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INTEGRITY ASSESSMENT OF VITAL BEAM COMPONENTS THAT ENABLE CONJOINT OPERATION OF TWO BRIDGE CRANES

OCENA INTEGRITETA NOSEĆIH GREDA KOJE OMOGUĆAVAJU ZAJEDNIČKI RAD DVE MOSTNE DIZALICE

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Keywords
- cranes
- ultrasonic testing
- braces
- threaded spindle
- structural integrity

Abstract

Vital components of the beam that enable conjoint operation of two bridge cranes are braces and threaded spindle. The beam connects two bridge cranes with overall lifting capacity of 500 t (2 × 250 t) and enables their simultaneous conjoint operation during the rehabilitation or major overhaul of hydroelectric generating set equipment at the hydro power plant ''Djerdap 2'. Two braces are being installed instead of two hooks when this situation occurs. The threaded spindle is loaded with 500 t (5 MN), while braces are loaded with 250 t (2.5 MN) each.

Integrity of structures is a relatively new scientific and engineering discipline which in a broader sense comprises condition analysis, behaviour diagnostics, service life evaluation and rehabilitation of structures, which means that beside the usual situation in which it is necessary to evaluate the integrity of a structure when a flaw is detected by means of non-destructive tests, this discipline also comprises stress condition analysis for the crackless structure, most often through the use of finite element method. This is the way to obtain precise and detailed distribution of displacements, deformations and stresses, which enables determination of weak spots on the structure, even before crack initiation.

Non-destructive tests are performed in order to analyse the current condition of braces and the threaded spindle. On the basis of performed analytical calculations it is determined that the integrity is not threatened, although some internal non-homogeneities are detected by ultrasonic testing.

Ključne reči
- dizalice
- ultrazvučno ispitivanje
- podupirači
- vreteno s navojem
- integritet konstrukcija

Izvod

Glavne komponente greda koje omogućavaju zajednički rad dve mostne dizalice su podupirači i vreteno sa navojem. Ova greda povezuje dve dizalice, ukupne nosivosti od 500 t (2 × 250 t) i omogućava njihov istovremeni, zajednički rad pri rehabilitaciji ili generalnoj popravci opreme za generisanje hidroelektrične energije u okviru hidroelektrane 'Đerdap 2'. U ovom slučaju, umesto kuka su korišćena dva podupirača. Vreteno sa navojem je opterećeno sa ukupno 500 t (5 MN), dok su podupirači opterećeni sa po 250 t (2.5 MN).

Integritet konstrukcija je relativno nova naučna i inženjerska disciplina koja u širem smislu obuhvata analizu uslova, dijagnostiku ponašanja, procenu radnog veka i rehabilitaciju konstrukcija, što znači da, pored uobičajenih situacija u kojima je neophodno oceniti integritet konstrukcije kod koje su uočene greške nakon ispitivanja bez razaranja, ova disciplina se takođe bavi analizom naponskog stanja za konstrukcije bez prslina, najčešće primenom metode konačnih elemenata. Na taj način se dobija precizno i detaljno polje pomeranja, napona i deformacija, na osnovu kojih se određuju slaba mesta u konstrukciji, čak i pre nego što se prsline pojave.

Ispitivanja bez razaranja su izvršena kako bi se analiziralo trenutno stanje podupirača i vretena s navojem. Na osnovu izvedenih analitičkih proračuna je utvrđeno da integritet nije ugrožen, uprkos određenim unutrašnjim nehomogenostima koje su otkrivene primenom ultrazvučne metode ispitivanja.

