DOI: https://doi.org/10.15407/pmach2026.03.071

UDC 621.165.62

MODELING THE THERMAL STATE OF THE LOW-PRESSURE ROTOR OF THE K-200-130 TURBINE DURING START-UP

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

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

Dmytro V. Ryndiuk
reletive@gmail.com
ORCID: 0000-0001-7770-7547

Anatolii P. Bovsunovskyi
apbovsunovsky@gmail.com
ORCID: 0000-0001-9562-0250

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute",
6, Politekhnichna str., Kyiv, 03056, Ukraine

Under the current operating conditions of the Integrated Power System of Ukraine, the reliability and operational safety of thermal power plant equipment are of critical importance. Ensuring long-term operation and evaluating the individual service life of critical turbine components following mechanical damage and repair restorations require a comprehensive investigation of their thermomechanical state. The aim of this study is to perform computational research of the spatial thermal state of the low-pressure rotor of the K-200-130 steam turbine to provide scientific and technical justification for extending its reliable operational life. The research methodology is based on the fundamental principles of transient heat conduction and continuum mechanics, utilizing the finite element method within the SolidWorks environment. A spatial 3D model of the symmetric half of the LPR (approximately 6.2 million elements) was developed with adaptive mesh refinement in stress concentration zones. The model incorporates actual post-repair geometric modifications, specifically a reduction in the shaft journal diameter in the bearing No. 5 area from 435 mm to 420 mm. Second- and third-kind boundary conditions for heat transfer were determined using similarity theory criterion equations, accounting for the thermodynamic and hydrodynamic characteristics of the steam flow in the flow path. Three-dimensional temperature fields of the rotor were obtained for the rated 200 MW load regime and during a transient cold start-up. It was found that under steady-state operation, the metal reaches a thermally stabilized state, with temperatures ranging from 160–170 °C in the steam inlet region to 40–65 °C in the last stages. During cold start-up, significant transience was observed: during rotor rolling and speed acceleration, an extreme radial temperature gradient occurs, with the outer surface heating up to 130–150 °C while inner layers warm up only to 30–40 °C. A notable thermal lag in the warming of the shaft symmetry axis was recorded, resulting from the massive rotor dimensions and the thermophysical properties of 25Cr1Mo1V steel. The resulting temperature fields and gradients provide a foundational basis for subsequent numerical analysis of the rotor's stress-strain state, evaluation of cumulative low-cycle fatigue damage, and prediction of the power unit's remaining individual service life.

***Keywords**: thermal power plant, steam turbine K-200-130, low-pressure rotor, temperature, resource, non-stationary thermal conductivity, thermal state.*

Introduction

Nowadays, thermal power plants (TPPs) play a leading role in ensuring the reliability and stability of the Integrated Power System of Ukraine. Currently, all power units at Ukraine's thermal power plants have exhausted their equipment resource [1]. Moreover, the equipment at these plants is sustaining significant damage due to constant air attacks by the enemy – the russian army. Under these conditions, the scientific and technical justification for extending the service life of major thermal power plant equipment and enhancing the safety of critical energy infrastructure become a priority for both authorities and specialists. Modeling the thermal and stress-strain states of power equipment components – factors that significantly influence plant operation following damage – is a matter of considerable importance.

The primary causes of emergency steam turbine shutdowns include vibrational fatigue of rotor materials, erosive damage to rotors, and resonance issues arising during operation in variable modes [2–5].

It should be noted that integrating the Ukrainian energy system into the European one is a key component of Ukraine's strategic goal of EU accession and a guarantee of the energy system's stable operation. However, it is important to consider that, unlike the countries that joined the EU during the "new wave" of enlarge-

This work is licensed under a Creative Commons Attribution 4.0 International License.
© Olha Yu. Chernousenko, Vitalii A. Peshko, Dmytro V. Ryndiuk, Anatolii P. Bovsunovskyi, 2026

ment, Ukraine already possessed robust and well-developed gas, oil, and electricity networks interconnected with EU infrastructure. This, in turn, enabled the country to participate in shaping European energy policy and the common energy market, as well as to play a significant role in energy cooperation among EU nations. The energy situation in Ukraine has currently become more complex due to the destruction of numerous thermal power plants caused by shelling. Consequently, the reliable operation of the TPP units remaining in the power grid is now critically important.

Based on this, ensuring the uninterrupted operation and extending the service life of 200 MW power units – particularly following accidental damage to steam turbine components – requires an assessment of the individual service life of the K-200-130 steam turbine. This assessment must be based on a comprehensive approach combining non-destructive metal testing results with structural strength calculations and a detailed analysis of the unit's specific operational history [6–10]. The initial stage involves determining the thermal and stress-strain states of the low-pressure rotor of the K-200-130 steam turbine.

