ISSN 2223–5620 (Print), ISSN 2411–1554 (Online)
Електромагнітна сумісність та
безпека на залізничному транспорті, 2017, № 14

UDC 656.25

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EXPERIMENTAL DETERMINATION OF BASIC DATA FOR PROBABILISTIC RESEARCH OF ELECTRICAL TONAL TRACK CIRCUIT

Introduction

Development of theoretical principles requires further communications with practical problems solutions. At the example of electrical tonal track circuit (TTC) after the development of probabilistic mathematical model to determine its state [1] is needed to identify practically statistical data and take them into account for changes in the mathematical model.

Purpose

To determine the investigated probabilistic characteristics and the mathematical model of TTC it is necessary to choose a mathematical apparatus for determining the probabilistic parameters, output data of the control system of electrical parameters, to measure and bring the results of measurements on the example of one object, to determine the probabilistic parameters and boundary values of the probability states of the object.

Theoretical determination of the probabilistic state of the object

To determine the state of an object using probabilistic characteristics, it is necessary to determine $P(D_i)$, $P(k_j)$ and $P(k_j/D_i)$. The order of determining the following [1, 2]: probability $P(D_i)$ founds when observing the quantity N_i of states D_i from the N of general observations.

$$P(D_i)=\frac{N_i}{N} \quad (1)$$

For what, for all probabilities $P(D_i)$, the following is true

$$\sum_{i=1}^{n} P(D_i)=1 \quad (2)$$

The probability of occurrence of a feature k_j in the presence of a diagnostic state D_i define from the following formula

$$P\left(\frac{k_j}{D_i}\right)=\frac{N_{ij}}{N_i} \quad (3)$$

where N_{ij} is the number of definitions of signs k_j in the presence of a state D_i

An event k_j occurs with one of the incompatible events $D_1, D_2 \ldots D_n$ (see formula 2). Therefore, the probability of the occurrence of this feature will be:

$$P(k_j)=P(D_1k_j)+P(D_2k_j)+\ldots+P(D_nk_j)= \\ =P(D_1)P\left(\frac{k_j}{D_1}\right)+P(D_2)P\left(\frac{k_j}{D_2}\right)+\ldots+ \\ +P(D_n)P\left(\frac{k_j}{D_n}\right) \quad (4)$$

In analytical form gets next expression:

$$P(k_j)=\sum_{i=1}^{n} P(D_i)P\left(\frac{k_j}{D_i}\right) \quad (5)$$

The final formula for determining the probabilistic state of the TTC taking into account the full group of independent actions takes the form:

$$P\left(\frac{D_i}{k_j}\right) = \frac{P(D_i)P\left(\frac{k_j}{D_i}\right)}{P(k_j)} \qquad (6)$$

Accepted conditions for measuring the electrical parameters of the tonal track circuit

The order of accumulating of statistical data with continuous determination of the state of the TTC [1] by the automatic control system is next: during multichannel measurement execute automatic recording of electric parameters of the track circuit during the day. The recording period (1 day) characterizes the period of traffic along the station-to-station block described by the schedule traffic, thus taking into account the minimal iterations the movement mode on the rail track (number of moving units, their length, speed) when measuring the following electrical parameters TTC. Proceeding from the fact that the rail track state is determined by track relay [2] and the track receiver, all measurements are made with the registration of the voltage at the input of the Track Receiver (originally named PP). Using the window Fourier transform [3, 4], data are obtained from the amplitude values of the voltages. The selected window time interval is 0.5 s, which includes full periods of modulation and industrial frequency to reduce the error of the received frequency characteristics [5]

$$T_{\mathrm{W}} = n_{50} \cdot T_{\mathrm{I}} = n_8 \cdot T_{\mathrm{M8}} = n_{12} \cdot T_{\mathrm{M12}} \qquad (7)$$

where T_{W} is the period of the Fourier transform window; $n_{50} = 25$ – number of periods of industrial frequency; $n_8 = 4$ – number of frequency periods of modulation of 8 Hz; $n_{12} = 6$ – the number of periods of modulation frequency is 12 Hz; $T_{\mathrm{I}}, T_{\mathrm{M8}}, T_{\mathrm{M12}}$ – periods of the signal of industrial frequency, frequencies 8 and 12 Hz.

When taking into account T_{W}, the maximum number of determined electrical parameters in the selection for 1 day is 172800 values. For the implementation of continuous information processing, the time distance between the measurements is reduced to 5 s, which makes it possible to simplify the load on the measuring and computer apparatus.

