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RE-EXTENSION OF 200 MW TURBINE CAST CASING SERVICE

Olga Yu. Chernousenko
chernousenko20a@gmail.com
ORCID: 0000-0002-1427-8068

Dmitriy V. Ryndyuk
rel_dv@ukr.net
ORCID: 0000-0001-7770-7547

Vitaliy A. Peshko
vapeshko@gmail.com
ORCID: 0000-0003-0610-1403

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute",
37, Peremohy ave., Kyiv, 03056, Ukraine

To date, the fleet service life of a significant number of DTEK Energy power units is exceeded. In particular, this relates to the structural components of the K-200-130-3 steam turbine of the power unit No. 9 of DTEK Luganskaya TPP. There is a need to make a decision on the admissibility of further exploitation. This requires a comprehensive study of the technological state of the base metal and the check calculation of its most critical high-temperature elements. A complex of such works was performed earlier in 2009. A special feature of re-extending the service life of this power unit is the super long fleet equipment operating time, presence of damages in the form of cracks and crack surfaces in the high- and intermediate-pressure cylinder casings, as well as the active involvement of equipment to operate in maneuverable modes when covering peaks of electrical load. This paper assesses the residual life of casings on the basis of three-dimensional models of the K-200-130-3 steam turbine high-pressure (HP) and intermediate- pressure (IP) cylinder casings. In doing so, the paper takes into account the actual operating conditions according to the damage data obtained from the results of inspecting the power equipment metal condition during preventive maintenance overhauls. The calculation of temperature fields is performed for typical operation modes, namely stationary operation at nominal power and starts from cold, warm, and hot states. The boundary value problem of heat conduction was solved using the finite element method of computational domain discretization. The calculation of the stress-strain state (SSS) was made taking into account the effects of the main types of forces – temperature stresses, uneven temperature fields, forces from the steam atmosphere pressure, supporting forces. The maximum stress intensities for all the investigated modes of operation are observed in the toroidal parts of cylinder casings in the region of steam admission and correspond to the crack formation zones that were determined during the non-destructive testing of the metal. The assessment of long-term strength and low-cycle fatigue resistance showed that the residual life of the high-pressure cylinder (HPC) casing is satisfactory, and allows extending the operation by 100 thousand hours with standard safety factors. For the intermediate-pressure cylinder (IPC) casing, the residual life is 50 thousand hours with reduced safety factors.

Keywords: *steam turbine, high-pressure cylinder casing, intermediate- pressure cylinder casing, damage, safety factor, low-cycle fatigue, long-term strength, residual life.*

Introduction

According to the regulatory documents of the Ministry of Energy and Coal Industry of Ukraine, the fleet service life of K-200-130 LMP steam turbines is 220 thousand hours with 800 start-ups [1, 2]. In the period of 2005-2009, the Department of Cogeneration Installations of Thermal and Nuclear Power Plants of I. Sikorsky Kyiv Polytechnic Institute carried out work to assess the residual life of the high-temperature power equipment of the K-200-130 200 MW steam turbines of DTEK Luganskaya TPP power units Nos. 11, 13–15, DTEK Kurakhovskaya TPP power units Nos. 3–9, Starobeshevskaya TPP power unit No. 10. According to the results of that work, the operation of that power equipment was extended by 50 thousand hours and 400 start-ups for each power unit. To date, the term for extending the operating time of the high-temperature power equipment of some power units has expired.

The 200 MW steam turbines of Luganskaya TPP power units Nos. 9–15 were commissioned in 1963–1969. As at 10 January 2015, the turbines have worked 199 661–322 672 hours with a total number of start-ups from 687 to 1896 [3].

It became necessary to reassess the individual service lives of the HP and IP cylinder casings of the K-200-130 steam turbine of DTEK Luganskaya TPP power unit No. 9 in order to determine the possibility of their re-extention. A special feature of re-extending the service life of this power unit is the super-long fleet operating time, presence of damages in the form of cracks and crack formation zones in HP and IP cylinder casings, as well as equipment operation in different maneuverable modes (more than 1700-2500 start-ups from different thermal states (TS)) when covering peaks of electrical load.

