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## ASSESSMENT OF INDIVIDUAL RESOURCE OF HIGH-PRESSURE ROTORS OF NUCLEAR POWER PLANTS STEAM TURBINES

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*Integration of the Ukrainian energy system into the European one is a component of Ukraine's strategic goal – joining the EU. Our country has sufficiently strong and developed gas and oil transport networks, as well as electricity networks, all connected with the transport networks of the EU and CIS countries, which allows it to participate in shaping European energy policy and common energy market, play an important role in energy cooperation between CIS and EU countries. The resource indicators of high-pressure rotors of nuclear power plants steam turbines with a capacity of 220, 1000 MW are estimated. An integrated approach to the study of the individual resource of steam turbines and the possibilities of prolonging the operation of power equipment is applied. For power units no. 6 of Zaporizhzhia NPP, no. 4 of Rivne NPP, no. 2 of Khmelnytskyi NPP, the total damage of high-pressure rotors is 59–83%, and the residual life is 40,604–94,383 hours, which allows to prolong the operation for 40–50 thousand hours. According to the results of calculations of resource indicators of high-pressure rotors of NPP turbines, the total damage of high-pressure rotors of power units no. 3–5 of Zaporizhzhia NPP, no. 1 of Khmelnytskyi NPP, no. 2, 3 of South-Ukrainian NPP varies between 85–90%, and the residual life is 22,403–34,494 hours, if we set the allowable equipment resource of 270 thousand hours. This will allow to prolong the operation of high-pressure rotors of NPP steam turbines for 25 thousand hours. The individual resource of high-pressure rotors of NPP turbines for power units no. 1, 2 of Zaporizhzhia NPP, no. 1, 2, 3 of Rivne NPP, no. 1 of South-Ukrainian NPP is exhausted.*

**Keywords:** static damage, cyclic damage, residual life, steam turbine, low-cycle fatigue, long-term strength.

### Introduction

An integral part of Ukraine's strategic goal of joining the EU is the integration of the Ukrainian energy system into the European one. By the way, our country, unlike the countries of the new wave of EU enlargement, has a strong and developed gas and oil transport networks, as well as electricity networks, combined with the transport networks of the EU and CIS countries, which allows it to participate in shaping European energy policy and common energy market, play an important role in energy cooperation between CIS and EU countries.

According to the results of 2000–2022, the structure of power generating capacities of Ukrainian power plants tends to increase due to the launched capacities at NPPs [1]. In the overall structure of the installed capacity of the energy system (hereinafter – ES) of Ukraine, the maximum share, more precisely about 54%, belongs to TPPs and CHPs, followed by (with the indicator of about 25%) NPPs, followed by (with a share of about 10%) HPPs and PSPSs. The last place in the general structure of the installed capacities belongs to block-stations and power plants on alternative sources (wind farms, seismic stations, biomass), the share of which is almost 10%.

According to statistics in 10 months of 2021, the volume of electricity production by power plants that are part of the Integrated Power System of Ukraine reached 127,722.1 million kWh, which is 7,855.7 million kWh, or 6.6%, more than in the corresponding period of 2020. At the same time, TPPs and CHPs generated 37,178.6 million kWh of electricity, which is 2,154.4 million kWh (5.5%) less than in the corresponding period of 2020. On the other hand, nuclear power plants generated 69,183.3 million kWh of electricity in 10 months of 2021, which is 6,155.6 million kWh, or 9.8%, more than in 2020. The installed capacity usage rate from the beginning of 2021 was 68.5% (for the corresponding period of 2020 – 62.2%). Electricity production of HPPs and PSPSs increased by 2,732.0 million kWh (43.8%) compared to last year and amounted to 8,972.5 million kWh. It should be noted that compared to the corresponding period of 2020,

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the production of electricity by renewable energy sources (wind farms, seismic stations, biomass) in 10 months of 2021 increased by 1,358.4 million kWh, or 14.0%, and amounted to 11,048.0 million kWh, and by power plants of other types (block-stations and other sources) decreased by 235.9 million kWh (by 15.0%) and amounted to 1,339.8 million kWh. In addition, TPP and NPP and district boilers in 10 months of 2021 released 16,004.1 thousand Gcal of heat, which is 1,692.6 thousand Gcal (or 11.8%) more than in the corresponding period of 2020.

