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Insulating joints as a destabilizing factor in the operation of the track circuit

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Abstract. The role of railway transport in the modern economy is highlighted in the article. Directions for improving automation and telemechanics devices have been determined: the creation and implementation of modern devices for monitoring track occupancy of a new type, as well as increasing the reliability of track devices to a large extent, and putting into operation systems for interval regulation of train traffic. The importance of such an element of the railway infrastructure as a rail circuit is also determined. The authors of the work revealed the function of track circuits. In addition to this, the article presents an information diagram of the search for failures in an extensive rail circuit of electrical centralization. The concept of a decision device is disclosed. Possible expressions of the Bayes criterion are also considered. A priori probabilities of finding rail lines are singled out. As a result, a decision rule is revealed that leads to the minimization of the average damage.

1 Introduction

The main purpose of the track circuit decision device is to perform the final step in the process of detecting a moving unit or a damaged rail, namely, to decide on their presence or absence within the rail line. The decision is made based on the results of monitoring of the mixture of signals for rail lines state control (RLSC) and interference that enters the input of the decision device from the output of the receiver. It must be made according to a certain rule: the consequences of these decisions must be optimal in the sense of some criterion.

1.1 Problem statement

The purpose of the work is to analyze various approaches to the decision-making process by decision devices in track circuits and to determine the optimal criteria for decisions.

Tasks set during the study:

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- Determination of requirements for criteria and decision-making rules.
- Analysis of decision devices.
- Identification of obstacles that affect decision-making.
- Study of errors that occur as a result of interference.

1.2 Research questions

One of the main ways to properly improve the safety of complex automation and telemechanics systems in railway transport is to study the nature and causes of common cause failures. The operation of the decision device is negatively affected by failures in the track circuits. They can be caused by various reasons. They must be combated in order to increase the reliability of the decision device, as well as the safety of the railway automation system, which, in turn, directly depends on accurate and up-to-date information about the location and movement of trains provided by train detection devices . Track circuits in this case are the most popular systems used around the world to provide information about the location and movement of trains and ensure traffic safety. The failure or malfunction of track circuits has two consequences: unreliable operation that leads to train delays and accidents.

2 Materials and methods

Rail circuits are used as the main track sensor and continuous type telemechanical channel in automatic blocking (AB), automatic continuous cab signaling (ACCS), electrical centralization (EC), dispatcher centralization (DC) (Figure 1).

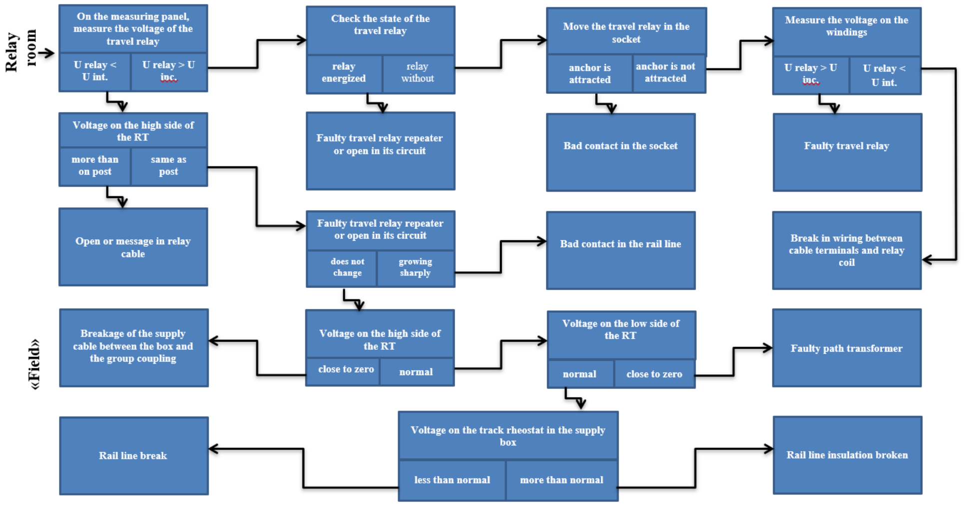

Fig. 1. Information diagram of the search for failures in an extensive rail circuit of electrical centralization.

Rail circuits are an important element of the railway infrastructure [1]. They are used to transmit impulses from the track to the train along the rails to carry out subsequent control of the movement of the train.

