Presentation ID: Mon-Af-Po1.01

Submission No:A1 - #1032

Beam Trajectory Simulation Considering Each Harmonic Components in HTS Quadruple Triplet

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Introduction

- Quadrupole magnets are used for beam focusing in accelerators. However, it's very difficult to design the quadrupole magnets by beam focusing analysis. Generally, the harmonic components of field quadrupole magnets of are considered as the source of beam defocusing and the quadrupole magnets are designed by reducing the harmonic components.
- In our previous study, two kinds of HTS quadrupole 3,400 mm length point-to-point triplets – iron core triplet and air core triplet were designed [1] as shown in Fig. 1. In this study, the beam analyses of two triplets and an ideal triplet were compared, the magnetic fields of three triplets were shown as shown in Fig. 2. And the effects of the harmonic components on beam defocusing were checked.

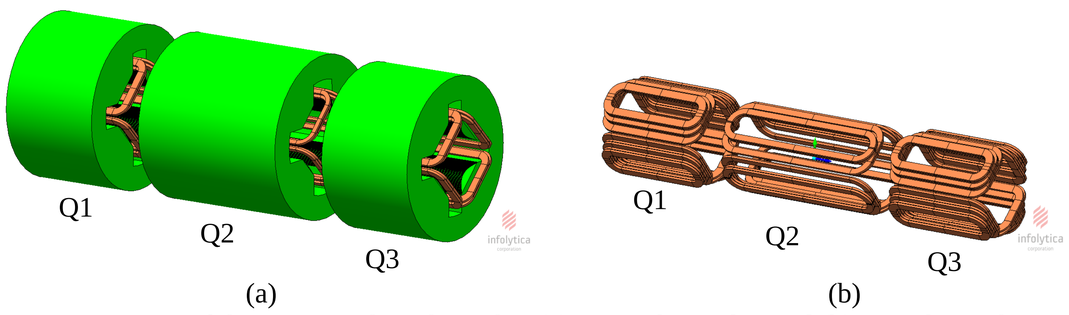

Fig. 1. Structure of the HTS quadrupole triplet: (a) iron yoke triplet, and (b) air yoke triplet.

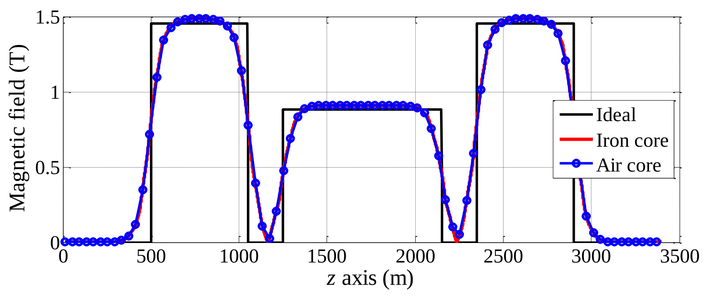

Fig. 2. Magnetic field distribution of ideal triplet, iron core triplet, and air core triplet at reference radius 120 mm in z direction.

Simulation

- Fig. 3 shows the flow chart of beam analysis in triplet. The process is shown as following [2]:

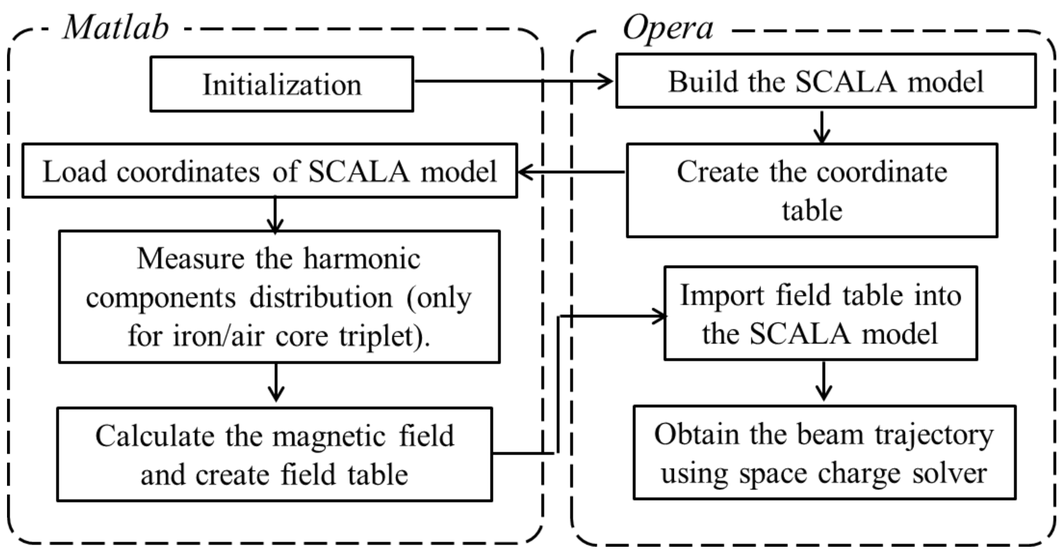

Fig. 3. Flow chart of beam analysis in the triplet.