Aim and objectives of the paper

The aim of this paper is to study the thermal state of the K-200-130 turbine low-pressure rotor through computational analysis in order to justify the possibility of extending its service life.

To achieve this aim, the following problems were solved:

– development of a model of the K-200-130 turbine low-pressure rotor;

– assessment of the thermal state of the K-200-130 turbine low-pressure rotor using modern mathematical modeling methods based on the fundamental principles of transient heat conduction and solid mechanics, as well as analytical methods for solving mathematical physics problems and computational engineering analysis methods.

Object of study and features of the computational model

The dual-flow low-pressure rotor of the K-200-130 turbine – featuring four stages of mounted disks for both left and right flows – after 77,000 hours of operation is considered in this paper. The penultimate stage is designed as a Baumann stage: a special shelf is installed midway along the rotor blade's airfoil, splitting the steam flow into two substreams – one directed straight to the condenser and the other one – to the nozzle blades of the final stage. A distinctive feature of the rotor is the absence of a manufacturing bore (axial hole) in the shaft.

The thermal state of the low-pressure rotor was studied using a 3D spatial model that accounts for the design's key geometric features and the results of restoration work performed during scheduled turbine overhauls. The computational domain was discretized using the finite element method within the SolidWorks environment, incorporating algorithms for disk contact interaction and a virtual Babbitt element.

This paper builds upon previous studies [7–10] that determined the thermal and stress-strain states of key components in high-capacity steam turbines. Future computational analyses of the thermal and stress-strain states of the power unit's main components will enable the assessment of damage accumulation and remaining service life, thereby facilitating the continued operation of the unit. Computational studies regarding the individual service life of these components will enable the management of the safe operation of power plants.

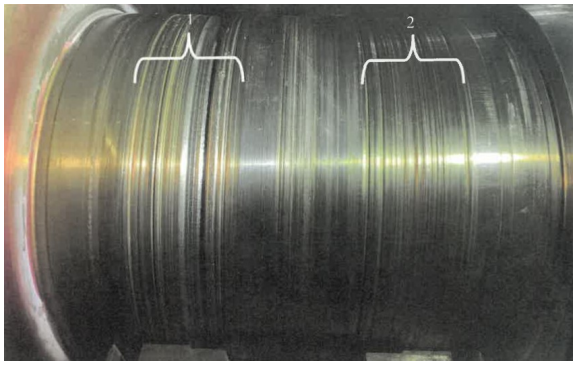


Fig. 1. Photo of the damaged low-pressure rotor shaft journal in the area of the bearing No. 5 seat

During the most recent major overhaul of the power unit, damage was discovered on the bearing No. 5 seat of the low-pressure rotor (Fig. 1). Specifically, two zones exhibiting scuffing and scoring marks were identified along the entire circumference of the shaft. The dimensions of the detected defects are as follows: Zone 1 – 136×100×≤7 mm; Zone 2 – 136×90×≤3 mm.

Further operation of the rotor with such defects is impermissible; therefore, a decision was made to perform machining by turning the low-pressure rotor journal in the area of bearing No. 5. As a result of the restoration work, the shaft journal diameter was reduced from 435 mm to 420 mm.

Computational model for analyzing the thermal and stress-strain state of the K-200-130 turbine low-pressure rotor

Based on the drawings of the low-pressure cylinder of the K-200-130 turbine, a spatial three-dimensional finite element model of the rotor was developed (Fig. 2). Due to the symmetry of the operation of both steam flows of the low-pressure cylinder of the K-200-130 turbine, the low-pressure rotor part was modeled from the central plane of symmetry to the right end of the shaft, and the stage landing disks were modeled from the contact surface to the root section of the rotor blades. The rotor blades themselves were not modeled, but their presence was taken into account as boundary conditions.

The finite element method was used to discretize the computational space. The computational grid was constructed using tetrahedral finite elements of the second order of condensation. The total number of finite elements for the LPR model is about 6.2 million, which provides the necessary accuracy of calculations and convergence of results (Fig. 2).

Particular attention is paid to zones of high stress concentration: fillets and the edges of the seating surfaces of mounted discs. In these areas, the finite element mesh is refined according to a geometric progression down to a minimum element size of 0.2 mm; this aligns with standard engineering analysis practices and ensures accurate calculation of local stress gradients during contact interactions involving incompatible meshes.

