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Reliability Of An Automatic Adjustable Current Transformer

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ABSTRACT

In the article the reliability calculations of automatic transformers with adjustable range are performed. Since reliability is one of the main characteristics of current transformers, several parameters of its range are included in the calculation of the reliability of an automatic adjustable current transformer, and as a result, high-precision values of reliability were achieved.

KEYWORDS

Broadband current transformer, Probability of failure, Probability of failure, Frequency of failure, Failure intensity, Average downtime

INTRODUCTION

We use the following indicators to assess the reliability of DARTT before the first failure [1]:

Probability of failureP(t) – probability of failure of the system or element in a given time interval(0,t) [2].

According to statistics, the value of P(t) is determined by the ratio of the number of elements N(t) worked without failure to the moment t to the number of elements observed at the initial moment:

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$$P(t) = \frac{N(t)}{N(0)}. \qquad (1)$$

$(0, t)$ the number of elements that can be used over time

$$N(t) = N(0) - n(0, t) \qquad (2)$$

Where is $n(0, t)$ - $(0, t)$ the number of elements out of order at the time

Probability of failure$Q(t)$ – the probability of failure of the trace or element in a given time interval $(0, t)$ the probability of failure in a time interval. Statistical estimate of $Q(t)$ [3]:

$$Q(t) = \frac{n(0, t)}{N(0)}. \qquad (3)$$

Frequency of failure $a(t)$- is the product of the probability of failure of the element in units of time, $(t, t + \Delta t)$:

$$a(t) = \frac{dQ(t)}{dt} = -\frac{dP(t)}{dt}. \qquad (4)$$

$a(t)$ statistical evaluation can be used to determine the value:

$$a(t) = \frac{n(t, \Delta t)}{N(0)\Delta t}, \qquad (5)$$

Where is $n(t, \Delta t)$ - t from the number of failed elements in the time interval up to $+\Delta t$.

Failure intensity$\lambda(t)$ — t conditional probability of failure in the unit time after t, provided that the element does not fail before [4].

The intensity of the failure is related to the frequency of the failure and the probability of failure as follows:

$$\lambda(t) = \frac{a(t)}{P(t)}. \qquad (6)$$

Since $P(t) \leq 1$ the relation $\lambda(t) \geq a(t)$ always holds. According to statistics, the intensity of dismissal is determined as follows:

$$\lambda(t) = \frac{n(t, \Delta t)}{N(t)\Delta t}. \qquad (7)$$

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The reliability indicators considered are interrelated through the relationships presented in Table 1.

Table 1

Indicators	Formulas for determining unknown indicators			
	$P(t)$	$Q(t)$	$a(t)$	$\lambda(t)$
$P(t)$	-	$1-P(t)$	$-\frac{dP(t)}{dt}$	$-\frac{1}{P(t)}\frac{dP(t)}{dt}$
$Q(t)$	$1-Q(t)$	-	$-\frac{dQ(t)}{dt}$	$-\frac{1}{1-Q(t)}\frac{dQ(t)}{dt}$
$a(t)$	$\int_t^\infty a(x)dx$	$\int_0^t a(x)dx$	-	$\frac{a(t)}{\int_t^\infty a(x)dx}$
$\lambda(t)$	$e^{-\int_0^t \lambda(x)dx}$	$1-e^{-\int_0^t \lambda(x)dx}$	$\lambda\cdot e^{-\int_0^t \lambda(x)dx}$	-

Average downtime T - represents the mathematical expectation of object failure before the first downtime [5]. This figure is expressed geometrically as follows through the surface below the probability curve:

$$T=\int_0^\infty P(t)dt, \text{(year)}. \qquad (8)$$

Given that the breakdown intensity for a range-adjustable current transformer is practically unchanged during normal operation, i.e. $\lambda(t)=\lambda=const$, the relationship between the main reliability indicators given in Table 1 can be more conveniently and simply stated as follows:

$$P(t)=e^{-\lambda t}, \qquad (9)$$

$$Q(t)=1-e^{-\lambda t}, \qquad (10)$$

$$a(t)=\lambda\cdot e^{-\lambda t}, \qquad (11)$$

Formulas (9) - (11) characterize the exponential law of reliability, ie the exponential distribution of downtime at a constant intensity of failure [].

(8) The average time of absence for the expression exponential law has the following form:

$$T=\frac{1}{\lambda}, \text{(year)}. \qquad (12)$$

The following expression is used for statistical evaluation of T values:

$$T = \frac{\sum_{i=1}^{N(0)} t_i}{N(0)}, \qquad \text{(year)}. \qquad (13)$$

t_i - i- the time it takes for the element to fail.

The probability of failure due to heat exposure *is determined using the following data*:

a variational series of excess of ambient temperature (20C°), τ_i:

№	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
τ_{TT}, C°	25	26	32	27	27	29	33	28	29	31	26	29	27	30	35
τ_i, C°	5	6	12	7	7	9	13	8	9	11	6	9	7	10	15

The average value of the increase in ambient temperature, $\tau_{aver.} = 8{,}93$ C°; allowable value $\tau_{pyx.} = 15$ C°.