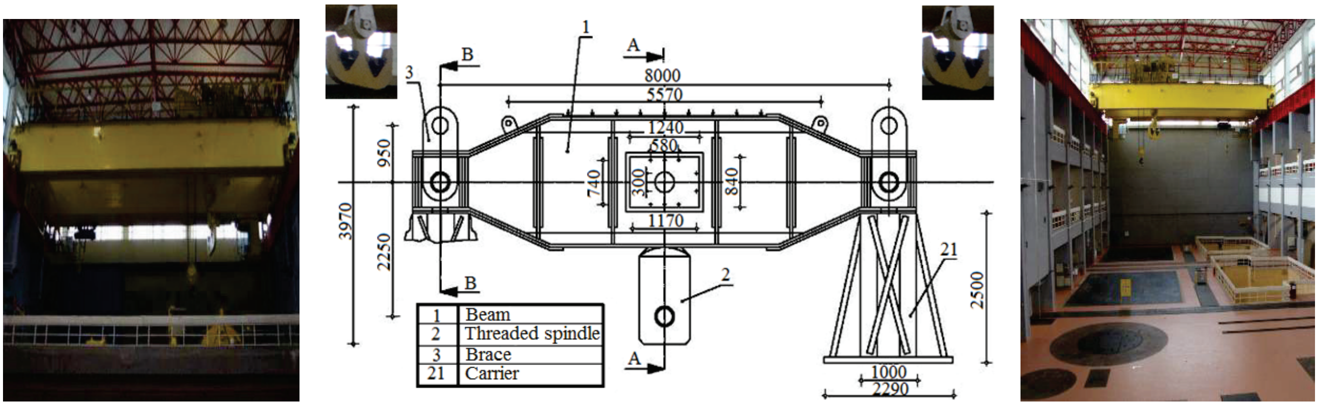
INTRODUCTION

Inspection, conditional analysis and testing of beam components for simultaneous conjoint operation of 2 bridge cranes with overall lifting capacity of 500 t (5 MN) are performed as a preparation for work during rehabilitation or major overhaul of hydroelectric generating set equipment at the hydro power plant 'Djerdap 2', because they are subjected to regulations for load lifting devices.

Therefore, it is necessary:

- to carry out conditional analysis, check the load carrying capacity and integrity of the material of the vital components of the beam for simultaneous conjoint operation of bridge cranes at the hydro power plant ‘Djerdap 2’, on the basis of results of non-destructive tests,
- to make a proposition regarding the repair of vital components if they become unusable in case when the check of load carrying capacity, or integrity evaluation, proves that material degradation of particular beam components for simultaneous conjoint operation of bridge cranes causes the reduction of load carrying capacity, or threatens the structural integrity.

The beam connects two bridge cranes and enables their simultaneous conjoint operation, Fig. 1. It is used during the rehabilitation or major overhaul of the hydroelectric generating set equipment at the hydro power plant ‘Djerdap 2’. The threaded spindle (position 2 in Fig. 1b) is loaded with 500 t, while braces (position 3 in Fig. 1b), which are installed instead of hooks during the simultaneous conjoint operation of cranes, are loaded with 250 t each. A drawing of the device for simultaneous conjoint operation of bridge cranes is presented in Fig. 2.



a) First bridge crane b) Beam for simultaneous conjoint operation of bridge cranes c) Second bridge crane

Figure 1. Appearance of the beam for simultaneous conjoint operation of 2 bridge cranes.

