SUB-mm THERAPEUTIC CARBON-ION IRRADIATION PORT IN GUNMA UNIVERSITY

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Abstract

Gunma University Heavy-Ion Medical Center (GHMC) has started carbon-ion cancer therapy on March 16, 2010. 92 patients are experienced the carbon-ion therapy in 2010. The GHMC accelerator complex is composed of electron-cyclotron resonance (ECR) ion source, RF-quadrupole (RFQ) linac, alternating phase focusing (APF) linac, and synchtrotron. There are three treatment rooms and four therapeutic beam extraction port for medical use. For future carbon therapy, an optional beam extraction port is prepared. The design of this beam port is aimed to generate a "sub-mm" scanned carbon beam. The beam transfer design and beam optics is presented in this report.

OVERVIEW

Gunma University has started to construct a carbon-ion irradiation facility (Gunma University Heavy-ion Medical Center, GHMC) from 2006. Building of the GHMC was completed in November 2008, and started carbon ion therapy from Merch 16, 2010.

The main target of constructing the GHMC, as national project with collaboration of the National Institute of Radiological Sciences (NIRS), is to establish "compact carbon ion therapy facility". There are major two improvements for compact facility design: one is the shortening the APF linac [1], and the other is the compact designing of the synchrotron [2]. Figure 1 and Table 1 shows the schematic view of the GHMC facility and the GHMC accelerator specifications. For reaching a patient's target depth of over 25cm water equivalent, maximum accelerated beam energy is set to 400 MeV / nucleus.

The accelerated beam is slowly extracted by using 3rd resonance (5/3). The GHMC synchrotron can storage 3E9 carbon particle and extraction duration time is 1sec. There are three treatment rooms in GHMC: the room A serves horizontal beam, the room C serves vertical beam. The room b serves both horizontal and vertical beam. The combination design of treatment room and the beam ports is decided for making the high energy beam transfer line compact and for serving the each treatment room as backup of horizontal or vertical irradiation task, when any equipment of irradiation port gets trouble in one of the treatment rooms.

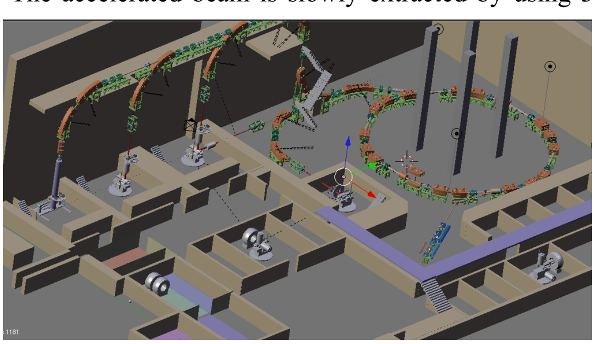

Figure 1: Schematic View of Gunma University Heavy-Ion Medical Center.

Figure 2: Synchrotron of Gunma University Heavy-Ion Medical Center.

Table 1 : GHMC Accelerator General Specifications

Ion Source Type	ECR
ECR Operation Frequency	10GHz
Ion Current	200 uA
Injector	RFQ linac / APF linac
Linac Operation Frequency	200MHz
Circumference	63.3 m
Injection Energy	4 MeV/u
Lattice Type	FODO Lattice
Superperiod	6
Charge of Carbon Ion	4+(@4MeV/u), 6+(@synchrotron)
Average Radius	9.75m
Tune(Qx, Qz)	(1.68, 1.25)
Repetition Time	2.8 sec
Vacuum	~10^{-7} Pa
Maximum Beam Energy	400MeV/u (Z/A=1/2)

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In practical medical treatment, currently applied beam irradiation methods are 1: simple circular wobbling method, 2: spiral wobbling method.

EXPERIMENTAL PORT DESIGN

The GHMC has an experimental vertical irradiation port, room D, for physics and biological research with scanned carbon ion beam. As future plan, the room D can utilized for precise carbon ion therapy with refurbishing.

Required Specification

The purpose of room D is focused on generating small size beam and wide irradiation field by spot scanning irradiation method. A required beam size is 1(mm) (1-sigma) with beam emittance of 0.3 (πmm-mrad), and irradiation field of 150(mm) x 150(mm). The beam transfer line of the GHMC is not achromatic lattice, and usual treatment beam (room A-C) is irradiated with divergent angle. In order to satisfy conflict specification request, the lattice of room D was designed similar to the "half of a hadron beam colliding section": this lattice equips strong focusing quadruplet and long straight line. Thus designed betatron function at isocenter is $\beta_{iso} = 0.5$ (m), and maximum betatron function must not be exceed 200(m). The position of last quadrupole magnet is restricted by aperture of the transfer line of $r < 75$ (mm), maximum quadrupole field gradient of 19.1 (T/m) and longitudinal length of 400 (m), longitudinal distance from an end of final bending magnet to the isocenter of 9.0 (m) under the condition of the betatron function through a drift tube $\beta_x = \beta_{iso} + s^2 / \beta_{iso}$.

Arrangement of Lattice Elements

In order to ensure the beam size, the betatron function must be largely expanded first, and then strongly focused. The point of the maximum betatron function is set to within the quadruplet. The maximum betatron function should be 150 (m), therefore the betatron function at entrance of the quadruplet must be around 50 (m) with divergent angle both x and y direction, with dispersion = 0 (m). As for keeping the irradiation field and inserting the beam handling device (range shifter, ridge filter, and beam monitors), the end position of the scanning magnet is set to 3000mm above from the isocenter. A exterior of the irradiation port is shown in Figure 3 and designed

Figure 3: Irradiation Port of the Room D in GHMC.

geometrical arrangement of the lattice elements referred above is shown in Figure 4.

