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INJECTION AND EXTRACTION FOR SUSE

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Summary

The injection onto the first cyclotron orbit differs essentially from injection schemes for normal conducting sector cyclotrons because of two reasons:
1) The central region is occupied by the RF-cavities.
2) The stray field between the sectors is strongly non scaling with the mean field level.

An appropriate injection and extraction system was developed using a series of superconducting channel magnets which cause practically no field perturbation outside and produce field levels of several Tesla inside. These magnets have a closed structure - like a shielding Faraday box in the electrostatic analogon. Therefore the injection path is below the median plane in the region of the circulating orbits. The accelerated beam will be extracted with an electrostatic septum (10 MV/m). Single turn extraction is achieved primarily by the acceleration voltage of 2 MV/turn, giving a turn-separation of 2.5 mm for 300 MeV/u and Q/A = 0.5. The separation may be increased by coherent betatron-oscillations.

Introduction

The superconducting sector cyclotron SuSe will be a booster behind the existing 13 MV-tandem accelerator at the Munich laboratory[1]. Stripping to the required charge state of the heavy ions takes place between both accelerators. The connecting beam line is designed according to the principles outlined in ref.2 and is described in more detail in ref.3. Subject of this article is the design of the injection system inside and the extraction out of the cyclotron.

Basic Constraints

There are some differences to existing normal conducting sector cyclotrons, which basically influence the design of the injection and extraction system for SuSe.

1) The high Q-cavities[4] needed for an accelerating voltage of two times 1 MV occupy most of the inner region of the cyclotron for the return flux of their magnetic RF field. Therefore no central space is available for injection elements.
2) Magnetic injection and extraction elements in the vicinity of the high sector field behave like air-coils. They must be superconducting, and their magnetic return flux cannot be collected by the highly saturated pole iron. Their stray field must carefully be compensated to avoid orbit distortions[5].
3) There is a risk of quenching magnetic injection and extraction elements due to beam heat up. In the case of a quench the magnetic coupling of their stray field to the main magnets may induce a quench in the big main coils. This is another reason why the stray field of the injection and extraction elements should be kept as small as possible.
4) At high mean field level the iron of the sector magnets is partly saturated, and the return flux squeezes in the valley region, resulting in a negative field between the sectors. Reducing the mean field level from 1.8 T to about 1.3 T, the iron gets out of saturation and the field between the sectors rises by 0.5 T. This strongly non scaling behaviour must be compensated along the injection beam path in order to get similar central trajectories for different final energies.

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The Injection System

In the past we have looked for several approaches to this complex problem. Extra coil windings below and above the median plane were considered for stray field compensation. Mirror reflection at the origin was provided for the injection elements resulting in a cancellation of all odd harmonic stray field components[6]. All these ideas gave not a solution to the problem in a really satisfactory way. The break through seems to be the development of stray field free superconducting channel magnets, which are now basic elements in the design of the injection and extraction system. These magnets resemble modified coaxial current cables. Like these they produce no stray field outside besides the negligible contribution coming from the entrance and exit window for the beam. The current distribution and shape has been modified to fit a desired field gradient and mechanical requirements. In fig.1 the cross sections of two different kinds of channel magnets are shown. These magnets are discussed in detail in another contribution to this conference[1].

Fig. 2 shows the injection path and the inner region of the cyclotron. All magnetic elements are superconducting stray field free channel magnets. As seen in fig.1 these magnets must have a closed surface - like a Faraday box in the electrostatic analogon. Between the two sector magnets SM1 and SM4 the beam is therefore guided 10 cm below the medium plane through the identical magnets K1 to K4 (radial region 2.6 m to 1.0 m). These magnets have a B_z-dipole component (max. ±0.5 T) to compensate the mid valley field of the main magnets and seperate windings for alternating focusing quadrupole fields. In the region M1 to M3 the beam is bent into the medium plane. Therefore the magnets M1 and M3 have a dipole field of ±0.5 T parallel to the medium plane. The maximum B_z-values of M2, M3 and M4 are -1.8 T, -1.8 T and +1.5 T (positive values increase the main field). M2 and M4 have maximum gradients of 5 T/m and 6 T/m which scale with their B_z-value. M3 needs independent windings to produce a maximum gradient of 18T/m. Finally two electrostatic inflectors (max. field: 8MV/m) bend the beam into the first orbit. The magnets M2 and M4 will be built as septum magnets as shown in fig. 1a, which allow a distance of about 10 mm between the useful magnetic field inside and the unpertubed region outside. The other magnets have to produce two or more independent field components. They can be built more easily in the second version like fig. 1b, where a box of superconducting Nb_3Sn foils serves for stray field compensation simultaneously for all field components. The injection system has been calculated for the acceleration of four ions, i.e. 300 MeV/u, 150 MeV/u, Q/A = 0.5, and 24 MeV/u, 12 MeV/u, Q/A = 0.16. The overall maximum difference in the central beam position is ± 5 mm in the region of the magnet M3. The entrance and exit positions of the two electrostatic inflectors must be adjustable by about ±5 mm. The turn separation at injection is at least 9 mm. The mean injection radius is 0.4 m.

