SIS100 FAST RAMPED MAGNETS AND THEIR CRYOPUMP FUNCTIONALITY FOR THE OPERATION WITH HIGH INTENSITY INTERMEDIATE CHARGE STATE HEAVY IONS

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Abstract

The FAIR SIS100 accelerator at GSI Darmstadt will be equipped with fast ramped superconducting magnets. The high current Uranium beam modes with intermediate charge states, require ultra low vacuum pressures which can be achieved in long term operation only by cold beam pipes acting as a cryopump with stable temperatures well below 15 K for all operating cycles. The straightforward layout for reliable cooling usually conflicts with an efficient design for fast ramped superconducting accelerator magnets, strongly affected by AC loss generation, field distortion and mechanical stability problems. A full functional vacuum chamber design for SIS100 has to take into account all these conflicting boundary conditions and trade off between mechanical stability, acceptable field distortions, AC loss minimisation and achievable temperatures. We discuss the cooling conditions for the dipoles and for the beam pipe including first test results. The analysis of the principal design aspects for the vacuum chamber with respect to the magnets operation parameters and an integral design approach are given. We present a technological feasible solution for model testing and full scale manufacturing.

INTRODUCTION

SIS100, the heavy ion synchrotron (rigidity 100 Tm), utilises superconducting magnets providing a field of 2 T (dipole), ramped with a cycle frequency of 1 Hz (4 T/s). The magnets have to be operated at 4.5 K and use Nuclotron type cables. In this cable the superconducting wires are wrapped around a tube which is cooled by a two phase forced helium flow [1]. The coil is hold mechanical tight by the cold iron yoke, cooled in series with the coil. The magnets create heat when they are ramped due to hysteresis and eddy current effects. With respect to the first prototype dipole, a new one (called CSLD) shall be build near to series production design and will incorporate a curved, single layer coil topology. The higher cooling limits allow to use the space of the former inner coil layer to enlarge the dipole aperture for an increased field quality and for a stable vacuum chamber design [2]. The coil is made of the high current cable with lower hydraulic resistivity and reduced AC losses using new NbTi strands with a Cu-Mn interfilamentary matrix. The curved 3 m long magnet will have a bending angle of 3 1/3 deg. The vacuum chamber has to provide the following functionalities [3]:

1. the vacuum chamber wall temperature must be sufficiently low to use it as an efficient cryopump
2. minimise the eddy currents induced by the ramped field to an acceptable level so that the field distortion and the dissipated power are tolerable (by geometrical design and material choice)
3. be sufficiently mechanical stable to sustain a pressure of 1 bar so that a break of the cryostat pressure will not damage the whole machine
4. provide a return path for the beam image current and
5. shield the beam from the outside (skin depth).

Given that the surface temperature of the beam pipe is a major issue for the cryopump performance of the vacuum chamber, there are two principal approaches to stabilise its temperature field during ramping: 1. using an additional coolant circuit, independent from magnet cooling or 2. by providing a well defined thermal and mechanical contact of the vacuum chamber to the yoke. The former straightforward approach was based on a vacuum chamber given in [4], the latter one was discussed first in [5, 3, 6]. It simplifies design and operation, but must be carefully assembled.

VACUUM REQUIREMENTS

Intermediate charge state heavy ions (U^{28+}) are used for beams with up to $5 \cdot 10^{-11}$ heavy ions per cycle. These also restrict the incoherent space charge tune shift, but their ionisation cross section is large for collisions with residual gas atoms. If the ions of the particle beam hit the chamber wall, the cryopumped gas could be desorbed and generate pressure bumps leadings to possible further beam loss, owed to the enhanced cross section of the intermediate charge states. A peaked distribution of the expected ionisation beam is reached in a charge separator lattice [7], which allows installing an efficient ion catcher system to control ionisation beam loss and to suppress the unwanted desorption of cryopumped gas. The peaks of the ionisation beam loss distribution are located in between two quadrupoles of the doublet lattice. The vacuum chamber, used as effective croyopump, provides high pumping speed and thus the beam loss can be localised [8]. During beam operation the residual gas spectrum will be dominated by CO and CO_2 and other desorbed molecules, whose cross section is roughly at least 100 times higher than for hydrogen. The ionisation beam loss can be minimised providing a high linear pumping speed for all critical gases. This,

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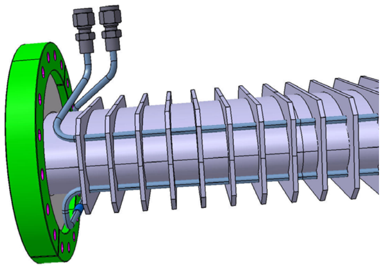

Figure 1: Vacuum chamber with mechanical stabilising ribs and the additional cooling scheme on the beam pipe.

