Z_{ebr} + z_2 l_2}\right)}{-\left[\left(1 + \frac{Z_{ebr}}{Z_{ebr} + z_2 l_2}\right) * z_2 l_2 + 2 Z_{ebr}\right]} . (1)$$

where

$$A_n = ch\gamma_2 l_2 + \frac{z_{v2} * sh\gamma_2 l_2}{Z_{vx3}};$$

$$B_n = z_{v2} * sh\gamma_2 l_2;$$

$$C_n = \frac{ch\gamma_2 l_2}{Z_{vxsh}} + \frac{1}{Z_{v2}} + \frac{1}{Z_{vx3}} * \left(\frac{z_{v2} * sh\gamma_2 l_2}{Z_{vxsh}} + ch\gamma_2 l_2\right);$$

$$D_n = \frac{z_{v2} * sh\gamma_2 l_2}{Z_{vxsh}} + ch\gamma_2 l_2,$$

arecoefficients rail quadripole controlled section in normal mode.

In equation (1), the value of X is determined from the condition of ensuring reliable shunting when the two trains approach each other at the relay end of the track circuitaccording to the equation.:

$$X^4 + X^3 M_3 + X^2 M_2 + X M_1 + M_0 = 0 \qquad (2)$$

where

$$M_0 = \frac{P_0^2 - Z_2^2}{P_2^2}$$

$$M_1 = \frac{2P_0 P_1 \cos(\varphi_1 - \varphi_0)}{P_2^2}$$

$$M_2 = \frac{P_1^2 + 2P_0 P_2 \cos(\varphi_2 - \varphi_0)}{P_2^2};$$

$$M_3 = \frac{2P_1 P_2 \cos(\varphi_2 - \varphi_1)}{P_2^2};$$

$$P_0 = -[z_2 l_2 \left(1 + \frac{Z_{ebr}}{Z_{ebr} + z_2 l_2}\right) + Z_{ebr}];$$

$$P_1 = -[\frac{Z_{ebr}}{R_{sh2}} + \frac{Z^2 l(2Z_{ebr} + Zl)}{(Z_{ebr} + z_2 l_2) R_{sh2}};$$

$$P_2 = -\frac{z_2^2 (2Z_{ebr} + z_2 l_2)}{(Z_{ebr} + z_2 l_2) R_{sh2}}.$$

Based on the found values of X, its optimal value is selected and substituted in equation (1).

Resistance modules $Z_{ebr}$ corresponding to the given and maximum allowable lengths of track circuits are determined by the solution of equation (1).

Solving equation (1) with respect to $Z_{ebr}$ in complex form, we obtain:

$$\mathrm{N} * [Z_{ebr}^3 * C_n * Z_v + Z_{ebr}^2 * Z_v *$$
$$* (A_n + C_n * z_2 * l_2 + D_n) +$$
$$+ Z_{ebr} * Z_v (A_n * z_2 * l_2 + B_n + D_n * z_2 * l_2) +$$
$$+ B_n * Z_v * z_2 * l_2]$$
$$= Z_{ebr}^3 * (1 + \frac{z_2 * x_{sh2}}{R_{sh2}}) + Z_{ebr}^2 [Z_v \left(1 + \frac{z_2 * x_{sh2}}{R_{sh2}}\right) +$$
$$+ \frac{2z_2^2 * x_{sh2}(l_2 - x_{sh2})}{R_{sh2}} + \frac{z_2^2 * x_{sh2} * l_2}{R_{sh2}} + 3z_2 * l_2] +$$
$$+ Z_{ebr} \{Z_v \left[\frac{2z_2^2 * x_2 (l_2 - x_{sh2})}{R_{sh2}} + \frac{z_2^2 * x_{sh2} * l_2}{R_{sh2}} + 3z_2 * l_2\right] +$$
$$+ z_2^2 l_2^2 + \frac{z_2^3 * x_2 (l_2 - x_{sh2})}{R_{sh2}}\} + Z_v [z_2^2 l_2^2 +$$
$$+ \frac{z_2^3 * x_{sh2}(l_2 - x_{sh2})}{R_{sh2}}]. \qquad (2)$$

Denoteinequation (2)

$$C_n Z_v = P_1;$$

$$Z_{ebr}^2 * Z_v * (A_n + C_n * z_2 * l_2 + D_n) = P_2;$$

$$Z_v (A_n * z_2 * l_2 + B_n + D_n * z_2 * l_2) = P_3;$$

$$Z_v * B_n * z_2 * l_2 = P_4;$$

$$1 + \frac{x_{sh2}}{R_{sh2}} = P_5;$$

$$Z_v \left(1 + \frac{x_{sh2}}{R_{sh2}}\right) + \frac{z_2^2 * x_{sh2} * l_2}{R_{sh2}} + \frac{z_2^2 * x_{sh2} * l_2}{R_{sh2}} + 3z_2 * l_2 = P_6;$$

$$Z_v \left[\frac{2z_2^2 * x_2 (l_2 - x_{sh2})}{R_{sh2}} + \frac{z_2^2 * x_{sh2} * l_2}{R_{sh2}} + 3z_2 * l_2\right] +$$
$$+ z_2^2 l_2^2 + \frac{z_2^3 * x_2 (l_2 - x_{sh2})}{R_{sh2}} = P_7;$$

$$Z_v [z_2^2 l_2^2 + \frac{z_2^3 * x_{sh2}(l_2 - x_{sh2})}{R_{sh2}} = P_8.$$

After replacing, we get:

$$N(Z_{ebr}^3 P_1 + Z_{ebr}^2 P_2 + Z_{ebr} P_3 + P_4) = Z_{ebr}^3 P_5 + Z_{ebr}^2 P_6 +$$
$$+ Z_{ebr} P_7 + P_8. \qquad (3)$$