The aim of this paper is to substantiate the admissibility of the subsequent operation of the high-temperature structural turbine components of DTEK Luganskaya TPP power unit No. 9.

Analysis of the results of the control of metal high- and medium-pressure casings

DTEK Luganskaya TPP 200 MW power unit No. 9 was commissioned as part of the second stage in 1963. The operating time as at November 2017 was 329 942 hours, the number of start-ups was 1704.

Throughout the turbine operating time, the control of its metal components was carried out during the period of preventive maintenance overhauls. The following types of control were carried out: the magnetic-particle flaw detection of the radius blends of the HPC and IPC upper and lower halves, check and control valves, radius blends and horizontal division plane of flanges and cylinders; the ultrasonic control of rotor blades, rivets of locking blades, studs of the HPC and IPC, safety and check valve connectors; the visual inspection with the etching of fillets, disks, rotor blades, high- and intermediate pressure rotor shafts, guide vanes and welded diaphragm casing, radius blends of HPC and IPC upper and lower halves, and check valves.

According to the station data, the HPC actual operating time is 129 435 hours and 961 start-ups, the IPC assessed operating time corresponds to the total operating time of the power unit (329 942 hours and 1704 start-ups). During the mid-life repair conducted by the Laboratory of Metals and Welding, belonging to SE Luganskaya TPP of LLC DTEK Vostokenergo, in 2017, cracks were found in both the HPC and IPC (Laboratory report No. 44-17-25). Symmetric 100×20×12 mm and 110×20×12 mm crack zones were found in the steam inlet channel of the HPC lower half. Also, there were 1800 mm long, and 4 and 8 mm deep cracks in the fastening zones of diaphragm holders. Cracks with a length of 60–230 mm and width of 2–5 mm were found in the HPC upper half, in the fastening zones of diaphragm holders. In the IPC lower half, from the side of the HPC, 150×50×20 mm and 200×50×10 mm symmetric crack formation zones as well as 270 mm long and 5 mm deep cracks were found. In the IPC upper half, in the cold part abutment region, a 1800 mm long and 10 mm deep crack was revealed. Also, from the side of the HPC, 200×80×10 mm and 200×100×10 mm crack nets were found. According to the results of the technical audit of the state of the metal of high-temperature elements, when modeling the casing geometry, all the defects detected in the process of check calculation were introduced into the manufacturer's design structure.

Estimated Residual Life of Turbine Casing Elements

The simulation of the thermal and stress-strain states of the elements (operating in stationary and varying modes) of DTEK Luganskaya TPP power unit No. 9 K-200-130 steam turbine was conducted in a three-dimensional formulation using the graphic packages of SolidWorks Simulation software according to [3, 4]. For the SSS analysis, three modes were considered: start-up from a cold state, CS, ($t_{0\text{met}}$=100 °C), start-up from a warm state, WS-1, ($t_{0\text{met}}$=240 °C), and start-up from a warm state, WS-2, ($t_{0\text{met}}$=410 °C. The calculated evaluation was carried out taking into account the damageability of casings by organizing metal samples in the places of crack formation. The dimensions and depths of such samples were taken according to the monitoring data of the metal of the cast casing parts of the K-200-130-3 turbine of Luhanskaya TPP power unit No. 9 during the period of overhaul.

The geometrical models of the HPC and IPC casings were built taking into account the complex geometry with bores for fixing the diaphragm holders, the seal holders on the inner side of the casing, as well as the steam inlet and bleed pipes, horizontal parting flanges, holes for fixing studs and pickups. For the HPC casing flanges and studs, steam heating is arranged along the groove.

