The Superconducting Separated Orbit Cyclotron TRITRON

U. Trinks / Techn. Univ. München

Abstract:

At the Munich 13 MV-Tandem Laboratory the TRITRON is under development, which will be the prototype of a superconducting separated orbit cyclotron for acceleration of heavy ions with $0.04 < \beta_{in} < 0.14$ and $0.1 < \beta_{ex} < 0.3$. It consists of 12 flat, superconducting sector magnets with 20 neighbouring channels for the spiral-orbit ($r_{in} = 70$ cm, $r_{ex} = 150$ cm). Due to the individual magnetic channels the transversal and longitudinal focusing properties are as in synchrotrons. The constant turn separation of $\Delta r = 4$ cm requires a maximum accelerating voltage of 3 MV per turn, which will be provided by 6 superconducting cavities positioned in each second field free sector gap (see contribution of L. Dietl). Due to the longitudinal focusing the RF-frequency (~170 MHz) may be a high harmonic ($h \geq 20$) of the revolution frequency. Thus the frequency range for acceleration of ions with different revolution frequency can be kept small (± 3 %). The magnets as well as the cavities are contained in the same cavity.

At the Accelerator Laboratory of the Technical University and the University of Munich heavy ions are accelerated to specific energies of up to $T \leq 5$ MeV per nucleon by means of a 13 MV-tandem Van de Graaff. As an electrostatic accelerator the tandem yields quasi continuous beams of excellent qualities: energy spread $\Delta T/T \approx \pm 10^{-3}$ at a micropulse length of $\Delta t = 200$ psec and transversal emittances of $\varepsilon_{x,y} \leq 2\pi$ mm mrad. As a booster for the tandem a super-conducting separated orbit cyclotron - the Tritron - is under development. Though the principle of separated orbit cyclotrons was proposed already in 1963 (SOC [1,2]), the Tritron is thought to be a prototype of a new technological development [3,4,5]. Therefore the energy gain factor $T_{ex}/T_{in} \approx 4.6$ is chosen rather small (injection radius $r_{in} = 70$ cm, extraction radius $r_{ex} = 150$ cm).

The starting point at the design of the Tritron was the severe disproportion
of the magnetic field volume produced in conventional separated sector
cyclotrons to the volume really needed for bending the beam along the spiral
orbit (10^2 to 10^3). Hence instead of leading the returning magnetic flux
over long distances to the outside yoke of the sector magnets, the flux lines
should be kept as short as possible. This is achieved by narrow window-frame
magnets along the separated orbits with superconducting coils in order to
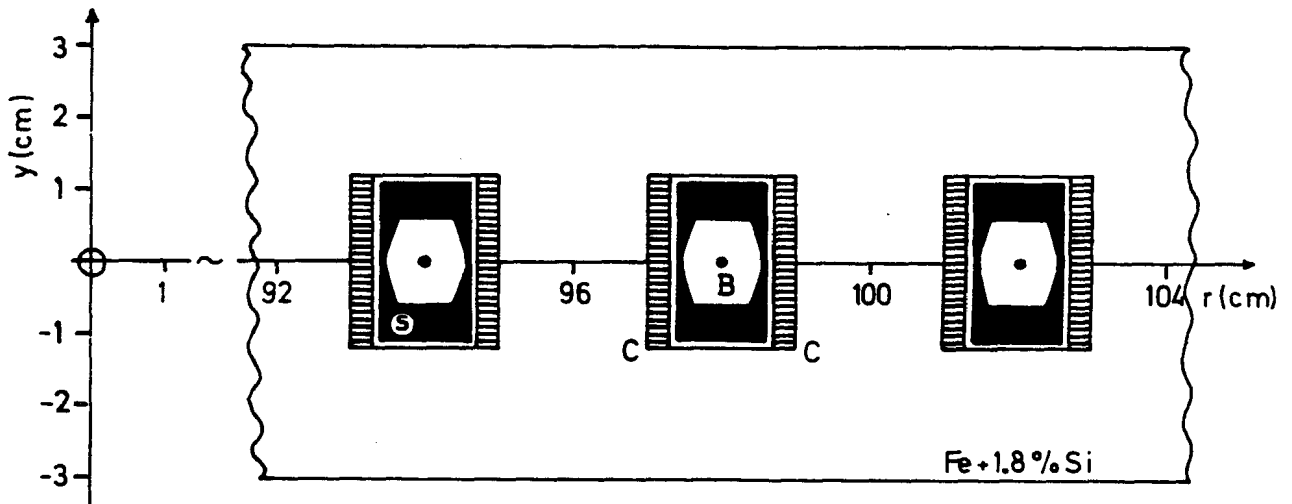keep the turn separation moderate (see fig. 1).

