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Analysis of the Stress-Strain State of the Surfaced Tooth in the T-FLEX CAD Application Program

Buzauova T.M.[1*], Sarbaev D.A.[1], Smailova B.K.[1], Toleubayeva Sh.B.[2]
[1]Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan
[2]L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
*corresponding author

Abstract. This work is devoted to the analysis of the stress-strain state of the surfaced gear teeth using the T-Flex CAD software. The study showed that the surfaced teeth are able to withstand workloads, as well as loads increased by 50%, demonstrating a deformation of only 2%. Zones of maximum stresses and deformations have been identified, which makes it possible to predict the durability and reliability of the surfaced teeth. The conducted studies confirm the effectiveness of the electroslag surfacing method for restoring gears and its application to improve the performance of gears under high loads.

Keywords: stress-strain state, analysis, T-Flex CAD, gear tooth, surfaced tooth, material, finite element method.

Introduction

The restoration of gear teeth is an important task in mechanical engineering, especially in conditions of intensive operation and high loads. One of the effective methods of tooth restoration is electroslag surfacing, which allows to restore the geometry and properties of the teeth, ensuring their long-term operation [1, 2]. As part of this study, a laboratory installation for electroslag surfacing of gear teeth was developed. This installation was designed taking into account all necessary technical requirements and tested in a laboratory [3, 4].

The quality of the tooth sample was assessed using visual, capillary, ultrasound, micro- and macrostructural analyses. The results of the analyses showed that the surfaced tooth has high performance characteristics and can be effectively used in real conditions [5, 6].

To analyze the stress-strain state of a gear with a surfaced tooth, the T-Flex application program was used, which allows mathematical modeling of common physical phenomena and solving important practical problems that arise in everyday design practice. All calculations are performed using the finite element method (FEM). At the same time, an associative relationship is maintained between the three-dimensional model of the product and the calculated finite element model. Parametric changes of the initial solid-state model are automatically transferred to the grid finite element model [7].

In this paper, the finite element method using T-Flex software is used to analyze the stress-strain state of a surfaced tooth. A comprehensive analysis of the surfaced teeth allows to identify possible defects and helps prevent premature failures and wear of the gear.

The purpose of this study is to analyze the stress-strain state of the surfaced teeth in order to assess their performance characteristics.

The object of the study is a model of a surfaced gear tooth.

The relevance of the study is due to the need for effective methods of restoring gears that are subjected to high loads and intensive operation. Electroslag surfacing significantly extends the service life of gear teeth, which is important for the engineering industry and other industries where the reliability and durability of gears play a key role.

The novelty of the research lies in the use of T-Flex software for detailed analysis of the stress-strain state of the surfaced teeth, as well as modeling with an increased load by 50%.

Research method: literary review, modeling, analysis.

Research methodology: simulation modeling of the stress-strain state, creation of a three-dimensional model of surfaced teeth in T-Flex software, static analysis by the finite element method (FEM) to determine the distribution of stresses and deformations; analysis of simulation results under workloads and under loads increased by 50%; comparison of the results of the analysis of surfaced teeth with the results for non-surfaced teeth; determination of maximum stress and strain zones and assessment of the performance characteristics of surfaced teeth.

1. Research methodology

To simulate a surfaced tooth, the following parameters were used as initial data: module $m = 20$, number of teeth $z = 29$, pitch diameter $d = 580$ mm, material of the surfaced tooth - steel 70 (GOST 14959-79).

Characteristics of the objects of study, such as strength, modulus of elasticity, shear modulus, density, tensile strength, compressive strength are shown in Table 1.

Table 1. Initial data for modeling

Physical and mechanical properties	Steel 70 (GOST 14959-79)
Modulus of elasticity	206000 N/mm²
Poisson's ratio	0,29
The shear modulus	79844.96 N/mm²
Density	7810 kg/m³
Yield strength	834 N/mm²
Tensile strength	1030 N/mm²
Compressive strength	1030 N/mm²

The static analysis in the program is carried out by calculating the stress-strain state of structures under the action of forces applied to the system constant in time. To determine the forces acting in cylindrical gears, using the "Analysis" tab, three main forces were used (Fig.1): circumferential, radial and normal.

