The Statistical Analysis Of Operating Reliability Of Electropump Units CN 60-180 For Reactors VVER-1000 By Root Estimation Methods

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Abstract

This article is devoted to the question of statistical information processing received during the operation of pump units CN 60-180, which are working as a part of reactor VVER-1000 staff equipment. Analyzing information is taken from applied-research database VNIIAES. The observation period of objects operations is from 01.01.1990 to 31.12.2007. Statistical information was processed by using nonparametric estimation method, called root estimation. There are received such units reliability characteristics as distribution density, survival function and failure rate. Results received are used for accepting control decisions.

Introduction

Cost-effectiveness and safety of nuclear power plants are mostly defined by reliability of power units and their components. Reliability system analysis is important step in power unit operation quality management process. Operation quality includes: safety (technical, fire, radiation and nuclear) operation; cost-effectiveness and environmental load minimization. The main parts of technical object reliability system analysis are technological analysis of object operation history and quantitative analysis of its safety and maintainability. Quantitative analysis makes it possible to estimate reliability level reached and get prognostic evaluations of reliability rating for specialists who makes management decisions for protection, increasing effectiveness, updating maintenance policy, including rescheduling maintenance cycles and material and technical resources modification, safety probabilistic assessment execution. In this work there is a calculation of reliability rating for pump units CN 60-180 which are used in supply and NPP with VVER-1000 reactors boric regulation systems is represented. This system is intended for chemical neutron absorber concentration changing to regulate the reactivity, to supply heat-transfer with required quality in primary coolant circuit, leakage compensation, to supply locking water to main circulation pump, supply boron solution in primary coolant circuit in emergency situations and etc. Reliability analysis keeps on basis of applied-research database VNIIAES. There are units of Balakovo NPS (units 1-4), Kalinin NPS (units 1, 2) and Novovoronezh NPS (unit 5) included to consideration. The observation period of objects operations is from 01.01.1990 to 31.12.2007. To process statistical data nonparametric root estimation method is used. Information about failures of supply and NPS with ВВЭР-1000 reactors boric regulation pumps equipment given in allows to calculating objects failure time for each equipment item. In to-tally 162 failures with known failure time and 21 failure times which are right censored are detected among 21 objects in equipment group.

Pump equipment reliability rating calculation by using root estimation methods

To calculate of the reliability coefficients of pump equipment system root estimation method was applied. Density root estimation method is described in [1]. The method essence is that instead of required density expansion offer to factorize by orthonormal system so-called psi-function $\psi(x)$, connected with required density $f_\xi(x)$ by equation

$$f_\xi(x) = |\psi(x)|^2 \tag{1}$$

The transition from expansion $f_\xi(x)$ to expansion $\psi(x)$ allows to finding effective calculating scheme of the required expansion parameters estimation by using maximum likelihood method. Lets

$$\psi(x) = \sum_{i=1}^{m} c_i \varphi_i(x), \tag{2}$$

where $\{\varphi_i(x)\}$ is orthonormal system, $\{c_i\}$ are estimating expansion coefficients. Applying in what follows, that functions $\varphi_i(x)$, $\psi(x)$ and coefficients c_i are real. From normalization condition $\int f_\xi(x)\,dx = 1$ follows the equation

$$\sum_{i,j=1}^{m} c_i c_j \int \varphi_i(x)\varphi_j(x)\,dx = \sum_{i=1}^{m} c_i^2 = 1. \tag{3}$$

Therefore, it is necessary to estimate $m-1$ unknown coefficients. Use maximum likelihood method for their estimation. If the sample is repeated $\vec{\xi} = (\xi_1, ..., \xi_p)$, then likelihood function (LF) is:

$$L_n(\vec{c}) = \prod_{k=1}^{p} \hat{f}_\xi(\xi_k) = \prod_{k=1}^{p} \left(\sum_{i=1}^{m} c_i \varphi_i(\xi_k)\right)^2. \tag{4}$$

Logarithmic likelihood function (LLF) is:

$$l_n(\vec{c}) = \ln L_n(\vec{c}) = \sum_{k=1}^{p} \ln \hat{f}_\xi(\xi_k) = \sum_{k=1}^{p} \ln \left(\sum_{i=1}^{m} c_i \varphi_i(\xi_k)\right)^2 = \sum_{k=1}^{p} \ln \sum_{i=1}^{m} \sum_{j=1}^{m} c_i c_j \varphi_i(\xi_k)\varphi_j(\xi_k). \tag{5}$$

