MAGNETIC FIELD SIMULATION USING RADIA AND TOSCA FOR KOLKATA SUPERCONDUCTING CYCLOTRON

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Abstract

Detail magnetic field measurement of the Kolkata Superconducting Cyclotron, in the acceleration and the extraction region is carried out for several excitations of the cyclotron. However it was not possible to measure the fields at all excitations spanning over the entire operating region of the cyclotron. Moreover, measurement in the extraction trajectory is limited by the in-accessibility of the region to the measurement jig system. So the magnetic field simulation is performed using 3-D magneto static codes (RADIA and TOSCA) to compute the field data required for running the beam dynamics codes. This paper presents a scheme to generate field data by excluding the part of the model which is nearer to the median plane and saturated, thus avoiding detail/minute modelling of that region (like shims, trim-coil inserts etc.). The comparison between all the measured data and the corresponding simulated ones shows the deviations are within a few gauss, which justifies the reliability and acceptability of the scheme to extrapolate the field for higher excitation.

INTRODUCTION

The main magnet of Kolkata Superconducting Cyclotron (SCC) consists of two coils (α-coil & β-coil), which has been excited to different measurement grid points and field mapping has been carried out [1]. However it is not possible to measure the field at all excitations and the measurement in the extraction region is limited by the in-accessibility of the region to the measurement jig system. The axial field is measured and compared along the central plug of the SCC. This paper presents the 3-D simulation of magnetic field to compute the field data for all the excitations spanning over the entire operating region of the cyclotron. The simulation data provides the iron-produced field, both for the azimuthal modulation and the average field required for beam dynamic codes. The measured data is compared with calculation to establish the reliability of the simulation. The edge field is also simulated and compared, which is required for the studies of extraction system.

SIMULATION SCHEMES

The field is calculated by 3-D modelling of Kolkata SCC main magnet. Both OPERA-3D (TOSCA) and RADIA codes are used for simulation. OPERA 3-D [2] is a commercially available finite element code whereas RADIA [3] is freely available and is interfaced with MATHEMATICA [4], uses boundary integral method to solve. The RADIA requires geometry creation using simple MATHEMATICA code requires less CPU time of the solver however have some weak points as well. The finite element code requires significant skills and time for the input of geometry, materials and proper meshing [5]. The median plane view of the main magnet constructed in RADIA is shown in figure 1. The pole tip hill is machined into two pieces to approximate its spiral profile. The hill is chamfered on both azimuthally edges at 45º. There are several small assemblies and sub-assemblies like hill-shoe, pole tips, central plug with its hill and valley part and so on which produce assembly errors besides several holes for trim coil inserts and others. Apart from this, the geometrical complexity of the magnet poses dimensional uncertainties. It is likely that the splitting of the pole-tips, different holes etc may have definite influence on the local saturation both in strength and direction, because of the topography of the coil generated field [6]. During field measurement several shims of different shape and sizes have been added to remove field imperfection. However we modelled the full magnet and compared the field data thus obtained with measured ones. Because of some limitations (computer memory) and other reasons as mentioned we could not arrive to the accuracy as desired for the internal field. So, in order to calculate accurately the field arising from such complex structure it is assumes that the pole tip surfaces to be fully saturated. So
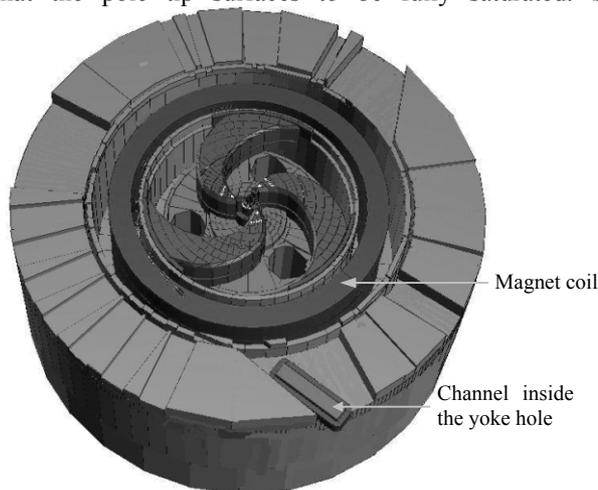

Figure 1. Lower half portion of the magnet.

