BEAM ALIGNMENT PROCEDURE FOR SCANNED ION-BEAM THERAPY

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Abstract

It's important to control the beam position for the 3D pencil-beam scanning because the position accuracy of the beam has a serious matter on the alignment of the irradiation field. In order to suppress this matter, we have been developed a simple procedure for the beamline tuning. The fluctuation of the beam position is tuned with the steering magnets and bending magnets with monitoring the beam positions using the fluorescent screen monitors. After the tuning, the beam position at the isocenter is checked on the verification system which is consists of the screen monitor and the acrylic phantom. These adjustments are iterated until the deviation for all energies of the beam are within 0.5 mm. We had been performed the beam commissioning using our procedure in Kanagawa Cancer Center.

INTRODUCTION

Heavy-ion beams such as carbon-ion beams are superior in terms of high dose localization and biological effect around the Bragg peak. Three-dimensional (3D) pencil-beam scanning is an ideal irradiation technique to use these fundamental advantages [1]. In 3D pencil-beam scanning, extremely precise dose distribution could be deliver to the tumour since beams interact only with a low material budget in the beamline. Misalignment of the beam position at the patient position causes discrepancy between irradiated dose distribution and prescribed dose distribution. The difference of dose distribution increases unwanted dose to normal tissue. Thus, beam adjustment is important, periodically check of beam position is necessary. We have been developed a simple procedure for beam adjustment.

Adjustment of the beam transfer line is performed by steering beam position to the central orbit. There is difference between central orbit and the reference axis in the treatment room. The reference axis is defined with the acrylic phantom that steel sphere is embedded. The reference axis is called isocenter. Coordinate axes of the CT image and X-ray image are adjusted to the isocenter as well as beam position. All devices concerning patient setup have to be adjusted against the isocenter in order to deliver accurate dose distribution to the tumour. In this paper, we report our beam alignment procedure which we applied to beam transfer line in Kanagawa Cancer Center.

A compact dissemination treatment system of carbon-ion therapy had been constructed at Kanagawa Cancer Center. The carbon-ion scanning system which is designed by National Institute of Radiological Sciences had been installed. We are undertaking the commissioning to start treatment in December this year.

BEAM ALIGNMENT METHOD

A layout of high energy beam transfer line in Kanagawa Cancer Center is shown in Fig.1. Carbon-ion beams extracted from the synchrotron are transported to four treatment rooms. Two treatment rooms have a horizontal beamline, other two rooms have horizontal and vertical beamlines. In the beam transfer line, some fluorescent screen monitors (SCN) are installed for monitoring beam position and profile. Center of a beam profile is moved to central position at each screen monitor.

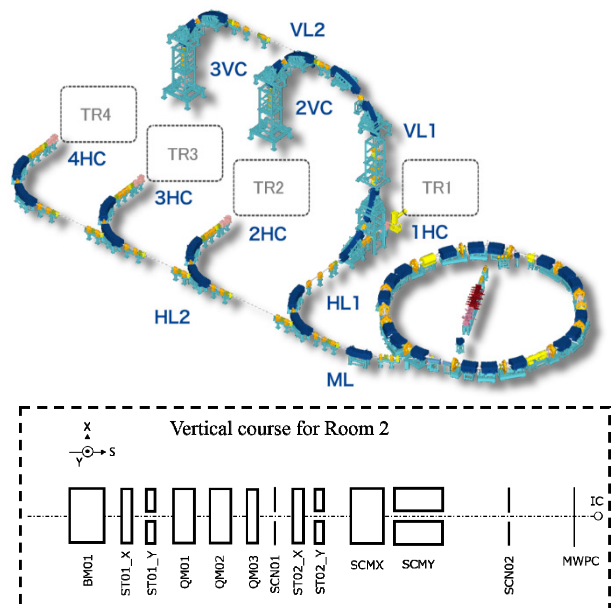

Figure 1: A layout of high energy beam transfer line in Kanagawa Cancer Center. The beamlines are composed of the horizontal and vertical beamlines. A figure surrounded with dotted line is configuration of magnets and SCN on the vertical beamline for Room 2.

In our beam alignment method, we basically steer the beam position using steering magnets. If deflection angle of steering magnet is large, beam position is steered with bending magnet. Since beam duct aperture is most narrow at the bending magnet for deflecting the beam toward upstairs or downstairs, beam adjustment of vertical beam line is performed before the adjustment of horizontal beam line. If the beam position is tuned at upstream SCN,