Thus we have optimization task: $L_n(\vec{c}) = \prod\limits_{i=k}^{p} \hat{f}_\xi(\xi_k) = \prod\limits_{i=k}^{p} \left(\sum\limits_{i=1}^{m} c_i \varphi_i(\xi_k)\right)^2 \to \max\limits_{\vec{c}}$ with constraints of equation type: $\sum\limits_{i=1}^{m} c_i^2 = 1$. (It is necessary to choose expansion coefficients c_i in such way that LF is maximal and the sum of their squares is 1). To find maximal meaning of logarithmic likelihood function $l_n(\vec{c})$ taking into account constraints (3) lets form Lagrange function:

$$L(\vec{c}) = l_n(\vec{c}) + \lambda \left(1 - \sum_{i=1}^{m} c_i^2\right). \tag{6}$$

After that it is necessary to derive function (6) and equate them with zero:

$$\frac{\partial l_n(\vec{c})}{\partial c_i} = \sum_{k=1}^{p} \frac{\partial}{\partial c_i} \ln \hat{f}_\xi(\xi_k) = \sum_{k=1}^{p} \frac{1}{\hat{f}_\xi(\xi_k)} \frac{\partial}{\partial c_i} \hat{f}_\xi(\xi_k) = \sum_{k=1}^{p} \frac{1}{\hat{f}_\xi(\xi_k)} \frac{\partial}{\partial c_i} \left(\sum_{j=1}^{m} c_j \varphi_j(\xi_k)\right)^2 =$$

$$= \sum_{k=1}^{p} \frac{2\varphi_i(\xi_k)\left(\sum\limits_{j=1}^{m} c_j \varphi_j(\xi_k)\right)}{\hat{f}_\xi(\xi_k)} = 2\sum_{k=1}^{p} \sum_{j=1}^{m} \frac{\varphi_j(\xi_k)\varphi_i(\xi_k)}{\hat{f}_\xi(\xi_k)} c_j.$$

Then we have

$$\frac{\partial}{\partial c_i} L(\vec{c}) = 2\sum_{k=1}^{p} \sum_{j=1}^{m} \frac{\varphi_j(\xi_k)\varphi_i(\xi_k)}{\hat{f}_\xi(\xi_k)} c_j - 2\lambda c_i = 0. \tag{7}$$

Multiplying both parts of equation (7) by c_i and summing by i, we will get $\lambda = p$. Substitute it in (7):

$$c_i = \frac{1}{p} \sum_{k=1}^{p} \varphi_i(\xi_k) \frac{\sum\limits_{j=1}^{m} c_j \varphi_j(\xi_k)}{\hat{f}_\xi(\xi_k)} = \frac{1}{p} \sum_{k=1}^{p} \varphi_i(\xi_k) \left(\sum_{j=1}^{m} c_j \varphi_j(\xi_k)\right)^{-1}. \tag{8}$$

To structure iterative procedure rewrite equation (8) in following form:

$$\alpha c_i + (1-\alpha)\frac{1}{n}\sum_{k=1}^{n}\left(\frac{\varphi_i(x_k)}{\sum\limits_{j=0}^{s-1} c_j\varphi_j(x_k)}\right) = c_i. \tag{9}$$

Here a new parameter $0 < \alpha < 1$ was entered, which doesn't change the equation anyway but as it provided to be influences on stability and speed of iterative procedure. Let's represent iterative procedure in following form:

$$c_i^{(r+1)} = \alpha \cdot c_i^{(r)} + (1-\alpha)\cdot\frac{1}{n}\sum_{k=1}^{n}\left(\frac{\varphi_i(x_k)}{\sum\limits_{j=0}^{s-1} c_j^r\varphi_j(x_k)}\right). \tag{10}$$

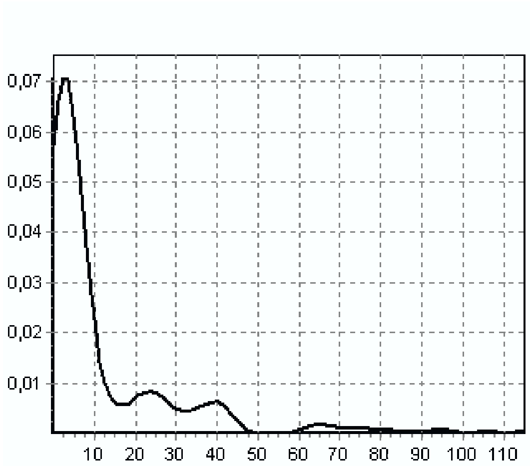
If we know density of distribution $f_\xi(x)$, then we may pass to reliability characteristics definition.

