M2Po2B-02: Numerical study of the clamping system and mechanical stress amplitudes in powerline busbars of SIS100 synchrotron fast ramped superconducting magnets

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1. Introduction

The superconducting cryogenic bypass line (BPL), is a part of the SIS100 at the international Facility for Antiproton and Ion Research (FAIR), currently under construction in Darmstadt, Germany. The design, manufacturing, and installation of the BPL is a part of the Polish in-kind contribution to the FAIR project, realized by the Wroclaw University of Science and Technology (WUST).

Six BPLs with a total length of 300 m transfer liquid helium and electrical current to the superconducting magnets and bypass warm sections of the SIS100. A main innovative feature of the cryogenic bypass line is the transfer of electric current and liquid helium in one vacuum vessel.

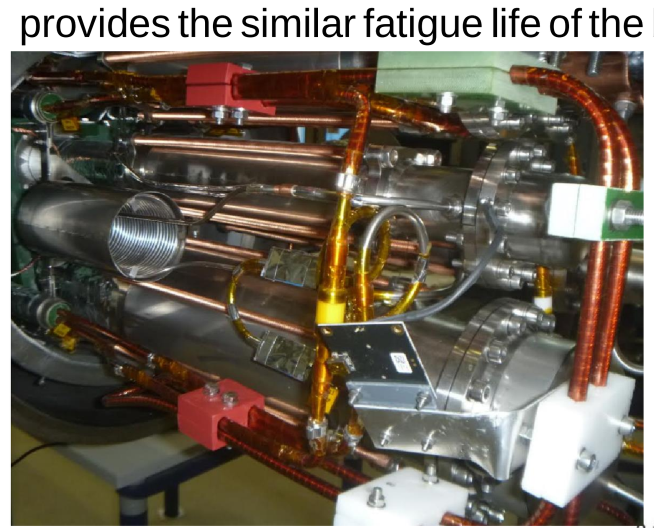
The mechanical stress in the superconducting magnets has been investigated by many researchers. Unfortunately, much less attention was paid to the mechanical stress and stability of the busbars that power the magnets. When the magnet is powered by an AC current, pulsation of the Lorentz forces can be a cause of fatigue damage to the busbars.

In the SIS100 synchrotron power lines, the busbars in each pair are clamped close to each other at distance 9 mm. The clamping of the busbars in a single pair effectively cancels an external electromagnetic field, minimizing the crosstalk between the busbar pairs.

The special G10 busbar clamps are spaced along the busbar pair at a distance of 45 mm. This design was tested and is used in around 2000 m of the powerline busbars of the SIS100 synchrotron. However, the problem of excessive busbar movement was revealed in the interconnection areas:

- between powerline busbar sections,
- between powerline busbars and magnets,
- between magnets.

The goal of the study was to design a clamping system in the interconnection area with a busbar distance other than 9 mm, which provides the similar fatigue life of the busbars.



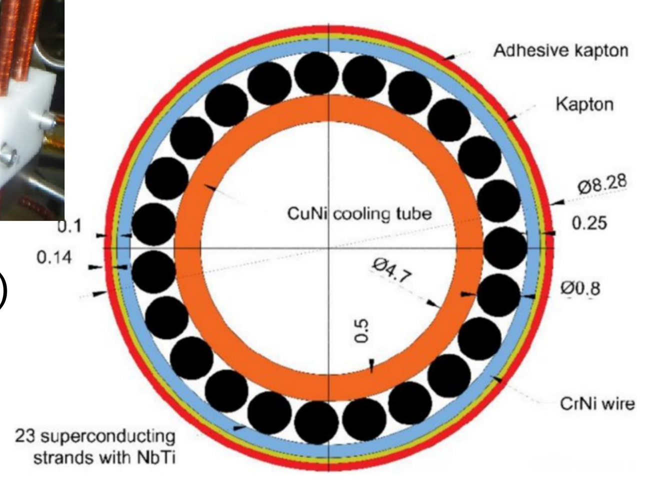


Fig. 1. Busbar interconnection area in SIS100 BPL module(up) and SIS 100 busbar cross section (right)

2. Numerical model

The model for Finite Element simulation was prepared as a mixed beam/shell/solid model in Ls Dyna software. Explicite approach was used because of huge number of internal contacts between wires, pipes and clamps.