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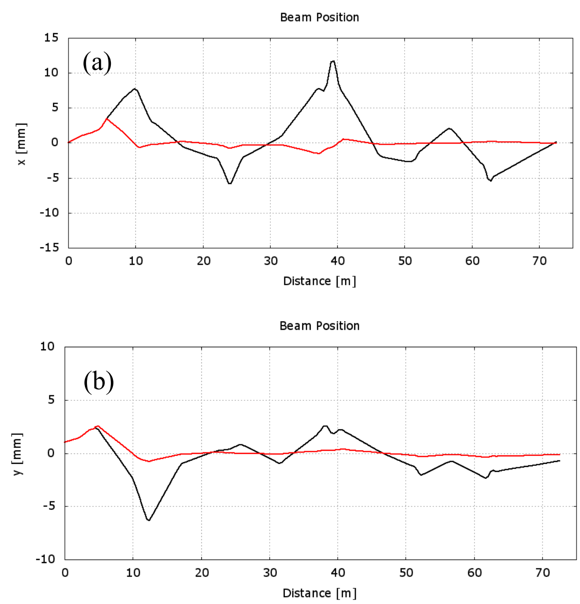

Figure 2: Simulation results of beamline tuning of vertical course for Room2. Horizontal (a) and vertical (b) beam's trajectories are shown. The beam's trajectories before the beamline tuning (Black) and after the beamline tuning (Red) are shown.

we tune the beam position at downstream SCN using a pair of steering magnets which are placed behind of upstream SCN. This rule is to converge beam's trajectory to central orbit. If this rule is applied for tuning, it is required that the distance between downstream SCN and steering magnet is shorter than the distance between upstream steering magnet and SCN [2].

Excitation current of steering magnet for beam adjustment could be calculated if we know strength of the quadrupole magnet and distance of drift space and length of magnet. In Fig. 1, an illustration surrounded with a dotted line represents configuration of magnets and SCNs on the downstream of the vertical beamline. A pair of steering magnets are placed at downstream of the bending magnet. One of the SCN (SCN01) is placed at downstream of the triplet quadrupole magnets. Another pair of steering magnets (ST01) are placed behind of SCN01. Another SCN (SCN02) is placed at downstream of scanning magnets. Multi wire proportional chamber (MWPC) is placed just upstream from isocenter. In this beamline, transfer matrix equation from ST01 to SCN01 is as follows:

$$\begin{bmatrix} \Delta x_{SCN01} \\ \Delta x'_{SCN01} \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \begin{bmatrix} x_{ST01} \\ \Delta x'_{ST01} \end{bmatrix}$$

where $\Delta x'_{ST01}$ is deflection angle of ST01, Δx_{SCN01} is the measured beam position at SCN01, m_{11}~m_{22} are the transfer matrix elements. The deflection angle ($\Delta x'_{ST01}$) generates deviation of beam position at SCN01 (Δx_{SCN01}). Required deflection angle of ST01 is calculated from measured beam position at SCN01 using the following expression:

$$\Delta x'_{ST01} = -\Delta x_{SCN01} \,/\, m_{12} \,.$$

The last steering magnets (ST02) are tuned by deviation of beam position at SCN02 and $\Delta x'_{ST01}$ in a similar way. Moreover, ST02 are also tuned by deviation of beam position at MWPC. These deflection angles of steering magnets are converted to electric current with measured coefficient.

Figure 2 shows the simulation results when this procedure is applied for beamline tuning. The beam's trajectory could be converged to the central orbit. In this simulation, error incident angles to the transfer line (~0.1 mrad) and error deflection angles (~10^{-3}%) of bending magnets were assigned. In the vertical axis, error of incident position (1 mm) was assigned.

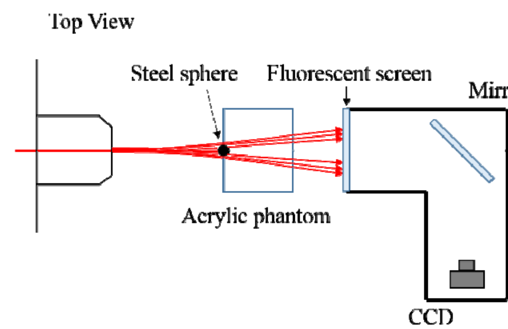

Figure 3: Configuration of the verification system. Light emissions are detected by CCD camera via 45 degree rotated mirror.

Eleven energies (430~140 MeV/u) could be provided due to multiple synchrotron operation. Beamline tuning is carried out for eleven energies, respectively.

Beam position is fluctuated by several factors such as fluctuation of extracted angle from a synchrotron and fluctuation of the excitation current of bending magnet. For every days tuning, it is important to know the magnitude of fluctuation of the beam position. Especially, fluctuation of beam position at MWPC is important. If the magnitude of fluctuation of the beam position is small, every days tuning will be performed only with most downstream steering magnets.

VERIFICATION OF BEAM ALIGNMENT

The measurement for verification of isocentric beam alignment is carried out after the beamline tuning. Figure 3 shows the setup of isocentric beam alignment verification. Verification system consists of acrylic phantom and fluorescent screen monitor which is located behind of the acrylic phantom [3]. Screen monitor is consists of fluorescent screen with terbium-doped gadolinium oxysulfide (Gd2O2S2:Tb) and high-speed 8-bit CCD camera (Type XG-H035M, KEYENCE, JAPAN). Mirror is placed at 45 degree to the beam direction for protecting the camera from radiation damage. The spatial resolution of screen monitor is about 0.2 mm/pixels.

