PRELIMINARY DESIGN OF BEAM DIAGNOSTIC SYSTEM IN THE HUST-PTF BEAMLINE*

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Abstract

Proton therapy is now recognized as one of the most effective radiation therapy methods for cancers. A proton therapy facility with multiple gantry treatment rooms is under development in HUST (Huazhong University of Science and Technology), which is based on isochronous superconducting cyclotron scheme. The 250MeV/500nA proton beam will be extracted from a superconducting cyclotron and injected into the beam-line. Many beam diagnostic instruments are distributed throughout the beam line to measure the beam profile, position, current, loss, energy and energy spread. Some of them will send the beam information to the treatment control system (TCS) and serve as the safety interlock. This paper presents the considerations for the distribution of beam diagnostic instruments and shows the layout of beam diagnostics monitors in the beamline.

INTRODUCTION

A proton therapy facility based on an isochronous superconducting cyclotron is under development in HUST, by a collaborative team from HUST, CIAE (China Institute of Atomic Energy), Tongji Hospital and Union Hospital affiliated to HUST. For HUST proton therapy facility (HUST-PTF), a 250 MeV proton beam with 500 nA will be extracted from a superconducting cyclotron. After passing through the energy selection system (ESS) in which the energy will be modulated in the range of 70~240 MeV, it will be switched and delivered to three treatment rooms: two gantry rooms and one room with fixed beam line. The main specifications [1] are listed in Table 1.

Many beam diagnostic instruments are distributed throughout the beam line to measure the beam profile, position, current, loss, energy and energy spread. In this paper, the primary design considerations of beam diagnostics system within one gantry beamline are described and the layout of beam diagnostics monitors in the beamline is presented.

Table 1: Main Specifications of HUST-PTF

Parameter	Specification
Max. Beam Energy	250 MeV
Max. Beam Current	500 nA
Energy Range for ESS	70-240 MeV
Energy Modulation Time	≤150 ms per step
Gantry Type	360 degree, normal conducting
Treatment scheme	Pencil beam scanning (PBS)
Max. Dose Rate	3 Gy/L/min
Field Size	30 cm × 30 cm

OPERATION MODE

For a proton therapy facility, beam diagnostics system shall perform functions covering functions beam parameters measurement, and guarantee of the treatment safety. Several beam parameters shall be measured in real – time.to ensure the safety of treatment. Thus in the HUST-PTF system, the beam diagnostic instruments will operate in two modes: debugging mode and treatment mode. These two modes can arbitrary switch. The overview of this two modes is shown in Fig. 1.

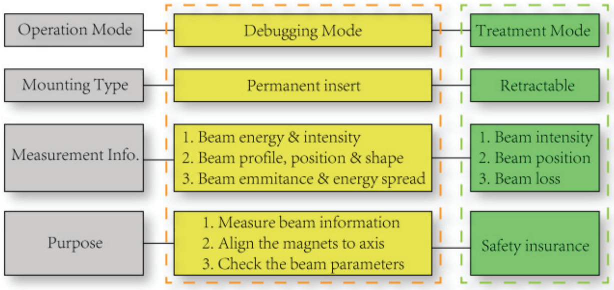

Figure 1: Overview of two operation modes.

Debugging Mode

In the debugging mode, all monitors are retractable and locate at the axis to measure the beam information. Based on the reading data, all dipole and quadrupole magnets can be aligned in the beam line. In addition, the beam envelop is rebuilt to check the beam optics.

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Treatment Mode

For the destructive or semi-destructive instrument, it will create a bit of beam loss and increase the beam divergence angle due to the scattering with the monitor material. To avoid creating much beam loss in the monitors and ensure the safety of treatment, most monitors are retracted from the beam pipe and only a few monitors are reserved to detect beam current and beam loss in real time, and their signals shall be transferred to Treatment Control System (TCS) as a safety interlock.

MONITORS LAYOUT

The beam optics was designed and 1 sigma beam envelope of the beamline was calculated [1], as shown in Fig. 1, by using Transport code [2]. The beam energy and beam current in some key points which corresponds to the points in Fig.2 are listed in Table 2.