The central cooling pipe and the external Kapton layer were model with the shell elements, the clamps and bolts were modeled with the solid elements, while the superconducting wires and external CrNi wire wrapping were modeled with the beam elements. The Kapton layer to decrease simulation time was included only under the clamps. The components of the model are shown in figure 2.

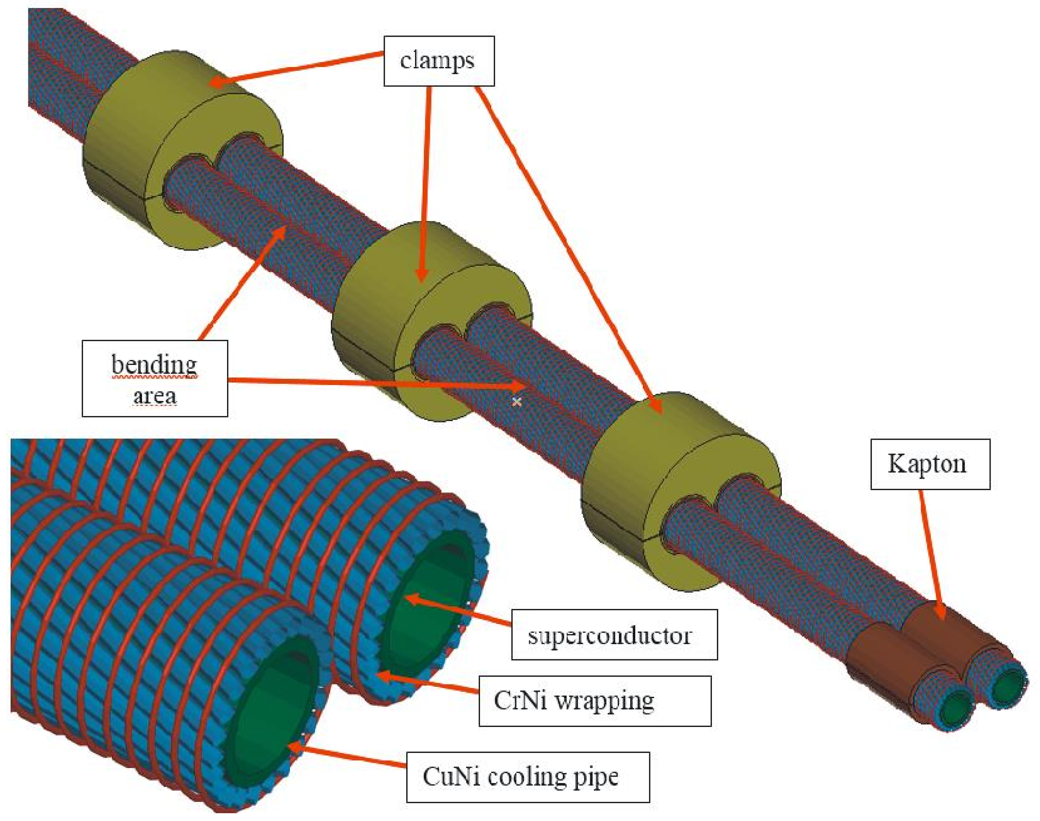


Fig. 2. Components of the numerical model - baseline clamps

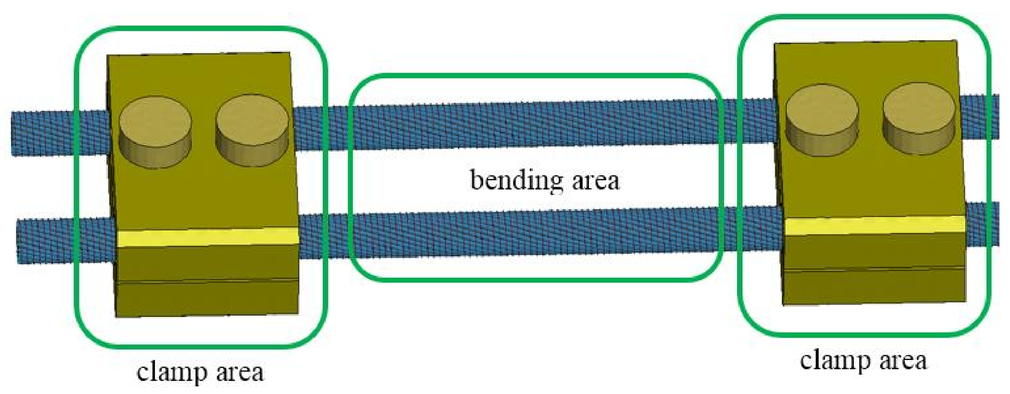


Fig. 3. Areas of stress amplitude check - 25 mm clamp design

3. Loads

The clamped busbars were preloaded by clamping forces, operating pressure and sequence of dynamic Lorentz forces due to the magnet power pulses.