However, wind farms and seismic stations are characterized by instability of electricity generation (this is due to such factors as seasonality, daily irregularities, weather conditions, etc.) and create imbalances. At the same time, the increase in renewable energy production (wind farms, seismic stations) and the lack of shunting capacity in Ukraine's energy system will cause forced systemic constraints for wind farms and seismic stations, consisting in limiting the intake of 8–10% of the generated electricity into the power system.

One should not forget about the fact that pulverized coal units with capacity of 200–300 MW were designed to work in basic modes. According to the analysis of technical solutions of power equipment manufacturers and decisions of design organizations on start-up schemes of units from 150 to 300 MW, such a task as the implementation of shunting modes in the design of power units of 200–300 MW was not set. Although the mentioned mode significantly affects the operation of boilers and turbines, which are one of the dangerous elements of TPPs.

No less important is the fact that about half of the consumed electricity is produced by nuclear power plants. It is nuclear energy that occupies a leading position in meeting the energy needs of the national economy in Ukraine, and the reliability of its work has a positive impact on the socio-economic development of our country. However, the service life of power units no. 3 of Rivne NPP, no. 3, 4 of Zaporizhzhia NPP and no. 1 of Khmelnytskyi NPP expired in 2017–2018, and the project operation of nuclear power units no. 3 of South-Ukrainian NPP and no. 5 of Zaporizhzhia NPP expired in 2020. By the way, about 80% of nuclear power units in the world nuclear energy sector have exhausted the project resource during 2020.

As world experience shows, extending the life of NPP units after expiration of project operation time is potentially possible, and, provided compliance with nuclear and radiation safety standards, becomes one of the most effective ways to partially solve the problem of generating capacity replacement [2, 3]. Of course, in the conditions of gradual depletion of the power equipment resource and deficiency of fossil fuels at thermal power plants, all of the above acquires special value.

Given the above, Ukraine is currently implementing a program to extend the life of nuclear power plant equipment. Thus, out of fifteen power units operating in our country, the operation of units no. 1, 2 of Rivne NPP, no. 1, 2 of Zaporizhzhia NPP and no. 1, 2 of South-Ukrainian NPP was prolonged by 10–20 years. Experience has shown that the specific financial costs for complying with the requirements of regulatory documents that provide the opportunity to obtain a license to operate power units during the additional service life, are much less than the cost of construction of new power units [1].

### **Research of individual resource of high-pressure rotors of nuclear power plants steam turbines**

The calculated study of the resource parameters of the high-pressure cylinder rotor (HPR) of the K-1000-60/3000 steam turbine 1000 MW unit of the state enterprise NNEGC "Energoatom" that was carried out during operation, was performed in accordance with regulations [4, 5]. Based on this, a comprehensive approach to the study of individual life of steam turbines and prolongation of power equipment operation, which involves: analysis of individual life and the allowable number of starts from different thermal states with cyclic loading of K-1000-60/3000 steam turbine HPR; calculated study of individual operating time at static load of K-1000-60/3000 steam turbine HPR; assessment of the possibility of further continuation of operation of K-1000-60/3000 steam turbine HPR over the equipment resource.

The purpose of the analysis of technical (operational, design and repair) documentation of the inspected equipment is to identify elements of structures and areas operating in the most stressful conditions and/or affected by negative factors that may cause accidents or failure; identification of modes in which changes in the structure and properties of materials are possible; determination of the dynamics of defects development; development of an expert examination program.

Tracking of wear out of the power unit equipment is carried out at all stages of the life cycle. This involves the development of station programs for wear out control of the power unit elements and structures; compiling a list of the power unit elements and structures that need repair or replacement; detection and study of wear out processes of the power unit elements and structures (understanding of wear out); taking measures to monitor the wear out of the power unit elements and structures (metal control) and degradation mitigation; assessment of the current technical condition of the power equipment elements and forecasting its replacement due to wear out; optimization of programs for maintenance, control and repair of power equipment of the power unit; introduction of additional means of control and diagnostics of the current technical condition of the elements and structures of the power plant power unit; analysis of resource and reliability indicators of structures, systems and elements, performance of work on reassignment of resource elements, replacement of those that have reached the limit of technical condition; development of technical and organizational measures for modernization and reconstruction of power equipment of the power plant, as well as minimization of degradation of elements and management of their wear out; continuous improvement of the wear out management program, taking into account operational experience and research results, as well as self-assessment and expert assessments (development and implementation of additional measures to monitor and mitigate degradation); documentation of activity as well as creation and maintenance of the database of technical condition of the power equipment elements and the revealed defects on the basis of the generalization of the information on manufacturing, operation, maintenance, repairs, etc.

