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Mechanical stability of SIS100 Bypass Line busbars clamping system under AC current load

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Abstract. This paper presents the lessons learned from tests of first module of superconducting cryogenic bypass line (BPL), a part of the international Facility for Antiproton and Ion Research (FAIR) SIS100 cryogenic system, currently under construction in Darmstadt, Germany. Design, manufacturing, and installation of the superconducting cryogenic bypass line is a part of a Polish in-kind contribution to the FAIR project, realized by the Wroclaw University of Science and Technology. The main goal of the tests was to check the superconducting, Nuclotron type busbar system containing four pairs of busbars, transferring 13.2 kA pulsing current with the ramp rate of 28 kA/s. The mechanical stability of the busbars, especially at the connection region, was investigated with the use of vibration sensors and cameras located inside the vacuum space. The tests revealed insufficient mechanical stability of the busbars in the connection area due to pulsing Lorentz forces, and necessity of additional supports and clamps. Results of the tests were presented and discussed. The conclusions can be significant not only for the bypass line design, but also for design of the busbar connections in the superconducting magnets.

1. Introduction

Facility for Antiproton and Ion Research (FAIR) is the particle accelerator facility currently being under construction by at GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany [1]. It will be unique particle accelerator facility which will use ions, antiprotons and the special isotopes (new atomic nuclei) for research in the many fields, among of others for particle physics, plasmas physics, atomic and anti-matter physics as well as for bio, medical and material science.

FAIR layout is schematically presented in the figure 1. It will compose of the accelerator infrastructure already existing at GSI site, as UNILAC linear and SIS18 circular accelerators, but also of the infrastructure provided within the FAIR project, which main elements are the SIS100 superconducting accelerator ring, Superconducting Fragment Separator (Super-FRS), storage rings and experimental stations.

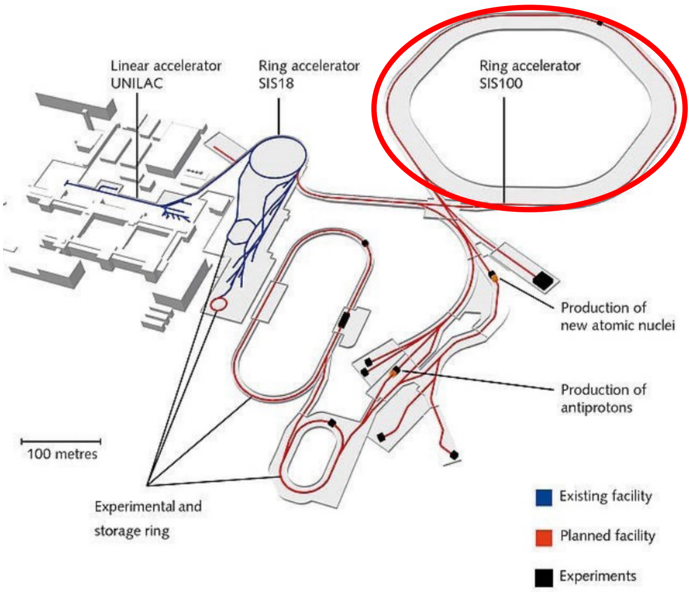

Figure 1. Layout of the FAIR accelerator facility and location of the SIS100 synchrotron [2]

The primary, ion beam will be produced and pre-accelerated up to 20% of the speed of light in the UNILAC and then up to 90% of the speed of light in the SIS18 accelerators. Next the beam will be directed to the SIS100 ring for further acceleration up to 99% of the speed of light or transferred directly to the ions research experiment stations or the string rings. The ions beam, by the collision of with dedicated targets, will be also used for production of antiprotons or special isotopes secondary beams. Before a dedicated experiment, the isotope beams will have to be filtered out of particles that are not of interest to the experiment. Sorting of particles according to their mass and charge will be done in the Super-FRS.

