BEAM TRACKING ON THE HIGH ENERGY BEAM TRANSPORT LINE IN KHIMA MEDICAL MACHINE

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Abstract

The Korea Heavy Ion Medical Accelerator (KHIMA) launched the synchrotron based hadron beam therapy facility for combined medical cancer treatment and cancer related research. The Korea Institute of Radiological & Medical Sciences (KIRAMS) synchrotron system has been designed to accelerate the particle beams having the kinetic energy interval of 60-230 MeV proton and 110-430 MeV/u carbon ions respectively. An accelerated beam from the synchrotron is transported to the patient position through the High Energy Beam Transport (HEBT) lines. In the HEBT lines, the lattice was designed with beam optics codes. In order to check and confirm the beam loss at the HEBT lines, the tracking code, TRACK, has been used with encoded field map and also with simulated field map by Opera3D code. The performances are described and also compared with two methods for manufacturing the components in the HEBT lines.

INTRODUCTION

The Korea Heavy Ion Medical Accelerator (KHIMA) project at the Korean Institute of Radiological And Medical Sciences (KIRAMS) has proceeded the development of an accelerator based on synchrotron with multi-ion sources for various cancer treatements. The synchrotron is designed to accelerate the proton beam (the carbon ion, $^{12}C^{6+}$, beam) from 60 MeV (110 MeV/u) to 230 MeV (430 MeV/u). These energy ranges cover the penetration depth of 3.0 cm to 31.0 cm in water. A schematic layout of the accelerator centre is shown in Fig. 1. At the Electron Cyclotron Resounce

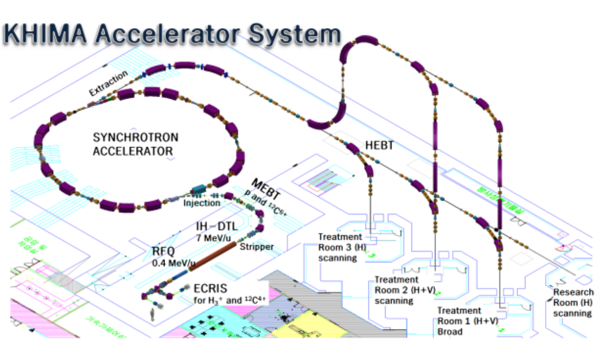

Figure 1: A schematic layout of KHIMA accelerator system including each clinical and research rooms.

Ion Source (ECRIS), ions with a charge to mass ratio q/m = 1/3, either H_3^+ or $^{12}C^{4+}$, are generated up to 8.0 keV/u. These ions are accelerated up to 7 MeV/u through Radio Frequency Quadrupole (RFQ) linac and Interdigital H-mode Drift Tube Linac (IH-DTL). At the beginning of Medium Energy Beam Transport (MEBT) two corresponding ions are selectively stripped and fully ionized to either proton or $^{12}C^{6+}$, then are transported to the synchrotron being accelerated up to designed energies. Each ion is injected into the synchrotron by multi-turn injection mechanism, accelerated by switching the RF system and extracted into High Energy Beam Transport (HEBT) line by slow resonance extraction scheme [1, 2].

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BEAM OPTICS SIMULATION

Three medical treatment rooms and one research oriented irradiation room are prepared for the centre. The HEBT lines thus compose the 6 different transport branches with 4 horizontal- and 2 vertical-lines as shown in Fig 1. A slowly extracting beam through electrostatic septum magnet in the synchrotron ring is to be selectively transported into each treatment room. The HEBT lines are based on a modular design considering the strong asymmetry between two transverse beams. The trapezoidal distribution of the horizontal beam profile is taken into account. For horizontal beam in phase space, the bar of charge is applied to manage an independent control of the horizontal beam size by rotating the bar in an unfilled ellipse [3], while the Gaussian shaped beam distribution is considered in the vertical beam profile.

Horizontal Beam Lines

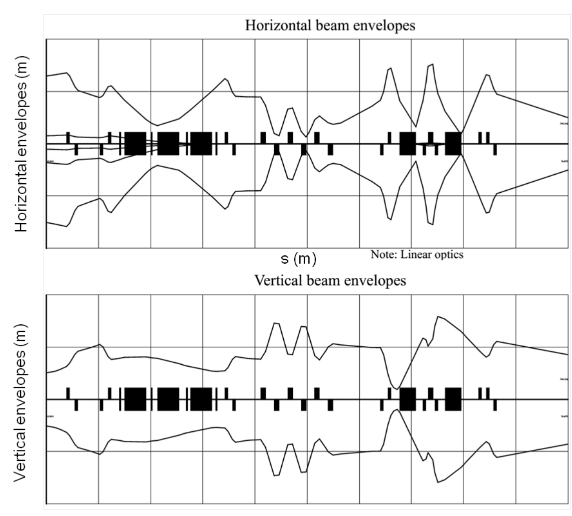

Figure 2: Beam envelope for the 3rd Horizontal (H3) line by WinAgile code, where Λ_y = 9 mm with E = 110 MeV/u carbon beam at the iso-center is set.

