COOLING SYSTEM OF THE SIS300 ACCELERATOR

A. Ageev, S. Kozub, S. Zintchenko, V. Zubko, IHEP, Protvino, Russia

Abstract

The Facility for Antiprotons and Ion Research (FAIR) being under construction in Germany as an international project is a cascade of accelerators; two last accelerators from this cascade will be made with the use of superconducting magnets. The large volume of the executed work on the SIS300 superconductive equipment allowed to start the estimation of the basic parameters of SIS300 cooling system. On the base of many research notes and calculations the item-by-item heat load budget at the helium temperature level is composed. Cooling system flow diagram is proposed, the calculated single phase helium temperature profiles along the string of magnets are presented and discussed. Helium flow pressure drop along the string of magnets during cooling down is calculated on the basis of "temperature wave" model and cooling down time of the accelerator is estimated.

GENERAL COOLING SCHEME OF SC MAGNETS

According to [1], all SIS300 magnets will be divided into two equal cryogenic strings, each one to be supplied with separate flow of single-phase helium.

Based on this, following flow scheme is proposed for cryostating the string of superconducting (SC) magnets (Fig.1). In this scheme single-phase (supercritical) helium from the helium refrigerator is cooled in the subcooler and enters the string of the magnets, where it is heated due to the heat leaks and heat release, and simultaneously it is cooled in the heat exchangers located in the dipoles.

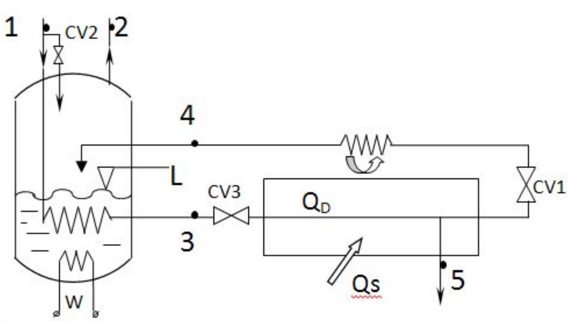

Figure 1: Flow scheme proposed for cryostating the string of SIS300 superconducting magnets.

At the end of the magnet string the single-phase helium is throttled in the J-T valve CV1, and it is converted into two-phase helium, which flows through the dipole heat exchangers of the magnet string into the subcooler. In the subcooler two-phase helium is separated to the vapor and liquid. Liquid helium is used for cooling single-phase helium in the heat exchanger of subcooler and helium vapor returns to the refrigerator.

The flow scheme is considered functional if one of the main conditions for the cryostating is satisfied: the quality factor x of the two-phase flow of helium at the exit from the magnet string is less than or equal to 0.95 (for Fig. 1 $x_4 \leq 0.95$). This is necessary for the stable heat exchange between the two-phase and single-phase flows of helium in the heat exchangers of dipole magnets.

Heat balance equations for the flow scheme in Fig. 1 at the conditions of maintaining the fixed level of liquid helium L by the control valve CV1 (CV2 is closed) and of zero flow rate through the current leads at point 5:

$$G_1 * i_1 + Q_D + Q_S = G_1 * i_2 \quad (1),$$

$$G_1 * i_3 + Q_D + Q_S = G_1 * i_4 \quad (2),$$

where i - enthalpy of helium flow; G_1 – helium mass flow rate; Q_D and Q_S – AC losses and static heat leaks.

From equations (1) and (2):

$$i_4 = i_3 + i_2 - i_1 \quad (3).$$

Equation (3) clearly shows that parameters of helium flow in point 4 at the exit from the magnet string, including its quality factor, do not depend on the heat leaks and heat release values, but depend only on the input/output parameters of the subcooler (points 1 and 2, Fig. 1). For the values given in table 10, using the thermodynamic properties of helium tables [2], one could obtain quality factor at the string exit x_4=0.951, which practically corresponds to the requirement of $x_4 \leq 0.95$. In fact, due to the presence of certain helium flow for cooling of current leads (point 5, Fig. 1), quality factor at the string exit will be below 0.95. This quality factor can be decreased by powering the electric heater W (Fig. 1).

The main part of SIS300 dipoles are about 8m length so for cooling the magnets it was decided to use single-phase (supercritical) helium, which directly washes the single-layer superconducting coil.

In the upper part of the cold mass this dipole magnet the heat exchanger is located, in which single-phase helium is cooled by two-phase helium. Thus, in each dipole magnet the heat released in the superconducting coil is removed by single-phase helium and the heat from the single-phase helium is removed by two-phase helium [3], [4].

Heat load on the cryogenic system from the cryomodules and the multipoles is considerably less in comparison with the load from the dipoles; therefore cooling of the single-phase flow by two-phase flow is not arranged in their designs. This means that in the cryomodules and in the multipoles both the heat release and the heat leak are removed only by single-phase flow.