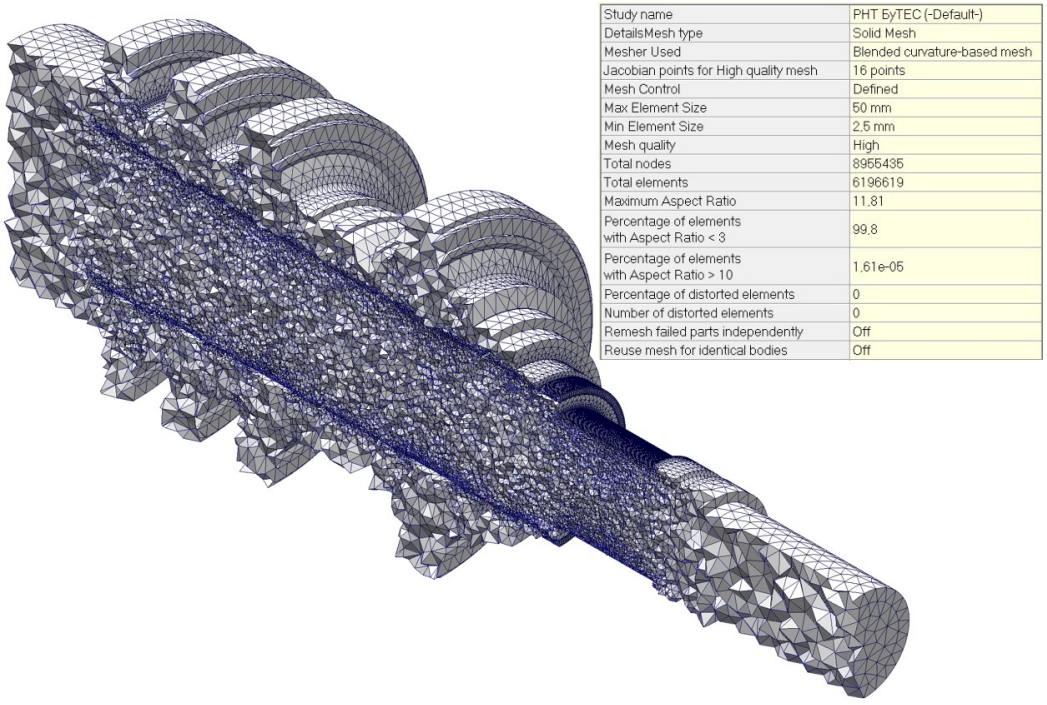


Fig. 2. Finite element model of the K-200-130 turbine low-pressure rotor

The mathematical model for simulating steam flow within the flow path is based on fundamental equations of thermodynamics and fluid dynamics – specifically, the equations for energy conservation, flow continuity, process and state, and the kinematic relations linking flow angles and velocities. In particular, for the flow path region downstream of the nozzle assembly, the continuity equation is applied in conjunction with the energy, process, and state equations

$$G_1 = \frac{G_{1z}F_1}{v_1} = \frac{C_1 \sin\alpha_1 F_1}{v_1\left(p_1\left(h_0 - \frac{C_1^2}{2\varphi^2}; S_0(p_0; h_0)\right); h_0 - \frac{C_1^2}{2}\right)}. \quad (1)$$

A similar continuity equation for the space downstream of the turbine rotor blade row

$$G_2 = \frac{W_{2z}F_2}{v_2} = \frac{W_2 \sin\beta_2 F_2}{v_2\left(p_2\left(H + \frac{u^2 - W_2^2}{2\psi^2}; S_1(p_1; h_1)\right); H + \frac{u^2 - W_2^2}{2\psi^2}\right)}, \quad (2)$$

where G is the steam mass flow rate; F is the flow area of the blade cascades; v, p, and h are the specific volume, pressure, and enthalpy of the steam, respectively; φ and ψ are the efficiency coefficients of the nozzle and rotor cascades; and C, W, and u are the absolute, relative, and circumferential steam velocities. The subscript 1 denotes steam parameters after the nozzle cascade, 2 – after the rotor cascade, and 0 – before the nozzle cascade.

These equations make it possible to account for changes in velocity, pressure, enthalpy, and other steam characteristics as the steam flows through each turbine stage. Calculations were performed stage by stage, providing a comprehensive picture of the distribution of thermodynamic and kinematic steam parameters throughout the flow path of the low-pressure cylinder of the K-200-130 turbine.

The boundary value problem of transient heat conduction is described by an equation of the form

$$div\left[\lambda(T) \cdot grad(T)\right] = c(T) \cdot \gamma(T) \cdot \frac{\partial T}{\partial \tau}, \quad (3)$$

where λ, c, γ – functions of temperature and coordinates subject to the initial condition $T_0=T(x, y, z, 0)=f_0(x, y, z)$ and boundary conditions of the first, second, third, and fourth kinds.

To solve this problem, heat transfer boundary conditions of the second and third kinds – determined using similarity theory – are specified for all rotor surfaces. For example, the experimental similarity equation describing heat transfer conditions on the inter-blade surfaces of rotor disks takes the form

$$\mathrm{Nu} = 0{,}0145\,\mathrm{Re}^{0,8}\,\mathrm{Pr}^{0,43}\,\beta^{1,54} K_{Tu} K_{\mathrm{rot}} \left(\frac{h}{b}\right)^{-0,7} \left(\frac{t}{b}\right)^{-0,2}, \quad (4)$$

where Nu, Re, Pr – Nusselt, Reynolds, and Prandtl similarity numbers, respectively; β – effective blade angle coefficient; K_{Tu}, K_{rot} – turbulence and rotation coefficients, respectively; h – blade profile camber; b – blade chord; t – relative blade pitch.

