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OPTIMIZATION OF STRATEGIES FOR EXTENDING THE OPERATION OF SYSTEMS IMPORTANT FOR THE SAFETY OF NUCLEAR POWER PLANTS

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The original efficiency optimization method of strategy of operation extension of the heat engineering equipment of the safety related systems of nuclear power utilities is developed. The developed method is realized for the pump cases and armature of the safety related systems, as well as for the cases of a spent fuel pool of nuclear power plants with WWER. It is recognized that the reasonable time of operation extension for the pump cases and armature of the safety related systems is 10 years and for the case of a spent fuel pool is 13 years. The critical reliability parameters defining a residual life of the cases of the heat engineering equipment are dynamic metal stresses during beyond design basis earthquakes and the actual quantity of loading cycles during transient and accident operation. Optimization of test periodicity is one of effective approaches to reduce metal degradation/ wear rate of the heat engineering equipment cases during the beyond design basis operating period. These questions will be considered in the subsequent publications of authors.

RATIONALE

Operation extension of the heat engineering equipment of the safety related systems of nuclear power utilities important for the safety of nuclear power utilities during the beyond design basis period is one of the most effective directions of the development of nuclear power engineering. Economic expenditures on complete replacement of systems and equipment (except for the nuclear reactor pressure vessel) cannot be compared to the expenditures on the removal from service and construction of new electrical power units [1].

According to the sectorial programmes of operation extension of ukrainian nuclear facility life extension of the 1st and 2nd electrical power units of Rovenskaya NPP; the 1st, 2nd and 3rd electrical power units of Yuzhno-Ukrainskaya NPP and the 1st, 2nd, 3rd and 4th electrical power units of Zaporozhskaya NPP has been realized for the moment. Operation extension benefits figure up to billions of American dollars.

According to IAEA recommendations and sectorial programmes of operation extension of Ukrainian nuclear facility overriding problems are [2, 3]:

reliability analysis of operating experience, in-service inspection, maintenance and repair of safety related systems of nuclear power utility;

surveillance and condition monitoring of systems and equipment upon the expiration of installed life;

analysis of strength system rate, equipment and structures of safety related system of nuclear power utility (including the external severe abuse – earthquakes, tornados, floods, etc.)

Basic limitations of technical data reports (e.g. [8, 9]) on operation extension of Ukrainian nuclear facility are as follows.

1. Rates of residual life, degradation/ware rates and the duration of operation extention terms of separate systems and equipment are insufficiently substantiated.

2. Rates of optimal efficiency of strategy of operation extension in relation to providing of the necessary reliability level of safety related systems of nuclear power utility and corresponding economic expenditures are insufficiently substantiated.

These ideas define the rationale of the development and application of the companion analysis of the efficiency optimization method of strategy of operation extension of safety related system of nuclear power utility.

PRINCIPLE OF THE EFFICIENCY OPTIMIZATION METHOD OF STRATEGY OF OPERATION EXTENSION

1. The efficiency optimization of strategy of operation extension is the defining of the maximum allowed operation life extension providing the necessary level of reliability and minimizing economic expenditures.

2. The criterion of the efficiency optimization of strategy of operation extension is the ratio of the duration of the relative operation life extension during the beyond design basis period $\Delta T_п$ and the corresponding expenditures of technical and organizational measures taken to extend the operation:

$$\mathbf{K}_{\text{opt}} = \frac{\Delta T_п}{T_0} \frac{C_0}{\Delta C_п}, \quad (1)$$

where T_0 is the operation life designated by the project; C_0 – equivalent cost of the system extended for operation; ΔC_0 –- total expenditures of technical and organizational measures in operation extension, including the change and repair of system components.

The efficiency optimization of strategy of operation life extension is defined by a condition

$$\mathbf{K}_{\text{opt}} \to \max . \quad (2)$$

Under condition of complete replacement of system components $\mathbf{K}_{\text{opt}} = 1$.