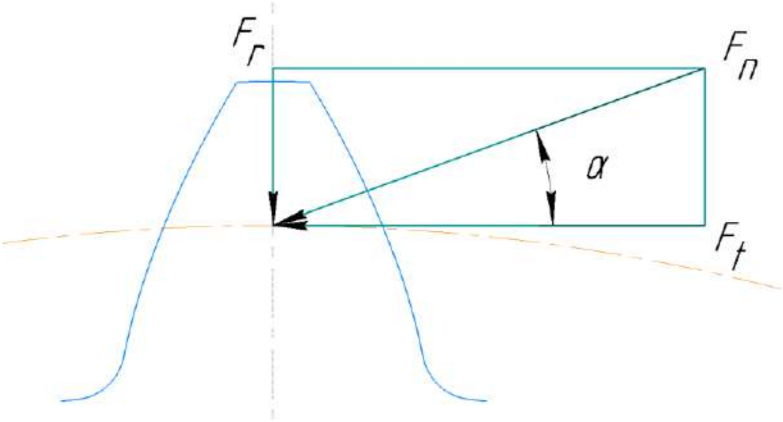


Fig. 1. – Diagram of the force in the engagement of cylindrical gears

The circumferential force F_t is directed tangentially to the dividing circle of the gear tooth and is responsible for the transfer of power between the teeth, which is determined from the following equation [8]:

$$F_t = \frac{2T_{\max}}{d}, \tag{1}$$

where d – pitch diameter;

$T_{\max}$ – the greatest moment of a normally flowing technological process ($T_{\max} = 39226$ N/m).

$$F_t = \frac{2 \cdot 39226 \cdot 10^3}{580} = 135262 N.$$

The radial force F_r acting perpendicular to the circumferential force is directed from the center of the gear to the point of contact of the teeth and affects the bearings, creating a radial load [8]:

$$F_r = F_t \frac{tg\alpha}{\cos\beta}, \tag{2}$$

where α – angular correction;

β - helix angle.

There is no angular correction for the gear tooth under study, tgα = tg20° = 0.36. In straight tooth gears cosβ = 1.

$$F_r = 135262 \frac{0,36}{1} = 49235 N.$$

The normal force F_n is determined by the formula [8]:

$$F_n = \frac{F_t}{\cos\alpha\cos\beta}. \qquad (3)$$

In straight tooth gears tgβ = 0.

$$F_n = \frac{135262}{\cos 20° \cdot 1} = 143942 N.$$

When the normal force is distributed to all teeth of the gear, the normal force is set according to the formula [8]:

$$F_n^{'} = \frac{F_n}{z}, \qquad (4)$$

where z – number of teeth.

$$F_n^{'} = \frac{143942}{29} = 4963 N.$$

It is also possible to take into account the expansion/compression stresses of the material or deformation of the structure by the amount of known displacements. Displacements are the value of the absolute displacements of the model at the measurement points (sensors) determined at each point 1, 2, 3, etc. (Fig. 2). The points are fixed along the involute of the tooth surface [9, 10, 11, 12, 13], and the surfaced tooth (A) is highlighted taking into account the depth of penetration [14].

The displacement is determined by the formula:

$$\Delta = \sqrt{x_i^2 + y_i^2 + z_i^2}, \qquad (5)$$

where x, y, z - the components of the displacement vector of a certain i node of the finite element grid.

The equivalent stress in the surfaced tooth is analyzed to determine the distribution of internal forces arising in the material under the influence of external loads. This analysis allows us to identify stress concentrations that can become potential zones of the onset of cracks or other defects. The equivalent stress is calculated using the formula [8]:

$$\sigma_\upsilon = \frac{1}{\sqrt{2}}\sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{xz}^2)}, \qquad (6)$$

where $\sigma_{x,y,z}$ - stress in the direction of the corresponding axis OX, OY, OZ of the global coordinate system;

τ_{xy}, τ_{xz}, τ_{yz} - the stress in the direction of the OX, OY, OZ axis of the global coordinate system acting on a site with a normal parallel to the OX, OY, OZ axis.

