ISBN: 978-3-95450-212-7 ISSN: 2673-5482 doi:10.18429/JACoW-CYCLOTRONS2022-WEA006

DEVELOPMENT OF HEAVY ION RADIOTHERAPY FACILITIES IN CHINA*

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Abstract

In China, there are currently 2 carbon facilities in operation, Shanghai proton/heavy ion center and Wuwei heavy ion therapy center, 8 facilities are under construction. This paper will introduce the development of heavy ion radiotherapy facilities in China.

INTRODUCTION

Currently, there are about 19 million cancer cases arise every year and 10 million cases dead from cancer every year globally; these numbers will increase to 29.5 million and 16.4 million at 2040 according to the prediction of IARC (The International Agency for Research on Cancer), with an annual increase rate of 2.4% and 2.6% respectively. In China, whose population is about 20% of the world, there are 4.5 million new cases and 3 million cases dead from cancer every year, which will increase to about 6.7 million and 5.1 million at 2040, with an annual increase rate of 2.2% and 2.9%. Heavy (Carbon) ion radiotherapy offers superior dose conformity in the treatment of deep-seated tumors compared with conventional X-ray therapy due to its Bragg-peak feature of energy deposition, the higher RBE (Relative Biological Effectiveness) and lower OER (Oxygen Enhancement Ratio).

Shanghai Proton Heavy Ion Hospital purchased a heavy ion facility from Siemens in 2008 and began operation in 2015. At present, more than 1000 patients receive treatment every year. Wuwei Heavy Ion Center purchased HIMM (Heavy Ion Medical Machine) facility, which is designed and produced by IMP (Institute of Modern Physics). The construction of the facility was completed in 2019 and was put into operation in 2020. Affected by COVID-19, the number of patients treated in the first year was only 200, but the number of patients treated is increasing every year.

STATUS OF HEAVY ION RADIOTHERAPY FACILITIES IN CHINA

In China, there are 2 heavy ion facilities in operation. They are Shanghai proton and heavy ion center and Wuwei Heavy ion therapy center. There are also 8 facilities under construction, which are Lanzhou Heavy ion therapy hospital, Xuzhou heavy ion center (Hitachi), Mazu Health center, Hubei general hospital, Zhejiang cancer hospital, Jiangsu cancer hospital, The First Bethune hospital of Jilin University, Heyou international hospital (Hitachi). All the heavy ion facilities that are under construction list above are produced by IMP except Xuzhou and Heyou hospital.

HIMM FACILITY DEVELOPED BY IMP

Heavy ion medical machine (HIMM) was constructed on the basis and with the experience gained from the Heavy Ion Research Facility in Lanzhou-Cooler Storage Ring (HIRFL-CSR) project [1]. The facility consists of an electron cyclotron resonance (ECR) ion source, a cyclotron injector, a compact synchrotron ring, and 5 treating terminals [2]. The C^{5+} beam generated by the ECR ion source is accelerated by the cyclotron to 6.2 MeV/u and then injected into the synchrotron using the CEI (charge exchange injection) method [3]. The injected beam is accelerated from 6.2 MeV/u to an extraction energy ranging from 120 to 400 MeV/u.

Figure 1 shows an aerial view of the HIMM. The facility consists of four treatment rooms, A, B, C, and D. Five fixed irradiation ports are installed in the rooms: horizontal, horizontal plus vertical, vertical, and 45° irradiation ports. Active scanning is conducted in Room A, while passive scanning is adopted in the other rooms. The maximum irradiation field at the tumor is 200 × 200 mm^2 for all the irradiation ports.

