A SUPERCONDUCTING ELECTROMAGNETIC CHANNEL FOR AGOR

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ABSTRACT

In the design of the superconducting cyclotron AGOR (light and heavy ion accelerator[1]), extraction will be partially achieved by a superconducting electromagnetic channel.

Three extraction elements are foreseen; an electrostatic deflector, an electromagnetic channel and a superconducting electromagnetic channel (in this order). Some superconducting quadrupoles, to be employed in the beam exit hole, are also foreseen.

The main difficulties for the superconducting channel are: the energy dissipation in the superconductors (highly energetic protons and alphas), the production of a field bump of .4 Tesla with a very small stray field in the acceleration region and a very small (60-80 mm) vertical clearance.

This paper presents the studies and the design of the channel's superconductor configuration (the cryogenic design is presented elsewhere at this conference[2]).

INTRODUCTION

The AGOR extraction system is mainly inspired from the experiences of MSU[3] using electrostatic deflectors as first extraction elements followed by a number of movable magnetostatic elements.

The electrostatic deflectors of the MSU extraction system have to work at very high electric field levels to complete the beam extraction in one turn.

The high electric field needed on the electrostatic deflector is the weak point in this type of extraction. To avoid this problem the AGOR extraction system will be made with the use of electromagnetic channels, following an electrostatic deflector working at relatively low electric field levels, maximum 105 kV/cm (see fig. 1).

The electromagnetic channels can be made to give a much smaller local magnetic field disturbance than the corresponding magnetostatic elements. The trim coils foreseen to create a

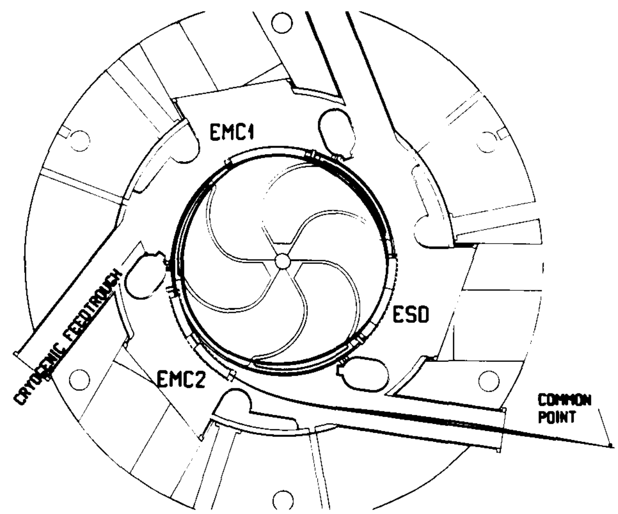


Fig. 1 - View of the extraction system of the AGOR superconducting cyclotron.

field bump in order to increase the beam turn separation at the vicinity of the electrostatic deflector, can be used as correctors for the stray field of the channels. The electromagnetic channels can therefore be placed near enough to the internal beam and the $\nu_r=1$ region, without any correction at the symmetric azimuthal positions.

In the practical application, small movements, of some millimeters, to adjust the channel would change the optimal currents in the trim coils and in the correction coil of the channel but, as the form factors are quite flat in the sensible region ($\nu_r=1$), a readjustment of the extraction parameters can be avoided.

SUPERCONDUCTING EXTRACTION ELEMENTS

Calculations on the extraction parameters have shown the need for quite high magnetic field and gradient levels in the electromagnetic channels previewed. The maximum values are .22 Tesla for the first one with 12 Tesla/M gradient, and .4 Tesla with 16 Tesla/M gradient for the second one.

It is natural to think of superconducting channels in this context.However one of the main problems of superconducting elements are the beam spill in the superconductors.

To avoid this problem the conductors should be placed as far as possible from the beam, but due to the very limited vertical space typical of the compact construction of a superconducting cyclotron, this becomes very difficult

In the case of the first electromagnetic channel, the beam separation at the septum level has a minimum of 10 mm, which gives the septum maximum thickness. This means that a channel with a superconducting septum is impossible since the beam spill would quench the channel at very low intensity levels. It is possible to conceive a superconducting channel where the superconductors do not cross the medium plane but since the vertical space in this case is very small this would mean a very complicated and probably impossible realisation, especially at the extremities of the coils. For these reasons the first electromagnetic channel will be a classical one.