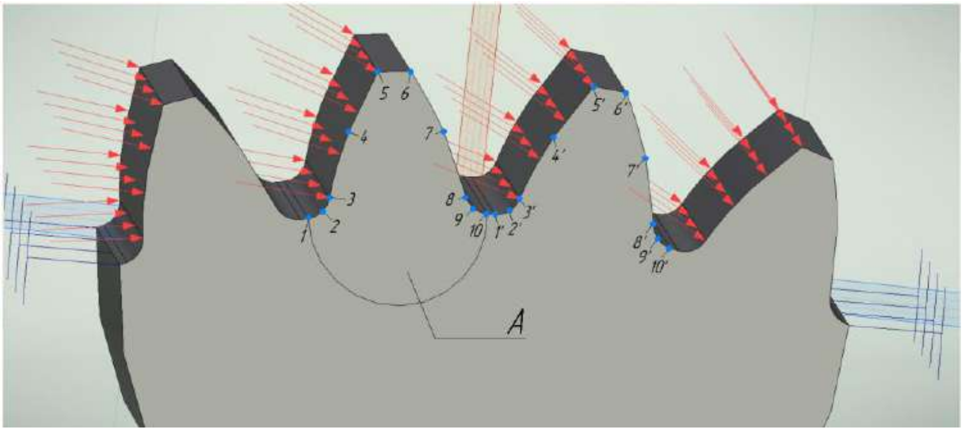


Fig. 2. – Fixing points along the tooth involute: A-surfaced tooth (the arrows indicate the applied forces).

The design sequence (Fig.3) includes the creation of a model of a gear with a surfaced tooth (A), a grid for the finite element method, fastening, applied forces and measurement points of the calculation result of finite element analysis. The grid type is absolute, the grid size is 10, the minimum curve size is 5, the number of finite elements is 142805 (Fig.4).

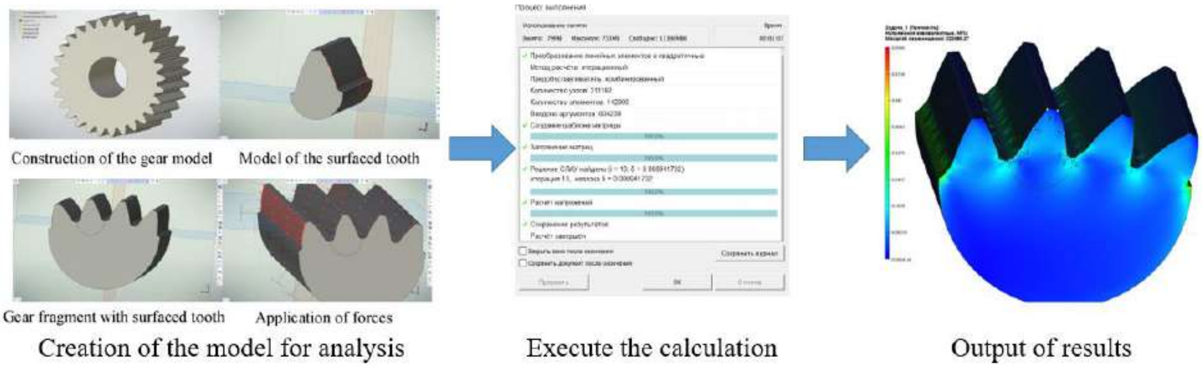
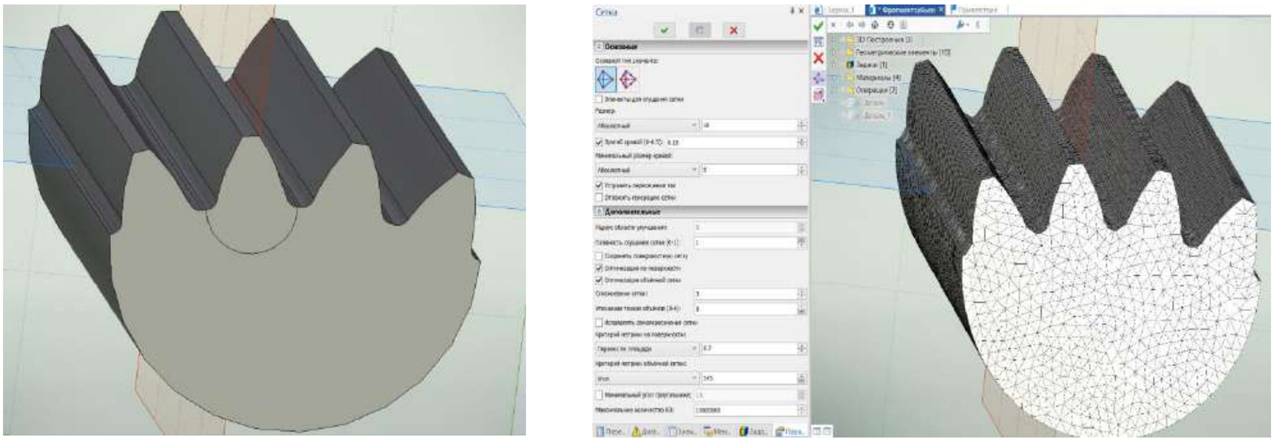


