STATUS OF THE FAIR SIS100/300 SYNCHROTRON DESIGN

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Abstract

SIS100 and SIS300 are the main accelerators of the FAIR project. The two stage synchrotron concept provides maximum intensities of heavy ion and proton beams in average and per cycle. To accommodate optimal technical solutions, the structure of the magnet lattices of both machines were recently reviewed and in case of SIS300 modified. Consequently, more appropriate technical solutions for the main magnets and quench protection systems could be adapted. The general machine layout and design, e.g. of the demanding extraction schemes, have been detailed and open design issues were completed. The development and design of all major technical systems is in progress and prototyping has started or is in preparation.

SIS100

Lattice Structure

The SIS100 doublet lattice structure as described in the FAIR Baseline Technical Report (FBTR) [1] is based on superferric, straight dipole- and quadrupole magnets. The lattice structure itself has basically remained unchanged. However, major properties of the main dipole- and quadrupole magnets were reconsidered and optimised [Table 1]. In order to provide a reasonable beam acceptance (at minimum three times the KV emittance), quite large apertures were required especially in the straight dipole magnets. Consequently, the AC loss, which was substantially reduced by the magnet R&D, did not match the original design goals anymore. Due to the increasing sagitta and beam displacement in the fringe fields, it was not possible to consider a longer dipole magnet. The required field strength of 2.1 T resulted in a significant increase of the stored energy with consequences for the quench protection system. Due to the high dipole field strength and also quadrupole gradient the field quality in both magnet types was considered to be marginal. Therefore, it was decided to reduce the apertures and the maximum field strength by focussing the magnet R&D on an elongated, curved dipole magnet. Making use of a curved magnet instead of a straight enables an increased length without affecting the beam acceptance. After reviewing the available warm straight section length, the length of the quadruple could also be increased by 10% and accordingly the maximum gradient reduced.

System Design

The technical planning of the six sections and the lattice cells was further detailed. The distribution and positioning of all accelerator components has been finished, allowing us to start planning the technical infrastructure (e.g. cable trays, media supply). The review of the supply buildings, as proposed by an external civil construction company, has been continued, with updates of the floor space requirements and drawings of the distribution of the supply units in the individual building and levels. Power load for the water recooling and air conditioning system, double floor and crane requirements could be specified.

Table 1: Comparison of the modified and FBTR main magnet parameters of SIS100

	Straight dipole FBTR	Curved dipole
$B \times L_{eff}$ [Tm]	5.818	5.818
B [T]	2.11	1.9
L_{eff} [m]	2.756	3.062
Estimated L_{yoke} [m]	2.696	3.002
Bending angle [deg]	3 1/3	3 1/3
Radius of curvature [m]	47.368	52.632
Aperture (h x v) [mm]	130 x 60	115 x 60
Ramp rate [T/s]	4	4
	Quadrupole FBTR	Quadrupole elongated
$B' \times L_{eff}$ [T]	35	35
B' [T/m]	32	27
L_{eff} [m]	1.1	1.3
Estimated L_{yoke} [m]	1	1.2
Aperture (h x v) [mm]	135 x 65	135 x 65
Ramp rate [T/ m s]	67.5	57

Magnets

Superferric magnets as developed for the NUKLOTRON synchrotron [2] will be used in SIS100. Based on this technology, an R&D program aiming for a further improvement of the properties of these magnets has been conducted together with the Joint Institute of Nuclear Research in Dubna [3]. The major goals of the R&D program were:

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- Reduction of the AC loss during fast ramping with 4 T/s
- Improvement of the 2D and 3D field quality
- Long term mechanical stability over $2x10^8$ cycles

The experimental part of the R&D program has been conducted to a large extend at JINR, using a number of available magnets for modifications. The design goal of 13 W/m for the AC has almost been reached by re-designing the yoke, especially the lamination on both ends, the coil loop, the brackets and endplates. Due to the difficulties with the straight dipole magnet described above and because of ion optical advantages, it was decided to develop an alternative elongated, curved dipole with smaller aperture. Two full length dipole magnets are presently under construction. The magnets will be delivered including thin wall vacuum chambers and cryostats. One straight dipole with large aperture is being built by BNG in Würzburg, Germany, and a curved dipole is under production in BINP, Novosibirsk, Russia.

