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SUPERCONDUCTING SECTOR CYCLOTRON SUSE FOR THE MUNICH TANDEM LABORATORY

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Summary

A proposal for a superconducting separated-sector cyclotron for the acceleration of heavy ions using the Munich tandem as injector is presented. Highly stripped ions from the tandem (Z/A=0.5) can be accelerated to energies of up to 300 MeV/n.

1. Introduction

It is of great interest for heavy ion physics to make the energy range from the Fermi energy up to and beyond the pion production threshold accessible for experimental studies. A superconducting sector cyclotron with a tandem injector seems best suited to reach the anticipated energies with excellent beam qualities and sufficient intensities for the lighter heavy ions. The strong fieldflutter provides for the necessary axial focusing even at the highest energies. The separated sectors offer additional advantages for injection and acceleration with high energy gain per turn and thus also for extraction, due to the large orbit separation.

2. General layout of SUSE

Fig. 1 shows a schematic presentation of the main elements of SUSE. The bending system consists of four sector magnets with superconducting coils and large iron yokes. The

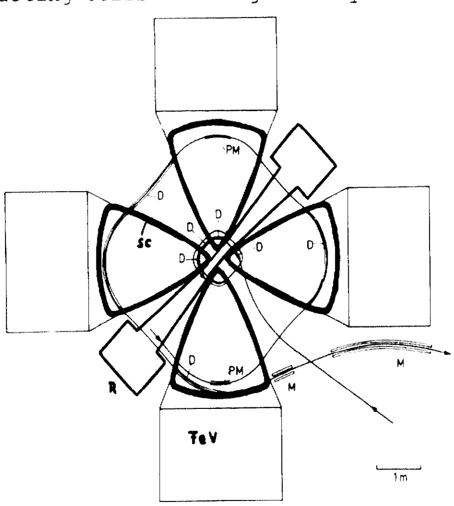

Fig. 1. Top view of the cyclotron, schematically. The magnetic system and the cavity are sketched. D means electrostatic deflectors, M magnet, PM perturbing magnetic field, R resonator, FeV iron yoke, SC superconducting coils.

acceleration is provided by a single resonator extending through two opposite sections between the magnets. It is excited in the TE111-mode to a peak voltage of 1 MV, yielding an acceleration voltage of 2 MV per turn. One possible way of injection and extraction using electric and magnetic deflection elements is sketched. Alternative schemes are considered. Following acceleration in the tandem, the ions are stripped to high charge states outside of the cyclotron. After selection of the desired charge state, a rf acceleration and bunching system matches the beam to the phase space requirements of the cyclotron injection.

Table 1 summarizes the main characteristics of SUSE. Maximum energies per nucleon for typical ions are: ${}^{12}C^{6+}$(306 MeV/n), ${}^{74}Ge^{32+}$(79 MeV/n), ${}^{238}U^{33+}$(24 MeV/n).

Table 1. Main cyclotron parameters

Injector:	13 MV-tandem with rf acceleration, bunching and post stripper
Injection radius	0.5 m
Extraction radius	2.4 m
Mean field at extraction	2.24 T
Bending power K_B	1200
Cavity in TE111-mode	
Resonant frequency range	23 - 39 MHz
Harmonic operation modes	3, 5, 7, ...
Peak voltage of the resonator	1 M V
R.F. power approx.	450 kW
Beam separation at extraction (Z/A=0.5)	2.6 mm

3. Magnet design

The approximate form of the isochronous field can be produced by a single pair of superconducting sector coils mounted close to the particle plane inside of a large C-shaped iron yoke as shown in fig. 2. The coils are flat to keep the stored magnetic energy at a minimum (18 MJ per magnet).

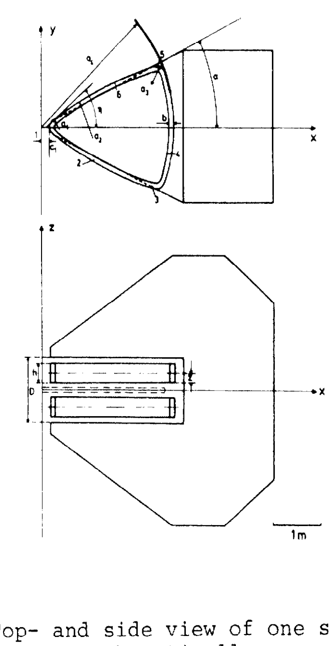

Fig. 2. Top- and side view of one sector magnet, schematically.

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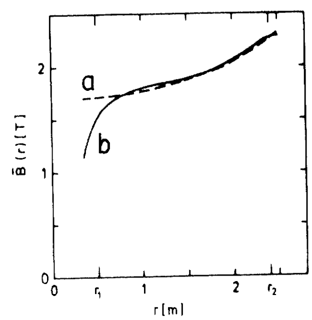

Fig. 3. Mean field versus radius. a) Desired field for ions with Z/A = 0.5 (K = 1200). b) Field produced by a four-fold magnetic system consisting of sector magnets as shown in fig. 2.