HEAT LOAD OF SIS300 CRYOGENIC SYSTEM. PARAMETERS OF THE MAIN HELIUM FLOWS

Below we will consider the cryogenic system heat load at the helium temperature level (~4.5 K) only, as the thermal shields heat load at 50-80 K in the allowable range does not effect the functionality of SC magnets.

*Work supported by ROSATOM, contract H.4e.45.03.10.1027

The heat load in question is composed of the heat release in the superconducting coils and in the iron yokes, of the heat release in the beam pipe and of the ambient heat leaks. The heat load is calculated for the most stressed SIS300 magnetic cycle presented in Table 1.

Table 1: Most stressed SIS300 magnetic cycle

Cycle time, s	Maximum field, T	Increase and reduction of magnetic field, s	Flat-top at Bmax, s
17.0	4.5	7.0	10

The specific values of heat releases and heat leaks along particular design elements are determined in different GSI reports and documents, in the communications at the SIS300 project meetings, and also in the course of mutual consultations. Calculated heat loads will be given below, first for the groups of uniform ring elements (Table 2 – Table 8) and then for the system (Table 9).

Table 2: Dipole magnets heat leaks and heat release

Type of the dipole magnet	Long	Short
AC losses	29.7 W	14.8 W
Supports heat leak	2 W	1 W
Cryostats heat leak	5.3 W	2.6 W
Total per dipole	37 W	20.1 W
Number of magnets including the reference ones	49	13
Total heat leaks and heat release	1813 W	261 W

Table 3: Cryomodules and the multipole corrector magnets (multipoles) heat leaks and heat release. Standard cryogenic module contains quadrupole magnet and one/two corrector magnets

Type of the magnet	Cryomodule	Multipole
AC losses	3 W	0.002 W
Supports heat leak	2 W	1 W
Cryostats heat leak	2 W	1 W
Total per article	7 W	2.002 W
Number of articles including two reference quadrupole cryomodule	86	12
Total heat leaks and heat release	602 W	24 W

Table 4: Heat leaks along the beam pipe cold-warm-transitions, along the connections with “warm” equipment

Single transition heat leak	2.5 W
Number of the transitions	48
Vacuum connection heat leak	1.5 W
connection heat leak vacuum connections	54
Safety valve connection heat leak	1 W
Number of the safety valve connections	40
Total heat leaks	241 W

Table 5: Heat release in the superconducting bus bars and beam pipe RF mirror current heat release

Heat release in the superconducting bus bars	566 W
Beam pipe RF mirror current heat release	450 W

Table 6: Heat leaks to the cryogenic transfer lines and to the feed and end boxes. Cryogenic transfer lines include bypass lines with the superconducting bus bars and connecting lines without the superconducting bus bars

Heat leaks to the cryogenic transfer lines	165 W
Heat leaks to the 8 boxes	54 W

Table 7: Heat load from beam position monitors, from HTS current leads and from voltage taps

42 beam position monitors	126 W
10 HTS current leads	18 W
1662 voltage taps	25 W

Table 8: Mass flow rate of liquid helium for cooling the corrector magnets current leads. Heat leaks along the corrector magnets current leads are small and they are not taken into account

Flow rate of liquid helium for cooling the 231 pairs of the corrector magnets current leads	4.53 g/s

Table 9: Total SIS300 heat load at T=4.5 K

AC losses	2472 W
Ambient heat leak	1367 W
Beam pipe RF mirror current heat release	450 W
Total heat load	4289 W
Flow rate of liquid helium for cooling the current leads	4.53 g/s

It follows from tables 2-9 that the largest heat load on the cryogenic system, almost 50%, comes from dipoles, and approximately 70% of dipole heat release is generated directly in the superconducting coil. The static heat leaks account for about 32% of the total heat load.

Table 10 presents SIS300 helium flows parameters which were defined on basis the calculated heat load.

Table 10: SIS300 helium flows parameters

Pressure of supercritical helium at the entrance into the string of magnets	3 bar
Temperature of supercritical helium at the entrance into the subcooler of the string of magnets	4.6 K
Temperature of supercritical helium at the entrance into the string of magnets	4.35 K
Pressure of two-phase helium at the exit from the string of magnets	1.105 bar
Temperature of two-phase helium at the exit from the string of magnets	4.3 K
Two-phase helium flow quality factor at the exit from the string of magnets	≤95%

COOLING DOWN THE SC MAGNETS FROM ROOM TEMPERATURE DOWN TO LIQUID HELIUM TEMPERATURE

All superconducting magnets: dipoles, quadrupoles and correctors are designed taking into account the fact that their longitudinal and transverse temperature gradient can reach the value from 4.5 K to 300 K. It allows to cool "warm" equipment of the SIS300 magnet string directly by liquid single-phase helium, which substantially simplifies the cooling down process.