Thus, when estimating the residual life of high-power steam turbine elements that have used up the equipment resource, it is necessary to perform a calibration strength calculation for power equipment elements that change the structure and properties of metal and accumulate damage from creep and low-cycle fatigue [6–8].

In case of NPP steam turbine rotors, when estimating their residual life, a calculated study of thermal and stress-strain state, low-cycle fatigue, static damage and individual life is performed, taking into account actual data on NPP high-power steam turbine operating modes and the properties of the metal of its main elements, as well as repair and restoration measures for the main elements of the equipment [9, 10].

The calculated assessment of the thermal and stress-strain state of the high-pressure rotor involves solving the boundary value problem of unsteady thermal conductivity with boundary conditions of heat exchange on the rotor surfaces in accordance with the developed software [11]. The schemes of steam leaks in the flow part and in the seals, as well as real graphs of work under typical operating modes, namely stationary and starts from cold, uncooled and hot states were taken into account. For a structurally complex high-pressure rotor, the geometric model is made in a three-dimensional formulation, taking into account the main structural elements based on the passport drawing of the K-1000-60/3000 turbine.

The stress-strain state of the high-pressure rotor was evaluated in the elastic-plastic formulation using the finite element sampling method of the calculation area. Significance was given to the main types of stresses, namely temperature, non-uniformity of temperature fields, stresses from pressure and centrifugal forces. The results of the calculation of the thermal and stress-strain states of the high-pressure rotor under typical operating modes are given in [11].

In addition, according to the normative documents [5–8], the estimated assessment of the accumulated cyclic and static damage of turbine equipment is realized according to the allowable number of start-up cycles from different thermal states. Experimental curves of low-cycle fatigue and long-term strength of steel are used for this purpose. A key feature of the calculation model is that the experimental curves of low-cycle fatigue for steel 30HN3M1FA, from which the rotor is made, are absent in the literature, so it is proposed to calculate the allowable number of cycles by correlation dependences of low-cycle fatigue [9].

The thermal and stress-strain state for the stationary operating mode is performed in a quasi-stationary formulation [10]. The temperature level is 165–270 °C. The maximum stress intensity is observed in the axial and unloading holes of the disks of all five stages and is equal to 158 MPa, due to the large values of centrifugal forces acting on the pressure disks and blades. The highest level of stress is observed in the area of the fifth stage, which is the most massive and covered with the heaviest blades.

Start-up modes are considered in unsteady formulation. Information on the non-uniformity of temperature fields over time, depicted in the form of the dynamics of changes in the temperature gradient for the most characteristic areas, is of particular interest in the variable operating modes [10]. For cold start-up, the

temperature gradient at the initial stages of start-up reaches 1,200–1,300 K/m, which indicates the existing temperature non-uniformity.

The highest values of stress intensity are observed in the initial stages of start-up from the cold state and are equal to 231 MPa for unloading holes of the disk of the first stage. They remain unchanged until 6,800 s, when the turbine speed reaches the nominal value (3,000 rpm). In this case, the high-stress zones are the load transitions of the stage disks and the axial hole of the rotor, where the stress intensities are 168 MPa. Similar data were obtained for the start-up mode from hot and uncooled states [10].

The calculations allow to estimate the long-term strength and resistance to low-cycle fatigue of the base metal of the high-pressure rotors of NPP steam turbines with a capacity of 1000 MW.

According to NNEGC "Energoatom", the allowable equipment service life of the K-1000-60/3000 turbine is at least 30 years, which corresponds to the duration of operation for basic power units (220 thousand hours), the allowable equipment number of starts – 600, the number of starts during the year – 20. The service life is designed to reach the limit state, based on ensuring the maximum number of cycles per year.