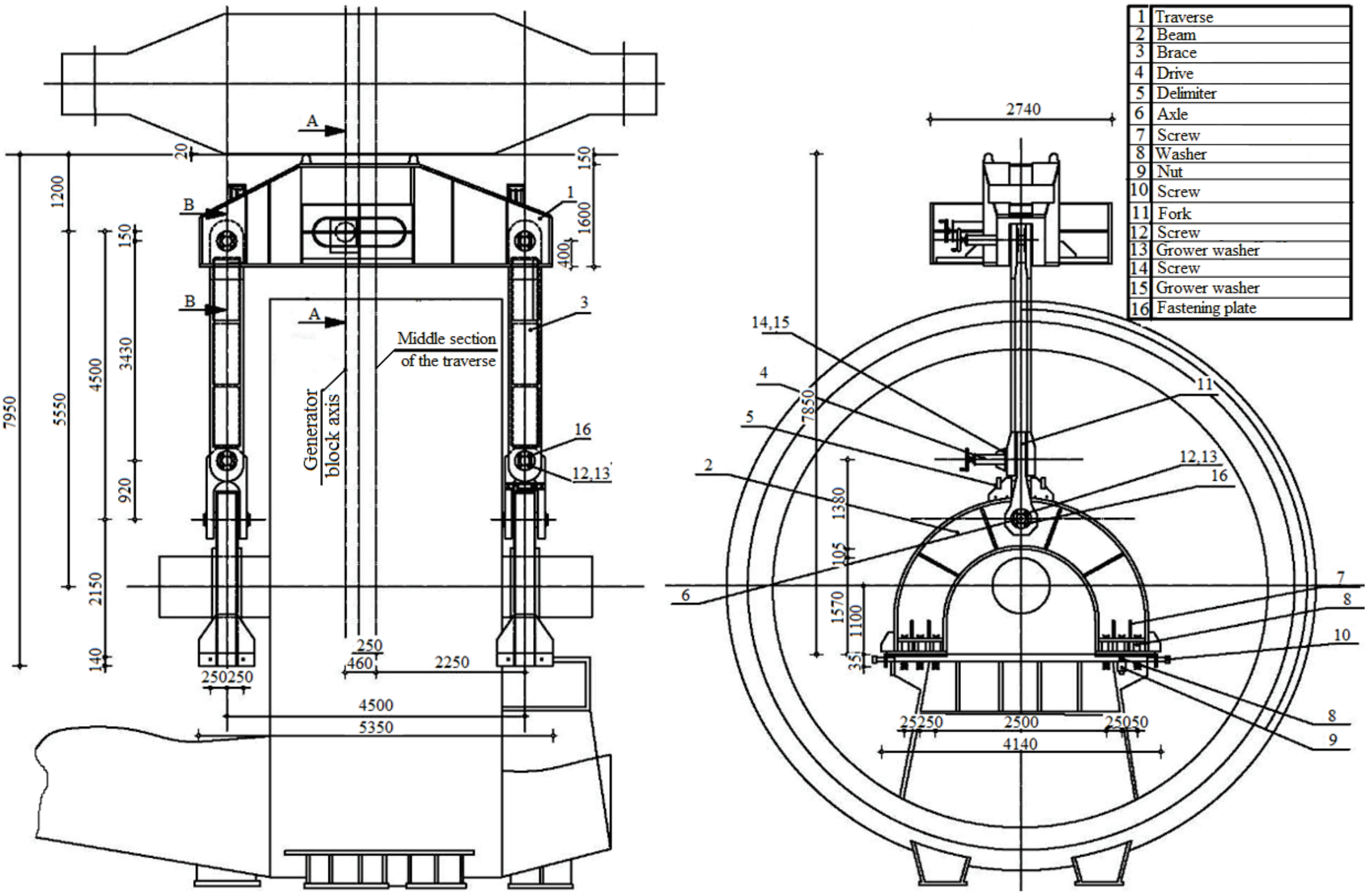


Figure 2. Assembly drawing of the device for simultaneous conjoint operation of 2 bridge cranes.

According to design documentation /1/, braces and threaded spindle are a forged steel of guaranteed chemical composition OLC 35 (Romanian standard designation). The chemical composition is presented in Table 1, while the mechanical properties are given in Tables 2 and 3.

Table 1. Chemical composition, values in [%].

Steel	C	Si	Mn	Cr	Ni	Mo	S	P
OLC 35	0.32-0.39	max 0.4	0.5 - 0.8	max 0.4	max 0.4	max 0.1	max 0.045	max 0.045

Table 2. Mechanical properties of steel OLC 35 for brace forging thickness t = 220 mm.

Steel	Yield strength, YS [N/mm^2]	Tensile strength, TS [N/mm^2]	Elongation, A5 [%]
OLC 35	245	500	min. 15

Table 3. Mechanical properties of steel OLC 35 for threaded spindle forging thickness t = 900 mm.

Steel	Yield strength, YS [N/mm^2]	Tensile strength, TS [N/mm^2]	Elongation, A5 [%]
OLC 35	210	470	min. 15

NON-DESTRUCTIVE TESTING OF BEAM BRACES AND THREADED SPINDLE

In order to perform analysis of the current state, to check the lifting capacity and evaluate the integrity of vital components (braces, threaded spindle) of the beam for simultaneous conjoint operation of bridge cranes, visual testing (VT), magnetic particle testing (MT), and ultrasonic testing (UT) are carried out.

Results of visual testing

Visual testing of all components of beam equipment has confirmed the existence of corrosion products, as well as the existence of insignificant mechanical damages. Mechanical damages are repaired by fine grinding, and afterwards all of the components are submitted to sandblasting and applied anti-corrosive protection.

Magnetic particle testing

No surface defects are detected during magnetic particle testing performed on braces and the threaded spindle.

Ultrasonic testing

In Figs. 3 and 4, results of tests carried out on the right brace of beam (where internal non-homogeneities are detected), as well as on the threaded spindle, are presented. Findings, marked by red and yellow colour, refer to areas where the tests were carried out.

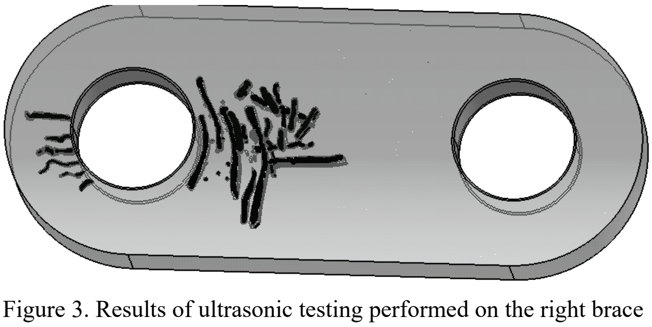


Figure 3. Results of ultrasonic testing performed on the right brace of the beam (upper view).