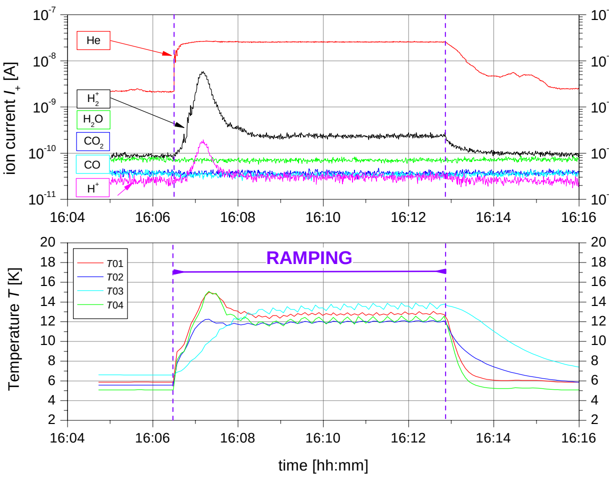

Figure 2: Chamber temperatures and partial pressure conditions during magnet ramping with 4 T/s between 0 - B_{max} - 0 with a repetition rate of 0.5 Hz.

in turn requires vacuum chamber temperatures below ($<$ 15K), where the partial pressure of these gases are below 10^{-12} mbar; due to the lower ionisation cross section of hydrogen its initial hydrogen partial pressure can be 10^{-10} mbar. Thus the pumping cryocatcher chamber and the magnet vacuum chambers stabilise effectively the residual gas pressure during operation. The ramping field induces eddy currents, and heats up the chambers, so they must be cooled efficiently.

TEST RESULTS

A vacuum chamber, cooled by a forced helium flow within an additional circuit was built and tested experimentally in the first prototype dipole [9]. It consists of four longitudinal tubes serial connected and located on optimised positions on the beam pipe [10] (see Fig. 1).

The magnet was operated in the different cycling modes of the machine [11]. The vacuum chamber surface temperature was measured at critical hot spot positions of the vacuum chamber (T01, T02 ... T04, see Fig. 2). One can see that the chamber walls heat up from 5 to 6.8K to maximum temperatures of 12 to 14K immediately. At these temperatures only He and H_2 desorb from the chamber walls.

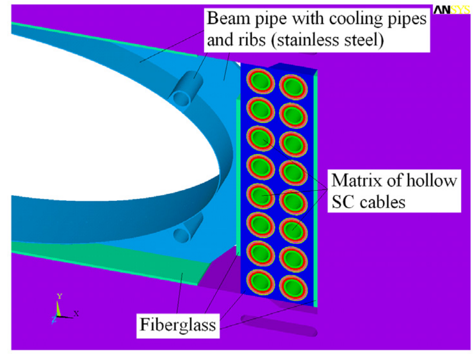

Figure 3: FEM magnet – vacuum chamber model.

All other residual gases remain stuck to the cold surface. Only Helium desorbs completely from the wall, indicating that He can not be removed by wall-pumping during machine operation. Therefore, auxiliary pumps are needed for He. In contrast, H_2 desorbs intensively only after ramping starts. After passing a short-term maximum the hydrogen partial pressure declines again to twice the initial value. From this finding one can conclude that the vacuum chamber meets the requirements on cryopumping properties even under dynamic conditions. Adjusting the necessary coolant flow, similar results were obtained for the other operation cycles proving the design concept based on additional cooling tubes is suitable for SIS100 machine.

RECOOLING BY CONTACT

First FEM calculations showed that the vacuum chamber can be cooled by the yoke if a proper contact is made between them [5] (see Fig. 3) and the cooling power available is sufficiently large, as is the case for the foreseen dipole. The manufacturing of the vacuum chamber with the additional cooling tubes is tedious as well as it either adds an additional hydraulic resistance to the cooling circuit, or if this option is properly implemented, requires its own dedicated cooling line in the SIS100 ring, further complicating the cryogenic layout. Given that the temperatures, required to achieve, are modest, and are higher than the yoke temperatures, the vacuum chamber can be contacted to the yoke and the coil. This concept ensures that: the cryogenic layout is simplified and the contact between the vacuum chamber and the magnet yoke is well defined.

Springs, welded to the vacuum chamber ribs, and thin layers of copper provide thermal paths (see Fig. 4). The additional cooling tubes, sources of large eddy currents and thus field inhomogeneity and losses [3], are not required any more. These modifications change the rib, a simple piece of stainless steel to a high end technological product. Two production processes are foreseen: The stainless steel piece is fabricated (stainless steel, 3 mm thick, punched or laser cut) next to the beam pipe (stainless steel 0.3 mm), and the end flanges. Only the ribs, which will be finally within the "2D" field of the magnet (i.e. $B_z \approx 0$), will be

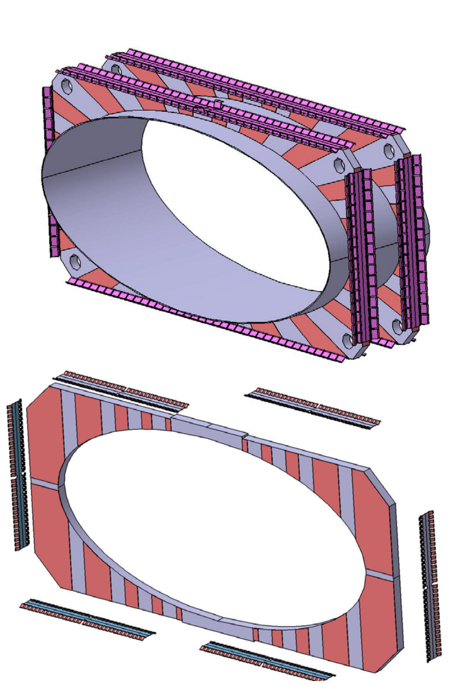

Figure 4: The vacuum chamber adapted for contact cooling. Only 2 periods are shown. The copper paths are given in red.