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part of the model (pole tip surface) which is nearer to the median plane is excluded to avoid detail/minute modelling. The field from these saturated surfaces is obtained from one of the measured field data. In addition this also incorporates the field due to all the shims added in the pole tips. The small assembly errors, if any, around the pole tip region, which has major contribution, will be absorbed. This constant field, $B_{sat}(r, \theta)$ is added with the field obtained from the model calculation to get the internal field. The coil field, $B_{coils}(r, \theta, I\alpha, I_\beta)$ is calculated analytically, which is used to get the iron generated field, $B_{iron}(r, \theta, I_\alpha, I_\beta)$. The contraction of coil at liquid helium temperature that is confined to 0.3% [6] is not taken into account in calculation. The uncertainties of the coil dimension and its placement with respect to surrounding yoke produces non- negligible errors especially in the higher radii. We can write the total field, $B(r, \theta, I_\alpha, I_\beta)$ as the sum of $B_{sat}(r, \theta) + B_{coils}(r, \theta, I\alpha, I_\beta) + B_{iron}(r, \theta, I_\alpha, I_\beta)$. The iron field, $B_{iron}(r, \theta, I_\alpha, I_\beta)$ is consist of the field generated by the variable saturation of the yoke and primarily depends on the magnetisation of iron.

RESULTS AND DISCUSSION

Coil Field:

The field due to two independent α-coil & β-coil is calculated analytically. This is air-core field. It is likely to have some discrepancies form this calculated field on account of thermal contraction, dimensional in-accuracy, assembly errors and so on. This field is used to get iron field from the total field as mentioned above.

Iron Internal Field:

The internal field is measured upto radius of 673 mm in the median plane, and coincides roughly with the extraction radius of cyclotron. Beyond this radius internal field mapping is not feasible because of the presence of coil tank inner wall. Data's are taken at 2.54 mm radial and 1 ° azimuthal interval respectively. Different im-perfection present in the field is reduced by applying
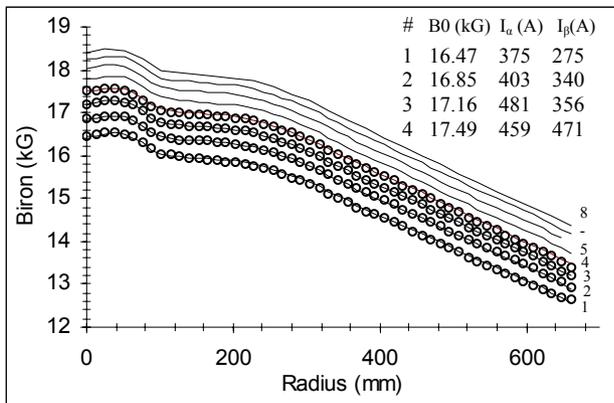

Figure 2. Average Iron field profile for the listed coil currents. Top 4 curves are obtained from simulation. [― calculated, oo measured]

various iron shims. This is an iterative process. The final measured data is smoothened, analysed and compared with simulated ones. The comparison of Iron average for different currents combination of α-coil & β-coil is shown in figure 3. The top five curves (5 to 8) are extrapolated data for which measurement data are not available. The observed discrepancy in iron average field is less than ± 0.5% for all sets of measured data as shown in figure 3. The variable saturation of the yoke depending on the coil currents affects both the absolute level and average slope of iron field. The comparison for the 3rd, 6th and 9th harmonics is shown in figure 4 for one set of coil currents and it is found that the maximum deviation is less than 0.2%.
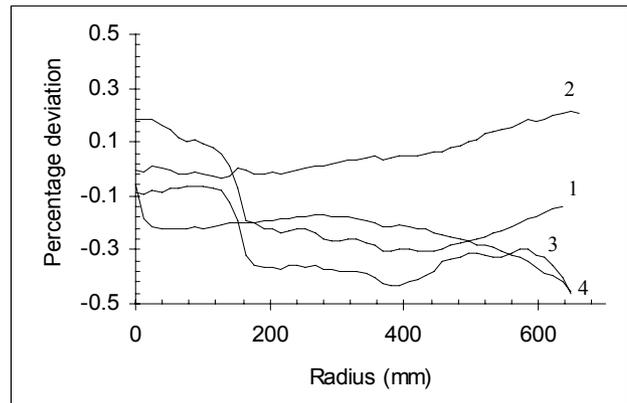

Figure 3. Percentage difference between measured and calculated iron average field for the given set of currents.
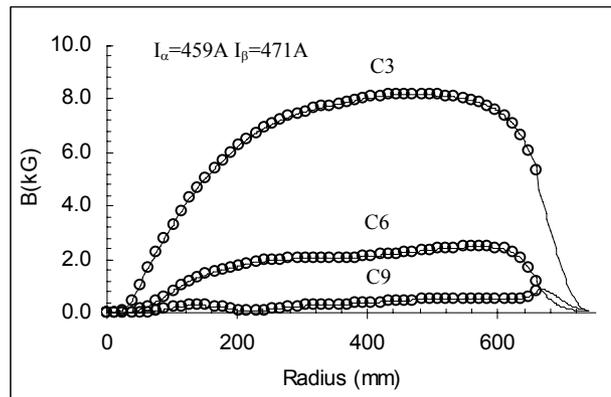

Figure 4. Measured and calculated amplitude of the 3rd, 6th and 9th harmonics, as function of the radius at the listed coil currents [― calculated, oo measured] .