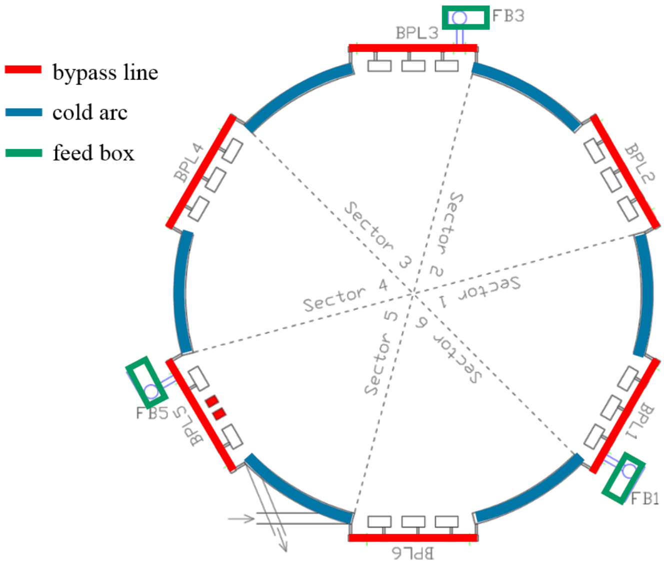

Figure 2. Schematic representation of the SIS100 accelerator showing the six Bypass Line (BPL) sections. The cold arc sections and BPL sections are for clarity not shown proportional to each other. FB1, FB3, FB5 – feed boxes

Wroclaw University of Science and Technology (WUST), in close collaboration with GSI Helmholtzzentrum für Schwerionenforschung, is responsible within Polish In-Kind contribution to

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FAIR project for design, production, installation and commissioning of the local cryogenic system combined with the power transfer system for the SIS100 synchrotron including 6 Bypass Lines, 3 Feedboxes (FB) and 6 Current Lead Boxes (fig. 2).

2. Cryogenic Bypass Line

The BPLs and FBs are dedicated to transferring liquid helium and AC electric current between SIS100 arc sections and superconducting quadrupole magnets located in warm straight sections of the synchrotron [3, 4]. A main innovative feature of the cryogenic bypass line is transferring the electric current and liquid helium in one vacuum vessel, while in other similar projects, namely, the Large Hadron Collider at CERN (CH) [5] or the Tevatron at FermiLab (USA) [6], those functions were separated.

The view of the BPL module is presented in figure 3. The endcap areas 1 and 2 the interconnection to the subsequent BPL modules closed for test bay the test Endcaps. The feedbox connection was connected during the test to the test Feedbox providing LHe/GHe and electrical current. The general cross section of the Bypass Line is shown in figure 4. The design and operational parameters of the process pipes are presented in the table 1.

The coexistence of superconducting busbars and liquid helium process pipes in one limited space was a source of the serious design and production challenges.

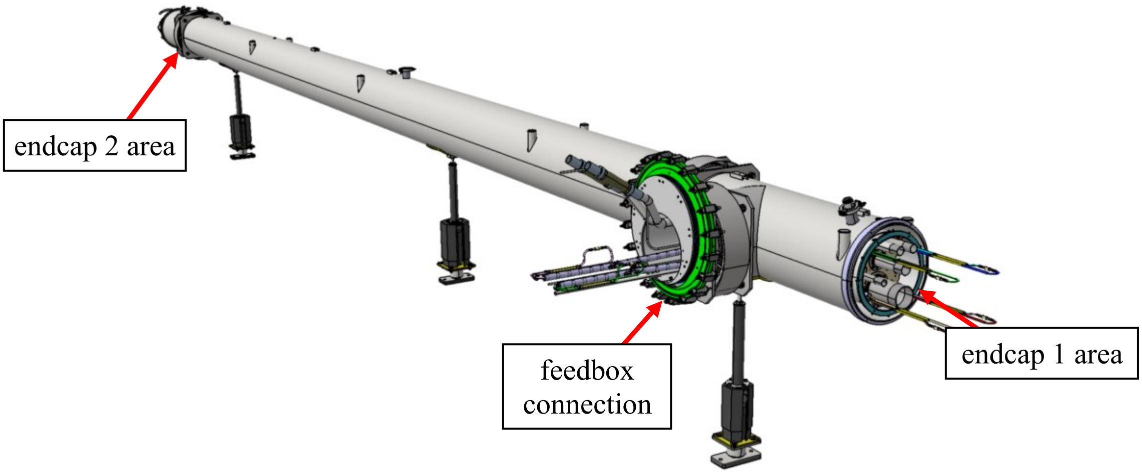


Figure 3. General view of the SIS100 Bypass Line (BPL) module.

