

CHARACTERISTICS OF THE MAGNETIC CHANNEL IN THE YOKE HOLE OF K500 SUPERCONDUCTING CYCLOTRON

J. Pradhan, U Bhunia, J Debnath, S Paul, Z A Naseer, A Dutta, S Bhattacharya, MK Dey, C Mallik and RK Bhandari,

Variable Energy Cyclotron Centre, I/AF, Bidhan Nagar, Kolkata-700 064,INDIA

Abstract

The detail magnetic field measurement of K-500 superconducting cyclotron has been carried out. The last magnetic channel of the extraction system placed in the yoke hole of the cyclotron before external beam line is active, unlike others, which are all passive. This channel comprises a coil and a special shaped iron to produce both quadrupole and dipole field for focussing and radially aligning the different ion species coming out from the cyclotron, with the external beam transport line. The magnetic field inside the channel along with the outside stray field has been measured for different channel currents as well as main magnet excitations. A 3-D model of the full magnet is constructed using magneto- static code RADIA [2] to simulate the yoke field. This paper reports the comparative study of measured and calculated field and studies the trajectories for the representative ions through the stray field calculated from the model. The later being used to locate the starting point (or matching point) for the external beam transport line.

INTRODUCTION

The main magnet of K-500 superconducting cyclotron (SCC) consist of two coils (α coil and β coil), which has been excited to different measurement grid points and detail field mapping is carried out. The last magnetic channel of the extraction system is located in the yoke hole and is active unlike others, which are all passive. This channel is used to focus the beam radially as it passes through the yoke and also help to align the beam with the central trajectory of the external beam line. The magnetic field can be changed by varying channel current in both positive and negative direction, depending on the requirement of different ion species. The channel consists of ten pancake coils made up of $6\text{mm} \times 6\text{mm}$ hollow copper conductor. Its tapered iron pole piece (as shown in fig. 2) produces constant gradient field. The uniformity of the field gradient is maintained to avoid the deterioration of the exit beam quality. The detail design studies have been published elsewhere [1]. This paper reports the results of field measurement inside the channel and its comparison with the results of 3-Dimensional magneto-static code RADIA [2]. Particles with different charge to mass ratio and final energy have different trajectories along the extraction path. So the particle tracking for different representative ions is performed to locate the matching point of the external beam transport line.

MEASUREMENT SCHEME

The magnet was mapped using a special zig, which is inserted inside the channel. The field is measured with the help of transverse hall probes and F W Bell make gauss meter. The measurements are performed under three main coil excitations: $I_\alpha / I_\beta = 300\text{ A}/300\text{ A}$; $I_\alpha / I_\beta = 575\text{ A}/75\text{ A}$; and $I_\alpha / I_\beta = 459\text{ A}/471\text{ A}$. The channel current is varied from 0A to 300A in both positive and negative direction. Fields have been measured on a rectangular grid aligned with channel, having long dimension (+z) pointing in the direction of the beam. In the transverse direction (x), there were three points for each z, measured at -8mm , 0 , $+8\text{mm}$ from the centre of zig. The measurement step is 0.5 inch along z direction. The stray magnetic field outside the main magnet is also measured up to about 5 m from the yoke.

FIELD SIMULATION AND RESULTS

This active magnetic channel is situated in the yoke hole and it is necessary to generate the yoke field for estimating the actual field inside the channel and compare it with the experimentally measured data. A complete 3-D model of K-500 SCC main magnet is made with the help of code RADIA. This is three sector cyclotron having mirror symmetry about its median plane. The median plane view of the magnet along with channel in the yoke hole is shown in figure 1.

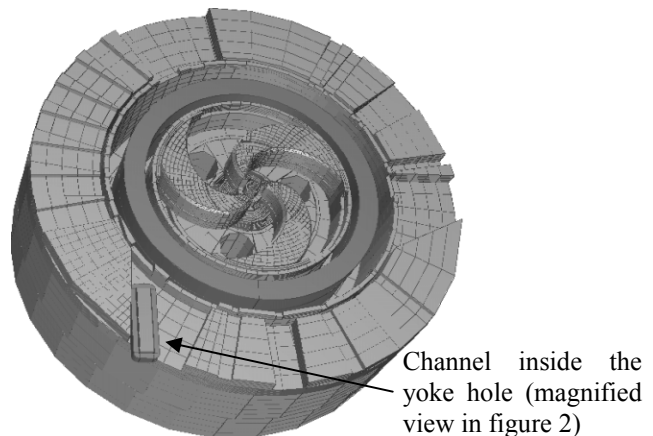


Figure 1. Median plane view of main magnet of K-500 Superconducting Cyclotron (SCC)