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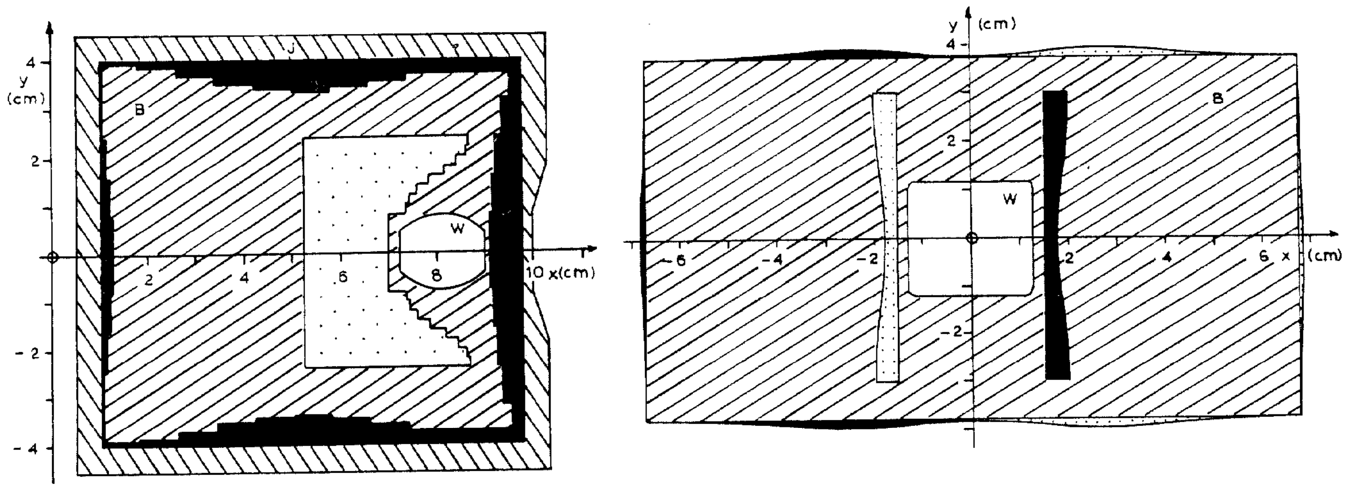

Fig. 1: Cross sections of two types of channel magnets.
B: magnet body, J: jacket, W: beam window

a) ▬ j = ± 220 A/mm², I_{tot} = 257 kAturns
for 7≤ x ≤ 9 cm: B (x,0) = 2.0 T

b) ▬ j = ± 300 A/mm², I_{tot} = 107 kAturns
for |x| ≤ 1.5 cm: B (x,0) = 0.6 T
The outer conductor is a box of superconducting foils. More coils (e.g. for producing a superimposed quadrupole field) can be built into the box.

