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SIS100 By-pass line - from the sketch into the tunnel

Marcin Bernat[3], Thomas Eisel[1], Artur Iluk[2], Marion Kauschke[1*], Katharina Kopp[1], Branislav Streicher[1], Marcin Urbaniak[3*], Pawel Wójcik[2**]**

[1] CRY, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
[2] Wrocław University of Science and Technology, Wroclaw, Poland
[3]KRIOSYSTEM Sp. z o.o Wroclaw, Poland

[*]E-mail: M.Kauschke@gsi.de
[**]E-mail: pawel.wojcik@pwr.edu.pl
[***]E-mail: marcin.bernat@kriosystem.com.pl

Abstract. In Darmstadt, Germany, the Facility for Antiproton and Ion Research (FAIR) is presently under construction. One of the most complex machines is the SIS100, a synchrotron with a circumference of 1100 metres. Since the accelerating structures for heavy ions are normal conducting and have to be operated at room temperature a cryogenic by-pass line is required to by-pass these warm components.
The by-pass line provides continuity around the synchrotron for liquid helium and houses the superconducting bus bars for the electric current.
This 300m long by-pass line system has been developed in close collaboration between GSI and the Wrocław University of Science and Technology (WUST). The design must fulfil both the mechanical requirements of the overall system in respect of interfaces to other components and the demanding requirements for the arrangement of the bus bars.
The magnet system of SIS100 will be a fast-ramped from a few hundred amperes to almost 14 kA within 0.5 seconds. The bus bars must therefore be both stable against electromagnetic forces and flexible to compensate for thermal shrinkage.
Following an intensiv design phase, the production responsibilities were assigned to Kriosystem. After the production of the first prototype, the complete series of 27 diverse by-pass line modules, consisting of 5 main layout, was finalised.
This article summarises some of the challenges during design and production phase, tests which were successfully carried out and, last but not least, the installation in the tunnel. Furthermore, an outlook is given on the upcoming final assembly and connection to the magnets.

1. FAIR

The international contract for the Facility for Antiproton and Ion Research (FAIR) [1] was signed 2010; nine countries have agreed to contribute components to FAIR to create a leading heavy ion research facility for their scientists. In this construction stage, FAIR comprises two superconducting machines which require a local infrastructure for the cryogenic supply of the magnet system. During the foundation phase of the FAIR GmbH Poland made its Expression of Interest for the components of the local cryogenic system.

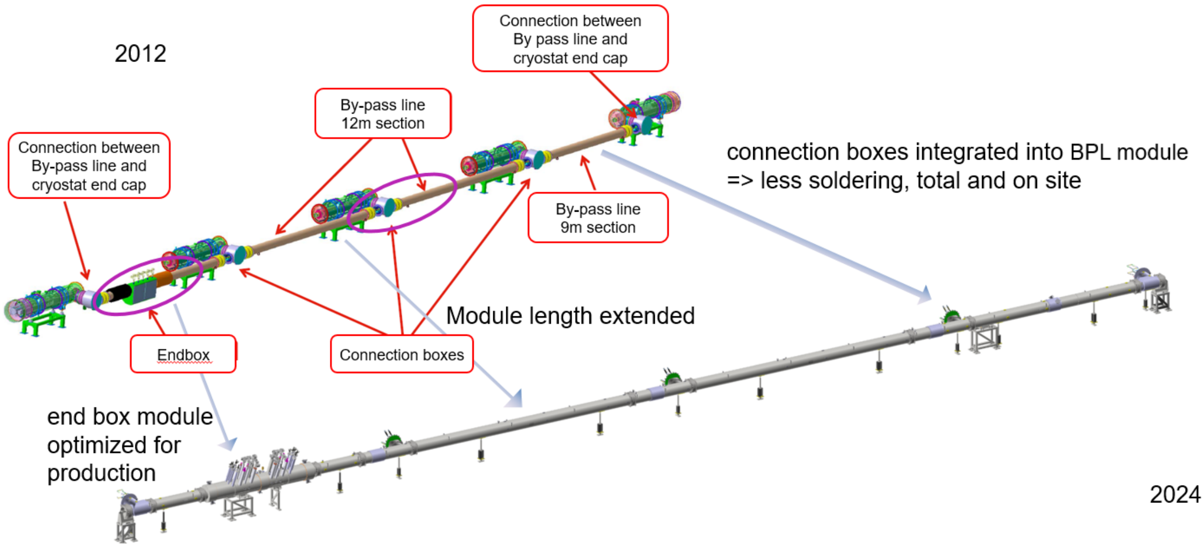

Figure 1. Evolution of the by-pass line design.