The rise and fall times are not corresponding to the real profile of the electrical current pulses, but has been selected to reduce the simulation time and simultaneously to avoid excessive inertial effects.

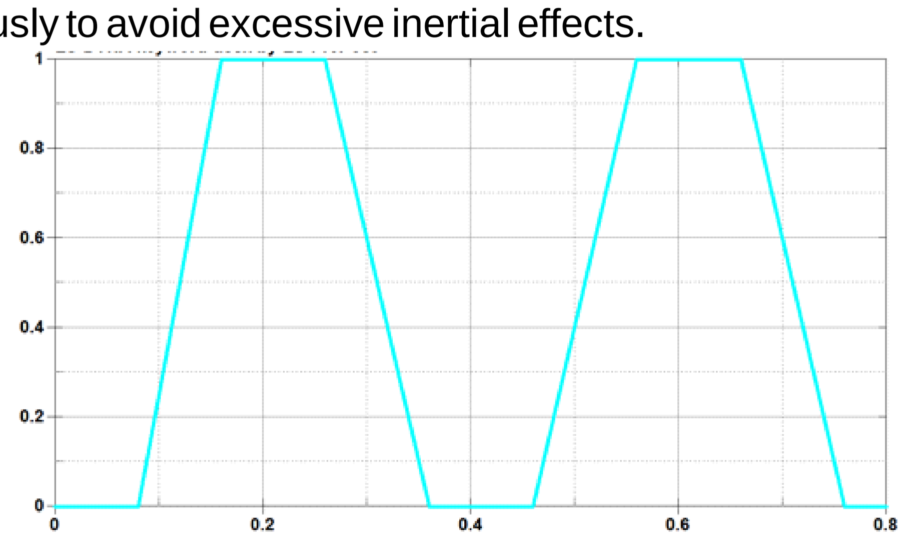


Fig. 4. The time profiles of the Lorentz force multiplier

4. Methodology of evaluation

The primary reason for busbar failure is the fatigue damage caused by excessive stress amplitude due to current ramping and resulting Lorentz forces. The stress is the result of the busbar bending between clamps: a higher clamp distance means higher bending stress (fig. 3).

The baseline for the clamp evaluation was the standard BB clamp used in Bypass Line. The goal was to achieve similar a fatigue life similar to that in the standard clamps in the Bypass Line, with the nominal clamp distance equal to 45 mm. Subsequently the stress amplitude for other clamp design and distances was checked and evaluated according to the baseline clamps.

Because the first pulse behavior after clamping can be affected by the cable and clamp fit proess, two subsequent current pulses were simulated. The amplitude of fatigue load was checked between lowest value after first pulse and highest value of the second pulse (fig. 5).

