ION OPTICAL LAYOUT OF THE FAIR SYNCHROTRON AND BEAM LINE SYSTEMS

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Abstract

The ion-optical layout of the two main synchrotrons and the high energy beam transport system of the FAIR project [1] is summarized. SIS100 will be used to generate high intensity beams of all ion species from protons to uranium with a maximum rigidity of 100 Tm. However the ion optical layout is optimized for the operation with heavy ions of medium charge states. For this purpose we developed a new ion optical design which provides a separation of the ionized beam particles from the circulating beam in each lattice cell. The chosen lattice structure provides a peaked loss distribution and enables the suppression of beam loss induced pressure bumps. Furthermore a compact layout of the extraction systems for slow, fast and emergency extraction at 100 Tm and 300 Tm has been developed. Since both synchrotrons are situated in the same tunnel, the SIS300 ion optical layout has to match the geometrical shape of the SIS100 precisely - although both rings use different lattice structures. The design of the beam transport system (HEBT) allows a highly efficient parallel operation of the synchrotrons, storage rings and experiments of the FAIR complex.

SIS100

Lattice

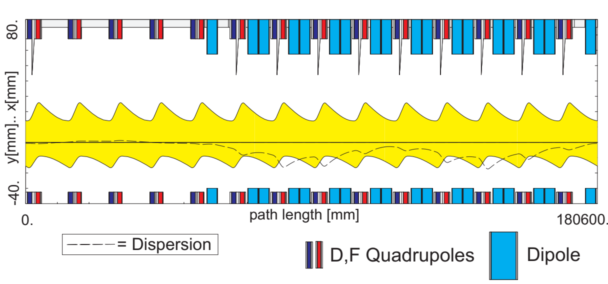

Figure 1: One sextant of the lattice structure of SIS100. The dispersion is plotted for a momentum spread of dp/p=1%.

The lattice design of SIS100 is unchanged since the FBTR. It uses a doublet focussing structure which is optimized to prevent dynamic vacuum effects due to charge change induced beam loss [2]. The main dipoles have been changed from straight to curved magnets. The main quadrupole magnets have been increased from 1 m to 1.2 m in length to reduce the maximum gradient required. Figure 1 shows one sextant of the SIS100 lattice. The lattice parameters are shown in Table 1.

Table 1: SIS100 lattice parameters

Lattice structure	Doublet
Number of superperiods	6
Machine circumference	1083.6 m
Magnetic rigidity	Bρ = 100 Tm
Number of DP magnets	108
Bending angle	$3\,\frac{1}{3}^\circ$
max. Dipole field	1.9 T
Bending Radius	52.6315 m
Dipole Magnets per sextant	8 x 2 + 2 x 1
Number of QP magnets	168
Maximum field gradient	27 T/m
Number of lattice cells	N_f = 6 x 14
Length of lattice cell	L_f = 12.9 m
Straight sections length	4 x L_f

SIS100 will be operated at three different working points: WP1 for fast extraction, WP2 for slow extraction and WP3 for a shifted transition energy during proton operation. The parameters of the three workings points are listed in Table 2.

Table 2: SIS100 workingpoints

	WP2	WP1	WP3
Tunes (h/v)	17.3/17.42	18.84/18.73	20.84/20.73
Mode of operation	Ions, slow ext.	Ions, fast ext.	Protons, fast ext.
Dispersion α_p max [m]	1.44	1.73	1.30
α_p min [m]	-1.11	-0.12	-0.33
phase adv. (h/v) per cell [°]	74/ 75	81/ 80	89 / 89
γ_t	14.29	15.58	17.48
Natural chrom. ξ_{nat}/Q (h/v)	-1.16/-1.16	-1.19/-1.2	-1.25/-1.26
Acceptance (h/v) (mm · mrad)	201 / 54	206 / 54	203 / 53

Injection into SIS100 from SIS18 is realized in the horizontal direction via bunch to bucket transfer. The beam is deflected by a magnetic septum and kicked into a closed orbit by a fast kicker system in the same straight section.

