

MAGNETIC FIELD CALCULATION AND MAGNET SHIMMING SIMULATION FOR CYCHU-10 CYCLOTRON

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Abstract

The compact internal ion source cyclotron CYCHU-10 developed in Huazhong University of Science and Technology (HUST) is in magnet machining, and will be assembled soon later. The accuracy of the finite element analysis (FEA) prediction of the magnetic field compared to the measurement is an important guarantee for virtual magnet shimming. In this paper, a further study on magnet field computation using FEA is implemented. Both An 1/8 and a 1/4 models are established to make a comparison. Based on the computation, researches on virtual magnet shimming are also carried out. A new shim tool using an improved matrix method combining the multiple linear regressions is employed to simulate the virtual shimming process. With the aid of 3D finite element code and beam dynamics code, an iterative shimming process has been accomplished successfully. The results verify the feasibility and effectiveness of the shimming method.

INTRODUCTION

Commercial cyclotrons are widely applied in medical field, especially for proton therapy and isotopes production in recent years [1]. A compact H- cyclotron with 10MeV extraction energy CYCHU-10 is being developed in HUST, which is designed for short-life isotopes production in PET system. The essential parameters of the cyclotron are exhibited in Table 1. Some details of the model are optimized by iterative computation, and a good isochronism of the magnetic field is observed.

Table 1: Parameters of the cyclotron

Number of pole	4
Extraction energy	10MeV
Extraction radius	27.2cm
RF frequency	100.12MHz
Dee voltage	35KV
Dee angle	40°
Average flux density	1.64Tesla

When machining of the main magnet is completed, measurement of the magnetic field using mapping system will carried out to confirm if it meets the requirement for particle accelerating [2]. According to experience, the initial machining will not reach the goal of a good isochronism, for there exists about $\pm 0.5\%$ difference by

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TOSCA software comparing to the real magnetic field, so magnet shim work should be put on the agenda [3][4]. Generally, there are mainly two ways to shim the magnetic field: (1) adjust the trim coils; (2) change the shape of the magnet pole. To CYCHU-10, only primary coil is employed to supply excitation, so method (2) will be adopted [5].

CALCULATION OF THE MAGNET

The model of the main magnet of CYCHU-10 cyclotron has been constructed by using pre-processor of TOSCA. To reduce the amount of elements, an 1/8 model was formerly adopted, and periodic symmetric boundary condition is applied on the edge of the magnet pole. Nevertheless, the periodic symmetric boundary condition is actually an approximate dispose in this model, since the magnet yoke of the cyclotron is not strictly periodic symmetrical. What we concerned is whether it will bring unpredictable error to the calculated magnetic flux density B . In fact, we could gain a more accurate field result by using a 1/4 model in theory. So a 1/4 magnet model is created for a comparison. Fig. 1 shows the 1/8 and 1/4 models of the CYCHU-10 with scalar plot of magnetic field, which are meshed by 190,000 and 450,000 quadratic hexahedra elements, respectively.

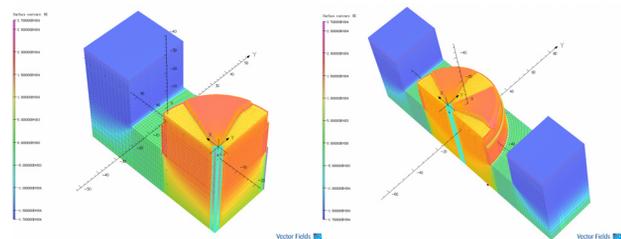


Figure 1: 1/8 and 1/4 models of the main magnet.

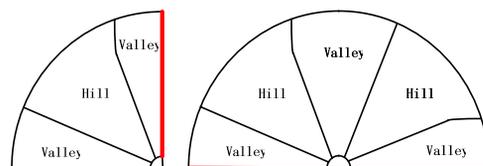


Figure 2: The periodic symmetric edge on two models

The periodic edges on the two models are shown in Fig. 2 decorated with red-thick line. Fig. 3 gives the calculated circular magnetic field difference between 1/8 and 1/4 models at various radiuses. We can obtain that the influence is smaller at the hill of the pole. And the subtraction of the two fields at different radius is about 13 Gauss on average.

Fig. 4 exhibits the isochronous B in mid plane of the

models, and the difference between the two isochronous magnet fields is about 12 Gauss at most radius, which is a small change compared to the integral average magnetic flux density 1.64T. It indicates that the periodic symmetric condition and mesh grid will not bring enormous influence.

