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CRYOGENIC MAGNET TEST FACILITY FOR FAIR

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For testing fast-pulsed superconducting model and pre-series magnets for FAIR (Facility of Antiproton and Ion Research), a cryogenic magnet test facility was built up at GSI. The facility is able to cool either cold masses in a universal cryostat or complete magnets in their own cryo-module. It is possible to operate bath cooled, 2 phase cooled, and supercritical cooled magnets with a maximum current up to 11 kA and a ramp rate up to 14 kA/s. Measurements of magnet heat loss, with calorimetric and a V-I methods, are available, as are quench and magnetic field measurements. Design and functionality of the test facility will be described. Results of measurements with a supercritical cooled magnet and with a 2 phase cooled SIS100 model magnet will be shown.

INTRODUCTION

GSI is building the new accelerator facility FAIR (**F**acility for **A**ntiproton and **I**on **R**esearch) [1] in the east of the existing facilities (see Figure 1).

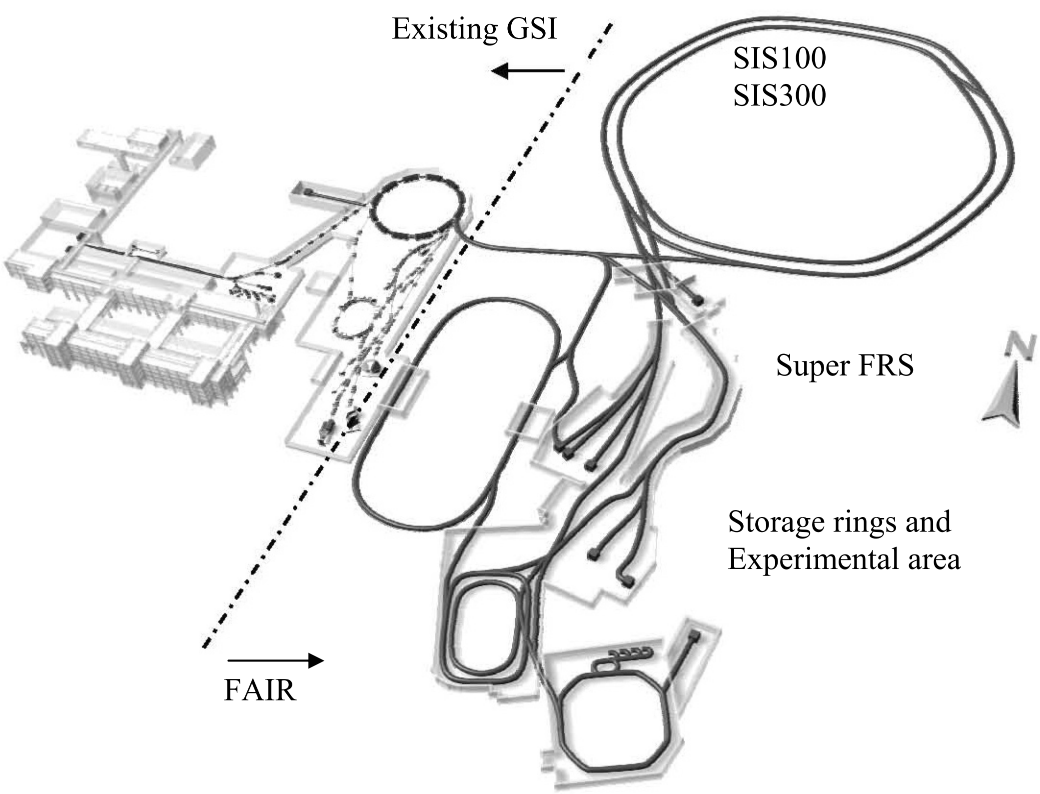

Figure 1 Topology of FAIR in the east of existing GSI

The existing facility will act as an injector for the FAIR. Main component is a twin ring with 2 superconducting heavy ion synchrotrons (SIS100 and SIS300), which will be in a tunnel 20m below ground with a circumstance of 1100m followed by the Super FRS (Super **Fr**agment **S**eparator) and a number of different experimental and collector rings in the south.

In FAIR the SIS100, SIS300 and Super FRS are planned with superconducting magnets. In order to test model-, prototype- and pre-series magnets GSI built the prototype test facility.

SUPERCONDUCTING MAGNETS AT FAIR

SIS100-magnet

This magnet is a window frame, iron dominated magnet. The superconducting wires are wound around a CuNi-tube in which 2 phase helium is flowing to provide the cooling [2]. Ramp rate is up to 4 T/s.

