# DESIGN OF THE BEAM EXTRACTION SYSTEMS OF THE NEW HEAVY ION SYNCHROTRONS SIS100 AND SIS300 AT FAIR*

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*Abstract*

The proton and heavy ion synchrotrons SIS100 and SIS300 are the central part of the new FAIR facility which shall be constructed next to the present GSI accelerator facility. A variety of ions from protons to uranium may be accelerated up to a magnetic rigidity of 100 Tm and 300 Tm, respectively. The design of the beam extraction systems of both synchrotrons has been completed and is presented in this paper. The extraction devices of both synchrotrons are situated in one common straight section. The beams of both machines are extracted in vertical direction with equal angle and in parallel. The SIS100 extraction system is optimized for the extraction of compressed, single bunches by a fast kicker system, however, slow extraction of coasting beams is also possible. The SIS300 extraction system provides only slow extraction. The choosen layout of the slow extraction system combines horizontal deflection by an electrostatic septum with vertical deflection by a Lambertson septum magnet and two subsequent magnetic extraction septa. Both extraction systems allow an immediate beam abort in an emergency case within one turn to an internal beam dump.

## DESIGN CONCEPT

The design of the beam extraction system of SIS100 and SIS300 has been revised [1], [2]. The main reason was the change of the lattice concept of SIS300 from doublet structure to FODO structure [3], which was necessary to obtain a geometrical matching between SIS100 and SIS300. Both synchrotrons have six fold symmetry comprising straight sections with four cells each and arc sections with ten cells each. This structure is suitable to the different technologies of the main magnets.

The chosen extraction scheme of SIS100 combines slow, fast, and emergency extraction in one straight section. Slow extraction is performed in two stages: a) horizontal excitation of the beam by a third order resonance and deflection of the excited particles by two consecutive horizontal electrostatic septa, and b) horizontal transport into a Lambertson septum and vertical deflection towards the main septum magnets. A careful adjustment of the chromaticity via additional sextupole magnets is indispensable. Knockout extraction is proposed as standard method. However, conventional slow extraction by means of a fast quadrupole is used as back-up solution. Fast extraction and dumping is performed in SIS100 by means of three sets of kicker magnets. For extraction the kicker magnets deflect the beam upwards directly into the vertical extraction septa. Emergency extraction is realized by using the same kicker magnets in bipolar operation but deflecting the beam downwards into an internal beam dump. The two sets of kicker magnets in SIS300 are only foreseen for fast beam dumping. The extraction beam line has sufficient physical space to transport a beam with twice the expected maximum emittance.

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## EXTRACTION SYSTEM OF SIS100

### *Slow Extraction*

Slow, resonant extraction will be performed using a third order resonance in the horizontal plane which is excited by a family of 'resonance' sextupole magnets, see Figure 1. Two of these magnets are situated symmetrically distributed in each of the six warm straight sections. Because of insufficient space in the injection section, the first sextupole magnet had to be eliminated. In order to suppress chromaticity contributions the resonance sextupoles are placed at positions with a dispersion close to zero.

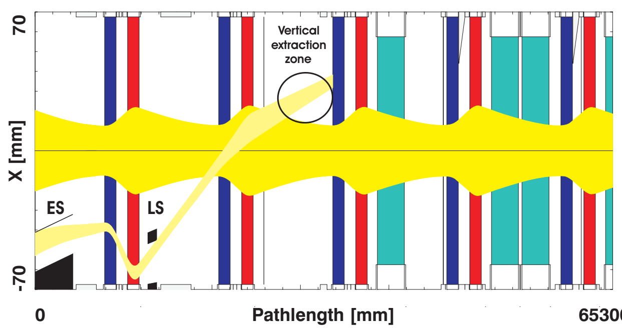


Figure 1: Scheme for slow, resonant extraction in the horizontal plane of SIS100. The spill (light yellow) is separated at the electrostatic septum ES from the circulating beam and transported into a vertically deflecting Lambertson septum LS.

The electrostatic septum ES, separates a spill with a step width of 10 to 15 mm at the separatrix. The spill is guided into a Lambertson septum LS via a quadrupole doublet. The Lambertson septum deflects the spill in vertical plane through a quadrupole doublet towards a three stage magnetic extraction septum. At the subsequent doublet the spill has gained sufficient height to pass the cold mass of the quadrupoles. However, the horizontal drift of the beam axis must be corrected. For this reason the last magnetic extraction septum comprises a horizontal steering field. The final correction of the horizontal angle is performed by two steering magnets integrated in the extraction beam line. The steeres deflect