In order to obtain a complete dependence on each electrical parameter, according to the above-mentioned procedure, measurements were made in 7 different conditions of operation of the rail track circuit [6, 7], taking into account weather changes in temperature and humidity. The given results are taking into account the worst conditions of operation.

Statistical results of measurements

Because the large number of data obtained, the results of measurements of the voltage at the track receiver input are presented in the form of relative density distribution of this value, that shown in fig. 1.

In fig. 1, two maximums are clearly expressed, expressing two basic states of the rail track circuit: normal mode – a greater maximum with more measurements, and a shunt mode – a lower maximum. Due to the prolonged finding of the TTC in normal mode, the maximum with the range 0.58…0.63 V characterizes a greater probability of the state S1 in the presence of a being sign, that is the value $P(k_{33}/D_i)$. Actually from fig. 1 received probability data $P(k_{3j}/D_i)$.

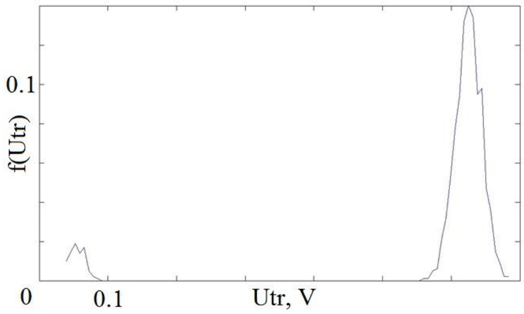

Fig. 1. Relative density distribution of voltage at the track receiver input

Fig. 2 shows the relative distribution density of voltage *U*g for the mentioned measurement period.

Fig. 2 shows a slight change of voltage. As conclusions can be admitted the independence of voltage *U*g from the power supply of, and, consequently, the independence from the current mode of the rail track circuit. From fig. 2 define the relative probability $P(k_1/D_i)$. The relative probability of sign k_2 is characterized by fig. 3, which shows the relative density distribution of the voltage at the filter output.

Similar to fig. 1, the voltage *U*f takes 2 main ranges of values. The middle value of the lower range in relation to the state of the TTC is most often obtained within the presence of a moving unit on the track. The physical meaning of the voltage *U*f change is into misbalances of the resonance circuit of the track filter [8, 9] due to the change in the phase of its power supply within the presence of additional resistance in the rail line.

The voltage on the coil relay relies directly from the state of the track receiver. In the presence of a moving unit, the track receiver fixes the occupation of the track circuit [1] and reduces the voltage at the output, that is on the coil of the track relay, which can be seen from the relative density of the voltage *U*cr distribution (fig. 4).

The values of the voltage in the range (5…5,6) V conform to the free state of the rail line from the rolling stock. Thus, with the help of fig. 4 defines relative probabilities $P(k_{4j}/D_i)$.

Fig. 5 depicts the relative density of the voltage distribution, from which the probability of the appearance of the sign k_7 is found.

By the definite values it is possible to draw the conclusion that the voltage at the time of measurement did not go beyond the admittance of the values. In relation to the state of the TTC determine the relative probability of the appearance of the sign $P(k_7/D_i)$.

Observation of the voltage of the code transformer, formed in the view of specific density, are shown in fig. 6.

In fig. 6 there is no clear dependence of the distribution from the modes of operation, is confirmed by the ratio with the state of the track circuit (null voltage value do not shown).