The numerical study of the thermal and stress-deformed states showed that for the HPC and IPC the total stress level determining the resource characteristics of power equipment at nominal operating conditions and during start-ups from different thermal states occurs in the steam-inlet area, at the fixing points of end seal surfaces, as well as on the inner casing surfaces in the zone of the regulating stage and the first three pressure stages. For example, when starting from a cold state, CS, (Fig. 1), in the HPC, the maximum values of the temperature gradient appear at all check nodes at the initial start-up stages (idling at 1200 rpm – 2100 s). The maximum intensity of conventional elastic stresses from the joint action of the temperature difference and vapor pressure effect in the HPC was noted in the toroidal part of the casing in the crack formation zone, where the transition from the casing wall to the steam inlet pipes takes place and amounts to σ_{imax}=473.8 MPa, the metal temperature values at these points not exceeding 295 °C.

For the IPC casing, the maximum stress values also arise during start-up from a cold state (Fig. 2). The most loaded moments of time are the idling at 3000 rpm (2700 s) and loading up to 30 MW (12 600 s). The maximum intensity of the conditional elastic stresses σ_{imax}=493.3 MPa for the IPC casing is on its inner surface in the steam inlet part zone.

Similar calculated data were obtained for all typical operating conditions. These data allowed us to proceed to the calculation of static and cyclic damageability of the base metal. According to [5], the strain amplitude was determined from the strain intensity values during the loading cycle (initial state – loading – nominal regime – unloading – initial state). The number of loading cycles before the appearance of cracks was determined from the experimental low-cycle fatigue curves obtained from the results of sample tensile-compression tests at a rigid symmetric cycle and constant temperature. The total damage D' accumulated in the metal of the casings operating under the conditions of joint creep under various steady-state conditions and cyclic loads under different varying modes, as well as the residual operating time before the appearance of cracks $[\tau]_{resid}$, was determined according to [6]. In calculations for low-cycle fatigue, check points of maximum intensities of conditional elastic stresses were studied.

The results of the calculated evaluation of the low-cycle fatigue strength of metal, taking into account the damageability of the HPC and IPC casings, by organizing metal samples in the places of crack formation, are presented in Table 1. In accordance with the recommendations of [6], when calculating low-cycle fatigue, stocks are taken according to the number of cycles n_N=5 and the number of deformations n_ε=1.5. In the second case, the same factors are taken at the level of n_N=3 and n_ε=1.25. Such values were obtained as a result of the experimental studies of the structure and properties of the metal in order to clarify the characteristics of long-term strength and strength margins [8]. These works were performed by both I. Sikorsky Kyiv Polytechnic Institute and G. Pisarenko Institute for Problems of Strength of the NAS of Ukraine on the basis of steel samples of the HPC and IPC of the K-210-130 steam turbine at Kurakhovskaya TPP of LLC DTEK Vostokenergo. The analysis of the real state of 15H1M1FL steel showed that the degradation of its properties according to the number of cycles (up to 35%) does not exceed the allowable [40%] one over the entire range of strain amplitudes (from 0.157 to

