COMMISSIONING OF NIRS FAST SCANNING SYSTEM FOR HEAVY-ION THERAPY

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Abstract

The commissioning of NIRS fast scanning system was started in September 2010, when the first beam was successfully delivered from the HIMAC synchrotron to the new treatment room. As a result of the commissioning, we verified that the new scanning delivery system can produce an accurate 3D dose distribution for the target volume in combination with the planning software. After intense commissioning and quality assurance tests, the treatment with scanned ion beam was started in May 2011. This paper describes the commissioning results and the performance of the NIRS scanning system.

INTRODUCTION

At the HIMAC, more than 6000 patients have been successfully treated by carbon beams since 1994. To make optimal use of these characteristics and to achieve accurate treatment, three-dimensional (3D) pencil beam scanning [1-3] is one of the sophisticated techniques in use. For implementation of this irradiation technique, at HIMAC, a new treatment facility [4] was constructed. The commissioning of NIRS fast scanning system was started in September 2010, when the first beam was successfully delivered from the HIMAC synchrotron to the new treatment room. The commissioning was carried out as following steps; 1) verification of the beam size, position and intensity stability, 2) verification of beam scanning performance and calibration, 3) verification of beam monitor performance, 4) dose measurement of the pencil beams for the beam parameterization in the treatment planning system, and 5) verification of 3D dose conformation. After intense commissioning and quality assurance tests, the treatment with scanned ion beam was started in May 2011.

NIRS FAST SCANNING SYSTEM

The challenge of this project is to realize treatment of a moving target by scanning irradiation, because pencil beam scanning is more sensitive to organ motions compared with conventional broad-beam irradiation. Our approach [5] is a combination of the rescanning technique and the gated irradiation method. One of the most important features of the system is fast scanning to realize moving target irradiation with a relatively large number of rescans within an acceptable irradiation time. The system was designed so as to provide a modulated dose delivery with beam-scanning velocities of 100 and 50 mm/ms at the isocenter. These scanning velocities enable us to achieve the fastest irradiation time of around 40 ms for an example uniform 2D field having a 102×102 mm^2 size with spot spacing of 3 mm. In the performance test of 3D delivery [6], the average of the spot-staying time was considerably reduced to 154 μs, while the minimum staying time was 30 μs. Layout of the fast scanning system installed to the new facility is shown in Fig. 1. It consists of the scanning magnets, main and sub flux monitors, position monitor, mini-ridge filter and range shifter. To achieve the fast beam scanning, the distances from the scanning magnet to the isocenter are designed to be 8.4 m. Technical detail of the system are described in Ref. [6].

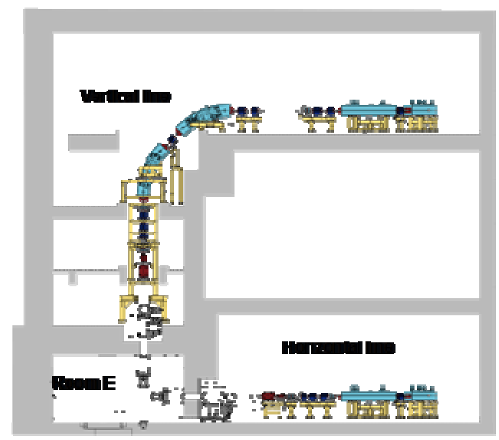

Figure 1: Delivery system of new treatment facility.

COMMISSIONING OF THE SYSTEM

Stability Check of Non-scanned Beam

In the 3D pencil beam scanning irradiation, the stability of the pencil beam, i.e. non-scanned beam, is very important issue to assure the scanned field quality. The slowly extracted beam from the synchrotron, needs to be stable in position, size and spill. Therefore, the measurement of the beam profile during 50s extraction was carried out to test the stability of both beam size and position. The measurement was carried out by using the fluorescent screen with CCD camera system [7] set at the isocenter. As a result, it was verified that both the position and size during the extended flattop operation are well stabilized within ±0.5 mm. On the other hand, the spill stability was also tested by using the ionization chamber measurement, in which the commissioning of the RF-knockout control was performed [8]. Further, the beam ON/OFF response and its repeatability were verified.

Accuracy of Scanned Beam

Since the scanned beam position is directly affects the delivered dose distribution, the verification and the calibration of the conversion between the position and the scanning magnet current setting should be carefully performed. Thus, this verification was carried out by two different measurements: 1) film and 2) fluorescent screen with CCD camera system. In order to check the effect of hysteresis and its correction, three different scanning amplitudes, ±120, ±80, and ±40 mm, were tested. Typical results are shown in Figure 2. In both measurements, the result show the accuracy of ±0.3mm at 2-sigma.