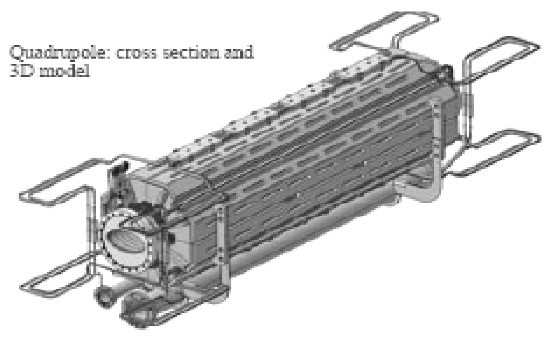

Figure 2 SIS100-quadrupol cold mass model

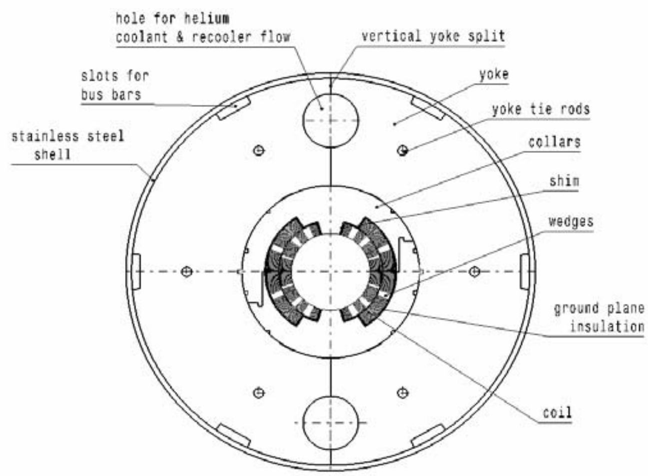

Figure 3 SIS300-dipole cold mass cross section [3]

SIS300-magnet

In this case a "classical" accelerator magnet type will be used. It is a coil dominated cosθ magnet which uses Rutherford cable. The coil is directly cooled by a supercritical helium flow with a high mass flow rate up to 150 g/s. In figure 3 a cross-section of this magnet type is shown. The first magnet tested at GSI was a 4 T straight dipole that was built at Brookhaven [4]. The next straight dipole, a cross section is shown in figure 3, (2 layers, 6 T) should be delivered at the end of this year. The final SIS300 dipole prototype [5] will be a curved one and will operate up to 4.5 T with 1 T/s ramp rate.

Super-FRS-magnets

For Super-FRS bath cooled magnets are planned. For the dipoles only the coil is cooled and the iron will be at warm. For the multiplets (quadrupoles and correctors), both coils and iron will be at 4.5K, which requires cooling down up to 40 t (Figure 5, [6, 7]).

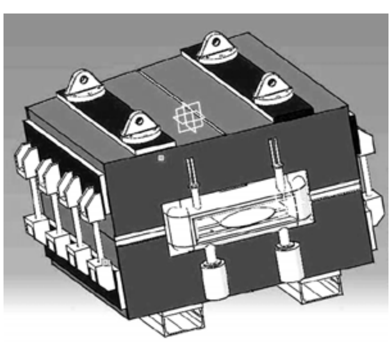

Figure 4 Super FRS-dipole

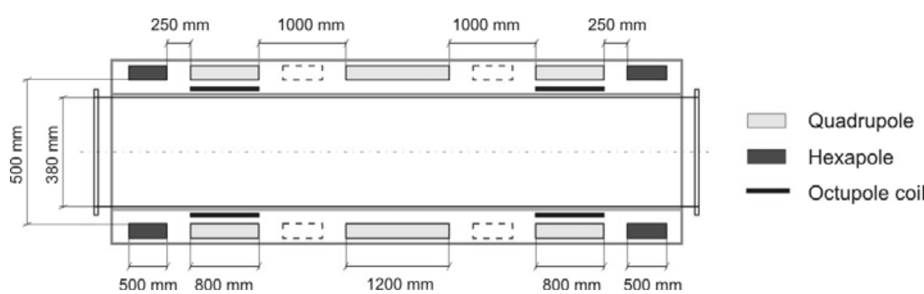

Figure 5 Super FRS-multiplet

PROTOTYPE TEST FACILITY

The first planning of the facility took place in 2001. Since 2006 the test facility is in operation. After several test measurements the first model magnet was installed and tested in September 2006. Figure 6 presents a schematic sketch of the facility.

