DEVELOPMENT OF QA SYSTEM FOR THE ROTATING GANTRY FOR CARBON ION THERAPY AT NIRS

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Abstract

At the National Institute of Radiological Sciences (NIRS), we have been developing the rotating-gantry system for the carbon-ion radiotherapy. This system is equipped with a three-dimensional pencil beam scanning irradiation system. To ensure the treatment quality, calibration of the primary dose monitor, range check, dose rate check, machine safety check, and some mechanical tests should be performed efficiently. For this purpose, we have developed a measurement system dedicated for quality assurance (QA) of this gantry system. The ion beam's dose output are calibrated by measurement using an ionization chamber. A Farmer type ionization chamber is inserted into the center of a water equivalent phantom. The thickness of the phantom could be changed so that employ both calibration of the output at entrance and output checking at center of the irradiation field. The ranges of beams are verified using a scintillator and a CCD camera system. From the taken images, maximum gradient points are determined by some image processing and compared with reference data. In this paper, we describe consideration of the daily QA for the rotating-gantry.

INTRODUCTION

Since carbon ion deposits most of their energy in the last final millimeters of their trajectory, the accuracy of the beam energy/range is required for carbon ion treatment especially for using scanning method. Physical advantages of carbon ion are not only for the beam direction, but also for the lateral direction compare with conventional photon or proton beam. Although QA procedures are necessary for establishing safe and accurate dose delivery of any radiation therapy treatment modality, much high level of QA procedures are required for carbon-ion therapy. There are few guidelines for QA of the particle radiotherapy. The recommendation of the International Commission on Radiation Units and Measurements ICRU [1] that the uncertainties in the delivered dose to patients be limited to within 5% of the prescribed dose is the fundamental principle of the QA guidelines. To ensure the treatment quality, calibration of the primary dose monitor, range check, machine safety check, and some mechanical tests should be performed efficiently. We made the Daily QA list based on the ICRU 78 [2]. Table 1 indicate the list of the daily QA and tolerances. The new treatment room using the rotating-gantry system will be opened at 2016 in addition to existing 4 fixed beam port. Totally 5 of irradiation port have to be check the condition before the treatment within a limited time. For this purpose, we have developed a measurement system dedicated for quality assurance (QA) of this gantry system. The system includes a dose measurement system, a range measurement system, and a slide rail. The system position can be switched for the purpose of the measurement.

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Table 1: List of Daily QA and Tolerances

Procedures	Tolerances
Calibration of the primary dose monitor	-
output at center of SOBP	2%
Range	0.5mm
Dose rate and monitor ratios for the pencil beam	5%
Performance of the beam-position monitors	Functional
Interlocks	Functional
Isocenter	0.5mm
Gantry angle	0.2 degree

CALIBRATION OF THE PRIMARY DOSE MONITOR

The dose measurement system is used for the calibration of the primary dose monitor. Fig. 1 is the photograph of the dose measurement system. This calibration is performed for the correction of the dose output from the treatment machine. The Farmer type ionization chamber (30013, PTW Freiburg, Germany) was positioned at a depth of 2.0 cm from top of the front surface of a water equivalent phantom. The depth of 2 cm was chosen to ensure that measurements were made in a low dose gradient region of the pristine Bragg Peak curve. The calibration was performed with 10x10 cm2 field size. By comparison of the dose between reference and measured, daily calibration factor is calculated. This measurement is performed at 0 degree of the gantry angle. From the result of the calibration for the existing fixed beam port, our beam control system is very stable. Almost all of the calibration factor from 2011 were within 1 percent. At this moment, only one energy is measured on a daily basis.

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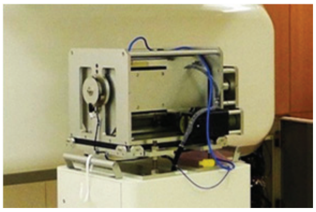

Figure 1: Photograph of the dose measurement system. This is a part of the Daily QA system for the rotating gantry.