Unlike other cancer therapy machines, the HIMM synchrotron uses a cyclotron as the injector. The beam intensity of the cyclotron injector is approximately 10 μA, and the emittance of the beam is approximately $25\,\pi \cdot \mathrm{mm} \cdot \mathrm{rad}$ ($\pm 3\sigma$). Compared to the linear injector, the beam intensity is much weaker and the beam emittance is much larger. To store enough particles in the ring, the CEI method is adopted. This method overcomes the limitations set by Liouville's theorem so that beams can be injected at the point of phase space already occupied by previously injected beam. Therefore, an intense beam can be accumulated in the ring without increasing the beam emittance too much. In addition, the injected beam can be painted in the horizontal phase space by changing the local closed orbit during injection to reduce the probability the particles hit the stripping foil, thus increasing the injection efficiency. This scheme has been proved to be very efficient in the CSRm for light-heavy ions.

The beam orbit and envelopes during injection are shown in Fig. 2. Four bump magnets (Bpi1-Bpi4 in Fig. 1) are used to sweep the closed orbit of the circulating beam. Special vacuum chambers with large aperture are used at magnets located in the injection section. C^{5+} beam with an energy of 7 MeV/u from the cyclotron injector are injected into the synchrotron at a small angle (1.85°) and then reach the stripping foil, by which they are stripped to C^{6+}. The stripping

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23rd Int. Conf. Cyclotrons Appl. CYCLOTRONS2022, Beijing, China JACoW Publishing
ISBN: 978-3-95450-212-7 ISSN: 2673-5482 doi:10.18429/JACoW-CYCLOTRONS2022-WEA006

Figure 1: Aerial view of the HIMM

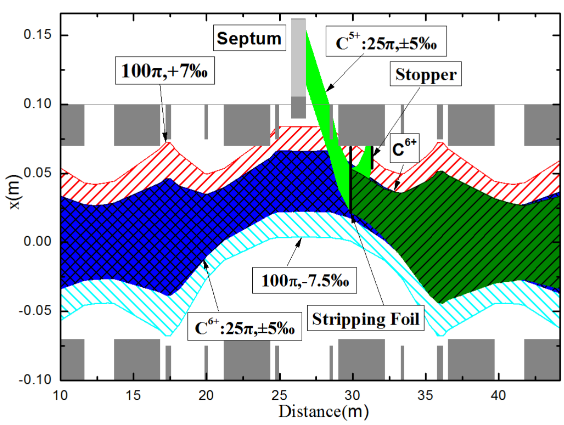

Figure 2: The beam orbit and envelop during injection

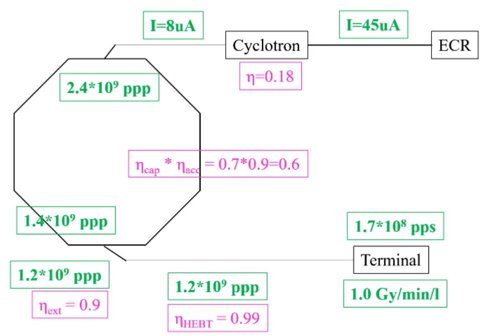

Figure 3: The beam intensity in the whole facility

foil is located 0.84 m away from the entrance of the main dipole with a thickness of 20 µg/cm^2.

The RF-KO (radio frequency knockout) [4] method is widely used for third-order resonant extraction because it has many advantages over other methods, such as a fast response to beam-on/off signal, the production of static target beam spots during extraction, the ability to easily control the spill intensity and the ability to keep the lattice of the synchrotron constant.

The beam commissioning is finished in 2018 [5] and the the beam intensity of the whole facility is shown in Fig. 3.

Besides the part of the accelerator, the typical equipment in the treatment room is shown in Fig. 4 as an example. There are 2 nozzles in this room, one is horizontal, another is vertical. The robot coach, CT (Computed Tomography), and DR (Digital Radiography) are the standard configuration in the treatment room. The TPS (Treatment Planning System), which is based on Simplified Monte Carlo algorithm, is configured. The features such as optimization engine based on GPU (Graphics Processing Unit), supporting multiple biophysical models and multiple particle types, dose comparison among multiple radiation treatment devices (X ray, proton, helium, carbon, and so on) are included.

Figure 4: A typical treatment room

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