The common module downstream two successive magnetic septum magnets in the horizontal common line is interleaved for controlling beam size at the iso-center. This module has an important advantage for commissioning and operation. The vertical beam size at the iso-center is controlled by the vertical β function. In order to fulfil the requirements, the module can be tuned to provide the variable values among $2 < \beta_y < 27$ m with $\alpha_y = 0$ at the iso-center. As a variable component, a continuative arranged 6 quadrupole magnets in the common line are used. This composition of consecutive six quadrupole magnets functions as a phase shifter on the horizontal plane and while as a stepper on the vertical plane. As shortest one of the horizontal lines, Fig. 2 shows the envelope distributions up to iso-center at the 3rd-treatment room through the horizontal H3 line.

BEAM TRACKING SIMULATION

After designing a lattice structure of the HEBT line with WinAgile [4] or MAD-X [5] codes which are based on the matrix method, each HEBT line is simulated by using the tracking code TRACK [6]. The TRACK code is conducted to check and confirm the beam loss with encoded field map or with simulated field map by Opera3D code in the HEBT lines.

Method Using Encoded in TRACK Code

At the hard edge model, the fringe field falloff for dipole and multipole elements is used to be ignored. The TRACK code utilizes the encoded six-parameter Enge function [7] to include the parasitic fringe field components. The Enge function is described as [8]:

$$F(z) = \frac{1}{1 + exp(a_0 + a_1(z/D)^1 + ... + a_5(z/D)^5)} \quad (1)$$

where z is the distance along the line that is perpendicular to the effective bounday, D is the full air-gap of the element. A beam envelope distribution with respect to the reference orbit for both horizontal and vertical plane is shown in Fig. 3. The value of Full Width at Half Maximum (FWHM: Γ_y) seems much smaller than the estimated one obtained by optics code WinAgile as shown in Fig. 4.

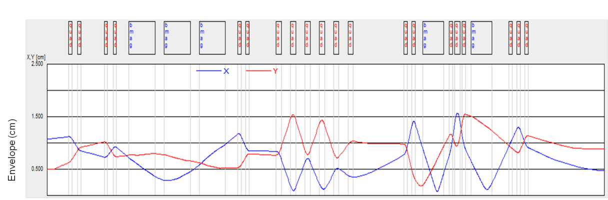

Figure 3: Beam envelope for the 3rd Horizontal (H3) line by using the encoded fringe field falloff, where $\Gamma_y = 9$ mm with E = 110 MeV/u carbon beam at the iso-center is estimated by optics code.

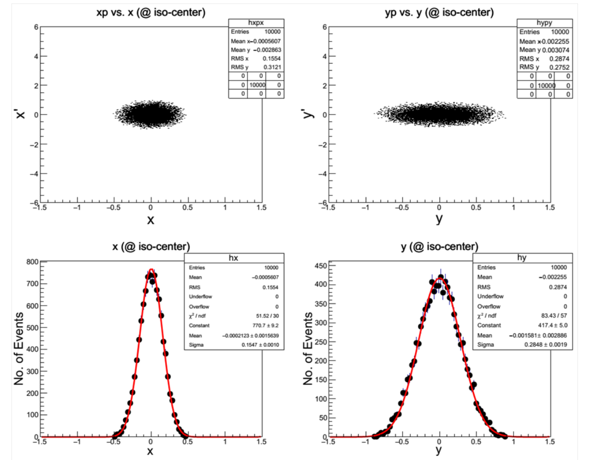

Figure 4: Particle distributions at the iso-center (top) in phase space and (bottom) in projected one.

Method Using Real 3 Dimensional Field Map

The determined specifications of dipole and quadrupole with beam optics code are realized with Opera3D code. The Fig. 5 shows the distributions of field map for 3 different bending angles 22.5, 30 and 45 deg. in the HEBT lines.