In particular, during the planned and preventive repairs at unit no. 3 of Rivne NPP in 2014, the operating indicators for the period of operation were (as of 01.07.2014): the total number of starts – 230, the number of cold starts (CS) – 49, the number of starts from the hot state (HS) – 181, operating time – 177,919 hours. Thus, in percentage terms, the number of cold starts is 21.3%, the number of hot starts is 78.7%. Assuming that the power unit was operated in the same mode for the next five years, as of July 2019, the operating time should have been 209,690 hours, the total number of starts – 271, the number of cold starts – 58, the number of hot starts – 213.

The safety margins in the calculations are as follows: 10 – by the number of cycles and 1.5 – by deformations in accordance with regulations, respectively [10].

The results of the calculated study of the resource characteristics of the high-pressure rotor of the K-1000-60/3000 turbine unit no. 3 of Rivne NPP are given below. Low-cycle fatigue was assessed by the allowable values of the start-up numbers from different thermal states, which were calculated using the correlation dependences of fatigue of steel 30HN3M1FA, from which HPR is made [9]. The calculated cyclic damage of the base metal is 11%, while static one is equal to 95% (Table 1). This indicates a less significant effect of low-cycle fatigue as a mechanism of destruction of the rotor compared to the depletion of long-term strength.

Static damage is estimated at the equipment resource of 220 thousand hours, according to regulations [10], it was found that it is 95%. The total damage of the base metal is 107%, i.e. it is more than 100%. This indicates the depletion of the HPR resource of the K-1000-60/3000 turbine with an equipment operating time of 220 thousand hours (Table 1).

Experimental studies of long-term strength of 25H1M1FA steel at a temperature of 500 °C, which is used in the manufacturing of high- and medium-pressure rotors of K-200-130 turbines, were conducted [12]. According to the results of research, the possibility of increasing the allowable number of working hours to 370 thousand hours was found.

**Table 1. Resource characteristics of the high-pressure rotor of the K-1000-60/3000 turbine unit no. 3 of Rivne NPP**

Resource characteristics		Value	
Operating time of the power unit		209,690 hours	
Total number of starts		271	
Annual operating time		6,354 hours/year	
Year of commissioning		1986	
The current number of starts from different thermal states	CS	58	
	HS	213	
Stress intensity at nominal operating mode		158.5 MPa	
Permissible number of start-up cycles from different thermal states	CS	1,945	
	HS	2,591	
Cyclic damage		11.20%	
Permissible number of operating hours		220,000 hours	270,000 hours
Static damage		95.4%	77.66%
Total damage		106.6%	88.86%
Residual resource		<0 hours	2,6287 hours

We will add that similar data concerning 30HN3M1FA steel from which HPR of the K-1000-60/3000 turbine is made, unfortunately, is absent in the literature. It is only clear that due to the difference in physical and mechanical properties of 25H1M1FA and 30HN3M1FA steels, curves of their long-term strength will also differ. However, given that the operating temperature of the HPR metal of the K-200-130 turbine is 540 °C, and it of the K-1000-60/3000 turbine is 270 °C, it is proposed to estimate the static damage of the HPR unit no. 3 of Rivne NPP using long-term strength curves of 25H1M1FA steel at temperature 500 °C as a calculation of the safety margin. In addition, it should be taken into account that NPP turbines have higher requirements for operational reliability. Therefore, a proposal to accept the allowable number of operating hours of HPR of the turbine K-1000-60/3000 steel at the level of 270 thousand hours was made. Then the calculated static damage will be 78%, and the total damage will be 89%.

If the expert commission, which consists of the representatives of the power plant, specialized and other organizations in accordance with SOU-N MFE 40.17.401:2004 [4], can accept the allowable operating time of the metal at 270 thousand hours, the estimated total damage will be 89%, and the residual metal resource of the HPR of the turbine unit K-1000-60/3000 power unit no. 3 of Rivne NPP will be 26,287 hours. This will allow to prolong the operation of the HPR steam turbine K-1000-60/3000 for 25 thousand hours.

The results of the calculated study of the resource characteristics of high-pressure rotors of turbines of NPP power units operating in Ukraine are given in tables 2–3. At the same time, low-cycle fatigue was assumed to be equal for all power units due to low values of temperatures in NPP steam turbines, i.e. the calculated cyclic damage of the base metal was 11%. The calculated static damage was estimated according to the terms of commissioning of NPP power units. The annual operating time of power units was taken at the level of 6,200–6,300 hours taking into account the operation of NPP power units in the basic load mode.

