IMPROVEMENT IN DESIGN OF 10 MeV AVF CYCLOTRON MAGNET

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Abstract

Design study of a 10MeV baby cyclotron which accelerates H− ions is started in March, 2012 at Amirkabir University of Technology (AUT). Up to this point, conceptual design of the cyclotron magnet is finished. This process has been done in two steps: initial design and then optimization.

After finishing the initial design of the magnet by the CST software [1] and adopting hard-edge approximation for finding the pole tip [2], an optimization process has been followed to smooth the pole edge in order to decrease the tension in sharp edges of the pole. In this paper, we are going to explain about the optimization process in details. Actually, we tried to fit the best curve at the pole edges of the magnet with goal of having minimum magnetic field error. Also a short report of results which was obtained before optimization is provided here. Precision of this design is ensured by checking the magnetic field and beam dynamic parameters during the optimization.

INTRODUCTION

The 10 MeV cyclotron magnet is designed to be made of steel-1008 with 4 sectors. Conceptual design of the magnet using the CST software is finished so far and its latest result has been presented previously. Figure 1 provides a short report of magnet design before applying the optimization method:

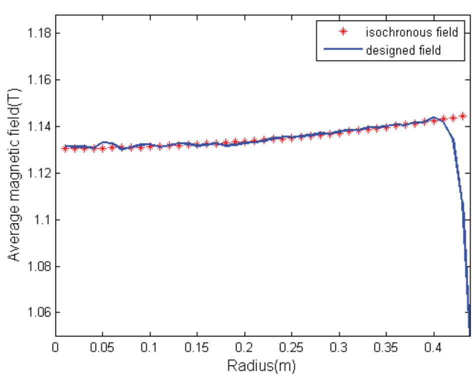

Figure 1: Average magnetic field before applying the optimization method.

Also betatron oscillation frequencies have been calculated considering the formulas [3] (Fig. 2).

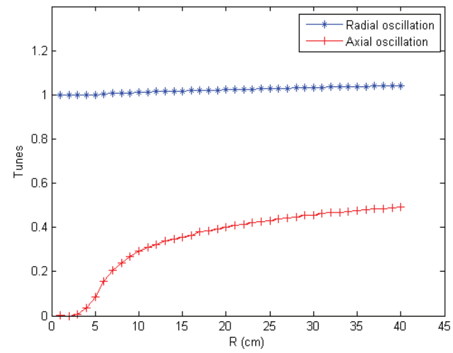

Figure 2: Betatron oscillation before applying the optimization method.

Dividing conceptual design of the magnet into two steps, the first one includes finalizing the magnet model by matching the average magnetic field to the isochronous field. And the second step consists of an optimization process that has been done subsequently. One of the activities which had been applied in order to optimize the model is explained in this paper.

METHOD EXPLANATION

A certain design might seem to be finalized but when you start the engineering design you may face some other aspects of modelling. One of the problems that may occur after manufacturing of the magnet is to have tension in the edges of the magnet. Usually this problem becomes more evident at the pole edge. As it is shown in Fig. 3, this area is not uniform; however the intensity of magnetic field is very sensitive here. So in order to solve this problem we tried to remove the uneven edges.

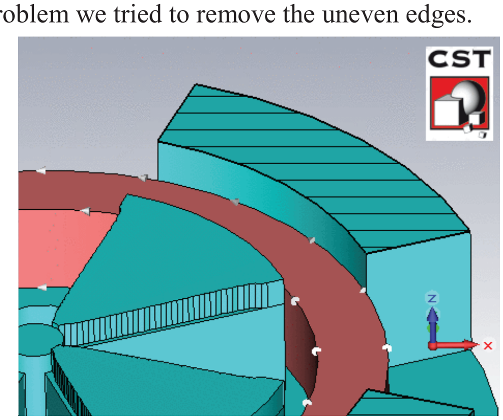

Figure 3: Pole edge before applying the optimization method.

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ISBN 978-3-95450-128-1

Actually what we did is to take the X-Y position of the points at the pole edge and import them into the MATLAB code. Then by applying an order which is called "CFTOOL", a curve would easily be matched to the imported points. Sample of a curve fitting is shown in Fig. 4.

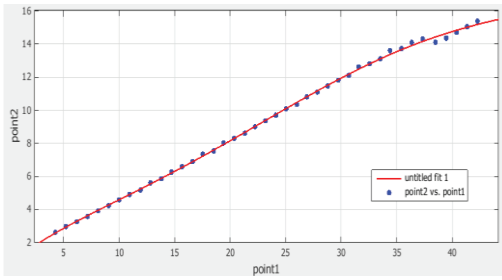

Figure 4: Sample of a curve fitting with MATLAB.

It is obvious when you fit a curve to some points, it would not exactly cross all the points and always some percentage of error is existed. So a number of more than 20 curves with different equations were investigated in order to fit the best curve to the points. Polynomial, sinusoidal and exponential equations with different degrees are among the curves that have been considered.

Each time that a specific equation was considered for the pole edge, its precision was checked by 3 parameters: RMS (Root Mean Square of vertical distance between points and curve), average magnetic field and beam dynamic parameters.

