Field Matching of F-D-F Variable Gap Magnets for the 2GeV FFA Accelerator

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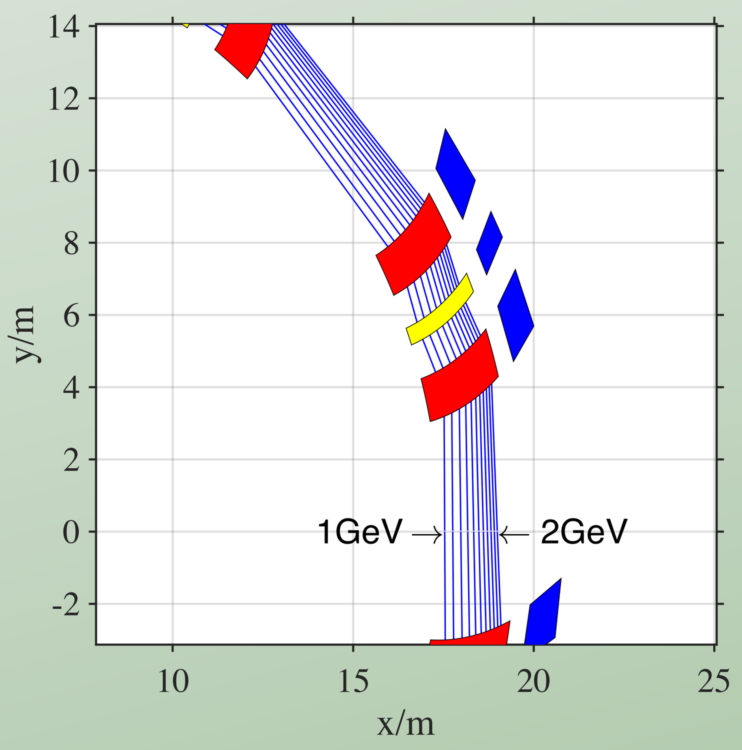
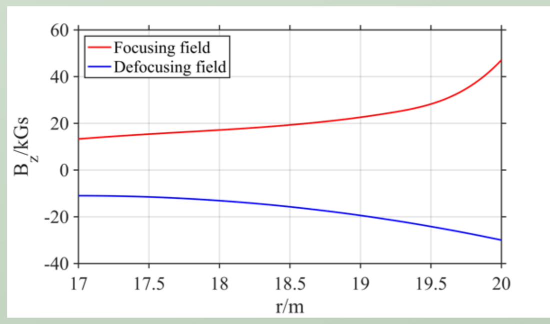
Abstract

Fixed Field Alternating Gradient Accelerators have been developed for decades. A continuous wave (CW) 2GeV FFA is under developing in CIAE. To avoid dangerous resonance lines and manipulate the tune diagram flexibly, third order field is applied along the radius and tenfold F-D-F scheme has been proved to be feasible. In this paper, an IEM-based method is introduced and shown more efficient than adjusting the variable gap manually. Firstly, the radial mean field is set as a main design goal and the ΔH at different radii is solved by linear equations. The isochronism is done when the mean field is well matched with the design value. But some precise corrections are needed for the tune resonant frequency Vr and Vz, such as fringe field effects and multipole components. The tune shift caused by fringe field is also included in this paper. It is more crucial especially for HTS magnets, since the leaked field of superconducting coil is ~1 kGs. Considering that, we apply an angular matching method to compensate the tune shift by fringe field.

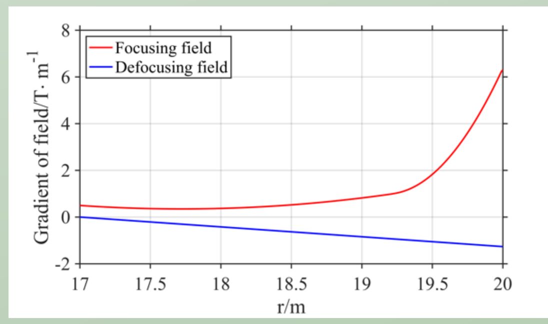
Introduction

High temperature superconducting (HTS) magnets are adopted in the overall design of 2 GeV CW FFA, for a higher energy efficiency and less operating cost. The 10-fold F-D-F lattice design is compeleted, which lead to next stage of magnet design. HTS magnets for FFA application are researched for serval years and some experimental coils are wound to support engineering feasibility. In practice, field matching is not crucial issue in FFA design. But for 2 GeV FFA, which introduces 3rd field along radius, it is important to math the 2nd and 3rd field to ensure isochronism and tune. Moreover, Fringing fields caused by HTS coils can affect the working diagram significantly, even if we match the mean field almost perfectly. This problem is more prominent in superconducting magnets and need to be well considerated. Above all, the basic design of lattice is introduced. The F-D-F lattice and field distribution are shown in right three figures, while the parameters of magent are listed in table.