For other types of surfaces (disk end faces, fillets, diaphragm and tip seals, smooth surfaces, etc.), various equations are used to describe the specific heat transfer conditions characteristic of the given area.

In the computational analysis of the low-pressure rotor's thermal state, all thermophysical and physical-mechanical properties of the steel used for the shaft (25Kh1M1FA) and the mounted disks (34KhN3M) were determined as a function of temperature in accordance with SOU-N MEV guideline 40.1-21677681-52:2011 [11].

Results of modeling the thermal state of the low-pressure rotor of the K-200-130 steam turbine

The low-pressure rotor of the K-200-130 steam turbine at a thermal power plant unit operates under specific thermodynamic conditions that differ significantly from those of high- and intermediate-pressure rotors. From a thermodynamic perspective, the low-pressure cylinder facilitates the expansion of a dual-flow, symmetrical steam volume – entering the cylinder's flow path at parameters of p_0=0.12 MPa and t_0=200 °C – down to a deep vacuum in the condenser (p_c=0.003–0.005 MPa) at a saturation temperature of approximately t_s=27–40 °C. Such moderate operating temperatures virtually preclude the development of the classic high-temperature metal creep mechanisms that dominate in high- and intermediate-pressure rotors. However, the low pressure and high steam moisture content in the final stages of the low-pressure cylinder necessitate the use of long, massive rotor blades, a factor that plays a crucial role in determining the stress state of the low-pressure rotor.

Operational specifics during start-up introduce additional non-stationarity into the temperature fields. During start-up, the relatively thin disk web heats up significantly faster than the massive central hub and the rotor shaft.

An analysis of the thermal state of the K-200-130 turbine's low-pressure rotor was conducted for the most typical operating modes: nominal operation at an electrical output of 200 MW and a cold start-up. Analysis of the temperature field of the low-pressure rotor during steady-state operation of the K-200-130 turbine (Fig. 3) indicates complete thermal stabilization of the metal. Due to the symmetrical double-flow design of the K-200-130 turbine's low-pressure cylinder, the temperature profile is strictly symmetrical relative to the central transverse cross-section of the steam inlet. The maximum metal temperature occurs in the central steam inlet zone,

reaching values of 160–170 °C. As the steam expands within the left and right flow paths of the turbine's flow section, the temperature of the working fluid and the rotor surface gradually decreases. In the region of the final stages (stages 26 and 27), the metal temperature drops to 40–65 °C, this value is determined by the vacuum level in the turbine condenser. Under steady-state conditions, the radial temperature gradient across the thickness of the shaft wall is practically zero. There is only a moderate axial temperature gradient extending from the hot steam inlet zone toward the cooler shaft bearing journals, where the metal temperature stabilizes at 50–60 °C, consistent with the operating conditions of the journal bearings.



Fig. 3. Temperature distribution of the low-pressure rotor of the K-200-130 turbine at nominal operating mode (200 MW of electrical power)

The start-up of the K-200-130 turbine from a cold state is characterized by significant unsteadiness in thermal and mechanical processes. The initial metal temperature prior to start-up is assumed to be equal to the ambient temperature (approximately 25 °C), resulting in high-amplitude temperature fluctuations and thermal stresses throughout the start-up period.

To investigate unsteady operating modes, several virtual sensors have been installed on the rotor; their locations are shown in the Fig. 4.

The graph showing metal temperature changes at the sensor locations during a cold start-up (Fig. 5) allows for the identification of several distinct time intervals within the thermal process. During the initial start-up phase (0–4400 s of calculated time), virtually no working steam enters the flow path; instead, sealing steam is supplied to the rotor end seals. The temperature on the outer surface in the steam inlet zone (point 1 in Fig. 4) rises slowly from 25 °C to 30–35°C. Due to the rotor's significant thermal inertia, the internal metal surfaces (points 3 and 4 in Fig. 4) do not have time to heat up, and their temperature remains at 25–27 °C. This results in the emergence of an initial radial temperature gradient.