OUTPUT MEASUREMENT

After the calibration of the primary dose monitor, to check the combination of the multi devices, the dose output measurements are done at the center of the SOBP width for different carbon beams for the standard 6x6 cm2 field size. The dose measurement system is also used for the output measurement. The Farmer type ionization chamber was positioned at a depth of 10.0 cm from top of the front surface of a water equivalent phantom by inserting the thick phantom. To check the reproducibility of the measurement, we measured 3 times. This measurement was performed at 0 degree of the gantry angle. From the result of the output measurement for the existing fixed beam port, all measurements are within 1 percent.

RANGE VERIFICATION

In the current daily QA at NIRS, Few-points depth dose measurement using ionization chamber is employed for range verification. For the existing fixed beam port, the doses are measured with combination of several range shifter (RSF) plates [3]. It takes about 1 minute for a measurement of one energy beam. Since the gantry beam port is designed for energy scanning method [4], there is not RSF anymore. In order to apply the range check for gantry beam port, independently measureable range verification system is required. For this purpose, we developed the range verification system using a scintillator and a CCD camera (scintillator + CCD system) and to estimate the accuracy of the range verification using the system. The data acquisition of the CCD camera was synchronized with irradiation. We measured pencil-beam having intensities between 8×10^{7} and 1.6×10^{8} particles per second. Measurement time is 0.1 sec for all energy.

The scintillator + CCD system is shown in Fig. 2. The system is consisted of a scintillator block, CCD camera, and opaque (black) box. Light distribution is detected by CCD camera through a mirror. The optical path length between the scintillator and lens is 400 mm. The system was placed on the treatment couch. The center of the scintillator was placed at isocenter. A EJ-200 plastic scintillator block was selected for pure tranceparent block, similar density with human body, and matching wavelength of maximum emission for CCD camera. The size of cylindrical scintillator block was 200 mm diameter ×20 mm thickness. For shading the light from the treatment room, the scintillator was wrapped by light blocking sheet. The CCD camera (Type BH-61M, 1932x1452 pixels, Bitran Corp., Japan) was installed on the light-shielding house. The spatial-resolution of the system is 0.2 mm/pixels. Measured two-dimensional images were processed by in-house program developed by c++. The workflow of image processing is shown in Fig. 2. After the background correction and median filter, projection on one-dimensional axis is performed. The common reference point of range is distal 80% of the dose distribution. However the system measures the range not with the dose distribution but with the light distribution. From our investigation, DOG method results in smaller discrepancies between the expected and measured ranges for carbon beams compared to the threshold method. DOG method is widely used in edge detection field instead of Laplacian filter [5]. Using DOG method, range position is determined by zero-crossing position in the difference between small-Gaussian smoothed image and large-Gaussian smoothed images. Sigmas for small and large Gaussian are 1 and 1.5 pixels respectively. Only the high-frequency edge position is enhanced when relative small sigma is used. In this work, range-scaling factor is applied. The Range Shifter that gave us the least deviation from the expected relative range for all RSF thickness is then used for all range measurements.

Figure 3 shows the example of depth brightness lines. A total of 124 energy carbon beams that were in the range from 81.7.8 to 326.4 MeV/n were measured sequentially, energy by energy. Relative range differences from the expected range were very small. Root mean square error (RMSE) was less than 0.05 mm for all measurements.

Fig. 4 shows the variation of the measured range for 140, 230, and 290 MeV/n carbon beams over a 6 days. Maximum deviation from mean range is 1.1 mm for 140 MeV/n. From the estimation of the impact of the setup error, beam position or setup error was not negligible, correction of these kind of error have to be considered.

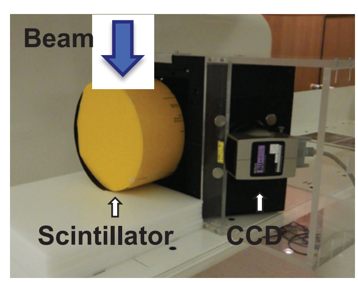

Figure 2: Photograph of the scintillator + CCD system. This is a part of the Daily QA system for the rotating gantry.