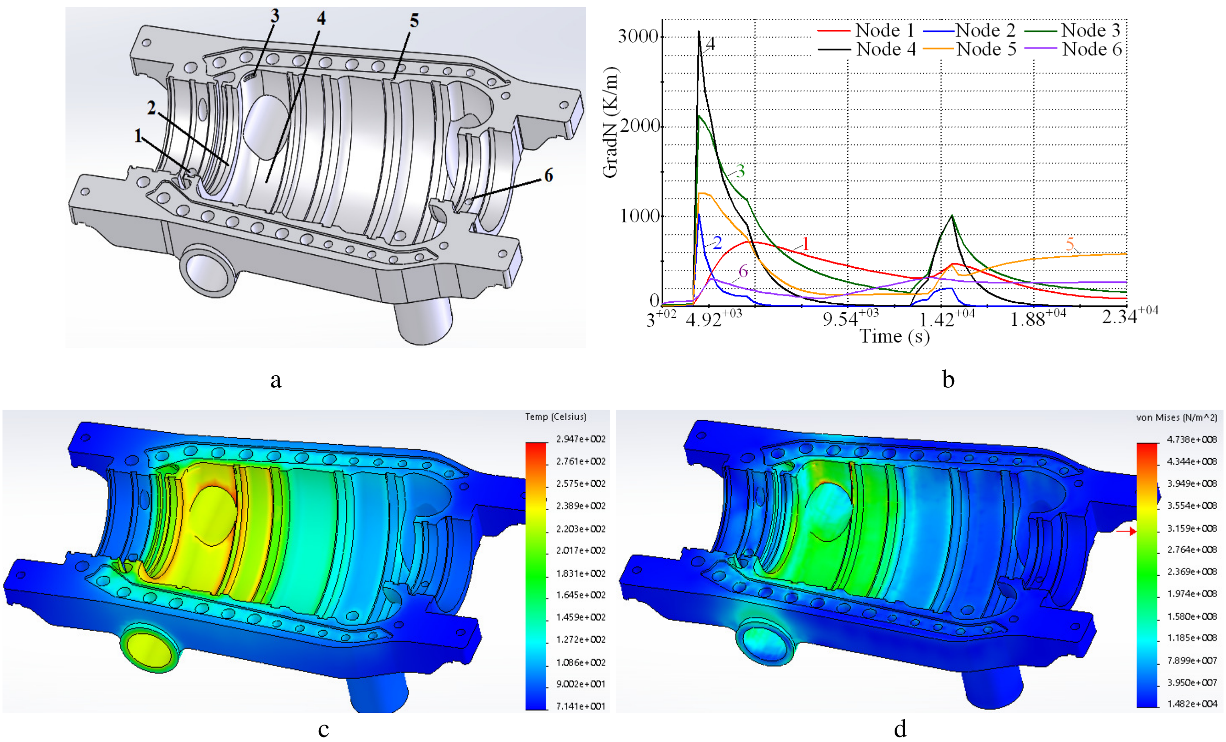

Fig. 1. Results of the calculation of the HPC state at start-up from CS:
a – fields of study of temperature gradients; b – change of temperature gradients in time;
c – TS at a point of 2100 s (idling at 1200 rpm); d – SSS at a point of 2100 s