3. Parameters of efficiency optimization of operation extension: rates of residual life for the moment of operation extension of pacing rates of system reliability

$$\Delta\mathbf{P}_{\text{op}} = \begin{pmatrix} P_1 - P_{1\text{д}} \\ P_2 - P_{2\text{д}} \\ \vdots \\ P_n - P_{n\text{д}} \end{pmatrix}, \quad (3)$$

where P_1, P_2, …, P_n – are the current values of pacing rates of reliability for the time of operation extension; $P_{1\text{д}}$, $P_{2\text{д}}$, …, $P_{n\text{д}}$ – maximum permissible rates of pacing indicators of reliability;

indicator of expenditures on technical and organizational measures on operation extension ($\Delta C_{\text{п}}/C_0 = \Pi_{\text{c}}$);

indicator of maximum allowed operation life extension

$$\Pi_{\Delta\text{T}} = \frac{\Delta T_{\text{п}}}{T_0}. \quad (4)$$

4. The duration of the operation life extension is defined by the rates of residual life and degradation/ware rate of system components

$$\Delta\mathbf{P}_{\text{op}} = \mathbf{V}_{\text{п}} \Delta T_{\text{п}}. \quad (5)$$

under condition that $\mathbf{V}_{\text{п}} > 0$ from equation (5) it can be interfered that

$$\Delta T_{\text{п}} = \min\left\{\frac{\Delta\mathbf{P}_{\text{op}}}{\mathbf{V}_{\text{п}}}\right\}, \quad (6)$$

where $\mathbf{V}_{\text{п}}$ is the degradation/ware rate of critical as to reliability system components during the beyond design basis period of operation

Conservatively (excluding the re-establishment and resource management measures) the degradation/ware rate of critical as to reliability system components can be defined according to the results of operation during the beyond design basis period:

$$\mathbf{V}_{\text{п}} = \mathbf{V} = \frac{\Delta\mathbf{P}_{\text{p}}}{T_0} = \frac{\mathbf{P}_0 - \Delta\mathbf{P}_{\text{op}} - \mathbf{P}_{\text{д}}}{T_0}, \quad (7)$$

where $\Delta\mathbf{P}_{\text{p}}$ is the shorter life of the pacing indicators of reliability within the operation life T_0 defined by the project; $\mathbf{P}_0$ – values of the pacing indicators of reliability in the beginning of operation overdesigned up to the rated values $\mathbf{P}_{\text{д}}$.

Hence, parameters of efficiency optimization of operation extension:

$$\Pi_{\Delta\text{T}} = \min\left\{\frac{\Delta\mathbf{P}_{\text{op}}}{\mathbf{P}_0 - \Delta\mathbf{P}_{\text{op}} - \mathbf{P}_{\text{д}}}\right\}, \quad (8)$$

$$\Pi_{\text{c}} = \frac{\Delta C_{\text{п}}}{C_0}. \quad (9)$$

5. Boundary values of the parameters of efficiency optimization of operation extension result from formulae (1)–(9)

$$0 \le \Pi_{\Delta\text{T}} \le 1, \quad (10)$$

$$0 < \Pi_{\text{c}} \le 1. \quad (11)$$

The condition of the optimization efficiency of strategies of operation extension

$$\mathbf{K}_{\text{opt}} > 1. \quad (12)$$

Domain of optimization efficiency of strategies of operation extension is illustrated below (Fig. 1).

Implementation procedure of the method of the efficiency of optimization of strategies of managing the operation is illustrated below (Fig. 2).

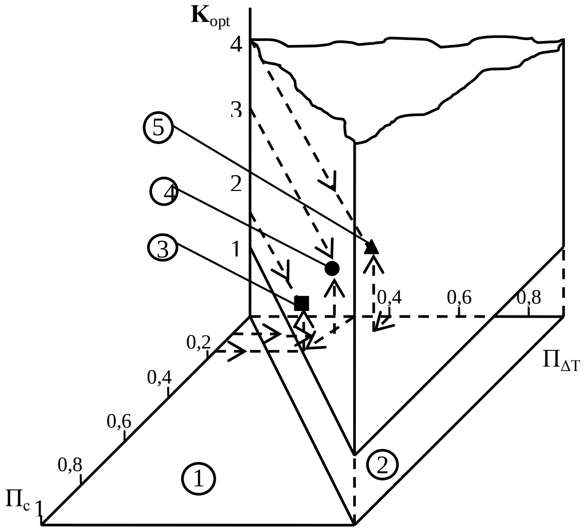

Fig. 1. Areas for optimizing the efficiency of the extension of operation:

① – domain of optimization efficiency of operation extension;

② – domain of parameters of optimization inefficiency of strategies of operation extension;

③ – pump cases of the safety related system of the 1st and 2nd nuclear power plant units of Zaporozhskaya NPP;