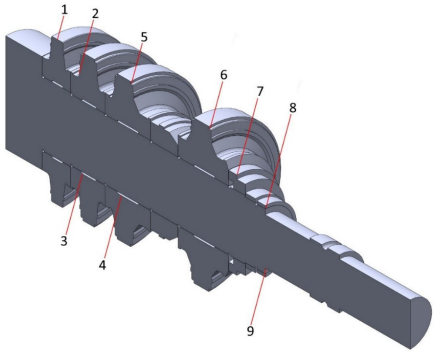


Fig. 4. Locations of virtual sensors for studying rotor temperature dynamics

Points 8 and 9 are located on the peripheral section of the rotor, where the shaft thickness tapers down to the dimensions of the bearing journals. At the start of the start-up process (up to 4,400 seconds), when hot steam is supplied to the labyrinth end seals, the outer surface of the shaft experiences a localized thermal shock. However, due to continuous heat removal via the support bearings and oil circulation, the temperature in the vicinity of points 8 and 9 changes very slowly and stabilizes at a low level – approximately 50–55 °C.

During the interval from 4,400 to 6,200 seconds, the rotors are impulsed by the working steam, and the rotational speed rises rapidly to the rated 3,000 rpm. Steam parameters in the steam admission zone increase sharply, causing a rapid rise in temperature on the outer surface (point 1 in Fig. 4) to 130–150 °C. Since points 3 and 4 are located on the inner surface of the discs, only a slight temperature increase (30–40 °C) is observed there; the radial temperature gradient reaches its peak value at precisely this moment (Fig. 6).

During the subsequent turbine loading phase (calculated time 5400–10000 s), the thermal wave penetrates deep into the rotor body. The temperature of the internal bore (points 3 and 4 in Fig. 4) rises rapidly, reaching 45–50 °C, while the outer surface approaches the 80–90 °C mark. The radial temperature gradient begins to decrease gradually (Fig. 6).

During the final stage of the start-up (calculated time 10000–18800 s), the temperature field asymptotically approaches a steady state. The temperature readings from all sensors stabilize, and radial temperature differentials are virtually eliminated.

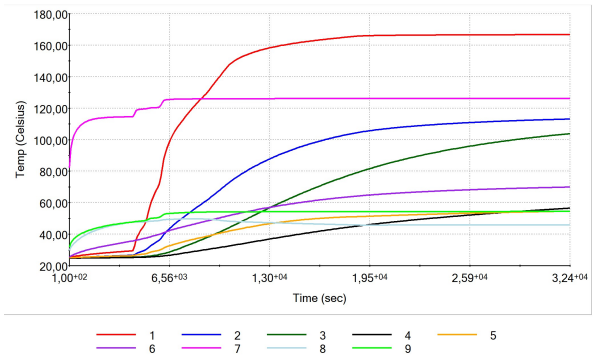


Fig. 5. Dynamics of temperature changes in characteristic regions of the low-pressure rotor of the K-200-130 turbine during start-up from a cold state of the metal

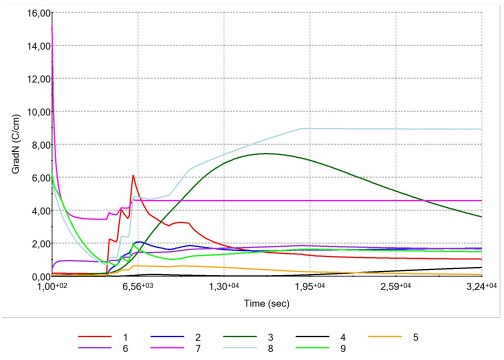


Fig. 6. Dynamics of temperature gradient changes in characteristic regions of the K-200-130 turbine low-pressure rotor during start-up from a cold state

Examples of temperature field distributions for the K-200-130 turbine low-pressure rotor during cold start-up modes are shown in Figs. 7–9. Similar data are available for other time points during the start-up process.

The graph showing temperature changes along the shaft's axis of symmetry (Fig. 10) clearly demonstrates the phenomenon of significant thermal lag. During the first 3500–4000 s of start-up, the metal temperature at the axis remains at the initial level of 25 °C, even though the temperature of the steam and the outer metal layers already exceeds 80–100 °C. This is due to the large radial dimension of the low-pressure rotor and the limited thermal conductivity of 25Kh1MFA steel.

A noticeable rise in temperature at the axis begins only after 4400 s. The highest rate of inner core heating is observed in the time interval of 5,400–10,000 s. The temperature in the central cross-section (beneath the steam inlet) rises most rapidly, whereas the temperature rise at the shaft ends along the axis of symmetry is significantly slower. This leads to the formation of a stable axial temperature gradient.

Full temperature stabilization along the axis of symmetry continues until the 32,400 s mark, at which point the temperature reaches its limiting values – approximately 170°C at the center and 40°C at the shaft ends.

