APPLICATION OF INTERVAL STATISTICS METHODS FOR POWER STATION EQUIPMENT DIAGNOSTICS IN CONDITIONS OF INITIAL DATA UNCERTAINTY

Aleksander Efimov*, Tatiana Potanina*

*National Technical University "Kharkiv Polytechnic Institute", potaninatanya@yandex.ru

Summary. In article principles of automated diagnostics system construction of the power units equipment and planning of repairs are investigated. The model constructed on the basis of interval data statistics of diagnostic functions is presented.
Key words: diagnostics of power station equipment, duration of planned repair work, duration of the between-repairs periods, availability factor, initial data uncertainty, interval statistics.

INTRODUCTION

Optimization of planning, organization of repair work on power units and calculation of their availability factor on the basis of the equipment's technical condition diagnostics are the most important and actual problems of the thermal and nuclear power engineering. The resolution of these problems concerning the practical issues of operation of power units enables to increase an economic efficiency of repair work and to determine an optimum reserve of capacity of the power supply system, being necessary for cancellation of underproduction of the electric power because of downtime of power units during repairs, having provided, thus, stabile functioning of a power supply system [1-3].

Operating experience of some foreign power stations, maintaining already since many years the high parameters of load factor, shows that achievement of such high factors is caused, appreciably, by applying of organizational and technical measures aimed at reducing and optimizing the duration and extent of repair work [4]. Thus realization of the concept of repairs of power units on a technical condition of their equipment is possible, including, and due to application of diagnostics effective systems.

Introduction in operational practice of equipment reparation depends in many respects on valuation of the sufficient amount of decision-making diagnostic attributes and methods of their processing [5-6]. During their operation the technical systems and power units equipment are influenced by a significant amount of perturbing factors, frequently stochastic by their nature; there occurs the dispersion of technical condition parameters of the diagnosed equipment, uncertainty factor is also true. Therefore adequacy of diagnostic models, validity of the decision to commence the equipment repair works and determination of the optimal duration of the between-repairs period are depending on taking into account the fuzzy information about the equipment condition and its total uncertainty which is collected during the operation time.

OBJECTS AND PROBLEMS

The technical condition of the power unit equipment during the operation is determined by the values of diagnostic functions set $D(W)$ which are parameters of its functioning quality at the moment $\tau_j, \tau_j \in [\tau_0, \tau]$.The automated diagnostics of the equipment power unit technical condition can be carried out with the help of the technological processes simulation models of the power unit [7-8]. The power unit simulation model organized as logic-numerical operators of calculation of technological processes parameters, allows to determine technical and economic parameters of power unit work and mutual influence of equipment parameters values. The analysis of these data in the concrete conditions of operation allows to determine the most essential constants and variable parameters and to generate the predictive background characteristics.

Among the criteria on which the decision of reparation, caused by the technical condition of systems and equipment is made, one of the important indications is the influence on efficiency of the change of power generation parameters and refusal of the equipment. Having determined on the basis of the given power units integrated operational characteristics (concerning an average level) the parameters of system and equipment functioning efficiency, it is possible to establish [9] the rate of decrease, the optimum service life, to predict duration of the between-repairs periods and terms of economically justified reparations. At prognostication of the technical and economical level of the power units equipment condition the analysis of its behavior in concrete conditions of operation allows to allocate the most essential (informative) constants and variable parameters, to generate characteristics predictive background and to receive, thus, sufficient volume of diagnostic attributes. With the help of operational characteristics it is possible to range parameters according the degrees of their influence on the technical systems condition and the power unit equipment [1-3, 10].

The process of automated diagnostics of power unit equipment technical condition can be presented with the following procedure:

1. Planning and organization of a series of checks $\Pi = \{\pi_1, ..., \pi_l\}$ representing experiments on the power unit simulation model $A_k, k = \overline{1, l}$ for all diagnosed equipment.

2. Determination while in service of the power unit system control and measuring devices of entrance influence value $Y_k, k = \overline{1, l}$ on the basis of indications, as the initial data of the power unit acting in simulation model, and the response of model to this influence as values of diagnostic function $D(W(Y_k))$ (result of check). With this purpose the optimization problem of checks choice determining a technical condition of the power unit equipment is solved: the total of checks should be minimal $\Pi \to \min$, and each check $\pi_k, k = \overline{1, l}$ should contain the greatest possible quantity of the information $I_{\pi_k} \to \max$.

3. Comparison of the diagnostic functions values $D(W(Y_k))$ received as a result of simulation experiment, to their measured and normative values with the purpose of a diagnostic conclusion about the reasons and factors of the equipment technical condition changes and determination of time remaining before its refusal.

