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CALCULATION OF SPARE ELEMENTS IN COMPLETE SETS OF THE ZIP ON THE BASIS OF DN-DISTRIBUTION

Abstract: *Design procedures of sufficiency of the ZIP, quantities of nonrestorable spare elements on the basis of use as theoretical model of refusals of elements and a product of two-parametrical DN-distribution are presented.*
Key words: *probability of non-failure operation, spare elements, the period of updating the ZIP, sufficiency of the ZIP.*

Анотація: *Представлено методики розрахунку достатності ЗІП, кількості невідновлюваних запасних елементів на основі використання як теоретичної моделі відмов елементів і виробу двопараметричного DN-розподілу.*
Ключові слова: *імовірність безвідмовної роботи, запасні елементи, період поповнення ЗІП, достатність ЗІП.*

Аннотация: *Представлены методики расчета достаточности ЗИП, количества невосстанавливаемых запасных элементов на основе использования в качестве теоретической модели отказов элементов и изделия двухпараметрического DN-распределения.*
Ключевые слова: *вероятность безотказной работы, запасные элементы, период пополнения ЗИП, достаточность ЗИП.*

1. Introduction

The complete set of spare parts, tools and accessories (ZIP) should include the spare parts necessary for repair and maintenance of an efficient condition of products during certain time (the period of updating the ZIP) and maintenance of a demanded level of reliability of the last. One of the major aprioristic information defining finally volume of spare parts, the theoretical model of refusals accepted at calculations of number of refusals is represented. In the present work it is accepted, that distribution of an operating time to refusal (on refusal) elements is described by DN-distribution which is represented the most universal and adequate model of refusals of electro technical products.

By development of a design procedure of spare elements in single complete sets the it ZIP following assumptions are accepted: the equipment consists of nonrestorable elements consistently connected reliability; reliability of working and spare elements of each standard rating is identical; at storage spare elements do not refuse; all working (reserve, spare) elements refuse independently.

Depending on purpose of the equipment, system of its maintenance service and repair, requirements to the equipment on reliability in coordination with the customer the period of updating $\left(T_{ПЗ}\right)$ is accepted to equal one, two or three years. The present technique allows to count volume the ZIP and on more long periods (10–20 and more years).

2. Estimation of reliability of a product and parameters of sufficiency the ZIP

Define a total operating time of products t_{Σ} at the moment of the beginning of the period of updatings in view of factor of intensity of operation during this period. Establish a demanded level of a parameter of reliability of a product at the moment of the ending of the period of updating: probability of non-failure operation $R_{изд}^{тр}$.

Parameters of sufficiency define the ZIP π_{∂} on the basis of the analysis of expected and demanded parameters of reliability ($\pi_{\partial} \geq R_{изд}^{тр} / R_{изд}(T_{ПЗ})$, approximating up to the nearest values of some: $0{,}9;\ 0{,}95;\ 0{,}99;\ 0{,}995;\ 0{,}999; 0{,}9995;\ 0{,}9999$.

The note. The parameter of sufficiency of the ZIP π_{∂} can be set by the customer irrespective of expected parameters of reliability of a product.

Nitial data for calculation of the nomenclature of the complete set the ZIP, quantities of spare parts are: structure and composition of a system; the nomenclature of making elements m (standard nominals) and number of elements of each type n_i $(i = \overline{1, m})$; parameters of reliability of each standard nominal T_{oi}, V_{oi}.

The task of requirements to parameters of sufficiency of the ZIP for products with nonrestorable spare elements

The ZIP of products with nonrestorable spare elements applies π_{∂} to an estimation of sufficiency of complete sets probability of that during $T_{ПЗ}$ work of a product there it will be no refusal the ZIP. The probability π_{∂} is applied to an estimation of sufficiency of complete sets the ZIP provided that all stocks in this complete set replenish periodically with the identical periods and a parameter of reliability of a product the probability of non-failure operation serves. Initial data for calculation of parameters of sufficiency π_{∂} of the ZIP are expected probability of non-failure operation of a product $R_0(T_{ПЗ})$ at the moment of the ending of the period of updating the ZIP and requirements to parameters of reliability of a product $R_{изд}^{тр}$.

If it is not known $R_0(T_{ПЗ})$, calculate

$$R_0(T_{ПЗ}) = \Phi\left(\frac{1-x}{V_0\sqrt{x}}\right) - e^{2V_0^{-2}}\Phi\left(-\frac{1+x}{V_0\sqrt{x}}\right).$$

Where $x = T_{ПЗ}/T_0$; T_0 – an average operating time to refusal of a product; $\Phi(\cdot)$ – function of normal distribution.

The note. In last formula value of an operating time $t = T_{ПЗ}$ that corresponds to the beginning of operation of a product is accepted. Generally, when count $R_0(T_{ПЗ})$, consider an operating time t_{Σ} prior to the beginning of the next period of updating the ZIP, $t = t_{\Sigma} + T_{ПЗ}$.