In fig. 3 the radial dependence of the mean field $\bar{B}(r) = 1/2\pi\int B(r,\phi)d\phi$ for a pair of coils with dimensions as given in table 2a is compared with the isochronous field for ions with Z/A = 0.5. The remaining field deviations at small radii can be corrected by inserting iron poles of proper shape inside of the coils. Superconducting trim coils are provided for fine adjustment.

Several ways of changing the radial form of the field for different values of Z/A and energies are considered: i) Small correction coils inserted inside the main coils. ii) Subdivision of the main coils into two coils with different sector- and vertex angles (α,η) (see fig. 2). A change of the radial increase of the mean field is obtained by appropriate excitation of the two parts. Using these simple coil arrangements the isochronous field can be obtained between an injection radius of 0.5 m and an extraction radius of 2.4 m for a sufficient range of Z/A to accelerate all ions provided by the tandem up to uranium. The field level can be lowered by a factor of two without destorting the field form in the particle plane.

The axial focusing is provided by the strong azimuthal field variation of the sector coils as shown in fig. 4 for various radii. The

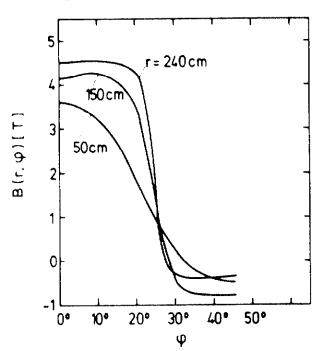

Fig. 4. Field corresponding to curve b in fig. 3 versus azimuth angle for different radii. ϕ = 0 marks the central axis of one magnet.

field reversal between the sector magnets is typical for a magnet system using superconducting sector coils, it can be controlled by a proper choice of the amount of flux returned with the iron yoke. Thus the working line of the cyclotron can be kept away from low order resonances. The yoke parameters are given in table 2b.

Table 2. Machine parameters

a. Coil geometry:	
Radial width b	8 cm
Axial height h (total)	43 cm
Axial distance from symmetry plane (enter)	31.5 cm
Radial distance from machine center c_1	18 cm
a_1	13 cm
a_2	680 cm
a_3	20 cm
a_4	280 cm
Sector angle α	22.5^o
Vertex angle η	27.5^o
b. Yoke:	
Height	5 m
Outer radius	4.8 m
Iron weight per magnet	260 t
c. Coil properties:	
Total ampere turns at maximum current	$2.75 \cdot 10^6$
Cross section of the windings	288 cm^2
Maximum current density	95 A/mm^2
Mean circumference of the coil	8 m
Weight of superconductor	0.5 t
Max. field at conductor	6.5 T
Total stored energy per magnet approx.	18 MJoule
Conductor	Nb-Ti/Cu
Conductor dimensions	4.8 x 2.5 mm^2
Filaments	1000, 53μ diameter
Twist length	50 mm
α (area of copper/area of superconductor)	4
Current in the conductor	1500 A
Critical current at 7 T	1750 A

4. Properties of the superconducting coils

The characteristics of the superconducting coils are summarized in table 2c. Due to the large value of the stored magnetic energy (15 MJ) at a current density of 95 A/mm^2 a special quench protection is necessary. The superconducting wire is wound on a coil frame made of a special copper alloy (Cu + 0.65% Cr + 0.5% Zr, with high conductivity and yield strength) which acts as the secondary winding of a transformer, thus taking up a large fraction of the energy and reducing the voltages in the main coils in case of quenching.

The magnetic force of about $6 \cdot 10^6$ N/m acting in the plane of the coil is taken up by a coil frame as indicated in fig. 5. All parts

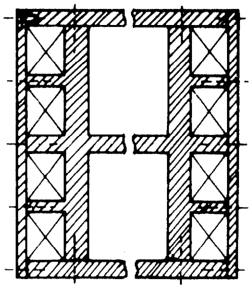

Fig. 5. Section through one sector coil, schematically.

are designed in such a way that the maximum tension is less than 100 N/mm^2, which is much lower than the yield strength of the chosen Cu alloy. The cooling of the coils is indirect by means of a two-phase helium tubular system.

5. Acceleration system

The design aim of the acceleration system is to provide an effective acceleration voltage of up to 2 MV/turn with a minimum of rf power. This would yield a large extraction orbit separation (minimum 2.6 mm) which makes extraction simple. An appropriate frequency tuning range corresponding to cyclotron frequencies of 14 MHz to 3 MHz should allow acceleration of heavy ions with Z/A-values from 0.5 - 0.17 and also change their energies. These requirements are achieved by an acceleration cavity sketched in fig. 1. It can be driven in odd harmonic modes starting with the third harmonic mode of the cyclotron frequency. The tuning of the resonator between 23 and 39 MHz is performed by insertion of large perturbing objects. The rf power consumption was estimated as 450 kW at 1 Mv cavity voltage. The use of a larger acceleration cavity operated at the cyclotron frequency was extensively studied with a 1:10 model. It would have the advantage of lower power consumption (110 kW),yet the problem of achieving a larger frequency tuning range is more difficult to solve.