Measurement of technological parameters with the help of instrumentations while in service the power unit is carried out usually in conditions of various casual interferences and errors. Taking this into account, during the fixed moment of time τ_j on the working equipment the valid value W is possible to count results of measurements of multi-parametric diagnostic function W interval estimation that is an interval between statistics, containing with the certain probability. Thus, measured function W can be counted a random variable from sample of measurements n with the unknown mean μ. The sample – a set of equally distributed random variables independent in aggregate. However the analysis of the majority of real practical problems shows, that sample W_i^l, and value $W_i^{l*} = W_i^l + \varepsilon^l$, where ε^l - the certain errors of measurements, supervision, the analysis, experiments, researches (for example, tool errors) is not known. Thus, at construction of statistics on which statistical conclusions are based and which is applied for parameterization, characteristics of distribution and check of hypotheses, observance of a principle is important, that value of statistics from a variable W_i^*, instead of W_i [11] is known. If errors satisfy to a condition $\forall l : |\varepsilon^l| \le \Delta$ the initial data are represented as intervals

$\left[W_i^l - \Delta; W_i^l + \Delta\right]$, and it is possible to set restriction on errors in the different ways - except for absolute other parameters of difference W_i^* are applied relative, and also from W_i.

Application of interval statistics methods determines a confidential interval for a mean value μ: $\left[\mu - \Delta - u(\alpha-1)\frac{S}{\sqrt{n}}; \mu + \Delta + u(\alpha-1)\frac{S}{\sqrt{n}}\right]$, where $(1-\alpha)$ – the set confidential probability, $u(\alpha-1)$ – $\frac{\alpha}{2}$-quantile of standard normal distribution with a zero mean value and an unitary variance. That is, at increase in volume of sample the length of a confidential interval cannot be less than 2Δ. It is necessary to note, that the important advantage of an estimation μ in such a way is not only the increase in an interval and the account, thus, errors of supervision, but also that distributions of supervision results in many practical problems differ from normal more often.

During diagnostics comparison average result of measurements of diagnostic function $\bar{W}_{\text{meas}}$ is performed and calculated with the help of power unit simulating model of value of the same function W_Σ representing the sum of influences of possible reasons (positive result of check π_k) is carried out at the moment of time τ_j. The check statistical theory of alternative hypotheses is applied for this purpose: $\begin{cases} H_0 : W_\Sigma = \bar{W}_{\text{meas}} \\ H_1 : W_\Sigma \neq \bar{W}_{\text{meas}} \end{cases}$.

The approach of interval data statistics in a problem of statistical hypotheses check allows to take into account the errors of measurements and consists in the following. Selective value of statistics of used criterion can accept any value in an interval in length of two “notna’s” (“notna” - size of the greatest possible deviation caused by errors of supervision $\varepsilon : N\left(\varphi(W_i)\right) = \sup_{\varepsilon}\left|\varphi(W_i) - \varphi\left(W_i^*\right)\right|$, φ – statistics). If decision-making is based on Student’s t-test, the statistics in view of dependence from measured W_i^*, instead of from the true W_i, is equal $t_0\left(W^*\right) = \frac{\sqrt{n}}{\nu}$, where $\nu = S\left(W^*\right) / \left|W_\Sigma^* - \bar{W}_{\text{meas}}\right|$ – selective constant of variation. The statistics change interval $\left[t_0\left(W^*\right) - N_{t_0}\left(W^*\right); t_0\left(W^*\right) + N_{t_0}\left(W^*\right)\right]$ and $N_{t_0}\left(W^*\right)$ are determined through “notna” for selective constant of variation $N_{t_0}\left(W^*\right)=\frac{\sqrt{n}}{\nu^2}N_\nu\left(W^*\right)$. Accordingly to that the value of a threshold C of the chosen criterion determining a deviation or acceptance of a null hypothesis (in a classical case for Student’s t-test $t_{n-1}^{1-\alpha/2}$), is in an interval $\left[C-N_{t_0}\left(W^*\right);C+N_{t_0}\left(W^*\right)\right]$, and the confidence level of criterion is in limits $\alpha\in\left(1-p\left(C+N_{t_0}\left(W^*\right)\right);1-p\left(C-N_{t_0}\left(W^*\right)\right)\right)$. Therefore, taking into account errors of measurements, it is expedient to replace C on $C+N_{t_0}\left(W^*\right)$. It guarantees probability of a deviation of a null hypothesis provided that the hypothesis is true, not big α.