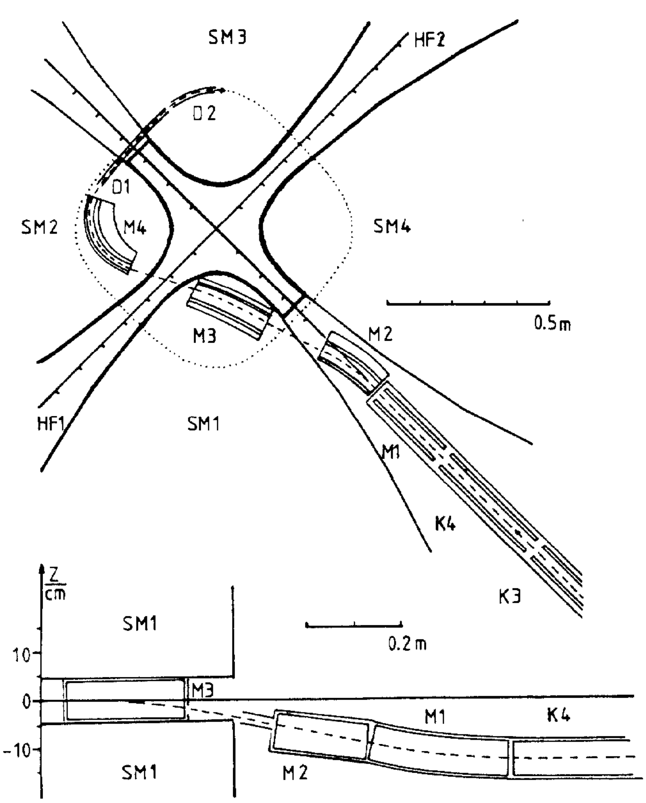

Fig. 2: The injection path with stray field free channel magnets

D: Electrostatic deflectors
M,K: Superconducting channel magnets without stray fields
SM: Superconducting sector magnets
HF: Accelerating cavities

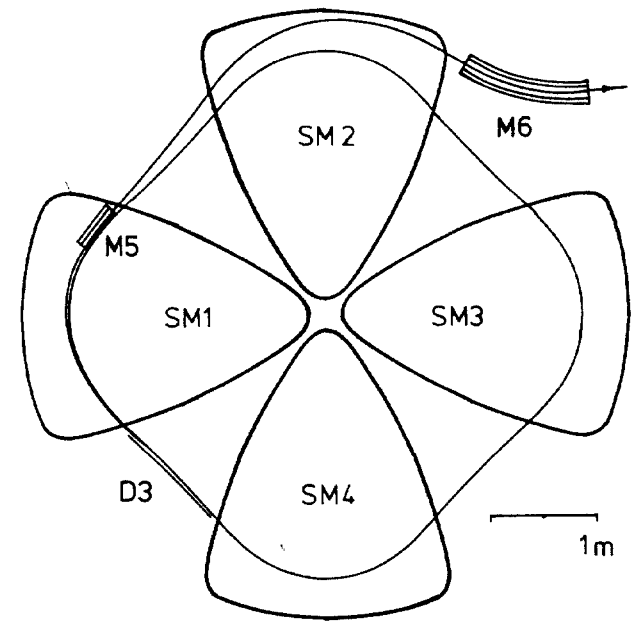

Fig. 3: The extraction system and the last orbit

The Extraction System

For 300 MeV/u the turn separation at extraction due to the accelerating voltage of 2 MV/turn is 2.5 mm. The radial beam width in the valley is less than 1 mm. Although these values seem to be sufficient for a clean single turn extraction, the turn separation may be enhanced by coherent radial betatron oscillations (up to 7.5 mm for 300 MeV/u).

Fig.3 shows the last orbit and the extraction system. Using the same method as for injection with stray field free magnets the system becomes quite simple. The first element is the electrostatic deflector D3 (max. el. field 10 MV/m). It must be split up into two parts with radial entrance and exit movement of ±1 cm to adjust the different curvature of the last orbit for maximum and reduced main magnetic field level (non scaling valley field). In the region of the septum magnet M5 the clearance to the circulating orbit is about 3 cm. The path between M5 and M6 crosses the fall off region of the main magnetic field, resulting in a radial defocusing of the extracted beam. A gradient coil in M5 (max. 6 T/m) is used to minimize the envelope in M6, giving radial widths of 2 mm and 20 mm in M5 and M6, respectively. The axial beam width in both magnets is about 2mm. A gradient coil within M6 (max. 6 T/m) refocusses the beam into the external beam line. The maximum B_z field components of M5 and M6 are -0.9 T and - 2.8 T.

The extraction has been calculated for the two mean field levels isochronized for 300 MeV/u and 150 MeV/u, Q/A = 0.5. The radial differences of the central paths are less than 5 mm in the region of M5 and M6.

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