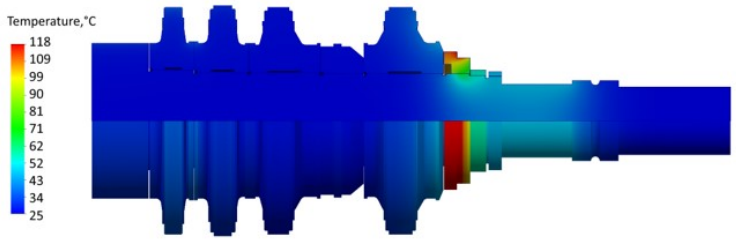


Fig. 7. Temperature distribution of the low-pressure rotor of the K-200-130 turbine during start-up from a cold state at time 4400 s (the moment of the rotors' push)

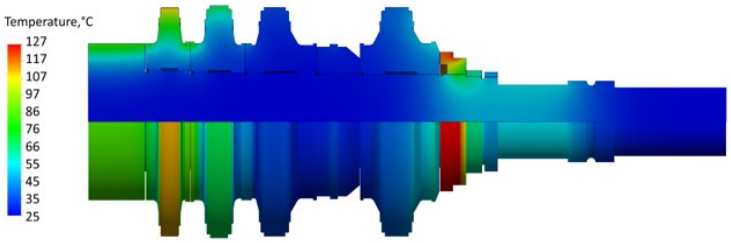


Fig. 8. Temperature distribution of the low-pressure rotor of the K-200-130 turbine during start-up from a cold state at time 7400 s (synchronization)

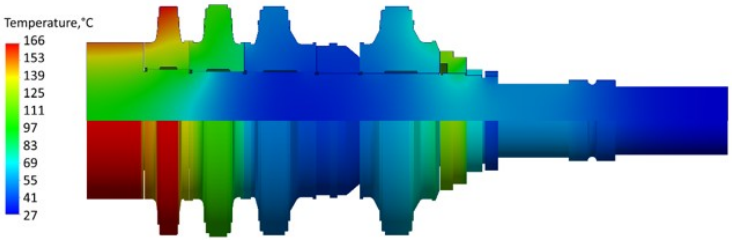


Fig. 9. Temperature distribution of the low-pressure rotor of the K-200-130 turbine during start-up from a cold state at time 18800 s (load output 150 MW)

Subsequent stages of the study involve determining the thermal stress distribution in the rotor, calculating accumulated damage based on low-cycle fatigue and long-term strength exhaustion mechanisms, and assessing the service life indicators of the K-200-130 turbine low-pressure rotor.

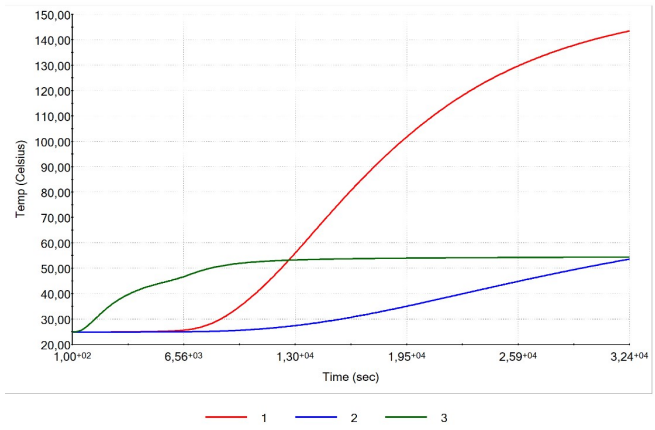


Fig. 10. Temperature variation plot along the axis of symmetry of the K-200-130 low-pressure rotor shaft:
1 – region under the steam inlet;
2 – region under the penultimate stage;
3 – bearing seat region

Conclusions

1. A 3D finite-element spatial model of the K-200-130 turbine low-pressure rotor (comprising approximately 6.2 million elements) has been developed; it accounts in detail for the design's key geometric features as well as the actual results of refurbishment – specifically, the reduction of the shaft journal diameter at bearing No. 5 from 435 mm to 420 mm.

2. Analysis of the steady-state operating mode revealed complete thermal stabilization of the rotor metal. The maximum temperature is localized in the central steam-inlet zone at 160–170 °C, gradually decreasing to 40–65 °C in the area of the final stages. In this mode, the radial temperature gradient is virtually absent, whereas a moderate axial gradient is present.

3. The non-steady-state behavior during start-up from a cold state was evaluated. It was determined that the start-up process is accompanied by significant thermal non-stationarity. Extreme values of the radial temperature gradient occur during the initial rotor acceleration phase (4400–6200 s), when the outer surface rapidly heats up to 130–150 °C while the inner layers remain at 30–40 °C.

4. A significant thermal lag effect has been observed: due to the large radial dimensions of the rotor and the limited thermal conductivity of 25Kh1M1FA steel, the heating of the shaft's axis of symmetry occurs with a substantial delay.