Figure 4. Indications of ultrasonic testing performed on the threaded spindle of the beam (upper view).

On the basis of results of ultrasonic tests performed on the right brace and threaded spindle, shown in Figs. 3-6, it can be concluded that detected non-homogeneities are discontinuous impurities of lamellar shape grouped around the central area that originated during the process of forging, which is a relatively common occurrence during the manufacture of large forgings.

CALCULATION OF BRACES AND OF THREADED SPINDLE DURING THE SIMULTANEOUS CONJOINT OPERATION OF BRIDGE CRANES

In order to perform a reliable check of load carrying capacity of braces (B) and the threaded spindle (TS) of the beam during simultaneous conjoint operation of 2 bridge cranes, the analytical and numerical calculations are carried out. Calculation is performed for brace loads Q_B = 250 t (2.5 MN), as well as for the load on the threaded spindle Q_{TS} = 500 t (5.0 MN).

Analytical calculation of stresses in critical cross-sections of braces

Beam braces are subjected to tension, each with 250 t (2.5 MN). Nevertheless, their analytical calculation is carried out for a load of 500 t (5 MN) in order to achieve safety in case when one of the braces fails. Dimensions and critical cross-sections used for the analytical calculation of beam braces are shown in Figs. 5 and 6.

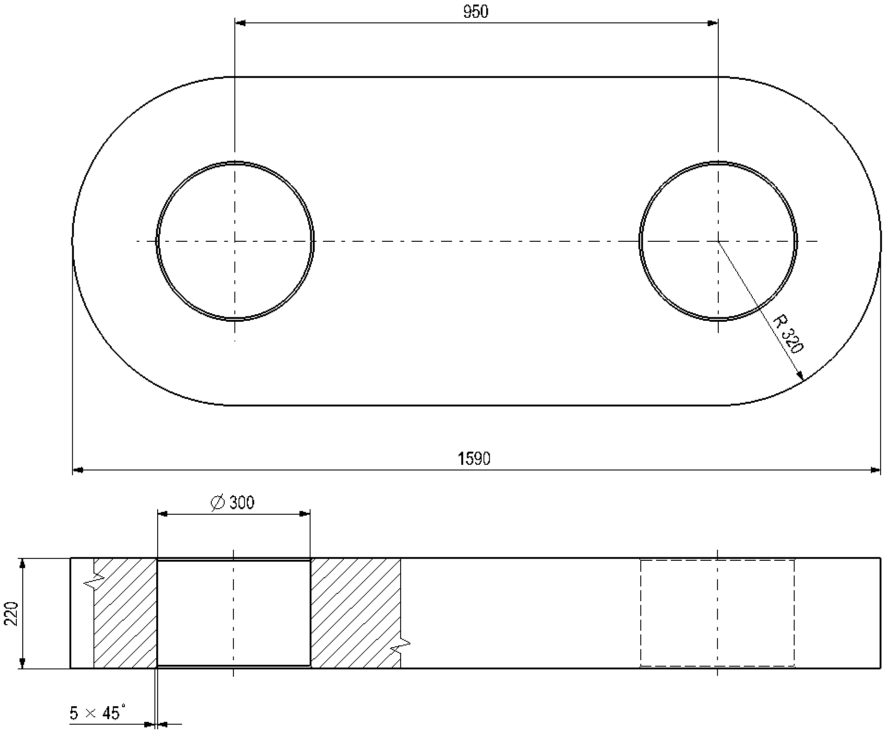


Figure 5. Basic dimensions of beam brace.

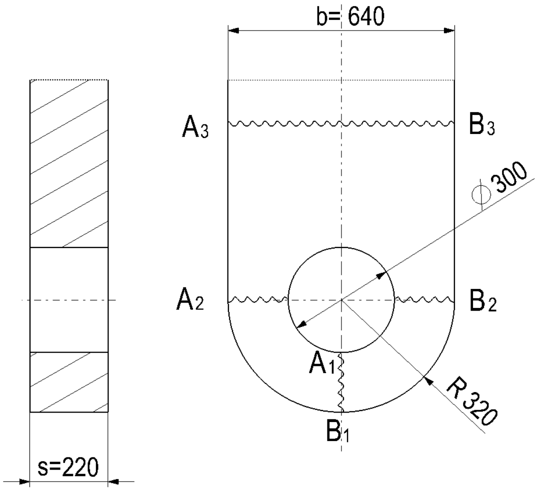


Figure 6. Detail around the opening at the brace with marked characteristic cross-sections.