Extraction

SIS100 provides fast and slow extracted beams. Compressed bunches can be generated with a powerful RF-bunch compression system. For fast extraction the beam is kicked vertically into the main magnetic septum and transported directly upwards towards the experiments as shown in Figure 2. For slow extraction we make use of a com-

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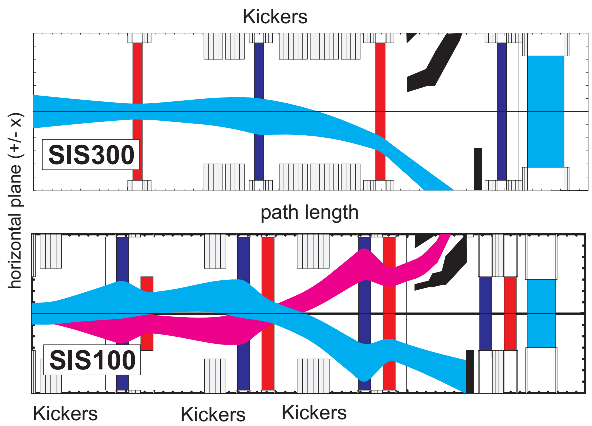

Figure 2: Fast extraction and emergency dumping from SIS100/300 in the vertical plane. The top panel shows the kicked beam of the SIS300 which is dumped on the internal beam dump. The bottom panel shows both, the fast extracted beam deflected into the main magnetic septum and the beam dumped on the internal target. Note that fast extraction is realized in the same straight section and uses the same extraction channel as the slow extraction shown in Figure. 3.

bined horizontal and vertical extraction scheme. First the beam is excited horizontally and deflected by the electrostatic septum into a Lambertson septum which bents the beam upwards into the same main magnetic septum used for the fast extraction (see Figure 3). In this way is realized a slow and fast extraction with all required devices in one straight section. Both beams are transported via the same extraction beamline towards the ground level. The magnetic kicker system used for the fast extraction is bipolar and may be used in the opposite direction to access the internal target.

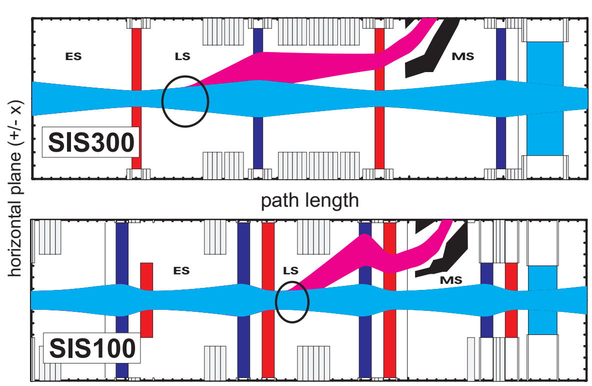

Figure 3: The vertical plane of the SIS100/300 slow extraction layout. The beam is in both cases exited in horizontal plane. The electrostatic septum (ES) deflects the beam horizontally into the Lambertson septum (circle and LS). Shown is the deflection of the ions in vertical plane into the main magnetic septum (MS). The extraction point is in the same straight sector in both machines leading into a parallel beamline towards the surface.

SIS300

Lattice

The ion optical layout of SIS300 has been changed since publication of the FBTR. The main design constraint is the geometrical matching to the SIS100 layout. We use a FODO structure which consists of seven FODO cells per sextant corresponding to 14 half cells. The 14 cells of SIS300 match the 14 doublet cells of SIS100. To arrange the rings directly on top of each other, the SIS300 lattice uses two half length dipoles to match the missing dipole scheme of SIS100. The SIS300 layout is now based on long curved, single layer dipoles with reduced maximum field strength (4.5 T instead of 6 T). Figure 4 shows one sextant of the SIS300 lattice with the two short dipoles at the end of the arc. The SIS300 lattice parameters are listed in Table 3.

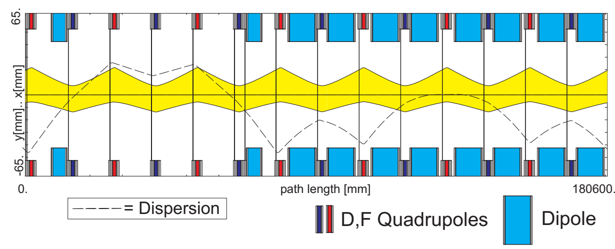

Figure 4: One sextant of the lattice structure of SIS300. The dispersion is plotted for a momentum spread of dp/p=1%.

Table 3: SIS300 lattice parameters

Lattice structure	FODO
Number of superperiods	6
Machine circumference	1083.6 m
Magnetic rigidity	Bρ = 300 Tm
Number of DP magnets	48 + 12
Bending angle	$6\frac{2}{3}^\circ + 3\frac{1}{3}^\circ$
max. Dipole field	4.5 T
Bending Radius	66.6667 m
Dipole Magnets per sextant	8 + 2
Number of QP magnets	84
Maximum field gradient	45 T/m
Number of lattice cells	N_f = 6 x 7
Length of lattice cell	L_f = 2 x 12.9 m
Straight sections length	2 x L_f

Only one working point is forseen for slow extraction. In high energy mode the beam will be injected above the transition energy. In the stretcher mode the beam will be injected below transition energy (see Table 4).

