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# Cold electrical connection for FAIR/ SIS100

Kauschke, M., Shim, S.Y., Quack[1], H.

Gesellschaft für Schwerionenforschung mbH (GSI), Planckstrasse 1, D-64291 Darmstadt, Germany
[1] Lehrstuhl für Kälte- und Kryotechnik, Technische Universität Dresden, 01062 Dresden, Germany

The Facility of Antiproton and Ion Research (FAIR) will be an international centre for atomic-, plasma- and nuclear- physics, located next to Gesellschaft für Schwerionenforschung (GSI), Darmstadt. FAIR will be composed from two synchrotrons and four storage rings. Both synchrotrons, SIS100 and SIS300, are designed with superconducting magnets. For radiation protection reasons and landscaping restrictions the synchrotrons will be placed underground, whereas the power supplies will be placed within three service buildings above ground level. To save space and refrigeration power a superconducting electrical connection will be implemented. The mechanical and thermal design of this connection will be presented in the paper.

## INTRODUCTION

The Facility of Antiproton and Ion Research (FAIR) will be constructed next to the existing heavy ion accelerator laboratory at Gesellschaft für Schwerionenforschung (GSI), Darmstadt. FAIR, in its final stage, will be comprised from two synchrotrons, four storage rings and approximately 1.4 km of beam transport, requiring different types of magnets and cooling regimes. Both synchrotrons, SIS100 and SIS300, are designed with superconducting magnets [1]. For SIS100 an iron dominated magnet is foreseen. For the coil winding a hollow conductor is used where liquid helium is throttled along the full coil winding. This magnet will be operated at a current of 13 kA. SIS300 will use cosinΦ magnets with a cored Rutherford cable, which are cooled by supercritical helium. The refrigeration power will be supplied by three refrigerators [2], whereof two will be build in the starting phase of FAIR.

To achieve a radiation protection, that is adapted to the surrounding landscape, the tunnel housing both synchrotrons is build approx. 24 m below ground level. The synchrotrons will be supplied from three building placed around the tunnel. The main building (building 1) is housing the refrigerator, the reference magnets and the main part of power converters. Two smaller buildings are housing the distributed power converters for the synchrotrons. Even if all dipoles and each quadrupole family are electrically connected in one loop the power converters have to be distributed in all three building due to the high inductance of each magnet. Therefore 24 electrical connections in 12 circuits between warm power converters and cold ring magnets are required [3]. The reference magnets are electrically in one loop with the ring magnets, but cryogenically independent from the ring. For reference magnets easy access is required, therefore they are placed in a radiation free area in building 1. For the electrical transition between 4.2K and ambient HTS current leads are designed. The current leads are gas cooled between shield temperature (~55K) and ambient. The current leads for each building and synchrotron are combined in one current lead box. This current lead box will be placed at the same floor than the power converter to reduce the electrical losses due to ohmic heating in the resistive warm cable.

Between the current lead box and the synchrotrons a cold electrical link is required. A schematic view on the installation of this link is given in Figure 1. For the radiation protection and the positioning requirements of other components several bends are necessary in the link. In principle there are two