According to manufacturers' documentation, braces are made of steel OLC 35, /1/. Taking into account that the calculation is carried out for allowable stress $S_{all} = 120$ MPa, it can be concluded that the safety factor with respect to yield strength (Table 2) is:

$$S_{BM} = \frac{YS_{0.2}}{S_{all}} = \frac{245}{120} = 2.00 \qquad (1)$$

The analytical calculation for the beam braces has determined the safety factor to be equal or larger than 2 in all critical cross-sections, shown in Fig. 8, /2/.

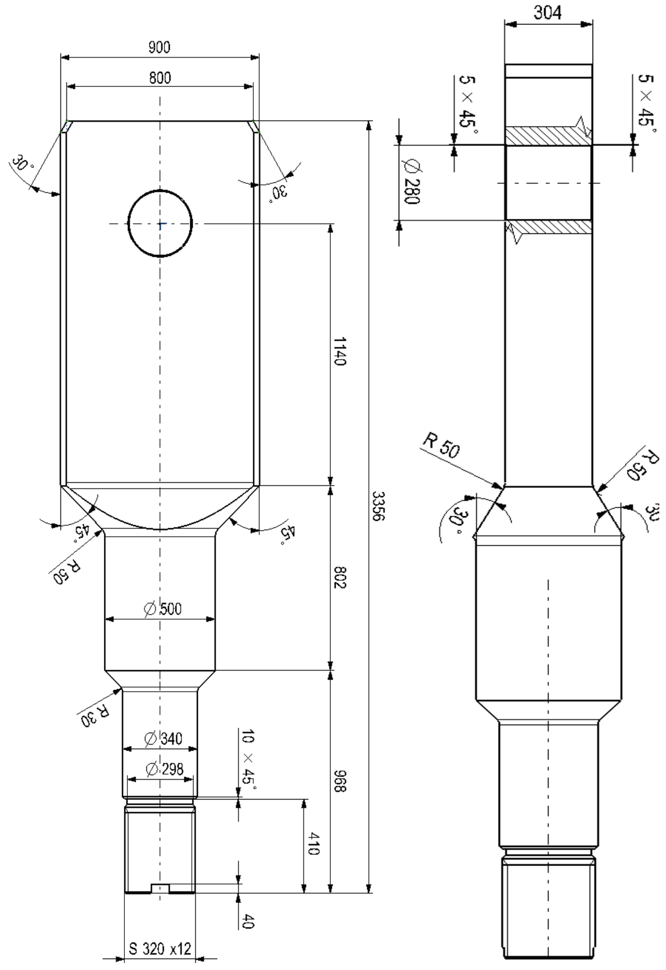


Figure 7. Basic dimensions of the threaded spindle.

Analytical calculation of stresses in critical cross-sections of the threaded spindle

Analytical calculation is performed for all characteristic cross-sections of the threaded spindle, which served as a basis for determining the minimal necessary diameter of the threaded segment. Dimensions and critical cross-sections are shown in Figs. 7 and 8.

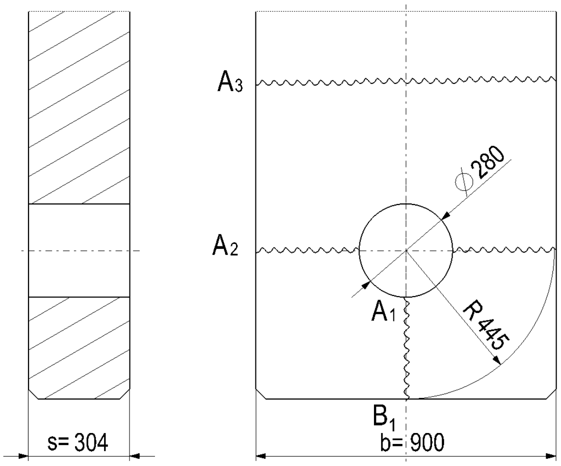


Figure 8. Detail around the eye opening at a threaded spindle with marked characteristic cross-sections

Taking into account yield strength of material OLC 35 (Table 3) and the allowable stress σ_{all} = 120 MPa, the safety factor for the threaded spindle is:

$$S_{mts} = \frac{YS_{0.2}}{\sigma_{all}} = \frac{210}{120} = 1.75 \qquad (2)$$

Analytical calculation of the threaded spindle in critical cross-sections, as shown in Fig. 10, has determined the lowest value of the safety factor at 1.67, /2/.

