DESIGN OF DIPOLE AND QUADRUPOLE FOR THZ-FEL AT CAEP

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Abstract

The high average power terahertz free electronic laser (THz-FEL) is being constructed at CAEP (China Academy of Engineering Physics), which is designed for lasing between 100-300 μm. The magnets of THz-FEL include 3 dipoles and 6 quadrupoles, and their fields and field quality were required by 6-9 MeV operation. This proceeding introduced the design and the main parameters of these magnets. The higher harmonic content of the magnetic field was also analyzed. All the design of magnets achieved the goal.

INTRODUCTION

The high average power terahertz source at CAEP (China Academy of Engineering Physics) is based on the routine of Free electronic laser (FEL). The facility is being built in Mianyang, Sichuan and will complete in 2015. It is planed to laze in 2016. The electronic energy, emission and energy spread are 6-8 MeV, 10π mm•mrad and 0.75%, respectively, and the facility will output with the average power 10 W between the range of 100-300 μm. The main component of the facility consists of high brightness electronic source, microwave system, superconducting accelerator, cryogenic system, beam transport section, undulator, resonance cavity, measurement system and control system, and the layout of the facility is shown in figure 1.

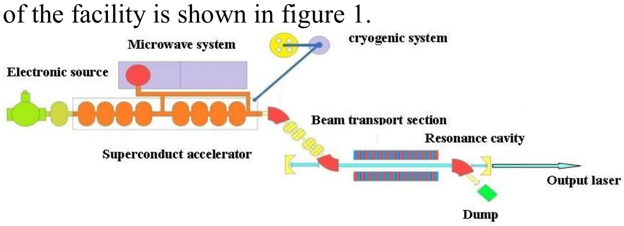

Figure 1: The layout of THz FEL at CAEP.

The key to high FEL gain and saturation is excellent electronic beam. The low brightness, high emission and high energy spread will weak the output power of laser. The beam quality of the facility lies on the quality of electronic source and beam transport section, and the quality of beam transport section lies on the design quality of magnet. In this paper, the design of dipole and quadrupole in beam transport section was introduced, and the design goal was to maximize transport efficiency magnet.

THE GOAL OF THE MAGNET DESIGN

The design of all magnets, which was based on experiential formula [1-2], was optimized for 6-9 MeV operation, and the magnetic field was calculated by Ansoft Maxwell 3D [3]. Table 1 gives the design goal of dipole and quadrupole.

Table 1: The Design Goal of Dipole and Quadrupole

Type	dipole	quadrupole
quantity	3	6
work mode	DC	DC
magnet length/mm	157	90
max field strength/T,T/m	0.15	5
bend radius/mm	200	-
bend angle/°	45	-
gap/mm	45	45
good field range/mm	±12.5	±15
field error	0.5‰	1‰
higher harmonic error	0.2‰	0.5‰
max current density/A/mm^2	1	1
cooling type	natural	natural
yoke material	DT4	DT4
max temperature rise/°C	15	15

DIPOLE

There are total 3 dipoles in the facility. C-type configuration has been chosen because it has space for the vacuum chamber and magnetic measurement and simplifies the design and installation of the magnet. The yoke and pole head can be solid because of the DC work mode. In the facility, the space for dipole is limited, which is about 110 mm along Z axis. Pole head with "nose" piece was introduced in NSLS-II, and the magnetic length can be significantly longer than the mechanical length [4]. The NSLS-II magnet design can help us resolve the above problem well, and the magnetic model of the dipole is shown in figure 2. The length of "nose" piece is 30 mm, which is not too long and will not create a situation where the iron in nose piece may saturate (see figure 3), and meanwhile the dimension along Z axis of dipole can be limited to 110 mm.

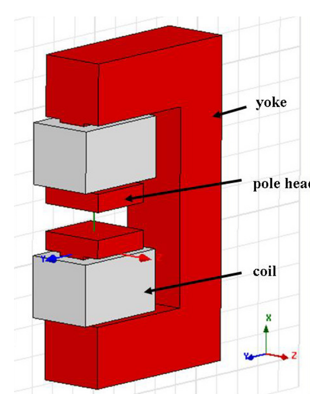

Figure 2: The magnetic model of dipole.

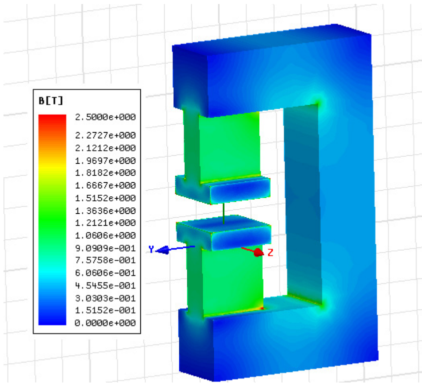

Figure 3: The magnetic flux distribution on the surface of yoke and pole head.

