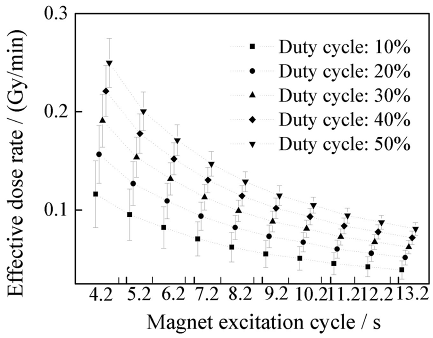

Fig. 1 Effect of the initial respiratory phase and synchrotron MEC as well as respiratory-gated DC on conventional FB-based, respiratory-gated, pulsed heavy-ion irradiation.

the standard deviations (SD), accounting for the initial phase effect from $\pi/2$ to 2π for the total breathing traces at various MECs with DC levels of 10%, 20%, 30%, 40% and 50%.

In general, the average EDR of the gated irradiation gradually decreased as the MEC increased from 4.2 to 13.2 s and was 1.73~11.09 times less than with non-gated beam delivery, depending on the DC settings. Fig. 1 also shows that variations in the initial phase of respiratory motion tended to have a greater influence (the error bar was longer) on the EDR with shorter DC settings. This influence gradually decreased when the MEC increased from 4.2 to 13.2 s.

Reference

[1] Y. Tsunashima, S. Vedam, L. Dong, et al., Phys Med Biol, 53(2008)1947.

3- 44 Monte Carlo Simulation Study on Optimizing the Active Beam Delivery System at HIRFL

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To obtain carbon ion beam suitable for the active spot scanning beam delivery system at the Heavy Ion Research Facility in Lanzhou (HIRFL), the Monte Carlo (MC) program SHIELD-HIT12A was used to study the influences of beam delivery distance and structure period of mini ridge filter on full width at the half maximum (FWHM) of beam spot and dose flatness at the iso-center of the treatment room.

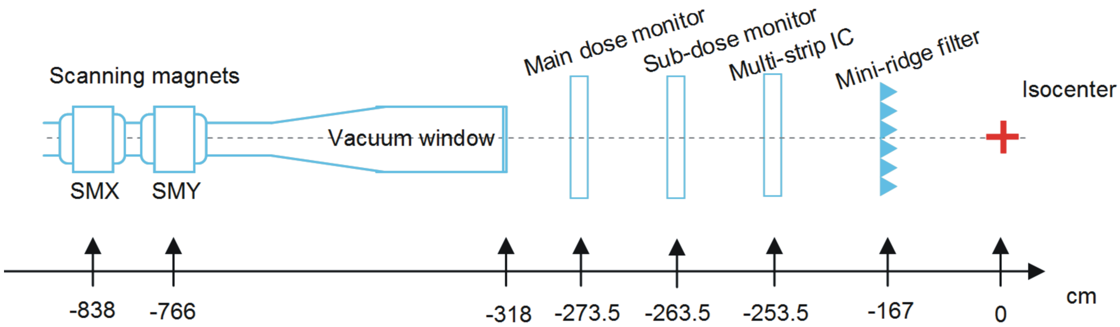

Fig. 1 The sketch map of the active spot scanning beam delivery system in the therapy terminal at HIRFL.

The three dimensional scanned carbon ion beam therapy requires that the beam lateral size at the iso-center is not too large. For example, the carbon ion beam width at the Heidelberg Ion Therapy Center (HIT) is 4~15 mm[1]. Through the simulation of the active spot scanning beam delivery system in the therapy terminal at HIRFL (Fig. 1), the FWHM of beam spot at the iso-center of the treatment room was obtained to be 26.2 mm for 100 MeV/n, 13.9 mm for 200 MeV/u, 9.7 mm for 300 MeV/u, and 7.5 mm for 400 MeV/u, respectively. This means that the lateral beam size in the therapy terminal at HIRFL-CSR is not suitable for scanned carbon ion beam therapy. Because lateral beam size is related to beam delivery distance and the structure period of mini ridge filter, 5 different beam delivery distances and 3 different mini ridge filter's structure periods were simulated with the SHIELD-HIT12A for the active spot scanning beam delivery system in the therapy terminal at HIRFL. Table 1 shows the 5 different beam delivery setups for the simulation. In the simulation, the origin was the iso-center of the treatment room and the positive direction was opposite to the beam direction. The 5 different beam delivery distances were represented by the distances between the beam delivery device vacuum window and the iso-center. Because the position and structure period of mini ridge filter infleuence dose flatness in the target volume, dose flatness at the iso-center was also investigated besides the FWHM of beam spot at the iso-center.

Table 1 Five different setups for the beam delivery system.