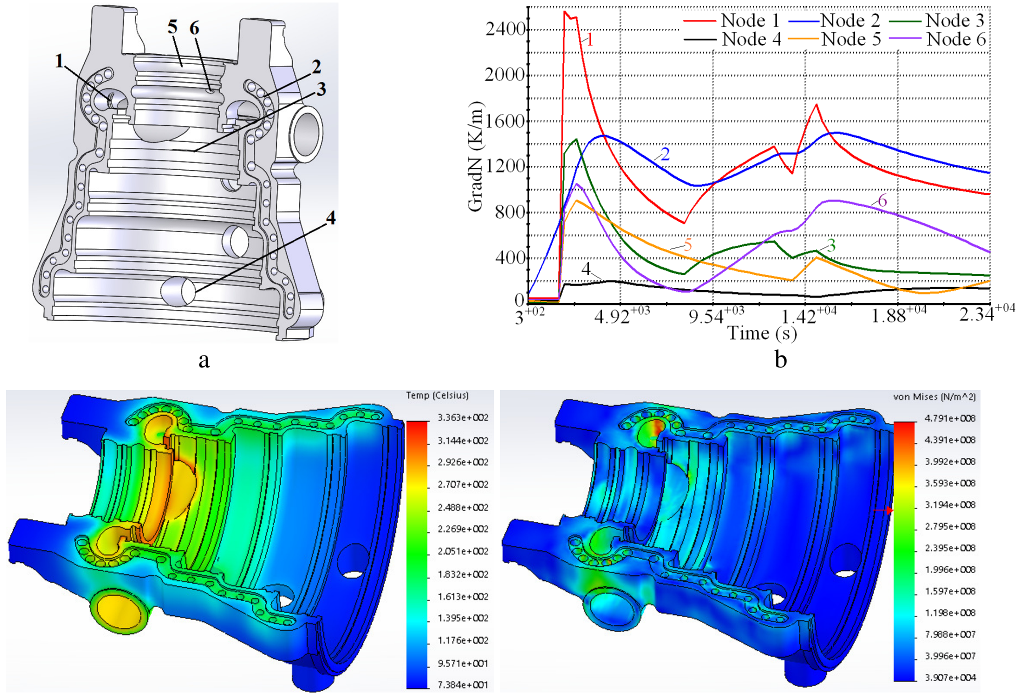

Fig. 2. Results of the calculation of the HPC casing state at start-up from CS:
a – fields of study of temperature gradients; b – temperature gradient change in time;
c – TS at a point of 2700 s (idling at 3000 rpm); d – SSS at a point of 2700 s

1.802%). As applied to deformations, the permissible limit of cyclic strength reduction [17%] occurs in the range of strain amplitudes from 0.0 to 0.352%. Consequently, in the specified range of stress amplitudes, the safety factors against the number of cycles and deformations can be set at the level of n_N=3 and n_ε=1.25.

The specified, with the normative safety factors taken into account, permissible minimum number of cycles to failure, permissible minimum number of cycles prior to destruction is 3660 start-ups for the HPC casing and 3400 start-ups for the IPC casing (Table 1). Taking into account the total number of start-ups (961) for the HPC casing, the residual minimum calculated number of start-ups is about 2699. For the IPC casing, this number is 1696 (with the current number of start-ups amounting to 1704).

Table 1. Calculated evaluation of low-cycle fatigue of metal in casings

Type of start-up / calculated element	Casing wall thickness temperature t_{max}, °C	Stress intensity amplitude, σ_a, MPa	Reduced deformation, $\varepsilon_{a\ red}$, %	Permissible number of start-ups, Np	
				n_N=5, n_ε=1.5	n_N=3, n_ε=1.25
WS-2 \ HPC	509	185.5	0.10317	9920	16 533
WS-1 \ HPC	509	256.5	0.12297	4200	7000
CS \ HPC	509	278.5	0.13351	3660	6100
WS-2 \ IPC	527	182.5	0.09665	9840	16 400
WS-1 \ IPC	527	272	0.12334	4020	6700
CS \ IPC	527	266.5	0.12899	3400	5670

There is no complete statistics on the types of start-up modes at the station. According to the available data, for the period from 01.01.2005 to 01.01.2008, the average number of WS-2 start-ups was 62.75%, that of WS-1 start-ups was 20.5%, and that of CS start-ups was 16.75%. It can be assumed that such an operating mode lasted until the present time. Then for the HPC casing the number of WS-2 start-ups was 603 (62.75%), that of WS-1 start-ups was 197 (20.5%) and that of CS start-ups was 161 (16.75%), totaling 961 start-ups from different thermal states. For the IPC casing the number of WS-2 start-ups was 1069 (62.75%), that of WS-1 start-ups was 349 (20.5%) and that of CS start-ups was 286 (16.75%), totaling 1704 start-ups from different thermal states.

It is to be taken into account that if in 2012–2017 the power unit operated in the maneuverable mode (increased number of start-ups from WS-2s and HSs), the resource characteristics can deteriorate significantly according to the work done for DTEK Energy [3].

Taking into account the data on TS, the SSS of the HPC and IPC casings, as well as the assessment of low-cycle metal fatigue (Table 1), the estimated assessment of damageability, residual permissible operating time in years and individual residual service life of the HPC and IPC casings of DTEK Luganskaya TPP power unit No. 9 are presented in Table 2.

When determining the residual life of cylinder casings, the assessment of short-term static strength can be performed using the maximum value of the nominal equivalent stress σ_{eq} according to the recommendations of [7]. The safety factor for the yield strength of the material of cast cylinder casings $\sigma_{02}^{в}$ at the calculated temperature t in the stationary mode must satisfy the condition n'_t, $n''_t \geq 1.5$ (Table 2).

