Magnetic Design for a Separated Sector Cyclotron*

Felix Marti
National Superconducting Cyclotron Laboratory
Michigan State University
E. Lansing, Michigan 48824, USA

Abstract

One of the upgrade concepts explored at NSCL was a superconducting separated sector booster cyclotron, injected with the present K1200 cyclotron beam. Although we have decided not to pursue this approach at the present time because of cost, some interesting coil configurations emerged from these studies.

1 INTRODUCTION

The NSCL at Michigan State University has operated the K1200 superconducting cyclotron since 1988. It is used for experimental nuclear physics. In the last few years, the research interest has shifted towards radioactive nuclear beams (RNB's) and they now constitute approximately 50% of the beam time. Our facility produces the RNB by the projectile fragmentation method and separates the different species in the A1200 fragment separator which are then transported to the different experimental vaults.

Late in 1992 through 1993 we studied different alternative possibilities to increase the capabilities of our facility. One of them was the construction of a separated sector cyclotron (SSC) to use the beams produced by the K1200 cyclotron and boost the energy of fully stripped light ions to 500 MeV/u with high intensities. At the same time, it should provide beams of heavy ions (Au-U) with energies above 100 MeV/u, but much lower intensities were needed. Due to the funding situation in the US the cost of this project was considered too high for the present time and an alternative upgrade that consists of coupling the K500 and K1200 cyclotrons (both already in operation) is being pursued (see paper in this conference by R.C. York et al.).

Although the SSC studies were far from complete some interesting results are presented in this paper.

2 SUPERCONDUCTING VS. ROOM TEMPERATURE

The proliferation of superconducting cyclotrons during the last decade shows that the technology is within reach of many laboratories [1]. All of these accelerators are of the compact type with the circular superconducting coils wound around the whole beam chamber. Only the coil package is at liquid helium temperature. By increasing the coil magnetic field, the flutter is decreased because of the smaller difference between the magnetic field in the hills and valleys, decreasing the vertical focusing frequency.

The separated sector cyclotron offers an attractive alternative when higher energies are required. The coils are wrapped around each sector and the difference between hills and valleys is very large, increasing the flutter and providing strong vertical focusing. An additional advantage is the large space in the valleys allowing RF cavities with high voltages, to provide increased turn separation. Injection from another cyclotron and extraction are also simplified.

Room temperature separated sector cyclotrons have been built at many laboratories (PSI, IUCF, GANIL, RIKEN, etc), but no superconducting coils have been used as the sector coils. The Munich group [2] worked for some time on the SuSe project, building a sector magnet for a superconducting SSC without finishing it. More recently the GANIL group [3] [4] studied in detail the design of an SSC with very similar characteristics to our own project. We have borrowed extensively from their studies.

3 MAGNETIC FIELD REQUIREMENTS AND TILTED COIL

We have concentrated on a six sector cyclotron with an injection radius of 2.5 m and extraction radius of approximately 5 m. One of the problems associated with designing a variable energy cyclotron capable of accelerating a broad range of charge over mass (Q/A) ratio ions, is the large dynamic range of magnetic fields necessary to keep the ions isochronous. Figure 1 shows as dashed curves the range of isochronous fields necessary to achieve the high energy limit for different Q/A in our booster project. As we can see, the field level and the gradient change substantially. This large variation makes it necessary to provide additional adjustment in the form of trim coils. As the adjustment is quite significant, it will be necessary to plan for superconducting trim coils. To accommodate the trim coil package (the GANIL design consisting of three layers) a large median plane gap between pole tips is necessary.

One way of obtaining a large gradient in radius is by increasing the fraction of azimuth occupied by the hills and adding spiral to the sectors. When using superconducting coils, the negative curvature needed to wind the coil around a spiraled pole tip becomes an important manufacturing difficulty, because of the large forces associated