Beam delivery setup	Vacuum window/ cm	Main dose monitor/ cm	Sub dose monitor/ cm	Multi-strip IC/ cm	Mini-ridge filter/ cm
Case 1	210	203.5	193.5	183.5	167
Case 2	150	143.5	133.5	123.5	107
Case 3	125	118.5	108.5	98.5	85
Case 4	115	108.5	98.5	88.5	75
Case 5	105	98.5	88.5	78.5	65

Shown in Fig. 2 are the simulated results of FWHM at the iso-center under the conditions of 5 different beam delivery setups and 3 different mini ridge filter's structure periods. Shown in Fig. 3 are the simulated results of dose flatness at the iso-center under the same conditions mentioned above. The present simulation study shows that the shorter the beam delivery distance was, the smaller the FWHM of beam spot was, but the worse the dose flatness was. This is due to that the shorter the distance was, the more difficult the scattering balance was. Our results indicate that the FWHM of beam spot in the beam delivery setup 3, 4 and 5 is suitable for scanned carbon ion therapy. The structure period of mini ridge filter was a key factor to account for the dose flatness at the iso-center. The smaller the structure period of mini ridge filter was, the better the dose flatness was. The clinic therapy standard of dose flatness is better than 5%. Fig. 3 indicates that 2 mm periodic mini ridge filter meets the requirement of dose flatness for 100 and 400 MeV/u carbon ion beams.

Based on the simulation results above, we conclude that 2 mm structure period for a mini ridge filter satisfies the requirements on the FWHM of beam spot and dose flatness at the iso-center for the active spot scanning beam delivery system at HIRFL when the distance between the vacuum window and the iso-center is set shorter than 125 cm in the nozzle.

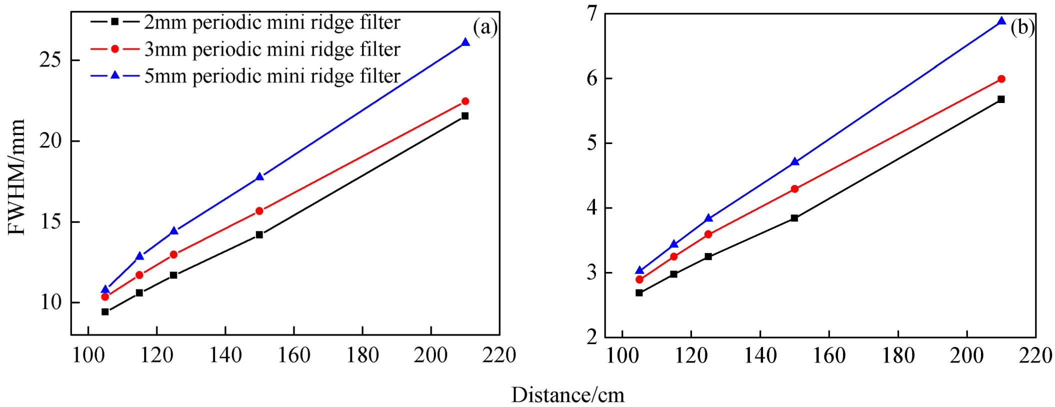

Fig. 2 (color online) The influence of beam delivery distance and mini ridge filter's structure period on the FWHM of beam spot at the iso-center in the treatment room. (a) 100 MeV/u carbon ion beam, (b) 400 MeV/u carbon ion beam.

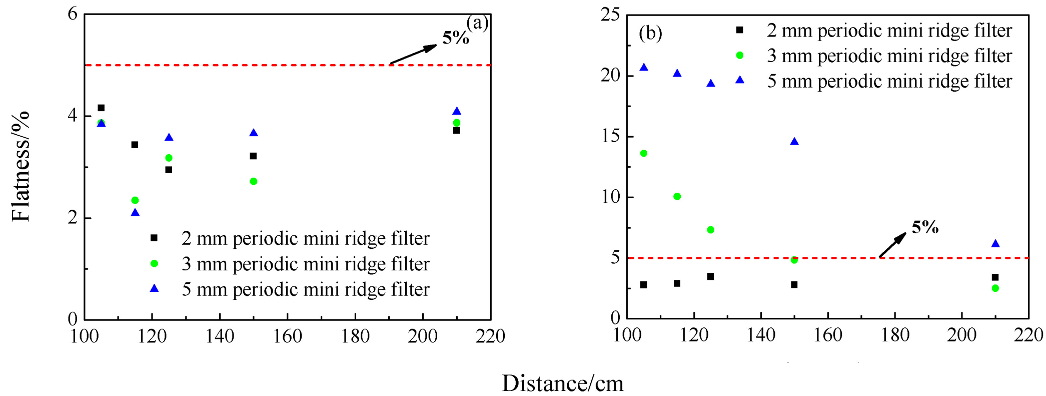

Fig. 3 (color online) The influence of beam delivery distance and mini ridge filter's structure period on dose flatness at the iso-center in the treatment room, (a) 100 MeV/u carbon ion beams, (b) 400 MeV/u carbon ion beams.

Reference

[1] S. E. Combs, O. Jaekel, T. Heberer, et al., Radiotherapy and Oncology, 95(2010)41.