Results Analysis Of Measurement of The Multipole Magnet With Hall Probe

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Abstract

Generally, multipole magnets are measured with the rotating coil and analyzed by the FFT method. A new analysis of the multipole magnet relies on the Hall effect. Only the vertical or horizontal field was mapped on a circular trajectory and via two-dimensional least-squares fitting analysis to obtain the harmonic field strength. With the Hall probe, magnet defects can be found easily, it is best used for measurements of the prototypical magnets. The harmonic field strength at the magnet center or integrated can be analyzed to simulate the electron beam behavior and to compare with a tolerance. The region of good field of the magnet center and the integral field can be test to match the specification. The measurement results were compared with the two-dimensional theoretical calculation. The effective length distribution and harmonic components of the fringe field are presented. A dipole trim on the quadrupole and sextupole magnet was performed to verify the feasibility.

1. INTRODUCTION

The Hall probe and adjustment supporter is fixed on a table with three orthogonal rectangular axes. The supporter can be not only rotated but also tilted by manual adjustment to measure the exact vertical or horizontal field. The advantage of this method of measurement is to obtain the detailed physical behavior of the entire magnet but the disadvantage is the time consuming.

The field characteristic can be derived from the scalar potential Laplace's equation. The solution of Laplace's equation has constrained the harmonic field strength. Measurement of the integrated field strength were made by placing the Hall probe along the three-dimensional coordinate and by using the trapezoidal rule to integrate the field strength along the z axis. At the same time, according to the magnetic field characteristic equation, a non-linear two dimensional least-squares fit was used to analyze the mapping data in order to find the normal and skew components.

Results of these measurements enable to be determined the detailed quality of the whole magnet. Series of measurements can be analyzed both to refine the design and quality and to examine the effects on the field shape of the multipole magnets. Measurements of the magnetic field at the magnetic center were made and compared with the two-dimensional calculation results to decide whether the magnet fabrication was as good as the magnet design. The fringe field behavior of magnet is physically explained to correct the magnet[1]. Finally, the effective length distribution was measured and compared with the physical length. These multipole magnets (e.g., quadrupole and sextupole) were useful for dipole trim correction. The field quality was confirmed at 1%; the region of the good field is about ± 20 mm.

2. MAPPING TRAJECTORY AND ANALYSIS

For the transverse plane, the Hall probe mapping trajectory was defined on a circular plane. The constrained trajectory equation $r=(x^2+y^2)^{1/2}$ is on the transverse plane, with r the radius of the mapping circle. The Hall probe did not rotate during the mapping process, therefore, the vertical field $B_y(x,y,z)$ was measured to obtain the normal and skew harmonic strength except the skew dipole strength. If the skew dipole strength is necessary, the Hall probe must be rotated 90° to measure the horizontal field $B_x(x,y,z)$.

For the normal magnet, the field characteristics were dominated by the magnet profile. In fact, the magnetic field equation can be expressed as

$$B_y(r,\theta,z) = \sum_{n=1}^{\infty} H_n(z)\, r^{n-1} \left[\mathrm{Sin}(n\theta-\alpha_n(z))\right] \quad (1)$$

in which θ is the phase angle and the $H_n(z)$ and $\alpha_n(z)$ are the harmonic field strength and an arbitrary orientation angle. As $\alpha_1(z)$ is unknown, the skew dipole strength is undetermined. Because the Hall probe maps point by point , the amplitude and arbitrary angle of orientation depend on z. To find the integrated values $H_n(z)$ and $\alpha_n(z)$, an iteration through the individual points was made according to the trapezoidal rule. The integrated values are expressed

$$\int_{-\infty}^{\infty} B_y(r,\theta,z)dz = \sum_{n=1}^{\infty} H_n r^{n-1} [\mathrm{Sin}(n\theta-\alpha_n)] \qquad (2)$$

The term with (2m+1)n is the allowed harmonic term of the field strength H_n for the fundamental of a 2n-pole magnet; otherwise H_n is the forbidden harmonic term for the 2n fundamental pole magnet; n=1, 2, 3, --- etc. represents the dipole, quadrupole, sextupole etc. The normalization fraction for the 2n-pole fundamental strength at analysis radius r is defined as $(N_n)_j = r^{j-n}((H_{nj})/H_n$, with j=1, 2, 3 ----, for the multipole term.

3. ANALYSIS RESULTS OF DESIGN AND MEASUREMENT

The pole profile was tested first by mapping the vertical field at the center z = 0 to verify whether it is consistent between the two-dimensional design and magnet construction. The calculation and field measurement of the vertical field $B_y(x,y)$ was expanded according to equation (1) to obtain the harmonic field strength $H_n(0)$. The normalization of the higher multipole field of the quadrupole and sextupole magnet, and the field deviation of quadrupole and sextupole magnet as functions of x and y are discussed in references [2] and [3]. These results show that the design and construction (including the fabrication and assembly) of the prototypical multipole magnets are exact and consistent with magnet design.

The integral harmonic fields of the quadrupole and sextupole magnets along the longitudinal were discussed in references [2] and [3]. These tables and figures indicate the comparison of results and tolerance (supported by the Beam Dynamics Group of SRRC) and show that most of the multipole field strength is within the tolerance except the first allowed pole strength (dodecapole strength) of the quadrupole magnet. The strong negative dodecapole strength has been modified[1] and is now within the tolerance. The first allowed term of the sextupole magnet is the eighteen-pole which is revealed in Fig. 1. Comparing the eighteen-pole between the central and edge regions in Fig. 1, we conclude that the eighteen-pole field strength is positive at the magnets central region but is strongly negative at the edge. Therefore the region of good field for integral strength is less than the central region. The reason is that the saturation behavior happened for each pole at the magnet edge. If the each pole is chamfered at 45 degrees or add shims at each pole, the strong eighteen-pole strength decreases and the good field region will become wider than before.