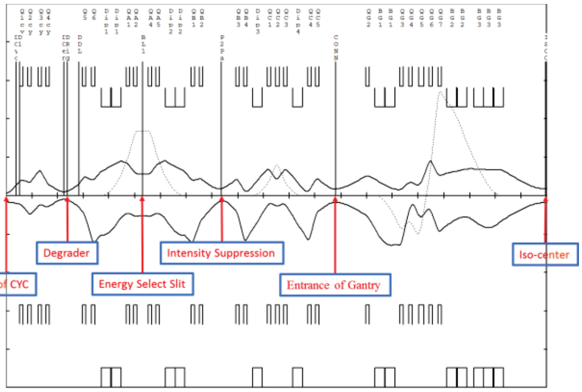

Figure 2: 1 sigma beam envelope for the main beamline including ESS and one gantry beamline (below: horizontal direction, above: vertical direction).

Table 2: Beam Energy and Current in some Key Points

Location	Beam Energy	Beam Current
Exit of CYC	250 MeV	500 nA
Degrader	70-240 MeV	2.65-105 nA
Energy Select Slit	70-240 MeV	0.4-89 nA
Intensity Suppression	70-240 MeV	0.4-4 nA
Entrance of Gantry	70-240 MeV	0.4-4 nA
Iso-center	70-240 MeV	0.4-4 nA

Figure 3 shows the layout of beam diagnostics monitors in the HUST-PTF beamline. The considerations of this layout will be subsequent described in detail. Some considerations have referred to monitors layout in the PSI PROSCAN project [3].

Exit of Cyclotron

At the exit of cyclotron, the designed beam parameters should be checked and acted as the input data of beamline. Beam energy, current, position, emittance and energy spread should be measured. The design specifications of extracted proton beam are listed in Table 3.

Table 3: Design Specifications of Extracted Proton Beam

Parameter	Specification
Beam Energy	250 MeV
Beam Current	500 nA
Emittance	< 5 π-mm-mrad
Energy Spread	< 0.5%

In front of the degrader, a scintillation screen is located to measure the beam position and emittance combined with a set of quadrupoles.

To switch the beam on/off mode in the spot scanning method, a kicker magnet is installed before the degrader. In front of degrader, a faraday cup (FC) locates above the axis 20mm in the treatment mode to collect the dump beam. This also can simultaneously realize the real-time beam current measurement.

In the ESS, the energy spread can be limited and changed for the need of treatment. This value will be fixed during the treatment and offline measured by the Multi-Leaf Faraday Cup (MLFC) after the switch magnet in the debugging mode.

ESS and Intensity Suppression Point

From the Table 2, the proton beam energy and current can be modulated with the help of ESS. In this part, we only measure the beam current and beam position and the beam energy will not be measured for two reasons: 1) The relationship between the thickness of degrader and the modulated beam energy will be tested and measured in advance. 2) The beam energy will be verified by the water tank at the iso-center.

In this region, a set of scintillation screens locate on the two sides of dipole magnet to detect the beam position in the debugging mode. A retractable faraday cup is set before the switch magnet and plays two roles: beam current measurement and beam stopper in the emergence condition which can stop the proton beam within 1s.

Gantry Section

In the gantry section, all instruments will rotate around the axis from −180° to 180°. In our design, the camera is integrated in the mechanical structure of scintillation screen, and the signal will be transferred by the network cable. It may be easily dropped out due to the rotation of gantry and thus it is not suitable to use scintillation screen in this section. Instead, four ionization chambers (IC) from PTC [4] are chosen to detect the beam information: profile, position and current. These ICs are all retractable.

The main specifications [5] of ionization chamber are listed in Table 4.

Table 4: Main Parameters of Pyramid Ionization Chamber

Parameter	**Specification**
Energy range	30 – 500MeV/n
Beam Current Density	10 pA/cm^2-20 nA/cm^2
Sensitive Area	38mm × 38mm
Readout strip geometry	16 strips, equal width 2.38 mm on 2.534 mm pitch.
Vacuum regime	1E-8 mbar
Travel	50 mm, Pneumatic

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 four ICs and two sets of X/Y steering magnets, the beam can be aligned. In addition, a FC is installed in the end of fixed beam line. This plays the same role with FC before the switch magnet. The measurement of beam position and intensity in real time can be realized by three ionization chambers in the treatment head [6], which can detect the beam current, position and dose simultaneously.