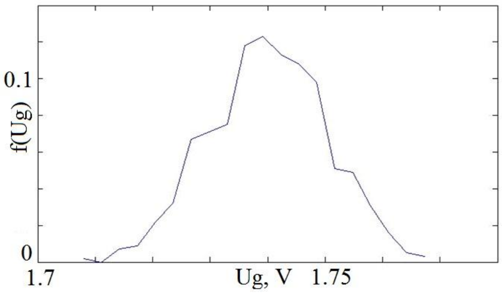

Fig. 2. Relative density distribution
of voltage at the output of the oscillator

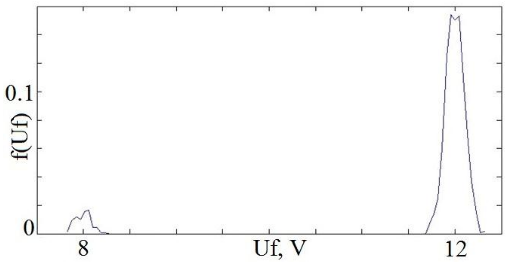

Fig. 3. Relative density distribution
of voltage at the filter output

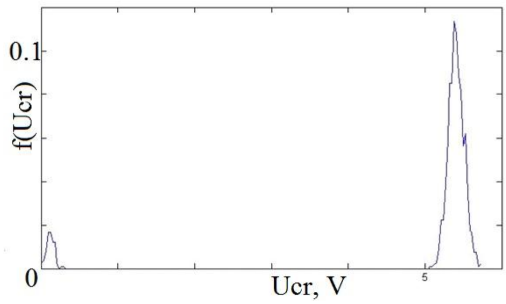

Fig. 4. Relative density distribution
of voltage on the coil relay

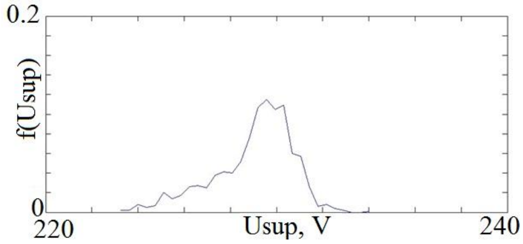

Fig. 5. Relative distribution density
of the supply voltage

Processing of measurement results

According to the results of observation and with the density of distribution the relative probabilities, which are summarized in the diagnostic table 1 [10] of the tonal track circuit, are determined.

In the diagnostic table, the values D1…D6 relate to the states of the TTC S1-S6 described in [1]. The sign "–" indicates the lack of data in the measured volume of data about the signs of electrical parameters in the appropriate state.

In determining the signs of electrical parameters of the TTC in the specified terms for 1 day, no defective state was observed, the determination of electrical parameters was carried out in the broadest operating conditions [11, 12]. Moreover, the unconditional probability of a state of S1 (diagnosis D1) is 0.9165, and S2 (D2) – 0.0835. That is, the shunt mode was observed on the track circuit for an average of 5 minutes at each hour.

In determining the state of the continuous control process, the following limits were used [10]: the probabilities of performing of operation mode – 0,99; the probability of breaking the performing of operation mode is 0.01.

Obtaining statistical characteristics

To determine the range of probabilistic finding of electrical parameters of a tonal track circuit, it is necessary:

– to determine the statistical data describing the change in the parameter in different operating conditions;

– to determine the law of distribution of the electric parameter on the received statistical data;

– to determine the probabilistic characteristics of the distribution law;

– to determine its permissible range of finding electrical parameters by analysing probability characteristics and given probabilities;

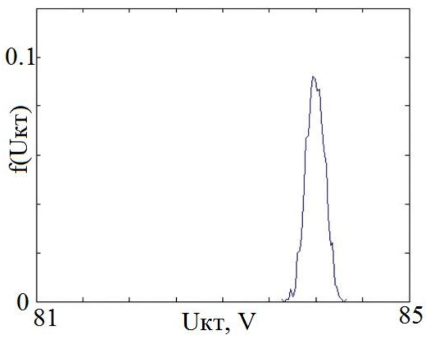

Fig. 6. Relative density distribution of the voltage of the code transformer

Table 1

Diagnostic table of the tonal track circuit

Діагноз Di	Sign kj								
	k1	k2	k31	k32	k33	k34	k35	k36	k37
	$P\left(\frac{k1}{D_i}\right)$	$P\left(\frac{k2}{D_i}\right)$	$P\left(\frac{k31}{D_i}\right)$	$P\left(\frac{k32}{D_i}\right)$	$P\left(\frac{k33}{D_i}\right)$	$P\left(\frac{k34}{D_i}\right)$	$P\left(\frac{k35}{D_i}\right)$	$P\left(\frac{k36}{D_i}\right)$	$P\left(\frac{k37}{D_i}\right)$
D1	1	1	0	0	1	0	0	0	0
D2	1	0	0	0	0	0	0	1	0
D3	–	–	–	–	–	–	–	–	–
D4	–	–	–	–	–	–	–	–	–
D5	–	–	–	–	–	–	–	–	–
D6	–	–	–	–	–	–	–	–	–
D1	0	1	0	0	1	1	1	–	0
D2	0	0	0	1	1	1	1	–	1
D3	–	–	–	–	–	–	–	–	–
D4	–	–	–	–	–	–	–	–	–
D5	–	–	–	–	–	–	–	–	–
D6	–	–	–	–	–	–	–	–	–

– with help of the maximum error between the ideal distribution law and the statistically obtained data, adjust the allowable range of electrical parameters of the TTC.