Axial Field:

The magnetic field along the axis has sharp gradient and appreciably large fringing field extending up to several meters. The field data is required to study the beam injection system into the cyclotron. The measurement has been performed using hall probes from the median plane up to the height of 1.7mts with interval of 5mm.The measured and simulated axial field

distribution is shown in figure 5, where 3 and 4 sets are extrapolated data for which measurements are not available.
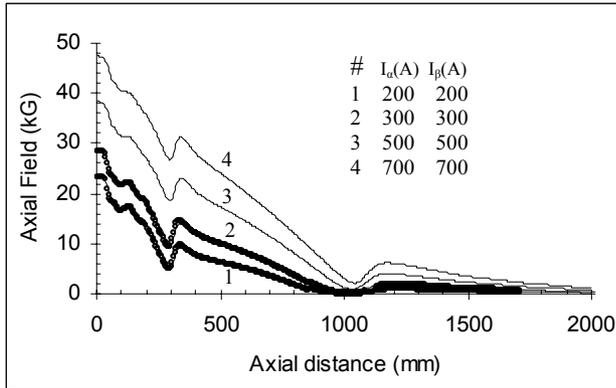

Figure 5. Axial field distribution [─ calculated, oo measured]

Edge Field:

It is necessary to calculate the path of the extracted beam, which requires edge field data. Edge field measurement is carried out by inserting the hall probes through a different radial holes existing in the median plane of the cryostat. Datas are taken at 12.7mm radial intervals at affixed azimuth. The possible errors in the edge field measurement like radial and azimuthal shift is incorporated by comparing with internal data of the same excitation. The comparison of the data for two   different
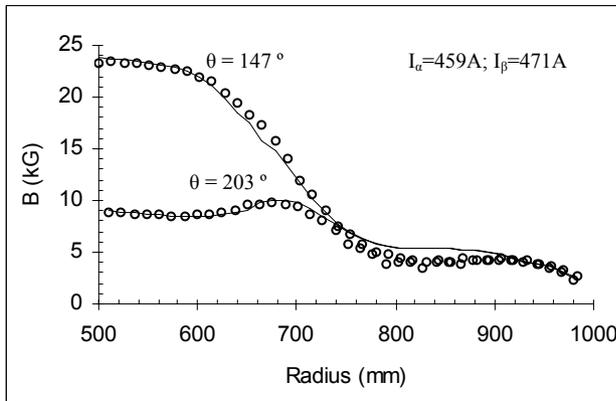

Figure 6. Comparison of Edge iron field at two different angles [─ calculated, oo measured]

azimuths for a given excitation is shown in figure 6. Possible sources of error in the edge field region due to coil field contribution are already mentioned. At the magnet edge especially in the proximity of iron structures (coil tank walls) the influence of the different coil excitations plays a substantial role in shaping the iron-produced field.

Channel Field inside the Yoke hole:

One active magnetic channel of the extraction system is placed in the yoke hole of the cyclotron as shown in figure 1. This channel is a combined function magnet used primarily to align the beam with external beam line. The magnetic field inside the channel and outside stray field has been measured for different channel currents as well as main magnet excitations using hall probes. The field along the length of the channel with the channel centre at S=0 is shown in figure 7 for different channel currents and main magnet excitations.
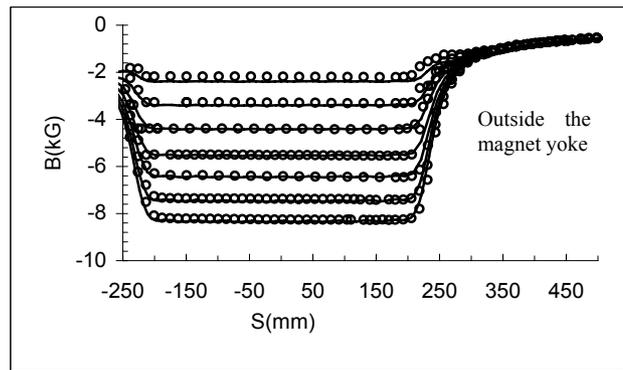

Figure   7.   Field   inside   the   active   channel. [─ calculated, oo measured]

CONCLUSIONS

The computational scheme used to simulate the magnetic field is quite satisfactory to compute field data, where the measurement data is not available. The detail comparison between measured and simulated data is performed to validate the simulation.

REFERENCES

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