The alignment of the energy degrader applied in the proton therapy

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Abstract

A new proton therapy facility based on a 250MeV/500nA superconducting cyclotron has been under construction in Huazhong University of Science and Technology (HUST) in Wuhan, China. Due to the fixed beam energy extracted from the cyclotron, an energy degrader is essential for the proton beam with variable energy to reach various tumour depths in human body. The alignment accuracy will have an obvious impact on the performance of the degrader. This paper will discuss how the beam energy, beam emittance and beam losses are influenced by the alignment accuracy including the positional accuracy, the angular accuracy, the coaxiality and others. Moreover, the detailed alignment program will be proposed.

INTRODUCTION

Because of the Coulomb interactions between the incident protons with the target atom, the beam emittance growth, the momentum spread and beam loss will take place after the energy degrader. The collimators and the double bend achromatic (DBA) section will be located downstream after the degrader (see Fig. 1) in order to restrict the beam emittance and the momentum spread respectively. The mechanical deviation of the energy degrader will lead to the error of the overlap thickness and then cause the deviation of the beam energy. The mechanical deviation of the collimators will lead to the deviation of the stopping proton number and then cause the deviation of the beam current.

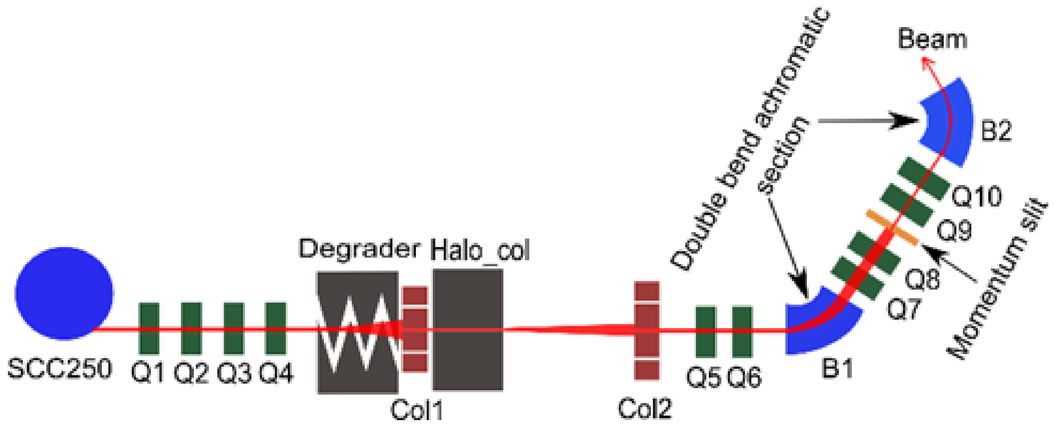

FIG. 1. Layout of energy selection system (ESS).

ALIGNMENT TOLERANCE

The energy degradation is determined according to the Bethe–Bloch formula, given in Eq. (1).

$$-\left(\frac{\mathrm{dE}}{\rho \mathrm{dx}}\right)=4\pi \mathrm{N}_a r_e^2 m_e c^2 z^2 \left(\frac{Z}{A}\right)\left(\frac{1}{\beta^2}\right)\left[\ln\left(\frac{2m_e c^2 \gamma^2 \beta^2}{I}\right)-\beta^2-\frac{\delta}{2}\right] \quad (1)$$

Combined with the results of Geant4 simulation (see Fig. 2), the energy degradation gradient with the overlap thickness is 1.48 MeV/mm at 70 MeV when the graphite density is 1.95 g/cm3 as the degrader material. The alignment deviation will result in 2.68 times overlap thickness deviation. The one-sided alignment tolerance of the energy degrader is set to 0.1mm and then the maximum energy deviation is 0.4 MeV when the beam energy is 70 MeV. Collimators with various aperture sizes are used to define the accepted emittance, given in Eq. (2). The alignment tolerance of the collimators is set to 0.2mm.

$$\varepsilon_{\mathrm{col}} = \frac{2\mathrm{r}_1 \cdot \mathrm{r}_2}{\mathrm{L}_{\mathrm{col}}} \quad (2)$$