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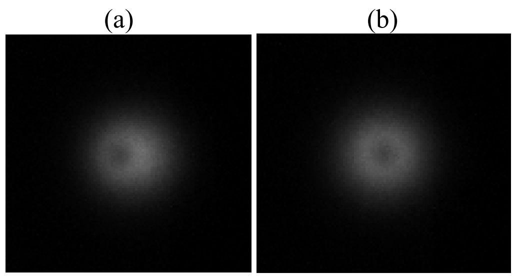

Figure 4: Beam spot images before the beamline tuning (a) and after the beamline tuning (b).

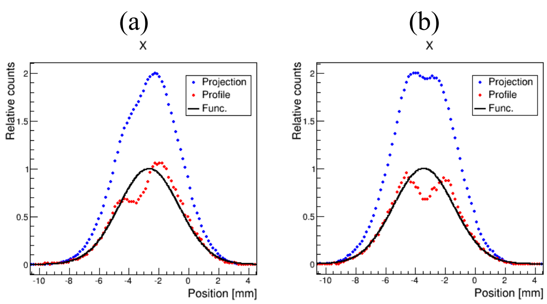

Figure 5: The beam profile before the tuning (a) and after the tuning (b). The red points show normalised line profile. The blue points show normalized projected image. The black line shows the 2D Gaussian distribution.

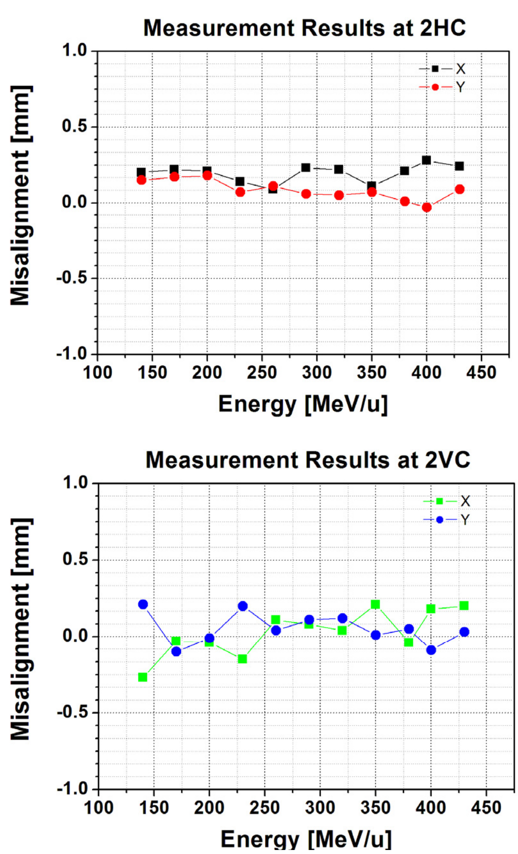

Figure 6: Measurement results of the beam misalignment.

A steel sphere (Ø=2.0 mm) is embedded in the surface of this phantom, and its position is on the reference axis.

Density of steel sphere is larger than that of acrylic. Beams which passed through the steel sphere are more scattered than beams which passed through the acrylic [4]. Thus, the difference of fluence generates a shadow at downstream of steel sphere as shown Fig. 4. Misalignment can be measured as a position difference between centroid of the beam spot and the center of the shadow. The center of the shadow is derived as a centroid of different map between original image and 2D Gaussian distribution. Standard deviations of horizontal and vertical projected image are used as sigma of 2D Gaussian distribution. In the Fig. 5, line profile of beam spot image and 2D Gaussian distribution are represented. The projected image is also represented. These profiles are normalized with maximum value of 2D Gaussian distribution. Excitation currents of steering magnets which are placed most downstream are calculated using measured deviation between the beam spot and shadow. Figure 4 (a) shows the beam spot image before the beamline tuning. The deviation between the beam spot and the shadow is observed. Figure 4 (b) shows the beam spot image after the tuning. The position difference between beam spot and shadow is smaller than that before beamline tuning. If the deviation is over the tolerance of 0.5 mm, beamline tuning is performed again. These adjustments are iterated until deviations for all energies are within 0.5 mm. Figure 6 shows measurement results of beam misalignment at horizontal and vertical course after the tuning. Finally, it was confirmed that misalignments are within ±0.5 mm for all energies.

CONCLUSION

We applied our adjustment procedure to beam transfer line in Kanagawa Cancer Center. Beam positions were tuned at each screen monitor until the deviations are within 0.5 mm. After the beamline tuning, isocentric beam alignment was verified with an acrylic phantom and screen monitor. It was confirmed that misalignments are within ±0.5 mm for eleven energies.

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