Track chains consist of two rails that run along the bottom of the track and are connected to each other by a fastener. Rail circuits can be used for such functions as data transmission and communications infrastructure support. Thus, track circuits are an important means for managing the transport system. They allow to transmit impulses to the train, control the movement, control the occupancy of the section.

3 Results

Railway automation and telemechanics systems use various methods (such as track circuits) to detect the presence of a train on a particular section of track and use them to activate signals at intersections or to prevent other trains from entering an occupied section of track. One of the ways to detect rolling stock on a rail line correctly and determine the accuracy of finding the faults in it is to use a decision devise [2-3].

The decision device is the simplest analog computing device, the main purpose of which is to perform one specific elementary mathematical procedure on the accepted continuous physical quantities that model certain initial continuous mathematical variables of the problem being solved [4-5]. That is why the reliability of its operation directly affects the accuracy of fault detection in the rail line.

In its' turn, the decision rule implies a procedure that it is important for the decision device to perform in order to identify the states of the rail line. Similar to correctly meet the specified requirements, which come from the standards and circumstances for track circuits.

Reducing the resistance of the insulating joint is one of the main factors affecting the performance of track circuits. Insulating joints are butt pieces designed to connect two strips of rails, and they are used for more efficient movement of trains on rails. Reducing the resistance of the insulating joint can significantly improve the permeability of trains on rails by reducing friction between the rail strips [6].

Insulating joints are two rails that are connected to each other by a metal plate and have two insulating surfaces [9]. While using butt joints with a gap of more than 30 mm, a fiberglass or rubber gasket with insulating materials is used as an intermediate material. They are designed to prevent the transfer of signal current from one rail to another.

4 Findings

The Bayes criterion is the amount of average damage from decision devise errors. Therefore, the optimal decision rule from the point of this criterion shall minimize the average damage from erroneous decisions [7-8].

Consider the possible expressions of the Bayes criterion. The decision device makes a decision about the state of the rail line S_0 or S_1, taking into account the results of monitoring the fluctuations at its input. If, after observing, the decision devise chooses the hypothesis H_1, i.e. decides whether the line is in the state S_1, then the expression for the a posteriori damage takes the following form:

$$C_1(\xi) = C_{11} P_{PS}\left(\frac{S_1}{\xi}\right) + C_{10} P_{PS}\left(\frac{S_o}{\xi}\right) \quad (1)$$

If, after observation, the decision device chooses the hypothesis H_0, then the possible average damage will have the following expression:

$$C_1(\xi) = C_{oo} P_{PS}(S_0/\xi) + C_{o1} P_{PS}(S_1/\xi), \quad (2)$$

Where C_{ij} is damages for specific decisions; - a posteriori conditional probabilities of the states of the rail line.

The physical meaning of various C_{ij} shall be considered. The first digit of the i index means the selected hypothesis, and the second digit j is the hypothesis corresponding to the state of the rail line.

C_{00} is the cost (damage) of the right decision, i.e. choice of hypothesis H_0 under the actual state S_0 of the rail lines. C_{11} is the cost of choosing a hypothesis H_1 in the actual state of the rail line S_1. Further, these costs of correct decisions are taken to be zero, i.e. $C_{00}= C_{11}= 0$, since in this case it is important to estimate the costs of erroneous decisions, and not the costs of correct decisions. C_{10} is the damage from the error of the second type, when the decision device chooses a hypothesis H_1 about the state S_1 of the rail line in its actual state S_0. C_{01} is the loss from the first kind of error when the hypothesis is chosen H_0 in the actual state of the rail line S_1. Average damages C_{10} and C_{01} can be determined on the basis of statistical data on damages obtained during investigations of the causes and consequences of derailments and train collisions due to erroneous decisions of track circuits.

