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RECONSTRUCTION OF A DAMAGED ROTOR SPOKE RIB - PART 1: STRESS ANALYSIS

REKONSTRUKCIJA OŠTEĆENE NOSEĆE GREDE ROTORA - DEO 1: NAPONSKA ANALIZA

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- reconstruction
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- rotor spoke
- RHPP Bajina Bašta

Abstract

Recently, during rehabilitation of RHPP in 2025, cracks were discovered in rotor spoke ribs. It was determined that cracking was caused by unexpected overloading due to weight. It was also concluded that cracks cannot be grooved and surface welded due to very limited space and some other limitations. Thus, a different approach had to be taken, leading to a reconstruction of the rotor spoke. To do so, it was necessary to stress release the rotor spoke ribs which was done by hydraulic lifting the whole rotor and then by strengthening the spoke ribs by new additional rib elements. This solution is based on detailed 2D and 3D stress analysis performed by the finite element method.

Ključne reči
- rekonstrukcija
- oštećenje
- oklop rotora
- RHE Bajina Bašta

Izvod

Tokom rehabilitacije RHE-e 2025. godine, otkrivene su prsline u nosećim gredama rotora. Utvrđeno je da su prsline nastale neočekivanim preopterećenjem od težine. Takođe je zaključeno da se prsline ne mogu žlebiti i površinski zavariti zbog veoma ograničenog prostora i drugih ograničenja. Stoga je morao biti usvojen drugačiji pristup, što je dovelo do rekonstrukcije rotorskog oklopa. Da bi se to uradilo, bilo je potrebno osloboditi noseće grede rotora od napona, što je urađeno hidrauličnim podizanjem celog rotora, a zatim ih ojačati novim dodatnim elementima. Ovo rešenje je zasnovano na detaljnoj 2D i 3D analizi napona metodom konačnih elemenata.

INTRODUCTION

The rotor spoke is a vital supporting component of the large vertical generator construction in the Reversable Hydro Power Plant (RHPP) Bajina Bašta in Serbia, as schematically shown in a simplified way in Fig. 1. Main supporting elements of the rotor spoke are 8 ribs (beams), dimensions 250×119.5×3461 mm, Fig. 2a, welded vertically along the length and horizontally along the circumference, Fig. 2b-c. Along entire ribs length grooves were made, 55x56 mm, to accommodate wedges, Fig. 2c-d.

Recently, during the rehabilitation of RHPP in 2025, cracks were discovered on rotor spoke ribs, as shown schematically in Fig. 3, and detected by penetrants, Fig. 4.

Through an analysis of the rotor spoke it was determined that cracking was caused by an unexpected overloading due to the weight of rotor rim and poles, i.e., its whole weight. It was also concluded cracks cannot be grooved and surface welded due to very limited space, even though the material is simple to handle - common carbon structural steel S275. Thus, a different approach had to be taken, leading to a reconstruction of the rotor spoke, as shown in this paper. To do so, the pre-condition was to stress release the rotor ribs and then strengthen them with new additional rib elements. This solution is based on a detailed stress analysis performed by finite element method (FEM) using software KOMIPS, /1/. Loading was taken as 10 % more than the total weight (440 tonnes) due to eventual non-uniformity, so that the force acting on 1 rib is 550 kN. The material chosen for new rotor ribs was also structural steel, somewhat stronger, S355.

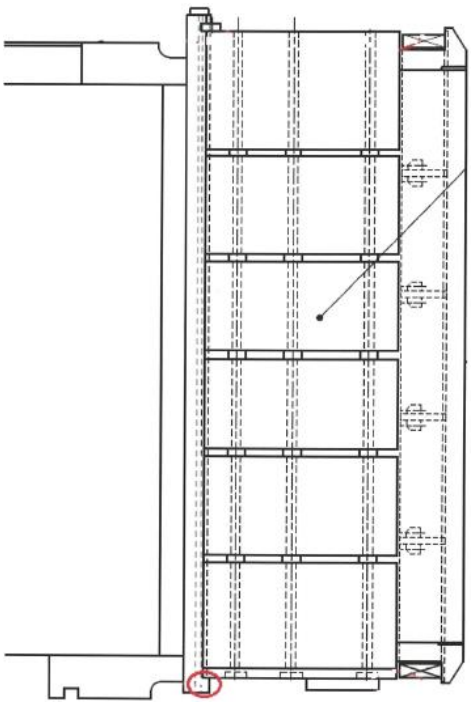


Figure 1. Rotor assembly.