Analysis

- Beam analysis without harmonic components shows in Fig. 4. Xmax and Ymax were defined as the maximum *x* and *y* coordinates of beam spots to show the beam spot range. There is no harmonic component in three triplets' magnetic field, but the results are different. there could be some other reasons which also can affect beam harmonic defocusing beside the harmonic components of the magnetic field of HTS quadrupole magnets.

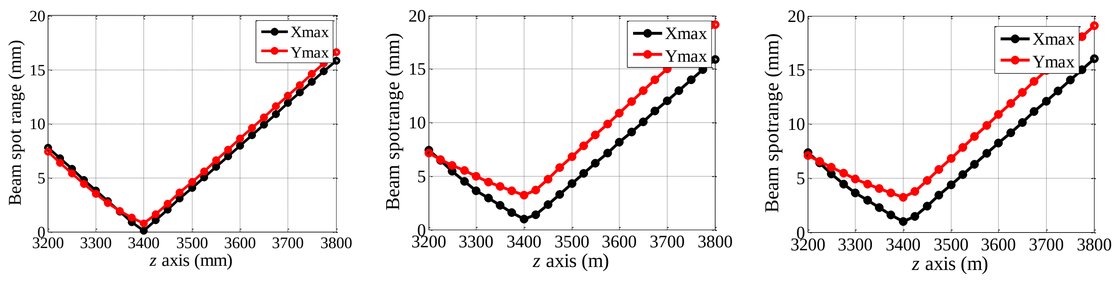

Fig. 4. Beam spot range without harmonic components: (a) ideal triplet, (b) iron yoke triplet, and (c) air yoke triplet.

- Define $b_{\rho n}$ and $b_{\varphi n}$ as the relative harmonics as the harmonics by the 2nd harmonic component. Beam analysis with respect to harmonic components shows in Fig. 5 and Fig. 6.

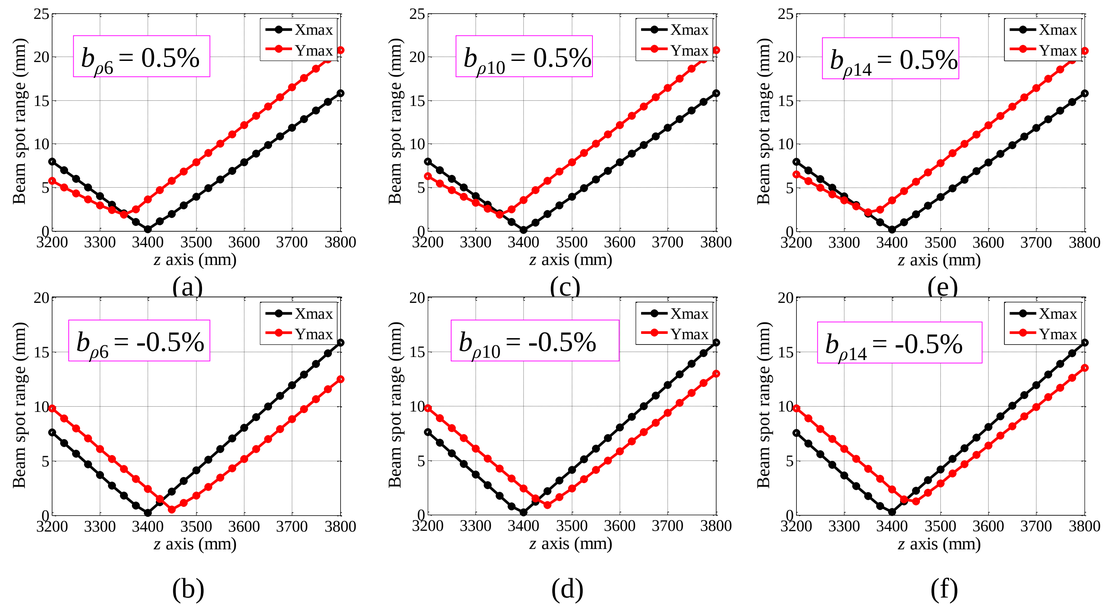

Fig. 5. Beam spot range with respect harmonic components for ideal triplet: (a) $b_{\rho 6}$ = 0.5%, (b) $b_{\rho 6}$ = -0.5%, (c) $b_{\rho 10}$ = 0.5%, (d) $b_{\rho 10}$ = -0.5% , (c) $b_{\rho 14}$ = 0.5%, and (d) $b_{\rho 104}$ = -0.5%.