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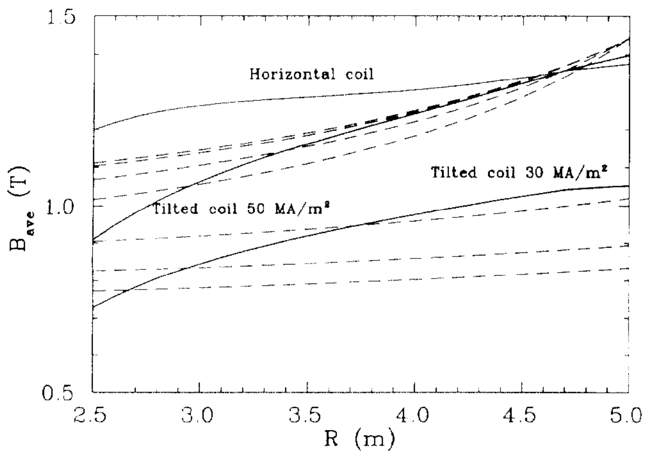

Figure 1: Average field for several different isochronous fields (dashed lines) ranging from Q/A=0.5 and E/A=496 MeV/A to Q/A=0.35 and E/A=98 MeV/u. The solid line on top shows the average field obtained in the TOSCA model with horizontal coils parallel to the median plane. The thicker solid lines show the average field for the tilted coil model at two different excitations.

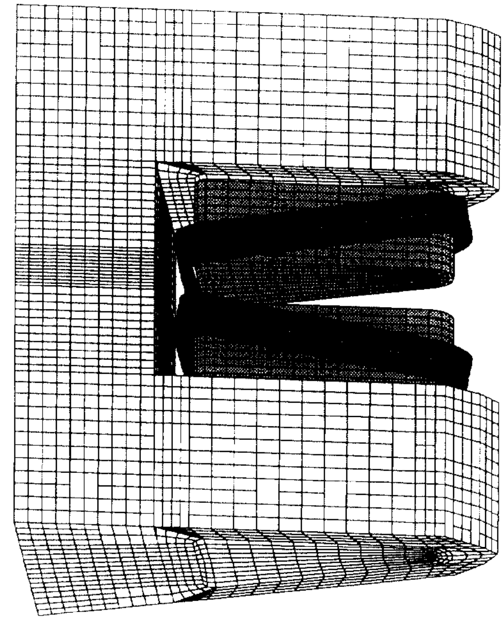

Figure 2: TOSCA model for the tilted coil sector magnet.

with the high magnetic fields. Traditionally the main sector coils have been placed parallel to the median plane, with the main contribution to the magnetic field coming from the iron. We have calculated with the computer code TOSCA [5] the magnetic field for several different configurations of the sector coil with a small tilt (approximately 10 degrees) with respect to the median plane (see Figure 2). This tilt moves the inner section of the coil away from the median plane, decreasing its field and increasing the gradient in the total resulting field. When the coil current is reduced, the iron contribution becomes more important and the effect of the tilt decreases, matching our need of a smaller gradient at lower excitations. Figure 1 shows the average fields for a horizontal coil with a current density of 50 MA/m^2 (solid line on top) and for one of the tilted coil models at two different excitations. The tilted coil produces a magnetic field better matched to the large gradient needed for the high energy fields. This implies that a smaller correction field has to be provided by the trim coils. Further refinements were considered like sloping the iron pole tip, but these details will not be discussed in this paper.

With the same goal of increasing the radial gradient of the field, a different coil arrangement has been proposed for the ASTOR project at PSI [6] and for a proton therapy separated sector cyclotron [7]. In this concept (S-coil), the coils are oriented with their axis horizontal and mounted on the "back edge" of the pole tips, see Figure 3. The comparison of the average field and 6th harmonic for similar S-coil and tilted coil magnets with the same coil cross section and current density are presented in Figure 4. The average fields are of similar magnitude, but the 6th harmonic is much lower, about one half. This difference makes the orbits vertically unstable when determining the closed orbit properties in an isochronized field, while they are stable in the tilted coil model. It seems that the large gap in our model (0.64m) needed to accommodate the trim coil package decreases significantly the flutter of the S-coil magnet. Changing the sector width may improve this difficulty.

4 SUMMARY

The proposed configuration for a separated sector magnet with tilted coils, provides a field much closer to the desired high radial gradient in a high energy cyclotron (Q/A=0.5, E/A=500 MeV/u). The disadvantage of this configuration comes from mechanical difficulties associated with the large forces on the coil, forcing the designer to have the pole tips at liquid helium temperatures, or resort to complicated mechanical structures. The S-coil arrangement provides a simpler mechanical scheme (the yoke is still cold) but seems to lack vertical focusing for large gaps like the ones considered here.