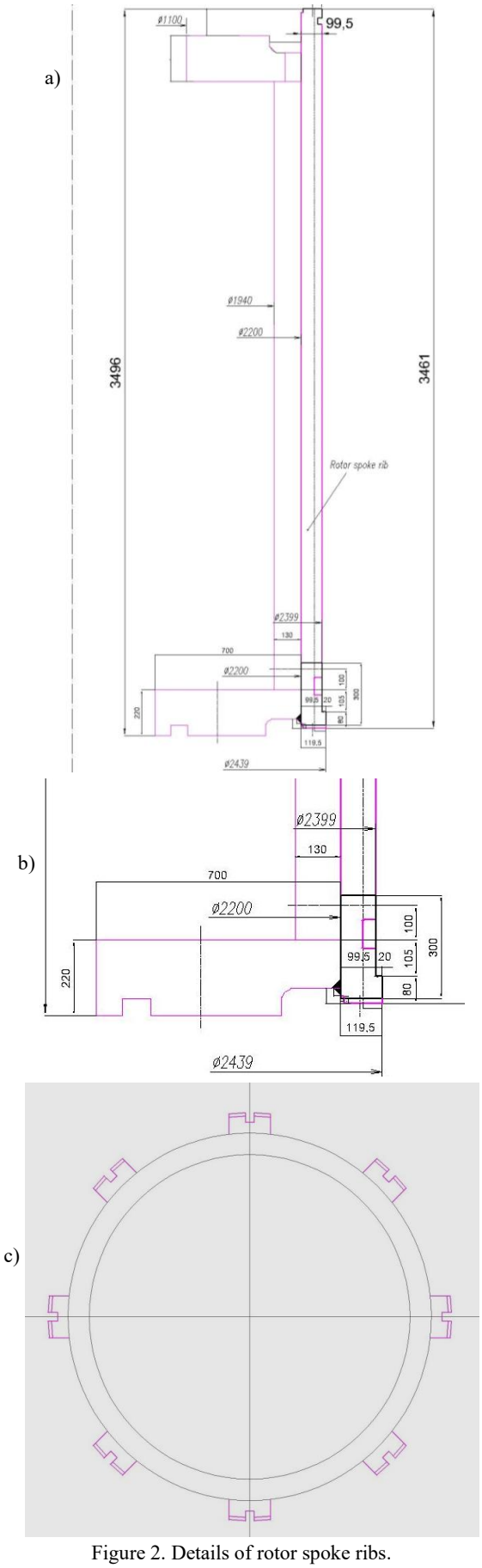


Figure 2. Details of rotor spoke ribs.

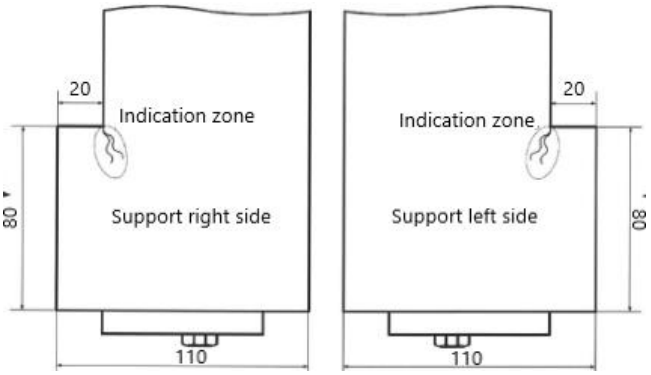


Figure 3. Schematic presentation of cracking.