The distribution of B_y along Z axis and X axis is shown in figure 4. The central filed B_0 is about 0.164 T, which is lager than the goal 0.15 T. One can see significantly flatness along either X axis or Z axis. Based on the curve along Z axis, the magnetic length is calculated 158 mm, which is slightly larger than the design goal 157 mm. The length of good field with error 0.5‰ reaches the design goal ±12.5 mm. The higher harmonic content in the range of good field is attained by the following formula:

$$B_y = \sum_{n=1}^{\infty} C_n x^{n-1} \qquad (1)$$

The analysis result is shown in figure 5. All the higher harmonic content is below 2×10^{-4}.

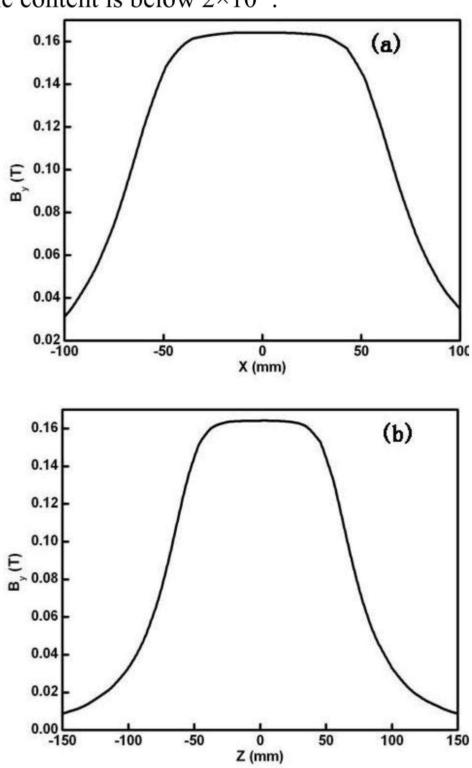

Figure 4: The distribution of B_y along X axis (a) and Z axis (b).

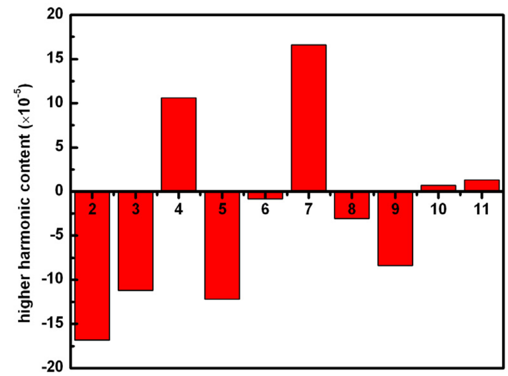

Figure 5: The higher harmonic content of B_y along X axis.

The major electricity parameters for the dipole are given in table 2. The coil is racetrack type and is wound using solid 2×4 mm rectangle Cu wire. The current density in conductor must be limited below 1 A/mm^2 because of the natural cooling type. The max power is only 24.5 W/pole and the temperature rise will not be visible. All the dipole will be powered in series.

Table 2: The Major Electricity Parameters of the Dipole

NI per pole/A·T	3000
turns per pole	375(15×25)
max current/A	8
conductor size/mm	2×4(solid Cu wire)
resistance/Ω	0.38
max power per pole/W	24.5

QUADRUPOLE

The facility requires total 6 quadrupoles. Figure 6 shows the magnetic model of quadrupole. The magnetic length of quadrupole is 90 mm and the mechanical length of yoke along Z axis is 70 mm. The bore diameter of quadrupole is 45 mm determined by vacuum chamber. The pole face is hyperboloid following the formula xy=R^2/2. Figure 7 gives the distribution of magnetic flux on XY cross section. One can see the magnetic flux flows smoothly in the yoke and pole head. There are no too serious saturation spot in pole head, which is the result of 4×4 mm and 1.5×2 mm chamfer on the side of pole head.

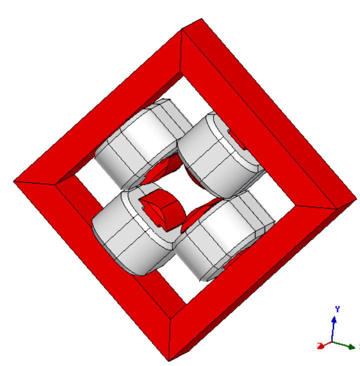

Figure 6: The magnetic model of quadrupole.