Reliability rating estimation of CN 60-180 by using root methods

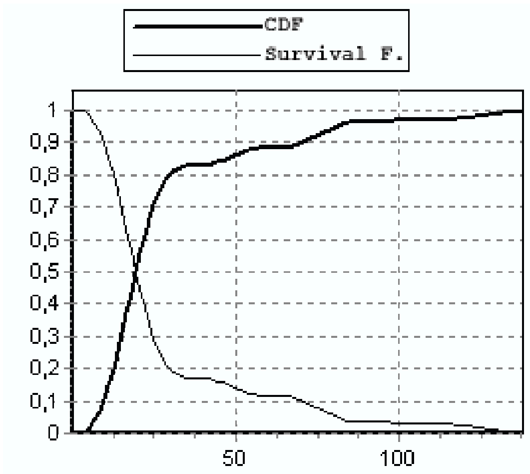
In this part there are reliability characteristics calculation results for pump units CN 60-180 by root estimation method. There were following calculations: - the estimations of density and failure time functions were built by using root method; - the following parameters were calculated on basis of received functional characteristics: "survival function;"failure rate. The results of density and failure time functions, survival function, received from data about supply boric regulation pumps CN 60-180 failures, are represented on pictures -. Measuring unit using for X-axis (failure time) is one thousand hours. Using total information about pumps units CN 60-180 failures the root estimations of following parameters were constructed: failure time density of distribution with taking into account right censoring, distribution function and survival function and failure rate. It should be noted that for such values as failure time density of distribution, survival function rating point estimates were calculated and confidence limits with confidence level 0.90 were represented as well. "Spectrum analysis"of failure rate is in particular interest (look at pictures). Each failure rate hump can be connected with objective failure reasons besides statistical noise. In this case failure rate function has three humps on operating time axis. Technical analysis of failure reasons in extreme field shows that the first hump is connected with lacks in technology of repair works executing including preventive. Indeed, if to turn back to failure data it is possible to notice that 60% failures during the period which is relevant to first intensity surge were due to the technical support and maintenance lacks. The second surge connected with separate pumps parts failures, which were due to the pumps units construction defects. 65% of failures during the second surge period occurred exactly because of this reason. Third hump can be explained by calculation mistakes on the domain boundary of failure intensity function because of the small data amount about failures during this period. Thus, nonparametric methods allow to keeping additional and more detailed technological reliability analyze and that is unusual for parametric methods. In generally the results for reliability characteristics estimation of pump unit CN 60-180 received, were used by university staff during the preparations of management decisions about NPP exploitation in part of comments elaborations for organization of maintenance policy and heat-transfer supply equipment system and NPS primary coolant circuit boric regulation and also about the explanation of auxiliary item optimal quantity for pump unit CN 60-180, which is necessary to provide power units with VVER-1000 reactors uninterrupted operation.

Reference

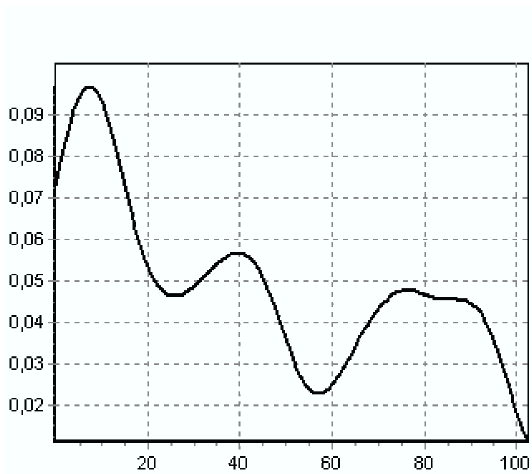
[1] Bogdanov Ju. (2002) The mane task of data statistical analysis: root method. - M.: MIET, -96p.



Picture 1 - Root estimation of failure time density of distribution built by using data about all de-vices (n=p=162)



Picture 2 - Root estimations of failure time distribution function and survival function



Picture 3 - Root estimation of failure rate