**Table 2. Resource characteristics of high-pressure rotors of NPP steam turbines power units no. 1–6 of Zaporizhzhia NPP**

Resource characteristics	no. 1	no. 2	no. 3	no. 4	no. 5	no. 6	
Year of commissioning	10.12.1984	10.12.1985	10.12.1986	10.12.1987	12.1989	10.1995	
Operating time of the power unit, years	36	35	34	33	32	25	
Operating time of the power unit, hours	226,800	220,500	214,200	207,900	201,600	157,500	
Annual operating time, hours	6,300	6,300	6,300	6,300	6,300	6,300	
Permissible number of working hours, hours	270,000	270,000	270,000	270,000	270,000	220,000	270,000
Cyclic damage, %	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Static damage, %	84.0	81.7	79.4	77.0	74.7	71.6	58.4
Total damage, %	95.0	92.7	90.4	88.0	85.7	82.6	69.4
Residual resource, hours	11,668	17,035	22,403	28,004	33,371	40,604	71,404

**Table 3. Resource characteristics of high-pressure rotors of NPP steam turbines power units no. 1–4 of Rivne NPP, no. 1–2 of Khmelnytskyi NPP, no. 1–3 of South-Ukrainian NPP**

Resource characteristics	Rivne NPP				Khmelnytskyi NPP		South-Ukrainian NPP		
	no. 1	no. 2	no. 3	no. 4	no. 1	no. 2	no. 1	no. 2	no. 3
Year of commissioning	12.1980	12.1981	1986	2004	1987	2004	31.12.1982	06.01.1985	20.09.1989
Operating time of the power unit, years	40	39	35	17	33	17	38	35	32
Operating time of the power unit, h	254,160	247,806	222,390	108,018	204,600	105,400	237,500	218,750	200,000
Annual operating time, hours	6,354	6,354	6,354	6,354	6,200	6,200	6,250	6,250	6,250
Permissible number of working hours, hours	270,000	270,000	270,000	220,000	270,000	220,000	270,000	270,000	270,000
Cyclic damage, %	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Static damage, %	94.2	91.8	82.4	49.1	75.8	47.9	88.0	81.1	74.1
Total damage, %	105.2	102.8	93.4	60.1	86.8	58.9	99.0	92.1	85.1
Residual resource, hours	<0	<0	15,536	93,899	30,312	94,383	2,319	18,288	34,494

### Discussion of the results

Static damage is estimated at the equipment resource of 220 thousand hours according to regulations [5]. For power units no. 6 of Zaporizhzhia NPP, no. 4 of Rivne NPP, no. 2 of Khmelnytskyi NPP, the total damage of high-pressure rotors is in the range of 59–83%, and the residual resource will be 40,604–94,383 hours. This will allow to prolong the operation of high-pressure rotors of NPP steam turbines for 40–50 thousand hours. All other power units have operating time near the equipment resource and can no longer be operated.

To prolong the operation, it is necessary to conduct experimental studies of 30HN3M1FA steel for long-term strength and increase the individual resource to 270 thousand hours. If the expert commission allows to accept such admissible time of operation of metal, the total damage of high-pressure rotors of power units no. 3–5 of Zaporizhzhia NPP, no. 1 of Khmelnytskyi NPP, no. 2, 3 of South-Ukrainian NPP lies within 85–90%, and the residual resource will make 22,403–34,494 hours. This will allow to prolong the operation of high-pressure rotors of NPP steam turbines for 25 thousand hours.

For power units no. 1, 2 of Zaporizhzhia NPP, no. 3 of Rivne NPP, no. 1 of South-Ukrainian NPP, the total damage of high-pressure rotors varies between 92–99 %, and the residual resource will be 2,319–18,288 hours. For power units no. 1, 2 of Rivne NPP the total damage of high-pressure rotors is 102–105%, i.e. exceeds 100%. This indicates the depletion of the individual resource of the steam turbines high-pressure rotors of the NPPs of these power units. Continuation of their operation requires additional calculation and experimental research, or replacement of high-pressure rotors.

If, according to the results of experimental studies of 30HN3M1FA steel for long-term strength, an expert commission consisting of representatives of the power plant, specialized and other organizations according to SOU-N MFE 40.17.401: 2004 [4], can accept the allowable operating time of metal at 370 thousand hours, the estimated total damage will be reduced to 64–80%, and the residual metal life of HPR of NPP units turbines will be 26,287–50,000 hours. This will allow to prolong the operation of high-pressure rotors for 25 thousand hours.