Magnetic field radial distribution



Gradient alone radial direction

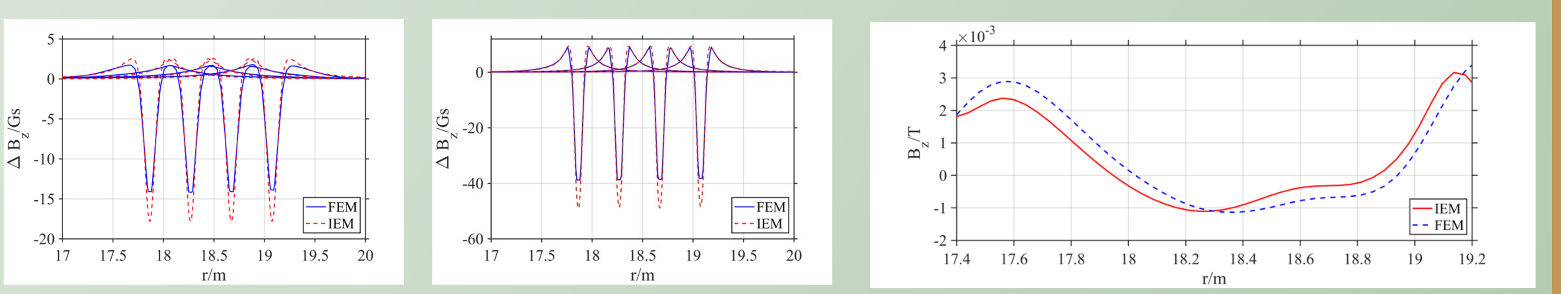
Item	Focusing magnet	Defocusing magnet
Pole length	2.1 m	2.1 m
Field Range	1.57 T ~ 2.66 T	1.15 T ~ 2.31 T
Angular width	4°	1.6°
Spiral angle	0~36°	0~36°

parameters of focusing and defocusing magnet

Analytical Model

Considering that in a superconducting magnet, due to the utilization of superconducting coils for excitation, the field in magnetic poles are close to saturation field, which is verified by an finite element model (FEM) later. Therefore, the state of iron magnetization can be regarded as saturated and the numerical calculation of small iron blocks with a cutting height of Δh can be performed using the IEM. We assume that the magnetic field contribution from iron at different radius can be linearly combined and the amplitude of field bump is linear to the height of iron block. The difference between the magnetic field required by the theoretical design and the magnetic field calculated by FEM can be expressed as ΔB in Equation 1.

$$\Delta B(r) = \sum_{i=0}^{n} \alpha_i \Delta B_i(r) \quad (1)$$



The linear assumption can only be established within a certain range. If the range of the adjustment quantity needs to be limited, the linear programming method must be used to solve it, that is, it can be transformed into the following minimum optimization problem.

$$\min \lambda$$

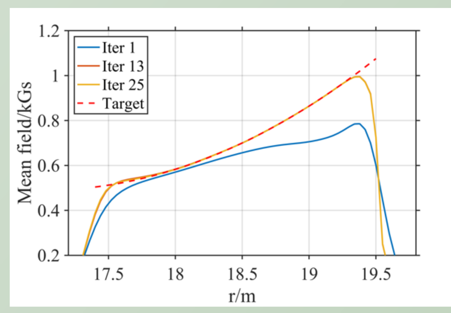
$$\begin{cases} M \cdot \alpha - \lambda \le 0 \\ -(M \cdot \alpha + \lambda) \le 0 \\ \alpha_l \le \alpha_i \le \alpha_u \end{cases}$$

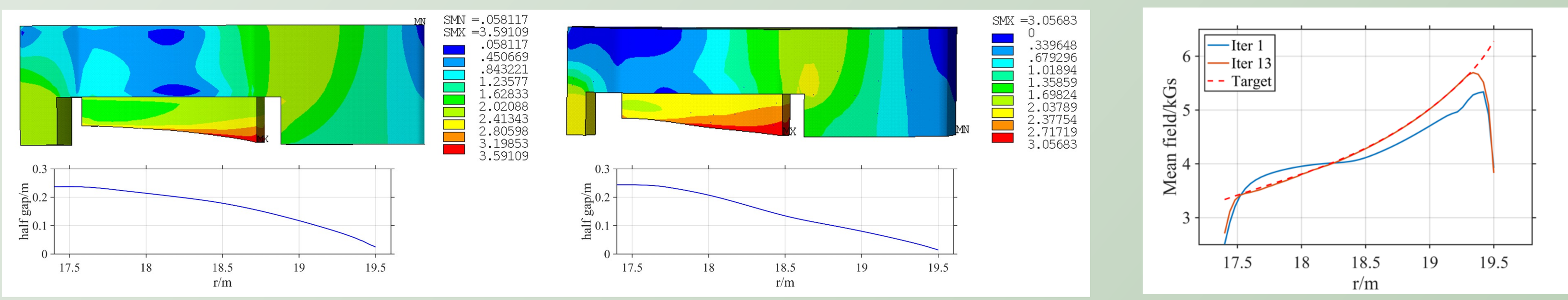
For fringe field correction, the flutter plays a important role in tune shift. Since the mean field has been well-matched with theoretical field distribution, only the $\langle B^2 \rangle$ items should be considered, which can be separated in equation below. With the concept of effective length, accessorial length δl is calculated using equation below.