Numerical calculation of stresses in critical cross-sections of braces

Numerical calculation of braces, performed through the use of finite element method, /3/, is carried out for the load of 500 t (5.0 MN). Calculation is performed taking into account that the braces are subjected to tension. Also taken into account is the elasticity modulus value of E = 210 GPa, Poisson's coefficient is ν = 0.3, while yield stress is YS = 245 MPa.

The 3D model of the brace is shown in Fig. 11a, while mesh of finite elements is presented in Fig. 11b. The mesh has 3438027 finite elements and 78755 nodes. Results of numerical calculation of tensile stress to which the brace is subjected for load of 5 MN that includes the use of von Mises equations is presented in Fig. 9.

Numerical calculation of stresses in critical cross-sections of the threaded spindle

Finite element model is formed by using two planes of symmetry and adequate boundary conditions, taking into account the geometry of the threaded spindle, Fig. 10. The load is introduced using the contact with a rigid body (shaft), as presented in the same figure. The linear elastic model of material behaviour is used. Calculation is performed taking into account that braces are subjected to tension. Also taken into account is the elasticity modulus value of E = 210 GPa, Poisson's coefficient ν = 0.3, while the yield stress is YS = 210 MPa.

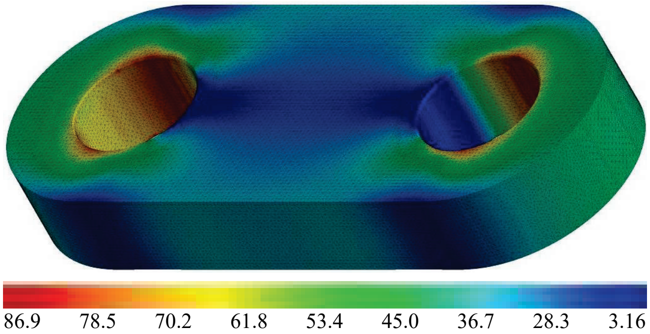


Figure 9. Results of numerical calculation and values of von Mises tensile stresses in MPa.

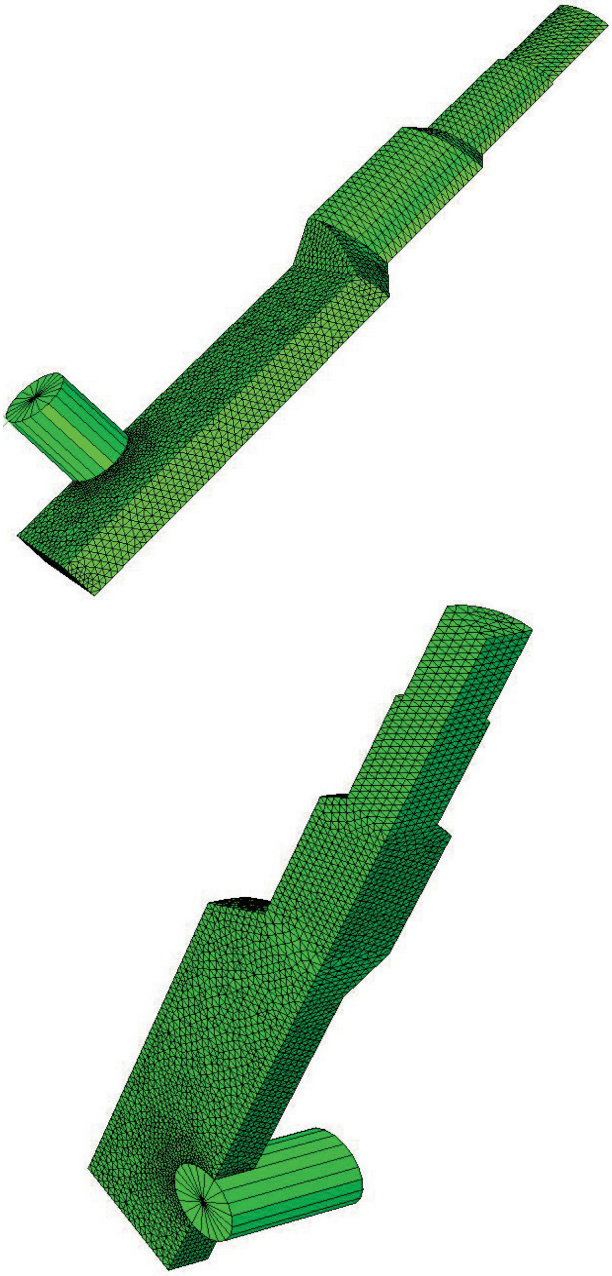


Figure 10. Mesh of finite elements of the threaded spindle.

