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Topology Optimization of the Pole Shape in Passive Magnetic Channel using MMA Method

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ABSTRACT: Passive magnetic channel is a kind of beam focusing elements in cyclotron. It consists of several soft iron bars which are magnetized by the main field in cyclotron. In this paper, we proposed a topology optimization method to design the pole shape in passive magnetic channel, this method does not require any fixed geometry pattern or initial design. The nonlinear static magnetic finite-element analysis model is used to calculate the objective magnetic field function. Persuade iron material with variable density is used to describe the iron distribution. Method of Moving Asymptotes (MMA) is used to optimize the control variable of iron density distribution on magnetic channel cross section. In three numerical examples, magnetic channels for a 250 MeV superconducting cyclotron is provided, where the design goal is to provide the given magnetic field gradient and bending angle. The relationship between the design goal and the pole shape pattern is discussed . The extraction beam is properly focused by the designed magnetic channels.

INTRODUCTION

Passive magnetic channels provide partial field gradient, field shielding and field strengthen. They are widely used in cyclotron to control the radial beam envelop of the extracted beam in the fringe field.

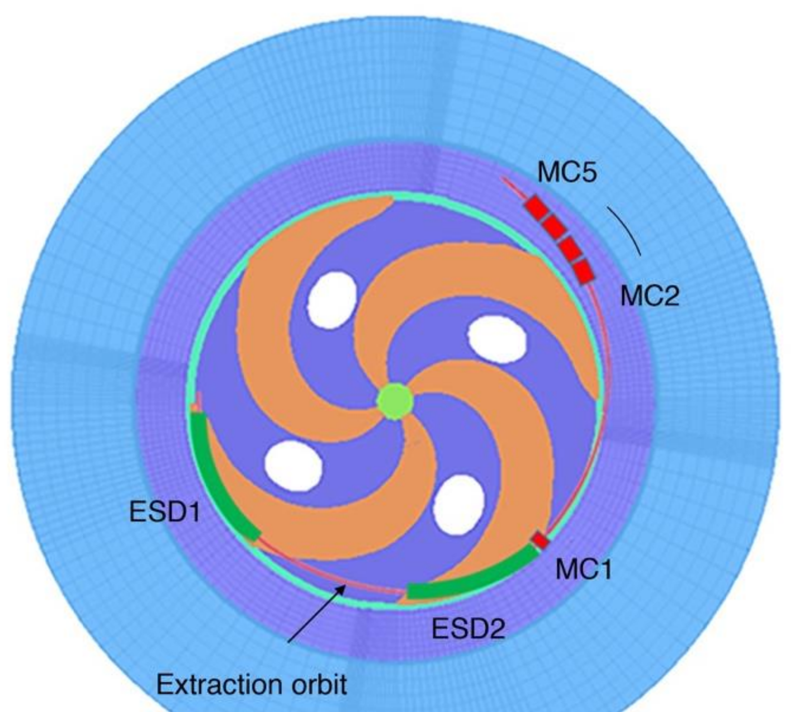


Figure 1: HUST SCC-250 MeV cyclotron with passive magnetic channels. The average back ground field is 3.1 T in the beam extraction region. M1-M5 are 5 magnetic channels placed in the gap of the main magnet.

Conventional method to design the pole shape of the magnetic channels is a shape optimization method, it's based on a current sheet analytical model. Thus, the optimization problem turns into a forward problem which solves the analytical equation to obtain the geometry parameters of the rectangular pattern pole shape. The current sheet model can only describe the iron bar with straight edges. In this paper we will using topology optimization method to design passive magnetic channels, and study the new pattern of the magnetic channel's pole shape.