The heavy ion synchrotron (SchwerIonenSynchrotron SIS100) is split into sextants; between the six cold arcs, warm beam line sections for the acceleration components are needed. As for current and liquid helium supply, so called by-pass lines to by-pass the warm components are needed.

The first by-pass line design of 2012 has been the base for the main parameters for the layout of the building's construction [2].

In Figure 1 the preliminary design [3], [4] is compared with the now realised design [4].

2. Production

The magnets of the SIS100 are constructed from a superconducting cable based on the development of the Nuclotron [6]. Therefore, the by-pass line uses the same cable, which is internally cooled by helium at two-phase conditions. Each by-pass line module consists of 4 pairs electrical bus bars (for 4 solenoid families) but only one hydraulic circuit. Ceramic voltage breakers electrically insulate the bus bars from each other, see Figure 2. During of the project, more and more knowledge about the bus bar system was gathered.

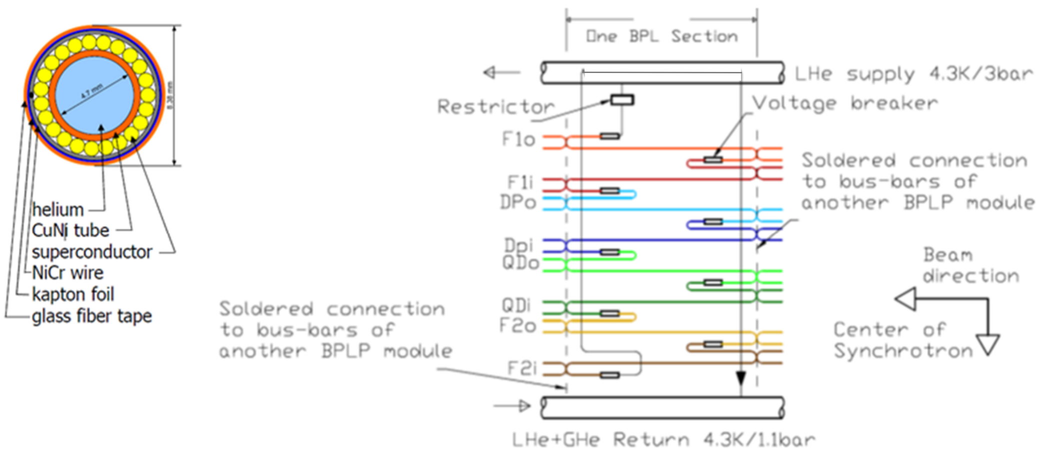

Figure 2. Left: superconducting cable; right: electrical and hydraulic circuits in by-pass line module


Figure 3. Compensation lyre for the compensation of the thermal shrinkage; left test set-up, right realisation for the 4 pairs of bus bar integrated in the BPL module.

Analogue to the magnet system, each hydraulic circuit uses a capillary tube as hydraulic resistor at the inlet to ensure that the pressure drop is matched to the operation of the dipoles [7]. The heat load to the sub-cooled supply line in each module is compensated by an internal re-cooler as for the magnets.

During the development of the SIS100 superconducting system, the soldering of the bus bar connections was tested and approved. Nevertheless, the aim for the design was to minimise the soldering, both on site during machine assembly and overall, in order to achieve higher reliability, as soldered joints have a much higher electrical resistance than the superconducting bus bars and thus increase the risk of quenches.

A reduction of nearly 50% was achieved by integrating the connection box into the modules, as the bus bars can be realised in longer hydraulic circuits without interconnection to the connection box. But this also increased the BPL length to up to 13 m so that a horizontal transport into the tunnel is not feasible.

Thus, the risk of tilting a by-pass line module was compared with the reduction of connections. Finally, the connection boxes were integrated into the modules and special modification of the transport covers allow the tilting by 30° during the transport into the tunnel.

