Tetyana NIKULENKOVA[1]

Anatolii NIKULENKOV[2]

[1] *National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine*

[2] *Separated Subdivision «Scientific and Technical Center» of the State Enterprise «National Nuclear Energy Generating Company «Energoatom», Kyiv, Ukraine*

Corresponding author: Tetyana.nikulenkova@gmail.com

DOI: 10.53412/jntes-2021-1.4

FEATURES OF RESIDUAL SERVICE LIFE DETERMINATION FOR HIGH PRESSURE ROTORS OF K-200-130 AND K-1000-60/3000 TURBINES

Abstract: *So far, certain approaches have been developed to extension of service life of equipment in the different stages of metal physical exhaustion. The possibility of defining operating conditions of plant equipment beyond the fleet service life becomes even more relevant with increased operating time. The service life is determined as an individual one and is assigned based on the results of individual an inspection of a separate element or the largest group of single-type equipment elements of the considered plant. The fleet service life being reached is followed by diagnostics of specific units of power installations and analysis of their operation, measurement of actual dimensions of components, examination of structure, properties and damage accumulation in the metal, non-destructive testing and estimate of stress strain state and residual service life of the component. The results of performed studies are used to determine an individual service life of each element of energy equipment.*

Keywords: *service life, steam turbine, temperature, boundary conditions, ANSYS, 2-D and 3-D geometrical models, K-200-130, K-1000-60/3000, nuclear power plants*

Introduction

The present situation in the energy market of Ukraine demonstrates the need to increase operating capacities, thus requiring renovation or complete replacement of equipment of thermal power plants during the next years. This would allow lifetime extension of thermal power units, including expanding installed capacity and load-following range, as well as decreasing the specific fuel consumption per kWh production.

The problem of defining service life of nuclear power plants considering life cycles of their major equipment is becoming increasingly important each year. This raises questions relating to reasonable decision-making scheme on the due time for decommissioning of NPPs and feasibility of replacing of any major equipment considering safety and economic factors.

Purpose and research objectives

The purpose of the paper is to justify a comprehensive scheme to assessment of residual service life of steam turbine rotors and extension of the operating life [1].

The set purpose is to be achieved by reaching the objectives as follows:

1. Analysis of the known ways for service life extension of energy equipment that has reached the end of its fleet service life.
2. The results of metal inspection throughout the entire operating lifetime and analysis of technical audit data relating to damages and geometry changes during refurbishment of steam turbine elements.
3. Analysis of the results of experimental researches and estimate of residual service life of steam turbines considering actual operating conditions and local damages of separate turbine components.
4. Elaborating proposals regarding approaches to extension of service life of steam turbines.

Material and research results

Initial data. The condensate steam turbines of thermal and nuclear power plants with high temperature elements in 3-D setting are considered. The boundary conditions are established for heat exchange on the rotor surfaces using ANSYS digital model based on built geometrical 3-D models corresponding to operating modes by start-up types from cold, hot and warm conditions and stationary mode.

Model description. In the first phase of the calculation a method for building spatial analogues of turbine machine elements was developed using Solidworks for high and medium pressure rotors.

In the second phase a method for solving non-stationary thermal conductivity equation was developed and boundary conditions of heat exchange on the surfaces of rotors were established using the ANSYS digital model based on 2-D and 3-D geometrical models. The boundary conditions (BC) correspond to operating modes by start-up types from cold, hot and warm conditions, stationary regime [2].

The problem of non-stationary thermal conductivity of steam turbine elements is solved with the equation type as follows:

$$div(\lambda gradt) = c\gamma \frac{\partial t}{\partial \tau} \tag{1}$$

where λ, c, γ are temperature functions and coordinates under the initial conditions $t_0 = t(x,y,z,0)$ = $f_0(x,y,z)$ and the boundary conditions of the I, II, III or IV kind.

The non-stationary boundary conditions of the I-IV kind were set with due account of operating transients for the surfaces of spatial geometrical models of LPC and IPC.

