MAGNETIC FIELD MAPPING OF KOLKATA SUPERCONDUCTING CYCLOTRON

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INTRODUCTION

The Superconducting cyclotron magnet at VECC, Kolkata was commissioned in July 2005 and magnetic field measurement and correction program was undertaken since then. The mapping task involved fabricating mapping jig and a reliable and automatic data acquisition system so that the task can be accomplished in a short time. The goal consisted of (i) correction of average iron field distribution by adding iron shims (ii) minimization of first harmonic component (iii) field measurement at different excitations up to ~68cm radius (iv) field measurement on discrete azimuthal bands beyond 26" radius at different excitations and (v) field measurement along axial hole and extraction path. During the field mapping several problems were debugged and corrected. The mapping was completed in March 2006 to allow trim coil and RF system to be assembled. Also efforts have been made to complete the field data (since the cyclotron presented regions which are difficult to map and grid points which could not be obtained) using TOSCA and RADIA.

DESCRIPTION

The MFM system is designed to be fully automatic to reduce human interference resulting into a minimum measurement time. The Magnetic Field Mapping (MFM) system comprises of a hardware system and a control & data acquisition software.
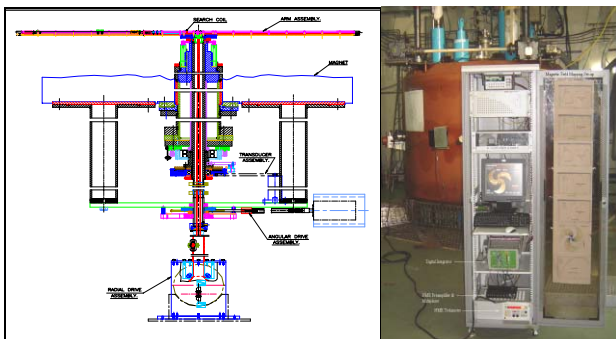

Figure 1. Mechanical assembly of magnetic field mapping jig. Computer control hardware for MFM

In order to obtain precise and accurate data, the mechanical system for the positioning the device had to be rugged and repetitive. The deflection of the total assembly in the vertical direction had to be restricted to less than 0.25 mm and the off-axis movement has to less than 10 micron so that the overall positioning error corresponds to the acceptable error band of less than 5

gauss in magnetic field. The mechanical system [1] comprises the arm assembly, radial drive assembly, angular drive and transducer assembly (Fig. 1).
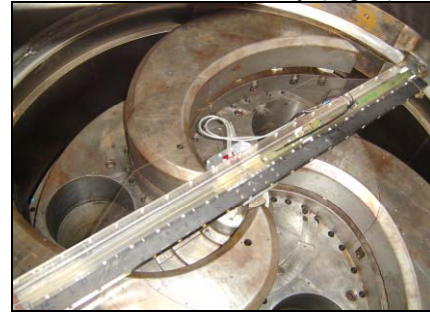

Figure 2. Measurement jig with radial arm and search coil

The arm assembly (fig.2) comprises a linear encoder, cart body carrying the search coil, straight track and support bar. All materials of the arm assembly are non-metallic to avoid distortion of the magnetic field locally and to avoid eddy current forces on them A linear encoder comprising a photo sensor assembly head, HEDS9200 and US Digital scale traveling over a linear strip (360 LPI)is used to measure the radial position of the search coil. This assembly enables the search coil to move radially from −50mm to 685mm on a base track One out of every thirty-six pulses from the encoder is used to trigger the digital integrator unit to read and integrate the search coil output between the triggers. The angular position of the search coil carrying arm is determined by absolute rotary Inductosyn encoder (256/2 pole, 128/1 speed, 8.15 inch stator O.D.). The standard accuracy of 1.7arc sec is obtained using two dual channel preamplifier (219200) and AWICS converter board (220500). A microcontroller based interface module, developed in house, reads the angular position from the AWICS board online.

A drive mechanism consisting of a DC brushless servo motor, spur gear set and a pulley drum, placed about 2.0 metres below the cyclotron median plane, was used to move the search coil radially at an uniform velocity of about 40cm/s. A Kevlar string wound on the pulley drum was connected to the search coil through the hollow angular drive shaft to the radial arm in the median plane of the cyclotron. An acceleration of 10m/s^2 ensures that the search coil attains a uniform velocity before magnetic field data collection starts. This acceleration induces a tension of around 5 N and stress of around 6.4 Mpa on string, which is within its allowable limit. After each radial scan is completed for a particular angular position, the arm assembly along with the search coil is moved usually in 1^0 or $1/2^0$ angular steps using an angular drive mechanism. An absolute angular encoder for accurately

measuring the angular position up to ±4 arc sec accuracy was integrated to the system.