Deviation from the average square:

$$\sigma_{av.} = \sqrt{\frac{\sum(\tau_i - \tau_{cp})^2}{n-1}} = \sqrt{\frac{\sum(\tau_i - 8{,}93)^2}{14}} = 2{,}8401. \qquad (14)$$

Coefficient of temperature variation:

$$\xi = \frac{\sigma_{av.}}{\tau_{av.}} = \frac{2{,}8401}{8{,}93} = 0{,}3179. \qquad (15)$$

The intensity of failure as a result of exposure to heat is t = 6 months:

$$\lambda(t) = 10^{-4}\left[\frac{1{,}01}{\xi} \cdot t + (200 - 80{,}5 \cdot \beta)[(1 - e^{-0{,}07t}) - \right.$$
$$\left. - \left(\frac{\tau_{add.}}{\tau_{max} + \tau_{add.}}\right) + \left(\frac{\tau_{av.} - \tau_{max}}{\sigma_{av.}}\right) + \left(\frac{\tau_{add.} - \tau_{max}}{\sigma_{av.}}\right)\right]\right] =$$
$$= 10^{-4}[1{,}5885 - 1{,}25(0{,}034 - 0{,}5 - 2{,}1373)] = 4{,}8426 \cdot 10^{-4}, \qquad (16)$$

Where β = 1,6 ÷ 3 is considered the equal interval β = 2,5.

Table 2 shows the calculated values of the reliability indicators of DARTT elements. The values in this table are approximate.

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Table 2

№	The name of the TT element	Number of elements *n*, ps.	Failure intensity, $\lambda \cdot 10^{-6}$(1/hour)	Failure intensity, λ (1/year)	The failure intensity of a group of elements, $n \cdot \lambda$ (1/year)
1	The core	1	0,2	0,001752	0,00175
2	Primary wrap	2	0,03	0,000263	0,00053
3	Secondary wrap	1	0,03	0,000263	0,00026
4	Insulation	6	0,3	0,002628	0,01577
5	Welding	2	0,004	0,000035	0,00007
6	Fastening details	10	0,002	0,000018	0,00018
7	Automatic system:				
-	Microcontrollers	1	0,8	0,007008	0,00701
-	Transistor	6	0,2	0,001752	0,01051
-	Capacitor	4	0,1	0,000876	0,00350
-	Inductive coil	4	0,13	0,001139	0,00456
8	Connectors	6	0,015	0,000131	0,00079
9	Heat effect	1	0,055	0,000482	0,00048
	Total	29	1,866	0,016346	0,04540

According to the expressions (9 – 12) we determine the following reliability indicators for DARTT elements at t = 6 months:

Probability of (not)failure $P(t)$:

$$P(0.5) = \mathrm{e}^{-0{,}04540*0{,}5} = 0{,}977554;$$

Probability of (may)failure $Q(t)$:

$$P(0.5) = 1 - \mathrm{e}^{-0{,}04540*0{,}5} = 0{,}022445799;$$

Frequency of failure $a(t)$:

$$a(0.5) = \lambda \cdot P(0{,}5) = 0{,}04438397;$$

Average time off work *T*:

$$T = \frac{1}{0{,}04540} = 22{,}02493752, \text{(year)}.$$

The probability of failure of the insulation between the layers is determined by the following layer data:

The allowable coefficient of insulation strength reserve: longitudinal, $\mathrm{k_{б.}}$; main, $\mathrm{k_{a.}}$; coefficient taking into account the insulation strength reserve:

$$q_1 = \frac{k_{б.}}{k_{х,б.} + k_{б.}} \cdot \frac{k_{a.}}{k_{х,a.} + k_{a.}}. \quad (17)$$

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The length of the conductor in the core, L (м)	Possible obvious defects, N	Total number of packages, n	One pack length, l (м)	Coefficient taking into account the insulation strength reserve, q_1	The method of insulating the bent areas of the conductor and the coefficient taking into account the presence of gaskets, q_2	Percentage of the number of bends corresponding to a defect in an adjacent package, k	The coefficient that takes into account the location of the coil in the core, m
44	3	200	0,22	0,5	0,1 ÷0,2	0,004	1

Probability of coincidence of defects in the pelvis:

$$Q' = 1 - e^{-\left(\frac{N}{L}\right)^2} \cdot l = 1 - e^{-\left(\frac{3}{44}\right)^2} \cdot 0{,}22 = 0{,}78102. \quad (18)$$

Possibility of short circuit of windings in the winding:

$$Q'' = Q' \cdot q_1 \cdot q_2 = 0{,}78102 \cdot 0{,}5 \cdot 0{,}1 = 0{,}03905. \quad (19)$$

The possibility of failure of the coils as a result of a short circuit of the windings:

$$Q_{ins.} = 1 - (1 - Q'')^{(n-1)k \cdot m} = 1 - (1 - 0{,}039051)^{199 \cdot 0{,}004} = 0{,}031210. \quad (20)$$

The probability of failure of the coils on the strength of the insulation:

$$P_{ins.} = 1 - Q = 0{,}9688. \quad (21)$$

Using the probability of failure of the insulation between the coils for DARTT, we determine the following reliability indicators:

probability of failure P:

$$P = P(0{,}5) \cdot P_{ins.} = 0{,}94705451;$$

probability of failure Q:

$$Q = 1 - P = 0{,}05294549;$$

average time off T:

$$T = -\frac{t}{\ln P} = 10{,}190603, \text{(year)}.$$

Thus, more accurate values of reliability were achieved by covering several of its parameters in determining the reliability of an automatic adjustable current transformer. The obtained results will be used in the design, manufacture and operation of the proposed range-adjustable current transformer, as well as in the calculation of its cost-effectiveness.

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