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Algorithms and mathematical model for determining shunt power of intelligent track section control sensor

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Abstract. The normal operating state of jointless and butt track circuits depends on the state of change in the insulation resistance; respectively, the correct choice of the maximum and minimum limit resistance characteristics should be considered. The maximum and minimum limit resistance depends on the power consumption of the unlimited track circuit in the normal and the mode of movement of the wheelset at the supply end of the rail line. The article presents a study of an intelligent track circuit without insulated joints, where logical elements replace all the equipment of mechanical and electrical energy converters. The research aims to determine the shunt that affects the definition of the movable block, respectively, the definition of the power of the shunt. The method consists in choosing a sensor, namely an intelligent track control sensor, and developing a mathematical model for determining the shunt power, which provides the influence of the shunt on the track circuit.
Research carried out for track circuits with insulating joints has shown that with the value of the argument, modulus, and synthesis of the maximum-minimum limit resistance when the supply end is shunted, the maximum power will be the least minimum Rkmax. Because of the lack of more accurate data for an intelligent control sensor, studies were carried out.

1 Introduction

The general theory of track circuits can be mainly used in the analysis and synthesis of unlimited track circuits without insulating joints [1]. But at the same time, it is necessary to consider some specifics due to the lack of insulating joints. Calculations of the coefficients of track circuits were carried out with some assumptions [2, 3, 5], and no method was given for their exact determination [10-18]. To determine the exact equations, it is necessary to consider jointless track circuits as unlimited asymmetric track lines, in which, firstly, the primary and secondary parameters may differ significantly from each other and, secondly, there may be moving units on adjacent track circuits.

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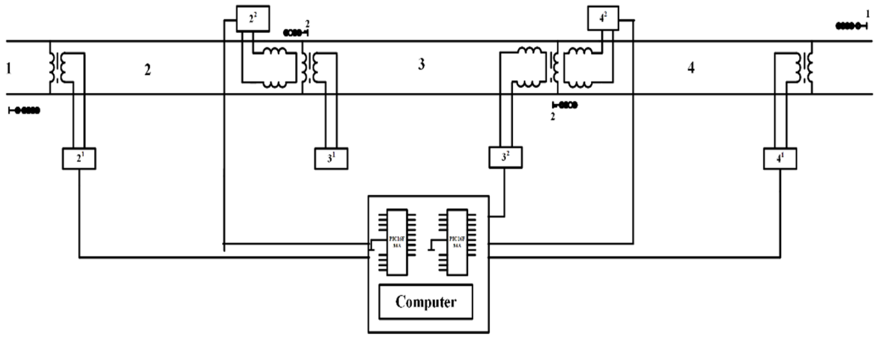

Fig. 1. Principal scheme of intelligent track circuit

2 Main Part

2.1 Mathematical model of the shunt power of an intelligent control sensor

For track circuits with insulating joints, it was calculated that the power Rmax calculated for track circuits with joints would have when $|Z_o|$=$|Z_{in}|$ and $|\varphi_{\text{o}}| \pm |\varphi_{\text{вх}}|$ =±180°, where Z_{in} is the input resistance of the rail line at the beginning between the points of the beginning of the track, Z_o is the reverse and direct limit resistance [1, 6, 7].
In smart sensors (intelligent seamless track circuits), there is a feature that consisting that calculates the maximum power at the smallest value produced by shunting the wheel sets at the beginning and end of the supply end is made taking into account the influence of two shunts by two trains [8, 9, 19-21] located on both sides of the supply end, as shown in the equivalent circuit of Fig. 2. To analyze a jointless unlimited track circuit when using shunt power, consider its substitution schemes in the absence of trains in Fig. 3 and Fig. 4, and in the mode of shunting the supply end Fig. 5, Fig. 6.