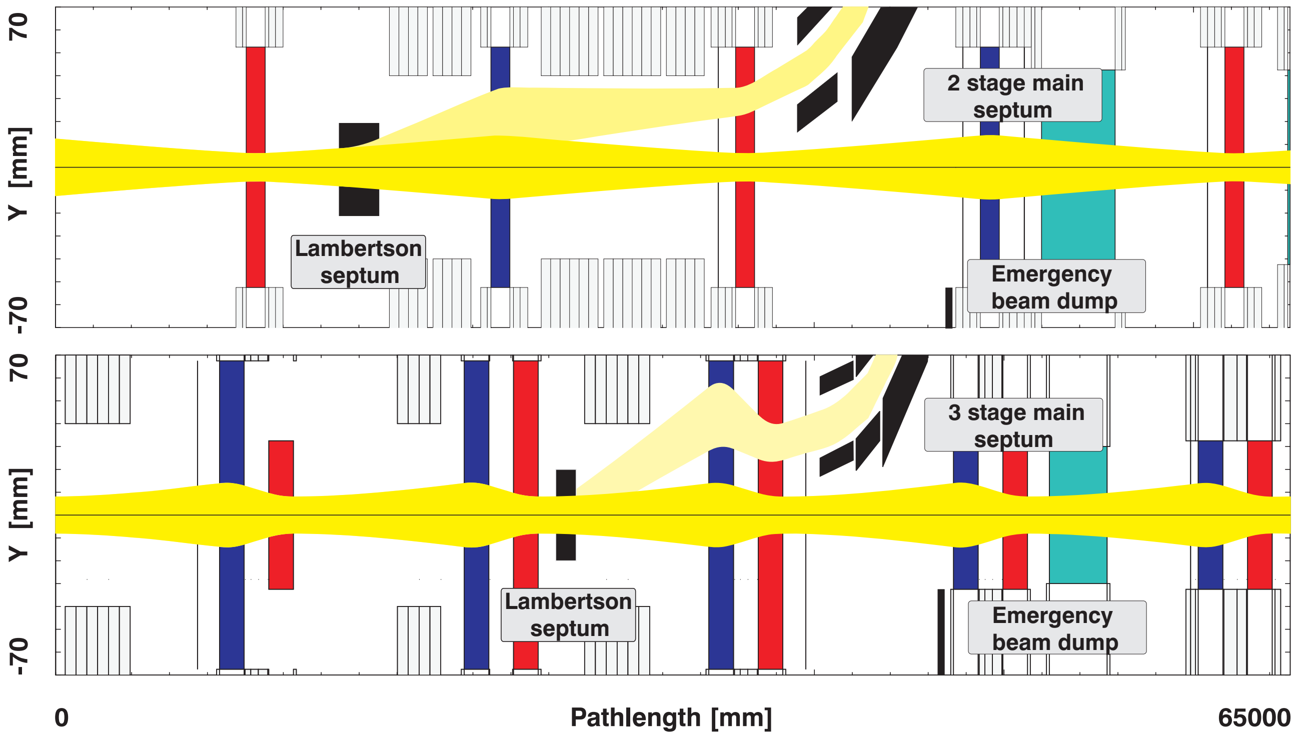


Figure 2: Scheme for slow extraction in vertical plane of SIS300, upper figure, and SIS100, lower figure. The orbits are vertically separated by 1.4 m. The Lambertson septa deflect the beam in vertical direction into the main magnetic extraction septa. The aperture of the quadrupole magnets are marked in blue and red, respectively, dipole magnets are marked green. Five star-shaped vacuum chambers (large aperture also in y-direction) are necessary in SIS100. The extraction angle of both synchrotrons amounts to 3 1/3 deg.

Table 1: Summary of the SIS100 Fast and Slow Extraction Devices

| **SIS100** | **Vertical bending angle** [mrad] | **Active length** [m] | **Field strength** [T] |
|---|---|---|---|
| Electrostatic septum | H: 1.3 | 4.0 | 84 [kV/cm] |
| Lambertson septum | 5.6 | 1.0 | 0.6 |
| Kicker, bipolar | 6.6 | 7.1 | 0.095 |
| Magnetic septum 1 | 5.1 | 1.5 | 0.35 |
| Magnetic septum 2 | 10.0 | 1.0 | 1.0 |
| Magnetic septum 3 | V: 40.5<br>H: 5.0 | 2.2 | V: 1.85<br>H: 0.25 |

the slow extracted spill back to the reference axis.

Due to scattering in the septum the momentum dependence of the separatrices generally leads to beam loss behind the electrostatic septum. Hence, the momentum dependence must be minimized by a proper control of the machine chromaticity. Two families of sextupole magnets, one acting in the horizontal plane and one in the vertical plane change the chromaticity to predefined values. These sextupole magnets are placed in the six arcs of the synchrotrons. In each arc 2x4 sextupole magnets are placed close to the quadrupole magnets with the maximum ratio between the horizontal and vertical beta functions. Horizontal and vertical sextupole magnets are powered independently. Each string is connected to one power supply which serves two arcs.

The natural chromaticity at the working point of slow extraction is -1.2/-1.2. These values are normalised by the tune. For slow extraction the chromaticity will be changed to -0.3/-2.2. This reduction in horizontal chromaticity sufficiently reduces the momentum dependence of the separatrices keeping the beam loss at the electrostatic septum at a low level. In this case the calculated dynamic aperture is large and does not cause any further beam loss.

Slow extraction times may reach up to 10 s.