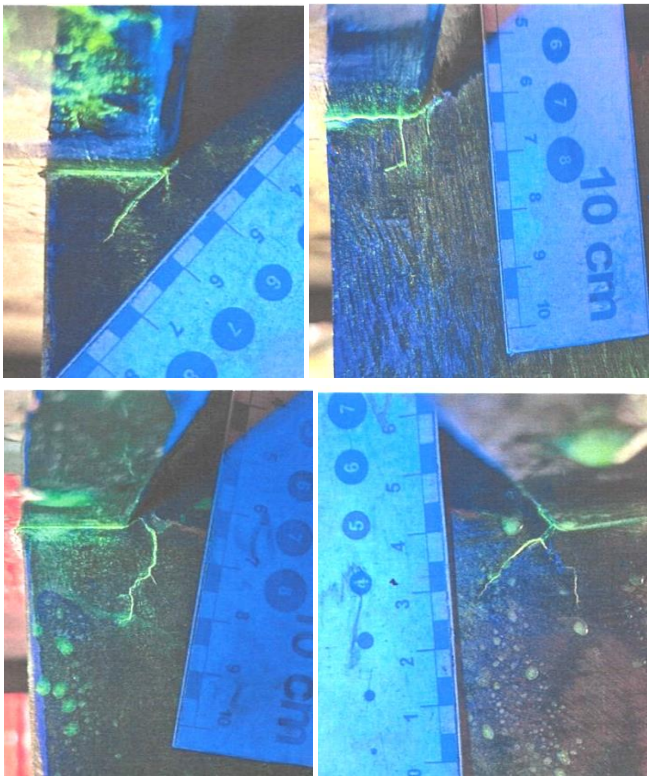


Figure 4. Cracks detected by penetrants.

STRESS ANALYSIS

Stress analysis was performed first by 2D finite element (FE) model, Figs. 5-6, with different element sizes (10×10, 5×5 and 2.5×2.5 mm) to check the convergence, and then by 3D analysis to get a more precise stress distribution, as well as the deformation state. Results have indicated high maximum von Mises stress values (from 222 to 237 MPa, Figs. 5-6) and very small maximal displacements (less than 0.1 mm). Results also proved good convergence, and as the most important practical fact that stresses are significant only at the bottom 300 mm of the rotor rib, Fig. 5, leading to the conclusion that the new ribs can be as short.

The 3D FE model with 9176 points indicated maximal displacement f_{max} = 0.138 mm and maximum von Mises stress 298 MPa, Fig. 7. This clearly points out the fact that the existing rotor rib cannot sustain the overload caused by total weight.

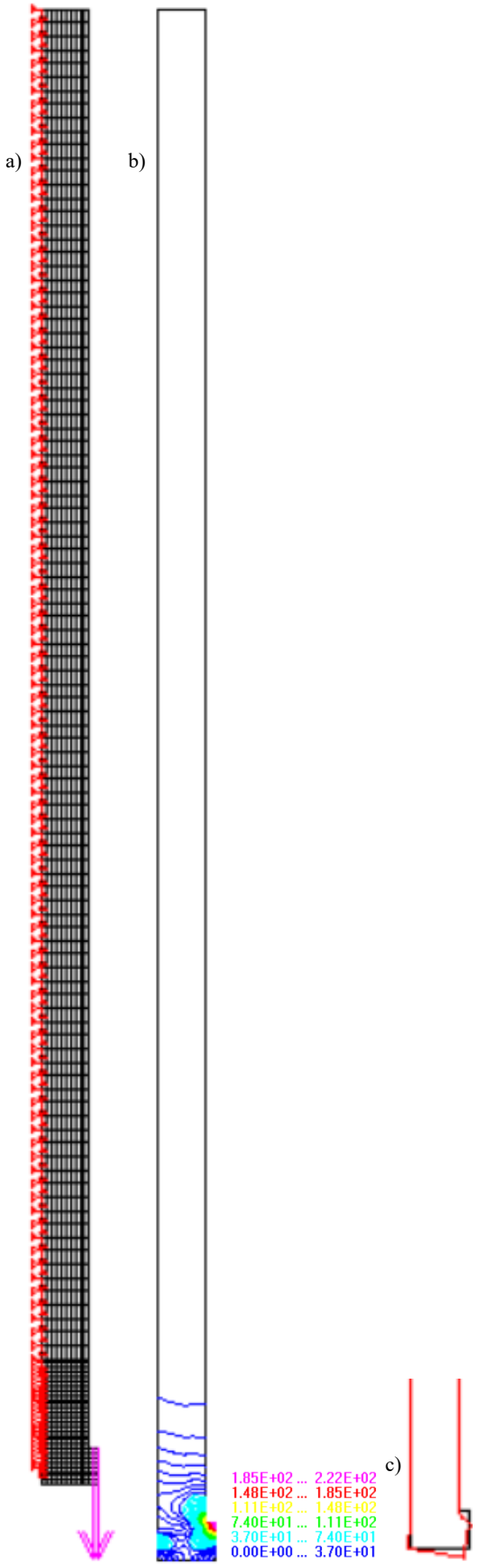


Figure 5. a) FE mesh; b) von Mises stress; c) deformation of a rib.