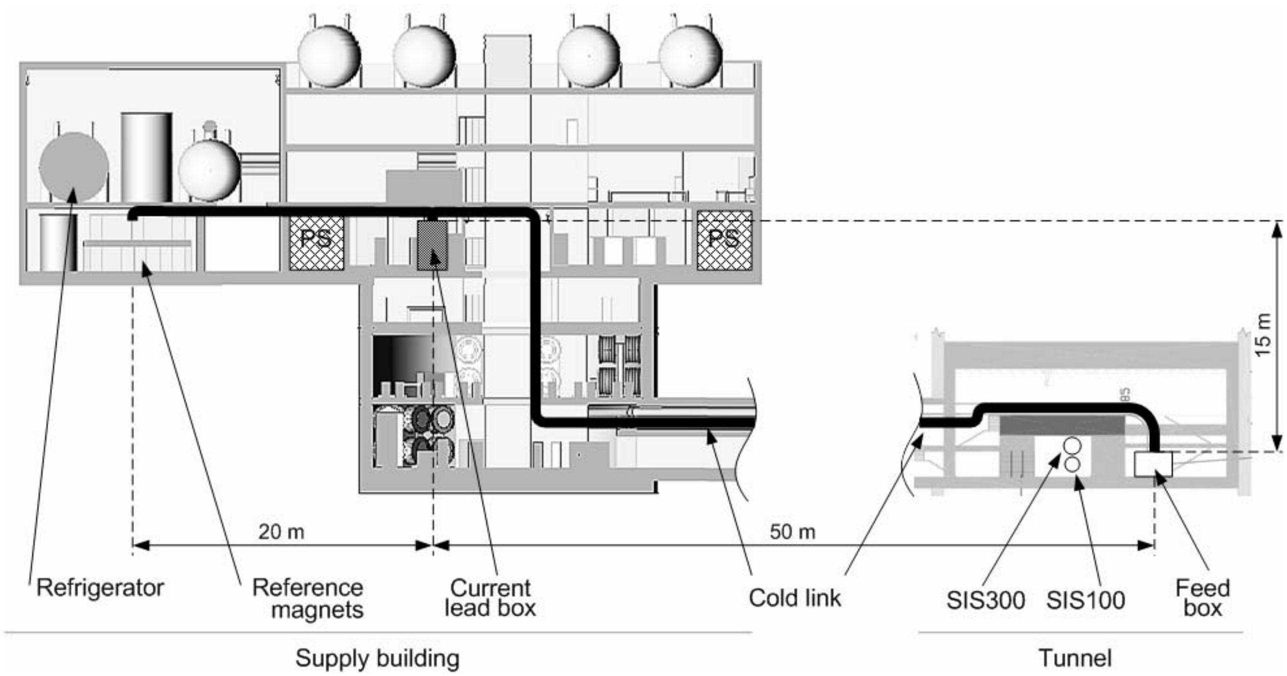


Figure 1 Schematic view of the installation of the cold link between the current lead box within the supply building and the synchrotron tunnel.

possibilities for such link; a rigid design or a flexible design. The rigid solution would require soldering and therefore a box in each bend. Therefore a flexible link would allow a more reliable installation.

For the feasibility of such a flexible cold link there are three main points, which have to be investigated before the production of a prototype:

- the producibility
- the thermal stability and
- the occurring electro-mechanical forces and the induced voltages.

For the foreseen new design option of the SIS100 dipole magnets these three aspects are investigated. The magnets will be operated at 13 kA. The required superconducting cable will be made from 23 superconducting wires, which will be twisted around a CuNi tube with an inner diameter of 4.7mm. The full cable will have an outer diameter of 8.38 mm [1].

## PRODUCIBILITY

The maximum number of cables, which are required in one cold link, is 16 (4 for the dipoles, 12 for Quadrupoles [3]). The maximum length that is required with in FAIR for such a link is in building 1, where the total length of link is 110 m. The idea for such a flexible link is to produce a stranded structure out of the cable and to place this into a flexible cryostat. The producibility of this solution was checked by industry and approved to be reasonable [4]. For symmetry reasons during production it is necessary to

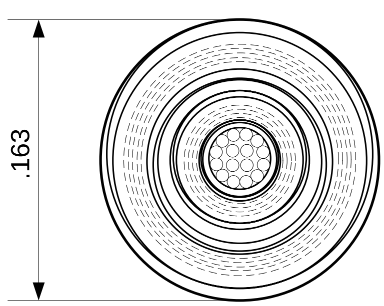


Figure 2 Schematic view on the 19 cable version of the cable with correct ratio of SC-cable to structure [4]

Table 1 Geometric data of the cold electrical connection

| | | | |
|---|---|---|---|
| Number of electrical circuits | | 3 | 8 |
| Number of cable | | 6 | 16 |
| Number of tubes for returning gas | | 1 | 3 |
| Outer diameter | [m] | .143 | .163 |
| Bending radius | | | |
| <= 3 bends | [m] | 1.3 | 1.4 |
| > 3 bends | [m] | 1.8 | 1.9 |

add dummy cable or tubes. A schematic view on the cross section of such cable is given in Figure 2. The geometric data that derive from this design are summarized in Table 1.

