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PRELIMINARY MAGNETIC FIELD CALCULATION OF A 30-DEGREE DIPOLE MAGNET*

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Abstract

Preliminary design and field calculation of a 30-degree H-type dipole which can be applied to the beamline is introduced in this paper. According to the physical requirements, 2D and 3D models are built and analysed using OPERA. For achieving the magnetic field specifications, air slots are adopted, and trapezoidal shim on pole surface is used to improve the magnetic field error. Rogowski curve and harmonic shim at the pole end is used to reduce the integral magnetic field error and the higher order harmonic field error.

INTRODUCTION

To delivery proton beam with energy range of 70 – 250 MeV (corresponding to rigidity of 1.23 – 2.43 T.m), the beamline dipoles should have a wide operation range for the central magnetic field of 0.82T-1.62T, with the bending radius 1.5 m. According to its physical design, the integral field error should be better than ±8E-4, and the harmonic field error should be better than 5E-4. The parameters of the dipole are shown in Table 1 [1]:

Table 1: Parameters of the Dipole

Parameter	Value
Bending radius / mm	1500
Bending angle / degree	30
Central magnetic field /T	0.82-1.62
Good field region / mm	±35
Transverse magnetic field error	<=±5E-4
Integral magnetic field error	<=±8E-4
Integral harmonic field Error	<=5E-4

2D MAGNETIC FIELD CALCULATION

According to physical parameters, the exciting ampere-turns can be calculated. The specification for a single coil is 13mm×13mm/Φ6 mm, and the coil cross-section size is 130 mm×182 mm in the dipole model. The cross section of the dipole magnet is shown in Figure 1. According to the empirical formula [2], the size of the magnet cross section is obtained, and it is shown in the Table 2. In order to optimize the magnetic field distribution at 1.62T, air slots can be used in the magnetic poles [3].

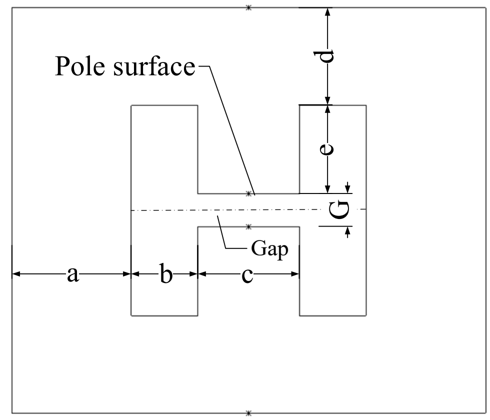

Figure 1: Cross section of the dipole.

Table 2: Magnet Cross-section Profile

Parameter	Value (mm)
Yoke width (a)	170
Coil window width (b)	150
Pole width (c)	380
Yoke width (d)	170
Coil window height (e)	200

According to the principle of harmonic shim [4], if we only consider the elimination of third-order and fifth-order harmonic field, the optimized pole surface equation is as follow:

$$b_1 y - \frac{b_3}{3!}(3x^2 y - y^3) - \frac{b_5}{5!}(5x^4 y - 10x^2 y^3 + y^5) = b_1 y_0 \quad (1)$$

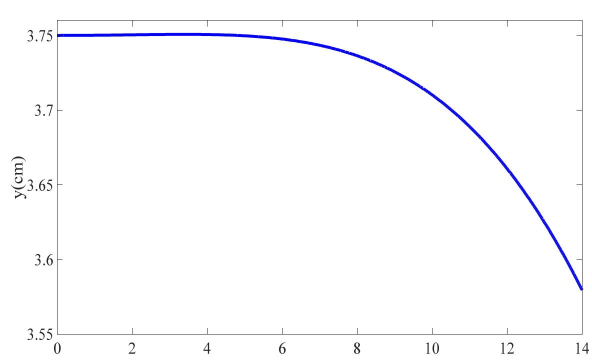

Figure 2: Pole surface curve.

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The curve of Eq. (1) is as shown in Figure 2. The two ends of the pole surface are theoretically a triangle with a specific height shown in Figure 3(a), however, the sharp part of the triangle will bring saturation for the magnetic field. The local saturation of the inner and outer sides of the pole surface is reduced by the transition of trapezoids and oblique edges, which are shown in Figure 3(b). In 2D optimization, the pole surface is composed of the parallel part, the trapezoidal part and the oblique edge part, which can be expressed as:

(1) Parallel part

$$H_1 = \frac{G}{2}, 0 \le x \le D_1 \tag{2}$$

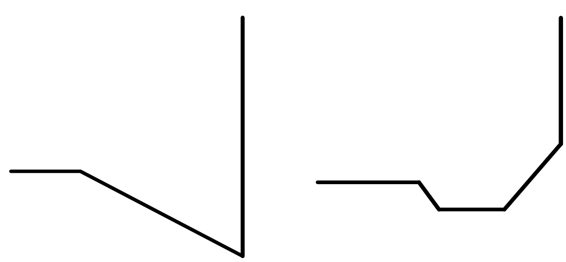
(2) Trapezoidal shim part

$$H_2 = \frac{G}{2} - \Delta H, D_2 \le x \le D_3 \tag{3}$$

(3) Oblique edge part

$$H_3 = H_2 + 25k, D_3 \le x \le 140 \tag{4}$$

where, H is the height of the magnetic pole, D is the position of the pole surface shim, $\triangle H$ is the thickness of the shim, k is the slope of the oblique edge.



(a): Triangle shim (b): Trapezoidal shim

Figure 3: Shape of the pole surface shim.