References

1. (2021). *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 40.17.401:2021. Kyiv: HRIFRE, Ministry of Fuel and Energy of Ukraine, 214 p. (in Ukrainian).
2. Li, H., Xiao, S., Sun, M., Zheng, Y., Xu, Y., Mi, K., & Zhang, F. (2025). Life damage evaluation of 600 MW supercritical condensing steam turbine rotor under start-up schedule. *Journal of Physics: Conference Series*, vol. 3086, article 012004. https://doi.org/10.1088/1742-6596/3086/1/012004.
3. Mazur, Z., Herna´ndez-Rossette, A., & Garci´a-Illesoas, R. (2006). L-0 blades failure investigation of a 110 MW geothermal turbine. Proceedings of the ASME 2006 Power Conference (Atlanta, Georgia, USA, May 2–4, 2006), paper no. POWER2006-88024, pp. 281–289. https://doi.org/10.1115/POWER2006-88024.
4. Suzuki, T., Matsuura, T., Sakuma, A., Kodama, H., Takagi, K., & Curtis, A. (2005). Recent upgrading and life extension technologies for existing steam turbines. Proceedings of the ASME 2005 Power Conference (Chicago, Illinois, USA, April 5–7, 2005), paper no. PWR2005-50342, pp. 577–582. https://doi.org/10.1115/PWR2005-50342.
5. Balitskii, A. I., Syrotyuk, A. M., Havrilyuk, M. R., Balitska, V. O., Kolesnikov, V. O., & Ivaskevych, L. M. (2023). Hydrogen cooling of turbo aggregates and the problem of rotor shafts materials degradation evaluation. *Energies*, vol. 16, iss. 23, article 7851. https://doi.org/10.3390/en16237851.
6. Gharehbaghi, H. & Aghaei, M. (2025). Investigation of creep-fatigue interaction in steam turbine rotor. *Forces in Mechanics*, vol. 19, article 100314. https://doi.org/10.1016/j.finmec.2025.100314.
7. Chernousenko, O., Rindyuk, D., & Peshko V. (2017). Research on residual service life of automatic locking valve of turbine K-200-130. *Eastern-European Journal of Enterprise Technologies*, vol. 5, no. 8 (89), pp. 39–44. https://doi.org/10.15587/1729-4061.2017.112284.

8. Chernousenko, O., Peshko, V., & Rindyuk, D. (2023). The system for planning cost-efficient and resource-saving operating modes of TPP. In: Altenbach, H., et al. Advances in Mechanical and Power Engineering. CAMPE 2021. *Lecture Notes in Mechanical Engineering*. Springer, Cham, pp. 88–97. https://doi.org/10.1007/978-3-031-18487-1_9.
9. Chernousenko, O., Rindyuk, D., & Peshko, V. (2025). Technical assessment of district heating pipelines under variable thermal loads with consideration of installation deformations. *Theory and Building Practice*, vol. 7, no. 2, pp. 1–10. https://doi.org/10.23939/jtbp2025.02.001.
10. Chernousenko, O. Yu., Peshko, V. A., & Ryndiuk, D. V. (2024). Determination of the thermal and stress-strain state of the medium-pressure rotor of the T-100/120-130 turbine after damage to the blades. *Journal of Mechanical Engineering – Problemy Mashynobuduvannia*, vol. 27, no. 2, pp. 6–17. https://doi.org/10.15407/pmach2024.02.006.
11. Shulzhenko, M. H., Hontarovskyi, 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, 42 p. (in Ukrainian).

Received 22 August 2026 *Accepted 02 September 2026* *Published 30 September 2026*

Моделювання теплового стану ротора низького тиску турбіни К-200-130 під час пуску

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

Національний технічний університет України
«Київський політехнічний інститут імені Ігоря Сікорського»
03056, Україна, м. Київ, вул. Політехнічна, 6

У сучасних умовах функціонування Об'єднаної енергосистеми України критичного значення набувають надійність і безпека експлуатації устаткування теплових електростанцій. З огляду на це для оцінки індивідуального ресурсу відповідальних елементів турбоагрегатів після механічних пошкоджень і ремонтних відновлень і забезпечення їх тривалої роботи необхідно комплексно вивчити їхній термомеханічний стан. Мета написання статті полягає у проведенні розрахункового дослідження просторового теплового стану ротора низького тиску парової турбіни К-200-130 для науково-технічного обґрунтування можливості продовження терміну його надійної експлуатації. Методи дослідження ґрунтуються на фундаментальних положеннях нестаціонарної теплопровідності й механіки суцільних середовищ із використанням методу скінченних елементів у середовищі SolidWorks. Побудовано просторову 3D-модель симетричної половини РНТ (близько 6,2 млн елементів) з адаптивним згущенням сітки у зонах концентрації напружень. У моделі враховано фактичні геометричні зміни після ремонту – зменшення діаметра шийки валу в зоні підшипника № 5 з 435 мм до 420 мм. Граничні умови теплообміну II та III роду визначено за допомогою критеріальних рівнянь теорії подібності з урахуванням термо- й гідродинамічних характеристик потоку пари у проточній частині. Визначено тривимірні температурні поля ротора для номінального режиму потужністю 200 МВт і нестаціонарного пуску з холодного стану. Встановлено, що при стаціонарній роботі метал перебуває в термічно стабілізованому стані з температурами від 160–170 °С у зоні паровпуску до 40–65 °С в області останніх ступенів. Під час холодного пуску виявлено значну нестаціонарність: у період поштовху ротора й набрання обертів спостерігається екстремальний радіальний температурний градієнт, коли зовнішня поверхня нагрівається до 130–150 °С, тоді як внутрішні шари прогріваються лише до 30–40 °С. Зафіксовано суттєве теплове запізнення прогріву осі симетрії валу через масивні геометричні розміри ротора й теплофізичні властивості сталі 25Х1М1ФА. Отримані поля температур і градієнтів слугуватимуть базою для чисельного розрахунку напружено-деформованого стану ротора, оцінки накопиченої пошкоджуваності від малоциклової втоми, а також прогнозування залишкового індивідуального ресурсу енергоблоку.