④ – valve cases of safety related system of the 1st and 3rd nuclear power plant units of Yuzhno-Ukrainskaya NPP;

⑤ – cases of the spent-fuel pool of the 3rd and 4th nuclear power plant units of Zaporozhskaya NPP

RESULTS OF THE DESIGN-BASIS JUSTIFICATION

Implementation of the offered method of the efficiency of optimization of strategies of operation extension was realized for:

pump cases of the safety related system of the 1st and 2nd nuclear power plant units of Zaporozhskaya NPP;

valve cases of safety related system of the 1st and 3rd nuclear power plant units of Yuzhno-Ukrainskaya NPP;

reinforced concrete structures cases of the spent-fuel pool of the 3rd and 4th nuclear power plant units of Zaporozhskaya NPP.

Critical parameters of reliability of the cases of the systems in question: wall thickness of the case δ;

sizes of defects found *r;*

dynamic stresses σ on the equipment body at the maximum design earthquake with an acceleration of the response of 0.17 g (more than 7 points on the MSK scale – 64);

quantity of the cycles of heat loading on the body metal during the transient or accident operation *N*.

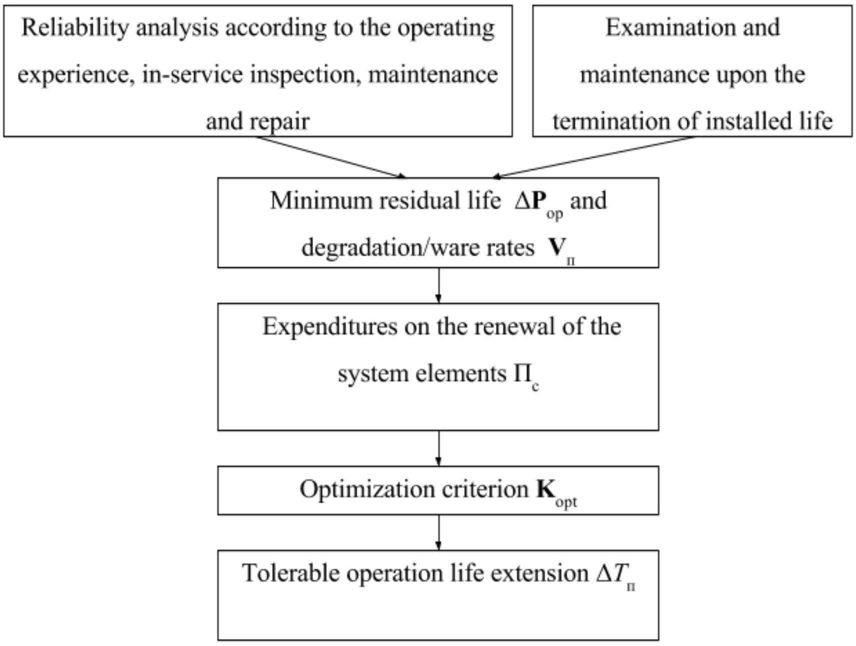

Fig. 2. Implementation procedure of the method of the efficiency of optimization of strategies of operation extension

Residual life is defined according to the minimum of critical reliability parameters of the systems in question:

$$\Delta\mathbf{P}_{\text{ор}} = \min\{\Delta P_{\text{ор}}(\delta,\delta_{\text{д}}); \Delta P_{\text{ор}}(r,r_{\text{д}}); \Delta P_{\text{ор}}(\sigma,\sigma_{\text{д}}); \Delta P_{\text{ор}}(N,N_{\text{д}})\}, \quad (13)$$

where $\delta_{\text{д}}$, $r_{\text{д}}$, $\sigma_{\text{д}}$, $N_{\text{д}}$ – are tolerable values of the wall thickness of the case, sizes of defects found, voltages and quantities of periods of loading accordingly.

Tolerable values of critical reliability parameters were defined according to the design and architect-engineering documentation of equipment, technical specifications of normal operation, as well as according to the known calculated reliance for critical defect size and voltage on the body systems. (contained, for example, in [1, 4])

The results of the application of the offered method of optimization of strategies efficiency of operation extension are illustrated by Fig 1. Hence, we can give the following findings:

1. All the robust strategies correspond to the domain of maximum efficiency of operation extension of the cases of safety related systems

2. The robust operation life extension for the valve and pump cases is 10 years, for the cases of the spent-fuel pool – 13 years

3. Critical parameters of reliability, defining the residual life of the heat engineering equipment of safety related systems is the dynamic voltage on metal on the condition of beyond design basis earthquakes and the actual quantity of the cycles of loading during the transient or accident operation.

