TESTING OF THE FIRST OF SERIES QUADRUPOLE DOUBLET MODULE FOR THE SIS100 SYNCHROTRON

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Abstract

A new international facility for antiproton and ion research (FAIR) is currently under construction in Darmstadt, Germany. The high intensity primary beam required for different research experiments will be provided by the SIS100 heavy ion synchrotron. The synchrotron is composed of fast cycling superconducting magnets from which about 300 will be integrated in Quadrupole Doublet Modules. Each module consists of two units composed of a quadrupole and corrector magnets.

The First of Series Quadrupole Doublet Module was delivered to the test facility at GSI in November 2019. The assembled doublet was subjected to a dedicated test program to verify the functionality of the module components at cryogenic temperature and operating conditions. The results obtained during the testing campaign are presented.

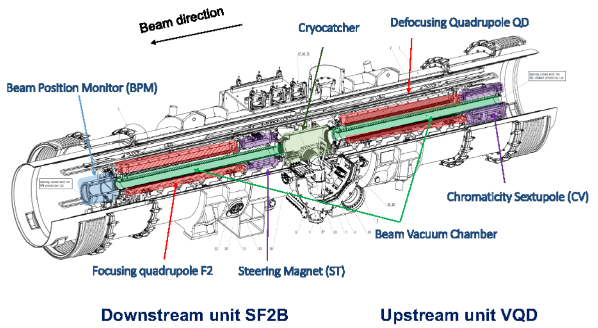

Figure 1: Schematic drawing of the FoS QDM 2.5. It consists of two quadrupole units, two beam vacuum chambers, a cryocatcher, and a beam position monitor.

INTRODUCTION

The Facility for Antiproton and Ion Research (FAIR) is a new accelerator complex which is currently being build at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany [1]. The experiments conducted at FAIR will cover a wide spectrum of topics ranging from fundamental questions of the evolution of the universe to the structure of matter. The main accelerator at the FAIR complex is the SIS100 heavy-ion synchrotron [2] which utilizes fast-cycling superconducting magnets operated at cryogenic temperatures to guide the particle beam. The SIS100 synchrotron will provide high energy and, in particular, high intensity beams [3]. The ring of the syncrotron consists of 417 superconducting magnets assembled in 190 cryogenic modules of which 83 will be quadrupole doublet modules. In order to prove the manufacturing quality and the functionallity of the module components, each magnet was subjected to an intensive testing program at both ambient and cryogenic conditions.

SIS100 FIRST OF SERIES QUADRUPOLE DOUBLET MODULE

All superconducting magnets of the SIS100 except for the dipoles are assembled in quadrupole units which are integrated in pairs into QDMs [4]. Each quadrupole unit consists of a main quadrupole magnet and up to two corrector magnets. There are 17 different configurations of the quadrupole units and 11 different QDM types. The modules can be subdivided into two groups: QDMs for the arc sections of SIS100 (including arc termination modules) and QDMs for the straight sections. The FoS QDM tested at GSI is of the type 2.5 [5] and of the arc section of SIS100.

The main parts of the QDM type 2.5 are (see Fig. 1) two quadrupole units, two beam vacuum chambers, a cryocatcher and a Beam Position Monitor (BPM). Looking in the beam direction, the upstream unit is composed by a chromaticity sextupole (CV) and a defocusing quadrupole (QD) and the downstream unit is composed by a steering magnet (a corrector which is built of two embedded dipole coils - one horizontal, the other vertical) (ST) and a focusing quadrupole (F2).

TESTING OF THE FIRST OF SERIES QUADRUPOLE DOUBLET MODULE

The production and testing of the SIS100 quadrupole units is carried out at the Joint Institute for Nuclear Research (JINR) in Russia [4] and the integration of the units into quadrupole doublet modules is contracted with the german company Bilfinger Noell GmbH. In order to qualify the QDMs for the operation of the SIS100 and verify the production quality, as well as acquire data required for the machine control, an extensive testing program was defined.

The testing program for the QDMs consists of the cryogenic tests at room temperature before and after the cold tests) and the tests at 4.5 K. More than 30 parameters are checked in order to verify the production quality regarding the specified values and the safe operation of the SIS100. These parameters include instrumentation check, electrical integrity tests of all circuits, alignment measurements of the cold mass position, leak tests of the process lines and Ultra High Vacuum (UHV) system, powering of the main quadrupoles and corrector magnets and testing of the Local Current Leads (LCLs) [6], quench study, functionality of the UHV system, measurement of the helium mass flow rates and static and dynamic heat load estimation.