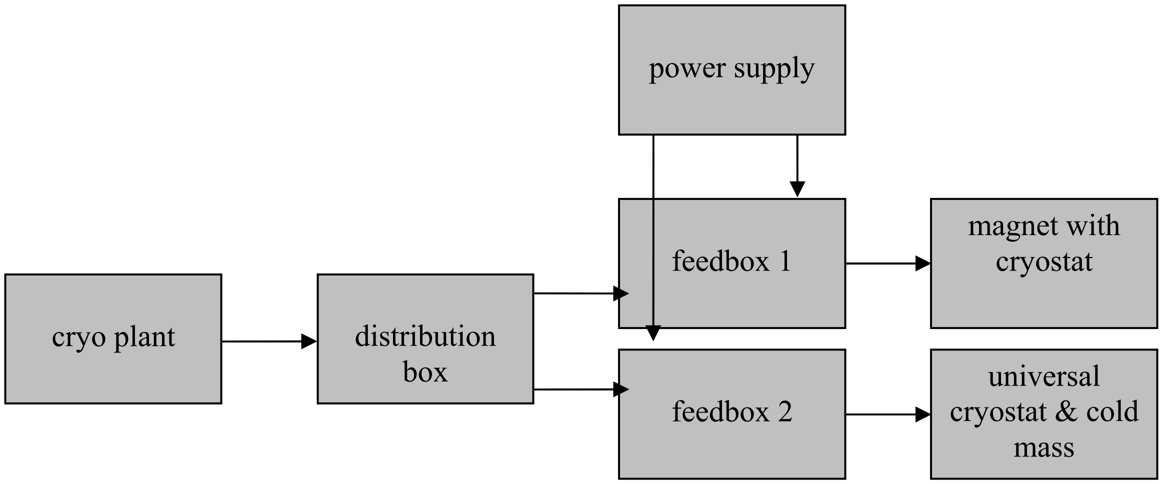

Figure 6 Schematic of the test facility

The cryo plant is a used TCF50 from Linde which is a long term loan by CERN. It has a cooling capacity of about 350 W at 4.5 K. The new distribution box allows not only to distribute the helium, but also to set up the 3 different cooling schemes:

- bath cooling
- 2 phase flow cooling up to 5 g/s
- supercritical cooling up to 200 g/s

The magnet inlet temperature can be varied down to 3.9 K and the inlet pressure from 1.3 to 5 bar. The power supply has a maximum current of 11 kA (100 V) and a maximum ramp rate of 14 kA/s. The feedboxes supply the magnets with helium and electrical current. The current leads are classical vapour-cooled copper leads. They are optimized for 6.5 kA and can operate up to 11 kA. Feedboxes contains "standard measurements" of:

- mass flows (warm and cold)
- temperatures
- pressures

These measured values are used to calculate the cryogenic heat loss of a magnet. Feedbox 1 is foreseen to test magnets with their own cryostats. Feedbox 2 is connected to a universal cyostat, which allows testing of magnet cold masses or other devices.

Additional anti cryostats, which can be installed in the aperture of a magnet, allow magnetic measurements at room temperature in the cold magnet [8]. The facility uses the same qench detection electronics and the same quench acquisition system than those installed at the LHC series test facility.

PRICIPLES

<u>Supercritical cooled magnets (SIS300-type)</u>

By measuring the inlet- and outlet temperatures and pressures (as shown in figure 7) one can calculate the corresponding enthalpy difference. Additionally measuring the mass flow allows calculating the heat loss as:

$$Q_{magnet} = \dot{m}_{He} \cdot \left[h_{out}\left(T_{out}, P_{out}\right) - h_{in}\left(T_{in}, P_{in}\right)\right] \tag{1a}$$

$$\dot{m}_{He} = \sum cold\_mass\_flow\_sensors - \sum warm\_mass - flow\_sensors \tag{1b}$$

<u>2 phase flow cooled magnets (SIS100-type)</u>

In this measurement it is possible to measure the heat loss in the coil and in the yoke separately. For the