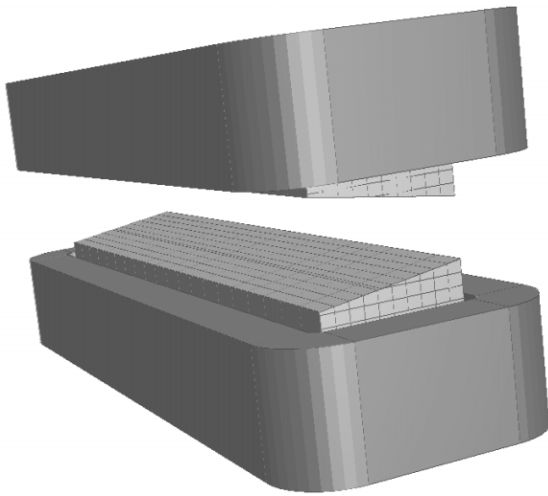


Figure 2. Magnified view of the magnetic channel

This model is also used to generate field in the extraction region, which is otherwise difficult to measure. The comparison is made using some scaling with measured data (accelerator and extraction region) and shows reasonable good agreement, in spite of various computational limitations like block sizes, material property and so on. The data in the yoke hole with channel and stray field outside are discussed here. The longitudinal field along the length of the channel with the channel centre at $Z=0$ is shown in figure 3. The stray field outside the yoke of main magnet is shown up to 20 inches from the channel centre. Similarly the increase of field gradient with the channel central field is compared and shown in figure 4. Moreover the deviation of calculated field gradient from measured data is more than 10% in higher field. This is possibility due to the saturation of iron in higher field besides others. The measured central field (B_c) inside the channel at zero channel current for four different excitations of the main coil increases linearly with the current and is in good agreement with the calculation as shown in figure 5.

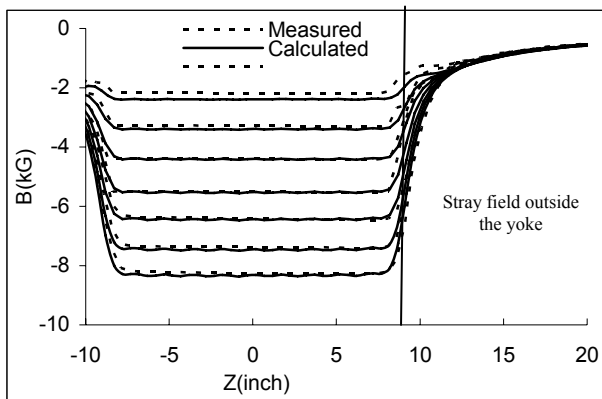


Figure 3. Longitudinal field inside the channel

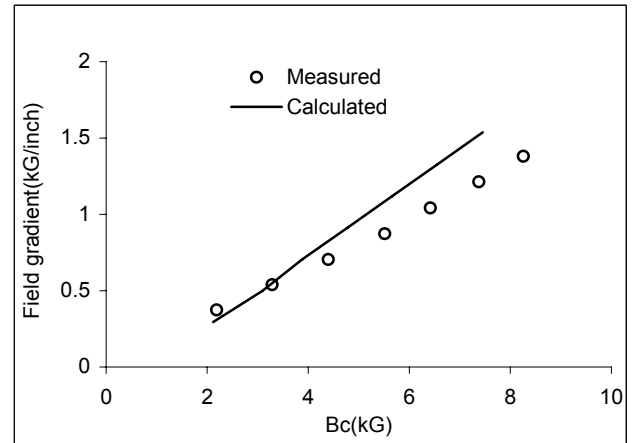


Figure 4. Field gradient at different field (B_c)

The comparison between the measured data and the calculated results using some scaling is made in order to confirm the reliability of the simulated model. It will be used for extrapolation to higher excitation where we are unable to take data. Still the calculation shows some deviation, which can be improved further.

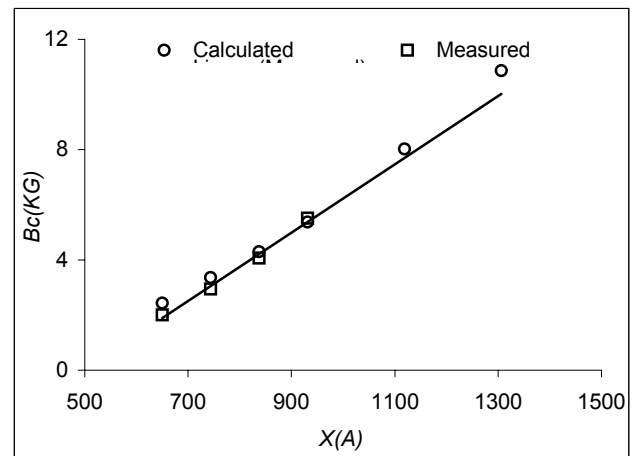


Figure 5. Central field (B_c) at zero channel current for different main coil excitation, where $X=I_\alpha+I_\beta$ & $Y=(7 \times I_\alpha - 3 \times I_\beta - 800)/3=333.33$