Transfer

The transfer from SIS100 into SIS300 had to be changed to enable a matching to the new lattice structure. To gain more space for the transfer line half of the kicker magnets are placed in the missing dipole gap of SIS100. The beam is kicked upwards by this set of kickers and is deflected into a magnetic septum which is placed in the first cell of the

Table 4: SIS300 workingpoint

Working point (h/v)	13.3/9.8
Dispersion α_p max [m] α_p min [m]	 2.33 -4.58
phase adv. (h/v) per cell [°]	 114 / 84
γ_t	9.35
Natural chrom. ξ_{nat}/Q (h/v)	 -1.358/-1.372
Transverse (h/v) acpt. [mm·mrad]	 50.9 / 44.3

straight section. Bending back towards the SIS300 beam axis is realized in the third cell of the straight section followed by a kick to a closed orbit in the fourth cell (see Figure 5). Since the new layout is about 13 meters longer compared to the FBTR design it allows to place 2 cold and 4 warm quadrupoles in the transfer line. With the new layout we achieve a perfect horizontal and vertical matching of the beam.

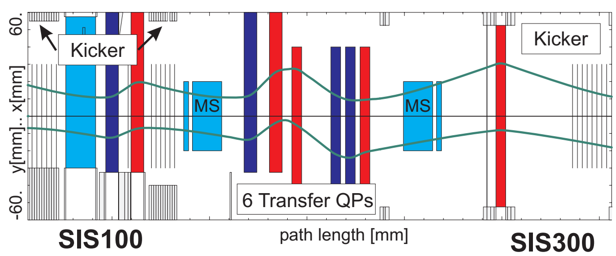

Figure 5: Transfer from SIS100 to SIS300. The two sets of kicker magnets in SIS100 deflect the beam into a two stage magnetic septum. The beam is matched by six quadrupole magnets and bent back to the SIS300 orbit with a similar magnetic septum and an additional set of kicker magnets.

Extraction

SIS300 provides only slow extraction for the experiments. The extraction scheme is similar to the one used for SIS100. First the beam is exited horizontally, by means of electrostatic septa the beam is deflected into a Lambertson septum which bents the beam upward into the main magnetic septum (Figure 3). SIS300 has no fast extraction system but is equipped with fast kicker magnets to dump the beam onto an internal target (Figure 2).

HIGH ENERGY BEAM TRANSPORT SYSTEM

The High Energy Beam Transport System (HEBT) consists of more than 2400+m of beam lines and comprises in the present layout 141 dipoles, 342 quadrupoles and 21 beam line junctions. It provides 22 connections between the various parts of FAIR. The beam lines generally provide an acceptance twice as large as the maximum emittance to be transported. The beam lines from the antiproton separator and the Super-FRS to the CR are exceptions to these design rule.

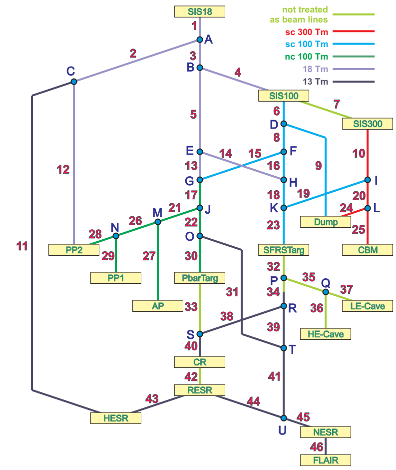

Figure 6: Beam line connection scheme of FAIR. Blue dots indicate beam dividers/combiners. Any beam line following a downward path is a possible connection. Super-FRS, Antiproton Separator and the connections from SIS100 to SIS300 and CR to RESR are not covered here.

A F0D0 focussing scheme is used to keep the quadrupole gradients low. It is well suited to focus dispersion trajectories. The beamlines are adapted to the local boundary conditions resulting in a highly individualized layout. No standard modules can be used. Series connections of magnets can only be used in individual beamlines where the flexibility of operation is unaffected. However, similar dipoles within each beam line section will be powered in series.

The beam from SIS100 has up to 1 % momentum spread. Therefore the transport of bunched beams is in sections achromatic. Higher order calculations show chromatic aberrations which do not strongly affect the beam transport. However space charge has an effect. This can not easily be compensated as the density of ions changes along the bunch. A design avoiding small intermediate beam waists reduces the influence of the space charge. For this reason the dispersion is usually kept non zero over distances covering several quadrupoles. Even in the case of lowest rigidity (27 Tm) the influence on the spot sizes at the targets can be kept under 50 %. With increasing rigidity the situation improves. Some beamlines were recalculated for using normal conducting magnets. The dipoles have a maximum field strength of 1.9 T, the quadrupoles a maximum pole tip field of 1.2 T. However special quadrupoles for the beam dividers where the beam line branches are still are needed.

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