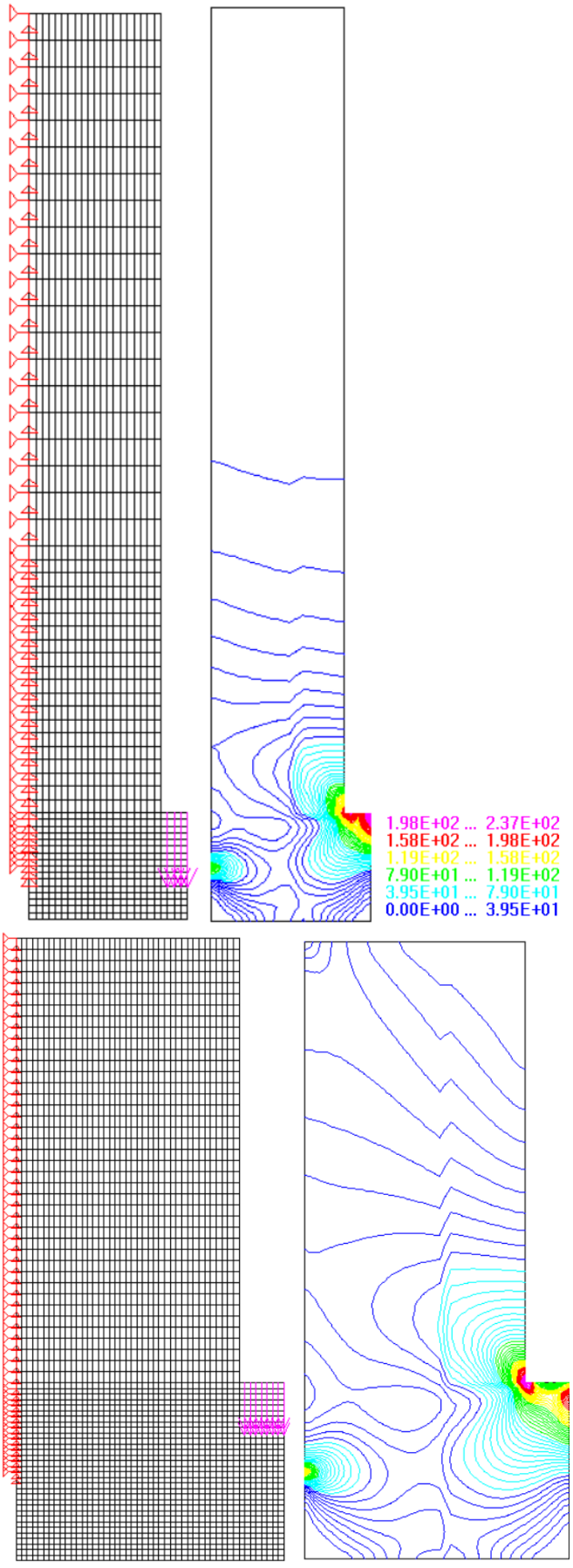


Figure 6. 2D FE meshes with 5×5 and 2.5×2.5 mm.