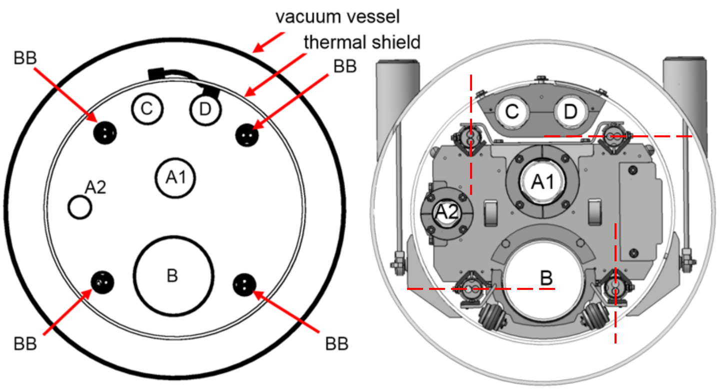


Figure 4. General cross-sectional layout of SIS100 bypass line: without supports (left) with supports and axes of busbar pairs (right). A1 – magnet supply line, A2 – vacuum chamber supply line, B – magnet and vacuum chamber return line , C –shield supply, D – shield return, BB – superconducting busbars (pairs)

Table 1. Operational and design parameters of the BPL process pipes

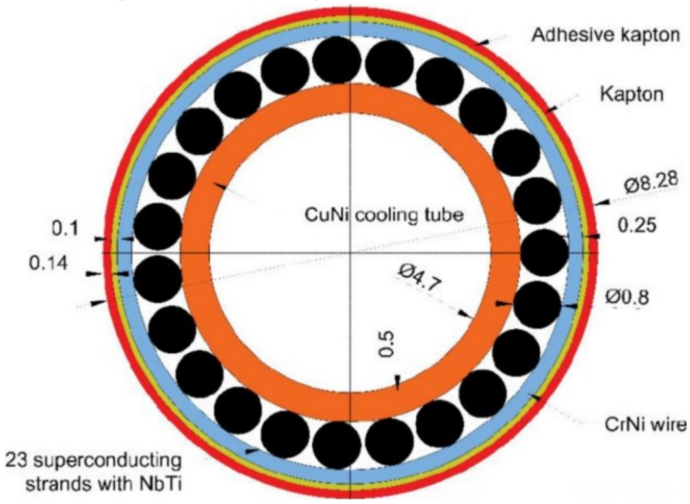
	Headers & Shells	O. Diameter & Thickness [mm]	Operating temperature [K]	Operating pressure [bar(a)]	Design pressure [bar(a)]	Test pressure [bar(a)]
A1	He supply magnets	54x2	4.5	3	20	28.6
A2	He supply vacuum chamber (VC)	32x2	4.5	3	20	28.6
B	He return magnets +VC	108x3	4.3	1.1	20	28.6
C	He supply shield	42.4x2	50	18	20	28.6
D	He return shield	42.4x2	80	17	20	28.6

The direct consequence of combining the helium process pipes and superconducting busbars into a common straight vacuum vessel was the necessity of providing thermal compensation on the busbars, with similar function as the axial compensators on the process pipes, within very limited space. It brings several challenges in the design:

- the busbars routing in the compensation loop area should minimize the electromagnetic cross-talk between busbar pairs,
- support system able to resist the significant Lorentz forces between busbars in the pair,
- prevention of cyclic movement of the busbars caused by AC current cycles.

Especially the electromagnetic cross-talk - the current induced in one cable by the electromagnetic field generated by the close, high-current cable – is a significant problem influencing the precise control of the fast-ramping SIS100 magnets [4]. For this reason the busbar pairs were located as far as possible from each other and two pairs were rotated by 90 deg (fig. 4 right, visible axes of BB pairs) [8].

The cross section of the NbTi superconductor is shown in fig. 5. The outer superconducting wires are cooled by the helium flowing through central CuNi tube. The details and mechanical properties of the cable components and are given in [7, 8].