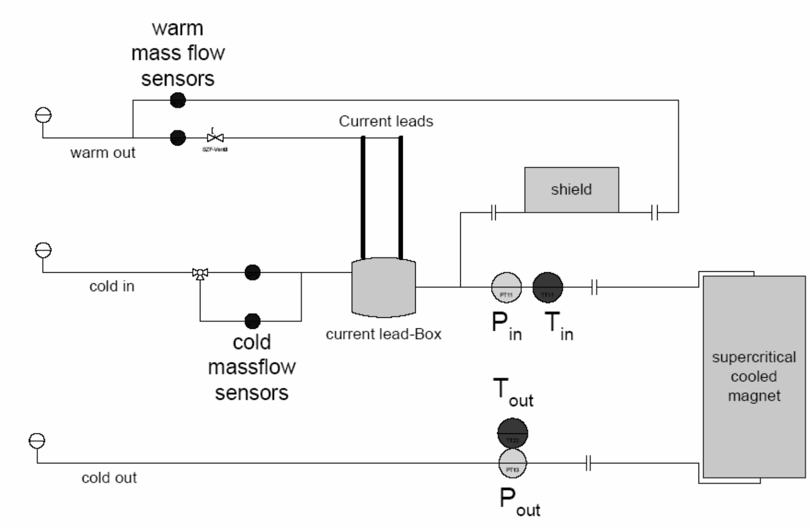

Figure 7 Test setup for testing supercritical cooled magnets

magnet designer this helps to localise the generator of losses. To do so, it is necessary to alter the mass flow to find X=1 (i.e. 100 % helium vapour) at the coil outlet. Which means to reduce the mass flow till T_{cy} starts to be higher than the saturation temperature at this pressure. To measure the mass flow the helium gas at the outlet is overheated by a heater and mass flow is calculated by formula 2a. At coil inlet there is 100 % liquid helium (X=0), by the use of a not shown phase separator. With the assumption that all pressure drop takes place only in the coil, the heat losses can be calculated as followed:

$$\dot{m}_{He} = \frac{Q_{superheating}}{h_{heater\_out}(T_{heater\_out}, P_{out}) - h_{heater\_in}(T_{heater\_in}, P_{out})} \tag{2a}$$

$$Q_{coil} = \dot{m}_{He} \cdot (h_{vapor}(x=1, P_{out}) - h_{liquid}(x=0, P_{in})) \tag{2b}$$

$$Q_{yoke} = \dot{m}_{He} \cdot (h_{out}(T_{out}, P_{out}) - h_{CY}(T_{CY}, P_{out})) \tag{2c}$$

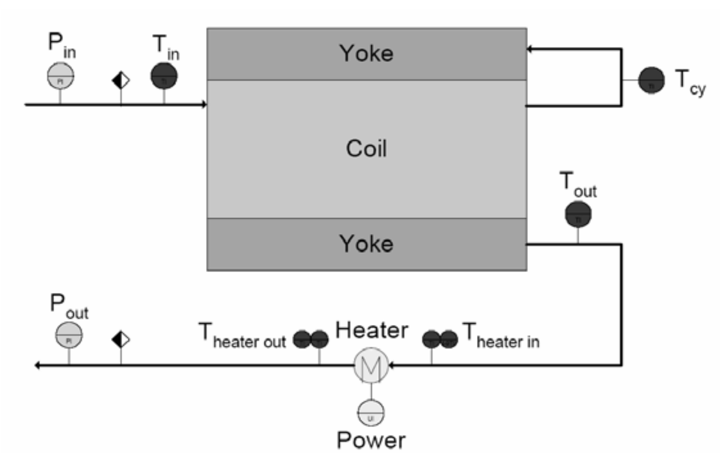

Figure 8 Test setup for testing 2-phase cooled magnets

OTHER MEASUREMENTS

In addition to the calorimetric loss measurement, AC losses were also measured using the V-I-method [9]. The facility also allows a complete measurement of magnet quench behaviour (magnet training, RRR, quench resistance, propagation velocities, and hotspot temperature measurements [10]. The facility is also equipped for magnetic measurements when the magnet is cold.

RESULTS

Supercritical cooled magnets (SIS300-type)

The first magnet tested at our facility was GSI001 [4]. It is a RHIC type dipole whose phenolic spacers were replaced by stainless steel collars. AC losses were measured using the V-I method at BNL in helium bath and at GSI in supercritical helium. These last results were confirmed by calorimetric measurements performed at GSI (figure 9).