2.1 Bus bar processing and finishing

The longest by-pass line modules are 13 m, so the thermal shrinkage of the bus bars is significant and must be compensated properly. Considering the bending radius limitations of the bus bar and that the two bus bars of the same circuit have to be touch a lyre with horizontally aligned bus bars was chosen [8]. A prototype was tested at nitrogen temperatures and the forces have been measured in order to estimate the impact to the ceramic insulators. In
Figure **3** the test set-up as well as the realisation in the by-pass line is shown. In order to compensate the strong repulsive forces between the bus bars of one pair and hinder the resulting movements, each pair is clamped to each other. These clamps are designed in different ways, for the various positions within the module [9]. During the SAT tests the design could be proven to be sufficient to reach the required ramp rates.

2.2 Endbox

Valves connect the supply and return lines at the end of each sextant allow cool down and warm-up of each individual sextant.

A further ring accelerator, SIS300, with the same diameter is planned above the SIS100 in future. Hence, the design of the endbox has to consider, the required space for the future

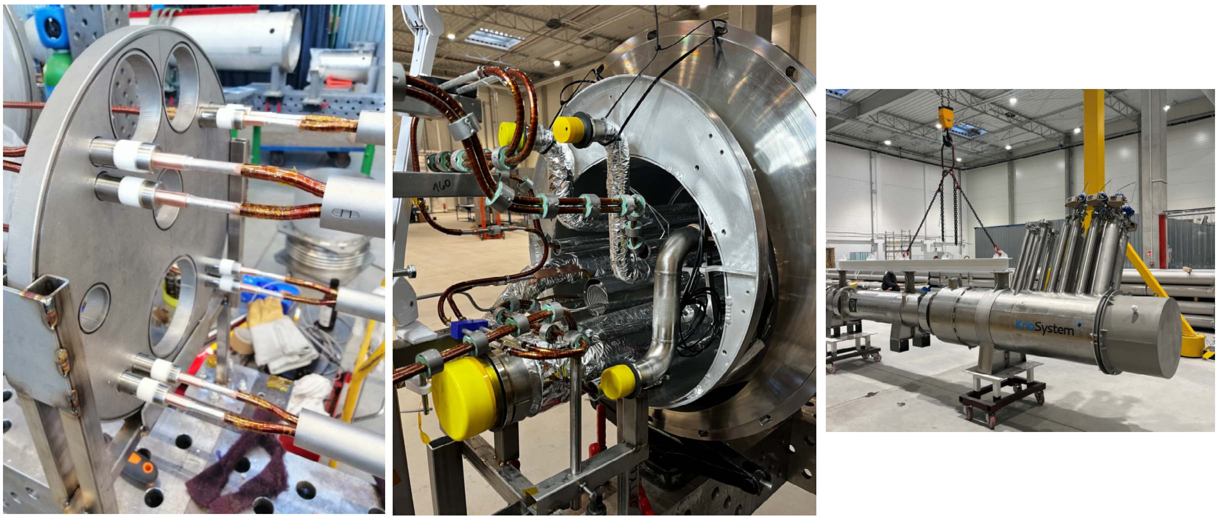

Figure 4. Production of end box; left: ceramic insulated feed throughs in the vacuum barrier, middle: bus bar bending avoiding connection boxes, right: transport

installation. In the first design, the endbox would have been positioned further outwards (see Figure 1). In the realised design the valves are installed at an angle of 25°.

Due to the radiation in the SIS100 Vespel as a sealing material for the valves has to be chosen, which has a higher resistance to radiation than standard polymers. Figure 4 shows a small impression of the production steps of an endbox. Particular attention must be paid to the absence of force on the ceramic components, in this case the feedthroughs of the vacuum barriers. Special tools are required for this, as the forces are only equalised in the final assembly.