Table 2. Estimated assessment of the damageability and residual life of the HPC and IPC casings of the K-200-130-3 steam turbine of DTEK Luganskaya TPP power unit No. 9

Variables	Formula	HPC casing		IPC casing	
Metal temperature	t, °C	509		527	
Stress intensity	$\sigma_{i\,мах}$, MPa	105		104.4	
Yield strength	$\sigma_{02}^{в}$, MPa	210.0		210.0	
Nominal equivalent stress	σ_{eq}, MPa	114		113	
Safety factor σiмах	$n'_т=\sigma_{02}^{в} / \sigma_{i\,мах}$	2		2.011	
Safety factor σeq	$n''_т=\sigma_{02}^{в} / \sigma_{eq}$	1.842		1.858	
Total number of start-ups	n_t	961		1704	
Total operating time	τ_t, h	129 435		329 942	
Safety factors	$n_N \setminus n_\varepsilon$	5 \ 1.5	3 \ 1.25	5 \ 1.5	3 \ 1.25
Permissible number of cycles for different types of start-ups	$[N_p]$ $n^{HPC}_{WS\text{-}2}=603$, $n^{ICS}_{WS\text{-}2}=1069$	9920	16 533	9840	16 400
	$[N_p]$ $n^{HPC}_{WS\text{-}1}=197$, $n^{IPC}_{WS\text{-}1}=349$	4200	7000	4020	6700
	$[N_p]$ $n^{HPC}_{CS}=161$, $n^{IPC}_{CS}=286$	3660	6100	3400	5670
Cyclic damageability	$[D_{cyl}]=\sum n_l/[N_p]$, %	15.17	9.10	27.94	16.76
Permissible time	$[t_{pl}]$, h	3.7×10^5	3.7×10^5	3.7×10^5	4.7×10^5
Static damageability	$[D_{static}]=\sum\tau_t/[t_p]$, %	34.98	34.98	89.17	69.46
Total damageability	$[D_\Sigma]=[D_{static}]+[D_{cyl}]$, %	50.15	44.08	117.11	86.22
Residual service life	T_{resid}, h	128 658	164 201	<0	52 727

According to the calculations (Table 2), it should be noted that a large current number of cycles and the sensitivity of the base metal to varying modes are selected taking into account the normative safety factors (n_N =5, n_ε=1.5), the cyclic damageability at the level of D_{cyl}=15.17% for the HPC casing and D_{cyl}=27.94% for the IPC casing. Taking into account static damage, the total HPC casing metal damageability D_Σ=50.15% and the total IPC casing metal damageability D_Σ=117.11% are provided. The maximum permissible total metal damageability should be less than 100%, so the subsequent operation of the IPC casing with the safety factors n_N=5 and n_ε=1.5 and the permissible operating time of its metal at the level of 370 thousand hours according to [7, 8] is not allowed.

With the safety factors against the number of cycles and deformations at levels 3 and 1.25, as well as the permissible operating time of the metal is 370 thousand hours, the total damageability the HPC casing metal is 44%, and that of the IPC casing is 86% [6, 8]. The short-term static safety factors of the HPC and IPC casings are nowhere beyond the limits of permissible ($n'_t \geq 1.5$), which allows their further operation. If the expert commission, consisting, according to [1], of the representatives of the power plant, specialized and other organizations, can allow a decrease in safety factors against the number of cycles and deformations at levels 3 and 1.25, and also accept the permissible operating time for the ICS casing metal at the level of 475 thousand hours, the individual residual life of the HPC casing is 164 200 hours and that of the ICS casing is 52 727 hours. This will allow extending the operation of the HPC and ICS casings by 50 thousand hours with the number of start-ups equal to half of the fleet quantity, i.e. 400 start-ups.