Fig. 3. – Modeling steps in the T-Flex program

As part of the study, the surfaced tooth will be tested for tensile strength by increasing the applied force by 50%. This will allow assessment of how the tooth material endures with increased loads and identify possible limits of its stability. A 50% increase in strength will give a more complete picture of the behavior of the surfaced tooth in extreme operating conditions, predicting its durability and reliability.



a) b)

a – gear fragment with surfaced tooth; b – finite element grid

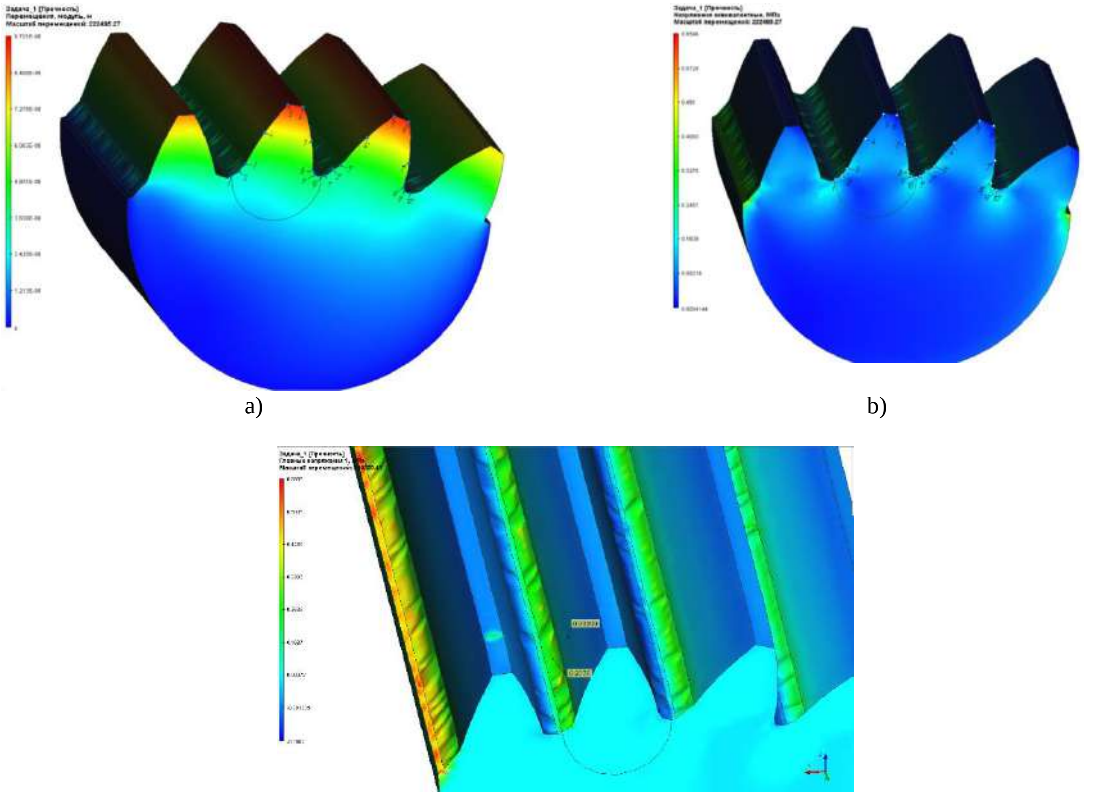
Fig. 4. – Preprocessing preparation of the problem solution