However, the large hydraulic resistance of the two layer coil made of a s.c. cable with a hollow pipe cross section as used in the Nuklotron does not provide the cooling power for operation with pure triangular cycles. Triangular cycles are considered as fall-back option in case problems (e.g. unacceptable beam loss) occur on the long injection flat-top of the reference cycles. Therefore, a third full length dipole magnet is considered to be built at JINR within the next year, using a single layer coil with eventually slightly increased cable cross section and high current conductor.

For the production of the full length dipole magnet, BNG has taken over and is going to modify a cable winding machine from the LHC magnet production. Thus, a second source for production and delivery of the NUKLOTRON type cable will be available.

After the decision to elongate the main quadrupole by 20% and to reduce the maximum field gradient correspondingly, the magnet has been redesigned for the accommodation of a six turn coil. Production of a full length model quadrupole is planned with a delay of three month to the JINR full length dipole model.

After a review of the specifications, the technical design of the correction magnets has been started. Different technical solutions are actually studied for the individual magnets. The high ramp rate and field requirements of magnets involved in the slow extraction process are an issue.

Power Converters

A 11 kA power converter making use of a silicon controlled rectifier (SCR) and a switch mode parallel active filter has been built for the s.c. magnet test stand at GSI.

The hardware, firmware and software for the digital control of dynamic high precision power converters has been developed and is in practical use in the power converters of the therapy accelerator of HICAT in Heidelberg. Because of the demanding quench protection system of the SIS100 dipole magnets, an electronic 8 kA DC circuit breaker has been developed. A prototype DC circuit breaker is under construction in TU-Darmstadt.

Rf Systems

In collaboration with the BINP, Novosibirsk a technical design study has been completed for the ferrite loaded acceleration cavities [4]. The collaboration has been continued with an engineering study with the goal to prepare the tendering process for prototype production in summer 2007. The same acceleration cavities as developed for SIS100 will be used in SIS300.

No R&D has been started for the bunch compression systems, assuming that the presently completed bunch compression cavity project of SIS18 and the prototyping of the CR de-compressor cavity is sufficient for a direct call for tender. However, GSI has conducted an extensive study on commercially available magnetic alloy core materials for the SIS18 projects.

Injection-Extraction Systems

The ion optical design of the extraction system for slow, fast and emergency extraction has been further optimized [5]. For slow extraction, a combined horizontal and vertical scheme has been developed which makes use of a third order resonance in the horizontal plane and a Lambertson septum magnet for deflection and extraction in vertical direction. Such a scheme allows the combination of devices for slow, fast and emergency extraction in one straight section. According to the ion optical layout, the injection- and extraction devices have been specified and design studies were started for the bipolar kicker system. In parallel, experimental investigations were conducted with pulse forming networks in collaboration with the Technical University of Darmstadt. HV pseudo spark switches as possible replacement for thyratron switches are under development in cooperation with the University of Erlangen.

Dynamic Vacuum

For the simulation of dynamic vacuum effects and beam loss due to a charge change of the projectiles, the program STRAHLSIM has been developed [6]. The accuracy of the predictions for ionization beam loss in the energy range of SIS100 could be further improved. The GSI atomic physics group and their collaborators could meanwhile extend the models for calculation of charge change cross section to relativistic energies [7]. The new cross sections, as well as a new scaling law for the desorption yield according to the specific energy deposition $(dE/dx)^2$ [8] were implemented in STRAHLSIM. The revised calculations show a significantly lower pressure increase and beam loss. However, experimental studies need to be considered to support these extrapolations to high energies.