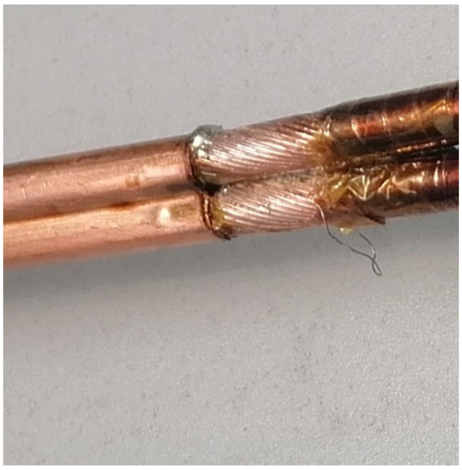


Figure 5. Cross-section of the Nuclotron type NbTi superconducting cable for the busbars of SIS100 (left) and the real superconductor uninsulated and soldered (right)

3. Cold electrical tests

The objective of the work was investigation of the mechanical stability of the busbar system installed inside BPL module and loaded by AC current. The high current flowing through the busbars results in a significant Lorentz forces applied to the system. The BBs with its support system was tested so far successfully for 3 BPL pieces manufactured by company KrioSystem. The tests were conducted in the conditions similar to the real one, with cooling by cold helium The modules was tested at 13.2 kA pulsing current with the ramp rate of 28 kA/s, i.e. with 1 Hz.

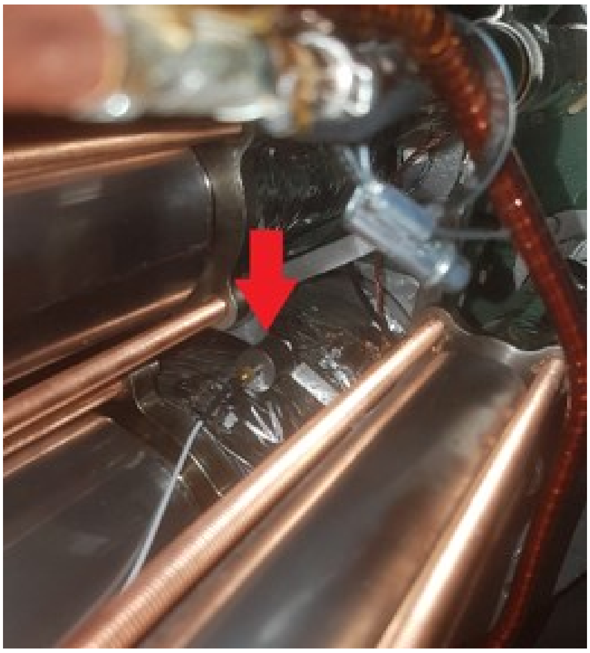


Figure 6. The location of the acceleration sensor on the support structure of the busbars

The mechanical stability of the busbars, especially at the region of modules interconnection, was investigated with the use of vibration sensors (fig. 6) and cameras located inside the vacuum space (fig. 7). For vibration measurements, the PCB Piezotronics ceramic shear ICP accelerometers PCB-352B has been used, with sensitivity 1000mV/g and frequency range 2 to 10000 Hz. The sensors were fixed to the busbar support structures in axial direction on both end the module. The tests revealed insufficient mechanical stability of the busbars in the connection area due to pulsing Lorentz forces, and necessity of additional supports and clamps shown in figures 8 and 9.

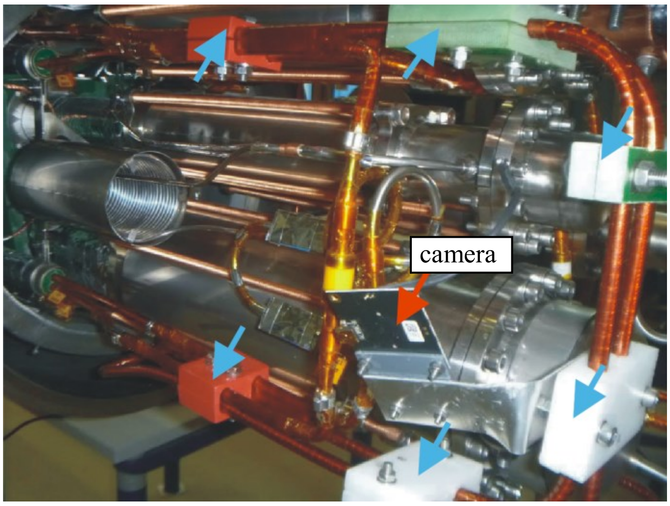


Figure 7. Camera installed inside the cold space of interconnection to observe busbar movement and additional clamps (arrows) used for stabilization of the busbars