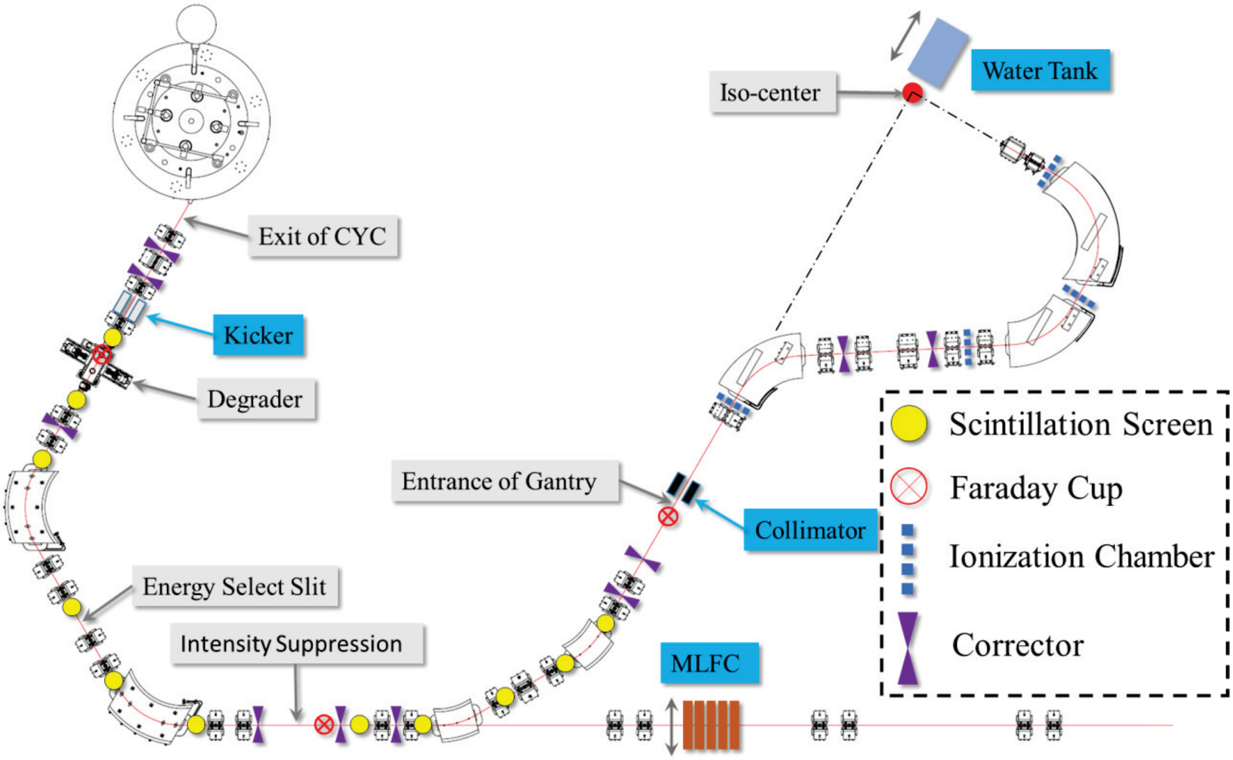

Figure 3: Layout of beam diagnostics monitors in the HUST-PTF beamline.

CONCLUSION AND OUTLOOK

HUST-PTF is a new proton therapy facility, and it's under development now. This paper introduces the primary design of beam diagnostics system in the beamline and presents the layout of monitors in the main beamline including ESS and one gantry. Two operation modes are switched in the commission and running stages. In the debugging mode, beam position, current are mainly detected and the beam parameters at the exit of cyclotron are also measured as the input data of beamline. In the treatment mode, we only detect the beam intensity in the beamline and set three faraday cups as the beam stopper in the emergency condition to ensure the safety of treatment. During the primary design, we only purchase two ICs and one faraday cup for testing, other monitors are still investigated and under design.

In the next stage, the position of monitors and correctors will be modulated and determined according to the calculation of misalignment and correct. The design and selection of monitors will be also completed.

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