The results of this test will help determine how effectively the surfaced material is able to withstand additional loads, and identify potential points of failure or vulnerabilities in the gear design.

After completion of the preprocessing preparation, the calculation is started, which allows to visually assess the stress-strain state of both the surfaced and other gear teeth.

2. Results and discussion

The results of static analysis under workloads of the stress-strain state of the fragment are shown in Figure 5.

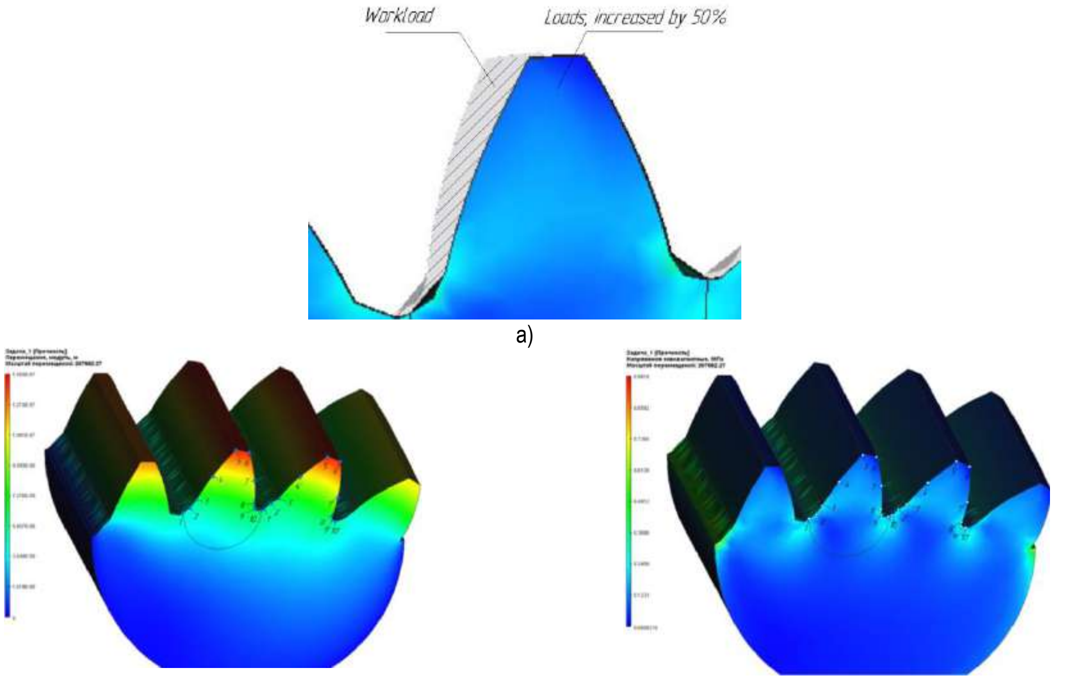


a) b)

c)

Fig. 5. – Simulation results of the stress-strain state: displacement (a), stress (b), stress concentration zones (c)

The results of modeling the stress-strain state with a load increased by 50% are shown in Figure 6.