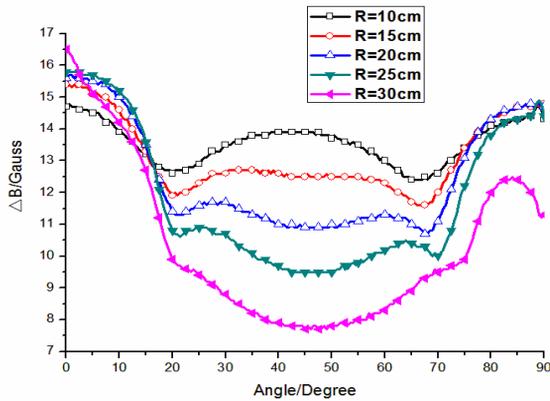


Figure 3: Circumferential ΔB at various radius

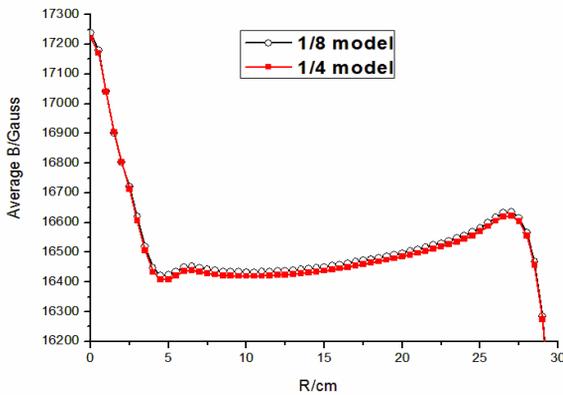


Figure 4: Isochronous magnet field of two models

According to analysis of the calculation result, we finally summarize that the magnet field difference between the two models is about 0.08% which means the frequency error is less than 0.1%. In consideration of the calculation error of TOSCA software, this will not arouse a large influence to accuracy of magnetic flux density B and beam dynamics simulation result. So the virtual shim work on the 1/8 magnet model is reliable.

MAGNET SHIMMING SIMULATION

When the initial machining of the magnet is completed, magnetic field should be measured for estimating its deviation from isochronal field. The task is to minimize the deviation of the field by magnet shimming.

Cutting strategy is adopted as the magnet shimming method for CYCHU-10. In general, our magnet shimming is an iterative process containing two main steps: (1) to qualify the isochronous field error; (2) to predict the magnet pole shape modification according to the

calculated field error in the first step [6]. We plan to employ a matrix method with nonlinear radial fringe field effect, which is based on multiple linear regressions to predict cutting quantity. A shim tool code based on MATLAB has been developed. Commonly, the shim tool will provide cutting quantity at each radius and TOSCA COMI files when we input the local phase slip of particle which is calculated by beam dynamic calculation software CYCLOP. With the aid of shim tool, the general procedure of magnet shim work is shown in Fig. 5.

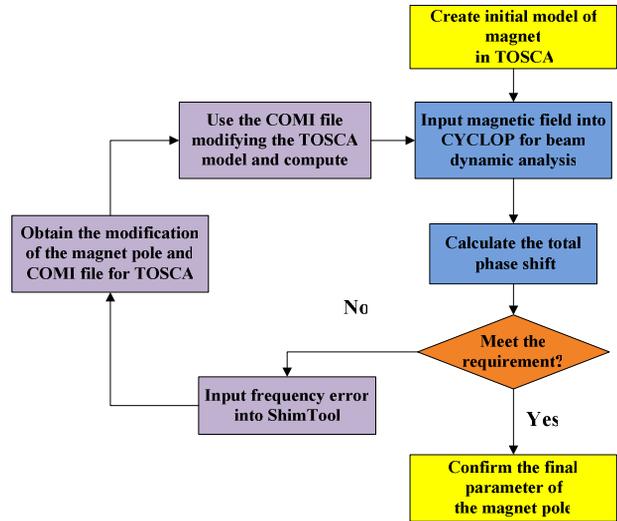


Figure 5: General procedure of magnet shimming

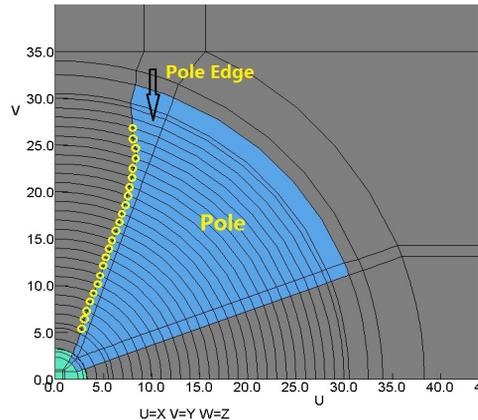


Figure 6: The cutting pole edge of the model

A virtual shim process is simulated on the 1/4 model. Firstly, an initial model with some allowance on the pole edge is established. As shown in Fig. 6, we leave some alterable key points distributed at different radiuses from 6cm to 28cm on the pole edge (marked by circles). The model will be modified when coordinates of these points are transformed. Then it will lead to changes to the average magnetic field at various radius. When the moderate RF frequency is set, we make the average magnetic field a bit higher than ideal isochronous magnet field by leaving a margin on the pole edge, so cutting strategy must be taken to lessen the error between our actual field and ideal quantity. The shim tool will automatically give the quantity should be cut.

