UDK 629.78

O. V. Danick, Y. E. Shapran, V. O. Kyrychenko
The Kyiv State Maritime Academy named after hetman
Petro Konashevich- Sahaydachniy; Ukraine, Kiev, Frunze, 9
State enterprise “Ukrainian research and training center of standardization,
certification and quality“ Ukraine, Kiev, st. Svyatoshinskaya 2

PROBABILISTIC MODEL OF THE FLOW OF FAILURES OF UNITS OF THE AUTOMATIC CONTROL OF THE SHIP POWER PLANTS IN THE UNSTABLE CONDITIONS OF OBSERVATION

The article presents features of development of forming of a probabilistic model of the flow of failures of aggregates of the system of automatic control of ship power plants in the unstable conditions of observation. The approach allows improving the existing system of technical operation of equipment of relevant type which in turn will improve the level of reliability.

Keywords: ship power plants, rejection units, probabilistic model, automatic control system.

ЙМОВІРНІСНА МОДЕЛЬ ПОТОКУ ВІДМОВ АГРЕГАТІВ СИСТЕМИ АВТОМАТИЧНОГО УПРАВЛІННЯ СУДНОВИМИ ЕНЕРГЕТИЧНИМИ УСТАНОВКАМИ ЗА НЕСТАБІЛЬНИХ УМОВ СПОСТЕРЕЖЕНЬ

Наведено особливості розроблення ймовірнісної моделі потоку відмов агрегатів системи автоматичного управління судновими енергетичними установками за нестабільних умов спостережень. Запропонований підхід дає змогу удосконалити систему технічної експлуатації суднового обладнання, що, своєю чергою, забезпечить підвищення рівня надійності.

Ключові слова: суднові енергетичні установки, відмови агрегатів, ймовірнісна модель, система автоматичного управління.

Introduction

Nowadays control automation of ship power plants is a promising direction of development of relevant equipment. It is necessary to develop a model failure flow units in unstable observation while improving the maintainance of such systems. This is caused by certain shortcomings of existing technology of collecting and processing of statistical information about failure.

Analysis of the existing reliability theory suggests a lack of adequate mathematical model of the flow of failures of units of the automatic control systems of ship power plants (ACS SPP) in unstable observation. The scientific researches in this area are important for analytical maintenance of the technical condition of assemblies of automatic control systems of ship power plants in terms of reliability. We know that the theory of reliability arose as a result of attempts to solve problems of providing a given level of reliability of complex technical systems. The scientific literature [1–5 and others.] is dedicated to solving these issues, but implementation of the reliability theory in each case requires improvement of approaches and methods concerning characteristics of a particular application.

The article aims to bring the results to develop a probabilistic model of the flow of failures of units of the automatic control system of ship power plant in the unstable conditions of observation.

The main body

The actual level of reliability of products R_f is determined according to the selected indicators of reliability. When using such indicators as failure flow parameter z and the number of failures per 1,000 hours of operation K_{1000} this method of control is usually used.

Background information:

product failure rate observed during the period of operation – n_f;

lifetime of the observed ships – t_Σ;

number of similar units on the ship – a.

The level of reliability of the set of similar units is controlled by comparing of observed number of failures n_f with the upper limit of the regulation (ULR), which describes the permissible level of reliability [2, 5].

The number of observed failures n has a casual nature and is a subject of known Poisson probability p of exactly n failures over time t_Σ:

$$P_n = \frac{(\hat{n}_{ex_k})^n}{n!} \cdot e^{-\hat{n}_{ex_k}} , \tag{1}$$

where $\hat{n}_{ex_k}$ – is an estimate of the number of expected failures in the k period determined by the formula:

$$n_{ex_{kj}} = \hat{z}_{ex_{kj}} \cdot t_{\Sigma_k} \cdot a_j . \tag{2}$$

Evaluation of a given parameter of the flow of failures in k control period can be defined as the average rate of the actual parameterof the flow of failures in previous periods of operation

$$\hat{z}_{ex_k} = \frac{\sum_{i=1}^{k-1} \hat{z}_{f_i}}{k-1} , \tag{3}$$

where i – is a number of previous control periods.