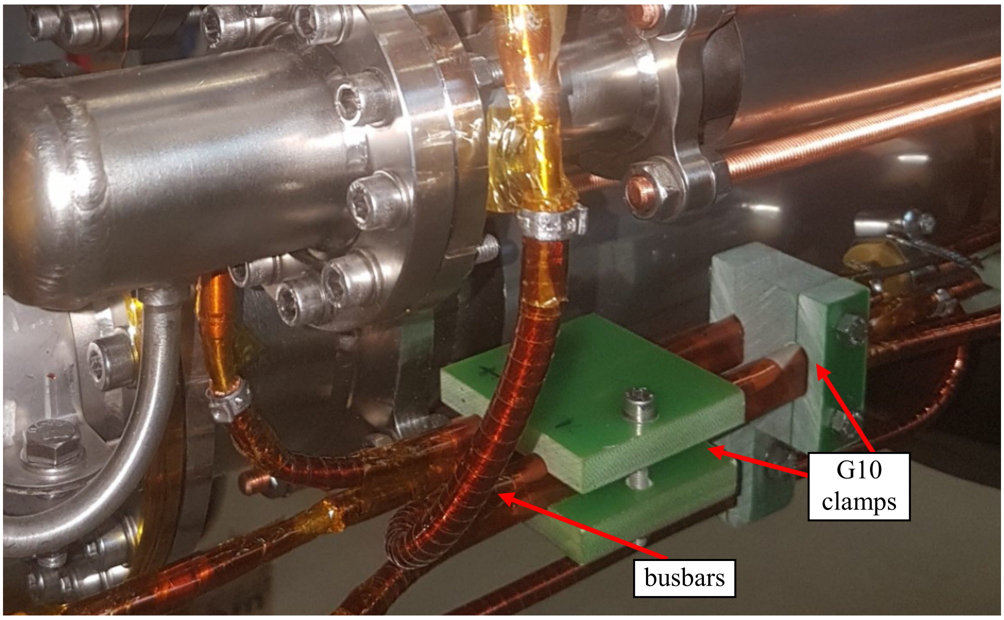


Figure 8. Additional clamps in BPL necessary to prevent excessive BB movement under AC current load

