Dose calculation model using the simplified Monte Carlo method with an initial beam model adapted to a beam-wobbling system

[Purpose] A simplified Monte Carlo (SMC) method was successfully implemented to a treatment planning system of National Cancer Center Hospital East (NCCHE) for a double-scattering beam delivery system [1]. We intend to extend the SMC method to a beam-wobbling delivery system at the NCCHE. A lateral dose distribution in one direction (x-direction) is observed to be different from that in other direction (y-direction) perpendicular to the x-direction for a proton beam traversing the beam wobbling system. It is clear that such an asymmetry cannot be reproduced by the initial beam model symmetric with x- and y-directions, which is assumed in the pencil beam algorithm (PBA) [2] and the SMC method applied to the double-scattering system [1]. We have developed an initial beam model adapted to the beam-wobbling system to reproduce the different dose distributions in x- and y-directions accurately using the SMC with the improved initial beam model.

[Materials and Methods]

1. An initial beam model adapted to the beam-wobbling system

When wobbler magnets are off, a distribution function of protons in an initial phase space at a point of interest (POI), \( f_{wob,off}(x, y, \theta_x, \theta_y) \), is described as

\[
f_{wob,off}(x, y, \theta_x, \theta_y) = \frac{1}{2\pi\sigma_{11}\sigma_{22}(1-r^2)} \exp \left\{- \frac{1}{2} \left( \frac{x^2}{\sigma_{11}} + \frac{(\theta_x - \alpha x)^2}{\sigma_{12}(1-r^2)} \right) \right\} \exp \left\{- \frac{1}{2} \left( \frac{y^2}{\sigma_{11}} + \frac{(\theta_y - \alpha y)^2}{\sigma_{22}(1-r^2)} \right) \right\}
\]

(1)

where \( \sigma_{11} \) is the projected spatial variance, \( \sigma_{12} \) is the projected spatial-angular covariance and \( \sigma_{22} \) is the projected angular variance. When wobbler magnets are on, the distribution function, \( f_{wob,on}(x, y, \theta_x, \theta_y) \), is expressed by integrating the \( f_{wob,off} \) along the wobbling trajectory as

\[
f(x, y, \theta_x, \theta_y) = \frac{1}{2\pi} \int_0^{2\pi} d\phi f_{scl}(x - R_{wx}\cos\phi, y - R_{wy}\sin\phi, \theta_x - \frac{R_{wx}}{L_{wx}} \cos\phi, \theta_y - \frac{R_{wy}}{L_{wy}} \sin\phi)
\]

(2)

where \( R_{wx} \) and \( R_{wy} \) are axis lengths in x- and y-directions of the ellipse orbit that the beam center draws by being kicked by the wobbler magnets, respectively. \( L_{wx} \) and \( L_{wy} \) are distances between the POI and the center of wobbler magnets giving a kick in x- and y-directions, respectively.

2. Experimental arrangements

Fig.1 shows an arrangement for a series of experiments to verify the accuracy of our calculation method. We used a 235 MeV modulated proton beam with a SOBP width of 60 mm passing through an acrylic range shifter of 60 mm in thickness. We sandwiched a 2D...
Array seven29® between polyethylene plates and measured the lateral dose distribution. The thickness of the upper plates is varied from 0 mm to 152 mm. We used two types of L-shaped range compensator: the one has an L-shaped structure in the x-direction and another has the same structure in the y-direction. We performed a series of experiments using one of them and another series of experiments using other of them.

[Results and conclusion]

Fig. 2 shows comparisons between the measured dose distributions in x- and y-directions and calculated ones when polyethylene plates with a total thickness of 35 mm are mounted on the detector. We observed that measured dose distributions in the x-direction are smoother than that in the y-direction in the central region. The difference can be attributed to the larger angular spread of incident protons in the x-direction compared with that in the y-direction. In addition, the local dose increments are observed in the edge region. We found that protons scattered on the surface of the aperture collimator contribute to the dose increments. In conclusion, the SMC method with an initial beam model adapted to the beam-wobbling system can reproduce the measured asymmetric dose distributions well.

Fig. 2 Comparisons between the measured dose distributions in x- and y-directions and calculated ones when polyethylene of 35 mm in thickness is mounted on the detector

(○ measurements ——calculations """"calculations (edge-scattered protons excluded))
