ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPWA065

UNIFORMIZATION OF THE TRANSVERSE BEAM PROFILE BY A NEW TYPE NONLINEAR MAGNET*

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Abstract

The uniform transverse profile beam is desirable in many beam applications. One method to get this type of beam distribution is using octupoles, but loss of particles in the halo will be produced by this method. To reduce the beam loss, a new type of magnet is proposed in this paper. The field in the middle region of the new type magnet is similar to the octupole magnet field, but the rate of rise decline quickly in the edge. So that the particle in the edge experience a lower magnet field compared with the octupole, and this would result in less particle loss. We also add a mechanical structure on the new type magnet to make it possible to adjust the size of middle region. So that the magnet can adapt to different transverse dimensions of the beam, and this would further reduce particle loss. Some numerical simulations have been done respectively with the octupole and the new type of magnet. The simulation results show that the new type of magnet could get the uniform distribution of particle beam with less particle loss. We are processing a magnet now, and an experiment to test the magnet will be arranged on CPHS.

INTRODUCTION

The beam with uniform spatial distributions is required in several practical applications such as irradiation of targets for isotope production, uniform irradiation of detectors for improved efficiency, irradiation of biological samples and materials. A general method to get a transverse uniform beam from a Gaussian profile beam is utilizing odd-order nonlinear focusing magnets. Many people have theoretically studied uniformization of the transverse beam profile with multipole magnets [1-4].

Yuri et al. have theoretically studied uniformization of the transverse beam profile using nonlinear-focusing forces produced by multipole magnets. They get distribution at the target is related to that at the multipole magnet position as follows [1],

$$\rho_t = \rho_0 \left(\frac{dx_t}{dx_0}\right)^{-1}$$
$$= \frac{\rho_0}{M_{11} - \frac{\alpha_0}{\beta_0} M_{12} - M_{12} \sum_{n=3}^{\infty} \frac{K_{2n}}{(n-2)!} {x_0}^{n-2}}$$
$$= \frac{\rho_0}{M_{11} - \frac{\alpha_0}{\beta_0} M_{12} - M_{12} \sum_{n=3}^{\infty} \frac{K_{2n}}{(n-2)!} {x_0}^{n-2}}$$

*Work supported by National Natural Science Foundation of China (11175195).
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Where $M_{ij}(i,j = 1,2)$ are the elements of M**.** M is the transmission matrix. Where K_{2n} is the 2n-pole integrated strength of the multipole magnet and the magnet is assumed to be a thin lens for simplicity's sake. Where ρ_0 and ρ_t are the particle density functions in the real space at the initial and at the target. Where β_0 and β_t are the beta functions at the initial and at the target. The initial particle distribution can be transformed into a different one at the target by using the nonlinear magnetic field.

Many beam distributions ρ_0 are Gaussian or can be fitting with Gaussian. After some algebraic transformation we can get all of the odd-order nonlinear fields are needed for transformation of an ideal Gaussian beam into a totally uniform beam. But the realistic case is that the multipole magnet produces only one nonlinear component. So we usually use the octupole magnet to get the uniform distribution beam. But loss of particles in the halo will be produced by this method. To reduce the beam loss, a new type of magnet is proposed in this paper.

THE NEW TYPE OF MAGNET

The new type magnet is shown in Figure 1. The top is the mode of the Opera 3D. And the bottom is the section of the central plane. To get a uniform distribution beam, the field in the middle region of the new type magnet is similar to the octupole magnet field. But the rate of rise decline quickly in the edge in the new type magnet. So that the particle in the edge experience a lower magnet field compared with the octupole, and this would result in less particle loss. We also add a mechanical structure on the new type magnet to make it possible to adjust the size of middle region.

Opera 3D is used for the new magnet design. The magnetic field of the new type magnet is compared with the magnet of the octupole for the distance between the C-type dipoles equal to 0.2m in the top of Figure 2. The magnetic field profiles are plotted at the centre plane. As we have mentioned, we would add a mechanical structure on the new type magnet to make it possible to adjust the size of middle region. The new magnet is separated for three parts (two C type dipoles and the shield block). The distance between the two dipoles can be changed with the mechanical structure. And the size of the middle region, the octupole-like region, can be changed with the distance change. The Figure 2 give the change of the magnet field with the distance from the centre. As shown in the Figure 2, the top figure is plotted while the distance is the minimum and the right figure is plotted while the distance is the maximum. While the distance is the minimum, the size of the middle region is also the minimum. The

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situation can be used for the smaller beam transverse profile. With the distance become large, the middle region is also become large. So the new type magnet can be adjusted to fit a wide change of the beam transverse profile without too large magnetic field making particles loss.