For determination of the dependences describing the change of a technical condition and equipment reliability, and also the time which has stayed before its refusal, with the purpose of planning terms and duration of repairs and calculation of power units availability factor the following approach is offered.

On a predicted time interval of power unit operation parameters of its equipment $X_r, r=\overline{1,m}$ are subject to evolution as change result of equipment technical condition. As a result of stability of the physical and chemical processes causing these changes, parameters are continuous and monotonous functions of time τ which can be counted as semi-Markovian dependences with known approximations of their realizations [13].

These approximations are represented by various functions. For those the most frequently encountered in operation practice of the power units equipment there are linear and exponential functions [14]: $x_r(\tau)=\alpha_r+\beta_r\cdot\tau$ and $x_r(\tau)=c_r\cdot e^{\gamma_r\tau}$, where $r=\overline{1,m}$.

With the beginning of equipment operation at the moment of time $\tau_0=0$, with the help of regular or special control system and measuring devices of the power unit and its simulating model the offered method carries out diagnostics of the equipment technical condition in all operation time interval $\delta\tau=\tau-\tau_0$ and, thus, realizations of functions $x_r(\tau), r=\overline{1,m}$ up to the end of operation predicted interval τ are consistently observed. From the discrete values of realizations received during supervision in points $\tau_j, \tau_j\in\left[\tau_0,\tau\right]$, the best extrapolation curves are getting out $x_r(\tau), r=\overline{1,m}$, that is factors α_r,β_r or c_r,γ_r approximate dependences are calculated, and each new value of observable realizations specify predictable curves $x_r(\tau), r=\overline{1,m}$. The point of intersection of the function $x_r(\tau), r=\overline{1,m}$ (describing change of a technical condition of the diagnosed equipment) with the desired borders $g_r, r=\overline{1,m}$ (determining boundary values of this function), proceeding from power unit technical and economic parameters or its operation reliability, is interpreted as a failure time of the equipment. It allows to determine time $\Delta\tau=\tau^*-\tau_j$, which has stayed till the moment of necessary repair of the equipment (before its refusal) τ^* from the moment of technical condition diagnostics τ_j.

The dependences $x_r(\tau), r=\overline{1,m}$ constructed for the whole set of operating equipment; make a database of equipment condition and reliability parameters evolutions for concrete types of power units and conditions of their operation. Such a base can be applied at different stages of power units life cycle, including for planning of duration of repair work on power stations and determinations of the duty factor installed capacity and availability factor.

As criterion on which planning of duration of repair work is carried out, economic parameters as the power station total cost $\mathrm{C}_{\mathrm{sum}}$ connected to repairs of power units [15] act:

$$\mathrm{C}_{\mathrm{sum}}=C_{\mathrm{ek}}+C_{\mathrm{spw}}+C_{\mathrm{mat}}+C_{\mathrm{w}},$$

where C_{ek} – the cost caused by electric power underproduction because of power units downtime during reparations which depends on a lot of technical and economic factors (a level power consumption in a power supply system during repairs, possible penal sanctions for excess of repairs terms, etc.); C_{spw} – cost for a spadework previous of reparation; $\mathrm{C}_{\mathrm{mat}}$ – cost for repair materials and spare parts; C_w - cost for direct carrying out of repair work.

Duration of planned repair work is function of cost for them $\tau_{\mathrm{drep}}=f\left(C_{\mathrm{drep}}\right)$ and satisfies to a ratio $\tau_{\mathrm{drep}}\geq\tau_{\mathrm{drep\,min}}$, where $\tau_{\mathrm{drep\,min}}$ – minimally possible duration of power unit.

Time $\Delta\tau$, which has stayed before refusal of the equipment of the power unit from the moment of diagnostics of its technical condition, and duration of scheduled repair τ_{drep} determine power unit availability factor K_g, being one of the reliability index, under the following formula:

$$K_g = \frac{\Delta\tau}{\Delta\tau + \tau_{drep}}.$$

Minimally possible duration of the power unit repair $\tau_{drep\,min}$ is determined, basically, by following technological and economic preconditions: repair work cannot be executed faster than for $\tau_{drep\,min}$ because of absence on power station of corresponding repair technologies; at $\tau_{drep} = \tau_{drep\,min}$ an expense for direct carrying out of repair work C_w are maximal; costs for a spadework previous to reparation, C_{spw} also, as a rule, are maximal; costs caused by electric power underproduction C_{ek} are minimal; costs for repair materials and spare parts C_{mat} do not depend on terms of repair.