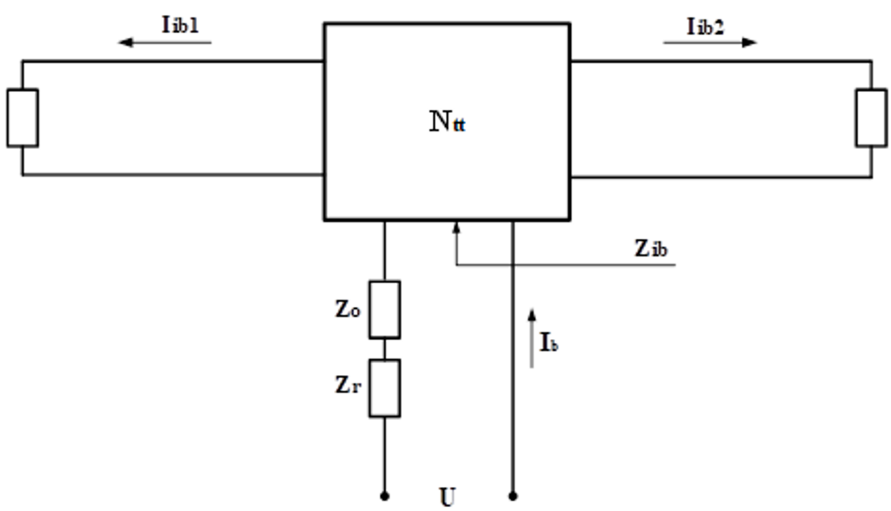

Fig. 2. General substitution scheme of track circuit in normal mode

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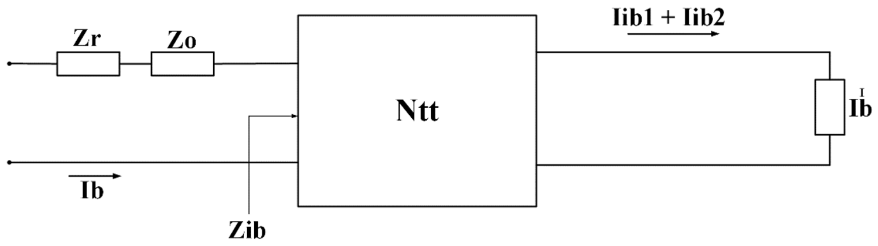

Fig. 3. Main substitution scheme of track circuit in normal mode

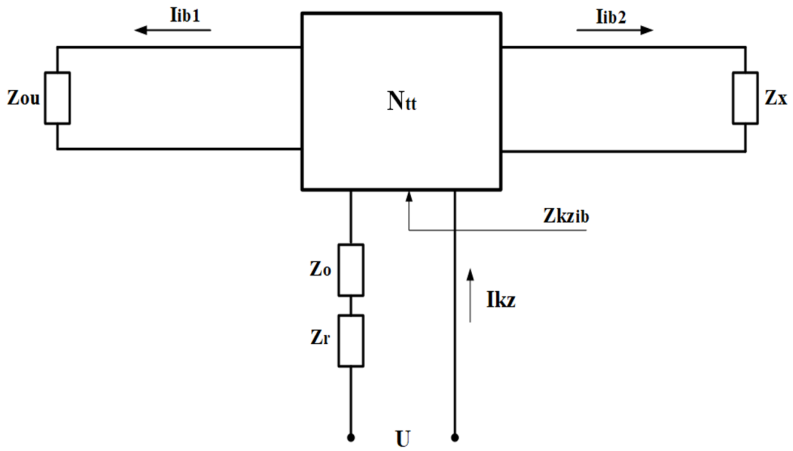

Fig. 4. General substitution scheme for shunt power of track circuit in presence of movable unit at the supply end

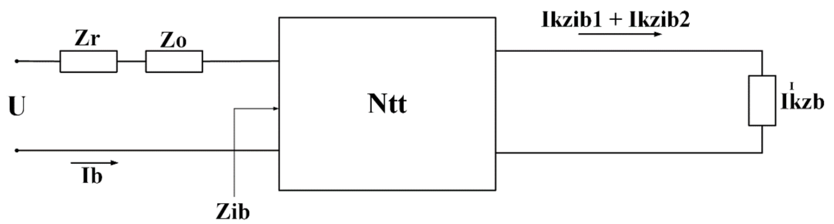

Fig. 5. Main substitution scheme of track circuit in presence of moving unit at the supply end

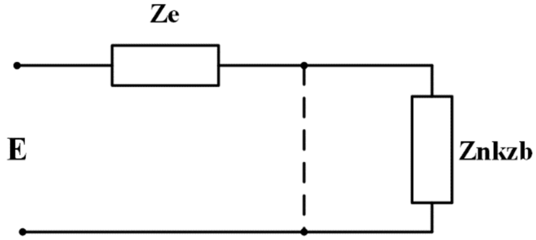

Fig. 6. Substitution scheme of track circuit with shunts at the ends

The module and argument of the limiting resistance and the values of x and y, at which the smallest possible maximum shunt power of the supply end will be possible, can be determined from the substitution schemes under normal conditions (Fig. 2) and shunt mode (Fig. 5).