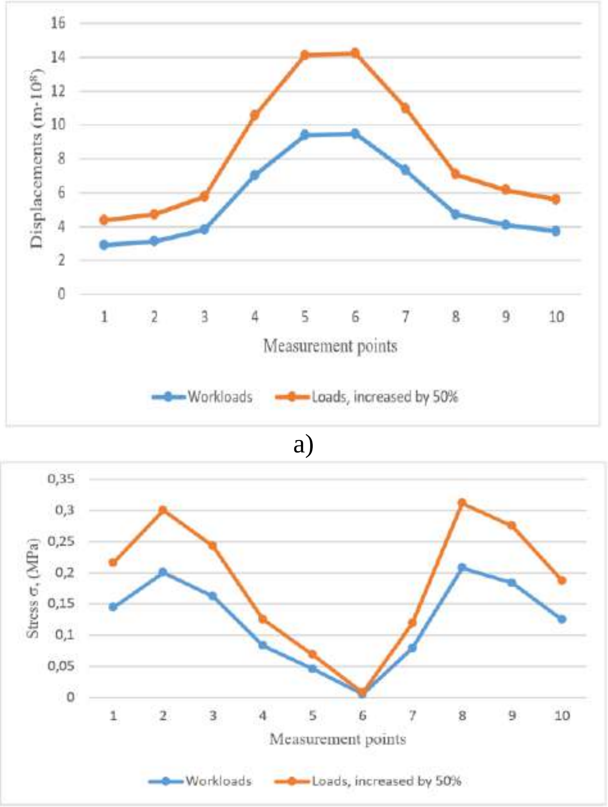


a)

b) c)

Fig. 6. - Simulation results of the stress-strain state with increased loads by 50%: in comparison (a); displacement (b), stress (c)

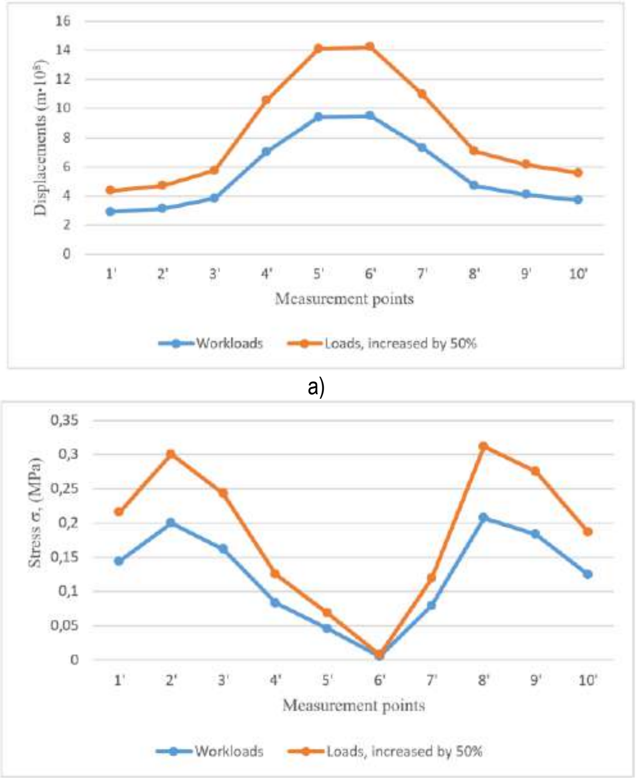
Displacements and stress values are recorded at the measurement points (Fig.7, 8).



a)

b)

Fig. 7. – Graphs of displacements (a) and stresses (b) of the surfaced tooth



a)

b)

Fig. 8. – Graphs of displacements (a) and stresses (b) of the gear tooth

According to the results of the analysis, it can be clearly seen that the surfaced tooth withstands working deformations and stresses (Fig. 5, 6, 7, 8). Stress is concentrated on the roots of the tooth (Fig. 5, c). With an increased load of 50%, the surfaced tooth is deformed by 2% (Fig. 6, a) compared to the rest of the gear teeth, while the maximum stress is fixed at the measurement points – 0.3116 MPa (Fig. 7, 8).

Conclusions

1) A qualitative and quantitative analysis of the surfaced tooth was carried out.
2) The stress-strain state of the surfaced tooth has been developed. The analysis allows to determine the stress zones and deformation of the surfaced gear tooth.
3) The surfaced tooth withstands workloads (Fig. 5).
4) The degree of deformation of the surfaced tooth with an increase in the workload by 50% is 2% (Fig. 6, a).
5) The high loads at points 2, 8 and 2', 8' (Fig.7, 8) are explained by the fact that tensile and compressive loads are concentrated on these zones.