## *Fast Extraction*

Fast extraction will be performed with a series of kicker magnets placed in the first three cells of the straight extraction section as depicted in Figure 3. In order to profit from the strong focusing strength of the subsequent quadrupole magnets the kicker magnets are distributed as indicated. This is advantageous for keeping the field values of the magnetic extraction septa reasonable low.

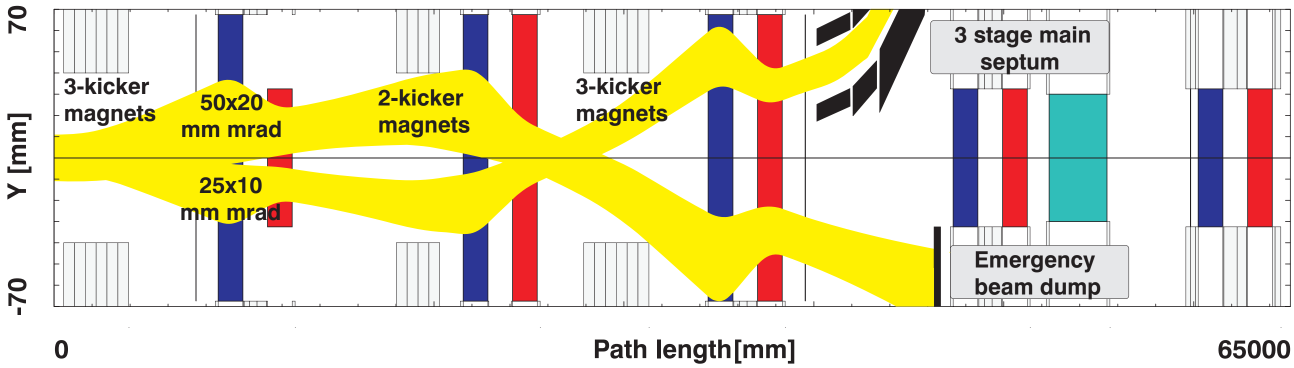


Figure 3: Scheme of fast and emergency extraction of SIS100. Three kicker sections deflect the beam either into the magnetic septa or into an internal beam dump.

The first series of kicker magnets deflect the beam downwards, while the next two series of kicker magnets in cell two and three deflect the beam upwards into the first extraction septum. The septa provide a beam height of 230 mm above the orbit in the subsequent quadrupole magnet, sufficient to pass its cold mass. The strength of the septa are adjusted such that the final vertical angle is the same as for slow extraction

### *Emergency Extraction*

In an emergency case the beam may be dumped within one turn into an internal beam dump by means of the bipolar kicker modules used for fast extraction, see Figure 3. The same concept as for the normal fast extraction is used, i.e. the first kicker magnet series deflects the beam upwards, the subsequent kicker magnet modules deflect the beam downwards into the internal beam dump. Technical specifications of the involved extraction equipment are listed in Table 1.

## EXTRACTION SYSTEM OF SIS300

The principles of the extraction system of SIS300 are quite similar to the one of SIS100. The number of cells and the total length is the same as in SIS100, see Figure 2. The single quadrupole magnets of the FODO lattice are placed at positions which correspond to the center-position of the SIS100 quadrupole doublets. Technical specifications of the concerned extraction equipment are listed in Table 2.

### *Slow Extraction*

Slow, resonant extraction is excited by a family of 6x2 resonance sextupoles which are symmetrically distributed on the straight sections. The chromaticity is controlled in each arc by 2x2 sextupole magnets acting mainly on the horizontal and the vertical plane, respectively. In contrast to SIS100 the beam optics of SIS300 can be adjusted to a full correction of the momentum dependence of the separatrices [4] keeping the dynamic aperture sufficiently large. This reduces beam losses due to scattering in the electrostatic septum wires to a minimum. In this case, the natural chromaticity of -1.3/-1.4 is reduced to -0.1/-0.1. Slow extraction times may reach up to 100 s.

### *Emergency Extraction*

An immediate beam abort within one turn into an internal beam dump is performed by means of fast kicker modules placed in the 2nd and 3rd cell of the extraction straight, see Figure 2 top.

Table 2: Summary of the SIS300 Fast and Slow Extraction Devices

| **SIS300** | **Vertical bending angle** [mrad] | **Active length** [m] | **Field strength** [T] |
|---|---|---|---|
| Electrostatic septum | H: 1.0 | 9.0 | 102 [kV/cm] |
| Lambertson septum | 2.8 | 2.0 | 0.4 |
| Kicker | 3.0 | 7.2 | 0.125 |
| Magnetic septum 1 | 6.3 | 2.0 | 1.0 |
| Magnetic septum 2 | 48.0 | 4.0 | 3.65 |

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## REFERENCES

[1] FAIR Baseline Technical Report, ed. H.H. Gutbrod, Vol. 2, pp. 370 (2006), ISBN 3-9811298-0-6
[2] FAIR Baseline Technical Report, ed. H.H. Gutbrod, Vol. 2, pp. 581 (2006), ISBN 3-9811298-0-6
[3] J. Stadlmann et al., these proceedings, contribution MOPC124
[4] W. Hardt, CERN Internal Note, PS/DL/LEAR Note 81-6 (1981)