The statistical data of the distribution of electrical parameters of the TTC are shown in fig. 1–6. At the relative densities of the distribution, the normal law of the distribution of electrical parameters is clearly observed. The verification of the adequacy of the normal distribution law is realized by selecting the probabilistic parameters and comparing the difference between the determined law and the statistical data. In general, the distribution law obtained is as follows:

$$f\left(x\right)=\frac{k_{\mathrm{MA}}}{\sigma\cdot\sqrt{2\cdot\pi}}\cdot \mathrm{e}^{-\frac{\left(x-M\right)^2}{\left(2\cdot\sigma\right)^2}} \qquad (8)$$

where $f\left(x\right)$ – distribution law; M – mean of a distribution law; x – the value of the input; σ – the standard deviation; k_{MA} – coefficient, which gives the amplitude of the normal distribution law to the obtained statistical data.

The found values of the mathematical expectation and the mean of square deviation of the distribution law of electrical parameters are summarized in table 2.

The brackets show the values of the voltage at the filter output, which relates to the busy state of the rail line. In the normal distribution law, according to the theoretical positions [11], there is a rule of three mean of square deviations (the probability of output of the parameter at the permissible limits of 0,27 %), then to set the maximum and minimum limits of the output of the electrical parameters. That is why it is necessary to select the intervals in this way (on the example of the voltage of the generator TTC):

$$U_{\mathrm{g}}\in\left[M_{\mathrm{g}}-3\cdot\sigma_{\mathrm{g}};M_{\mathrm{g}}+3\cdot\sigma_{\mathrm{g}}\right],$$
$$U_{\mathrm{g}}\in\left[1,71;1,77\right] \qquad (9)$$

Similarly, expression (9) defines the limit of the range in which the electrical parameter must be located. For the parameters specified in table 2 of the TTC, the limits (see table 3), which determine the ranges of finding these parameters in a normal operated condition, are given. Also, when the electrical parameter is out from limited range, the specified limits characterize the beforehand breaking operating state (relating to the functions of the failure of FR in [12]) with the additional condition of finding within the mentioned features.

Table 2

Statistical characteristics of the distribution of electrical parameters

Electrical parameter	Ug	Uf	Utr	Ucr	U_{KT}	U sup	Urtr	Urcr
Mean	1,74	12 (8)	0,62	5,4	84	229	0,06	0,15
Standard deviation	0,01	0,1 (0,1)	0,02	0,1	0,1	1,7	0,01	0,04

Table 3

Ranges of electrical parameters of the tone track circuit within operating state

Electrical parameter	Ug	Uf	Utr	Ucr	U_{KT}	Usup	Urtr	Urcr
Range of values defined by statistical data	1,71… 1,77	11,7… 12,3 (7,7…8,3)	0,56… 0,68	5,1… 5,7	83,7… 84,3	223,9… 234,1	0,03… 0,09	0,03… 0,27
Range of values defined by service technology	1,24… 1,77	8,75… 12,5	0,4…0,7	4…8	≥82,5	207… 241,5	≤0,24	≤0,42

On the basis of this table, for the sign of the voltage at the input of the track receiver values deviates between $U_{\text{КР}}\max$ and $U_{\text{КР}}\min$, which equal to 0.68 V and 0.56 V respectively. When taking into account the maximum error between theoretical and practical data, adjusting the ranges for the voltage, in particular for $U_{\text{КР}}\max$ and $U_{\text{КР}}\min$, perform as follows:

$$U_{\text{КР}}^{\text{В}}\max = U_{\text{КР}}\max\cdot\left(1+\frac{\delta}{100}\right),$$

$$U_{\text{КР}}^{\text{В}}\min = \frac{U_{\text{КР}}\min}{1+\dfrac{\delta}{100}} \qquad (10)$$

where $U_{\text{КР}}^{\text{В}}\max$ and $U_{\text{КР}}^{\text{В}}\min$ – corrected maximum and minimum values of the limits of established ranges; δ – percentage of maximum error between theoretical and practical statistical data.

For example, the voltage *U*tr limits $U_{\text{КР}}\max$ and $U_{\text{КР}}\min$ are finally obtained and the values are 0.7 V and 0.53 V at a maximum error of 5 percent. Determination of the changed limits of finding other electrical parameters of the TTC is similar.

Conclusions

In the paper for the first time, the probabilistic characteristics of the tonal rail circuit, the distribution density of electrical signals and probability limits are obtained, which in the future can be used for the formation of pre-failure states with the probability of failure during normal operation.

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Ключові слова: тональне рейкове коло, статистичні параметри, закони розподілу електричних величин.

Ключевые слова: тональная рельсовая цепь, статистические параметры, законы распределения электрических величин.

Keywords: track circuit of tonal frequency, statistical parameters, laws of distribution of electric values.

Reviewers:
D. Sc. (Tech.), Prof. A. B. Boinyk,
D. Sc. (Tech.), Prof. A. M. Mukha.

Received 04.04.2017.
Accepted 16.04.2017.