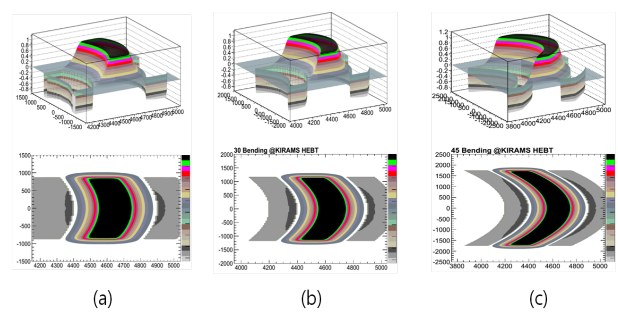

Figure 5: 3 dimensional field map distributions with Opera3D for (a) 22.5 deg., (b) 30 deg. and (c) 45 deg. respectively.

The envelope distribution with applying the real field map to TRACK code is shown in Fig. 6. Even though the realized field map is applied, the FWHM value at the iso-center is still inconsistant with expected one. A various methods are considered but the one of field scaling factor is most appropriate in the H3 line. The performance between before and after correction is shown in Fig. 7. Based on this analysis, the tracking analysis are successfully conducted through other beam lines on HEBT. The beam transport to the iso-center through each line is thus well operated with suitable and variable magnet components without beam loss.

CONCLUSION

The HEBT lines are based on the modular design considering the strong asymmetry between two transverse emittances and depend on the trapezoidal distribution of the beam in horizontal phase space. The KHIMA HEBT line has been

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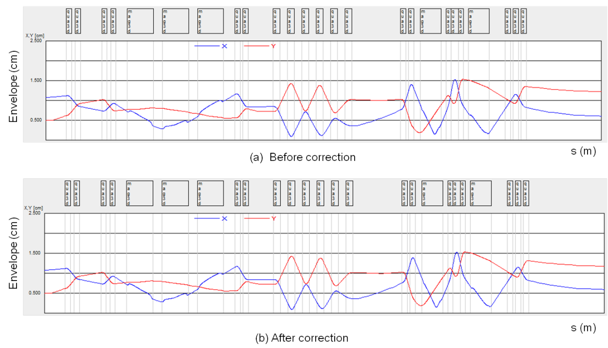

Figure 6: Beam envelope for the 3rd Horizontal (H3) line by using real 3 dimensional field map by Opera3D code, where Γ_y = 9 mm with E = 110 MeV/u carbon beam at the iso-center is set.

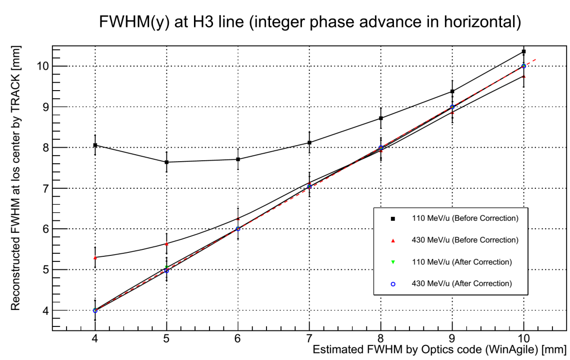

Figure 7: FWHM distributions with respect to the estimated one by optics code (WinAgile) at iso-center before and after correction in the minimum and maximum energy of carbon beam.

originally designed using the WinAgile/Mad-X codes for the whole beam lines up to each treatment room. In order to confirm the design by optics code and minimize the beam loss in the transport line, the tracking analysis by TRACK code has been conducted. The layout design based on the optics codes are fixed with suitble correction method. The designed beam line is expected to be constructed in near future.

ACKNOWLEDGMENT

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REFERENCES

[1] Heejoong Yim *et al.*, J. Korean Phys. Soc. **67**, 1364(2015).

[2] M. Benedikt *et al.*, Nucl. Instrum. Methods Phys. Res. A **430**, 523 (1999).

[3] M. Benedikt, “Optics design of the extraction lines for the MedAustron hadron therapy centre”, Nucl. Instrum. Methods A 430 **512-522** (1999).

[4] P. J. Bryant, AGILE program for synchrotron lattice design, `http://nicewww.cern.ch/~bryant`

[5] F. Schmidt and H. Grote, “MAD X an update from MAD8”, Proc. Part. Acc. Conference, Portland, U.S.A, 12.-16.5, **3497** (2003).

[6] P. N. Ostroumov and K. W. Shepard, Phys. Rev. ST. Accel. Beams 11, 030101 (2001).

[7] H. A. Enge, Rev. of Sci. Instr. **35**, 278 (1964).

[8] P. N. Ostroumov, V. N. Aseev, and B. Mustapha, “TRACK - a Code for Beam Dynamics Simulation in Accelerators and Transport Lines with 3D Electric and Magnetic Fields”, Technical Note (ver. 3.7), Mar. 2007, pp. 6.