4. Optimization of test periodicity is one of the effective approaches to reduce metal degradation/wear rate of the heat engineering equipment cases [6, 7] of safety related systems during the beyond design basis operating period. In this case optimization is connected with two factors: on one hand test periodicity of safety related systems needs to be increased to be able to detect the “hidden” malfunction, on the other hand the surplus test periodicity leads to the unreasonable degradation/wear of the equipment [6, 7]. Therefore this question needs additional research during the beyond design basis period, so it will be considered by the authors in the subsequent publications.

KEY INSIGHTS

1. The original method of the optimization efficiency of the strategies of operation extension of the heat engineering equipment of the safety related systems of nuclear power utilities has been developed.

2. The implementation of the developed method is realized for on the example of pump cases and armature of safety related systems, as well as for the cases of the spent fuel pool of Nuclear power plants with WWER. It is recognized that the reasonable time of operation extension for the pump cases and armature of the safety related systems is 10 years and for the case of the spent fuel pool is 13 years.

3. The critical reliability parameters defining a residual life of the cases of the heat engineering equipment are dynamic metal stresses during beyond design basis earthquakes and the actual quantity of loading cycles during transient and accident operation

4. Optimization of test periodicity is one of effective approaches to reduce metal degradation/wear rate of the heat engineering equipment cases during the beyond design basis operating period. These questions will be considered in the subsequent publications of the authors.

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ОПТИМИЗАЦИЯ СТРАТЕГИЙ ПРОДЛЕНИЯ ЭКСПЛУАТАЦИИ СИСТЕМ, ВАЖНЫХ ДЛЯ БЕЗОПАСНОСТИ АТОМНЫХ СТАНЦИЙ

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Разработан оригинальный метод оптимизации эффективности стратегий продления эксплуатации теплотехнического оборудования систем, важных для безопасности ядерных энергетических установок. Реализация разработанного метода осуществлена на примере корпусов насосов и арматуры систем, необходимых для безопасности, а также корпусов бассейна выдержки отработанного ядерного топлива атомных электростанций с ВВЭР. Установлено, что обоснованный срок продления эксплуатации для корпусов насосов и арматуры систем, имеющих большое значение для безопасности, – 10 лет, а для корпусов бассейна выдержки отработанного ядерного топлива – 13 лет. Критические параметры надежности, определяющие остаточный ресурс корпусов теплотехнического оборудования, – динамические напряжения на металл при запроектных землетрясениях и фактическое количество циклов нагружения в переходных и аварийных режимах. Для снижения скорости деградации/износа металла корпусов теплотехнического оборудования в запроектный период эксплуатации одним из эффективных подходов является оптимизация периодичности испытаний. Эти вопросы будут рассмотрены в последующих публикациях авторов.

ОПТИМІЗАЦІЯ СТРАТЕГІЙ ПРОДОВЖЕННЯ ЕКСПЛУАТАЦІЇ СИСТЕМ, ВАЖЛИВИХ ДЛЯ БЕЗПЕКИ АТОМНИХ СТАНЦІЙ

В.І. Скалозубов, О.О. Чулкін, Ю.О. Комаров, Т.В. Габлая, В.Ю. Кочнева

Розроблено оригінальний метод оптимізації ефективності стратегій продовження експлуатації теплотехнічного обладнання систем, важливих для безпеки ядерних енергетичних установок. Реалізація розробленого методу здійснена на прикладі корпусів насосів і арматури систем, необхідних для безпеки, а також корпусів басейну витримки відпрацьованого ядерного палива атомних електростанцій із ВВЕР. Установлено, що обґрунтований термін продовження експлуатації для корпусів насосів і арматури систем, важливих для безпеки, – 10 років, а для корпусів басейну витримки відпрацьованого ядерного палива – 13 років. Критичні параметри надійності, що визначають залишковий ресурс корпусів теплотехнічного обладнання, – динамічні напруги на метал при позапроектних землетрусах та фактична кількість циклів навантаження в перехідних і аварійних режимах. Для зниження швидкості деградації/зносу металу корпусів теплотехнічного обладнання в позапроектний період експлуатації одним із ефективних підходів є оптимізація періодичності випробувань. Ці питання будуть розглянуті в наступних публікаціях авторів.

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