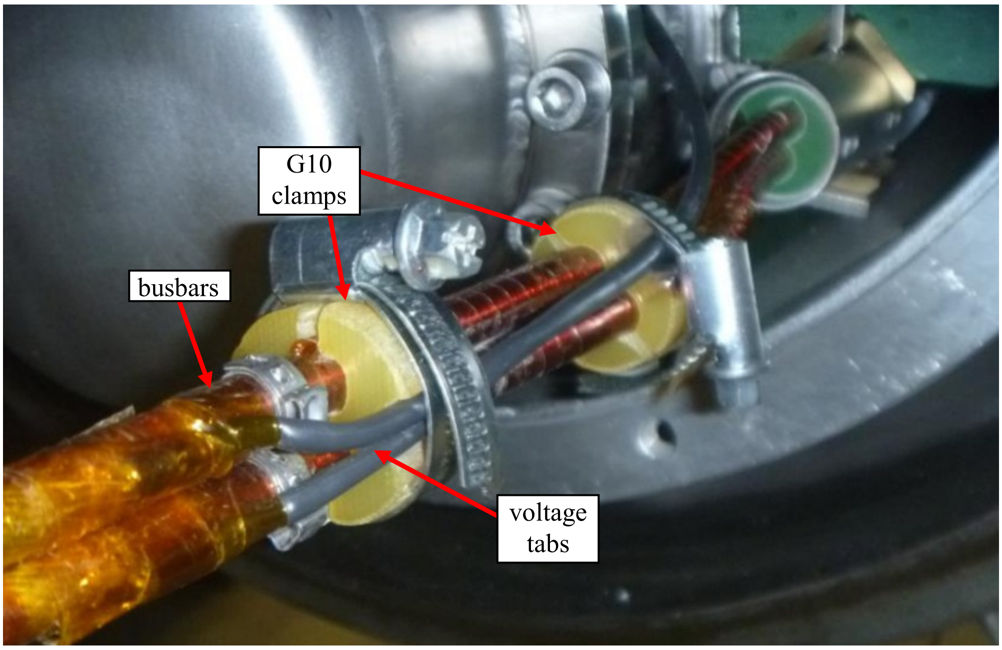


Figure 9. Additional clamps in voltage tabs area (connections to detect the quenches of BB) necessary to prevent excessive BB movement under AC current load

The final electrical scheme of connection used for cold tests of the BPL module is shown in figure 10. The current flow directions are shown by arrows. The helium circuits for the module itself (Helium In and Helium OUT) as well as the helium supply for additional small busbar piece making the shortcut on the right side of the scheme (Helium IN/OUT) were presented. It should be mentioned, that for initial tests the different connection scheme was where not all busbars were powered. When only single busbars in the pair was powered, the unbalanced Lorentz forces caused strange side effects, like very noisy work of the module or even observed movement of external metal equipment next to working BPL module. Powering all of the busbars solved these issues.

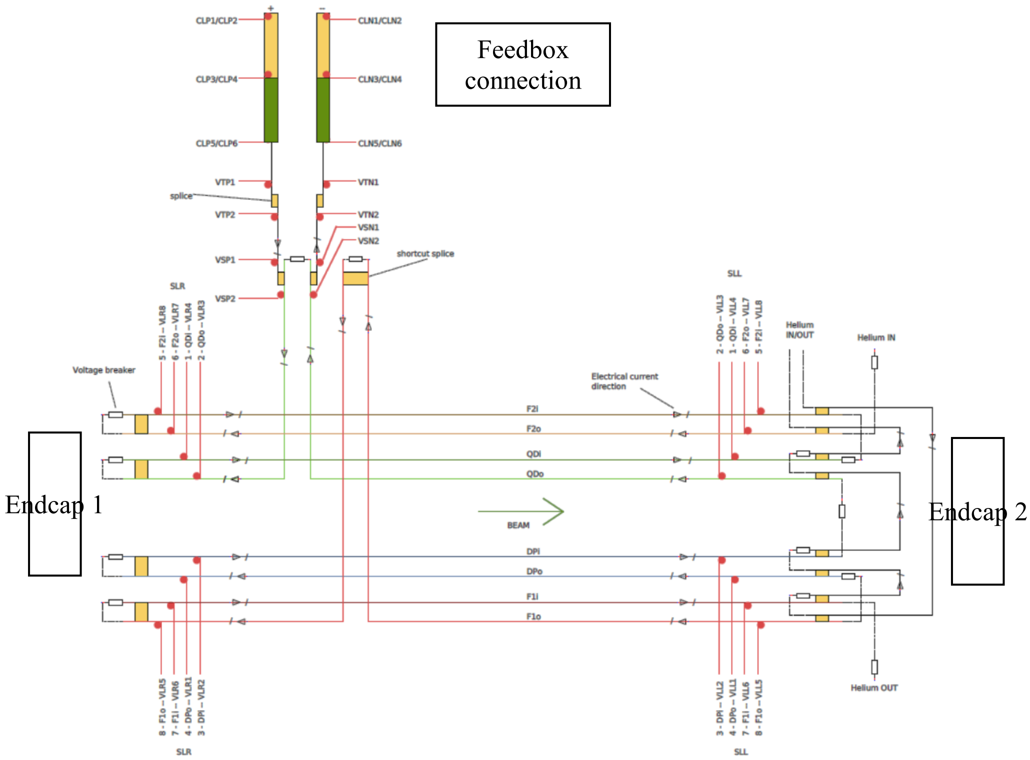


Figure 10. Electrical scheme of the BPL module cold test: VLxx – voltage tabs for quench detection, CLxx – current leads, F1x, F2x, QDx, DPx – busbars

The busbar cyclic movement due to Lorentz forces under AC current is an issue not only in the Bypass Lines. Similar situation is in the SIS100 synchrotron magnets. In figure 11 (left) the busbar pair in the superconducting magnet is shown. On the right hand side there is visible the BB clamp. The movement of the free parts of the busbars was captured by camera and analyzed by the photogrammetry software TEMA 3.4 [9].