References

[1] Kuskov, Yu. M. i dr. E`lektroshlakovaya naplavka. - M.: AO "Nauka i texnologii", 2001. - 180 p.
[2] Paton, B.E. E`lektroshlakovaya svarka i naplavka. - M.:, Mashinostroenie: 1980. - 512p.
[3] Smailova B.K., Buzauova T.M., Bartenev I.A., Davletova K. Restoration of large modular teeth of ball mill gears by electro-slag surface// Journal of applied engineering science, Vol. 22, No. 2 (2024), P.483-491.
[4] Buzauova, T., Bartenev, I., Smailova, B. Kristallizator dlya e`lektroshlakovoj naplavki krupnomodul`ny`x zub`ev. Patent RK na poleznuyu model`. №9186. 31.05.2024.
[5] Smailova1 B.K., Buzauova T.M., Bartenev I.A., Škamat J. Analysis of the quality of the restored gear tooth of large-module gears// Science and technology of Kazakhstan, Issue 1, 2024, P.16-24.
[6] Buzauova T.M., Sarbaev D.A. Optimizaciya rezhimov svarki dlya vosstanovleniya krupnomodul`ny`x zubchaty`x koles s ispol`zovaniem e`lektroshlakovoj naplavki// Trudy` Respublikanskoj studencheskoj nauchnoj konferencii. -Karaganda: Izd-vo KarTU, 2024.- P.147-148.
[7] T-Flex CAD. URL: https://www.tflex.ru/downloads/products/tfanalysis_documentation.pdf (date of application: 20.06.2024).
[8] Reshetov D. N., Gusenkov A.P., Drozdov Yu.N. Mashinostroenie. E`nciklopediya / Red. sovet: Frolov V. K. (pred.) i dr. – M.: Mashinostroenie. Detali mashin. Konstrukcionnaya prochnost`. Trenie, iznos, smazka. T. Sh-4; Pod red. Reshetova D. N. 1995. – 864 p.
[9] Sánchez-Majano A. R. et al. Accurate stress analysis of variable angle tow shells by high-order equivalent-single-layer and layer-wise finite element models //Materials, 2021, T. 14, №. 21, P. 6486.
[10] Mohammed J. K., Khdir Y. K., Kasab S. Y. Contact stress analysis of spur gear under the different rotational speed by theoretical and finite element method //Academic Journal of Nawroz University. – 2018. – T. 7. – №. 4. – S. 213-222.
[11] Hwang S. C. et al. Contact stress analysis for a pair of mating gears //Mathematical and Computer Modelling. – 2013. – T. 57. – №. 1-2. – S. 40-49.
[12] David Müzel S. et al. Application of the finite element method in the analysis of composite materials: A review //Polymers. – 2020, T. 12, №. 4. – P. 818.
[13] Muhammad A., Ali M. A. H., Shanono I. H. Finite Element Analysis of a connecting rod in ANSYS: An overview //IOP Conference Series: Materials Science and Engineering. – IOP Publishing, 2020, T. 736, №. 2, P. 022119.
[14] Smailova B.K., Buzauova T.M., Sarbaev D.A. Issledovaniya vliyanie rezhimov e`lektroshlakovoj naplavki na glubinu proplavleniya naplavlenny`x zub`ev// Trudy` Respublikanskoj studencheskoj nauchnoj konferencii. -Karaganda: Izd-vo KarTU.-2023. - P.347-348.

Information of the authors

Buzauova Toty Meirbekovna, c.t.s., associate professor , Abylkas Saginov Karaganda Technical University
e-mail**:** toty_77@mail.ru

SarbaevDalelehan Ardakovich, master's student, Abylkas Saginov Karaganda Technical University
e-mail: dalelhan20002@gmail.com

Smailova Baglan Kabdullaevna, PhD student, PhD student, Abylkas Saginov Karaganda Technical University
e-mail: bahlan@mail.ru

Toleubayeva Shamshygaiyn Bolatkyzy, PhD, senior lecturer, L.N. Gumilyov Eurasian National University
e-mail: shamshygaiyn@mail.ru