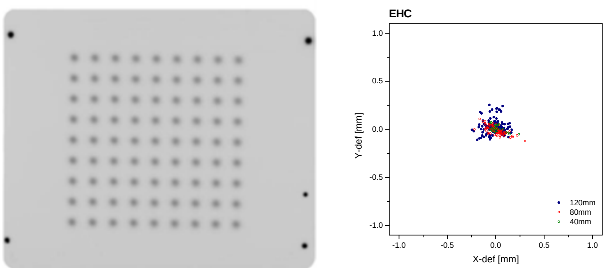

Figure 2: Result of beam position measurement, left: film measurement, right: scatter plot of the deviation between preset position and measured one.

Commissioning of Beam Monitors

The beam monitoring is one of the most important components in the scanning delivery. In order to measure and control the dose of each spot, two flux monitors (main and sub) and a beam position monitor were placed. In this section, the commissioning of these monitors are described.

The position dependence of the main flux monitor and the scanning control was tested by using 2D uniform field irradiation. By applying the same count for regular grid spots, 2D uniform irradiation was carried out. The uniformity of the delivered field was measured by using the 2D ionization-chamber array (2D-ARRAY xdr, PTW Freiburg) and the film. Figure 3 shows results of 2D uniformity measurement by the film. We see a uniform field distribution, indicating the main flux monitor has rather small position dependence. In both measurements, the standard deviation of the measured dose was around 1%. From these results, we concluded the position dependent calibration of the flux monitor is not necessary. Output linearity of the flux monitor was also checked by changing applied count in 2D uniform field delivery. The delivered dose was measured by reference ionization chamber of PTW30013 having sensitive volume of 0.6 cc. As shown in Fig. 3, the deviation from the linear relationship was less than 1%. The measurement of the recombination was also carried out. Although the typical beam intensity was 1-2×10^8 particles/s, the severe recombination was not observed up to 6×10^8 particles/s.

The verification of the beam position monitor output was carried out by comparing the film dosimetry. In this test, the film was attached onto the beam position monitor and irradiated with the irradiation pattern similar with Fig. 2. The differences measured position between the monitor output and the film were less than 0.5 mm. Thus, the position monitor output can be used for position monitoring with the tolerance of 2 mm. On the other hand, the position output is used for online display of the beam scanning process. Figure 4 shows the typical view of position monitor console.

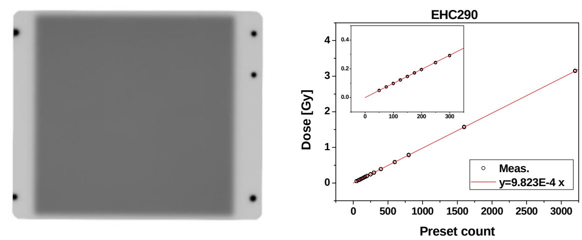

Figure 3: Typical result of flux monitor commissioning, left: position dependence measurement by film, right: output linearity measurement.

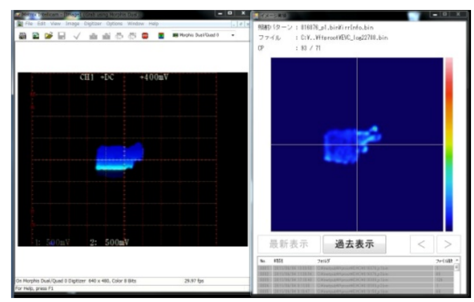

Figure 4: Online display of position monitor measurement, left: online display of beam position, right: measured fluence map for each iso-energy slice.

Check of intensity modulation in 2D delivery

Overall verification of the scanned beam can be realized by checking the 2D delivery with intensity modulation [9]. The checking irradiation pattern introduced by Flanz [9] was employed and measured by using the fluorescent screen with CCD camera system [9]. As shown in Fig. 5, we can see the 2D irradiation with the intensity modulation was successfully performed. Since the measured distribution was good agreement with the expected one, we can conclude that the beam control is correctly operating.

