PROGRESS OF THE BEAMLINE AND ENERGY SELECTION SYSTEM FOR HUST PROTON THERAPY FACILITY *

B. Qin†, W. Chen, X. Liu, Z.K. Liang, X.Y. Fang, Q.S. Chen,
K.F. Liu, J. Yang, D. Li, P. Tan, K.J. Fan, M.W. Fan
Institute of Applied Electromagnetic Engineering
Huazhong University of Science and Technology (HUST), Wuhan 430074, China

Abstract

HUST proton therapy facility is a 5 years National Key Research and Development Program of China. This facility is based on an isochronous superconducting cyclotron with two gantry treatment-rooms and one fixed beamline treatment station. The status for physical and technical design of the beamline and Energy Selection System (ESS) will be introduced in this paper.

INTRODUCTION

HUST proton therapy facility is a 5 years National Key Research and Development Program of China. This facility is based on an isochronous superconducting cyclotron, two 360 degree rotation gantry treatment-rooms and one fixed beamline treatment station will be constructed at first stage. The main specifications are listed in Table.1.

Table 1: Main Specifications of HUST PT Facility

Parameter	**Specification**
Accelerator type	Isochronous super-conducting cyclotron
Beam energy	250 MeV
Energy range from ESS	70-240 MeV
Energy modulation time	⩽ 150ms per step
Gantry type	360 degree, normal conducting
Irradiation method	Spot scanning
Max. dose rate	3Gy/L/min
Field size	30cm×30cm

The beamline is designed to have the ability to adjust all power supplies of the beamline magnets, as well as the energy selection system, for fast energy switch in the range of 70 to 240 MeV, with the modulation time ⩽ 150ms per step. The status for physical and technical design of the beamline and ESS will be introduced in this paper.

LAYOUT AND OPTICS

Figure 1 shows the layout of the beamline. The degrader is placed at the downstream of the cyclotron, for better radiation control of neutrons. A DBA (double bend achromatic section) is followed with the degrader, with an energy select slit. For the gantry beamline, a downstream scanning scheme is chosen to avoid construction of large aperture 90 degrees dipole which is required in upstream scanning. Another cons is the linear dependency between the beam position and the scanning magnet current relieves difficulty of the therapy planning. To avoid the dose accumulation on skins due to un-parallel beam, the SAD (source-axis distance) is designed to around 2.8m.

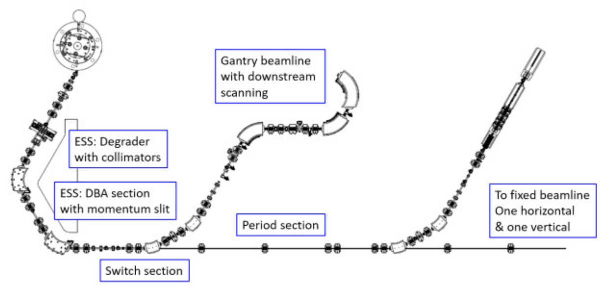

Figure 1: Layout of the beamline.

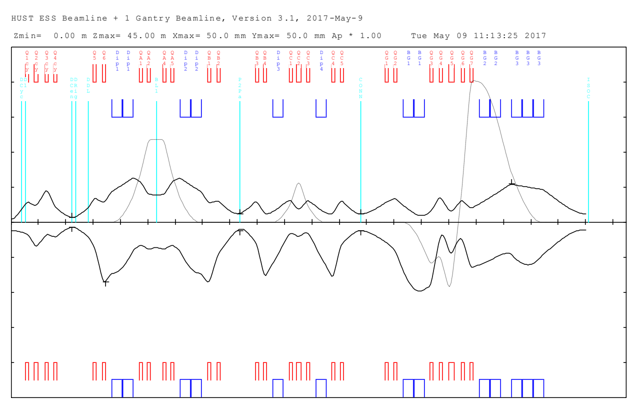

Figure 2: 1 sigma beam envelope for the main beamline including ESS and gantry beamline.

Figure 2 shows the 1 sigma beam envelope of the beamline using Transport code [1]. Main considerations on the bream optics and layout of the beamline are:

- A multi-wedge style degrader for fast and continuous energy modulation is positioned just after a four quadrupole set (Q1cy – Q4cy) from the exit of the cyclotron, to limit the neutron radiation far from the treatment room. Beam waist at the degrader center for both planes is designed to minimum the multiple Coulomb scattering in the degrader.
- A DBA section is followed after the degrader, with an size-changeable energy slit for limiting energy spread from 0.3% to 0.8%.
- At the connection point (CP) between the fixed beamline and the rotation gantry beamline, mirror beam x=y, x’=y’ is designed to make the gantry optics identical for different rotation angle. Beam waist is not an

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† bin.qin@mail.hust.edu.cn

necessary condition, however it will maintain a better transmission at CP.