The mesh consists of tetrahedral finite elements with square interpolation functions. The acting load on the model of 1 250 000 N presents 25 % of service load. The load acts on the shaft and is transferred by contact on the spindle. Connection of the spindle with the crane (through threaded coupling) is simplified in the model – the movement of the surface which responds to the threaded segment of the spindle is prevented.

Distribution of von Mises stresses is presented in Fig. 11, which also contains magnified detail at the threaded spindle in close proximity of the opening. In Figs. 11 and 12 the shaft is not shown in order for the complete distribution of stresses to be presented. It is clear that the highest values of stress are significantly lower than 210 MPa, which is the value of yield stress.

The two paths (A-B and C-D) along which the variation of stress values are monitored are shown in Fig. 11, in order to determine the stress state in close proximity of the opening as precisely as possible.

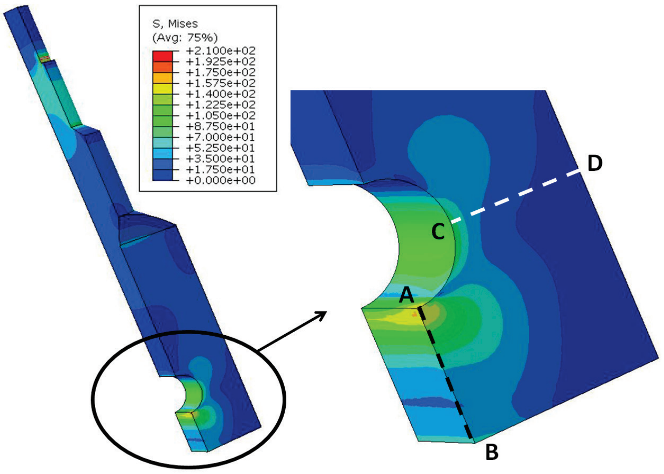


Figure 11. Distribution of equivalent von Mises stress.

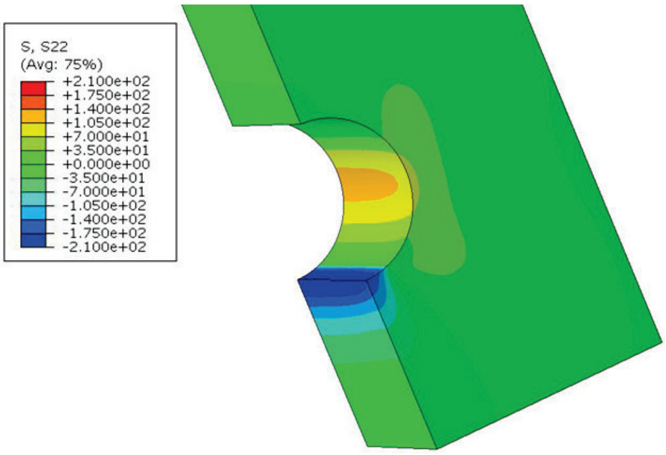


Figure 12. Stress distribution in the longitudinal direction, area of the opening.

The distribution of stresses in the longitudinal direction (axial stress) around the opening, with negative values of this component due to contact with shaft (i.e. to transfer of load across the contact surface) is shown in Fig. 13.

Variations of stress along the paths A-B and C-D are presented in Figs. 13 and 14. Equivalent Von Mises stress has higher values along the first path, due to the evident negative stress in the longitudinal direction.

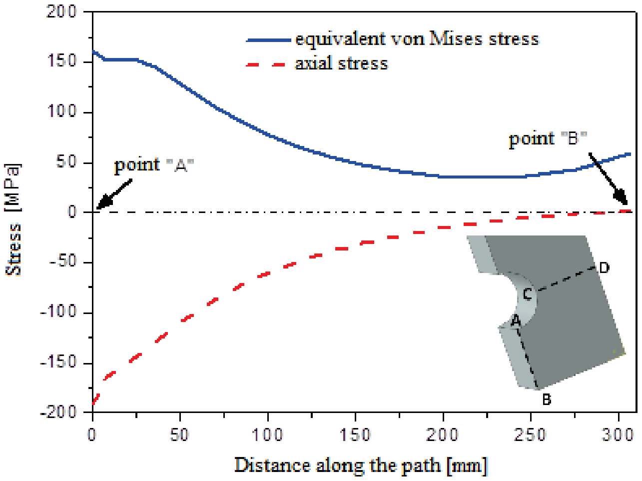


Figure 13. Variation of stress value along the path A-B.