Results

The following section is focussed on the most prominent data obtained in the course of the testing of the FoS QDM. Special attention is paid to reproducibility of the most critical parameters for the SIS100 synchrotron operation.

Cold mass position stability The position of the cold mass with respect to the cryostat was measured with a laser tracker. These data provide information for the alignment of the magnets in the SIS100 tunnel. Eight points on the cold mass were measured, four in each side of the module (see Fig. 2). In Table 1 is shown the comparison between the measurements of the cold mass position at 4.5 K on two different thermal cycles. The reproducibility is better than 0.1 mm. The same applies to the comparison between the measurements of the cold mass at 300 K and at 4.5 K presented in Table 2 which shows that the difference on the position at warm and at cold is negligible.

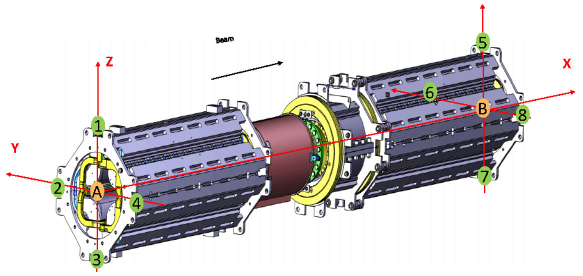

Figure 2: Schematic drawing of the FoS QDM 2.5 cold mass. The cold mass position was measured in eight different points of the FoS QDM.

Table 1: Comparison Between the Measurements of the Cold Mass Position at 4.5 K on Two Different Thermal Cycles

Point	dx (mm)	dy (mm)	dz (mm)
1	-0.011	-0.018	0.001
2	-	-	-
3	0.004	-0.031	-0.041
4	-0.014	-0.017	-0.016
5	0.051	-0.034	0.034
6	0.010	0.024	0.036
7	0.078	-0.023	-0.121
8	0.057	-0.037	0.038

Table 2: Comparison of Two Cold and Warm Mesurements

Point	dy (mm)	dz (mm)
A	-0.008	-0.056
B	-0.108	-0.005

Quench performance study In order to stabilize the coil mechanically, each superconducting magnet is subjected to a training process. The focusing and defocusing quadrupole magnets were ramped above nominal current (10.5 kA). In both cases, the quench performance study revealed a very stable operation with the first quench recorded at a maximum current of 11.6 kA at a ramp rate of 25 kA/s. Also the chromaticity sextupole was ramped and showed a very stable operation reaching the nominal current of 250 A at a ramp rate of 1.225 kA/s (nominal cycling rate) without any quench. In the case of the Steering magnet, the vertical Steerer (SV) showed an excellent performance (when it was powered individually) and it could be successfully operated up to 250 A with cycling rates of 1.225 kA/s. On the other hand, the horizontal Steerer (SH) circuit quenches at high cycling rates. The maximum current tolerated by the SH circuit during cycling at 1.225 kA/s is 200 A. At the cycling rate of 1 000 A/s, the maximum current can be increased up to 200 A in order to have a continuous cycling operation without a quench incident. The study of the simultaneous operation of both coils also showed that the magnet circuits SV/SH are not able to deliver nominal cycling operation without quenching. After these results were obtained, the possible cause of the Steerer performance below nominal values was investigated and it was identified as mechanically not fully fixed coil ends. Reinforced coil ends supports were introduced at the manufacture for the next Steerer magnet, which showed a satisfactory performance at the unit testing.

Cross talk The FoS QDM consists of 5 different magnets closely assembled and ramped simultaneously. If we define one of these magnets that is ramped as a primary magnet, a resultant inductive voltage is formed in a nearby or secondary magnet in its fringe field. A large enough cross-talk across secondary magnets could trigger spurious quench signals. It could also be added to the voltage feedback of the power converters causing complex deviation from the expected current output. In addition, the definition of cross-talk in this discussion is limited to the induction of voltage on the secondary magnet coil due to current in the primary magnet, although cross-talk in general could refer to other voltage induction such as between parallel bus bars. A direct method to quantify the cross-talk signal is to describe it in terms of coupling ratio (r), defined as the ratio of voltage induced in the secondary magnet to that in the primary magnet when it is ramped with a current. Given by the overlapped geometry around a common iron yoke [7], the horizontal and vertical coils in the steering magnet induce maximum cross-talk between each other. The coupling ratio obtained in this case is of the order of 10^{-3}. No strong cross signal was observed on the other magnets to each other. This means that the measured signals are below the standard quench protection threshold voltages and hence, they are not strong enough to cause quenches in the secondary magnets.