- For gantry beamline, a downstream scanning scheme was used to keep the same magnet aperture for the last dipole. A relative long SAD (Source to Axis Distance) was adopted to reduce the accumulation dose on skins when using this 'un-parallel' beam. Image optics is considered for a robust beam delivery.

Spot scanning method with pencil beam will be used as the main treatment mode at first stage. This mode is robust due to dose-driven at each spot and is not so sensitive to the beam current. The energy transition time for each energy stem $T_e = 150ms$ is expected to control the one field treatment within 5 minutes. Although $T_e = 80ms$ has been achieved by PSI [2], this specification is still very challenging with high requirements from distributed control of power supplies, motion control and also from the possible disturbance of the beam quality during fast magnetic field transition.

ESS AND INTENSITY MODULATION

ESS is an essential part for proton therapy facility based on fixed energy cyclotrons. In general configuration, it contains an energy degrader and a DBA energy selection section.

To achieve the ability of fast and continuous beam energy modulation, a multi-wedge style degrader [2, 3] was adopted. Figure 3 shows the schematic configuration of the degrader. A double multi-wedge scheme was chosen, due to its structure simplicity for easy maintenance and possibility for fast movement. A changeable collimator set: collimator #1 at upstream, and collimator #2 at downstream, is used to shape the beam size and divergence according to the treatment requirement. A halo collimator is place after the first collimator to 'collect' halo particles. Some essential beam diagnostic components are designed: a faraday cup, also acts as a beam stop is installed before the degrader wedge, a BPM is also considered to be installed after the halo collimator to monitor the beam position.

During energy degrading in the material, the beam emittance growth is mainly caused by multiple Coulomb scattering and angle scattering is a dominated factor [3]:

$$\Delta\epsilon \approx \beta \cdot < \theta_{x/y}^2 > \quad (1)$$

Since the rms multiple scattering angle $< \theta_{x/y}^2 >$ is mainly related to the material property and thickness, in order to minimize the emittance growth $\Delta\epsilon$, double beam waist should be designed at the centre of the degrader for a minimum β function.

High density graphite will be used for degrader material. Low Z element such as Beryllium has a longer radiation length that will supress the scattering angle, however, the material processing is more difficult.

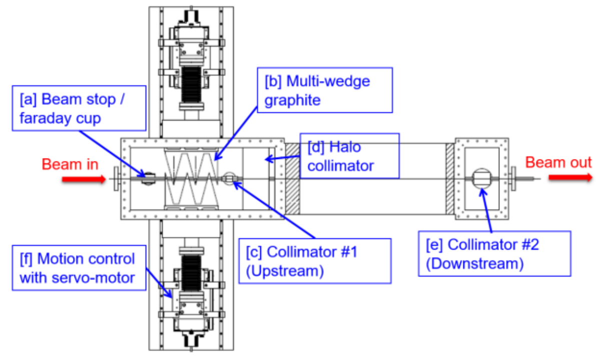

Figure 3: Schematic view of the multi-wedge degrader.

Geant4 code [4] based on Monte-Carlo algorithm was used for multi-particle simulation in the degrader [5] (see Fig. 4). For energy degrading to 70 MeV, the emittance and energy spread has a significant increase. To recover the beam to fulfil the treatment specifications, the collimator set and the energy slit in the middle of DBA will cut majority part of the beam, and lead to very low transmission rate. As shown in Fig. 5, the transmission for various energy point is calculated, for an output $10\pi \cdot mm \cdot mrad$ and $\pm 0.5\%$ spread beam.

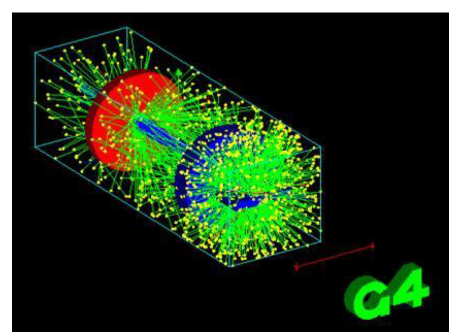

Figure 4: Simulation of energy degrading process with Geant4 code.