$$\langle B^2 \rangle = \langle (B_f + B_d)^2 \rangle \approx \langle B_f^2 \rangle + \langle B_d^2 \rangle, \quad \Delta l = l' - l = l_d \sqrt{\frac{\int f_1^2(s)\mathrm{d}s}{\int g^2(s)\mathrm{d}s}} - l \qquad (2)$$

Matching Result and Static Beam Dynamics

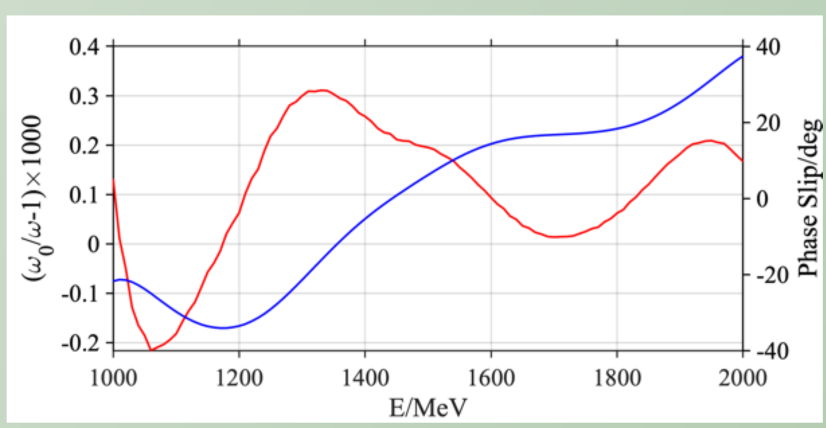
According to this IEM-based method, magnetic field differences between the FEM model and theoretical calculation are shown in right figures, which illustrates that the relative error of the mean field can be minimized to 2‰.

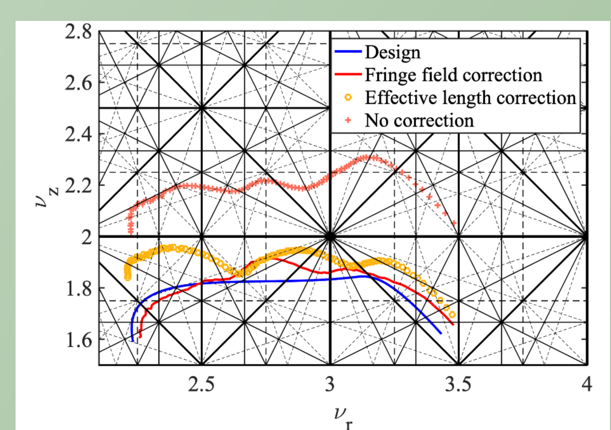




Statice beam dynamic of single partical is carried out to verify the FEM model. The local frequency error and phase slip is shown below, which indicates that average fields of FEM calculated field and theoretical design is matched.

The tune diagram calculated by different FEM models is shown in the figure below. The axial oscillation frequency is much higher than the design without any correction and the reason is the fringe field of the opposite direction. If we adopt the effective length correction mentioned in analytical equation , the working path is close to the design result. Furthermore, the gap between design and FEM result can be narrowed with fringe field correction using Equation 4.3. By adjusting the angular width, the change of flutter with the radius can be corrected, so that the axial working point calculated by finite element can be adjusted to the vicinity of the theoretically designed axial working point, which proves that the method is feasible.





Conclusion

In this poster, a method for matching field distribution between FEM model and theoretical design is introduced. There are some problems coming with high field and compact shceme of magnet, such as fringe field and high order components. We have solved two main problems, which are high order field matching and tune shift correction caused by fringe field. Particularly, the field matching result demonstates relative error between design and FEM model is 2 ‰, which guarantees the isochronism of whole machine. Based on this method, the gap between magnetic engineering and physical design is narrowed.