During the production of the endboxes, it became apparent that the valves were leaking. This is particularly critical for the valves, connecting the 50-80 K circuit with the 4.6 K circuit. The examination with an endoscope revealed scratches in the valve seat, see Figure 5. As the valve seat could only be replaced by completely dismantling the endbox, which risked the electrical integrity

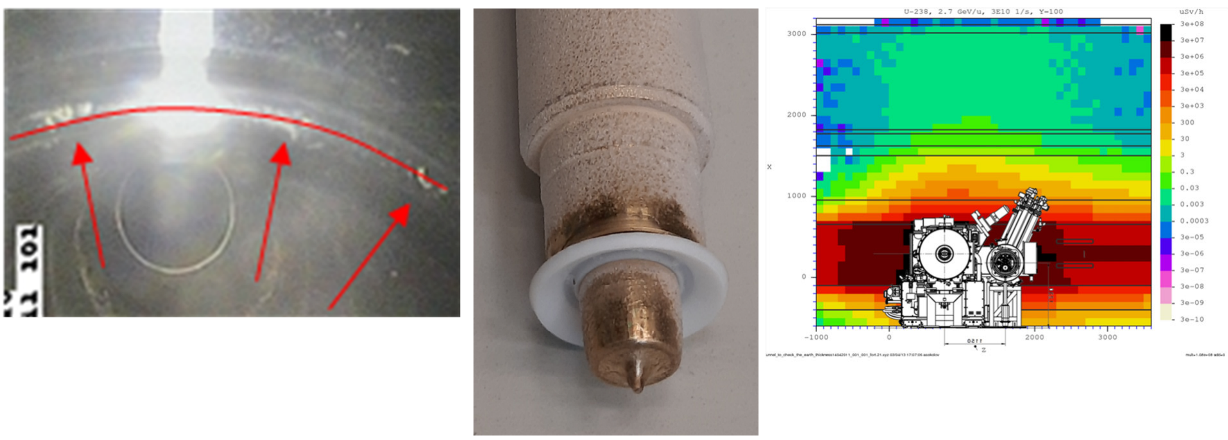

Figure 5. left: inspection of the valve seats by borescope; middle: trial set-up with Teflon sealing, right: radiation exposure in the tunnel (~2 Gy/a)

Table 1. Heat loads of different by-pass modules; for three of the module type the calculated heat load were measured at the serial test facility at GSI. The given heat loads are only static loads; the dynamic loads of the bus bar system has been measured separately: 0.055 W/m bus bar, 0.25 W/joint

Type	Amount	@4K		@50K	
		Calc. [W/pc]	Tested [W/pc]	Calc. [W/pc]	Tested [W/pc]
Standard BPL piece (13m)	12	15	15	70	79
Short BPL piece (9m) incl. Vacuum barriers	6	17		50	
Short BPL piece (9m) incl. Vacuum barrier	3	17	17	50	71
Very short BPL piece incl. Vacuum barrier	3	15		50	
BPL incl endbox incl. Vacuum barriers	3	40	48	120	< 85

of the bus bar system, a test was carried out using a hand-made Teflon seal. As it was shown that this Teflon seal could reduce the leakage rate, the radiation exposure was analysed at precisely this endbox location and it was determined that, this damaged endbox is positioned at a location with low exposure of ~ 2 kGy/a). A reduced service life is therefore accepted for these valves, and standard tips with Teflon sealings were implemented.

2.3 Production schedule

The production of the 30 by-pass line modules lasted from 2021 to mid-2024. Modules of a similar type were produced in series, so that the installation of the first sector including an endbox,

Figure 6. Installation of the by-pass line at semi-final position on temporary supports (top); installation of accelerator components-room temperature cavities- in front of the line (buttom)

could only take place after the entire production had been completed. During the production phase the heat load of similar types was measured at the serial test facility at GSI and compared to the assumed values of the heat load table as a base for the overall cryogenic supply system. The values are given in Table 1.

3. Installation

The by-pass line is mounted on the outer side of the accelerator. It is not possible to lift the by-pass line above other accelerator components for space reasons. The by-pass line must therefore be inserted first and parked in a semi-final position. After the magnets have been mounted and aligned, the by-pass line will be finally integrated; the process lines will be welded towards the magnets and the bus bar circuits will be soldered.

4. Conclusion

Production of the by-pass line was successfully completed and the first modules were installed in a semi-final position as planned. In Figure 6 the already installed by-pass line in sector 4 is shown. The bunch compression systems is placed in front of the by-pass line and construction of the SIS100 will continue. As part of this project, the design of the bus bar clamps and several production steps of the bus bar system were optimised and can thus improve the further production of cryogenic components for the SIS100 and other projects using internally cooled superconducting cable.

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