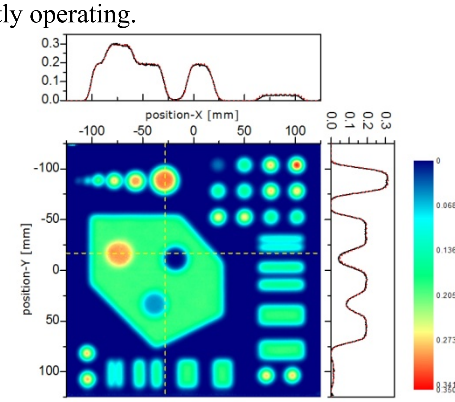

Figure 5: Measured distribution in 2D intensity modulation. Red dotted line shows the prediction.

Interlocks

The safety interlock features for errors of the beam flux, position and size are intensively tested. Since these undesirable errors deteriorate the dose distribution, the beam should be turned off as quickly as possible after their detection. The interlock signals are provided to the existing hardware interlock chain of the HIMAC facility, which can immediately turn the beam off.

Dose Measurement of Pencil Beam

As the basic performance of the system was verified, we moved to the next step which was the 3D irradiation test and its verification. Prior to the 3D irradiation test, it is necessary to prepare the data for a planning calculation [10-12], because the measured beam property is employed in the calculation. To acquire the data for the planning calculation, the following measurements were carried out for these energies: 1) integral depth dose distribution of pencil beam, 2) lateral dose distribution of pencil beam, and 3) measurement for characterization of large-angle scattered particles [11]. The measurements of 1) and 2) were carried out by using a cylinder-type water column with ionization chambers, which are a large area parallel-plate ionization chamber and a 94 channel cross-shaped monitor (pixel ionization chamber) with a spatial resolution of 2 mm. Figure 6 shows typical results of the measurement. The measurement of 3) was carried out to obtain the parameters describing the multi-Gaussian form of the pencil beam in the planning calculation, in which the central-axis dose for the various sizes of frame-like field was measured [11]. By introducing this model to the planning calculation, the field-size effect due to large-scattered particles can be successfully corrected [11]. With the results of the measurements on 1), 2) and 3), we performed the 3D irradiation test cooperating with our planning software.

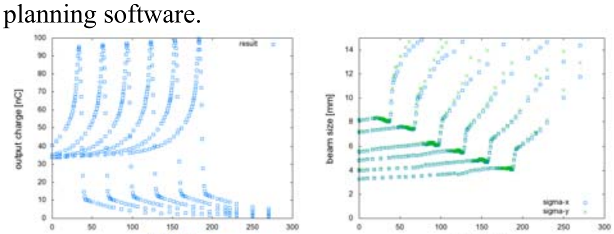

Figure 6: Typical result of pencil beam measurement.

3D Scanning Beam Delivery

For verification of the 3D delivery and the planning software, various plans were tested. In these irradiation tests, the MU calibration procedure, introduced by Jäkel et al [13], was employed. Typical results of the 3D dose conformation test are described as follows. Box-shaped targets with different SOBP thickness were planned to generate a uniform physical-dose field of 1 Gy. Figure 7 shows the dose distributions measured by an ionization chamber set in the water tank. These results were in good agreement with the planned values at various penetration depths. The uniformity was less than ±3%. Further, the reproducibility of the delivered dose within ±0.5% was also verified in these 3D delivery tests.

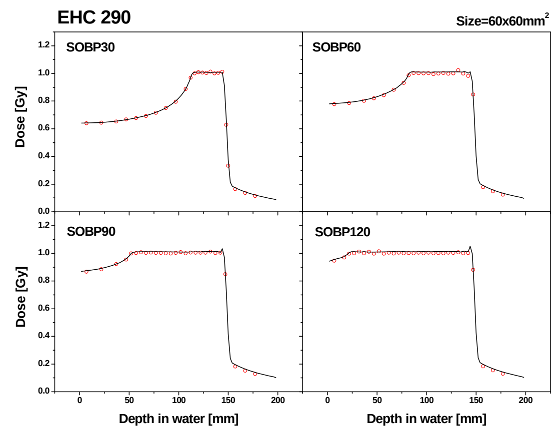

Figure 7: Comparison between measured and planned dose distribution.

STATUS AND OUTLOOK

The commissioning of the fast scanning system at the HIMAC new treatment facility were successfully performed, and the treatment with this system is in progress. In this stage, the range shifter, which consists of PMMA plates, is used for the longitudinal scanning. To enable the energy variation during the irradiation, and to decrease the range shifter usage, the preparation of multiple-energy operation [14] is in progress [8,15].

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