### Conclusions

1. For power units no. 6 of Zaporizhzhia NPP, no. 4 of Rivne NPP, no. 2 of Khmelnytskyi NPP, the total damage of high-pressure rotors is in the range of 59–83% for the equipment resource of 220 thousand hours, and the residual resource will be 40,604–94,383 hours. This will allow to prolong the operation of high-pressure rotors of NPP steam turbines for 40–50 thousand hours.

2. According to the results of calculation studies of resource indicators of high-pressure rotors of NPP steam turbines, if the expert commission allows to increase the allowable equipment resource to 270 thousand hours, the total damage of high-pressure rotors of power units no. 3–5 of Zaporizhzhia NPP, no. 1 of Khmelnytskyi NPP, no. 2, 3 of South-Ukrainian NPP fluctuates within 85–90%, and the residual resource will make 22,403–34,494 hours. This will allow to prolong the operation of high-pressure rotors of NPP steam turbines for 25 thousand hours.

3. For power units no. 1, 2 of Zaporizhzhia NPP, no. 3 of Rivne NPP, no. 1 of South-Ukrainian NPP, the total damage of high-pressure rotors is in the range of 92–99%, and the residual resource will be 2,319–18,288 hours. For power units no. 1, 2 of Rivne NPP, the total damage of high-pressure rotors varies between 102–105%, i.e. exceeds 100%. This indicates the depletion of the individual resource of the steam turbines high-pressure rotors of the NPPs of these power units.

4. If the expert commission, consisting of representatives of the power plant, specialized and other organizations in accordance with SOU-N MFE 40.17.401: 2004 [1], can accept the allowable operating time of the metal at 370 thousand hours, the calculated total damage will decrease to 64–80%, and the residual metal resource of HPR turbines of NPP power units will be 26,287–50,000 hours. This will allow to prolong the operation of high-pressure rotors for 25 thousand hours.

### References

1. Chernousenko, O. Yu., Ryndiuk, D. V., & Peshko, V. A. (2020). *Otsinka zalyshkovoho resursu ta podovzhennia ekspluatatsii parovykh turbin velykoi potuzhnosti* [Estimation of residual life and extension of operation of high-power steam turbines]. Part 3: monograph for scientists and doctors of philosophy in the specialty 144 "Heat Power