In the absence of a priori information about the form of the distribution of operating time between failures $F\xi(t)$, evaluation of the actual parameter of the flow of failures is given by:

$$\hat{z}_{f_{ij}} = \frac{n_{f_{ij}}}{t_{\Sigma_i} \cdot a_j} , \tag{4}$$

Then the probability that the total number of failures of devices during the lifetime will not exceed the upper limit regulation (ULR, acceptable level) with only accidental causes is determined as follows:

$$P_{\text{set}} = \sum_{0}^{n_{URL}} \frac{(\hat{z}_{ex_k} \cdot t_\Sigma \cdot a)^n}{n!} \cdot e^{-\hat{z}_{ex_k} \cdot t_\Sigma \cdot a} , \tag{5}$$

where $\hat{z}_{ex_k}$ – is scheduled parameter of the flow of failures, which is an acceptable level of reliability R_{acc}.

Setting the required level P_{set} using formula (5) is defined upper boundary adjustment, which is used in the control of reliability.

In foreign practice to determine the upper limit regulation scientists use $P_{set} = 0.975$. This means that the accidental release by the upper limit is 2.5 %, which is considered unlikely. Therefore, in case of exceeding the number of failures of upper limit regulation, nonrandom reasons are mentioned.

In this case, the analysis of possible causes is made (removal of blocks, dismantling with a comprehensive study of the technical state for the detection of weaknesses in the machine). Specific measures are developed and implemented to eliminate them. In addition, we can see trends of change of reliability, which is calculated for a reference period specified duration. The results of the control of the reliability of many foreign companies are made in a monthly report. For example, the report of one of the US company contained such information for each type of product [2]:

the number of failures for the reporting month;

upper limit of the allowed number of failures per month;

parameter of the flow of failures for the reporting month;

parameter of the flow of failures by the same month last year;

parameter of the flow of failures for the year that ending at the beginning of the reporting month;

parameter of the flow of failures for the year that ending at the end of the reporting month;

the top and lower confidence intervals for the parameter of the flow of failures for the year that ending at the end of the reporting month;

data of the regression analysis of values of the parameter of the flow of failures in the last 6 months.

In this case, control of the level of reliability made by comparing the values of n_f and n_{ULR}. The inequality $n_f < n_{ULR}$ is a signal to continue operation of products using the maintenance strategy to control the level of reliability. At $n_f > n_{ULR}$ (exceeding the upper limit) the product is added to the list of low reliability and all the measures to improve its reliability are developed.

The economic feasibility of introducing measures to improve the reliability is verified in the next step. With a negative conclusion the object faults (in design and engineering) are to be considered. If there is no progress as a result of measures, the product is entered into the list of the most frequently denied. For this type of products other maintenance strategy (for the operating time) are temporarily assigned and a new maintenance regime is defined.

Existing methods of statistical control provide usage of the Poisson's distribution law as characteristic of random value n of failures of products during the operation period. The parameter of the distribution $\hat{n}_{ex}$ depends on the total number of t_Σ products for the period. In turn, the parameter $\hat{n}_{ex}$ characterizes terms of observation and is variable depending on the serial number of observations. In terms of mathematical statistics, this case is classified as unstable conditions of observations in obtaining experimental data [4].

Cases of instability of terms of observation are classified according to the laws of change of the relevant parameters of the laws of distribution of original random value:

1. Conditions of observations are varied naturally, that is parameters of the laws of distribution of original random value are nonrandom function of ordinal number of observations.

2. Conditions of observations (i.e. the parameters of the laws of distribution of original random value) vary randomly depending on the serial number of observations.

Studies show that in this case of usage of the aggregates of ACS SPP there is a random change of conditions of observations. For accounting unstable conditions of observation as of the law of distribution of random variable n of the number of failures of products during the period of operation Poisson's distribution law should be used. Then the probability that the number of failures n for controlling operational period will not exceed the actual number of failures n_f in the parameter of distribution $\hat{n}_{ex}$ is determined by the expression:

$$P_{\hat{n}_{exi}}\left\{n \le n_f\right\} = \sum_{n=0}^{n_f} \frac{\hat{n}_{ex_i}^{\,n}}{n!} \cdot \mathrm{e}^{-\hat{n}_{exi}} \cdot F\left(\hat{n}_{ex}\right), \tag{6}$$

where $\hat{n}_{ex}$ – the statistical assessment of given (expected) amount of the refuses for i control period; $F(\hat{n}_{ex})$ – function of random value distribution $\hat{n}_{ex_i}$.