The flexible connection will be supplied on a standard cable drum (4.2m diameter). For the connection to the local feed box on the machine side and the current lead box on the other end a termination is needed that connects the helium supply for the different temperature levels. The first design of this required termination is given in Figure 3.

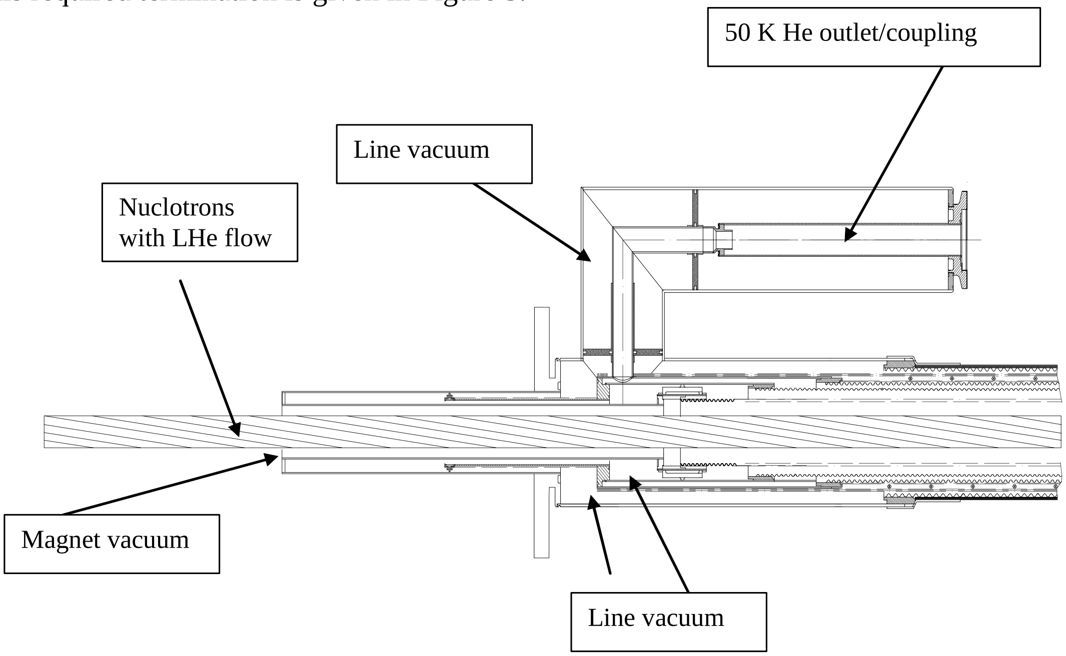


Figure 3 Design for the termination of the cold electrical connection [4]

## THERMAL STABILTY

For the save operation of the cold link enough cooling has to be provided to ensure a temperature below the critical temperature for the superconducting wire. In Figure 4 the helium supply for the cold link and the current feed box is presented for one circuit.

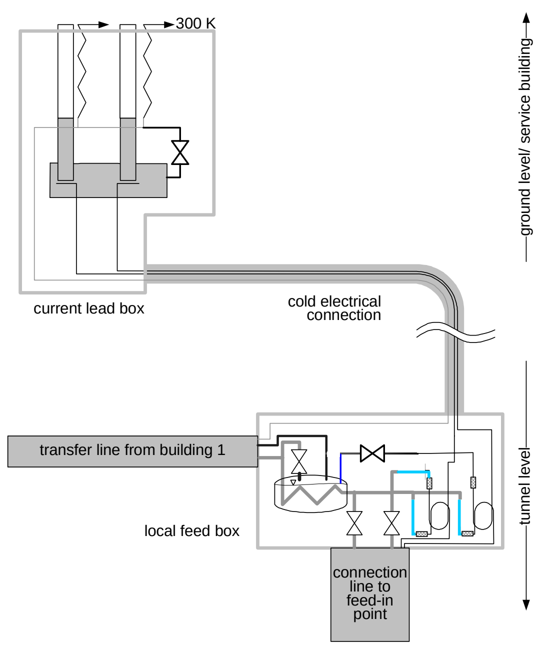


Figure 4 Schematic flow diagram for the 4K- flow of one exemplary current circuit and the 50 K flow required for shielding and the current leads