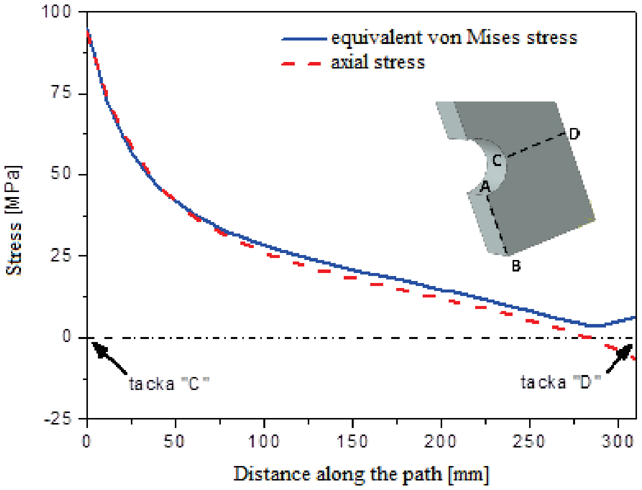


Figure 14. Variation of stress value along the path C-D

In cross-section C-D the values of von Mises stress and of the stress in the longitudinal direction are almost equal, with the highest value at the very opening (point C) of approximately 90 MPa.

ANALYSIS OF RESULTS OBTAINED FROM TESTS AND CALCULATION

Based on the results of non-destructive tests and calculation of stress condition of the right brace and the threaded spindle as parts of the beam for simultaneous conjoint operation of bridge cranes during rehabilitation or major overhaul of equipment of the hydroelectric generating set at HPP ‘Djerdap 2’, the following can be concluded:

- According to design documentation, /1/, braces and threaded spindle are made of steel with guaranteed chemical composition OLC 35 (Romanian standard designation) by forging.
- Visual testing of all components of beam equipment has confirmed the existence of corrosion products, as well as the existence of insignificant mechanical damages. Mechanical damages are repaired by fine grinding, and

afterwards all components are submitted to sandblasting and application of anti-corrosive protection.

- No surface defects are detected during magnetic particle testing of braces and threaded spindle for the simultaneous conjoint operation of bridge cranes.
- Based on reports OZPTT-ZA-01/013 UT for the right brace of the beam /4/ and OZPTT-VR-01/013 UT for the threaded spindle /5/, shown in 3D in Figs. 3 and 4, impurities of lamellar shape that occurred during the process of forging are detected locally. These impurities are grouped close to the central area, which is a relatively common occurrence during the manufacture of large forgings.
- Analytical calculations for braces and threaded spindle are carried out taking into account values of allowable stress σ_{all} = 120 MPa, yield stress YS = 240 MPa (for thickness t = 220 mm), yield stress YS = 210 MPa (for thickness t = 900 mm), as well as safety factor values S_{mb} = 2.00 and S_{mts} = 1.75. For calculated stress states of braces and the threaded spindle, in areas where non-allowable defects are detected, the calculated safety factor values are from S = 2.94 to S = 11.48, /2/.
- Numerical calculations of stress in critical cross-sections and in areas where non-allowable defects are detected proved that the integrity of braces and of the threaded spindle is not threatened, especially taking into account that bridge cranes are being used for simultaneous conjoint operation solely during rehabilitation or major overhaul of the hydroelectric generating set, therefore, they are subjected to negligible dynamic loading.

CONCLUSION

It can generally be concluded that non-allowable indications detected at the right brace and at the threaded spindle by ultrasonic tests do not influence the load carrying capacity of the equipment for simultaneous conjoint operation of bridge cranes 2500/500/50 Kn, because analytical and numerical calculations had proven that almost one third of characteristic cross-sections of the right brace and of the threaded spindle can carry the predicted load during rehabilitation or major overhaul of hydroelectric generating set equipment at HPP ‘Djerdap 2’.

Based on the performed tests, the use of vital components of beam equipment (right brace and threaded spindle) during rehabilitation or major overhaul of hydroelectric generating set equipment at HPP ‘Djerdap 2’ is allowed.

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