In fact these three factors are checked one after the other. First of all, the value of RMS should be investigated. If the intensity of this parameter was reasonable, then the next factor can be evaluated.

It is offered to work with low number of mesh cell if it is the first time that the magnetic field of a model is going to be checked. If the trend of the magnetic field was almost matched with isochronous field, then some methods like cutting the surface of the pole can be applied by higher number of mesh cells in order to create isochronous condition. In fact, an equation is accepted after being confirmed by all these three factors.

RESULTS

After applying this method, the shape of the pole edge becomes so smooth and the possibility of tension creation decreases. This uniformity is obvious in Fig. 5.

Among all the curve equations that have been investigated, a polynomial equation with degree number 5 was the most optimum one (see Eq. 1).

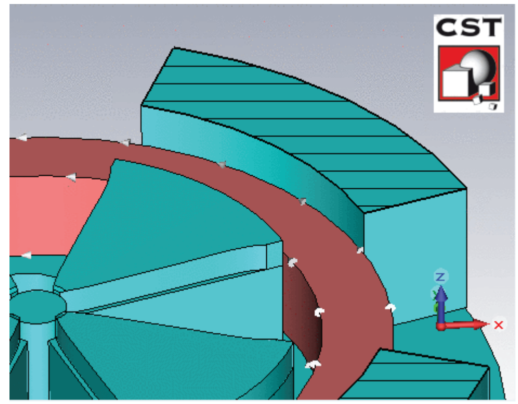

Figure 5: Pole shape after curve fitting.

$$Q(t) = (-8.9 * 10^{-7})t^5 + (9.1 * 10^{-5})t^4 - (0.2 * 10^{-3})t^3 + (6.8 * 10^{-2})t^2 - (2.6 * 10^{-1})t + 3.1 \quad (1)$$

Of course this equation is just specified to our model and would differ for any other design.

Final result of this 3-stage process is what you can see in Fig. 6.

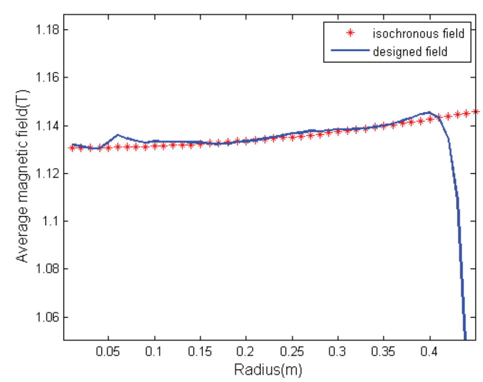

Figure 6: Average magnetic field versus radius.

Since a magnet design should also satisfy transversal focusing condition, betatron oscillations have been investigated after the 3D field computation. This parameter has been checked in order to validate stability of particle trajectory after the optimization process. As it is shown in the Fig. 7, the intensity of these parameters is positive and acceptable [3].

ISBN 978-3-95450-128-1

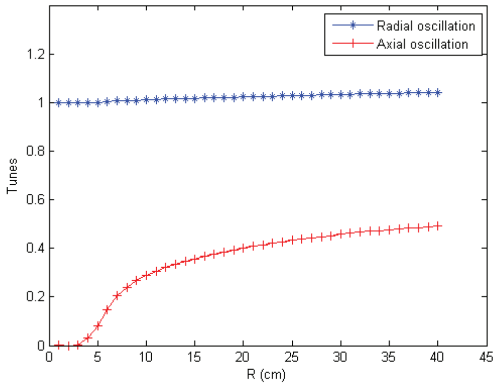

Figure 7: Betatron oscillation frequencies.

Also field distribution on the median plane, which is shown in Fig. 8, determines that the maximum magnetic field on the median plane is 1.84 T. So the situation is satisfying because the intensity of this value does not exceed the saturation point of the magnet material.

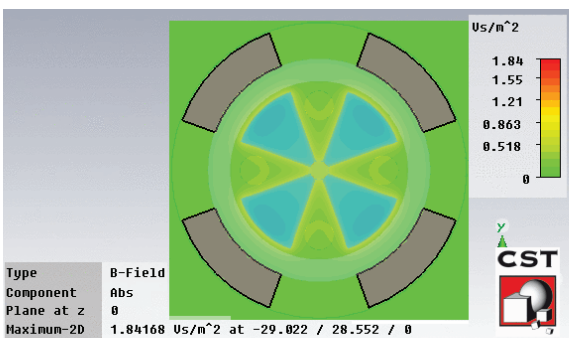

Figure 8: Magnetic field distribution.

CONCLUSION

In this study, an optimization process was carried out that can reduce the tension in the pole edge of the magnet. The accuracy of the result is insured by checking the average magnetic field. In addition, betatron oscillation frequencies have been investigated for checking the beam stability [4].

The study that was presented above is based on the computational magnetic field and might be a little different from the model that is going to be fabricated, but this accurate simulation result can give a good estimation for the real model and decrease the difference between simulation and experiment result.

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