MODEL

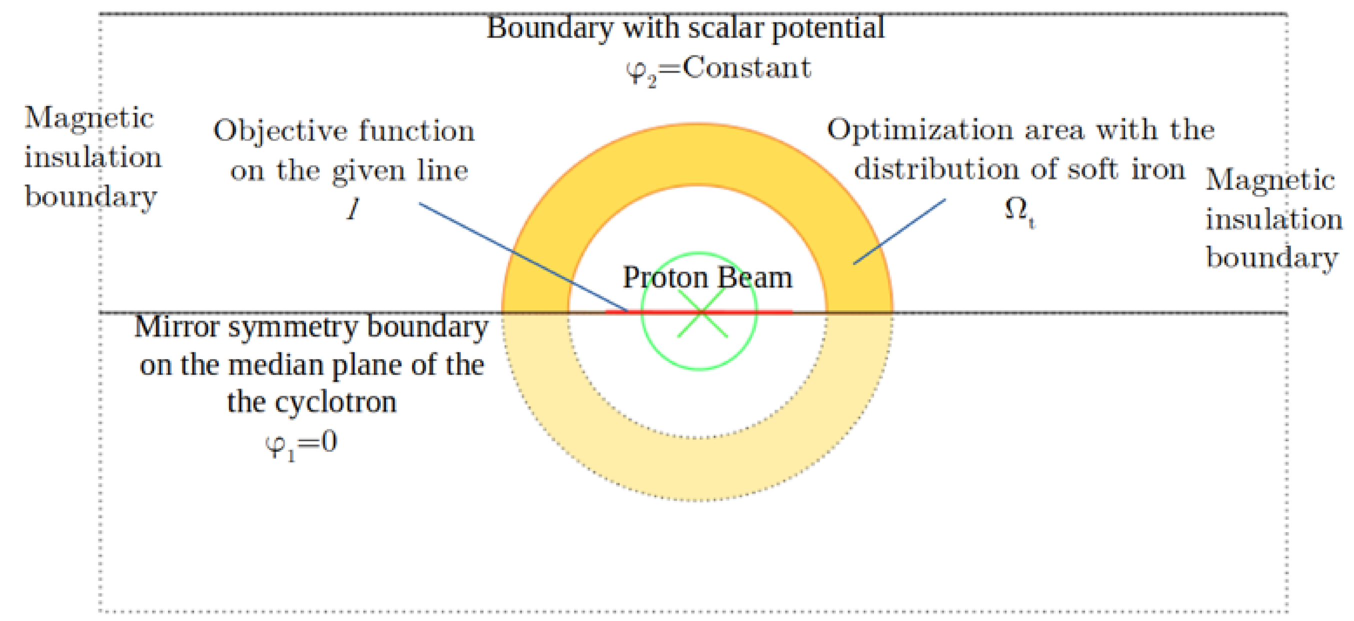
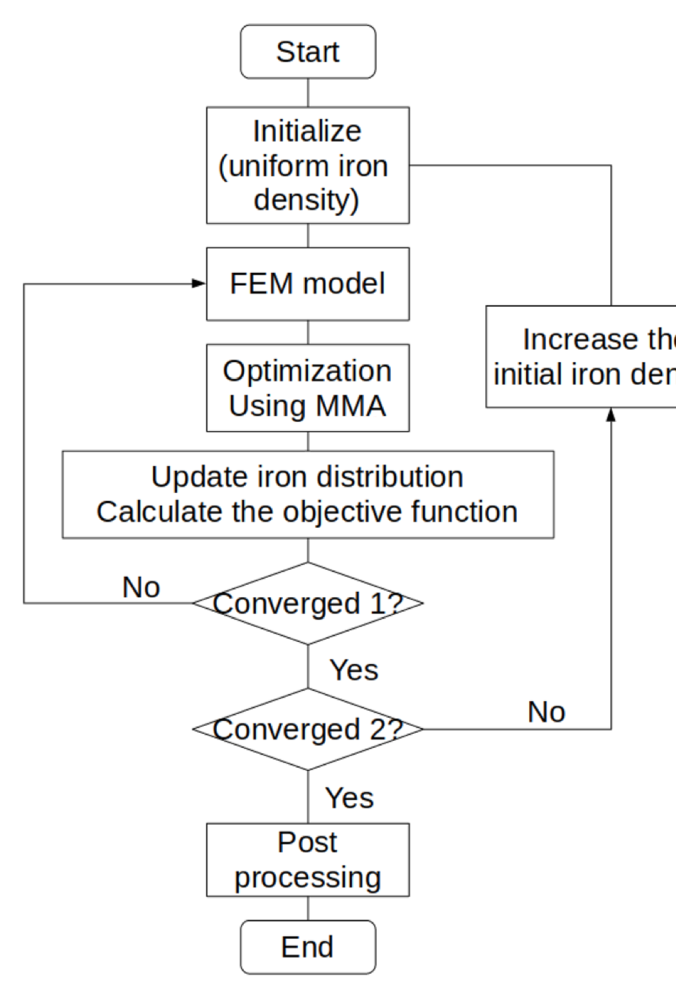


Figure 2: Model of the optimization. The model is mirror symmetry between the median plane of the cyclotron. To reduce the computation cost. A ½ model is used with the zero scalar potential boundary condition on the symmetry line. A constant scalar potential upper boundary is used to generate a uniform background field. Magneti insulation boundary condition is used for the far field.

FLOW CHART OF THE OPTIMIZATION



B-H curve is used To describe the nonlinear property of the soft iron in the passive magnetic channel

$$B' = \mu_0 H + \rho^p \left(B - \mu_0 H\right)$$

The iron density satisfies 0< ρ<1. A penalization factor *p* is used to penalize intermediate value of ρ.