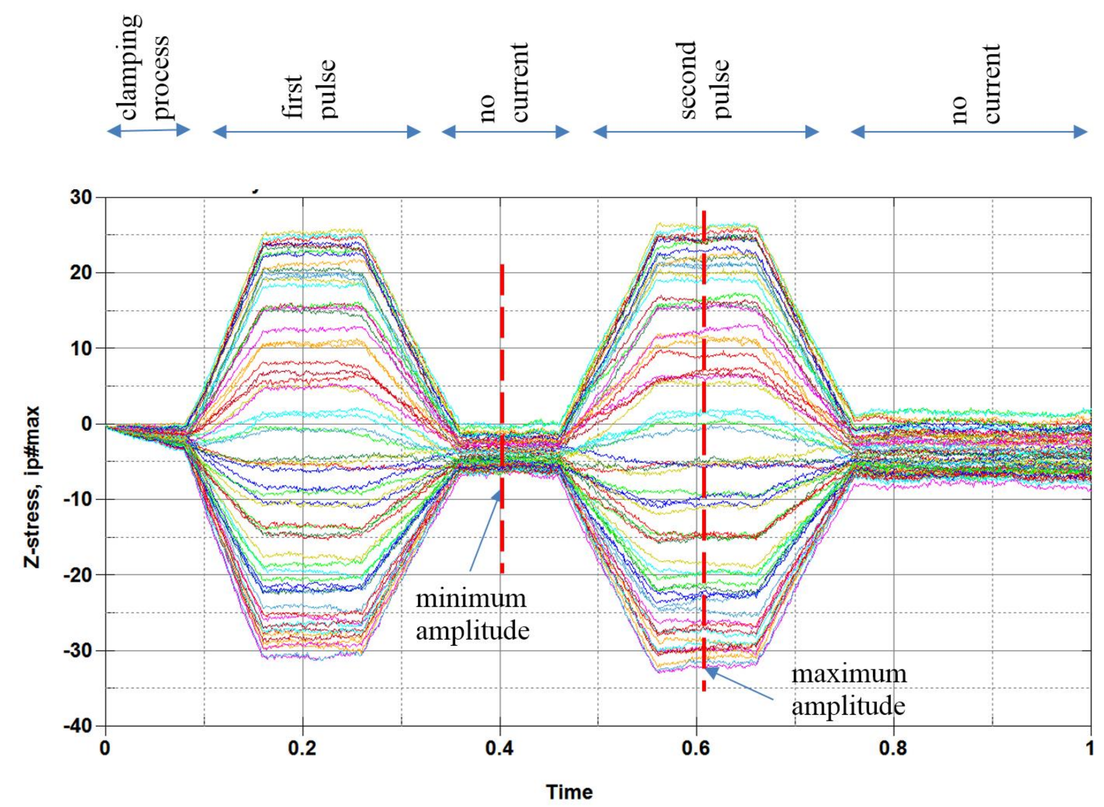


Fig. 5. Example of the axial stress in the CuNi pipe and point to the stress amplitude check during the sequence of load, bending area

5. Results

The stresses and displacement of clamped busbars were evaluated for different clamp types and clamp distances. The stresses in alll components of the cable and clamp were compared to the baseline design used in BPL modules. Example of results for baseline model and superconducting wires are presented in figures 6, 7 and 8.