Estimation of demanded probability of non-failure operation of elements

Accept the value $R_{изд}^{тр}$, satisfying to a parity $R_{изд}^{тр} \leq R_0(T_{ПЗ})$ and according to values of the aforesaid of some. Define a parameter of sufficiency of the complete set the ZIP from a ratio $\pi_{\partial} \geq R_{изд}^{тр} / R_0(T_{ПЗ})$. If $R_0(T_{ПЗ})$ less than the smallest value of number from recommended of some probabilities accept value

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$\pi_{\partial} = R^{mp}_{uз\partial}$ from these of some from reasons of importance of carried out functions and economic feasibility.

Calculate a demanded level of probability of non-failure operation R^{mp}_{i} for set of elements of i-th standard rating $\left(R^{mp}_{i} = (R^{mp}_{uз\partial})^{\frac{1}{m}} \right)$, approximating up to the nearest value from recommended.

Estimation of probability of non-failure operation of elements

Settle an invoice R_i (probabilities of non-failure operation of set n_i of elements of i-th type for an interval ($0,\ t_{\Sigma} + T_{ПЗ}$)). On values $F = \dfrac{1}{n_i + 0{,}5}$ and $\nu = V_{oi}$ from corresponding tables of DN-distribution define or deciding the equation:

$$F = \Phi\left(\frac{x-1}{\nu\sqrt{x}}\right) + \exp\left(\frac{2}{\nu^2}\right)\Phi\left(-\frac{x+1}{\nu\sqrt{x}}\right).$$

Further determine an operating time to first failure elements of i-th type under the formula $t_{1i} = x_i\,T_{0i}$. Calculate $x_i^* = \left(t_{\Sigma} + T_{ПЗ}\right)/\,t_{1i}$. On values x_i^* again from the same tables already a return entrance define (probability of occurrence of refusal for an interval ($t_{\Sigma} + T_{ПЗ}$) i-th type of elements) or deciding the above-stated equation for $x = x_i^*$ rather F. Calculate the required value $R_i = 1 - F_i$.

On values R_i also R^{mp}_{i} define a parameter of sufficiency $\pi^{mp}_{\partial i}$ of maintenance of nonrestorable spare making elements of i-th type (approximating up to the nearest greater value from some recommended) under the formula (under condition of $R_i < R^{mp}_{i}$):

$$\pi^{mp}_{\partial i} = \begin{cases} 1 - \dfrac{(1-R^{mp}_{i})}{(1-R_i)}, & npu \quad R_i < \left(\pi_{\partial}\right)^{\frac{1}{m}}; \\ \left(\pi_{\partial}\right)^{\frac{1}{m}}, & npu \quad R_i \geq \left(\pi_{\partial}\right)^{\frac{1}{m}}. \end{cases}$$

The note. If $R_i \geq R^{mp}_{i}$, elements of the given type are not included into the nomenclature of the ZIP (accept $z_i = 0$ for i=1, 2, …, q).

Calculation of factor of recalculation

Values of factor of the recalculation $\theta_{\partial i}$ providing the set level of sufficiency $\pi^{mp}_{\partial i}$ of nonrestorable elements of i-th type, is calculated under the formula:

$$\pi^{mp}_{\partial i} = \Phi\left(\frac{\theta_{\partial i} - 1}{V^*_{0i}\sqrt{\theta_{\partial l}}}\right) + \exp\left(\frac{2}{(V^*_{0i})^2}\right)\Phi\left(-\frac{\theta_{\partial i} + 1}{V^*_{0i}\sqrt{\theta_{\partial i}}}\right).$$

Where $V_{0i}^{*} = \frac{V_{0i}}{\sqrt{\alpha_i}}$; $\alpha_i = INT[a_i + 1]$; a_i – the average expected value of number of refusals for considered{examined} time.

At use of corresponding tables value $\theta_{\partial i}$ is defined on values $F = \pi_{\partial i}^{mp}$ and $\nu = V_{0i}^{*}$, i.e. tabulared value x is equal to factor of recalculation $\theta_{\partial i} = x(\pi_{\partial i}^{mp};\ V_{0i}^{*})$. For example, for $\pi_{\partial i}^{mp} = 0{,}95$ and V_{0i}^{*}=0,7 is defined from tables of DN -distribution: $\theta_{\partial i} = x(\pi_{\partial i}^{mp};\ V_{0i}^{*}) = x(0{,}95;\ 0{,}7) = 2{,}3634.$

3. Calculation of quantity of spare elements

Calculation of quantity of spare nonrestorable elements z_i, making out in the form of tabl. 1, make in the following order:

1. Define average operating time to refusal of making elements T_{0i}:

– if average operating time to refusal of elements accept $T_{0\,i} = T_{0\,i}$ is presented;

– if λ_{0i} given, calculate T_{0i} as follows:

– if $\lambda_{0i} > 10^{-5}$, $T_{0i} = \frac{1}{\lambda_{0i}}$;

– if $10^{-5} \geq \lambda_{0i} > 10^{-9}$, $T_{0i} = \exp[2{,}20568 + 1{,}0971(\ln \lambda_{0i}^{-1}) - 0{,}02443(\ln \lambda_{0i}^{-1})^2]$;

– if $10^{-9} \geq \lambda_{0i}$, $T_{0i} = \frac{0{,}002}{\lambda_{0i}}$.