Objective function:

$$\text{Minimize} \mid \rho_{design} : E(\rho) = \int_l [B_z(x) - G_r x - B_0]^2 \, dx$$

Figure 3: Flow chart for the optimization algorism. The FEM model used to calculate the magnetic field is evaluated using interface of the commercial software Comsol. There is a limited value for the objective function related to the initial iron density distribution, if the model does not converged with the given initial condition, we will adjust the initial iron density.

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RESULTS AND DISCUSSION

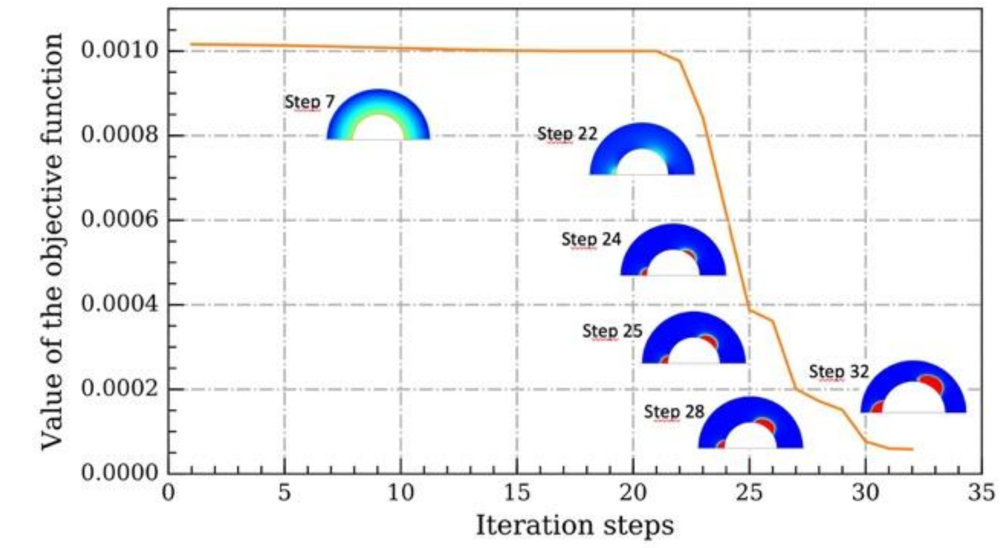

Figure 4: Iteration history with the iron distribution at different steps. The iteration is converged in 32ed steps. The fixed pattern emerges at the 20th steps. At 30th steps, the objective function achieves our goal of 1*10⁻⁴. After 31 steps. The objective function improves marginally.