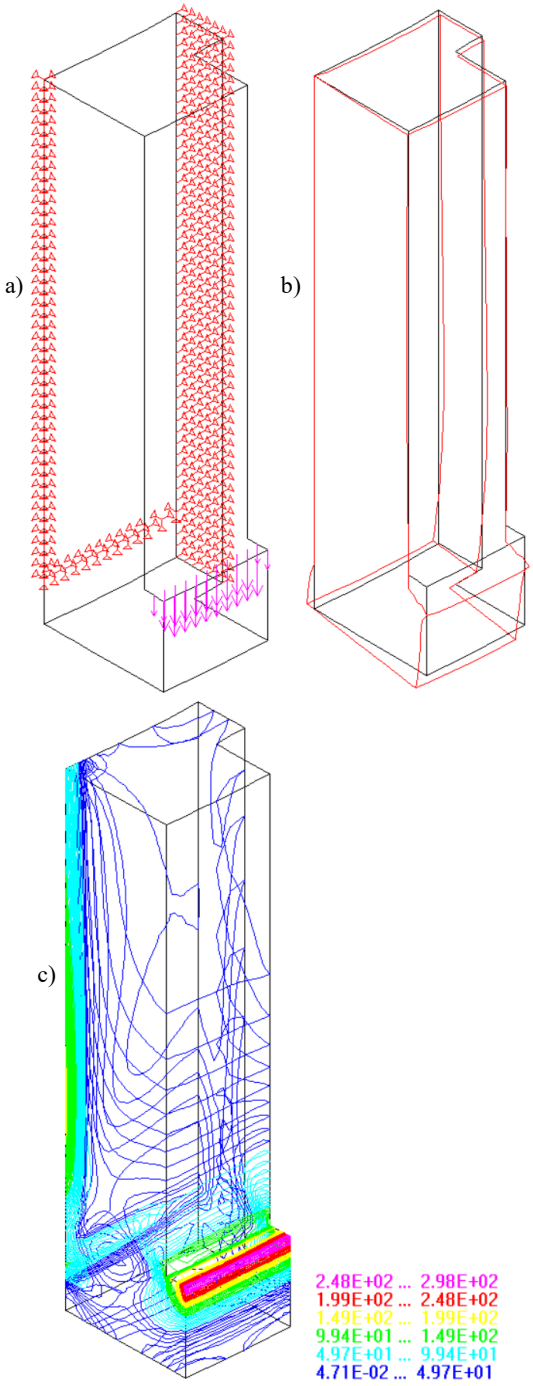
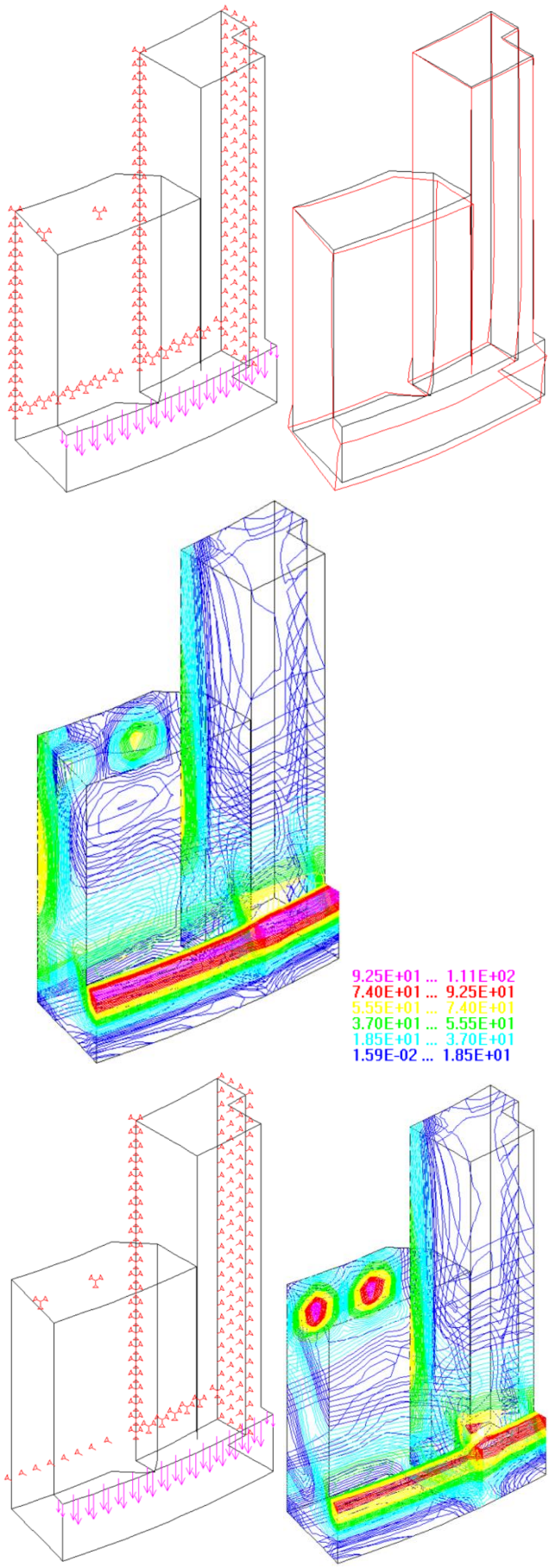


Figure 7. a) 3D mesh; b) deformation; c) von Mises stresses.