For the normal truncated distribution $F(\hat{n}_з)$ it is determined by the expression:

$$\left(\hat{n}_{ex}\right) = P_{\hat{n}_{ex_0},\sigma}\left\{\hat{n}_{ex} \le \hat{n}_{ex_i}\right\} = \frac{1}{\sigma\sqrt{2\pi}} \int_0^{\hat{n}_{ex_i}} \hat{n}_{ex} \cdot e^{-\frac{(\hat{n}_{ex_i} - \hat{n}_{ex_0})^2}{2\sigma^2}}, \tag{7}$$

where $\hat{n}_{3_i}$, σ – the mathematical expectation and standard deviation of a random value $\hat{n}_3$. Values $\hat{n}_0$, σ can be defined as follows [4]:

$$\hat{n}_{ex_0} \approx \frac{1}{l} \cdot \sum_{i=1}^{l} n_{f_i} , \tag{8}$$

$$\sigma^2 \approx S_n^2 - \hat{n}_{ex_0} , \tag{9}$$

$$S_n^2 = \frac{1}{l-1} \sum_{i=1}^{l} (n_{f_i} - \hat{n}_{ex_0})^2 . \tag{10}$$

For discrete random value $\hat{n}_{ex_i}$.= 0, 1, 2,.... distribution function $F(\hat{n}_{ex})$ is defined by the expression:

$$F(\hat{n}_{ex}) = P_{\hat{n}_{ex_0},\sigma}\{\hat{n}_{ex} \le \hat{n}_{ex_i}\} = \frac{1}{\sigma\sqrt{2\pi}} \sum_{\hat{n}_{ex}=0}^{\hat{n}_{ex_i}} \hat{n}_{ex} \cdot e^{-\frac{(\hat{n}_{ex_i} - \hat{n}_{ex_0})^2}{2\sigma^2}} , \tag{11}$$

It is notable that, the adequacy of the use of the proposed model of the flow of failures of the set of similar units of the automatic control systems of ship power plants should be provided by positive test results of distribution value $\hat{n}_{ex}$.

In accordance to the chosen method of reliability level statistical control, the models of the flow of failures of the set of similar units (ACS SPP), statistical hypotheses H_0 and H_1 should be phrased as follows:

H_0 hypothesis, which is lies in the fact that, under this datum value of actual quantity of failures n_f of units (ACS SPP) for the j-type i-th usage period, parameter n_{H_0} of the failure rate quantity distribution law n is a statistical evaluation of some specified number of failures $\hat{n}_{ex} > 0$ for the control period

H_1 hypothesis, which is lies in the fact that, under this datum value of actual quantity of failures n_f of units (ACS SPP) for the j-type i-th usage period, parameter n_{H_1} of the failure rate quantity distribution law n exceeds $\hat{n}_{ex}$ ($n_{H_1} > \hat{n}_{ex}$, generally $n_{H_1} \neq \hat{n}_{ex}$) [1–5].

Neyman–Pearson plausibility criterion statistics for the Poisson distribution has the following form:

$$W(n_f, \hat{n}_{ex}, n_{H_1}) = \frac{P_{ex(H_1)_i}\{n \le n_f\}}{P_{\hat{n}_{ex_i}}\{n \le n_f\}} \tag{12}$$

where n_{H_1} – parameter point n of the failure rate quantity distribution law for the i-th usage period that are corresponding to H1 hypothesis.

In order to determine the value $\hat{n}_{ex}$ which is the function of statistical evaluation of constrained parameter of failures $\hat{z}_{ex_i}$ of the set of similar units it should be used the parameters $\hat{z}_{ex_i}$ obtained as a result of forecasting, If the time series values of statistical evaluation of actual failure flow parameter $\hat{z}_f$ is transient. In case of stationary time series $\hat{z}_f$, the value $\hat{z}_{ex_i}$ can be determined as the average of the results of inquiry during previous periods of operation [3–5].

The statistical simulation model, which was worked out, was used for multifactorial machine experiment the purpose of which was the quantitative evaluation of the influence on technical exploitation process (TEP) characteristics which are connected with the following factors:

exploitation intensity K_1;

failure parameter of ACS SPP z unit flow, $hour.^{-1}$;

calendar terms of regular maintenance τ_{RM}, h .;

calendar terms of storage operations $\tau_{stor.}$, h.