A SUPERCONDUCTING ELECTROMAGNETIC CHANNEL

The second electromagnetic channel in the AGOR extraction system has been chosen to be superconducting since the constraints listed below are more favorable for this one:

1) the minimum beam separation is 65 mm, which is enough to allow a superconducting septum.
2) the vacuum chamber is farther away from the median plane which gives a larger vertical space (from 60 mm at the position of the first classical channel, to 80 mm).

This channel will be made in two parts, of identical sections, each having an azimuthal range of 19 machine degrees plus the coil extremities. The beam aperture will be 16 mm radially and 12 mm axially, which should allow the beam to pass without difficulties. A study has been made to assure that the magnetic field is homogeneous throughout the aperture.

Both parts are radially movable with radial rods attached at each end to adjust the form of the channel to the trajectory of the beam.

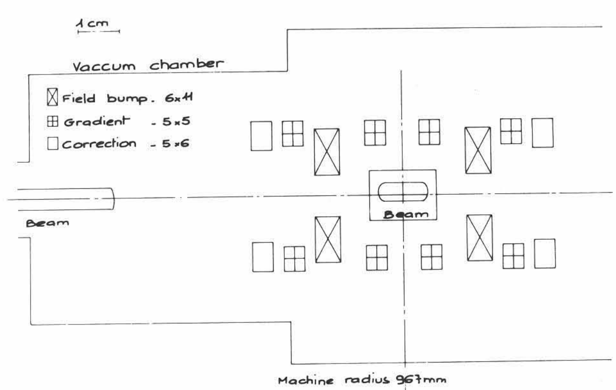


Fig. 2 - Cross section of the superconducting channel in the Cyclotron vacuum chamber

A conductor configuration which produces the needed fields and a small local disturbance of the cyclotron magnetic field was easily found (see fig. 2). It consistes of 3 types of coils with the following functions:

1) coils which creates a field bump (p.s. ±80 A)
2) coils producing a gradient (p.s. 80 A)
3) coils correcting (cancelling) the magnetic field in the sensible r=1 region (p.s. ±80A)

The superconducting wire allows a current density well above the calculated maximum value of 250 A/mm2

An analysis of the beam diffusion, especially of the high energy proton and alpha beams, in the different materials of the channel has been made, to assure that the dissipated energy in the superconductors does not reach the quench limits (see fig.3).

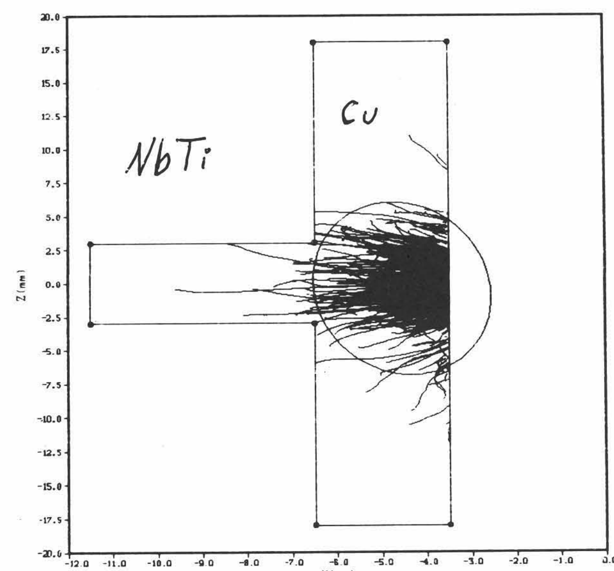
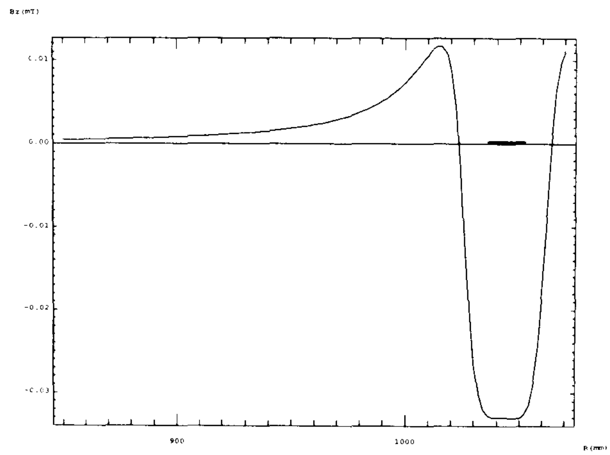