At increase in planned duration of equipment repair τ_{drep} in comparison with $\tau_{drep\,min}$ there is a reduction of power unit availability factor ΔK_g according to dependence

$$\Delta K_g = \frac{\Delta\tau\left(\tau_{drep} - \tau_{drep\,min}\right)}{\left(\Delta\tau + \tau_{drep\,min}\right)\left(\Delta\tau + \tau_{drep}\right)}.$$

For this reason the increase of duration of planned repair work at the stopped power units of power stations results in reduction of power units reliability on such parameter as availability factor K_g.

CONCLUSION

The offered methods and approaches allow to increase adequacy of diagnostic models and can be realized in power units industrial control, for diagnostics of the equipment technical condition, planning of repair work duration and calculation of power units availability factor.

REFERENCES

1. Gardzilewicz A., Jefimow A. The heat and flow diagnostic procedure leading to a steam turbine repair Plan. Proc. 10^{th} Conf. on Steam and Gas Turbines for Power and Cogeneration Plants. – Karlovy Vary (Czech. Rep.). – 1994. – p. 87-93.
2. Gardzilewicz A., Jefimow A. Thermal Diagnostics of Thermal Cycle Components on an Example of a Regenerative Heat Exchanger Rep. IFFM-PAS 256/94 – Gdańsk (in Polish). – 1994. – P. 34-40.

3. Głuch J., Gardzilewicz A. The analysis of performance of the turbine condenser with the prognosis of repair. Proc. of the International Joint Power Generation Conf. – Baltimore, Maryland (USA). – August 23-26, 1998. – V. 2. – P.179-190.
4. Skalozubov V. Optimization of power units scheduled repairs of NPP with WWER. – Institute of NPP safety problems, 2008. – 496 p.
5. Walusiak S., Pietrzyk W., Sumorek A. Ocena diagnostyczna stanu technicznego pojazdów samochodowych w wybranej stacji diagnostycznej. – MOTROL. – 2003, 5. – p. 219-226.
6. Tylicki H., Wilczarska J., Bartol M. Metodyka diagnozowania stanu maszyn. – MOTROL. – 2006, 8. – p. 230-239.
7. Palagin A., Efimow A., Menshikova E. Simulation of a functional condition and diagnostics of turbines. – K.: Naukova dumka, 1991. – 201 p.
8. Efimow A., Potanina T. Development of the NPP power unit simulating model with WWER-1000 for the tasks decision of the analysis, management and diagnostics. – NTUU «KPI». – 2, 2006. – p. 5-9.
9. Potanina T., Efimow A. Problem of optimal load distribution between power units on the power stations. – MOTROL. – 2009, Vol. 11A. – p. 25-30.
10. Jefimow A., Potanina T. Symulacyjne modelowanie funkcjonowania energobloku elektrowni atomowej z reaktorem WWER-1000. – Nauka i studia, 2009. – №2(14). – p. 59-69.
11. Orlov A. Applied statistics. – M.: Ekzamen, 2004. – 656 p.
12. Montgomery D. Planning of experiment and the analysis of the data. – L.: Sudostroenie, 1980. – 383 p.
13. Efimov A., Garkusha T. Estimation of power units thermal circuits efficiency on equipment condition and reliability parameters. – Kh.: NTU «KhPI». – 1, 2006. – p. 103-108.
14. Ostrejkovski V. Probability forecasting of serviceability of nuclear power installation elements. – M.: Energoatomizdat, 1990. – 416 p.
15. Yashchura A. Maintenance service System and repair of the power equipment. – M., 2006. – 504 p.

ПРИМЕНЕНИЕ МЕТОДОВ ИНТЕРВАЛЬНОЙ СТАТИСТИКИ ДЛЯ ДИАГНОСТИКИ СОСТОЯНИЯ ОБОРУДОВАНИЯ ЭЛЕКТРОСТАНЦИЙ В УСЛОВИЯХ НЕОПРЕДЕЛЕННОСТИ ИСХОДНЫХ ДАННЫХ

Александр Ефимов*, Татьяна Потанина*

*Национальный технический университет «Харьковский политехнический институт»,

Аннотация. В статье рассмотрены принципы построения автоматизированной системы диагностики оборудования энергоблоков электростанций и планирования ремонтных работ. Представлена модель построения диагностических функций на основе статистики интервальных данных.

Ключевые слова: диагностика оборудования электростанции, продолжительность плановых ремонтов, продолжительность межремонтного периода, коэффициент готовности, неопределенность исходных данных, интервальная статистика.