Generally in engineer, a conservative strategy will be employed, for once an excessive quantity is cut, there is no compensational measure. So a cutting factor is also introduced in shim tool. By multiplying a cutting factor no more than 1.0, the cutting amount will be under control. Here are the experimental results of the magnet shim on computational models shown in Fig. 7-9.

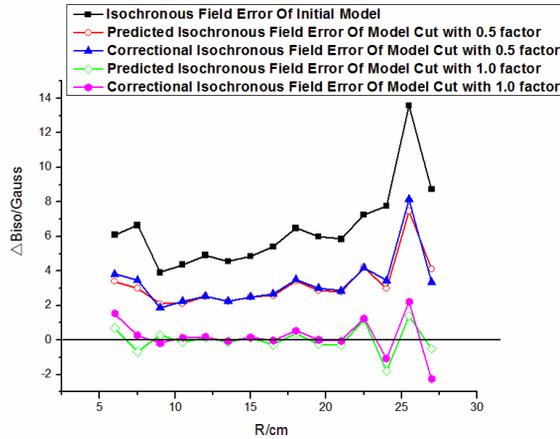


Figure 7: Isochronous field error of iterative models

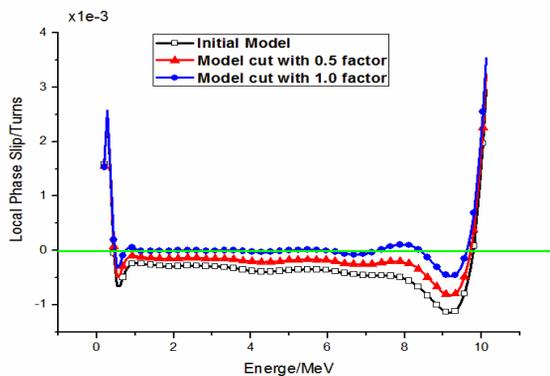


Figure 8: Local phase slip of iterative models

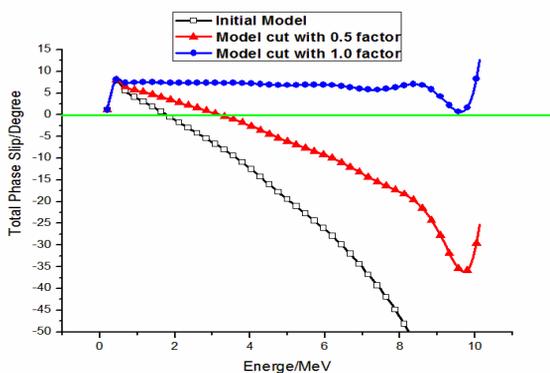


Figure 9: Total phase slip of iterative models

We cut the pole edge of initial model by shim tool separately with 0.5 and 1.0 cutting factor. Fig. 7 gives the isochronous field error of initial model, the predicted

isochronous field error and the correctional isochronous field error after shimmed with cutting factors. Obviously, by modifying magnet model, the isochronous field error has decreased, when the 1.0 cutting factor is adopted, the deviation of correctional field from ideal field is minimized nearly to zero Gauss, this means good a isochronism have reached.

The change of field will definitely improve the phase slip of particles. Fig. 8, 9 respectively exhibit the local phase slip and the total phase slip of the three models. It's clear that the local phase slip decreased with the increase of the cutting factor. And we find that the total phase slip of initial model has exceeded 50 degree when the energy comes to 8 MeV, particles will drop into decelerating zone rapidly. By cutting the pole edge, this situation has been changed. The total phase slip is under control after shimming work. After cutting with 1.0 factor, it finally don't exceed 10 degree in the whole accelerating procedure which shows a good shimming result.

Anyhow, those studies above are based on the computational magnetic field. When it comes to practical engineering, measured magnetic field will be used for magnet shimming instead.

CONCLUSION

By implementing a comparative magnetic field calculation, we finally eliminate some unpredictable factors in models, which will be beneficial to our magnet shim work. A shimming scheme using a shim tool has been verified, the result proved its feasibility and reliability, and this method will be employed in practical shim work later on.

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