Modification of Existing Beam Line

The aligned quadrupoles through the beam transfer line is limited a monopolar excitation, because the basic design of the transfer line is fixed before examining the room D specification requirement. Therefore a consistent beam transfer line discussed above without modifying the lattice element or power supply must be found. Fortunately, the consistent magnet excitation pattern without modification was found. The derived betatron function is shown in Figure 5 and Figure 6.

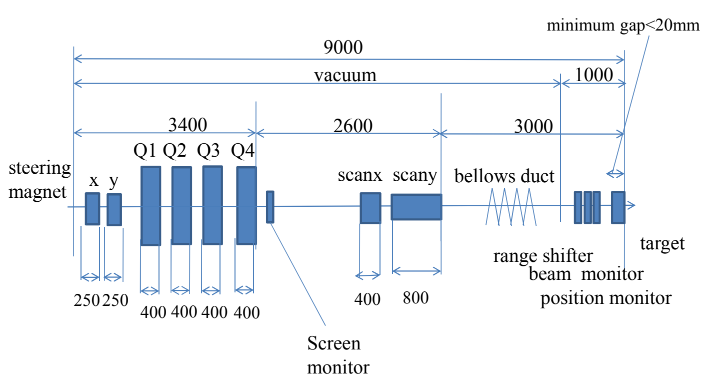

Figure 4: Geometrical Design of Irradiation Section in room D at GHMC.

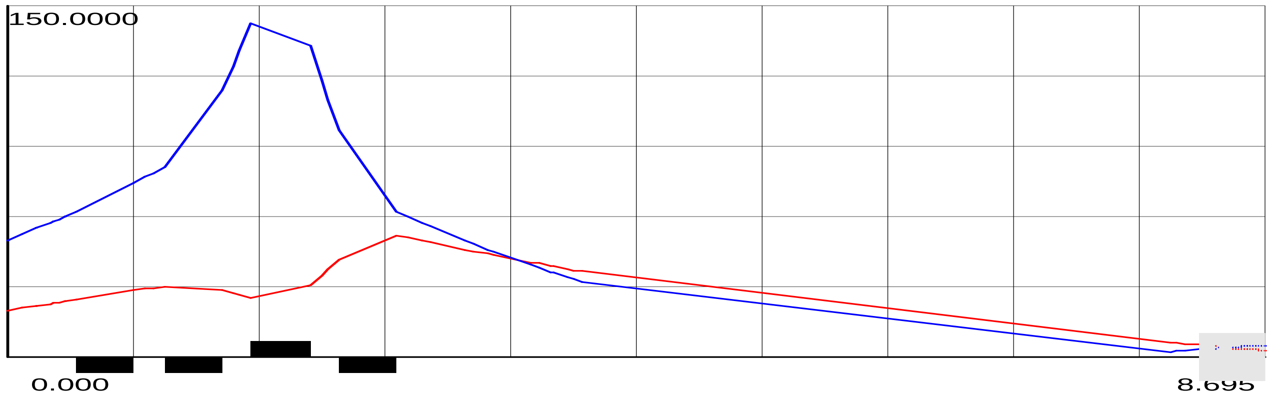

Figure 5: Final Focusing Design at Room D in GHMC.

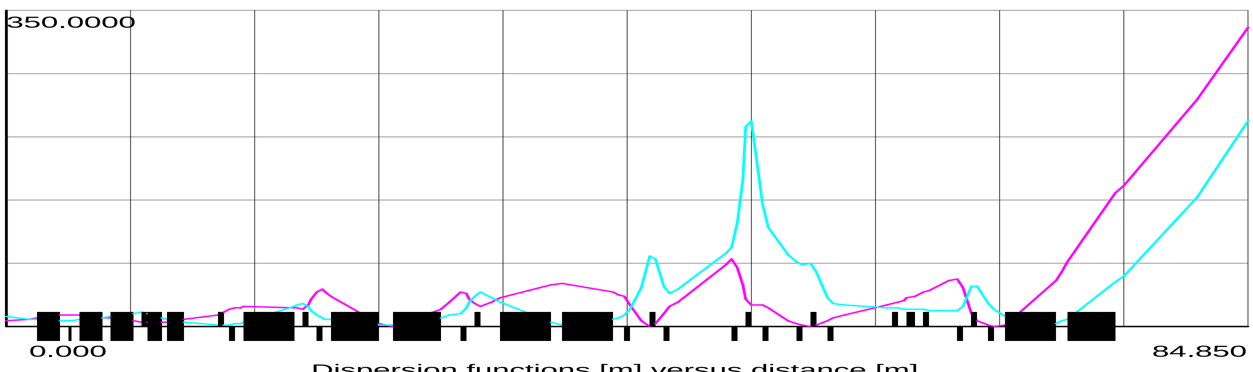

Figure 6: Modified Betatron Function from ESD Septum to Final Bending Magnet.

CONCLUSION

The irradiation test port at room D was designed and constructed. After a beam commissioning, physics and biological experiments will be started.

REFERENCES

[1] Y. Iwata, T. Fujisawa, S.Hojo et al., "IH-DTL AS A COMPACT INJECTOR FOR A HEAVY-ION MEDICAL SYNCHROTRON", Proceedings of LINAC08, Victoria, pp.715-719.

[2] T.Furukawa, K. Noda, K. Yoshida et al., "Design of synchrotron and transport line for carbon therapy facility and related machine study at HIMAC", Nuclear Instruments and Methods in Physics Research A 562 (2006) pp.420-422.