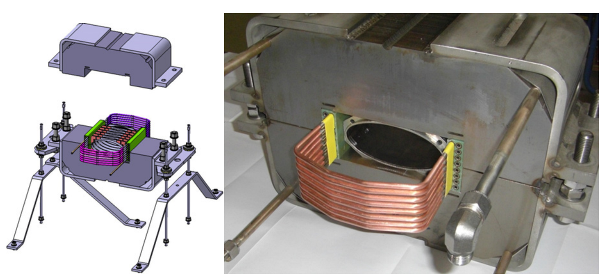

Figure 5: The vacuum chamber direct cooling test setup.

coated with two layers (8 μm Ni + 45 μm Cu), after face masking the missing areas. Afterwards the contact springs (stainless steel 0.15 mm coated with 8 μm Ni + 20 μm Cu or Ag) are welded on the rib. In the end the ribs are stapled on the beam pipe and the end flanges are welded on the pipe. Finally the beam pipe is cleaned so that it will fulfil its ultra high vacuum purposes. Analytical calculations show that the copper paths can transport 600 W accepting a temperature increase of 5 degrees over the rib, while additional 6 W are induced in the rib. The two values can be further adjusted choosing the thickness of the Cu layer.

This contact cooled vacuum chamber has highly favourable properties. The critical property is the thermal contact resistance achieved between the vacuum chamber and the yoke (see Fig. 5). A segment of the vacuum chamber was used, and the cooling pipes removed. The contact springs are made of 0.1 mm stainless steel foil, spot-welded to the rib. Afterwords 50 μm thick copper foils were vacuum brazed. Finally the foil was cut and bent to form the springs. Further a heater was added next to a simple coil, allowing to power the magnet.

CONCLUSION

The vacuum chamber of a superconducting fast ramped synchrotron has to fulfil a bunch of antagonistic requirements. A first vacuum chamber was built and tested reaching the required temperatures but generating significant additional loss next to large field distortions.

Alternatively the beam pipe can be contacted to the coil and the yoke, and will then be cooled by these parts. Estimates look promising, a first mockup model was assembled and will be tested next month. This concept will generate less AC losses as well as better field quality then the former next to a higher mechanical stability. Both cooling modes will be tested in the first built CSLD dipole.

The contribution of the dipole chamber to the stabilisation of the dynamic vacuum will be investigated in more detail within the next month, after the upgrade of the Strahlsim code has been completed and special and time resolved pressure calculations may be performed. Chamber temperatures sufficiently low for hydrogen pumping should be less important, since the cross sections for Hydrogen are significantly lower. The average hydrogen pressure can be guaranteed also by a system of adsorption pumps in between each second dipole pair.

REFERENCES

[1] E. Fischer *et al.* "Supercon. SIS100 prototype magnets design, test results" MT21, Hefei, China, October 2009

[2] E. Fischer *et al.* In *WAMSDO Workshop*, pp. 147–156. CERN, January 2009.

[3] E. Fischer *et al.* "Impact of the beam pipe design on the operation parameters of the superconducting magnets for the SIS100 synchrotron of the FAIR project", EUCAS09, September 2009.

[4] S. Wilfert, S. and K. Keutel, "Kryogene Vakuumkammern für SIS 100/300 ", Otto-von-Guericke-Universität, Magdeburg, Germany, 2004

[5] E. Fischer, R. Kurnishov, and P. Shcherbakov. "Coupled electromagnetic-thermal effects analysis in supercon. acc. magnets" In EUCAS07, Bruxelles, Scotland 2007

[6] E. Fischer, K. Macavei, and A. Mierau. GSI MT Internal Note: MT-INT-EF-2009-001, October 2009.

[7] P. Spiller "SIS100 Lattice Optimization and Dedicated Collimation System for Ionization Losses", ICFA'04, 2004.

[8] P. Puppel *et al.*, MOPEC058, this conference.

[9] E. Fischer, *et al.* "Thermodynamic properties of fast ramped superconducting accelerator magnets for the FAIR project". CEC-ICEC, Tuscon, Arizona, June 2009.

[10] S. Y. Shim *et al.* "Thermal analysis of UHV beam tube of SIS100 for FAIR". CEC-ICEC, Seoul, Korea July 2008.

[11] FAIR - Facility for Antiprotons and Ion Research, Technical Design Report, Synchrotron SIS100, GSI, December 2008.