2. Using the known information, establish values of factors of a variation of an operating time of elements V_{oi}. For products of electronic techniques (semi-conductor devices, integrated microcircuits, resistors, condensers, etc.) accept V_{oi} =1 if there is no the information specifying this value.

Initial data (the type of an element i, number of elements of i-th type n_i, an average operating time to refusal of i-th type of elements T_{oi}, factor of a variation of an operating time of elements V_{oi}) writes down in first four columns. Calculate values R_i and write down in 5 column of tabl. 1. Calculate values R_i^{mp} and write down in 6 column of тabl.1. On values R_i also R_i^{mp} define a parameter of sufficiency for corresponding elements $\pi_{\partial i}^{mp}$ and write down results in 7 column, approximating (if necessary) result up to tabulated values according to some accepted.

Calculation of the expected number of refusals of nonrestorable elements

If the expected number of refusals is not enough, at $x_{i2} = \frac{t_\Sigma + T_{\Pi 3}}{T_{0i}} \leq 0{,}5$, calculate the average expected number of refusals a_i as follows. Calculate probability of refusal of elements of i-th type at the moment of the beginning of the period of updating F_{i1}:

$$F_{i1} = \Phi\left(\frac{x_{i1}-1}{V_{0i}\sqrt{x_{i1}}}\right) + \exp\left(\frac{2}{V_{0i}^2}\right)\Phi\left(-\frac{x_{i1}+1}{V_{0i}\sqrt{x_{i1}}}\right).$$

If t_Σ=0, F_{i1}=0.

Calculate probability of refusal of elements of i-th type at the moment of the ending of the period of updating F_{i2}:

$$F_{i2} = \Phi\left(\frac{x_{i2}-1}{V_{0i}\sqrt{x_{i2}}}\right) + \exp\left(\frac{2}{V_{0i}^2}\right)\Phi\left(-\frac{x_{i2}+1}{V_{0i}\sqrt{x_{i2}}}\right).$$

Calculate the average expected value of refusals under the formula:

$$a_i = n_i(F_{i2} - F_{i1}).$$

The calculated values of the expected average of refusals a_i bring in 8 column of tabl. 1.

If a relative operating time $x_{i2} > 0{,}5$, repeated refusals a population mean of number of refusals elements of i-th type of the beginning for a moment of the period of updating $\Omega_{i1}(x_{i1})$ calculate are probable, using corresponding{meeting} tables, or under the formula:

$$\Omega_{i1}(x_{i1}) = \sum_{k=1}^{5}\left[\Phi\left(\frac{x_{i1}-k}{V_{0i}\sqrt{x_{i1}}}\right) + \exp\left(\frac{2k}{V_{0i}^2}\right)\Phi\left(-\frac{x_{i1}+k}{V_{0i}\sqrt{x_{i1}}}\right)\right].$$

If t_Σ=0, $\Omega_{i1}(x_{i1})$=0.

Calculate a population mean of number of refusals of elements of i-th type at the moment of the ending of the period of updating $\Omega_{i2}(x_{i2})$:

$$\Omega_{i2}(x_{i2}) = \sum_{k=1}^{5}\left[\Phi\left(\frac{x_{i2}-k}{V_{0i}\sqrt{x_{i2}}}\right) + \exp\left(\frac{2k}{V_{0i}^2}\right)\Phi\left(-\frac{x_{i2}+k}{V_{0i}\sqrt{x_{i2}}}\right)\right].$$

Calculate average expected value of refusals under the formula:

$$a_i = n_i\left[\Omega_{i2}(x_{i2}) - \Omega_{i1}(x_{i1})\right].$$

The calculated values of an expected average of refusals a_i, write down in a column 8 tabl. 1. On the basis of the received values $\pi_{\partial i}^{mp}$, a_i and α_i define factor $\theta_{\partial i}$ and result write down in 9 column of tabl. 1.

Define number of spare parts under the formula $z_i = \theta_{\partial i}\, a_i$ (in case of presence of not loaded number reserve (r_i – elements of i-th type) and $a_i > r_i$ calculate number of spare parts under the formula $z_i = \theta_{\partial i}\,(a_i - r_i)$). A rounding of settlement value z_i make up to an integer in greater side, for $z_i < 0{,}05$ accept $z_i = 0$.

The received values z_i bring in 10 column of tabl. 1.

Table 1

Type of an element, i	n_i, pieces	T_{oi}, h.	V_{0i}	R_i	R_i^{mp}	$\pi_{\partial i}^{mp}$	a_i	$\theta_{\partial i}$	z_i
1	2	3	4	5	6	7	8	9	10

4. The conclusion

Design procedures of parameters of sufficiency, calculation of number of nonrestorable elements are presented to the ZIP on the basis of the most adequate two-parametrical function of distribution of an operating time to refusal (on refusal) of Diffusion nonmonotonic distribution (DN-distribution). More precise definition of volume of the ZIP has the important practical value for maintenance of reliability at operation of technical systems.

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