Further stress analysis is performed using 3D FE models created for the redefined rotor rib geometry, i.e., for the strengthened rotor rib made with two additional short ribs welded from both sides onto the existing rib. In addition these 2×8 ribs (315 mm length) are fastened to the rotor spoke by 2 large screws M33, close to their top surface and welded vertically to the rotor spoke. It this way the existing and new ribs became an integral supporting element with approximately 3 times the capacity of the existing one.

Figure 8 shows 3 different stress distributions according to 3 different boundary conditions. The maximal stress is 111 MPa, almost 3 times less than the existing, making this new geometry significantly more resistant to loading.



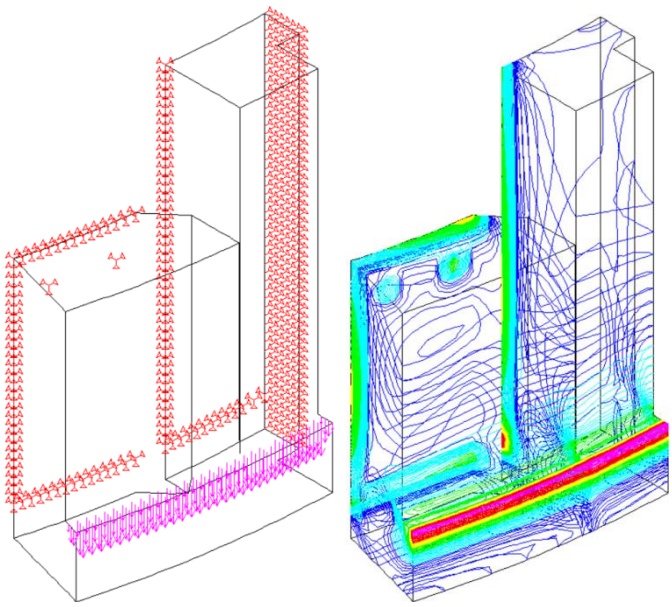


Figure 8. The FEM 3D stresses.

ASSEMBLING AND TESTING

After the welding, machining and mounting of the rotor spoke, it was necessary to test the stress state to verify both the FEM results and rotor spoke behaviour. This was done by careful lifting and lowering using hydraulic jacks, Figs. 9 and 10. Displacements are recorded while moving the rotor up and down, indicating uneven position of rotor spoke lower platform, not related to the reconstruction, as well as the reasonable agreement with the numerical stress analysis.

Figure 9. Hydraulic lifting and testing.

Figure 10. Assembled rotor.

DISCUSSION AND CONCLUSION

The reconstruction described here was successfully executed from September till mid-December 2025. This remarkable achievement is one of major aims of the reconstruction since the period of stoppage had to be as short as possible. Just to mention that alternatives were in the range of 15 to 36 months. Crucial operations were machining and welding, with many other tasks performed also with as high as possible precision and care. A detailed analysis will be presented in papers to follow.

The focus here was on stress analysis as a basis for the reconstruction of rotor spoke ribs. Many difficulties were faced and overcome, such as limited space and extraordinary precision required for all operations performed.

The role of vibrations is yet to be investigated. A reasonable assumption is that vibrations unlock coupled wedges (at least to some extent) that otherwise support the loading due to weight. It is yet to be proved, but a current thought is that this phenomenon had caused the cracking in rotor ribs which was not uniform. Namely, only two rotor ribs cracked all over their circumference, while others cracked only up to a few millimetres, or not at all.

Besides the machining and welding, the hydraulic movement up and down will be also analysed in future papers as another unique and original operation performed in the scope of this reconstruction.

REFERENCES

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