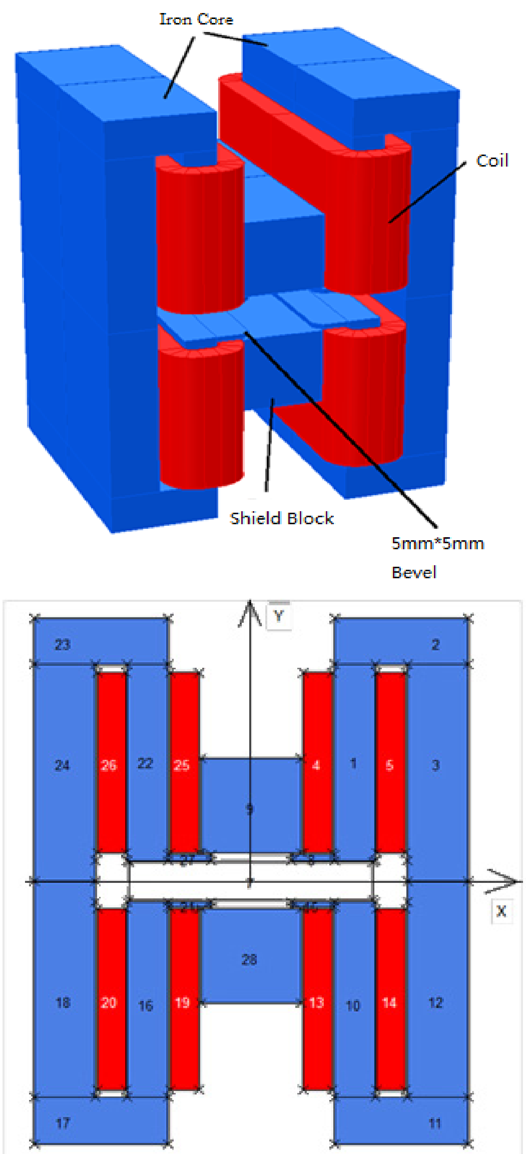

Figure 1: The 3D model of the new type of magnet (top) and the central plane of the magnet (bottom).

APPLICATION

To test the new type of magnet, I have make a simulation using CPHS lattice. The lattice has two octupoles which is designed for uniformization of the transverse beam profile. At first we adjust the two octupoles to get the uniform transverse profile. Something interesting happed. The vertical profile become uniform without any nonlinear magnet. Most of our studies were performed using the Tracewin code. When we match the beta function, the Tracewin code neglect the space charge effect. But while the particle tracing, we include the space charge effect. So the space charge effect make the beam unmatched in fact. And I am studying the effect so far. In this way, we just need to uniform the horizontal profile. In the later study, we just operate the horizontal. We first get the strength of the octupole which is needed to get the uniform horizontal beam profile with the theoretical study in the reference [1]. Then we fit the octupole with the new type magnet in the fixed size of middle region like the Figure 2. We can get the size of the middle region from the size of the transverse profile at the octupole or the new type magnet location. The width we use to fit the new type magnet can be got from the Figure 3.

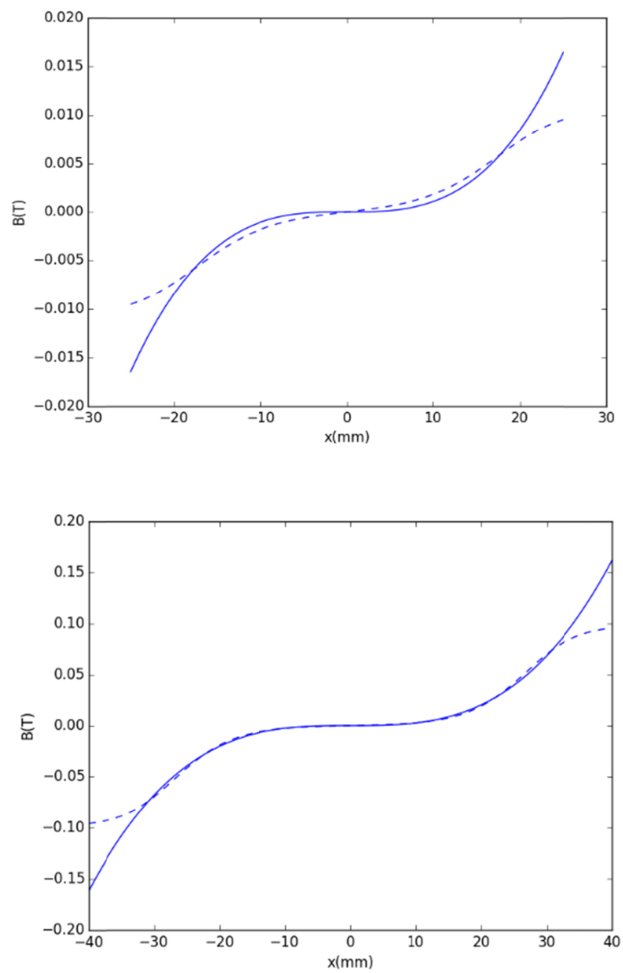

Figure 2: The magnetic field profiles with the minimum (top) and maximum (bottom) distance (dash line) between the two C-type dipoles compared with octupole (solid line).