For the scheme presented in fig. 3, fig. 4 we can write:

$$\acute{U}_i = \dot{I}_b(\dot{Z}_g+\dot{Z}_o + \dot{Z}_{ib}); \quad (1)$$

$$\dot{I}_b = \acute{K}_i(\dot{I}_{kzib1}+\dot{I}_{kzib2}), \quad (2)$$

where

$$\acute{K}_i = \frac{C_{tt}\dot{Z}_{ib}\dot{Z}_{ib2}+D_{tt}(\dot{Z}_{ib1}+\dot{Z}_{ib2})}{\dot{Z}_{i1}+\dot{Z}_{i2}}$$

$$\dot{Z}_{ib} = \frac{A_{tt}\dot{Z}_{ib1}\dot{Z}_{ib2}+B_{tt}(\dot{Z}_{ib1}+\dot{Z}_{ib2})}{C_{tt}\dot{Z}_{ib1}\dot{Z}_{ib2}+D_{tt}(\dot{Z}_{ib1}+\dot{Z}_{ib2})}.$$

$\dot{I}_{kzib1}$ is the current flow to an adjacent track circuit, $\dot{I}_{kzib2}$ is current flowing in its own track circuit, A_{tt}; B_{tt}; C_{tt}; D_{tt} are the coefficients of the quadripole substituting the inductor-transformer of the supply end. For the shunt power mode according to the scheme of Fig. 5, we can write:

$$\dot{I}_{kz} = \frac{U}{\dot{Z}_g+\dot{Z}_o+\dot{Z}_{kzi}} \quad (3)$$

$$\dot{P}_{kz} = U * \dot{I}_{кз} = \frac{U^2}{\dot{Z}_o+\dot{Z}_{kzi}} \quad (4)$$

$$Z_{kzi} = \frac{A_{tt}*\dot{Z}x*\dot{Z}y+B_{tt}(\dot{Z}x+\dot{Z}y)}{C_{tt}*\dot{Z}x*\dot{Z}y+D_{tt}(\dot{Z}x+\dot{Z}y)}. \quad (5)$$

According to the above equivalent scheme in Figure 1, equations have been developed and given that, in the presence of a train at the supply end of the rail line, greatly simplify the determination of conditions that provide a large minimum possible maximum power
In this scheme

$$\dot{E} = U = K_{ib}(\dot{I}_{ib1}+\dot{I}_{ib2}) * (\dot{Z}_g+\dot{Z}_o + \dot{Z}_{ib}), \quad (6)$$

$$\dot{Z}_э = \dot{Z}_g + \dot{Z}_o + \dot{Z}_{nkzb}, \quad (7)$$

$$\dot{Z}_{nkzb} = \dot{Z}_{ib} - \dot{Z}_{kzb} \quad (8)$$

transforming equation (6), we get:

$$\dot{E} = K_i(\dot{I}_{ib1}+\dot{I}_{ib2}) * [(\dot{Z}_g+\dot{Z}_o + \dot{Z}_{kzb}) + (\dot{Z}_{ib} - \dot{Z}_{kzb})] \quad (9)$$

Let us replace the quantities $\dot{Z}_g + \dot{Z}_o + \dot{Z}_{kzb}$ and $\dot{Z}_{nvx} - \dot{Z}_{kzvx}$ their values according to equations (7) and (8), we obtain

$$\dot{E} = \acute{K}_i(\dot{I}_{ib1}+\dot{I}_{ib2}) * (\dot{Z}_e + \dot{Z}_{nkzb}) \quad (10)$$

Or bracketing $\dot{Z}_{nkzib}$, we get

$$\dot{E} = \acute{K}_i(\dot{I}_{ib1} + \dot{I}_{ib2}) * \dot{Z}_{nkzb}(1 + \frac{\dot{Z}_e}{\dot{Z}_{nkzb}}) \qquad (11)$$

Denoting $\frac{Z_e}{Z_{nkzb}}$ through $\acute{K}_c$ making a substitution in equation (11), we obtain

$$\dot{E} = \acute{K}_i(\dot{I}_{ib1} + \dot{I}_{ib2}) * \dot{Z}_{nkzb}(1 + \acute{K}_{kz}) \qquad (12)$$