***Ключові слова**: теплова електростанція, парова турбіна К-200-130, ротор низького тиску, температура, ресурс, нестаціонарна теплопровідність, тепловий стан.*

Література

1. СОУ-Н МПЕ 40.17.401:2021. Контроль металу і продовження терміну експлуатації основних елементів котлів, турбін і трубопроводів теплових електростанцій. Типова інструкція. Офіц. вид. Київ: ГРІФРЕ: Міністерство палива та енергетики України, 2021. 214 с.
2. Li H., Xiao S., Sun M., Zheng Y., Xu Y., Mi K., Zhang F. Life damage evaluation of 600MW supercritical condensing steam turbine rotor under start-up schedule. *Journal of Physics: Conference Series*. 2025. Vol. 3086. Article 012004. https://doi.org/10.1088/1742-6596/3086/1/012004.
3. Mazur Z., Herna´ndez-Rossette A., Garci´a-Illesoas R. L-0 blades failure investigation of a 110 MW geothermal turbine. Proceedings of the ASME 2006 Power Conference (Atlanta, Georgia, USA, May 2–4, 2006). Paper no. POWER2006-88024. P. 281–289. https://doi.org/10.1115/POWER2006-88024.
4. Suzuki T., Matsuura T., Sakuma A., Kodama H., Takagi K., Curtis A. Recent upgrading and life extension technologies for existing steam turbines. Proceedings of the ASME 2005 Power Conference (Chicago, Illinois, USA, April 5–7, 2005). 2005. Paper no. PWR2005-50342. P. 577–582. https://doi.org/10.1115/PWR2005-50342.
5. Balitskii A. I., Syrotyuk A. M., Havrilyuk M. R., Balitska V. O., Kolesnikov V. O., Ivaskevych L. M. Hydrogen cooling of turbo aggregates and the problem of rotor shafts materials degradation evaluation. *Energies*. 2023. Vol. 16. Iss. 23. Article 7851. https://doi.org/10.3390/en16237851.
6. Gharehbaghi H., Aghaei M. Investigation of creep-fatigue interaction in steam turbine rotor. *Forces in Mechanics*. 2025. Vol. 19. Article 100314. https://doi.org/10.1016/j.finmec.2025.100314.
7. Chernousenko O., Rindyuk D., Peshko V. Research on residual service life of automatic locking valve of turbine K-200-130. *Eastern-European Journal of Enterprise Technologies*. 2017. Vol. 5. No. 8 (89). P. 39–44. https://doi.org/10.15587/1729-4061.2017.112284.
8. Chernousenko O., Peshko V., Rindyuk D. The system for planning cost-efficient and resource-saving operating modes of TPP. In: Altenbach H., et al. Advances in Mechanical and Power Engineering. CAMPE 2021. *Lecture Notes in Mechanical Engineering*. Springer, Cham, 2023. P. 88–97. https://doi.org/10.1007/978-3-031-18487-1_9.
9. Chernousenko O., Rindyuk D., Peshko V. Technical assessment of district heating pipelines under variable thermal loads with consideration of installation deformations. *Theory and Building Practice*. 2025. Vol. 7. No. 2. P. 1–10. https://doi.org/10.23939/jtbp2025.02.001.
10. Chernousenko O. Yu., Peshko V. A., Ryndiuk D. V. Determination of the thermal and stress-strain state of the medium-pressure rotor of the T-100/120-130 turbine after damage to the blades. *Journal of Mechanical Engineering – Problemy Mashynobuduvannia*. 2024. Vol. 27. No. 2. P. 6–17. https://doi.org/10.15407/pmach2024.02.006.
11. Визначення розрахункового ресурсу та оцінка живучості роторів і корпусних деталей турбін. Методичні вказівки: СОУ- Н МЕВ 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.