AC losses The SIS100 is a fast ramped machine with varying operating cycles. Therefore, the measurement of the AC losses of the magnets for the different machine cycles provides information about the expected heat load in the machine for an efficient operation of the cryoplant.

The highest AC losses in the quadrupole magnets are expected from the triangular cycle (Triangular U^{28+} Cycle (max. energy) [8]) with 1 Hz repetition rate. In the FoS QDM, the AC losses were measured at the SIS100 reference cycle (derived from the triangular cycle with minor changes) for each quadrupole and correctors alone and for the quadrupoles and corrector magnets powered simultaneously. In Fig. 3 is shown the comparison between the values obatined in two different thermal cycles measurements of the AC losses for the quadrupoles alone (blue) and for the quadrupoles and correctors powered simultaneously (orange). In both cases, the values obtained are within the expectation and the reproducibility is verified.

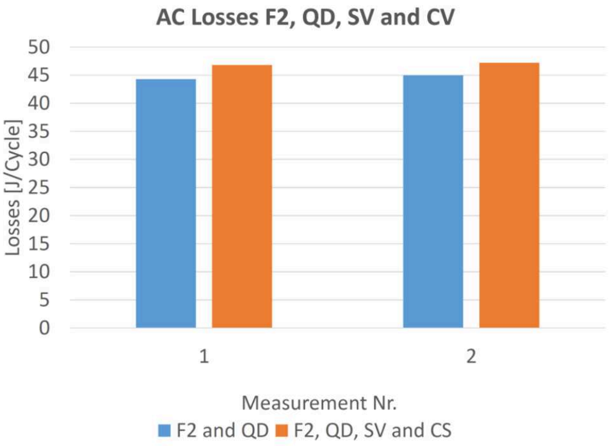

Figure 3: Measurements of the AC losses in two different thermal cycles for the quadrupoles alone (blue) and for the quadrupoles and corrector magnets ramped simultaneously (orange).

Functionality of the UHV system The partial pressure evolution and the temperature in the beam vacuum system has to be controlled in order to avoid H_2 desorption from the UHV chamber walls.

Thus, the quadrupole and corrector magnets were ramped at the SIS100 reference cycle. As one can see in the upper part of Fig. 4, the total pressure on the UHV system was very constant during the magnets ramping. In the lower part of Fig. 4, the recorded temperature data shows that the quadrupole and the the cryo-collimator chamber walls heat up to the theoretically expected temperature values below 10 K during the magnet ramping. Only the temperatures at or near the flanges are above 12 K caused by self-heating due to eddy currents and without active cooling. No H_2 desorption from the UHV chamber walls was observed. Also not active cooling of the BPM was observed with recorded temperatures above 20 K, which ia acceptable.

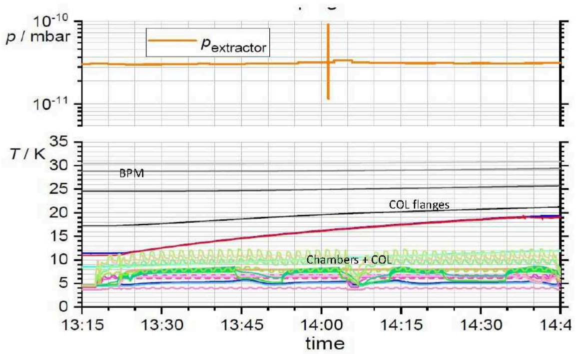

Figure 4: Results for the total pressure (top) and the temperatures (bottom) of the UHV system when the quadrupoles and corrector magnets were ramped at the SIS100 reference cycle.

CONCLUSION

The SIS100 First of Series Quadrupole Doublet Module was delivered to GSI in November 2019. The FoS QDM was subjected to a series of comprehensive functionality tests at ambient and cryogenic temperatures. The results obtain on the measurements after the testing campaign proved that the module design is suitable and the integration was succesfully carried out at the company Bilfinger Noell GmbH. The magnets fulfill most of the specifications and required parameters for a safe operation of the SIS100 synchrotron with the exception of the Steerer magnet performance below the expectation. The possible causes of the Steerer performance below nominal values was investigated after the test program was finished and it was found that the coil head of both Steerer coils was not completely mechanically fixed. This was corrected by the manufacturer during the production of the next Steerer magnet by introducing reinforced coil ends supports, which showed a satisfactory performance at the next units testing.

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