5 ACKNOWLEDGEMENT

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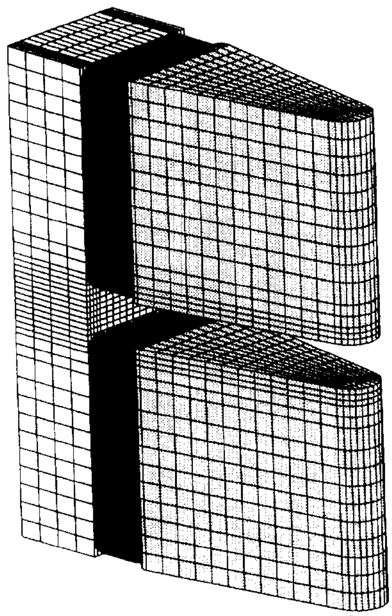

Figure 3: TOSCA model for the S-coil sector magnet.

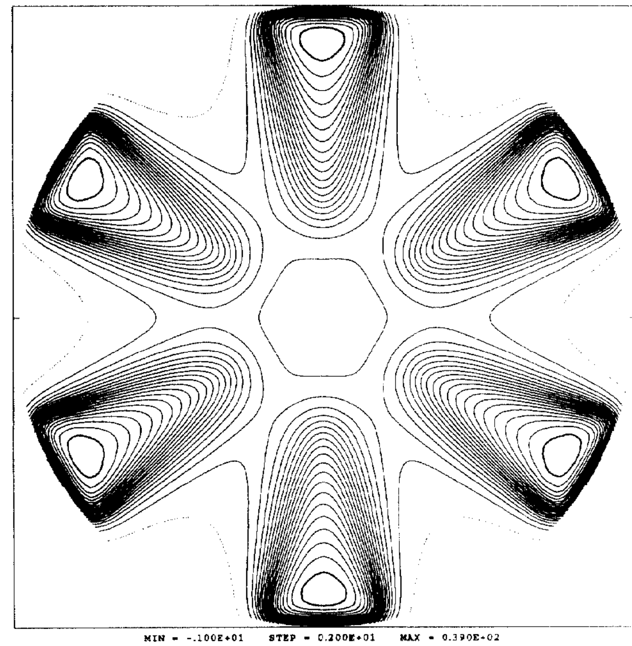

Figure 5: Median plane magnetic field contours for the tilted coil model. The low contour is -1 kG, the high is 39 kG and the step is 2 kG, maximum radius is 5.7 m.

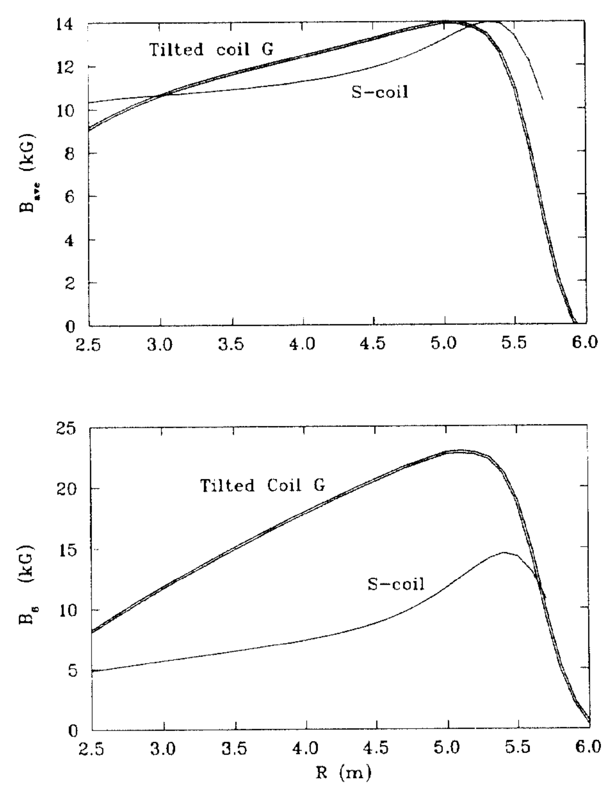

Figure 4: Average field (top) and sixth harmonic (bottom) for the tilted coil model and for the S-coil model.

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