Table 2 System parameters for the calculations

| | 4 K | 50 K |
|---|---|---|
| Current leads | 0.11 W/ kA | 0.065 g/s /kA |
| 13kA | 1.4 W | 0.85 g/s |
| Box | 20 W | 150 W |
| Per cable | 3 W | 22 W |
| Link | 0.011 W/m | 1.2 W/m |
| AC losses (triangular cycle) | 5.52E-2 W/m | |
| Eddy current losses | negligible | negligible |
| Length | 110 m | |
| Difference of level | 26 m | |
| Total load /cable | ~ 7 W | |
| Total load/ circuit | ~ 23.5 W | |

For all buildings the same flow scheme should be used. For landscape protection the transfer lines for the helium supply of the local feed boxes in building 2 and 3 is via the tunnel. Therefore the required helium for the cold link will be supplied from the local feed box, therefore from the tunnel level. In addition a helium flow at 55 K and refrigeration power at 4.4K for the HTS current leads has to be supplied. In Table 2 the system parameters for the calculations of the thermal stability are summarized. The heat load for the cold electrical connection consists of two main parts, heat conduction from the outside and AC losses in the cable. The heat conduction to the 4.4 K level will be of 80 mW/m for 7 cables and 100 mW/m for 19 cables. The heat inleak to the outer shielding gas with a temperature difference from room temperature to 50 K will be in the range of 1.2 W/m for 7 cables and 1.5 W/m for 19 cables. These data are based on measurements on existing transfer lines with the same design principle.

In Figure 5 the calculation model for one circuit is given. The pressure drop calculation is using Gnielinski equations for the friction factor [5]. The geodetic pressure change is assumed within the flow, if the void fraction is below 0.1. For the heat transfer a heat transfer coefficient of 20 $W/m^2K$ is assumed. The value is representing the heat transfer through the insulating Kapton foils and the thermal resistances for the contact between the cables.

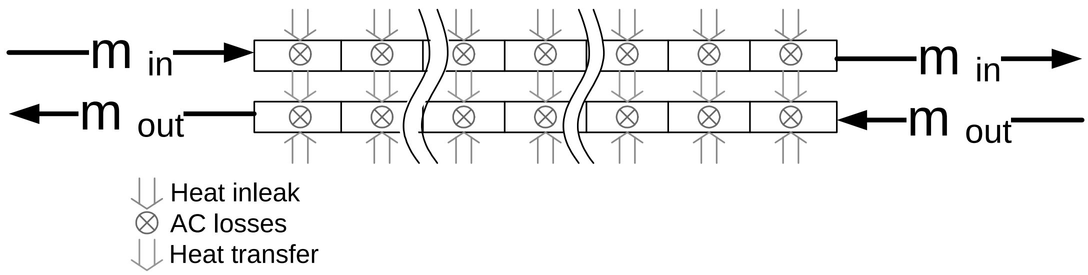


Figure 5 Model for one circuit for the calculation by the Finite Volume Method (FVM)

Within the SIS100 magnets the cables are cooled by subcooled helium that will be throttled into the two-phase region along the coil [1]. For the link this cooling regime seems not to be reliable. Due to large geodetic changes along a straight section the two-phase flow will separate, and some sections will accumulate liquid helium whereas others are not enough cooled. Therefore the cable in the cold link will be cooled by supercritical helium at the supply pressure of the distribution system. In Figure 6 the T-s diagram for the cooling with supercritical helium is shown. The temperature evolution within a link, being installed on one level is compared with a link of a 15m inclination. The temperature and pressure profiles along the length of the link are compared in Figure 7.