MFM User Interface Software

This software developed in LabVIEW 6.1 incorporating multi-threaded architecture, performs following three tasks simultaneously [3].

- Communication with Measurement Controller s/w for automatic and manual mode of operation, control and monitoring the MFM procedure and field data acquisition and storing.
- Transaction with a centralized Oracle Database server through Microsoft ActiveX Object in SQL to read and display different subsystem (Main magnet power supply System, Trim coil power supplies system, Cryogen delivery system) parameters to ensure the magnetic field during the mapping.
- Offline Fourier analysis of MFM data stored in database for the analysis of azimuthal field modulation.

Measurement Controller Software

A multithreaded C module was implemented using Windows API [2]. It was devided into five modules.
(i)Receive command from client program and decode the command to invoke appropriate job.(ii)Execute the current job.(iii)Execute a watchdog timer independently to monitor any unacceptable event and notify the client.**(iv)**NMR Gauss Meter thread reads online NMR Gauss meter output. **(v)**Angular movement thread positions the search coil carrying arm at desired angle by communicating with angular encoder and smart motor driver.

MAGNETIC FIELD MEASUREMENT RESULTS

The main magnet of K-500 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. However it was not possible to measure the field at all grid points.
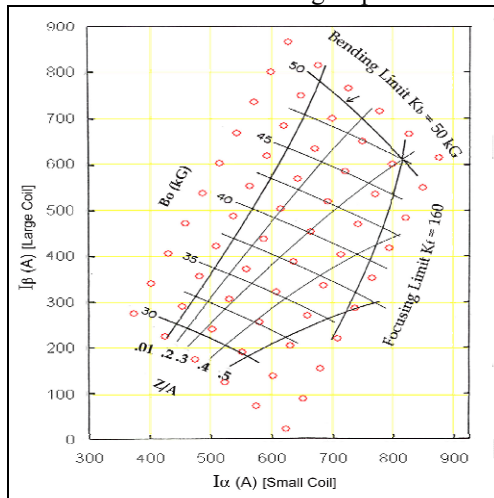

Figure 3: Field Mapping grid in (Iα, Iβ) plane.

The magnetic field has been measured with a search coil and NMR set up, with linear and angular positioning accuracy of 10 μm and 0.5 arc-seconds, respectively. NMR signal was easily obtained at centre but lot of efforts had to be given to get the signal at the RF hole which was required for search coil calibration.

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 tank inner wall. Data were taken at 2.54 mm radial and 1° azimuthal interval respectively. We have reduced the different imperfection present in the field by applying various iron shims. The final measured data is smoothened, analysed and compared with simulated ones. The debugging of errors and localising them was made much easier by polar plots showing differences from sector average as shown in Fig. 4. Second harmonic component were also plotted to understand the problem.
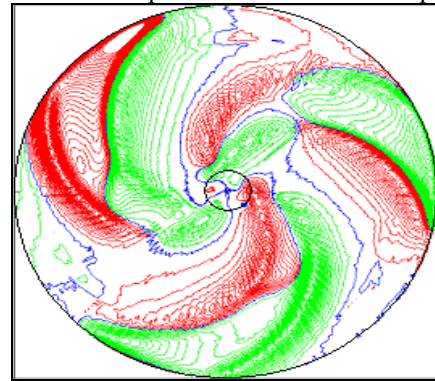

Figure 4. Polar plot of deviations from sector average

Average Field

The average iron field was deduced from the measurements taking into account the contribution from the coils calculated by POISSON.

Three iron shims were placed on each of the pole tips, near radius equal to 12 cm, 17 cm and 35 cm respectively, to smooth out the dips (~80G) in iron-average field, as shown in figure 5. The analytically calculated shimming gave very excellent results due to saturated iron approximation.The upper four curves in the fig.5 are extrapolated data. .
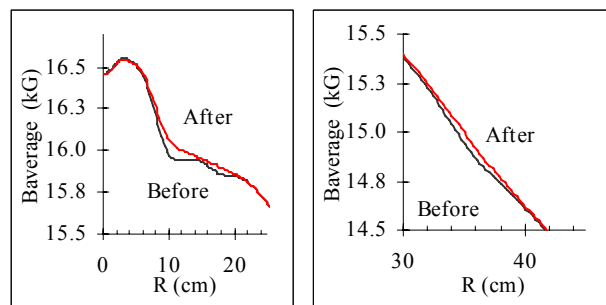

Figure 5. Average Iron field correction by adding shimms near R=10 cm, 18 cm & 35 cm

The comparison of Iron average for different currents combination of α-coil & β-coil is shown in figure 7.