To determine the short circuit power, the formula is given:

$$\dot{P}_{kz} = \frac{E^2}{\dot{Z}_e} \qquad (13)$$

Substituting the value of E from equation (12) into equation (13), we obtain

$$\dot{P}_{kz} = \frac{\acute{K}_i^2(I_{ib1} + I_{ib2})^2 * \dot{Z}_{nkzb}^2 * \left|(1 + \acute{K}_{kz})\right|^2}{\dot{Z}_e} \qquad (14)$$

or

$$\dot{P}_{kz} = \acute{K}_i^2(\dot{I}_{ib1} + \dot{I}_{ib2})^2 * \dot{Z}_{nkzbi}^2 * \frac{1}{\acute{K}_{kz}}\left|(1 + \acute{K}_{kz})\right|^2 \qquad (15)$$

When x, y = const in equation (15) with a change $\dot{Z}_o$ only one complex value will change $\acute{K}_{kz} = \left|\acute{K}_{kz}\right| e^{j(\varphi_e \pm \varphi_{bkz})}$. Determination of the minimum $\dot{P}_{kz}$ which is the modulus of the value for a given argument φ_o, with a constant value $(\varphi_e \pm \varphi_{bkz})$, we determine the value of the module $\left|\acute{K}_{kz}\right|$.

Combining the left and right sides of the equation (15), we obtain

$$P_{kz} = (I_{ib1} + I_{ib2})^2 * K_i^2 * Z_{nkzbi} * [\frac{1}{K_{kz}} + |K_{kz}| + 2 * \cos(\varphi_e \pm \varphi_{bkz})] \qquad (16)$$

Having examined equation (16) for max. and min. relatively K_{kz}, we get:

$$|K_{kz}| = 1 \text{ or } \left|\frac{\dot{Z}_e}{\dot{Z}_{nkzbi}}\right| = 1$$

From here $|\dot{Z}_e| = |\dot{Z}_{nkzbi}|$.

Thus, the smallest power when shunting the supply end of the track circuit for any argument of the limiting resistance φ_o and any values of x and y will be subject to the condition

$$\dot{Z}_g + \dot{Z}_o + \dot{Z}_{kzi} = \dot{Z}_{bi} - \dot{Z}_{kzi}.$$

To calculate the smallest shunting power of the supply end for the given values of φ_o, x and y, transforming it into equation (16), substituting its optimal value instead of K_c, we obtain equation (17)

$$P_{bkz\text{мaxleast}} = 2(I_{ib1} + I_{ib2})^2 * K_i^2 * Z_{nkzi} * [1 + \cos(\varphi_e \pm \varphi_{bkz})]. \qquad (17)$$

It can be seen from equation (17) that with x, $y = const$ and a variable value φ_o, with an increase in the difference in arguments $\varphi_e \pm \varphi_{bkz}$ up to $\pm 180^0$, when $[\sinh]\cos h(\varphi_э \pm \varphi_{нкз}) = \cosh(\pm 180^0) - 1$, when shunted by a train, the maximum power takes on the smallest value. In this case, $P_{kzmin} = 0$. From this, it can be concluded that such a case does not occur practically.

$\dot{Z}_{o}$ is the optimal value of the module, at which the maximum power takes the smallest value given in the equation:

$$\dot{Z}_{nkzbi} = \dot{Z}_g + \dot{Z}_o + \dot{Z}_{kzi}.$$

Expanding the quadrants of the models of the left and right parts of the equation, we reduce to $|Z_o|$, we get:

$$Z_o = -\left[Z_g \sinh\left(\varphi_o \pm \varphi_g\right) + Z_{kzi} \cosh(\varphi_o \pm \varphi_{kz})\right] \pm \rightarrow$$
$$\rightarrow \pm\sqrt{\left|Z_g \sinh\left(\varphi_o \pm \varphi_g\right) + Z_{kzi} \cos h(\varphi_o \pm \varphi_{kz})\right|^2 + Z_{nkzi}^2 - cth(Z_g + Z_{nkzi})^2} \quad (18)$$