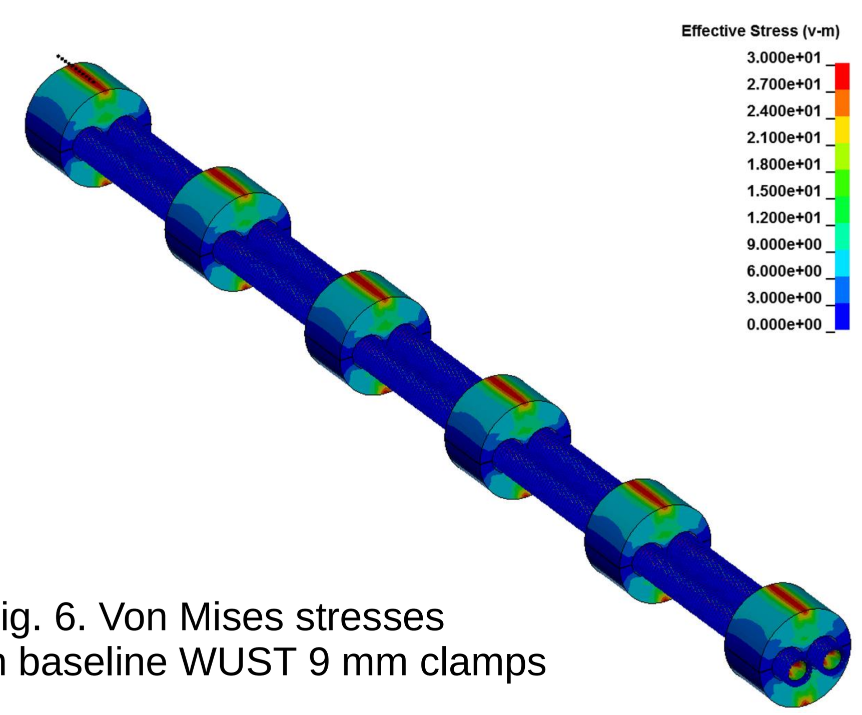


Fig. 6. Von Mises stresses in baseline WUST 9 mm clamps

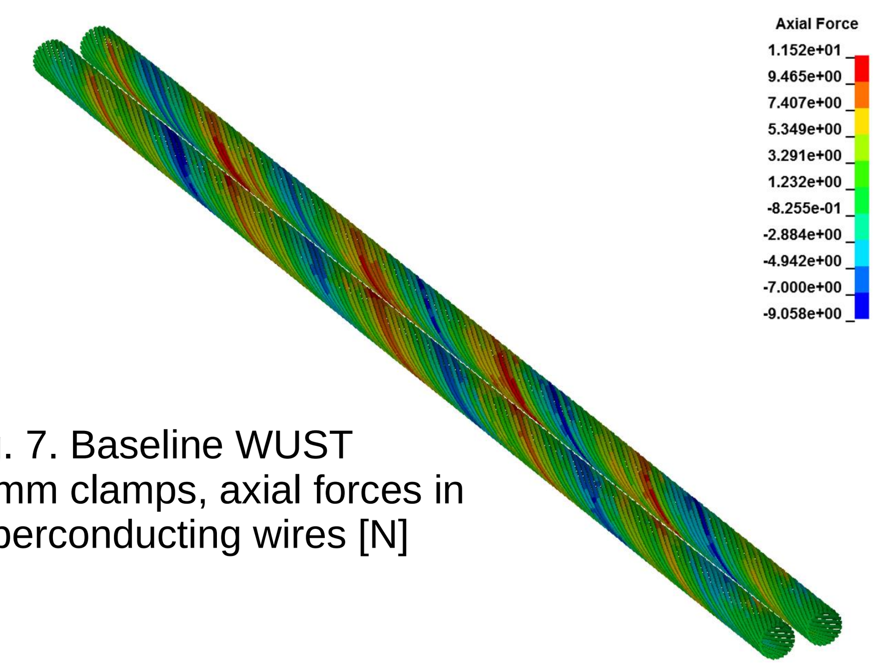


Fig. 7. Baseline WUST 9 mm clamps, axial forces in superconducting wires [N]

The results were evaluated separately for bending area and clamping area of the busbars (fig. 3). The maximum stresses from each area for each geometry were compared to the baseline design.