PARTICLE TRACKING

It is necessary to bring the central trajectory of different beams coming out of the cyclotron to be aligned with central axis of the external beam line. So the trajectories of the representative ions covering the operating region of K-500 cyclotron are studied. There is a slit located just before the channel. The beam is tracked from the slit to some distance beyond the yoke through the field obtained from the RADIA calculation and by running computer routines, which integrates the equations of motion. It is found that by tuning the available channel currents, all the particles could be

forced to deflect through a common point. Just one steering magnet at that point is needed to align all the beams along the successive external beam transfer line.

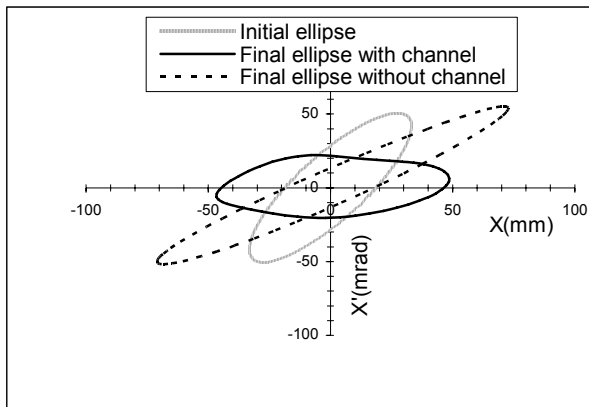


Figure 6. Radial phase space ellipse at the entrance and at the exit from the channel for the ion $Z/A=0.25$ and $T/A=30\text{MeV/n}$

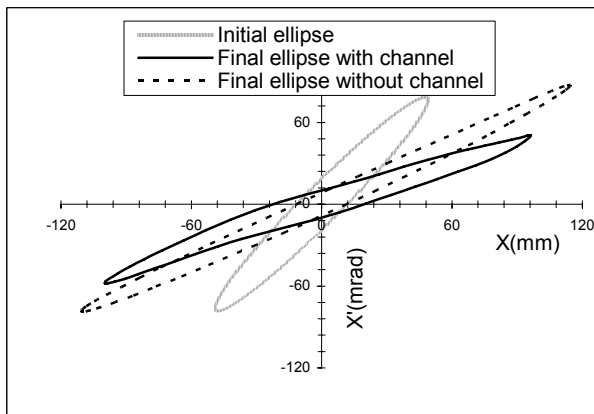


Figure 7. Radial phase space ellipse at the entrance and at the exit from the channel for the ion $Z/A=0.5$ and $T/A=56\text{MeV/n}$

Phase space ellipse is tracked through the yoke traversal path for different ion species. The initial phase space ellipse at the slit location is obtained from

the detail beam dynamics calculation, which is discussed elsewhere [3]. Results of radial phase space (area $\sim 950 \pi \text{ mm-mrad}$) at the entrance of the slit and the exit from the yoke for the two cases with and without magnetic channel inside the yoke hole is presented in figure 6 and figure 7 respectively. A focusing effect is evident from the figures, in presence of channel in the yoke hole with relatively small divergence and beam size, which do not pose any problem for the successive beam handling.

CONCLUSION

The comparison between the RADIA simulations and measured data was made to know whether the code can be use to generate field data, where the measurements are not performed. It is found that with proper use of scaling function and of course with further development, the code can be used to serve the purpose. The study of particle tracking of all the ion species yield the common point for all the beams and one steering magnet at that point is needed to align all the beams along the successive external beam transfer line. Because of relatively small divergences and beam sizes, at the exit of the channel it will not be any problem for successive beam handling.

ACKNOWLEDGEMENTS

The authors would like to thank all the colleagues of the field measurement team for their support and co-operation. Their contribution led to the successful completion of the magnetic field measurement.

REFERENCES

- [1] J Pradhan et al., "Design of Active Magnetic Channel M9 for the Extraction System of VECC K-500 Superconducting Cyclotron", Presented in InPAC-2003 at RRCAT, Indore.
- [2] RADIA Technical Reference Manual ESRF, Grenoble, France
- [3] S Paul et al., " Characteristics of Beam Extraction System of K-500 Superconducting Cyclotron" presenting in APAC-2007 at RRCAT, Indore.