SIS300

Lattice Structure

The required length of the six straight sections in SIS100, especially needed for Rf devices, defines (at a given circumference) the remaining length of the arcs. Since SIS100 and SIS300 are situated in the same tunnel on top of each other, this ratio between arc and straight section length is also valid for SIS300. However, the required slot length of s.c. cosΘ magnets for a given effective field length is much bigger than the one of superferric magnets. Therefore, the arc length, indirectly defined by SIS100, did not provide sufficient space for the originally foreseen doublet focusing structure. In order to save space in each lattice cell, the doublet structure has been replaced by a FODO structure. Another issue could be solved which was caused by the lateral displacement of the straight sections of both rings. The missing dipole lattice concept has been assigned to SIS300, leading to an almost perfect matching of both ring geometries.

Because of the transition from doublet to FODO structure in SIS300 it was necessary to change the layout of the transfer system between SIS100 and SIS300. In order to provide sufficient length for matching quadrupole magnets, it is required to prepare the transfer in SIS100 as early as possible. Therefore, the first set of kicker magnets has been positioned in the missing dipole gap at the end of the arc, which was considered to feed the cryogenics- and power bus. In spite of the tight geometry, an ion optical solution for the transfer system with a difference in height of 1.4 m could be found, providing almost perfect matching to the SIS300 FODO structure. Although the transfer system crosses quadrupole cryostats of both synchrotrons, most of the beam line components, especially the matching magnets are room temperature devices.

Magnets

As in SIS100 it was decided to focus the dipole R&D on curved dipoles with a lower maximum flux density of 4.5 T instead of 6 T and preferably a single layer coil instead of a two layer coil [Table 2]. First design studies on a curved SIS300 dipole magnet have been performed by SPA [9] and BNG [10] and are continued by the Italian National Institute of Nuclear Physics INFN. However, the introduction of the missing dipole lattice requires an additional short magnet design for the ends of the arcs. A MoU for the development and production of a short SIS300 prototype dipole magnet has been signed by INFN and GSI. The prototype completion is scheduled for 2009. Due to the weaker focusing strength of the FODO structure, the aperture of the quadrupole magnets had to be increased from 86 mm to 105 mm. However, only have of the gradient and half of the number of the quadrupole magnets is required.

A first conceptual design study has been completed for the s.c. high field extraction septum of SIS300 in collaboration with the BINP. The design study has proven the feasibility of such a 3.5 T septum magnet. The 2D layout could be integrated as a 3D CATIA model into the drawings of the extraction and emergency dumping system.

Table 2: Comparison of the modified and FBTR main magnet parameters of SIS300

	Straight dipole FBTR doublet	Curved dipole FODO
Type	Straight, short, two layer coil	Curved, long + short, single layer coil
B [T]	6	4.5
L_{eff} [m]	2.908	7.757 + 3.878
Estimated slot length [m]	3.989	8.727 + 4.818
Bending angle [deg]	3 1/3	6 2/3 + 3 1/3
Radius of curvature [m]	50	66 2/3
Aperture (circular) [mm]	86	86
Ramp rate [T/s]	1	1
	Quadrupole FBTR doublet	Quadrupole FODO
Number of magnets	156	84
B' [T/m]	90	45
L_{eff} [m]	1	1
Estimated slot length [m]	2.081	2.081
Aperture (circular) [mm]	86	105
Ramp rate [T/m s]	20	10

Injection-Extraction Systems

By removing the lateral displacement of the straights of SIS100 an SIS300 we could resolve the collision of the vertically extracted SIS100 beam with the SIS300 arc cryostat. Furthermore, the scheme for slow extraction benefits from the FODO structure, thus the maximum field of the s.c. extraction septum could be lowered. Furthermore, the new structure even allows adding a fast extraction scheme in a later stage of the project.

REFERENCES

[1] FAIR - Baseline Technical Report, GSI (2006)
[2] A.D. Kovalenko, EPAC 94, 1994, V. 1, pp.161-164
[3] G. Moritz, these proceedings
[4] G.Y. Kurkin et.al., "Design proposal for SIS100 10-th harmonic Rf system"; BINP
[5] J. Stadlmann et.al., these proceedings
[6] C. Omet et.al., New Journal of Physics 8 (2006)284
[7] T. Stöhlker, S. Shevelko private communications
[8] A. Molvik, H. Kollmus, private communications
[9] Ansaldo Superconduttori S.P.A. report (2006)
[10] Babcock Noell GmbH, GSI report 2006