When determining the difference of the φ_o the argument, it was found that with large negative values of the φ_o the argument, the maximum power is achieved in the place of the shunt, not at the feeding end, but in a place away from it, which is located at some distance. Using equation (13) to determine this distance and substituting in this equation instead of E and $\dot{Z}_3$their values from equations (6) and (7), we obtain:

$$\frac{|\dot{I}_{bi1} + \dot{I}_{bi2}|^2 \dot{K}_i^2 |\dot{Z}_g + \dot{Z}_o + \dot{Z}_{bi}|^2}{\dot{Z}_g + \dot{Z}_o + \dot{Z}_{kzi}} = P_{kz} \quad (19)$$

Transforming equation (19) and substituting instead of $\dot{Z}_{\text{кзвх}}$ from equation (5), its value, we get:

$$P_{kz} = \frac{|\dot{I}_{bi1} + \dot{I}_{bi2}|^2 \dot{K}_i^2 |\dot{Z}_g + \dot{Z}_o + \dot{Z}_{bi}|^2 \cosh(\varphi_e \pm \varphi_{bkz})}{\dot{Z}_g + \dot{Z}_o + \frac{A_{tt} * \dot{Z} * x * \dot{Z} * y + B_{t\text{т}}(\dot{Z} * x + \dot{Z} * y)}{C_{t\text{т}} * \dot{Z} * x * \dot{Z} * y + D_{t\text{т}}(\dot{Z} * x + \dot{Z} * y)} \sinh(\varphi_e \pm \varphi_{bkz})} \quad (20)$$

When changing X and Y, as seen from equation (20), only the denominator changes, respectively, and the shunting power of the supply end will be maximum at the smallest value. Hence it follows that it suffices to investigate the minimum and maximum equation (20).

$$\dot{Z}_{ob} = \dot{Z}_g + \dot{Z}_o + \frac{A_{tt} * \dot{Z} * x * \dot{Z} * y + B_{tt}(\dot{Z} * x + \dot{Z} * y)}{C_{tt} * \dot{Z} * x * \dot{Z} * y + D_{tt}(\dot{Z} * x + \dot{Z} * y)} \quad (21)$$

If we designate $\frac{\dot{Z}x * \dot{Z}y}{\dot{Z}x + \dot{Z}y} = l * z$, then by substitution, we get:

$$\dot{Z}_{ob} = \dot{Z}_g + \dot{Z}_o + \frac{A_{tt} * l * z + B_{tt}}{C_{tt} * l * z + D_{tt}} \quad (22)$$

Denote in equation (22)

$$A_{tt} * z = k_1;\ B_{tt} = k_2;\ C_{tt} * z = k_3;\ D_{tt} = k_4,\ \dot{Z}_g + \dot{Z}_o = k_5.$$

By substituting, we get:

$$\dot{Z}_{ob} = k_5 \frac{k_1 * l + k_2}{k_3 * l + k_4} \quad (23)$$

Or

$$\dot{Z}_{ot}(k_3 * l + k_4) = k_5(k_3 * l + k_4) + k_1 * l + k_2 \quad (24)$$

Having made transformations, we get the following:

$$\dot{Z}_{ob}(k_3 * l + k_4) = Sl + T \quad (25)$$

Where

$$S = k_5k_3 + k_1, \; T = k_5k_4 + k_2.$$

After transformations into equations (25), we obtain the following:

$$Z_{ob}^2 = \frac{S^2l^2+2STcos(\varphi_s \pm \varphi_t)+T^2}{{k_3}^2l^2+2k_3k_4lcos(\varphi_{k3} \pm \varphi_{k4})+{k_4}^2} \quad (26)$$

Having examined equation (26) for max. and min. concerning l, we get:

$$l = \frac{V_1}{2} \pm \sqrt{\frac{V_1^2}{4} - V_0} \quad (27)$$

Where

$$V_1 = \frac{S^2{k_4}^2 - {k_3}^2T^2}{k_3k_4S^2\cos(\varphi_{k_3} \pm \varphi_{k_4}) - {k_3}^2STcos(\varphi_s \pm \varphi_t)}$$

$$V_0 = \frac{{k_4}^2STcos(\varphi_s \pm \varphi_t) - k_3k_4T^2\cos(\varphi_{k_3} \pm \varphi_{k_4})}{k_3k_4S^2\cos(\varphi_{k_3} \pm \varphi_{k_4}) - {k_3}^2STcos(\varphi_s \pm \varphi_t)}.$$

Substituting Z_r, Z_o and φ_0 for different values, we obtain an expression that allows us to determine the value of l. To determine the x value when changing y under various conditions, we substitute a certain value of l into $\frac{\dot{Z}*x*\dot{Z}*y}{\dot{Z}*x+\dot{Z}*y} = l * z$.