When defining the BC for non-stationary operating modes the estimate of steam temperature in transient modes on the surfaces of steam turbine elements was applied. Under rapid changes of operating mode of the turbine one can observe a fast change of steam temperatures in its flow section. It has been established by experimental means that in the initial phases of power unit start-up the temperatures of main and reheat steam measured by regular sensors are lower than real temperature values of the steam both by their change speed and statically. Therefore, it was suggested to use the following method for estimation of temperature under transient modes of steam turbine (based on example of calculation of steam temperature in the control stage chamber that almost coincides with the temperate after the control stage).

The third phase implies application of the ANSYS digital model to determine the stress strain state of the HPC and IPC rotors with account of their complex spatial geometry, damages during operating period, repair and restore modifications of design geometry. The temperature gradient is used as a criterion to determine stresses when analyzing their behavior in the high temperature elements of steam turbine for operating modes. The distribution of stress strain state was calculated for the moments when temperature gradients reached extreme values.

The stress strain state was determined for:

- pressure loads;
- temperature loads;
- loads of centered forces (ω = 3000 rpm);
- loads of gravity forces;
- reaction resistance.

The calculations included defining principal stresses, stress intensity for the entire period corresponding to start-up and stationary operating modes in all division points of the high temperature elements of the steam turbine.

That start-ups of the turbine from different thermal conditions can be accompanied with thermal stresses on the rotor surface, which increase the yielding limit leading to residual strain of the metal. If physical and mechanical properties are come out in different values of the yielding limit σ along the cross section area of the shaft, then after reaching σ multiple times a summing of residual axial strains appears, and this is one of the causes of rotor bow.

In the fourth phase a methodological approach was developed to calculate the low cycle fatigue using a software complex of NTUU KPI and ANSYS digital models with application of the calculated change of the stress strain state of HPC and IPC shells and rotors and with account of optimized strength margin ratios by the number of cycles and deformations [3].

Analysis of the study results. The capability of forecasting the value of the residual life is provided under the conditions as follows:

- parameters defining technical condition of equipment are known;
- criteria of the boundary state of the equipment are known;
- it is possible to perform periodical or continued inspection of the technical state parameters.

The remaining operating life before cracks $[G]_{oct}$ (in years) is determined with the formula:

$$[G]_{oct} = \frac{1-\Pi'}{\Pi_g''} \tag{2}$$

where:

Π' – total damage accumulated in the metal of rotos and shells operating under combined creep implication in the different modes of q' types and cycle loading under different transient modes of k' types;

Π_g'' – the forecasting average annual loading for the operating period following the analysis that will be accumulated in the considered area of the rotor and shell during the alternation of q'' types of sustainable mode and k'' types of cycle.

All values relating to the period of operation after carrying out an estimation and continuation of a resource are marked by two strokes.

The author proposes to determine a total damage Π' accumulated in the metal of the rotors operating in conditions of joint action of creep at different steady modes and cyclic loads at different variable modes, by an improved formula, considering [4] and the effect of torsional vibrations:

$$\Pi' = \Pi_{st}' + \Pi_c' + \Pi_{kp.k}' = \sum_{j=1}^{q'} \frac{t_j'}{T_{pj}'} + \sum_{l=1}^{k'} \frac{n_l'}{N_{pl}'} + \sum_{i=1}^{s'} \frac{r_i'}{R_{pi}'} \tag{3}$$

where:

$\Pi_{st}', \Pi_c', \Pi_{kp.k}'$ – static, cyclic damage and damage from torsional vibrations accumulated in the area of the rotor checked at the time of assessment of the extension of service life;

$t_j^{'}$ – operating time in the j steady mode under the temperature of metal $T_{pj}^{'}$ and equivalent local creep stresses $(\sigma_{aj}^{'})_{\max}$;