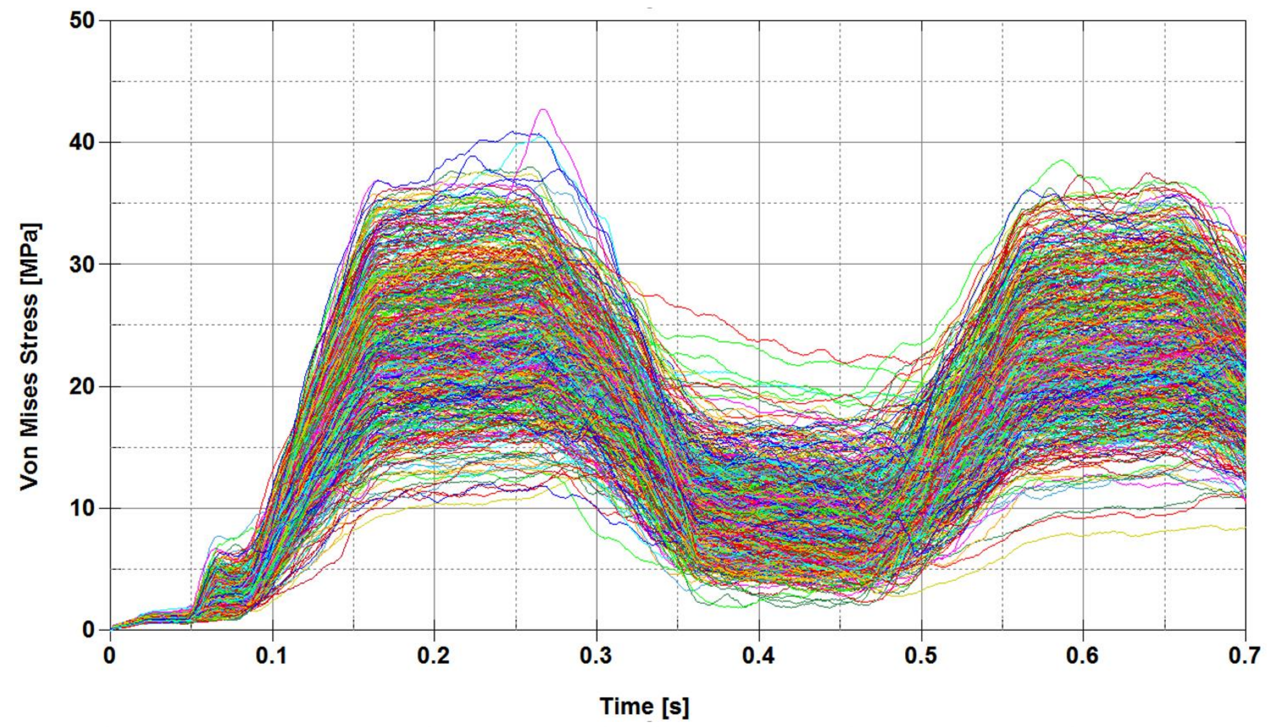


Fig. 8. GSI 25_80 clamp, equivalent stress in superconductor, bending area, max amplitude 30.6 MPa

The summary of results is presented in figure 9. The dotted lines show the baseline stress amplitudes in BPL cables, while solid lines of the same color represent the stress amplitudes increase with increasing clamp distances.

The first cable component with in which the stress amplitudes exceed the baseline value is central CuNi pipe in bending area. In the superconducting wires the stress amplitudes rise slower due to much higher elasticity of the set of wires.

For 25 mm GSI clamps, the bending stress in CuNi pipe equivalent to the baseline clamp is reached at clamps clearance equal to 70 mm.