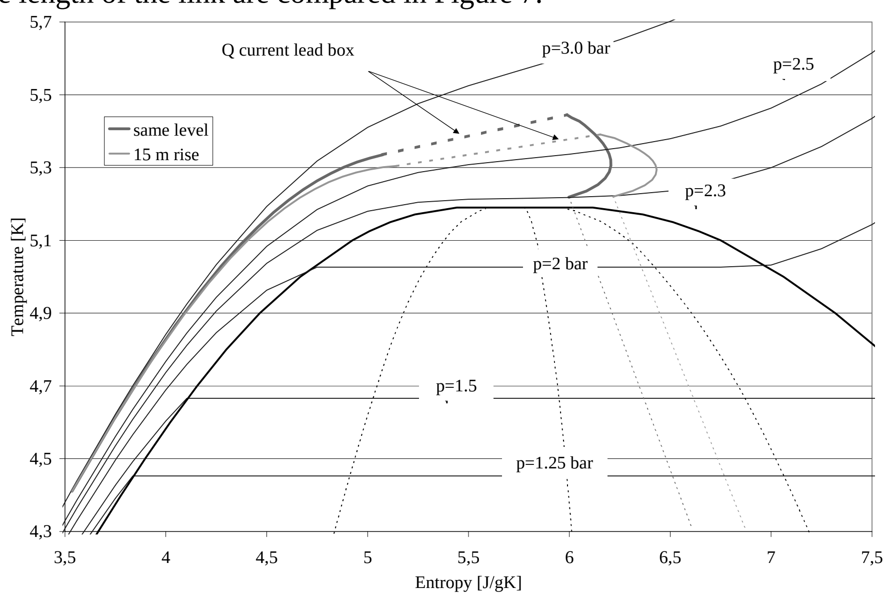


Figure 6 T-s Diagram fort he helium flow through one current circuit using supercritical flow ($p_{in}$=2.95 bar)

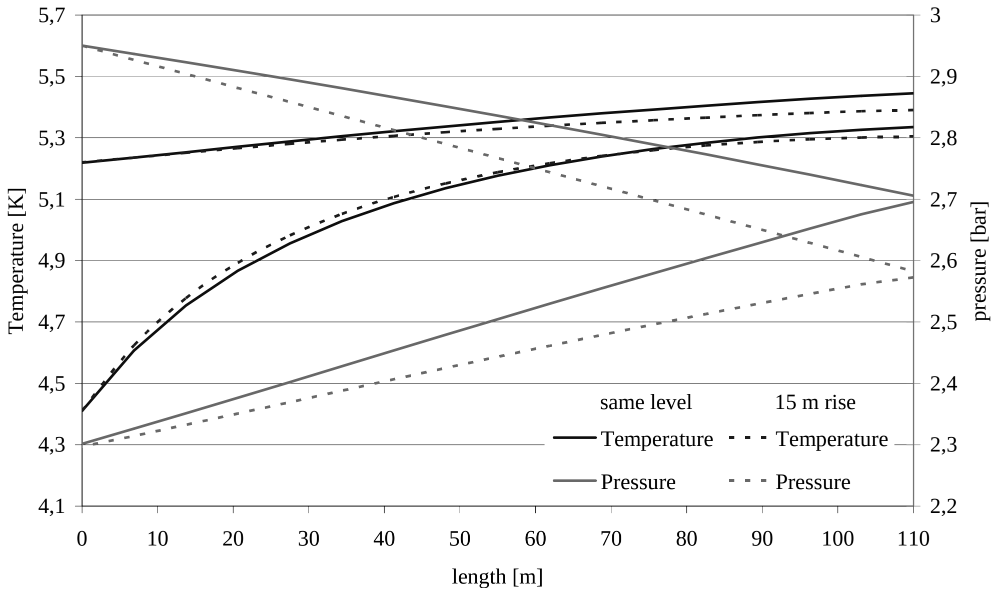


Figure 7 Temperature and pressure profile along the cold electrical connection for supercritical cooling. The dotted line represents the profile for a uniform 15 m rise.

From these temperature profiles one can expect a save operation of the system will be achieved by supercritical cooling of the link.

## ELECTRO MECHANICAL FORCES

The structure of the cable has to withstand the electro mechanical forces with in the cable. For the calculation of the forces all possible distributions of current during operation has to be examined. All dipoles will be operated maximal at 13 kA, the quadrupoles at 4.6 kA. All magnets will be ramped in parallel. Therefore the cable distribution can be optimized due to the electro mechanical forces and the 5544 possible combinations for the 4 dipole and 12 quadrupole cables can be reduced to 4 equally low force solutions. One possible distribution is given in Figure 8. The two cables supplying the dipole circuits are placed in that way, that the distance is maximized and therefore the force is minimized. The calculation of the forces is done by FEM calculations. The structure of the cable is simplified in that way, that the superconducting wires are reduced to an equivalent ring of superconductor surrounding the cooling tube. The simplified cable model is shown in left hand side in Figure 8.