Besides the equipment, depicted in Fig. 1, the quench header and the technological valves located in the SIS300 tunnel will be used in the cooling down procedure. The technological valves are installed at some intervals along the magnet string and they connect the single-phase helium channel with the quench header. In the ideal case, i.e., when at the magnets inlet is liquid helium, and at the exit is helium gas at an ambient temperature, the flow rate of helium being 100 g/s, the cooling down time will be about 60 hours, which is quite acceptable.

CRYOSTATING THE SC MAGNETS

The superconducting dipole magnet is most heat loaded. Because of this, if for any reasons the superconducting coil of dipole is warmed up to temperature of 5.7 K, then the coil will go into the normal state. Therefore the temperature of the single-phase helium, which cools the superconductive coil of dipole magnet, must not exceed 4.7 K. Experience shows that for the selected superconductor a temperature margin of 1 K is sufficient in most cases to guarantee the stable work of the superconducting dipole.

Each of the cryogenic strings contains three identical groups of magnets, the lattice is shown in Fig. 2. The alternating dipole and quadrupole magnets are located in the arc part of the ring, the separate quadrupoles - in the straight sections.

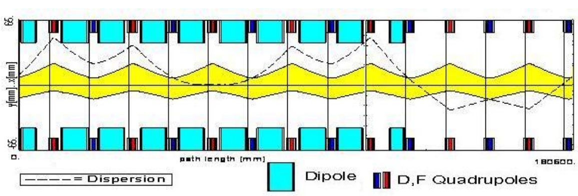

Figure 2: SIS300 magnet lattice.

For this arrangement of magnets the temperature profile of the single-phase flow along the cryogenic string was calculated for two additional heat exchangers of single-phase and two-phase helium flows into the cryogenic string. These heat exchangers (recoolers) are arranged in the first and second superperiods of magnetic structure, between the next-to-last and last quadrupoles. Temperature profile for this modernized cryogenic string is given in Fig. 3.

As it follows from Fig. 3, the temperature of single-phase helium in the dipole magnets of the modernized cryogenic string practically does not exceed value of 4.61K, which assuredly provides the condition for the stable work of dipole magnets (T<4.7 K). It is reached at the "small price" - only four additional heat exchangers for entire SIS300 ring. Moreover these heat exchangers are located in the straight sections, where space is sufficient for their convenient arrangement.

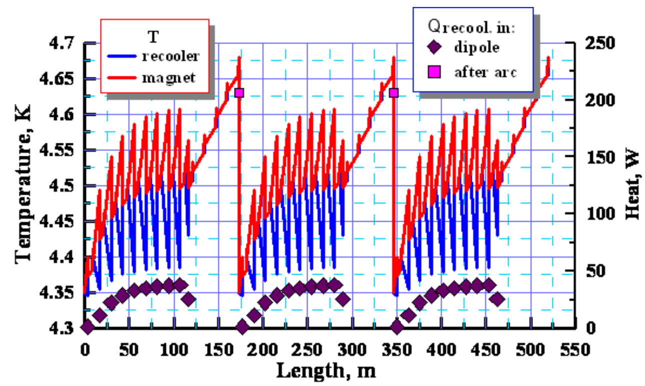

Figure 3: Temperature profile of the single-phase flow along the SIS300 modernized cryogenic string.

CONCLUSION

For the SIS300 accelerator the refined values of heat leaks and heat releases at T=4.5 K are given.

The flow scheme of cryostating the string of the SIS300 magnets is proposed, which makes it possible by sufficiently simple means to regulate the quality factor of the two-phase helium flow.

The time of cooling SIS300 magnets down to the operating temperature is estimated.

It was determined by calculations that it is enough to add to entire SIS300 machine only 4 additional helium heat exchangers (recoolers) to decrease the maximum temperature of single-phase helium flow.

REFERENCES

[1] FAIR Baseline Technical Report, Volume 2. Accelerator and Scientific Infrastructure, March 2006, http://www.gsi.de/documents/DOC-2006-Jul-40-1.pdf

[2] R. D. McCarty, Provisional Thermodynamic Functions for Helium 4 for Temperatures from 2 to 1500 K with Pressures to 100 MN/m2 (1000 Atmospheres), NBS REPORT 9762, August 1, 1970.

[3] P.Fabbricatore et al., R&D Activities Aimed at Developing a Curved Fast Ramped Superconducting Dipole for FAIR SIS300, Proceedings of EPAC08, Genova, Italy.

[4] F. Alessandria et al., Technical Design Report of a Superconducting Model Dipole for FAIR SIS300, INFN, Genova, Italy, INFN/TC-09/4, May 15, 2009.