The variable saturation of the yoke depending on the coil currents affects both the absolute level and average slope of Biron. The effect due to contraction of coils were not used during analysis but will be incorporated in the beam dynamics calculation as it is less than 0.3%.
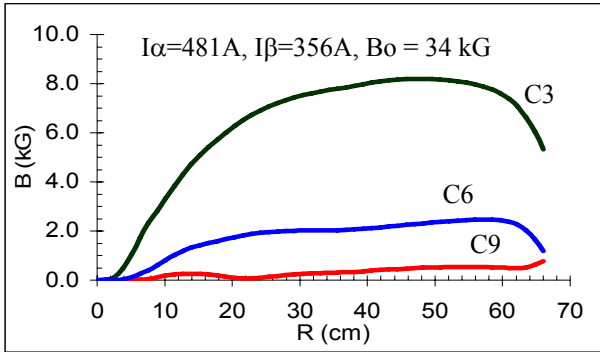

Figure 6. Measured 3rd, 6th and 9th harmonic amplitudes as a function of radius.

The comparison for the 3rd, 6th and 9th harmonics is shown in figure 6 for given set of coil current combination. The observed discrepancy between measured and calculated values is less than ± 0.5%.
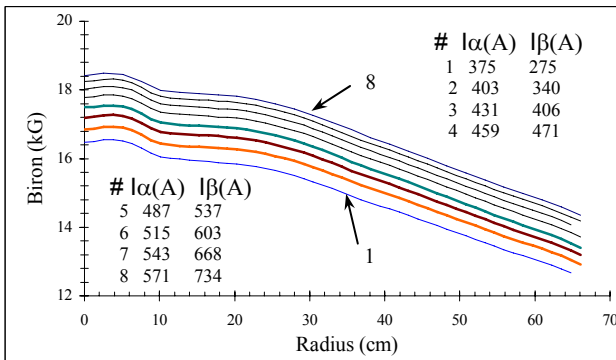

Figure 7. Average Iron Field profile at different set of currents. Top four curves are from simulation.

First Harmonic Corrections

The most important task was to minimize the first harmonic component in the field in the central and extraction regions. As shown in the figure 8, initial measurements showed large first harmonic (>20G) at the edges of pole tips and the centre region. Briefly, the corrections had to be applied at the following places

- Near the centre, the error was due to assembly error of small hill extension components.
- From 35cm onwards, the large first harmonic was contributed by one of the outer pieces of pole-tips. A large piece of 1mm thick iron sheet was attached to the outer pole piece.
- The pole pieces were fabricated in two pieces and this contributed to first harmonic error at around 35 cms.

- During reproducibility checks it was found that first harmonic fields were not reproducible by large amounts. This was finally attributed to the bolts in one of the sector being defective which had yielded.
- Finally first harmonic was brought down to less that 7 gauss at extraction by iron shimming   Finally first harmonic was brought down to less that 6G at extraction by iron shimming .
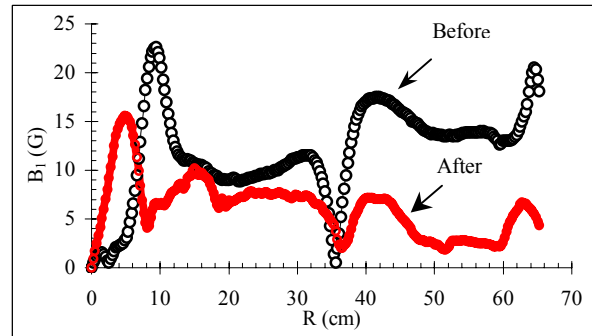

Figure 8. 1st harmonics magnetic field profile before and after correction by shimming

Edge Field

It is necessary to calculate with some accuracy the path of the extracted beam, which requires fringing field data. Fringing field measurement was carried out by inserting the hall probes through a different radial holes existing in the median plane of the cryostat. Data were taken at 12.7mm radial intervals at a fixed azimuth Measurements were done with magnetic channels in place and without them. The possible errors in the fringing field measurement like radial and azimuthal shift is incorporated by comparing with internal data of the same excitation. Measurements were also made along the extraction path from M4 magnetic channel onwards. However results have been supplemented with TOSCA calculations to obtain complete data. Field measurements were done for yoke field where active magnetic channel 9 will be placed.

Axial Field for Injection

The axial field was measured using Hall probes. The results are discussed separately in the paper describing the injection system

ACKNOWLEDGEMENT

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[1] Mechanical System For Superconducting Magnetic Field Measurement, C. Nandi et al., InPAC2003, Indore.

[2] Magnetic Field Mapping System For Superconducting Cyclotron, PCAPAC 2006, Jefferson lab., USA