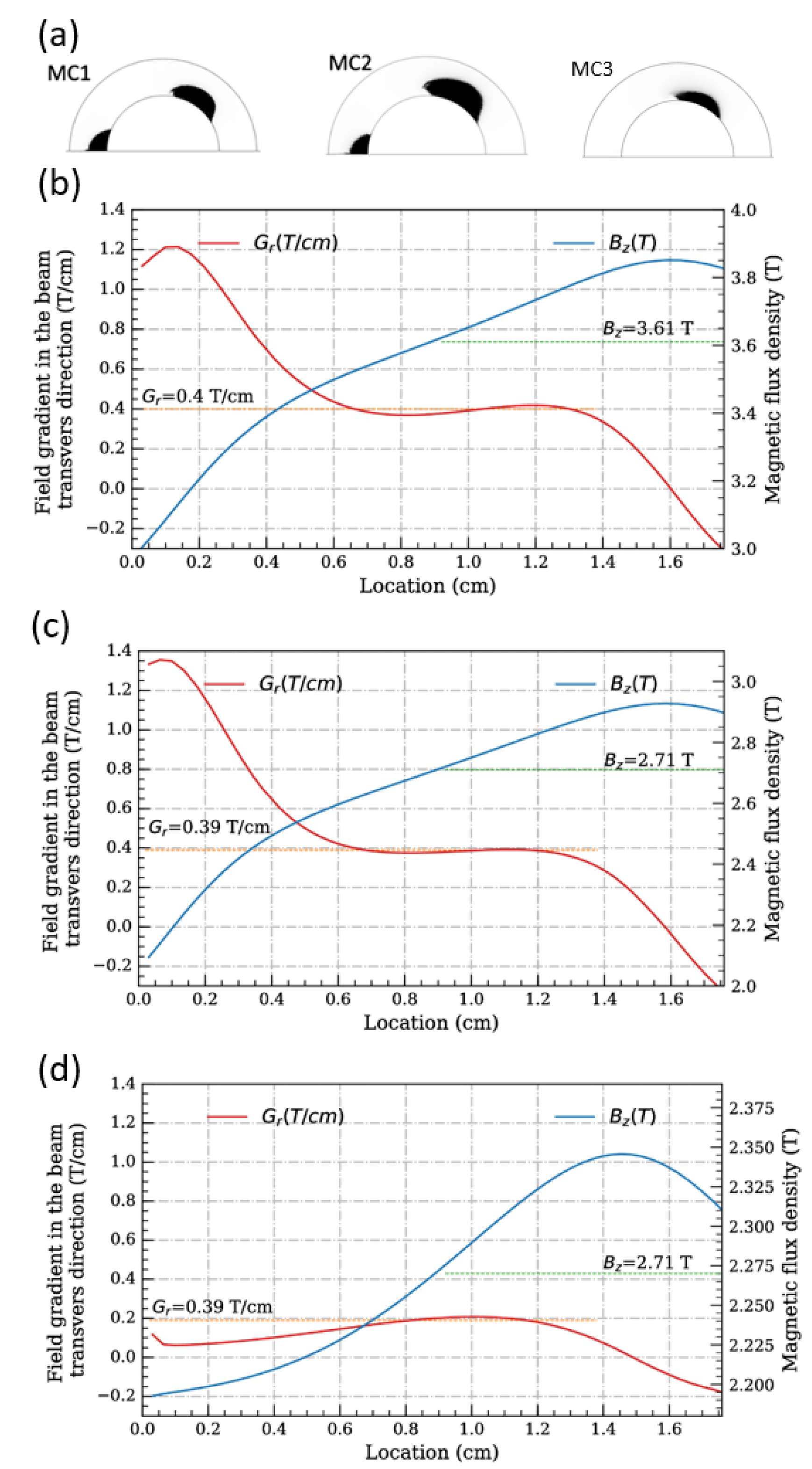

TABLE I
DESIGN GOALS

Magnetic channel NO.	Background field B_f(T)	Field gradient[a] G_r(T/cm)	Di-pole field B_0(T)
MC1	3.41	0.40	0.20
MC2	2.51	0.39	0.20
MC3	2.17	0.19	0.10

Figure 5 Different parameters given in table 1 is used to optimize the MC2 and MC3. While, the initial condition and the volume constraint of the 3 different magnetic channels are the same. The final iron distribution is shown in figure 5. Field gradient and dipole field in MC1 and MC2 is very closed. So that the MC1 and MC2 are both consists of 3 iron bars. The Background field difference between MC1 and MC2 is 1.1 T, leading to a thicker upper iron bar in MC2. The gradient in each magnetic channel is flat in the beam region and reaches the designed gradient.

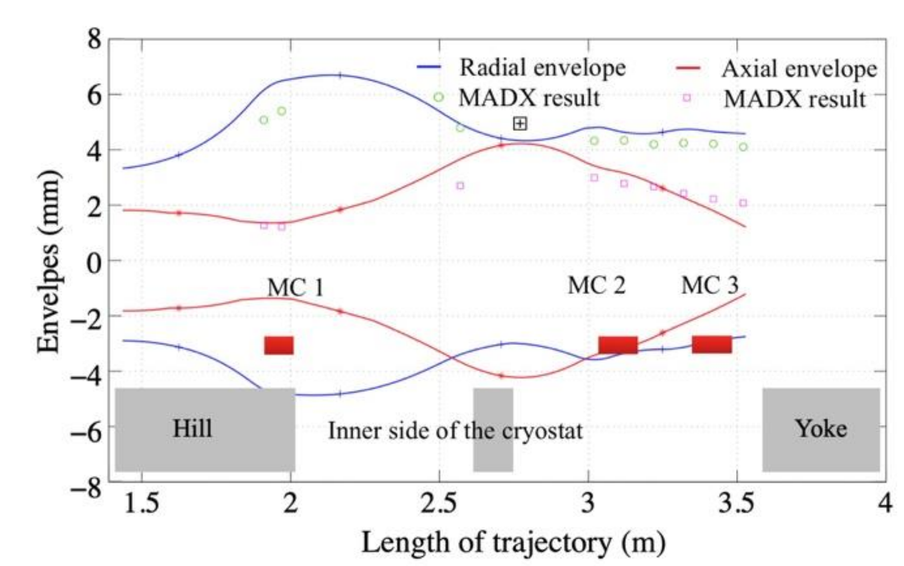

Figure 6. After designing the magnetic channels, particle tracing is accomplished obtaining particle trajectories through the extraction channel. Eight particles be-longing to the initial phase ellipse are used to calculate the radial envelope, and 4 particles are used to calculate the axial envelope due to the symmetry of the median plane. The initial motion condition of the particles are calculated using the twiss parameters of the beam, and the emittance are 5mm.mrad in both directions. The extraction beam is properly focused.