At last, we get the beam distribution and the number of the particle loss. In the Figure 3, we compare the beam distribution and the transverse profile on the target. The effect of uniformization of the beam with the new type magnet is the same with the effect of using the octupole. But the particle loss is less. As shown in the Table 1, the total macro particles we use in the simulation is 100000. The number of macro particles we get on the target without any nonlinear magnet is 99372. The number of

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macro particles on the target with octupole is 99190. The number of macro particle on the target with the new type magnet is 99310. The number of macro particle loss with the octupole is more than 100. We have to mention that there are many particle loss on the dipole which is located on the transport. The four pictures in the Figure 3 are the phase space at the different locations and different conditions. The top left one is the phase space at the location where the nonlinear magnet is located. From this one we can get the width of the middle region of the new type of magnet which we should fit with the octuple. The others are at the target without nonlinear magnet (the top right one) and with an octupole (bottom left one) and with the new type of magnet (bottom right one). The two bottom pictures indicate that both the new type magnet and the octupole can get the transverse uniform profile beam. The result shows that uniformization of the transverse beam profile by the new type nonlinear magnet is better compared with the octupole.

Table 1: Comparison of the Particle Loss

Method	Macro particle	Macro particle loss
Without nonlinear	99372	628
With octupole	99190	810
With new type magnet	99310	690

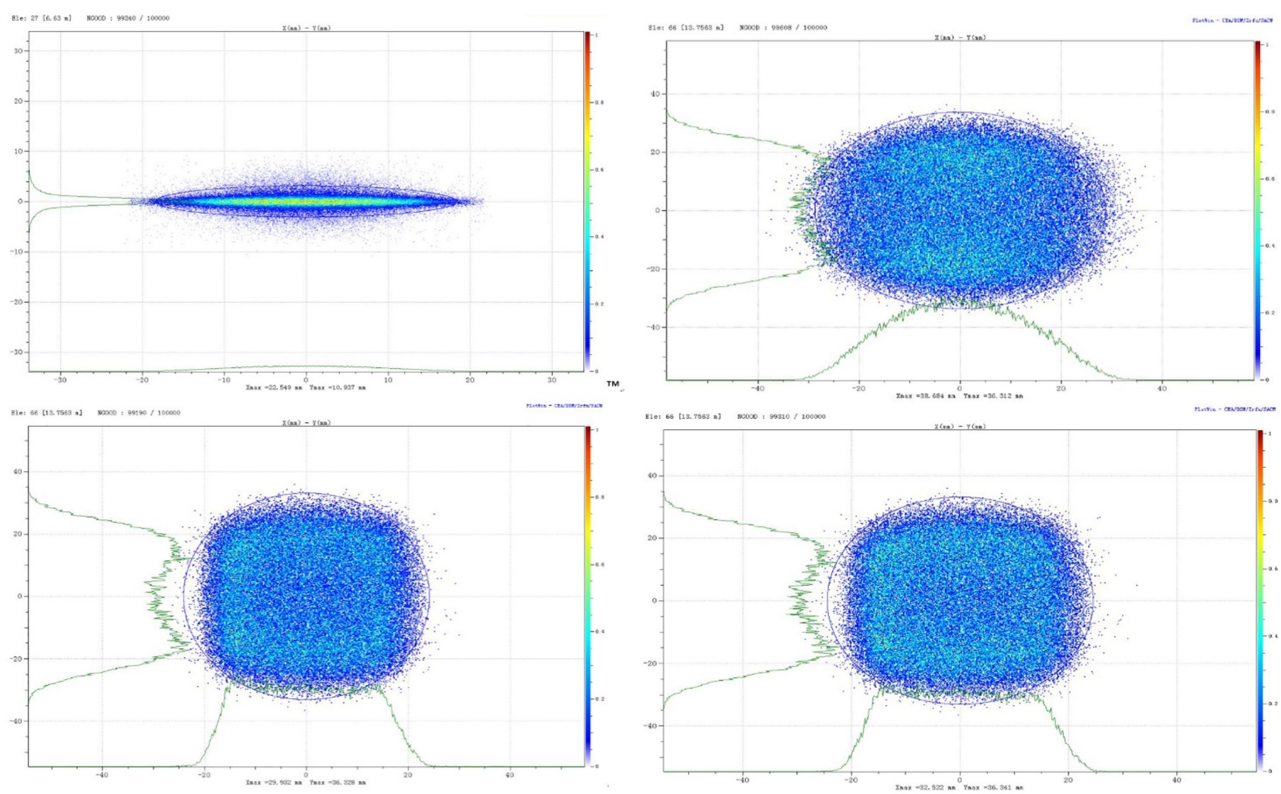

Figure 3: The phase space density distribution at different locations or different conditions.

SUMMARY

We design a new type magnet to get the uniform transverse profile beam, and make some simulation with the new type magnet. The simulation results show that with the new type magnet can get a uniform profile distribution just like the octupole. The new type magnet has two advantages compared with the octupole.

(1) Getting the uniform transverse profile beam with less particle loss.

(2) Adjusting the new type of magnet with the change of the beam transverse profile flexible.

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