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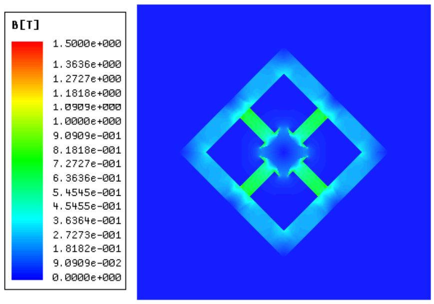

Figure 7: The distribution of magnetic flux on XY cross section of quadrupole.

The distribution of magnetic field gradient *B'* along Y axis and Z axis is shown in figure 8. The *B'* along the Y axis is almost uniform and is about 5.16 T/m, which slightly exceed the goal 5 T/m. The length of good field is ±15 mm with the error 1‰. There is a significantly flatness along Z axis in the curve of figure8 (b) and it is shown that the leak of magnetic flux has been restrained.

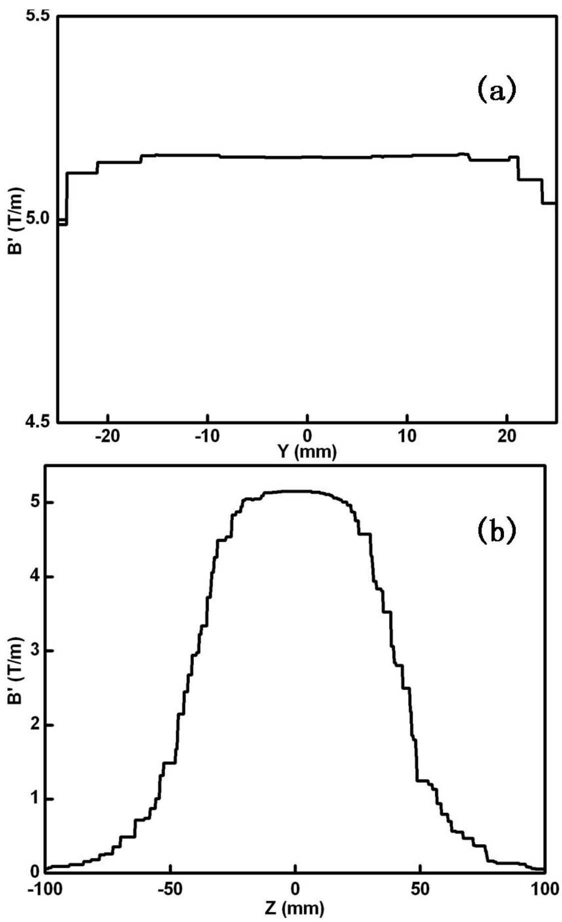

Figure 8: The distribution of magnetic field gradient *B'* along Y axis (a) and Z axis (b).

The higher harmonic content of magnetic field is analyzed based on the equation (1) and the result is shown in figure 9. All the higher harmonic content is below 5×10^{-4}.

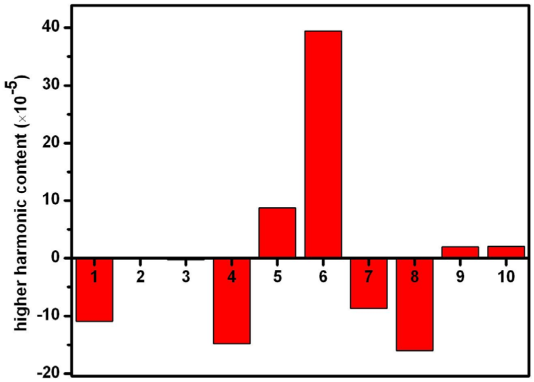

Figure 9: Higher harmonic content of magnetic field of quadrupole.

The major electricity parameters for the quadrupole are summarized in table 2. The racetrack type coil is wound using solid 2×4 mm rectangle Cu wire. The current density in conductor can't exceed 1 A/mm^2 because of the natural cooling type. The max power is only 5.6 W/pole, which will not bring in visible temperature rise. The quadrupole will be powered in pairs.

Table 3: The Major Electricity Parameters of the Quadrupole

NI per pole/A·T	1000
turns per pole	125
max current/A	8
conductor size/mm	2×4(solid Cu wire)
resistance/Ω	0.09
max power per pole/W	5.6

CONCLUSION

In this proceeding, the design of magnet for THz-FEL was introduced. The centre field B_0, length of good field and filed error of dipole are 0.164 T, ±12.5 mm and 0.5‰, respectively. The magnetic field gradient *B'*, length of good field and field error of quadrupole are 5.16 T/m, ±15 mm and 1‰, respectively. The higher harmonic content of dipole and quadrupole are below 0.2‰ and 0.5‰, respectively. The major electricity parameters of magnet are also designed.

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