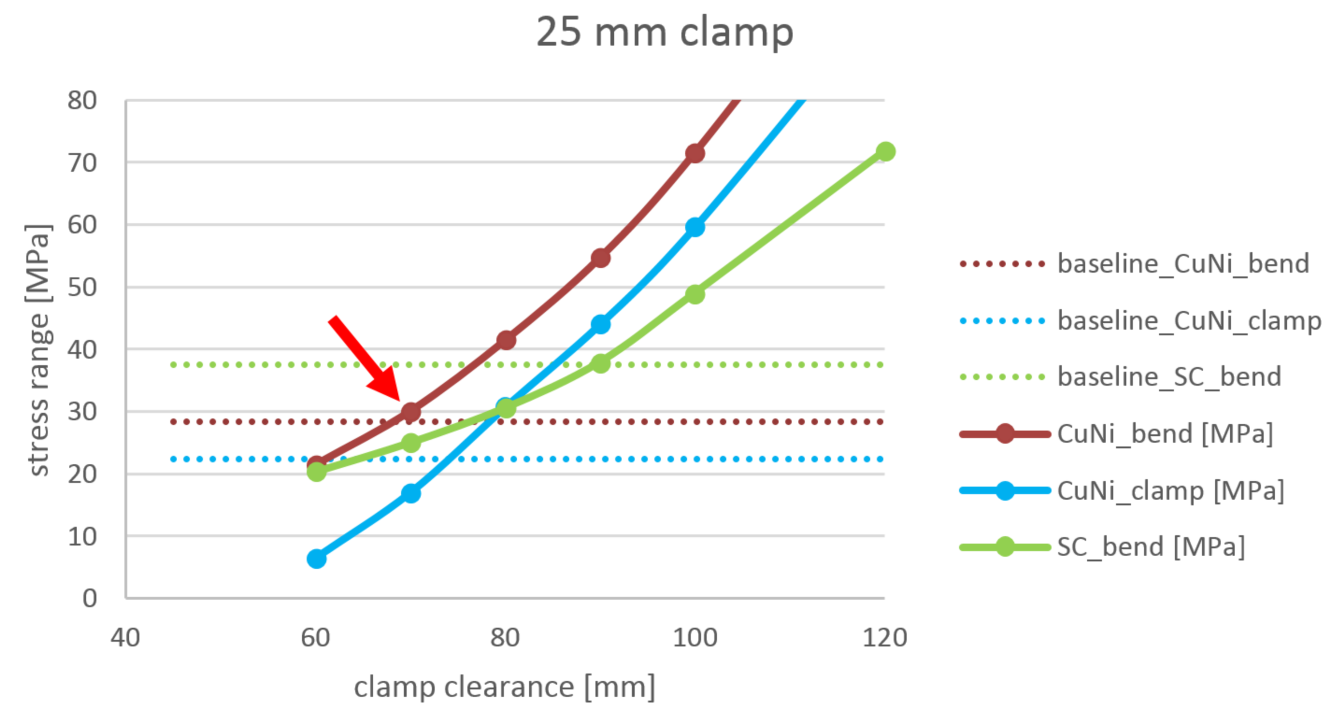


Fig. 9. Stress range in busbar as a function of the clamps clearance

Also deflection of the cables was checked. The deflection of cables in 25 mm clamp design reaches the baseline deflection at clamp clearance equal to 62 mm.

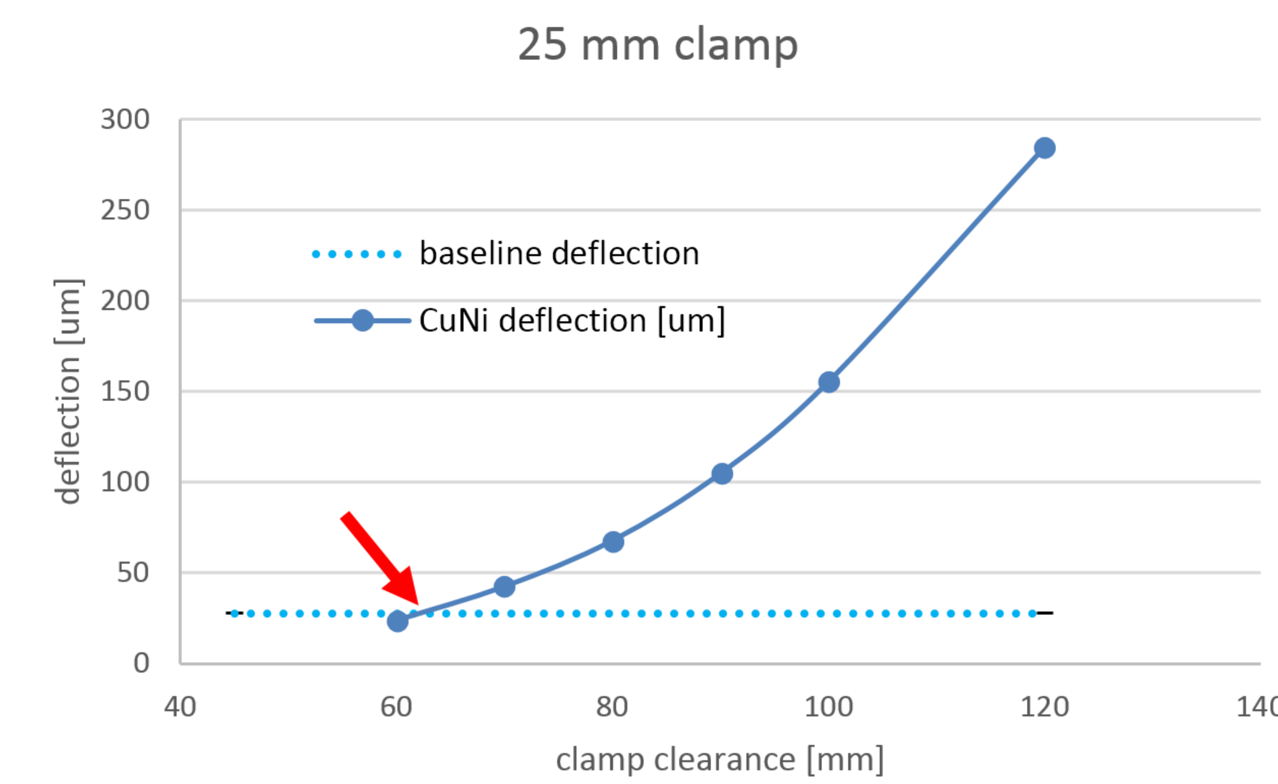


Fig. 10. Deflection of the busbars as a function of the clamps clearance

6. Conclusions

The mechanical load of busbars due to Lorentz forces is important factor not only in the superconducting magnets, but also in the power lines, especially in the interconnection areas, where busbars are not perfectly supported. The numerical study allows to design the additional clamping system in that area, which provide similar fatigue life of the busbars.