

STUDY OF MAGNETIC FIELD IMPERFECTIONS OF KOLKATA SUPERCONDUCTING CYCLOTRON

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Abstract

Analysis of the magnetic data obtained during the magnetic field mapping of Kolkata superconducting cyclotron showed imperfections in the main magnetic field. Since the main magnet of the superconducting cyclotron is three fold rotationally symmetric, any deviation from this symmetry creates imperfections in the magnetic field. Generally, 1st and 2nd harmonic components are inherently present in the field due to assembling errors in iron/coil. A major portion of these imperfections is attributed to the misplacement/tilting of the iron pole tip with respect to coil. The error in positioning of main superconducting coil with respect to surrounding iron produces another imperfection. Pole tip deformation due to rise of temperature produces field imperfection. This paper reports the various possible sources of imperfection in general and their estimation. The calculation was compared with measured data to find out the actual cause of imperfections and necessary corrections have been carried out.

INTRODUCTION

The Kolkata superconducting cyclotron magnet was commissioned and detail magnetic field mapping and corrections was carried out [1]. Measured data is analysed for field imperfection studies. It is found that the imperfections exist and it is required to identify the actual cause of imperfection in order to carry out the necessary corrections. Magnetic field has three fold rotational symmetry with respect to its axis and mirror symmetry with respect to the median plane. Any deviation from these symmetries creates imperfections in the magnetic field and can be express in terms of different harmonics. A first harmonic of 2 or 3 gauss is sufficient to disturb the beam as it passes through a $\nu_r=1$ resonance. This paper discusses the different sources of imperfections in general and it's analysis, which was carried out to estimate such errors. The calculation was compared with measured data to find out the actual cause of imperfections and necessary corrections have been carried out.

MODEL & ANALYSIS

Three-fold symmetry dominated magnetic field distribution is a characteristic feature of the three-sector geometry of this cyclotron. Deviation from the three-fold symmetry arises out of manufacturing tolerances and assembling errors, which create, unwanted harmonics (especially 1st and 2nd harmonics). The contribution of

field imperfection comes from the positional errors of superconducting coil and sectored iron pole tips. A major portion of these imperfections is attributed to the misplacement/tilting of the iron pole tip, which produces the main azimuthal variation in the field. It is important to determine the positioning errors of the pole pieces by calculating field imperfections produced from combinations of simple displacement of pole pieces and comparing it with the measured data. The presence of very large magnetic field ($\sim 5T$), in the superconducting cyclotron creates saturation of iron pole tips near the median plane. So, in the model used to calculate magnetic field produced by asymmetric pole tips, it is assumed that the iron is uniformly magnetised in the vertical direction. And the field can be represented in terms of surface current distribution flowing in the direction perpendicular to magnetization direction in a closed loop. The magnetization current density is given by $\vec{J} = \vec{\nabla} \times \vec{M}$, where \vec{M} is magnetization vector of iron [2]. The accuracy of the calculated field is reasonably satisfactory and calculation of this type has long been used [3]. The uniform M calculations are faster and in view of the reasonable accuracy, we have adopted this method to compute the field of 3-dimensional pole tips.

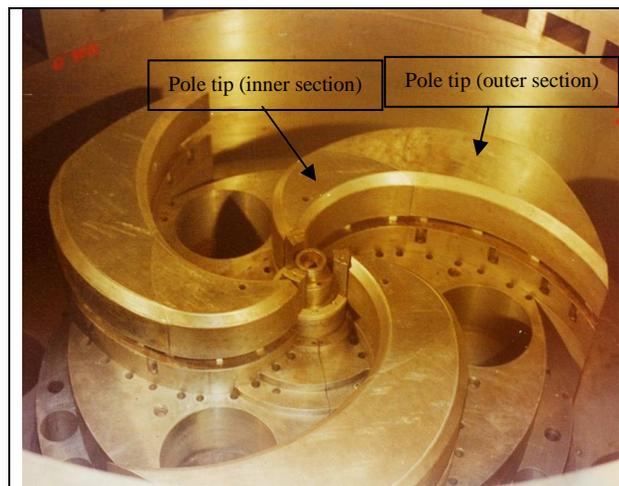


Figure 1. Pole tips view from the top

We have taken saturation magnetization $M=21.4$ kG. For a given geometry of the iron piece, the code generates the magnetic field using Biot Savart's law and carries out Fourier analysis to calculate field imperfections in terms of different harmonics.