3 Result and discussion

The growing needs of the industry in rail transportation determine the design of modern distillation systems railway automation, the introduction of new methods, to date, on the used tone rail circuits, the tasks of their analysis and are especially relevant since safety and throughput are most ensured by the performance of the work of intelligent track circuits. In the study of intelligent track circuits, a deep synthesis is carried out, taking into account the features and disturbing factors of influence; mathematical modeling and theoretical results are carried out, and the following conclusions can be drawn from them:

Considering the requirements for intelligent track circuits, the most difficult thing is to ensure the safety of transportation, depending on the characteristics of the operation of rail lines, the elements used in intelligent track circuits, their parameters, and damage. One of the methods has been developed, simulation modeling, which allows considering and expanding the details of the theory and analysis of intelligent track circuits, as well as applying various methods of using system elements and their structure, and using them in modeling electrical circuits.

On Fig. 7, a block scheme of a simulation model of an adaptive jointless tonal frequency track circuit, depending on the power resistance of the shunt of conjugated track circuits, and a program is presented.

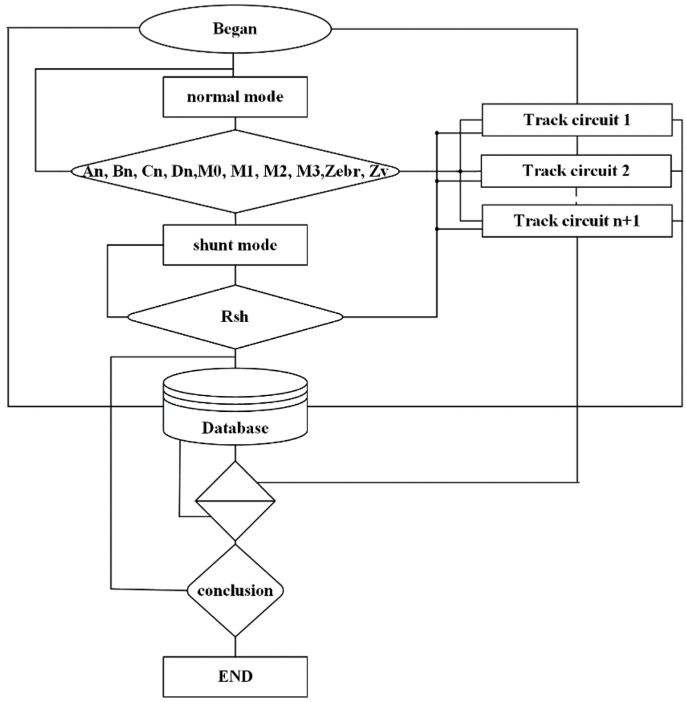

Fig. 7. A block scheme of simulation model of adaptive jointless tonal frequency track circuit

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Implementation
procedure qvs;{introduction of shunts following the location of train cars}
    Begin
    for i:=1 to v1  do rp[i]:=rs1;
    for i:=round(v1+s12/20+1)to round(v1+s12/20+v2) do rp[i]:=rs2;
    for i:=round(v1+s12/20+v2+s23/20+1)to
    round(v1+s12/20+v2+s23/20+v3)do rp[i]:=rs3;
    end;
    Procedure qid;
    Begin
    {manual correction of rl numbers}
    If sec100i then
    Begin
    If (rl0w<>rl0)then
    Begin
    m_hide; str(rl0:2,rl0s); bar(17,351,39,359);
    outtextxy(21,352,rl0s);  rl0w:=rl0;
    End;
    and so on
```

4 Conclusions

A new method for analyzing track circuits is needed, based on simulation methodology, eliminating the disadvantages existing and meeting the following requirements: low error, completeness and accuracy of the mathematical description of failures of the shopping center, work with continuous signal, taking into account the maximum number of system parameters systems, the ability to analyze the track circuit of any design, completeness, and visualization of results at intermediate points, susceptibility to manifestations of failures and introduction of malfunctions.

The conducted studies allow to accurately determine the shunt power that affects the definition of the mobile unit and eliminate the factors of failure to determine the unit on the site. The data show that using smart sensors increases the reliability and safety of the shunt effect on the jointless adaptive track circuit.

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