Let`s create a vector of controlled entrances $\bar{X} = \|x_1, x_2, x_3, x_4\|^T$ from selected options x_p, $p = \overline{1,4}$ ($x_1 = K_1$, $x_2 = z$, $x_3 = \tau_{RM}$, $x_4 = \tau_{stor}$) for simulation model building, which is named factors [2].

The vector $\bar{X}$ is a point in x-space of xj variable, $j = 1, 2, ..., p$ (in factorial space). Let`s make an experiment with a built model, changing the values (levels) of selected factors on your own.

Let`s set: *i*-experiment number *(i = 1, 2, ... N);* $\bar{x}_i = \|x_{i1}, x_{i2}, x_{i3}, x_{i4}\|$ – complex of conditions of the *i-th* experiment, x_{ij} – level of the *j-th* factor in the *i-th* experiment.

Calculated during the modelling parameters are forming the vector of $Y^{<R>}(T)$, the $y_r(T)$ ($r = \overline{1,13}$) characteristics components, which are scalar values. Let`s make an experiment plan with the built simulation model of TEP unit. The experiment plan is a set of point`s coordinates in selected factorial space ($x_{11}, x_{12}, x_{13}, x_{1p}$), ($x_{21}, x_{22}, x_{23}, x_{2p}$), ($x_{n1}, x_{n2}, x_{n3}, x_{np}$), where the experiments will be running.

If *p* factors are investigated and the *j-th* factor has *q* levels, the number of factor levels combinations will be equal as $N = q_1, q_2, \ldots, q_p$. If there are a large number of p factors and q_j quantization levels (values) then intense and extremely intense plans are used for running the imitation experiment.

Due to the fact that the total factors number which are exploring is $p < 5$, let`s make a plan of full factorial experiment (FFE). It is known [3] that the full factorial experiment is an implementing of all the possible combinations of *p*-factors, each in *q*-levels.

The coordinates set of the factor space corresponding to the real TEP, was chosen as a center of the plan:

$$\overline{x_0} = \left\| K_I = 0,\ 0016, z = 6,\ 82 \cdot 10^{-3} \textit{год.}^{-1},\ \tau_{ПО} = 68 \textit{год.},\ \tau_{збер.} = 720 \textit{год.} \right\| \quad (13)$$

As a result of realization the experiments plan above with the developed simulation model the dimension observation matrix was obtained $[(r+p)\times 3888]$, where $[(r+p)\times 3888]$.

The elements of matrix observations are: x_{ji} – value of the *j-th* factor in the *i-th* experiment, y_{ri} - value of the *r-th* TEP characteristic in the *i-th* experiment where $N = 3888$ – number of experiments, $p = 4$ – number of factors.

The dependence between K_I and z factors was found when analyzing the results of experiment. According to the accepted methods of determining the parameter of failure flow, while flow parameter values of failures are constant, the inherent level of reliability is reflecting while developing and manufacturing [5].

Conclusions

The approach of forming of a probabilistic model of the flow of failures of aggregates of the system of automatic control of ship power plants in the unstable conditions of observation allows improving the existing system of technical operation of equipment of relevant type which in turn will improve the level of reliability.

1. Dillon B. Inzhenernyie metodyi obespecheniya nadezhnosti sistem / B. Dillon, Ch. Singh; per. s angl. E. G. Kovalenko. – M.: Mir, 1984. – 318 s. 2. Gnedenko B.V. Matematicheskie metodyi v teorii nadezhnosti / Gnedenko B. V., Belyaev Yu. K., Solovev A. D. – M.: Nauka, 1965. – 524 s. – (Seriya: "Fiziko-matematicheskaya biblioteka inzhenera"). 3. Analiz nadYozhnosti tehnicheskih sistem po tsenzurirovannyim vyiborkam / [Skripnik V. M., Nazin A. E., Prihodko Yu. G., Blagoveschenskiy Yu. N.]. – M.: Radio i svyaz, 1988. – 184 s. 4. Shor Ya. B. Statisticheskie metodyi analiza i kontrolya kachestva i nadYozhnosti / Yakov Borisovich Shor. – Izdatelstvo "Sovetskoe Radio", 1962. – 552 s. 5. Spravochnik po teorii veroyatnostey i matematicheskoy statistike / [V. S. Korolyuk, N. I. Portenko, A. V. Skorohod, A. F. Turbin]. – M.: Nauka, 1985. – 640 s.