- Engineering". Kyiv: National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 297 p. (in Ukrainian).
2. Peshko, V., Chernousenko, O., Nikulenkova, T., & Nikulenkov, A. (2016). Comprehensive rotor service life study for high & intermediate pressure cylinders of high power steam turbines. *Propulsion and Power Research*, vol. 5, iss. 4, pp. 302–309. <https://doi.org/10.1016/j.jprr.2016.11.008>.
  3. Chernousenko, O., Butovsky, L., Rindyuk, D., Granovska, O., Moroz, O. (2017). Analysis of residual operational resource of high-temperature elements in power and industrial equipment. *Eastern-European Journal of Enterprise Technologies – Energy-saving technologies and equipment*, vol. 1, no. 8 (85), pp. 20–26. <http://dx.doi.org/10.15587/1729-4061.2017.92459>.
  4. Dobrovolskyi, V. Ye., Novychenok, L. M., Zavodnyi, M. A., Mukhopad, H. V., Pasternak, V. P., Horieshnik, A. D., & Veksler, Ye. Ya. (2005). *Kontrol metalu i prodovzhennia terminu ekspluatatsii osnovnykh elementiv kotliv, turbin i truboprovodiv teplovykh elektrostantsii* [Metal control and extension of service life of the main elements of boilers, turbines and pipelines of thermal power plants]. Regulatory document of the Ministry of Fuel and Energy of Ukraine. Typical instruction SOU-N MPE 40.17.401:2004. Kyiv: HRIFRE, Ministry of Fuel and Energy of Ukraine, 76 p. (in Ukrainian).
  5. Shulzhenko, M. H., Hontarovskiy, P. P., Matiukhin, Yu. I., Melezhyk, I. I., & Pozhydaiev, O. V. (2011). *Vyznachennia rozrakhunkovoho resursu ta otsinka zhyvuchosti rotoriv i korpusnykh detalei turbin*. [Determination of estimated resource and evaluation of rotor life and body parts of turbines: Methodological guidelines. Regulatory document SOU-N MEV 0.1–21677681–52:2011: approved by the Ministry of Energy and Coal Mining of Ukraine: effective as of 07.07.11. Kyiv: Ministry of Energy and Coal Mining of Ukraine (in Ukrainian).
  6. (1983). *Raschet temperaturnykh poley rotorov i korpusov parovykh turbin: RTM 108.020.16-83* [Calculation of temperature fields of rotors and casings of steam turbines: RTM 108.020.16-83]. Leningrad: Research and Production Association Central Boiler and Turbine Institute, 112 p. (in Russian).
  7. (1985). *Detali parovykh statsionarnykh turbin. Raschet na malotsiklovuyu ustalost: RTM 108.021.103-85* [Details of stationary steam turbines. Calculation for low-cycle fatigue: RTM 108.021.103-85]. Moscow, 49 p. (in Russian).
  8. (1996). *Metodicheskiye ukazaniya o poryadke provedeniya rabot pri otsenke individualnogo resursa parovykh turbin i prodlenii sroka ikh ekspluatatsii sverkh parkovogo resursa: RD 34.17.440-96* [Guidelines on the procedure for carrying out work in assessing the individual resource of steam turbines and extending their service life in excess of the park resource]: guidance document 34.17.440-96. Moscow, 153 p. (in Russian).
  9. Chernousenko, O. Yu., Ryndiuk, D. V., & Peshko, V. A. (2019). Napruzhenno-deformovanyi stan rotora turbiny K-1000-60/3000 pry typovykh rezhymakh ekspluatatsii [Stress-strain state of the turbine rotor K-1000-60 / 3000 under typical operating conditions]. *Visnyk NTU «KhPI». Seriya: Enerhetychni ta teplotekhnichni pro-tsesy y ustatkuvannia – Bulletin of NTU “KhPI”. Series: Power and Heat Engineering Processes and Equipment*, no. 3 (1328), pp. 4–10. (in Ukrainian). <https://doi.org/10.20998/2078-774X.2019.03.01>.
  10. Chernousenko, O. & Peshko, V. (2019). Assessment of resource parameters of the extended operation high-pressure rotor of the K-1000-60/3000 turbine. *Journal of Mechanical Engineering – Problemy Mashynobuduvannia*, vol. 22, no. 4, pp. 41–47. <https://doi.org/10.15407/pmach2019.04.041>.
  11. Chernousenko, O., Nikulenkova, T., Peshko, V., & Nikulenkov, A. (2021). Approach to impact assessment of the rated power uprate of NPP unit on the service life of the turbine critical elements. *Rocznik Ochrona Środowiska*, vol. 22, no. 1, pp. 105–116.
  12. Chernousenko, O. Yu. (2017). *Otsenka ostatochnogo resursa i prodleniye ekspluatatsii parovykh turbin bolshoy moshchnosti* [Estimation of residual life and prolongation of operation of high power steam turbines]: Part 2. Kharkiv: FOP Brovin A. V., 208 p. (in Russian).

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## **Оцінка індивідуального ресурсу роторів високого тиску парових турбін атомних електростанцій**

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Інтеграція української енергосистеми до європейської є складовою стратегічної мети України – входу до ЄС. Наша держава має достатньо потужні й розвинені газо-, нафтотранспортні й електричні мережі, поєднані з транспортними мережами ЄС і країн СНД, що дозволяє їй брати участь у формуванні Європейської енергетичної політики і спільного енергетичного ринку, відігравати важливу роль в енергетичній співпраці країн СНД і ЄС. У роботі проведено оцінку ресурсних показників роторів високого тиску парових турбін АЕС потужністю 220, 1000 МВт. Застосовано комплексний підхід до дослідження індивідуального ресурсу парових турбін і можливості продовження експлуатації енергетичного обладнання. Для енергоблоків № 6 Запорізької АЕС, № 4 Рівненської АЕС, № 2 Хмельницької АЕС сумарна пошкоджуваність роторів високого тиску дорівнює 59–83%, а залишковий ресурс складає 40604–94383 годин, що дозволяє продовжити експлуатацію на 40–50 тисяч годин. За результатами проведення розрахункових досліджень ресурсних показників роторів високого тиску турбін АЕС сумарна пошкоджуваність роторів високого тиску енергоблоків № 3–5 Запорізької АЕС, № 1 Хмельницької АЕС, № 2, 3 Південно-Української АЕС коливається у межах 85–90%, а залишковий ресурс складає 22403–34494 годин, якщо прийняти допустимий парковий ресурс 270 тисяч годин. Це дозволить продовжити експлуатацію роторів високого тиску парових турбін АЕС на 25 тис. год. Для енергоблоків № 1, 2 Запорізької АЕС, № 1, 2, 3 Рівненської АЕС, № 1 Південно-Української АЕС індивідуальний ресурс роторів високого тиску турбін АЕС вичерпано.