To exclude the argument $\varphi_N$, we equate the squares of the modules of the right and left sides of equation (3) and after the transformation, we obtain:

$$Z_{ebr}^6 + Z_{ebr}^5 M_5 + Z_{ebr}^4 M_4 + Z_{ebr}^3 M_3 + Z_{ebr}^2 M_2 + Z_{ebr} M_1 + M_0 = 0.$$

The values $M_5$, $M_4$, $M_3$, $M_2$, $M_1$, $M_0$ are real, defined by the following equations:

$$M_0 = \frac{N^2 P_4^2 - P_8^2}{N^2 P_1^2 - P_5^2};$$

$$M_1 = \frac{2N^2 P_2 P_4 \cos(\varphi_3 + \varphi_{ebr} - \varphi_4) - 2P_7 P_8 cos(\varphi_7 + \varphi_{ebr} - \varphi_8)}{N^2 P_1^2 - P_5^2};$$

$$M_2 = \frac{2N^2 P_2 P_4 \cos(\varphi_2 + 2\varphi_{ebr} - \varphi_4) - 2P_6 P_8 \cos(\varphi_6 + 2\varphi_{ebr} - \varphi_8)}{N^2 P_1^2 - P_5^2};$$

$$M_3 = \frac{2N^2 [P_1 P_4 \cos(\varphi_1 + 3\varphi_{ebr} - \varphi_4) + P_2 P_3 \cos(\varphi_2 + \varphi_{ebr} - \varphi_3)] -}{N^2 P_1^2 - P_5^2}$$
$$\frac{-2[P_5 P_8 \cos(\varphi_5 + 3\varphi_{ebr} - \varphi_6) - P_6 P_7 \cos(\varphi_6 + \varphi_{ebr} - \varphi_7)}{N^2 P_1^2 - P_5^2};$$

$$M_4 = \frac{2N^2 P_4 P_3 \cos(\varphi_1 + 2\varphi_{ebr} - \varphi_3) + N^2 P_2^2 - P_6^2 -}{N^2 P_1^2 - P_5^2}$$
$$\frac{-2P_5 P_7 \cos(\varphi_5 + 2\varphi_{ebr} - \varphi_7)}{N^2 P_1^2 - P_5^2};$$

$$M_5 = \frac{2[N^2 P_4 P_3 \cos(\varphi_1 + \varphi_{ebr} - \varphi_2) - P_5 P_6 \cos(\varphi_5 + \varphi_{ebr} - \varphi_6)]}{N^2 P_1^2 - P_5^2}.$$

The equation of the sixth degree with real coefficients is solved by the method of partial values or on a computer.

## 3. RESULTAND DISCUSSIONS

The substitution schemes presented of the jointless track circuit with current receiver, the equations of the shunt sensitivity and the critical location of the minimum value of the shunt sensitivity are derived. The equations for determining the optimal resistance values at the ends of the track circuit are derived.Comparative analyzes of track circuits with current and potential receiver are given.

Using the above formulas, an algorithm was developed and calculations were carried out to determine the optimal resistances at the ends of the control sensors in comparison with the known control sensors with potential receivers. The calculations were carried out for the signal current frequency f = 475 Hz, insulation resistance r*i* = 1 Ohm * km and different resistance arguments at the ends of the control sensors, the calculation results are shown in Table 1, bywhich shows that the resistances at the ends of the control sensors with a current receiver different from the resistances at the ends for control sensors with a potential receiver.

**Table 1:** Optimal resistances at the ends of control sensors with current receivers in comparison with known control sensors with potential receivers at **f =475 Hz, $r_i$=1 Om*km, $\varphi_{die2}$ =$0^0$**

| L-rail line length, km | $Z_{ebr}$is current track receiver,Om | $Z_{ebr}$is with potential receiver,OM | difference in % |
|---|---|---|---|
| 0,25 | 0,14 | 0,125 | 3,703703704 |
| 0,45 | 0,15 | 0,137 | 2,040816327 |
| 0,55 | 0,16 | 0,146 | 2,564102564 |
| 0,75 | 0,17 | 0,157 | 1,796407186 |
| 0,85 | 0,18 | 0,167 | 1,694915254 |
| 0,95 | 0,19 | 0,175 | 2,702702703 |
| 1,05 | 0,2 | 0,187 | 1,52284264 |
| 1,15 | 0,22 | 0,193 | 3,286384977 |
| 1,25 | 0,25 | 0,225 | 2,040816327 |
| 1,35 | 0,28 | 0,244 | 2,189781022 |
| 1,45 | 0,32 | 0,293 | 2,236421725 |
| 1,45 | 0,37 | 0,32 | 1,648351648 |
| 1,55 | 0,44 | 0,417 | 0,686498856 |

## 4. CONCLUSION

The proposed equations of the shunt sensitivity of a continuous track circuitwith a current receiver in the presence of two trains at the receiving end of the track circuit, by which it is possible to determine the critical value of the distance to the minimum value of the shunt sensitivity, as well as equations for determining the optimal resistance parameters at the ends of the track circuit, will allow research and selection optimum values of the resistances and the lengths at the ends of track circuits.

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