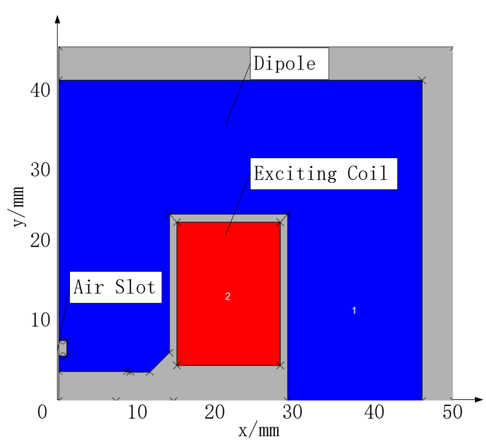


Figure 4: 2D optimization model of the dipole.

As shown in the Figure 4, OPEAR 2D is used to establish a quarter model of the dipole magnet with the optimized pole surface. In Figure 5, the results of simulation show that the magnetic field error in cross-section is better than ±5E-4 at 0.82T and 1.62T, which meets the design requirements.

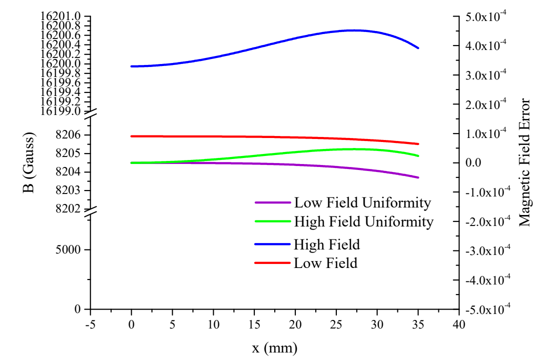


Figure 5: Magnetic field distribution in cross-section

3D MAGNETIC FIELD CALCULATION

Through the analysis of 2D magnetic field calculation, the 3D model of the magnet is built, as shown in the Figure 6. The magnetic field error in cross-section is shown in Figure 7, which is better than ±5E-4, while the integral field error and harmonic field errors need further optimizations at the pole ends[4]. The adjustable parameters are the position of the air slot, the shim size and the slope of pole ends, etc.

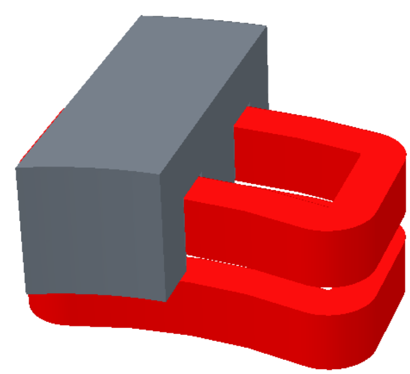


Figure 6: 3D simulation model.

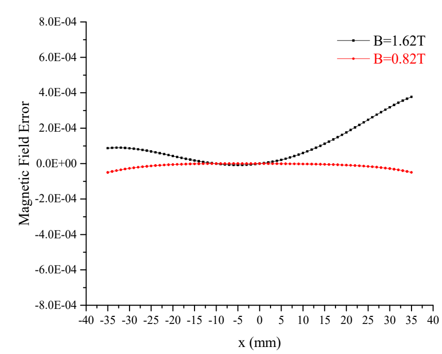


Figure 7: Magnetic field error in cross-section.

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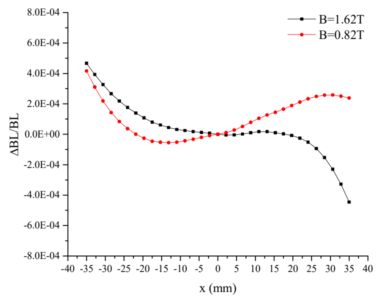
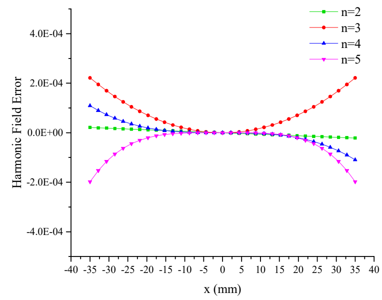
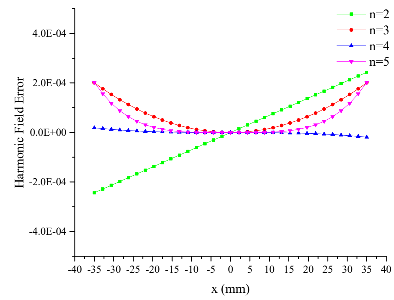


(a):Integral field error



(b): Harmonic field error at B=1.62T



(c): Harmonic field error at B=0.82T

Figure 8: Magnetic field quality of the dipole.

When the magnetic field reaches 1.62T, the saturation of the pole end is serious. In order to reduce the difference of the dipole magnet quality between high and low magnetic fields and improve the excitation efficiency, the Rogowski curve is usually used to reduce the local saturation before the harmonic shim [2, 5]. In actual optimization, two or three segments of broken-line can be used instead.

According to the principle of pole end optimization [4], the ideal shim value should be a smooth curve, but this will bring difficulties to optimization and processing. So the curve will be replaced by a broken-line in practice. Because there are many parameters that can be optimized, the theoretical values based on the optimization principle should be adjusted iteratively.

The final simulation results in Figure 8 show that the integral field errors is within±8E-4 and harmonic field errors are better than 5E-4.

CONCLUSIONS

The dipole magnet is important in the beamline, and its performances directly affect the efficiency and quality of particle transport. In this paper, through the calculation of 2D pole surface optimization and 3D pole end shim, the results ensure that the magnetic field error in cross-section is better than ±5E-4 within the good field area, the integral field error is better than ±8E-4, and the harmonic field error is better than 5E-4, which meets the design requirements.

The design of magnetic field measurement system is closely related to the magnetic field distribution. The magnetic field calculation will provide an important basis for error analysis of magnetic measurement system and the design of integral long coil.

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