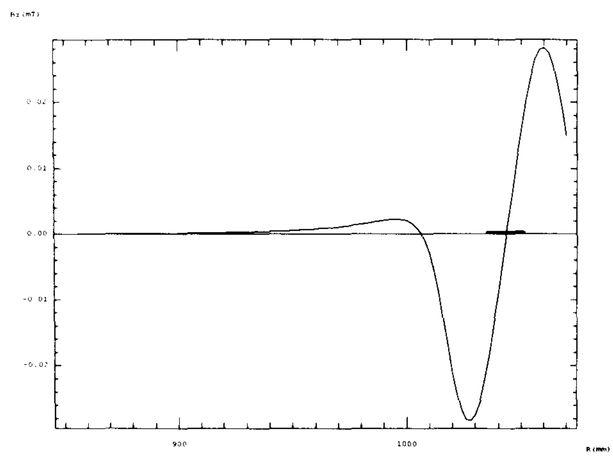
Fig. 3 - Sketch of the cross section of the channel, with the trajectories at the diffusion of high energy protons in the channel materials.The beam has an angle of a few mrad with respect to the inner wall of the channel (see also fig. 2).

MAGNETIC FIELD CALCULATIONS

A simple and efficient way of optimizing the current in the power supplies, for a certain ion beam, has been found. The method uses the form factors of the magnetic fields produced by the coil(s) corresponding to a power supply giving 1 Ampere, in a coordinate system associated to the channel itself (see fig. 4).

The wanted field is given by positioning the form factors in the cyclotron coordinate system, followed by an optimization of the power supplies. Such optimization is obtained by simply multiplying the form factors by their currents and summing the resulting field maps. The currents can be found by a trial an error method or more conveniently by using for instance, the least squares fit method (see fig.5).





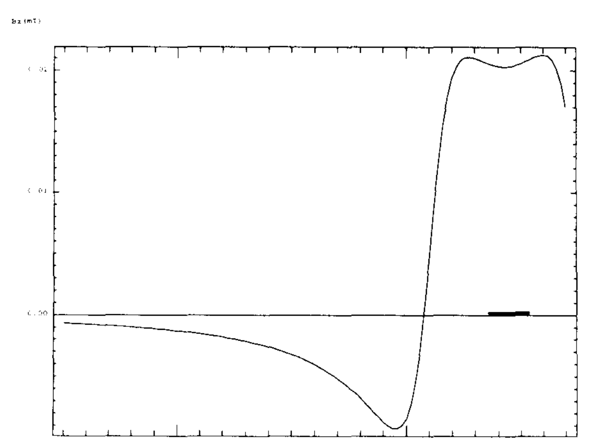


Fig. 4 – Form factors of the three alimentations versus the radius of the coordinate system associated to the channel.
a) field bump coil form factor
b) gradient coil form factor
c) correction coil form factor

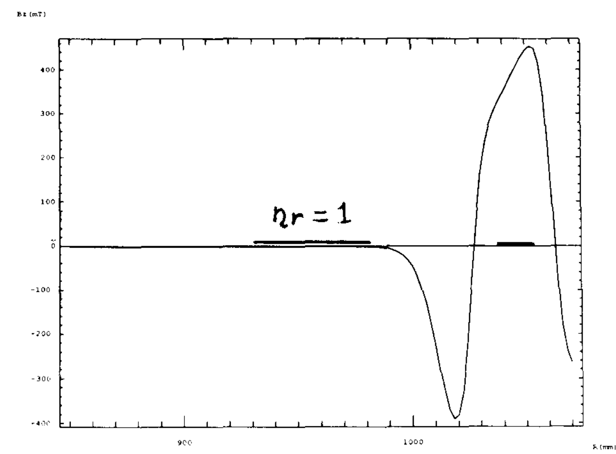


Fig. 5 – The resulting field, for the ion associated with the strongest field, Bz (mTesla) versus the radius of the channels associated coordinate system.