Taking into account the fact that $C_{00}= C_{11}= 0$ expressions (1) and (2) are reduced to the form:

$$C_1(\xi) = C_{10} P_{PS}(S_{o/\xi)} \tag{3}$$

$$C_o(\xi)= C_{o1} P_{PS}(S_{1/\xi)} \tag{4}$$

The a posteriori probabilities of events included in expressions (3), (4) are determined using the Bayes theorem:

$$P_{PS}(S_{o/\xi)=P_{PS}(S_o)P(\xi/S_o)P(\xi/S_o)/P(\xi)}; \quad P_{PS}(S_{1/\xi)=P_{Pr}(S_1)P(\xi/S_1)/P(\xi)}; \tag{5}$$

Where $P(\xi) = pP(\xi/S_o) + qP(\xi/S_1)$, $P_{pr}(S_o)$ is the a priori probability of finding the rail line in the state S_0; $P_{Pr}(S_{1)}$ is a priori probability of finding the rail line in the state S_1.

According to the probabilities multiplication theorem, it can be written as follows:

$$P(S_1/\xi) = P(\xi)P_{PS}(S_1/\xi) = P_{pr}(S_1)P(\xi/S_{1).} \tag{6}$$

Discarding the left side of the equality and taking into account that P (ξ) does not depend on S_1, the following can be written:

$$P_{PS}(S_1/\xi) = k_1\, P_{Pr}(S_1)P(\xi/S_1), \tag{7}$$

Where $k_1$is determined from the normalization condition.

The functions are called likelihood functions and are denoted:

$$L(S_1) = P\left(\frac{\xi}{S_1}\right), L(S_o) = P\left(\frac{\xi}{S_0}\right) \tag{8}$$

For a fixed value of ξ (t), they show how much one state of the rail line is plausible to another.

Taking into account the introduced notation:

$$P_{PS}(S_1/\xi) = k_1 P_{Pr}(S_1)L(S_1) \tag{9}$$

$$P_{PS}(S_0/\xi) = k_2 P_{Pr}(S_0)L(S_0) \tag{10}$$

Further, only expression (9) is used, since

$$P_{PS}(S_0/\xi) + P_{PS}(S_1/\xi) = 1 \tag{11}$$

A priori probabilities of rail lines being in the states S_0 and S_1 can be calculated as the ratio of the total time the rail line is in the state S_0 to the total time of the rail line operation or, in other words, to the total time it is in the states S_0 and S_1.

Taking into account the fact that the probability of finding a rail line in the control mode is significantly less than the time spent in the shunt mode, it is permissible to take into account only the time the track circuit is in the shunt mode while determining p. Then

$$p = \frac{1}{24}\sum_{i=1}^{N} t_{SHi}N_i \tag{12}$$

Where $t_{SHi} = (l_{RL} + l_{Ti})/V_i$ is the time during which the track circuit is in shunt mode while the train of N_i type is passing; l_{RL}, l_{Ti} are the lengths of the rail line and of the *i-th* train respectively, km; N_i is the number of trains of the *i-th* type that have passed along the rail line within 24 hours; V_i is the speed of the train of the *i-th* type , km/h.

However, it shall be borne in mind that the train can stop within the rail line and therefore the value of p can significantly exceed the value calculated by formula (12).

5 Discussion

Thus, from the above formulas it follows that two types of information are needed to calculate the Bayes criterion: a priori, known before receiving signals from the rail line, and a posteriori, obtained in the process of observing the fluctuation *ξ(t)* for some time *T*.

The a priori information includes information about damages $C_{ij}$and the probabilities of finding the rail line in the states S_1 and S_0. This information is obtained as a result of the processing of statistical data obtained during the previous processes of operation of track circuits. The a posteriori information includes information about the likelihood functions, which increases the total amount of information necessary to make the right decision about the state of the rail line. This information is obtained in the process of receiving and processing signals coming from the rail line.

Now consider the decision rule leading to the minimization of the mean damage. Obviously, to ensure the minimum average damage, it is sufficient that it provides a minimum of posterior damage $C_1(\xi)$or $C_0(\xi)$at each observation. To do this, according to (1) and (2), the decision device must decide whether the rail line is in the state S_1, i.e. choose a hypothesis H_1 if $C_0(\xi)>C_1(\xi)$, i.e.

$$C_{o1}P_{PS}(S_1/\xi) > C_{10}P_{PS}(S_0/\xi) \tag{13}$$

When the opposite inequality is satisfied, the hypothesis shall be chosen H_0.