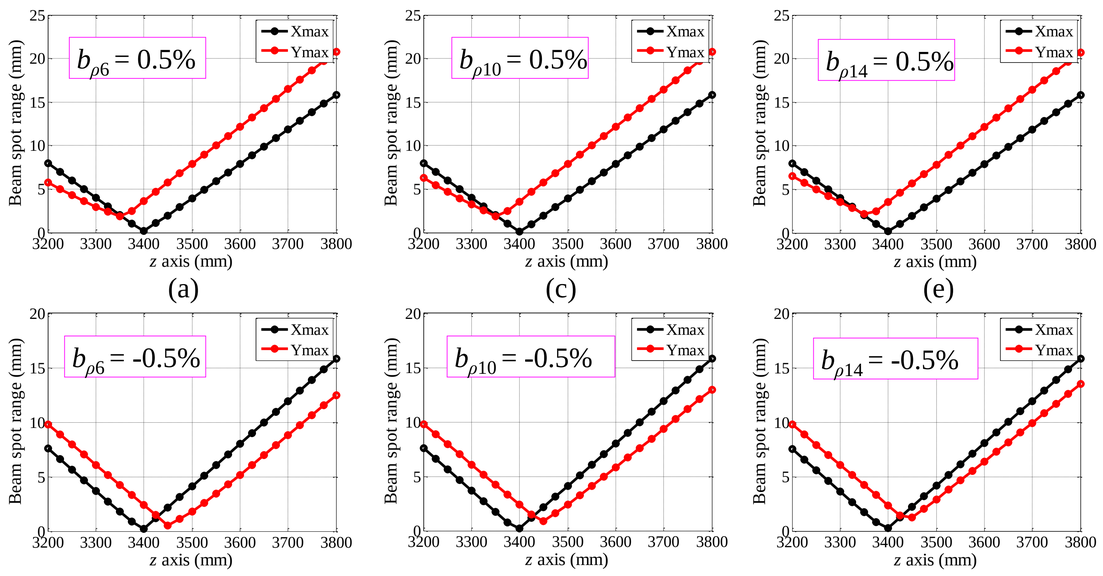

Fig. 6. Beam spot range with respect harmonic components for iron coretriplet: (a) $b_{\rho 6}$ = 0.5 %, (b) $b_{\rho 6}$ = -0.5%, (c) $b_{\rho 10}$ = 0.5%, (d) $b_{\rho 10}$ = -0.5% , (c) $b_{\rho 14}$ = 0.5%, and (d) $b_{\rho 104}$ = -0.5%.

TABLE I.

BEAM SPORT RANGES WITH RESPECT TO THE HARMONIC COMPONENTS FOR THE TRIPLETS @ Z = 3,400

Relative harmonics					Ideal		Iron core		Air core	
$b_{\rho 6}$(%)	$b_{\rho 10}$(%)	$b_{\rho 14}$(%)	$b_{\rho 18}$(%)	$b_{\rho 22}$(%)	XMAX (mm)	YMAX (mm)	XMAX (mm)	YMAX (mm)	XMAX (mm)	YMAX (mm)
0	0	0	0	0	0.1005	0.7473	0.9615	3.2131	0.9565	3.2019
0.5	0	0	0	0	0.1753	3.5872	1.2934	5.3843	1.2820	5.4114
0	0.5	0	0	0	0.0948	3.5793	0.7976	5.3284	0.7883	5.2238
0	0	0.5	0	0	0.2246	3.5599	1.1182	5.2843	1.1150	5.1815
0	0	0	0.5	0	0.0735	3.5511	0.8787	5.2837	0.8740	5.1810
0	0	0	0	0.5	0.2044	3.5496	1.1438	5.3623	1.1449	5.2581
-0.5	0	0	0	0	0.2301	2.3963	0.9044	4.5363	0.9063	4.5100
0	-0.5	0	0	0	0.2435	2.3938	1.1347	4.5360	1.1304	4.5098
0	0	-0.5	0	0	0.2575	2.3741	0.8069	4.5362	0.8001	4.5101
0	0	0	-0.5	0	0.2511	2.3664	1.2345	4.5358	1.2237	4.5099
0	0	0	0	-0.5	0.2554	2.3648	0.7847	4.5359	0.7729	4.5102

Conclusion

- According to the analysis, we can get the conclusions as following:
  - ✓ There could be some other reasons which also can affect beam harmonic defocusing beside the harmonic components of the magnetic field of HTS quadrupole magnets. The reasons would be discussed in the further work.
  - ✓ The effects of the plus and minus harmonic components can be different. The minus harmonic components would affect the beam focusing positively.
  - ✓ The effects of harmonics components are almost same as each other.
- This study suggested that the minus harmonic components could be reserved and all harmonic components should be considered and reduced, when an HTS quadrupole magnet was designed. The field quality of HTS quadruple magnets should be expressed by the all of the plus harmonic components.

Reference

[1] Zhan Zhang, Shaoqing Wei, and Sangjin Lee, "Design of an Air-Core HTS quadruple triplet for a heavy ion accelerator", Progress in Superconductivity and Cryogenics, vol.18, no.4, pp.35-39, 2016.
[2] Shaoqing Wei, Zhan Zhang *et al*, "Control the length of beam trajectory with a quadruple triplet for heavy ion accelerator," *Progress in Superconductivity and Cryogenics*, vol.18, no.4, pp.40-43, 2016.
[3] Z. Zhang, S. Lee and H. Jo et al., "Magnetic Field Characteristics from HTS Quadruple Magnet of In-Flight Separator for a Heavy Ion Accelerator", Progress in Superconductivity and Cryogenics, vol.17, No.3, pp. 23-27, 2015.