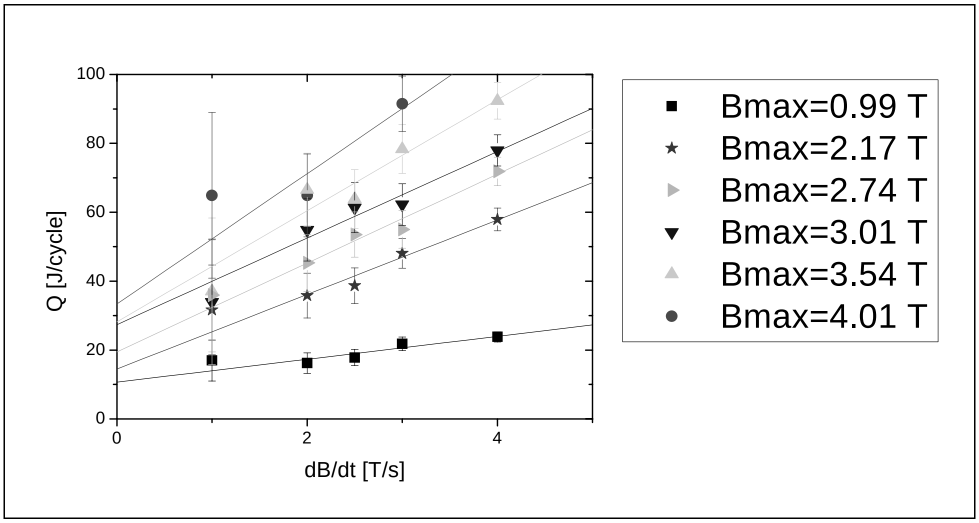

Figure 9 Heat losses of GSI001 for different ramp rates and different Bmax

Figure 10 shows the measured quench current Iq as a function of the ramp rate dB/dt. As seen in figure 10, BNL recorded higher quench currents because the helium bath cooling enables a better thermal transfer than the cooling in supercritical helium [11, 12].

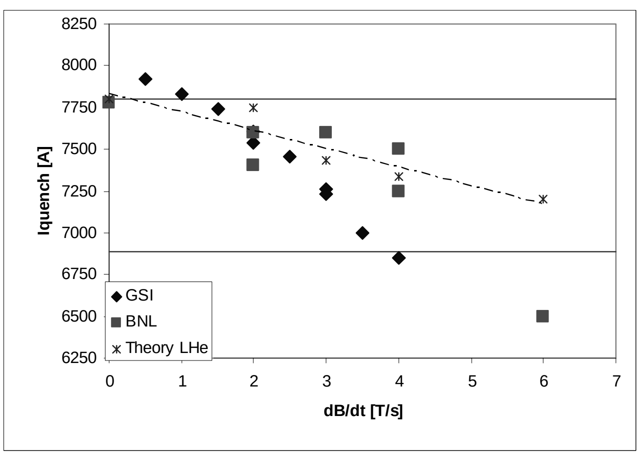

Figure 10 GSI001 ramp rate limitations. The upper line at 7750A gives the value of DC quench current; the lower line at 6775A presents the nominal operating current of the magnet

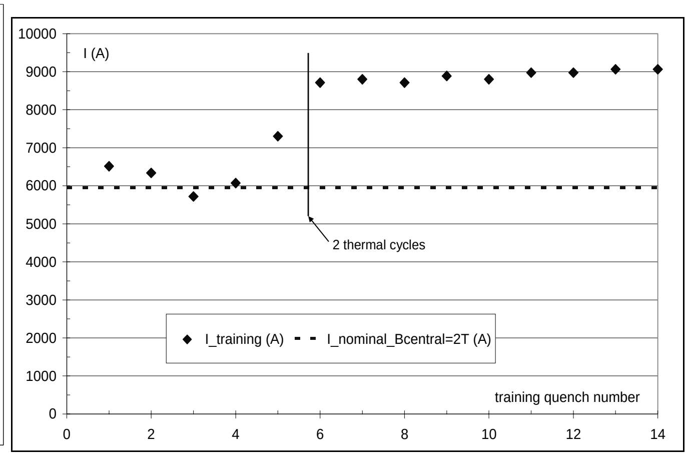

Figure 11 Training of 4KDP6a dipole

2 phase flow cooled magnets (SIS100-type)

The first SIS100 dipole prototype (called 4KDP6a), was tested at GSI test facility after tests at Dubna [13]. This 1.4 m long magnet was manufactured in Dubna and is an upgraded version of Nuclotron magnets. Figure 11 presents the magnet training done in 2 phases separated by 2 thermal cycles.

For a save operation of a 2 phase cooled magnet it is necessary to understand its hydraulic behaviour. To do so the mass flow was measured at different pressure drops and different ramp rates, which is equivalent to different heat losses. Figure 12 compares the experimental results to theoretical calculations. The good fit between computed and measured values, will allow us to better compute mass flow and pressure drops for 3m long dipoles.