Conclusions

1. The calculations for the low-cycle fatigue and static damageability of the casings of the HPC and IPC of DTEK Luganskaya TPP power unit No. 9 showed that the total damageability of the HPC casing metal is 44%, and that of the IPC casing is 86% with safety factors against the number of cycles and deformations of 3 and 1.25, as well as the permissible 370 thousand-hour operating time for the HPC casing metal, and 475 thousand-hour operating time for the IPC casing.

2. The individual residual life of the HPC metal casing of DTEK Luganskaya TPP power unit No. 9 is 128 658 hours and is depleted for the IPC casing with normative safety factors against the number of cycles and deformations, as well as with the permissible 370 thousand-hour operating time of the metal. If the expert commission can allow reduction of safety factors, as well as taking the permissible operating time of the metal for the HPC casing at the level of 470 thousand hours, this will extend the operation of the HPC and IPC casings by 50 thousand hours with the number of start-ups equal to half the fleet quantity, i.e., 400.

3. When re-extending the operation of the K-200-130 turbine HPC and ICS casings, it is necessary to repeat the experimental studies of the metal for low-cycle fatigue in order to change the safety factors against the number of cycles and deformations, as well as experimental studies for long-term strength to clarify the permissible operating time of the metal of cast casing parts during the further post-fleet life operation.

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Повторне продовження експлуатації литих корпусів турбін 200 МВт

Черноусенко О. Ю., Риндюк Д. В., Пешко В. А.

Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», 03056, Україна, м. Київ, пр. Перемоги, 37

На сьогодні парковий ресурс значної кількості енергоблоків ДТЕК Енерго перевищено. Зокрема, це стосується корпусних елементів парової турбіни К-200-130-3 енергоблока № 9 ДТЕК «Луганська ТЕС». Виникає необхідність прийняття рішення про допустимість подальшої експлуатації. Для цього потрібно провести комплексне дослідження технологічного стану основного металу і перевірочного розрахунку його найбільш відповідальних високотемпературних елементів. Комплекс таких робіт виконано раніше в 2009 р Особливістю повторного продовження експлуатації даного енергоблока є надпаркове напрацювання обладнання, наявність пошкоджень у вигляді тріщин і розтріскування в корпусах циліндрів високого та середнього тиску, а також активне залучення обладнання для роботи в маневрених режимах під час покриття піків електричного навантаження. У роботі проведена оцінка залишкового ресурсу на базі тривимірних моделей корпусів циліндрів високого (ЦВТ) і середнього тиску (ЦСТ) парової турбіни К-200-130-3 з урахуванням реальних умов експлуатації згідно з даними пошкодження, отриманими за результатами обстеження стану металу енергетичного устаткування в планово-попереджувальних ремонтах. Розрахунок температурних полів виконаний для типових режимів експлуатації, а саме стаціонарна робота на номінальній потужності і пуски з холодного, неостиглого і гарячого станів. Крайова задача теплопровідності розв'язувалася із застосуванням скінченноелементного методу дискретизації розрахункової області. Розрахунок напружено-деформованого стану виконаний з урахуванням впливу основних типів зусиль – температурні напруження, нерівномірність температурних полів, зусилля від тиску парового середовища, реакції опор. Максимальні інтенсивності напружень для всіх досліджених режимів роботи спостерігаються в тороїдальній частині корпусу в області паровпуску і відповідають зонам розтріскувань, які були встановлені в ході неруйнівного контролю металу. Проведена оцінка тривалої міцності і опірності малоцикловій втомі показала, що залишковий ресурс корпусу ЦВТ є задовільним і дозволяє продовжити експлуатацію на 100 тис. год за нормативних коефіцієнтів запасу. Для корпусу ЦСТ залишковий ресурс становить 50 тис. год за знижених коефіцієнтів запасу.

Ключові слова: *парова турбіна, корпус високого тиску, корпус середнього тиску, пошкодженість, запас міцності, малоциклова втома, тривала міцність, залишковий ресурс.*

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