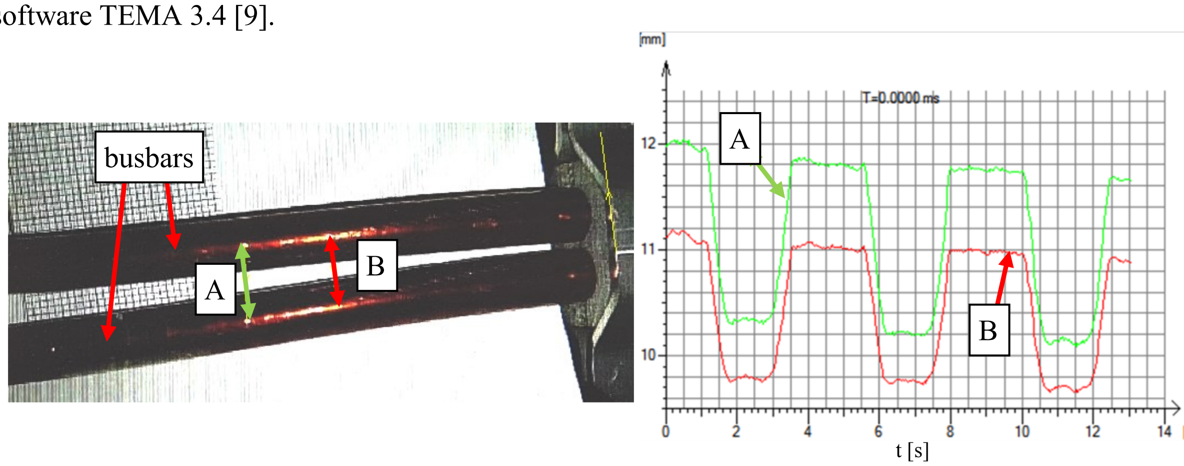


Figure 11. Busbar pair in the superconducting magnet of SIS100 synchrotron, the single busbar diameter equal to 8.3 mm, A, B – location of measured distances (left), the distance [mm] between busbars in the pair under AC current pulses (right)

In figure 11 (right) the example results of the photogrammetric measurements for magnet busbar pair shown in figure above are presented. Maximum detected amplitude of the busbar movement due to repelling forces during ramping was equal to 1.6 mm for initial busbar distance 10 mm.

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4. Summary

The electrical cold test of the superconducting Bypass Line of the SIS100 synchrotron were conducted for 3 BPL modules manufactured in Wrocław (Poland) by company KrioSystem. Initial test revealed a few issues connected mainly with electrical test connection scheme and insufficient clamping of the busbars in the test connection area.

During the electrical test of the high current superconducting lines, especially for AC current, always both BB in pair should be powered, because unbalanced Lorentz forces can damage the support system designed for balanced forces. The BBs of a pair shall be powered with the same current in opposite direction to achieve a stress compensation by the clamping system. The correction of the powering system to symmetrical one and application of additional clamps to stabilize busbars in the test endcap connection areas solved the problems.

The vibration sensors have been used to evaluate/compare the movement of the entire cold mass of the module. The sensors are not very useful in detection of stabilization issues, because provide little information about location of the problem. Much more useful tools were the optical cameras used during the cold at critical locations. The cameras and analysis by photogrammetric software provide very useful and precise information about stability of the busbar and actual thermal movements, especially in the crowded environment of the combined electrical/hydraulic transfer line.

Special attention should be paid to the stabilization system of the at the interconnection areas, not only during the test, but also in the interconnections between modules at final assembly location. In case of AC current, insufficiently stabilized busbars can undergo significant cyclic strains and fatigue damage. An implication of the results presented in this paper will be the extended investigation of the Lorentz force induced strain of superconducting cable components for a wide range of the cable routing and various designs of clamps in the interconnection areas of modules and magnets.

5. References

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