Fig. 1: Cross section of a superconducting Tritron magnet.
B: beam, S: shield, C: superconducting coil

Due to the good beam properties a radial acceptance of ~14 mm will be adequate.
Keeping the magnetic induction below $B_{max} \leq 1.5$ T the overal current density
of the superconducting coils can be made as high as 400 A/mm^2, so the coil
width will be less than 3 mm and the total width of one channel including the
lateral iron yokes 40 mm. A complete magnet sector consists of 20 neighbouring
channels, which can be produced from two iron sheets with milled slots (total
height 6 cm). The coils are potted and cooled across the iron. They are
shielded from the beam by means of a copper tube inside the channels.

As in a conventional cyclotron, the magnetic field at the central orbit has
to fulfil the condition of isochronism, which means the field at the central
orbit has to increase with radius corresponding to the relativistic mass
increase. But in contrast to cyclotrons the radial gradient of the field in
the channels may be set at will as in a synchrotron. From this follows:

1. The axial focusing problems of cyclotrons are irrelevant.
2. The betatron frequencies may be kept constant, there will be no problems with crossing of resonances.
3. Even longitudinal focusing will occur. This property has important consequences for the accelerating cavities.

The large turn separation of the Tritron leads to a considerable reduction of the cost for the magnetic bending system, on the other hand it causes enhanced effort at the accelerating system. At injection an accelerating voltage of about 1.4 MV, at extraction of about 3 MV per turn is needed. From considerations concerning the maximum electrical field, the transit time factor (gap width < 10 cm) and the total power consumption the number of cavities has to be at least six. The cavities will be installed between the magnet sectors. Four additional intermediate sectors are needed for the installation of beam position probes as well as for injection and extraction. Therefore the Tritron consists of 12 magnet sectors and 12 sector gaps in total.

The wedge shaped cavities (driven in the TE101-mode) have a length of 120 cm and a maximum height of 70 cm (see fig. 2). The cavities are capacitively loaded by the accelerating lips, which partly enclose the flat sector magnets. Due to the longitudinal focusing, the frequency and thus the harmonic numbers can be chosen quite high: $\nu_{RF} \approx 170$ MHz, $h \geq 20$. Hence the frequency range needed for accelerating various ions (concerning the specific charge and energy) has to be only about ±3 %. This may be achieved without sliding contacts, simply by deforming the cavities in azimuthal direction.

As the power consumption of six conventional cavities would exceed 300 kW in total, and since the heat would be produced in direct vicinity to the superconducting sector magnets, the cavities are planned to be superconducting as well. Because of the short range of the stray fields of the magnets, the background field at the cavities is far below the critical field of the superconductor. The cavities are planned to consist of 6 mm thick OFHC-copper sheets covered with lead as superconductor and cooled by 4.4 K helium flowing through two pipes from the reservoir by convection.