The other higher multipole behavior along the longitudinal direction of the quadrupole magnet is explained and revealed in reference [1]. The octupole and decapole field behavior of the sextupole magnet are shown in Fig. 2 and 3. Fig. 2 reveals the field symmetry behavior features and Fig. 3 reveals that there is a strong decapole strength but is untisymmetric at each magnet side. Therefore the strong decapole strength cancels each other after integrating the decapole strength.

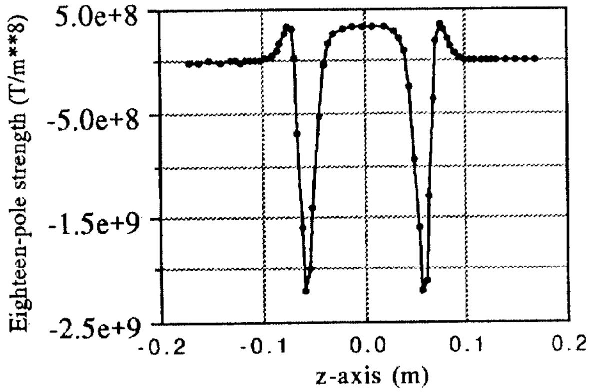

Fig. 1 Eighteen-pole strength distribution along the longitudinal direction.

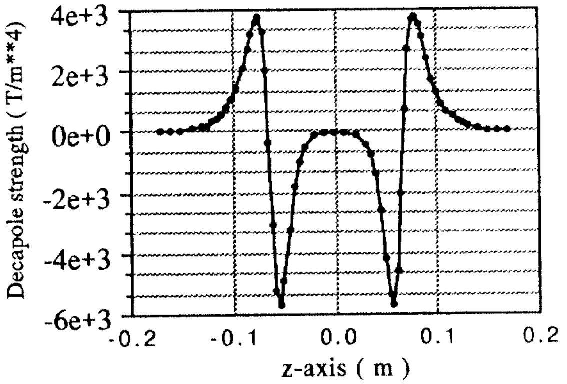

Fig. 2 Decapole strength distribution along the longitudinal direction of the sextupole magnet.

The effective length (∫F(x)dz)/F(0), in which F(0) is the fundamental field strength of magnet of each kind in the horizontal plane y=0. Fig. 4 shows the effective length as a function of x of the quadrupole and sextupole magnet. For the sextupole magnet (bore radius r=40 mm), the physical length of the magnet is 0.12 m but the effective length is 0.1456 m. For the quadrupole magnet (bore radius r=38 mm), the magnet physical length is 0.315 m but the effective length is 0.3519 m. There are 21% and 12% difference between the physical and effective length for the sextupole and quadrupole magnet individually, due to the fringe field to extend the length.

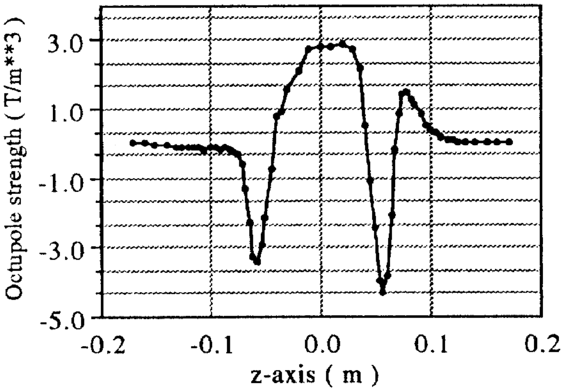

Fig. 3 Octupole strength distribution along the longitudinal direction of the sextupole magnet.

The quadrupole and sextupole magnet can create a dipole field such as the horizontal or vertical dipole corrector which is independent of the main coil. The dipole corrector feature of the sextupole magnet is revealed in reference [3]. The maximum dipole strength is about 1 mrad.

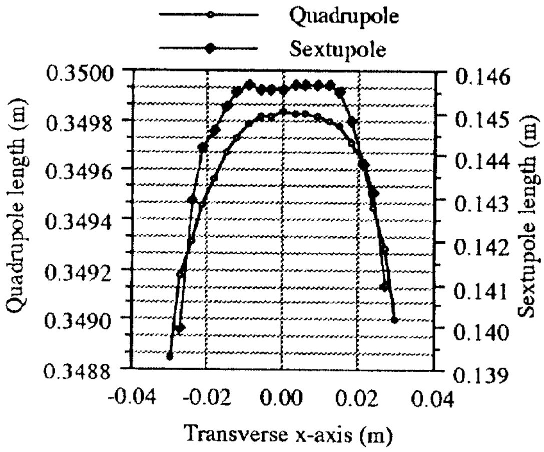

Fig. 4 Effective length distribution as a function of x-axis of the quadrupole and sextupole magnets.

4. CONCLUSION

The measurement results show that the multipole magnet (e.g., the quadrupole and sextupole) can be measured and analyzed by means of Hall probe measurements. The features of the harmonic field of the whole magnet region are seen clearly by the Hall probe measurement. We depend on this multipole field strength distribution to decide whether the magnet meets the specification and tolerance. Simultaneously, these harmonic field strength, integral field strength and effective length can support the electron beam behavior simulation to decide whether the dynamic aperture is enough or not.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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