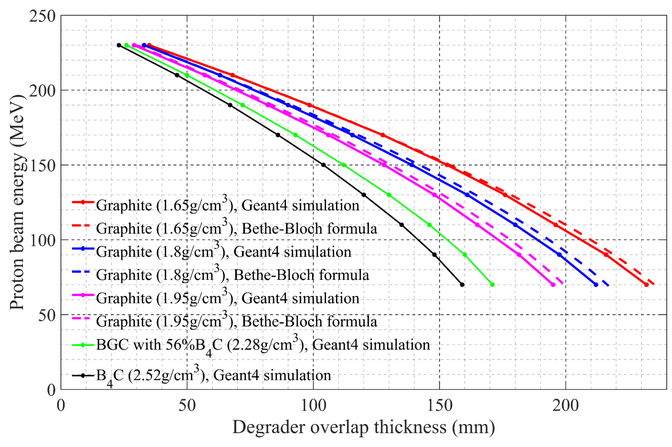

FIG. 2. Beam energy varying with the degrader overlap length.

ALIGNMENT PROGRAM

The laser tracker is used to calibrate the vacuum box. Four reference targets are welded to the upper surface of the vacuum box (see Fig. 3). The alignment telescope is chosen for the alignment of the energy degrader and collimators (see Fig. 4). The alignment telescope could be aligned with two objective lens mounted on the central flanges of the vacuum box to establish a line of sight along the reference axis of the proton beam. Then the degrader and collimators could be aligned in turn from upstream to downstream.

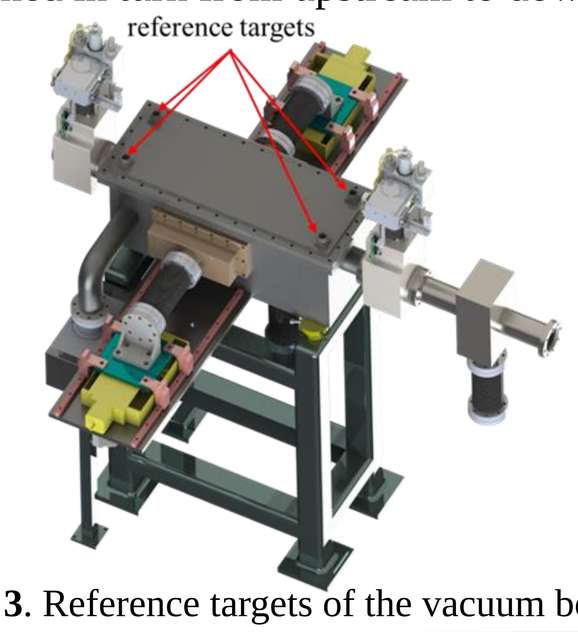

FIG. 3. Reference targets of the vacuum box.

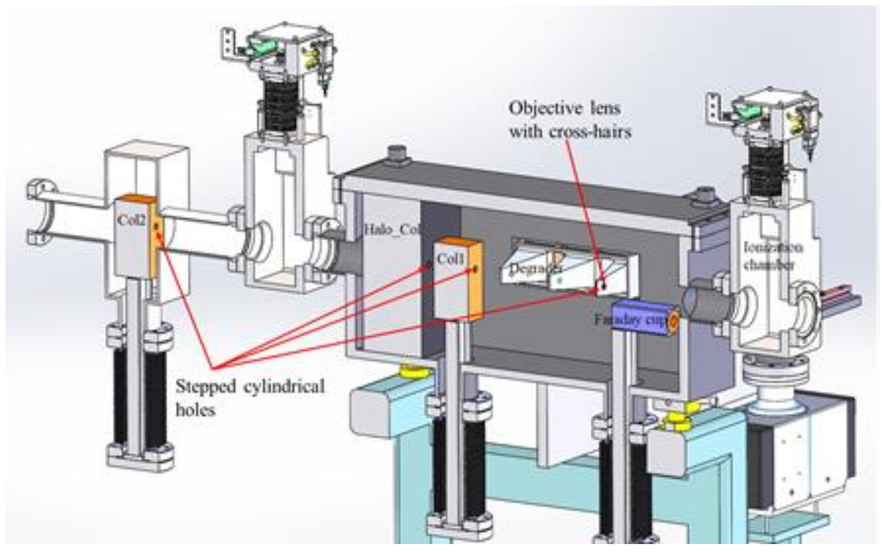

FIG. 4. Alignment diagram of the energy degrader and collimators.

CONCLUSION

The one-sided alignment tolerance of the energy degrader is set to 0.1mm and the alignment tolerance of the collimators is set to 0.2mm. The laser tracker and alignment telescope are adopted in the alignment.

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