$T_{pj}^{'}$ – time before the boundary state is reached subject to equivalent stresses $(\sigma_{aj}^{'})_{\max}$ under temperatures $T_j^{'}$ according to the diagram of long-standing strength of material;

j – number of different types of steady modes at the time of assessment with temperature $T_j^{'}$ and steady equivalent local creep stresses $(\sigma_{aj}^{'})_{\max}$;

$n_l^{'}$ – number of cycles of *i* type;

$N_{pl}^{'}$ – number of cycles before fatigue cracks appear only subject to cyclic loadings of *i* type;

k' – number of different cycle type at the time of assessment with different ranges of specified stresses $\Delta\sigma_l^{'}$ and strain amplitudes $\varepsilon_l^{'}$;

$r_i^{'}$ – number of loading cycles with strain amplitude τ_{ai} (τ_{ai} – amplitude of *i* cycle of the damped process);

$R_{pi}^{'}$ – number of cycles before damage under cyclic loading with strain amplitude $(\tau_{ai})_{\max}$ from torsional vibrations;

s' – number of stress levels (units).

All values relating to analysis of the previous operating period are marked by a stroke.

The forecasted residual service life of the high temperature equipment of steam turbine was determined with the formula:

$$[T]_{oct} = \frac{1}{\Pi'} \quad (4)$$

where Π' – summed damage.

When determining the reliability of equipment, the probabilistic methods of life estimation are changed for estimation of the individual life of aging equipment based on an integrated approach that combines destructive and non-destructive inspections supported by verifying calculations of strength [5-7]. There has been a tendency in the life estimation to switch from flaw detection to technical diagnostics methods raising the need in comprehensive examination of aging equipment in order to identify potentially dangerous zones.

There is no established procedure for comprehensive application of different techniques and means of non-destructive and destruction inspections to a specific item under inspection. The sequence, procedure, scope and frequency for inspection of a component are determined by fleet (estimated) life, damage, overhaul period, as well as the availability of means and techniques for metal inspection of equipment.

Extending the service life of existing power units is a common international practice with an important task to keep producing electricity at the achieved level until deployment of new capacities at thermal power plants.

A unique feature of the modern energy sector is operation of a significant number of turbines with expired intended service life. At the same time, domestic and foreign practice shows that the actual service life of turbines often significantly exceeds the term specified by the manufacturer.

A comprehensive study flow diagram for life extension of K-200-130 and K-1000-60/3000 turbine rotors with expired fleet life was improved within this scientific paper based on the technical audit of energy equipment of steam turbines using examinations of low and creep fatigue, and long term strength of rotors, as well as assessment of shaft line damages due to torsional vibrations. The main principal decisions within the comprehensive flow diagram for estimation of the residual life of large-scale steam turbine rotors is provided in Figure 1.