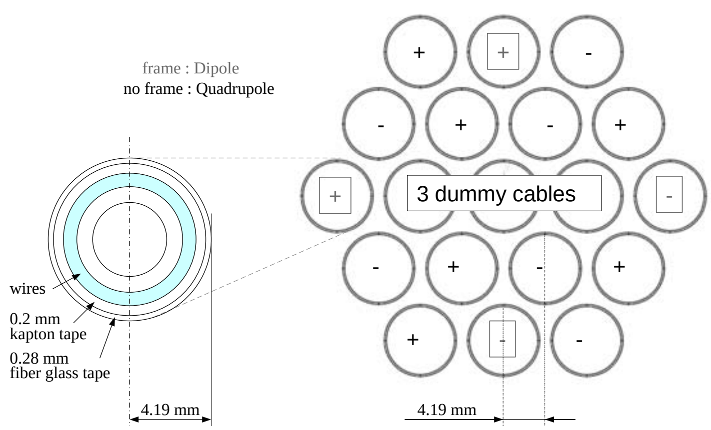


Figure 8 Calculation model for the mechanical force analysis indicating the polarities for each cable assigned for the calculation by the Finite Element Method (FEM)

In the following Figure 9 and the Table 3 the electro mechanical forces for each cable in the structure are given. Comparing the values with the coil winding the link structure should resist the upcoming forces.

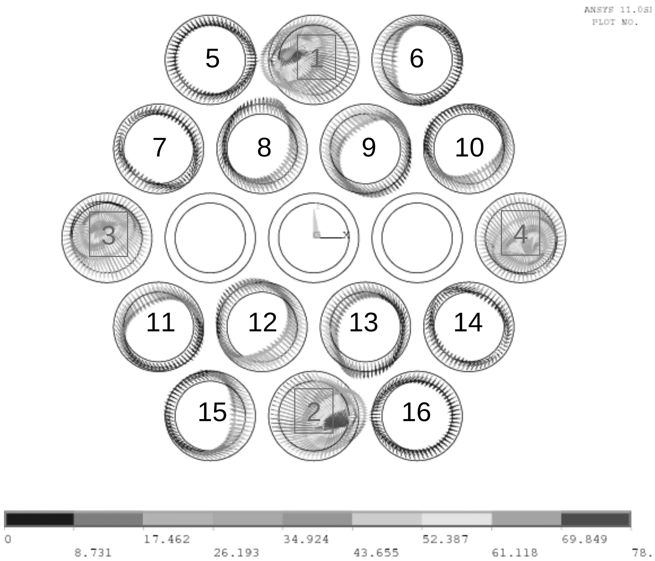


Figure 9 Electro mechanical forces on the cable structure

Table 3 Electro mechanical forces on each cable

| Cable | Force [N/m] | Cable | Force [N/m] |
|---|---|---|---|
| 1 | 5,08E+03 | 9 | 2,65E+03 |
| 2 | 5,08E+03 | 10 | 1,82E+03 |
| 3 | 2,26E+03 | 11 | 1,82E+03 |
| 4 | 2,26E+03 | 12 | 2,65E+03 |
| 5 | 8,00E+02 | 13 | 1,96E+03 |
| 6 | 1,92E+03 | 14 | 1,25E+02 |
| 7 | 1,25E+02 | 15 | 1,92E+03 |
| 8 | 1,96E+03 | 16 | 8,01E+02 |

The induced voltage on the cable during operation is governed by the ratio of magnetic flux and time, where the magnetic flux can be calculated from the product of integrated magnetic field and the length. With these equations a corresponding voltage 2.7033×10-2 V/m and 2.6058×10-2 V/m can be found with a time interval of 0.412 sec.

## CONCLUSION

The theoretic investigations have shown that this design for a cold electrical connection is a reliable approach for connecting the current feed box with the SIS100 machine at FAIR. For the further validation of the design a prototype have to be produced and investigated by testing to approve the heat transfer and the mechanical stability in any of the operating cycles.

## ACKNOWLEDGEMENT

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