The error in positioning of main superconducting coil with respect to the iron pole pieces produce 1st harmonic which is dominating at higher radius. Tilting of coils and

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measurement zig plane also produces field imperfections in the measured data. We introduced known shifts to 3-fold symmetric field at a particular direction and used 3rd order formula

$$B_z(r,\theta,z)=B_z(r, \theta,0)-0.5 * z^2 * LB_z(r, \theta, 0)$$

Where L is the 2-dimensional Laplace operator, to get the off-median plane field and carried out Fourier analysis in the shifted coordinate frame

We have simulated the thermal expansion of pole tip due to the rise of temperature, possibly because of water supply failure in the trim coils. Pole tip is assumed to be fixed at one side, where it is bolted. Magnetic field in the median plane is calculated using finite element code ANSYSTM. We have considered pole tips with a constant and uniform magnetisation. Temperature variation of iron magnetisation is also considered in the simulation.

RESULTS & DISCUSSION

Subtracting the fields from the original position of the pole tips with the field from the displaced position has generated a number of imperfection fields. Such displacement fields are then superimposed to study the combined effect. Fourier analysis is performed to calculate different harmonics specially 1st and 2nd harmonic component of the field.

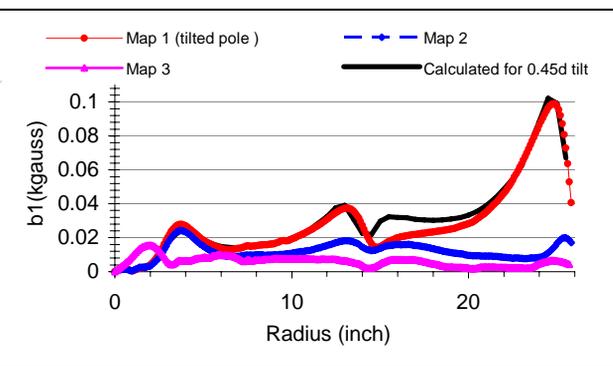


Figure 2. Comparison of 1st harmonic field amplitude for three successive measurements and calculation for 0.45° tilts of outer section of pole tip

We have studied number of imperfection caused by in-plane displacement, in-plane rotations, vertical displacement vertical tilts and so on and compare them with measurement. A series of measurement data taken initially has a 1st harmonic of about 100 gauss for all the grid points as shown in figure 2 as map 1(tilted one). Displacement fields are calculated for both the inner and outer section of pole tips. It is found from the calculation that a slight tilt of the outer section by about ~ 0.45° with respect to inner section of pole tip would create a similar 1st harmonic ~ 100 gauss to the main magnetic field data as shown in figure 2.

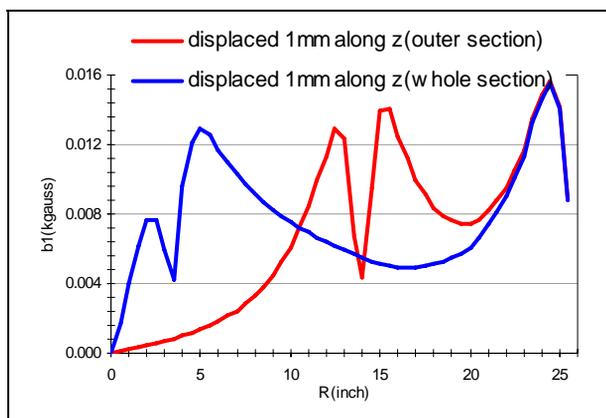


Figure 3. Radial distribution of 1st harmonic amplitude for pole tip displacement of 1mm along Z- direction

All the bolts were tightened properly, and further field mapping shows significant reduction of 1st harmonic imperfection in the magnetic field (map 2 in figure 2). The remaining imperfection of 1st harmonic component (~ 20 gauss) is from some other sources, which have been identified and reduced further by adding shims. Vertical displacements of 1mm along Z direction of the inner and outer section of the pole tip separately and combining the fields to get the first harmonic component is shown in figure 3.