In the superconducting coils the extremities occupy relatively much space, it is therefore necessary to calculate the field contributions from these. A program code (CANAL_3D) has been developed to study among other things these effects. This code calculates the magnetic field produced by a rectangular section conductor (or piece of saturated iron) with finite length, in an exact analytical way.

The conductor can be placed anywhere in the space and the 3 components of the field can be calculated at any point in the space (see fig. 5-7).

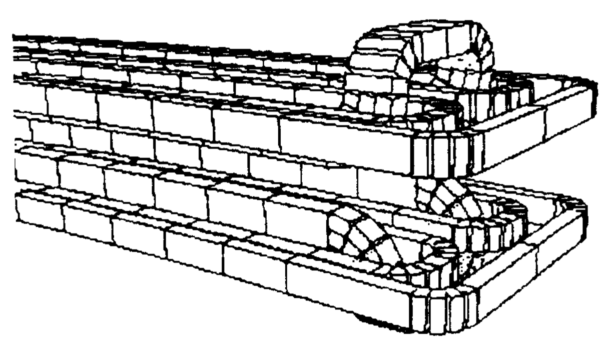


Fig. 6 – The mesh used for calculation of the magnetic field produced by the coils with their extremities (see text for details).

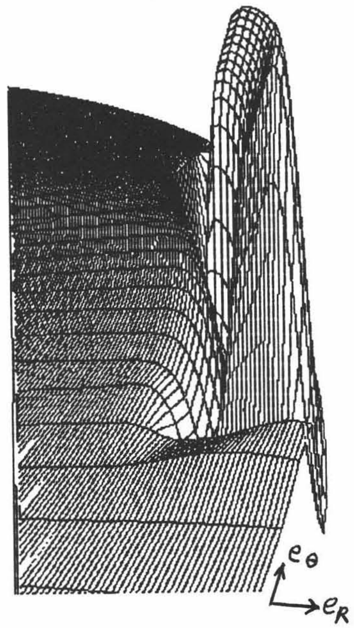


Fig. 7 - Surface of the magnetic field (Bz) in the median plane, shown in a 3D-view. (fig. 5 is a radial cut of this field).

An analysis of the magnetic field harmonics is made by a fast Fourier serie calculation (see fig. 8).

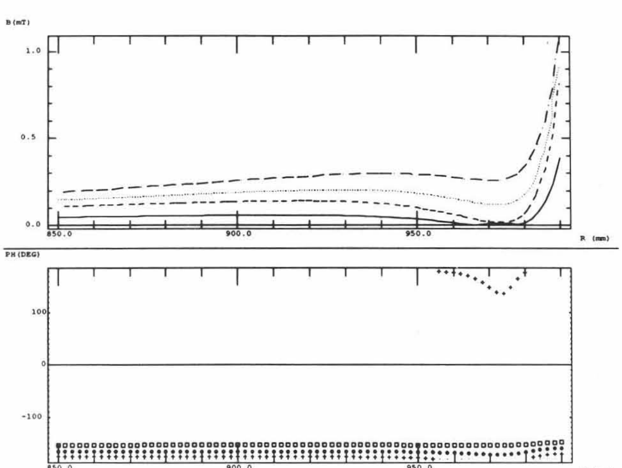


Fig. 8 - Amplitudes and phases of the Fourier series of the magnetic field (Bz) given in fig. 5 and fig. 7.

a) amplitudes of the first harmonics in mT.
0 —— 1 - - 2 ... 3 _._

b) phases in degrees corresponding to the amplitudes.
0 1 + 2 * 3 ◘

The first harmonic, which is the most critical one, is less or equal to .1 mTesla in all the concerned regions. This indicates that the stray field from the superconducting electromagnetic channel is small, and that it can be easily corrected for by the sectorized trim coils at the extraction radius.

CONCLUSION

The superconducting technology, as far as extraction is concerned, is almost unknown, besides Chalk River [4] which has a quite special extraction construction and some never realised proposals [5)6)]. The AGOR project will therefore include the first superconducting electromagnetic channel which will be movable (radial rods) and will have an independent cryogenic system [2)]. The realisation of this channel will therefore give a new extraction tool to the cyclotron community.

*
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