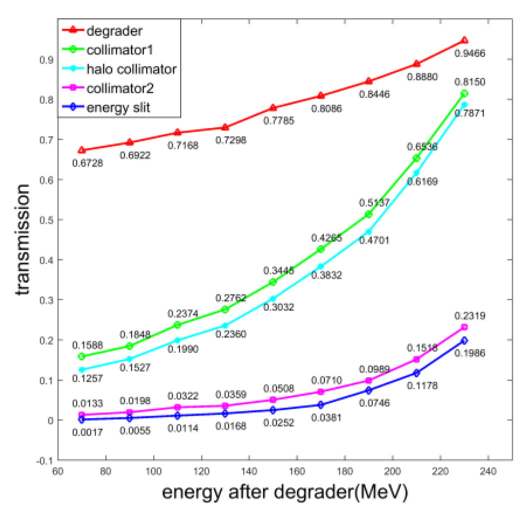

Figure 5: Transmission for energy degrading to 70-230MeV.

According to present calculation, the intensity ratio between 230 MeV and 70 MeV is higher than 100. For spot scanning, the beam intensity is normally in nA level and the ratio between high/low energy should be controlled within 10. Fig. 6 shows an intensity suppression scheme by using two quadrupoles QB1/QB2 after the second dipole in DBA, to defocus the beam and then collimate it at the downstream collimate. This method has been applied in PSI [6]. We performs suppression for beam energy beyond 150 MeV, and after this, the highest beam intensity is under 5nA and the intensity ratio can be equal or less than 10.

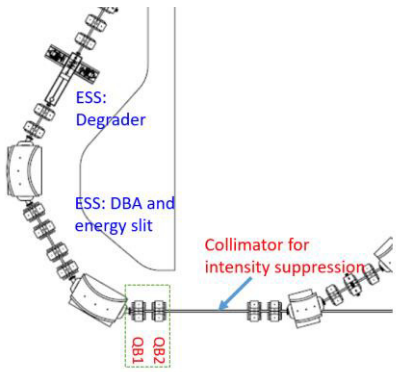

Figure 6: Intensity suppression scheme.

For the degrader, during the degrading process, high dose rate exists and should be well concerned. Good shielding and quick assemble / disassemble of crucial parts need be designed for operations and maintenance. To study the radiation exposure of electronics surrounding the degrader, Fluka code [7] was used for evaluation.

GANTRY BEAMLINE WITH IMAGE OPTICS

To obtain stable beam with desired beam size and intensity range, the optic of the gantry beamline should be designed with robustness feature, which means even some parameters such as the beam divergence are changed at the entrance of the beamline, the beam size is still stable at the iso-center. The point-to-point image optics can fulfil this requirement [2, 8]. The main method is to match the transport matrix to have $r11\approx r22\approx r33\approx r44\approx\pm1$, and $r12\approx r34\approx 0$. In this case, the beam size in two dimensions at the iso-center are imaged to the entrance of the gantry with a nearly 1:1 magnification factor. The beam envelope is shown in Fig. 2.

Figure 7 shows the layout of the 360 degrees' rotating gantry beamline. A downstream scanning scheme with the 2.8m length SAD was adopted. Two separated scanning magnets are located after the last dipole magnet B3. At the connection point (CP) between the fixed beamline and the rotating gantry beamline, a parallel circular beam x=y with beam waist condition is designed to make the gantry optics independent of the rotation angle.

For safety concerns, a collimator is installed at the entrance of the gantry to guarantee the beam size and remove uncertainties from beam misalignment. It's important to monitor the beam position and intensity at the gantry beamline. With the help of two sets of BPMs and X/Y steering magnets, the beam can be aligned. The ionization chamber IC1 is permanently mounted in the beam line to detect the beam current, position and profile in real time and the signal from IC1 is also transferred to TCS. In addition, two ion pumps are used to maintain a good vacuum status.

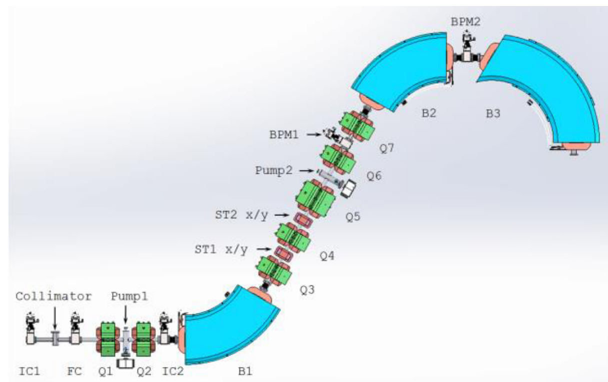

Figure 7: Layout of the gantry beamline with downstream scanning (Scanning magnets and nozzle not shown).

CONCLUSIONS

Main considerations and optics design for HUST proton therapy beamline are introduced in this paper. Physical design of the ESS with help of Geant4 code has been performed. Beam intensity suppression and image optics on the gantry beamline have been applied to achieve stable beam delivery during treatment.

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