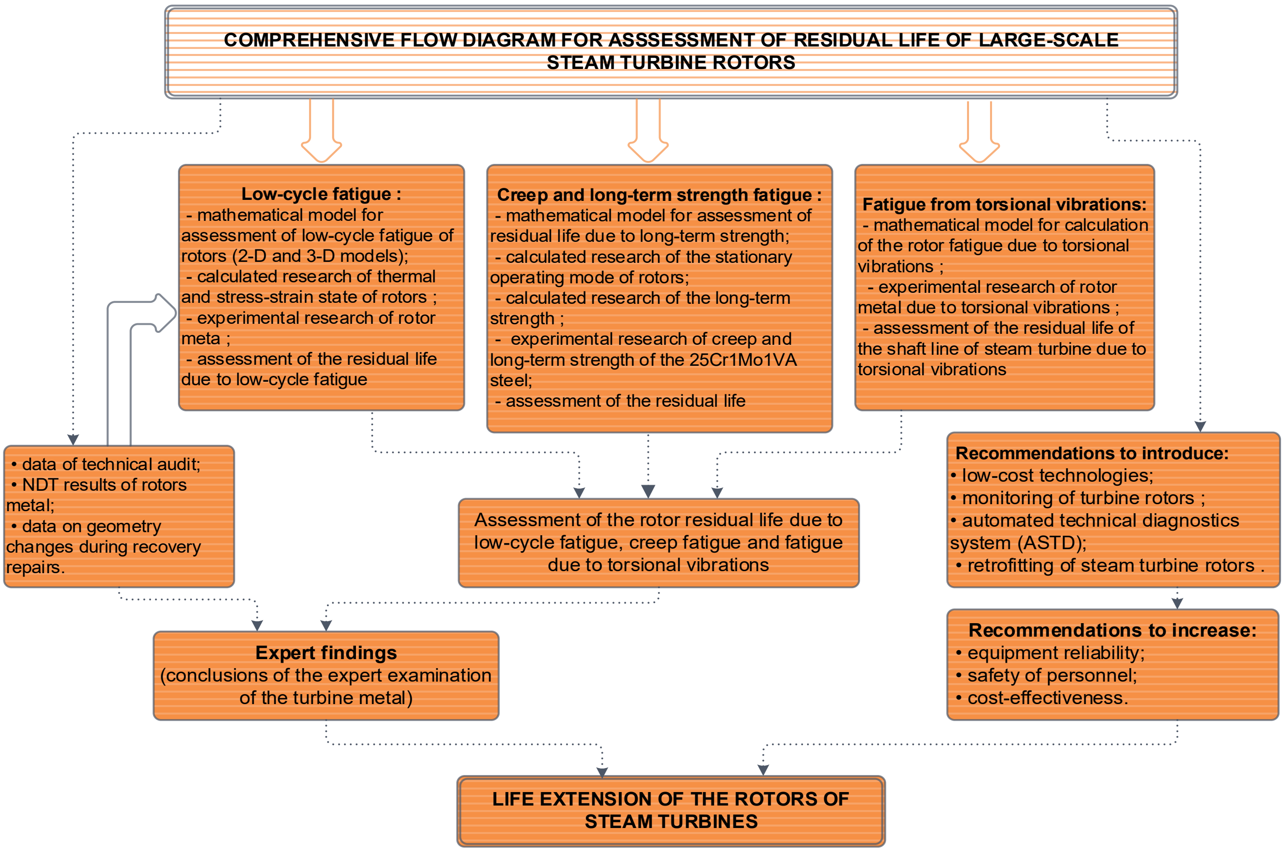

FIGURE 1. *Comprehensive flow diagram for assessment of the residual life of the steam turbine rotors*

The main reason for consideration of long-term operation of power plant equipment is that the cost of extending the service life of high-temperature equipment is several times less than buying new ones. Under such circumstances, one of the most important diagnostic tasks, formally not provided by regulations, is the assessment of residual life. This problem is not simple and cannot be solved by conducting standard studies.

The first element for estimating residual life of steam turbine rotors is low cycle fatigue of K-200-130 and K-1000-60/3000 turbine rotors. Based on the results of the technical audit and visual inspection conclusions, different types of damage are localized in the geometric model of the element in the form of metal samples of different shapes. The estimated temperatures at individual points of the metal of the high and intermediate pressure cylinder rotors were determined for their further use in calculating the number of cycles before failure. This approach allowed to bring the calculated model of steam turbine rotors closer to the real state after long-term operation [8, 9]. Calculated studies of thermal, stress-strain state and low-cycle fatigue of rotors allowed to develop recommendations of constructive and mode nature, which reduce temperature stresses in start-up modes and metal damage accumulation.

The second element for estimating residual life of steam turbine rotors is a calculated and experimental study of long-term strength. The calculated studies of TC and SSS of the rotors of K-200-130 and K-1000-60/3000 steam turbines in the stationary mode of operation were performed, creep stresses and strains were determined and the data on residual life was received [10, 11].

The third element for estimating residual life of steam turbine rotor is fatigue from torsional vibrations. The mechanism of torsional vibrations of shafts is one of the main causes of metal cracking of turbine rotors and their fracture, often with catastrophic consequences.