**Ключові слова:** статична пошкоджуваність, циклічна пошкоджуваність, залишковий ресурс, парова турбіна, малоциклова втома, довготривала міцність.

## Література

1. Черноусенко О. Ю., Риндюк Д. В., Пешко В. А. Оцінка залишкового ресурсу та подовження експлуатації парових турбін великої потужності (частина 3): монографія для науковців та докторів філософії за спеціальністю 144 «Теплоенергетика». Київ: НТУУ «КПІ імені Ігоря Сікорського», 2020. 297 с.
2. 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. Iss. 4. P. 302–309. <https://doi.org/10.1016/j.jprr.2016.11.008>.
3. Chernousenko O., Butovsky L., Rindyuk D., Granovska O., Moroz O. Analysis of residual operational resource of high-temperature elements in power and industrial equipment. *Eastern-European Journal of Enterprise Technologies – Energy-saving technologies and equipment*. 2017. Vol. 1. No. 8 (85) P. 20–26. <http://dx.doi.org/10.15587/1729-4061.2017.92459>.
4. Контроль металу і продовження терміну експлуатації основних елементів котлів, турбін і трубопроводів теплових електростанцій: СОУ-Н МПЕ 40.17.401:2004. Офіц. вид. Київ: ГРІФРЕ: Міністерство палива та енергетики України, 2005. 76 с. (Нормативний документ Мінпаливенерго України, Типова інструкція).
5. Визначення розрахункового ресурсу та оцінка живучості роторів і корпусних деталей турбін. Методичні вказівки: СОУ-Н МПЕ 40.1–21677681–52:2011 / М. Г. Шульженко, П. П. Гонтаровський, Ю. І. Матюхін, І. І. Мележик, О. В. Пожидаєв. Київ: ОЕП «ГРІФРЕ»: М-во енергетики та вугільної пром-сті України, 2011. 42 с.
6. РТМ 108.020.16-83. Расчет температурных полей роторов и корпусов паровых турбин. Ленинград: НПО Центр. котлотурбинный институт, 1983. 112 с.
7. РТМ 108.021.103-85. Детали паровых стационарных турбин. Расчет на малоцикловую усталость. Москва, 1985. 49 с.
8. РД 34.17.440-96. Методические указания о порядке проведения работ при оценке индивидуального ресурса паровых турбин и продлении срока их эксплуатации сверх паркового ресурса. Офиц. издание. Москва, 1996. 153 с.
9. Черноусенко О. Ю., Риндюк Д. В., Пешко В. А. Напружено-деформований стан ротора турбіни К-1000-60/3000 при типових режимах експлуатації. *Вісник НТУ «ХПІ»*. Сер.: Енергетичні та теплотехнічні процеси й устаткування. 2019. № 3 (1328). С. 4–10. <https://doi.org/10.20998/2078-774X.2019.03.01>.
10. 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 – Problemy Mashynobuduvannia*. 2019. Vol. 22. No. 4. P. 41–47. <https://doi.org/10.15407/pmach2019.04.041>.
11. Chernousenko O., Nikulenkova T., Peshko V., Nikulenkov A. Approach to impact assessment of the rated power uprate of NPP unit on the service life of the turbine critical elements. *Rocznik Ochrona Środowiska*. 2021. Vol. 22. No. 1. P. 105–116.
12. Черноусенко О. Ю. Оценка остаточного ресурса и продление эксплуатации паровых турбин большой мощности. Часть 2: монография. Харьков: ФОП Бровин А. В., 2017. 208 с.