Let us rewrite expression (13) as follows:

$$\frac{C_{o1}P_{PS}(S_1/\xi)}{C_{10}P_{PS}(S_0/\xi)} = \frac{C_{o1}P_{Pr}(S_1)P(\xi/S_1)}{C_{10}P_{Pr}(S_0)P(\xi/S_0)} = \frac{C_{o1}P_{Pr}(S_1)}{C_{10}P_{Pr}(S_0)}l(\xi) > 1 \tag{14}$$

Where:

$$l(\xi) = \frac{P(\xi/S_1)}{P(\xi/S_0)} \tag{15}$$

Is the likelihood ratio.

Then the final expression for the decision rule, which is optimal in the sense of the Bayes criterion, can be written as:

$$\left.\begin{array}{r} l(\xi) > h - H_1 \ is \ selected \ , \\ l(\xi) \leq h - decision \ H_0 \ is \ taken \end{array}\right\} \tag{16}$$

Where *h* is the threshold of the decision devise. it is equal to:

$$h = \frac{C_{10} P_{Pr}(H_0)}{C_{01} P_{Pr}(H_1)} \tag{17.1}$$

And therefore it can be calculated based on a priori information about C_{10}, C_{01}, $P_{Pr}(H_0)$ and $P_{Pr}(H_1)$.

Now it is important to establish how it is technically possible to create a signal corresponding to the likelihood ratio at the input of the decision device.

In order to do it an example related to its interpretation in relation to track circuits shall be considered.

Let the oscillation at the input of the track circuit receiver (t) be a following mixture:

$$\xi(t) = \lambda s(t) + n(t), 0 \leq t \leq T \tag{17.2}$$

Where n(t) is white normal noise with spectral density N_o and an average value equal to zero; $s(t)$ is the RLSC signal of a known shape, located on the interval T , but with an unknown moment of its appearance at the receiver input; λ - a parameter that randomly takes the value 1 in the normal state of the rail line (S_1) and the value 0 in shunt or control modes (S_0).

In this case, $n(t) = \xi(t) - s(t)$.

Thus, in the normal mode $\lambda = 1$ and, therefore, in the received oscillation $\xi(t)$ there is a CRL signal $s(t)$. In other states of the rail line $\lambda = 0$ and, consequently, in the received oscillation $\xi(t)$ there is no RLSC signal. Thus, the decision device must decide whether or not there is a RLSC signal $s(t)$ in the received oscillation $\xi(t)$.

It was shown in [2] that with continuous processing of the received implementation $\xi(t)$ during the time T , the a posteriori probability of the presence of the RLSC L signal $s(t)$ in this implementation is determined by one formula:

$$P_{PS}(1) = kP_{Pr}(1)exp\left\{-\int_{O}^{T}[\xi(t) - \mathrm{s(t)}]^2 dt\right\} \tag{18}$$

And the a posteriori probability of the absence of the RLSC signal $s(t)$ in $\xi(t)$ is determined by another formula:

$$P_{PS}(0) = kP_{Pr}(0)exp\left\{-\int_{O}^{T}\xi^2(t)dt\right\} \tag{19}$$

Where $P_{PS}(1) + \ P_{Pr}(0) = 1$

Hence, the ratio of the likelihood functions will be determined by the ratio of only the exponential functions included in (18) and (19):

$$l(1) = l(\xi) = \frac{exp\left\{-\frac{1}{N_0}\int_0^T [\xi(t) - s(t)]^2 dt\right\}}{exp\left\{-\frac{1}{N_0}\int_0^T \xi^2(t) dt\right\}} \tag{20}$$

After transformation, the expression of the likelihood ratio is obtained in the following form:

$$l(1) = exp\left\{\frac{2}{N_0}\int_0^T \xi(t)s(t)dt - \frac{E_{ES}}{N_0}\right\} \tag{21}$$

Where $E_{ES} = s^2(t)T$ is the energy of the Raman signal.

6 Conclusion

Thus, to obtain a signal at the input of the solver, representing the likelihood ratio *l* (1), it is necessary that the receiver performs the multiplication of the received waveform *ξ(t)* with the signal *s*(*t)*, and also integrates the result over time *T* by realizations *ξ*(*t)*. Such operations, as shown in the study, are performed by a coherent receiver with a synchronous detector.

List of abbreviations

RLSC – rail lines state control.
AB – automatic blocking.
ACCS – automatic continuous cab signaling.
EC – electrical centralization.
DC – dispatcher centralization.

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