Conclusion

The main reason for consideration of long-term operation of power plant equipment is that the cost of extending the service life of high-temperature equipment is several times less than buying new ones.

Under such circumstances, one of the most important diagnostic tasks, formally not provided by regulations, is the assessment of residual life. This problem is not simple and cannot be solved by conducting standard studies.

When forecasting, depending on the service life of the equipment, two approaches are used. Fort short service life (relatively to fleet) and insignificant damage of the equipment only the information on loading is used for forecasting of its residual life. With a service life close to the fleet or significant damage to the equipment elements the degree of equipment damage is additionally investigated. The advantage of the first approach is its lower complexity, the second, which we adhere to – is a more accurate forecast allowing to identify additional reserves of equipment life.

Conflicts of Interest: The author declares no conflict of interest.

References

[1] Peshko V., Chernousenko O., Nikulenkova T., & Nikulenkov A., *Comprehensive rotor service life study for high & intermediate pressure cylinders of high power steam turbines*, Propulsion and Power Research, 2016, vol. 5(4), pp. 302-309. doi: 10.1016/j.jppr.2016.11.008.

[2] Chernousenko O., Nikulenkov A., Nikulenkova T., Butovskiy L., & Bednarska I., *Calculating boundary conditions to determine the heat state of high pressure rotor of the turbine NPP K-1000-60/3000*, Bulletin of the National Technical University "KhPI", 2018, vol. 12(1288), pp. 51-56. doi: 10.20998/2078-774X.2019.03.01.

[3] Nikulenkova T., Nikulenkov A., *Calculation of boundary conditions using CFD modeling as part of a comprehensive approach to impact assessment of modifications on the service life of critical elements of a nuclear power plant turbine*. The 16th International Conference of Young Scientists on Energy Issues, 2019, VII, 267-278.

[4] Wähner H., *Turbinenleitrechner TENSOSIM auf microprozessorbasis zur Thermischen Überwachung von Dampftuhinen*, Wähner H., Preusse W., Tappe W. u.a., Mitteilungen Kraftwerksanlagenbau DDR. 1984. Bd. 1. No. 12, S. 16-20.

[5] RTM 108.020.16-83. Calculating the Temperature Fields of Steam Turbine Rotors and Housings, M., 1985, 115p.

[6] RTM108.021.103, Details of stationary steam turbines. Low cycle fatigue calculation. M., 1985. No. AZ-002/7382, 49 p.

[7] RD34.17.440-96, Methodological guidelines to perform works within assessment of individual service life of steam turbines and its extension beyond the fleet service life. M., 1996, 47p.

[8] Chernousenko O., Rindyuk D., & Peshko V., *The strain-stress state of K-1000-60/3000 turbine rotor for typical operating modes*, Bulletin of the National Technical University "KhPI", 2019, vol. 3(1328), pp. 4-10. doi: 10.20998/2078-774X.2019.03.01.

[9] Chernousenko O., Rindyuk D., & Peshko V., *Features of prolongation of the service life of high- and intermediate-pressure rotors of K-200-130 steam turbine of Luhansk TPP*, The Problems of General Energy, 2018, vol. 2(53), pp. 65-70. doi: 10.15407/pge2018.02.065.

[10] Nikulenkov A., Samoilenko D., and Nikulenkova T., *Study of the impact of NPP rated thermal power uprate on process behavior at different transient conditions*, Nuclear and Radiation Safety, 2018. vol. 4(80), pp. 9-13. doi: 10.32918/nrs.2018.4(80).02.

[11] Chernousenko O., & Peshko V., *Assessment of Resource Parameters of the Extended Operation High-Pressure Rotor of the K-1000-60/3000 Turbine*, Journal of Mechanical Engineering, 2019, vol. 4(22), pp. 41-47. doi: 10.15407/pmach2019.04.041.