At the same time the torus shaped reservoir serves as support for the cavities and the magnets. The whole device hangs on the upper half of a cryostat (Ø 3.6 m). By removing the lower half of it one gets access to all parts of the machine (see fig. 2).
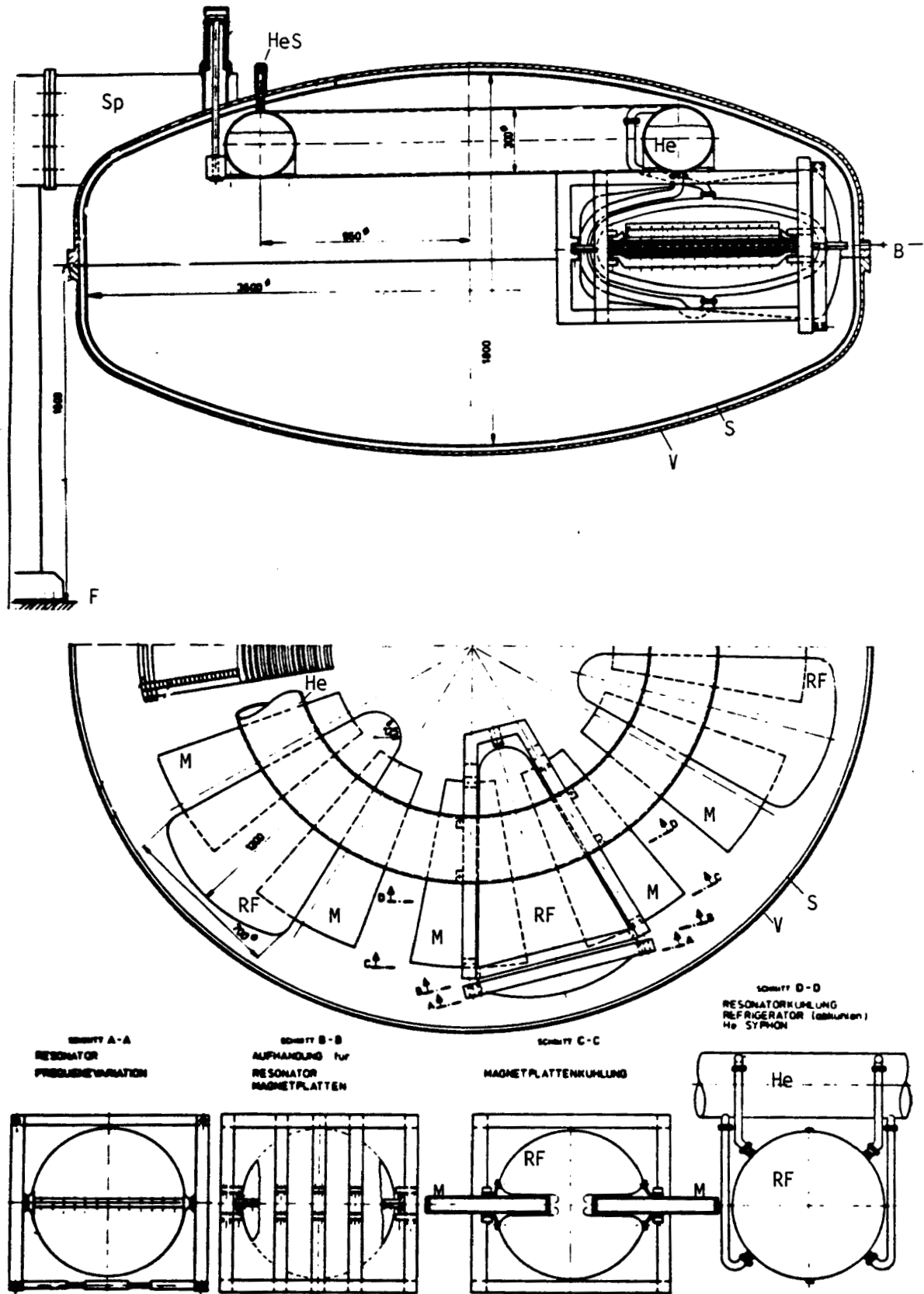
Fig. 2: Above: vertical cross section of the cryostat with one accelerating cavity
        in supporting frame and magnet sector. Centre: half plan view with magnet
        sectors (M), cavities (RF) and helium reservoir (He). Below: azimuthal
        cross sections, A-A: frame for frequency variation, B-B: supporting structure,
        C-C: cavity with two magnet sectors, D-D: cooling system of the cavity
        hanging on the helium reservoir. V: cryostat, S: 80K shield, Sp: support,
        HeS: helium supply.

As superconductor for the cavities lead instead of niobium was chosen for three reasons. First, on account of the large dimensions of the Tritron this technique is relatively simple and cheap. Secondly, the thermal conductivity of lead is nearly as good as that of copper and at least ten times better than that of niobium. A good thermal conductivity considerably helps to hinder the spreading of normal conducting spots on the superconducting surface. This aspect is important considering the large dimensions of the cavities. Thirdly, the shape of the Tritron cavities can be optimized with respect to maximum magnetic and electrical fields, so that the superior critical data of niobium become irrelevant. More details on the cavities and experimental results of a test cavity are given in another contribution at this workshop by L. Dietl.

An important figure concerning the feasibility of the Tritron with both the magnets and cavities superconducting is the time needed for cooling down from 300 K to 4 K (total mass < 6 tn) and for warming up in case of a failure. A refrigeration system (120 W at 4 K level) is provided, so that these periods would take about 12 hrs only.

The project is supported by the Federal Government (BMFT).

References:

1) F.M. Russell, A Fixed-Frequency, Fixed-Field, High-Energy Accelerator, Nucl. Instr. and Meth. 23 (1963) 229
2) J.A. Martin, The Separated Orbit Cyclotron, IEEE-NS-13 (1966) 288
3) U. Trinks, Superconducting Cyclotrons as Boosters for Tandems, Nucl. Instr. and Meth. 220 (1984) 186
4) U. Trinks, New Cyclotron Concepts, X. Int. Cycl. Conf., East Lansing, April 1984
5) G. Hinderer, U. Trinks, Das Tritron als Zwischenbeschleuniger für SuSe, TUM - Int. Report, Dec. 1983