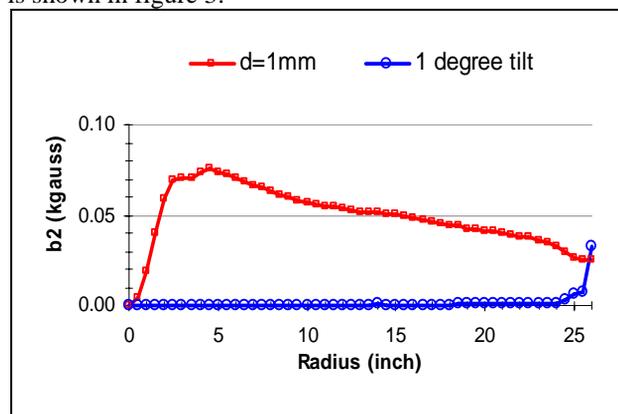


Figure 4. Radial distributions of 2nd harmonic distribution for a shift of 1mm and 1° tilt of measurement zig

The axis of measurement grid generally does not match with the symmetry axis of the magnetic field, and will introduce additional field imperfection. It is found that the 2nd harmonic component is more dominant, about 75 gauss for a shift of d=1mm compared to other harmonics and is shown in figure 4. The figure also shows 2nd harmonic imperfection due to 1° tilt of measurement zig about its axis. The symmetry axis required for field analysis is obtained by minimizing the 2nd harmonic component from the measured field by iterative search [4].

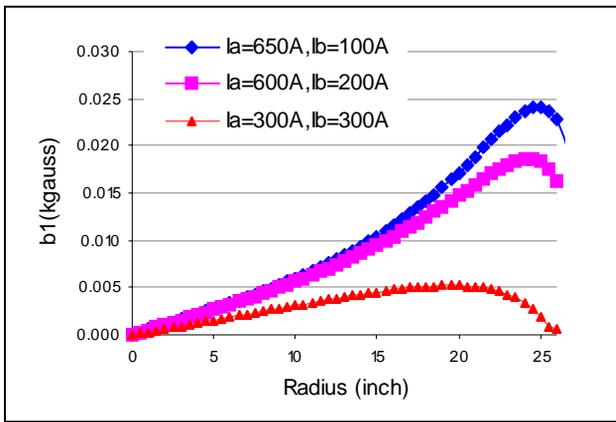


Figure 5. Radial distribution of 1st harmonic amplitude for 1mm shift of coil for different combination of α -coil and β -coil

In superconducting cyclotron two superconducting coils (α -coil & β -coil) should be well centred with respect to iron pole pieces, otherwise it produces 1st harmonic imperfection and also un-balanced forces. This is a variable term, which depends on the current settings of both the coils as shown in figure 5 for 1mm off-centre. Superconducting coils were centered with respect to iron pole pieces by reducing this 1st harmonic amplitude and knowing its phase.

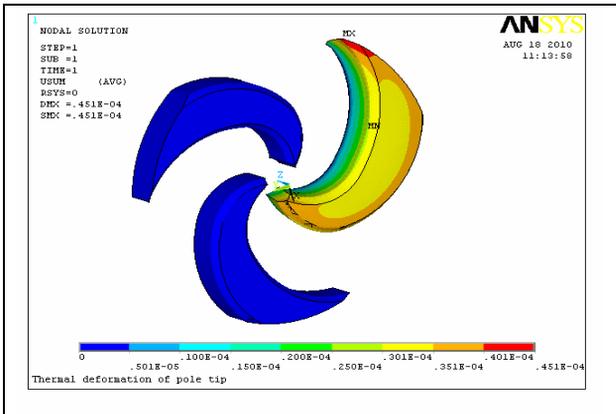


Figure 6. Thermal deformation of one of the pole tip due to temperature rise of 10° C

The rise of temperature in the pole tip will deform it and produce field imperfection in the median plane. We

have estimated the 1st and 2nd harmonic amplitude for 10-degree rise of temperature and is shown in figure 7. It is observed that the harmonic amplitude is proportional to the rise of temperature. Pole tip deformation due to rise of 10° C is also shown in figure 6.

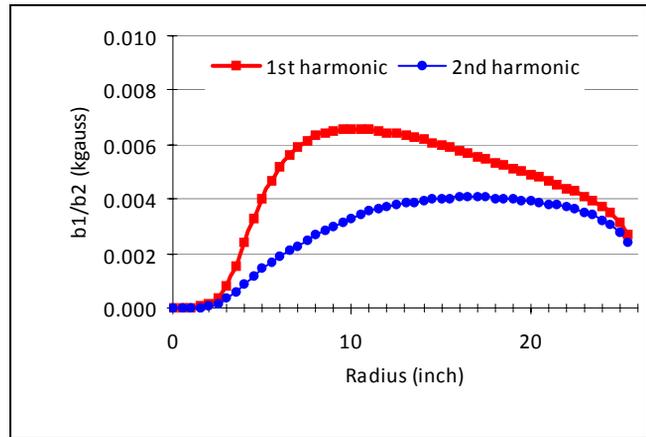


Figure 7. Radial distribution of 1st harmonic amplitude due to temperature rise of 10° C in the pole tip.

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