ISOCENTER AND GANTRY ANGLE

As a part of the mechanical QA procedures, the accuracy of the isocenter position and gantry angle is tested daily. The beam position is checked the coincidence from the center position of patient positioning system. The gantry angle is checked to ensure

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the accuracy of the digital display and coincidence between mechanical angle and radiation beam angle. Prior technique for isocenter verification in radiation center is to measure the distance between center of the metallic ball and beam center by using screen monitor system. For this technique, preparation of the target and measurement device i.e. screen monitor system are required. We decide to verify the isocenter position and gantry angle using scintillator + CCD system for Daily QA for efficiency. The proposed method extends the basic star shot technique [6]. The star shot test was relatively simple and became quite popular, but it was based on films; therefore, it inherited all film-related problems. The general disadvantages in using films include the cost of films, chemicals and processor maintenance, and occupation of archiving space. we developed the software to analyze the beam angle. we tested for the couch rotation instead of the gantry rotation. Fig. 5 is example of the measured data. Image acquisition was performed sequentially beam by beam.

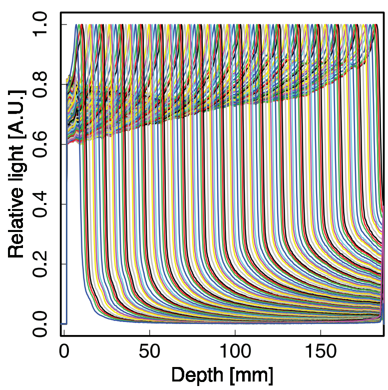

Figure 3: Examples of depth brightness lines. A total of 124 energy carbon beams that were in the range from 81.7.8 to 326.4 MeV/n were measured sequentially, energy by energy.

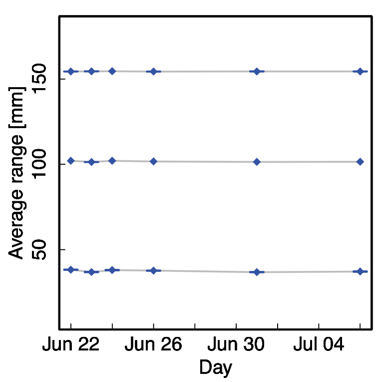

Figure 4: Variation of measured range for 140, 230, and 290 MeV/n carbon beams over a 6-day period.

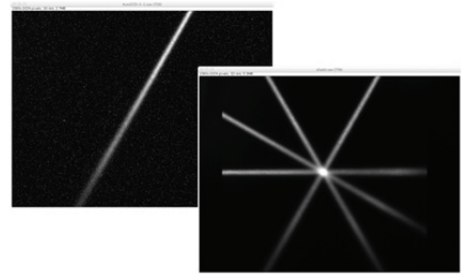

Figure 5: Example of star shot test using scintillator + CCD system. The carbon beam track was measured beam by beam.

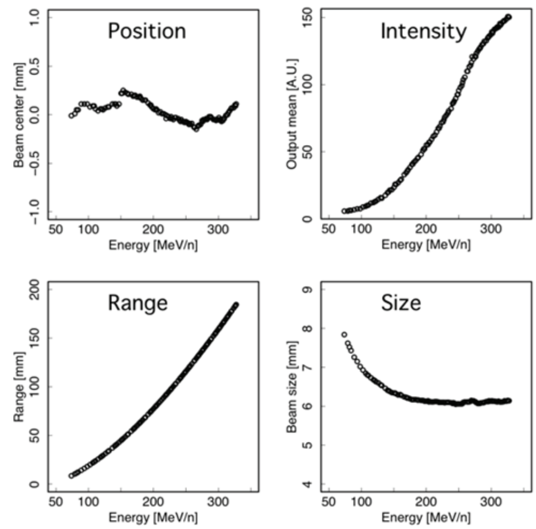

Figure 6: Example of beam position, intensity, range, and size measurement. These data were analyzed using the data for range measurement. A total of 124 energy carbon beams that were in the range from 81.7.8 to 326.4 MeV/n were measured sequentially, energy by energy.

The data acquired by scintillator + CCD system enclose the informative data, such a beam position, intensity, size, and etc. Fig. 6 shows the example of these data. We plan to use utilize these data for analyzing the trend of the machine condition.

CONCLUSION

In this work, Daily QA system for the rotating gantry for the carbon ion therapy with combination of the dose measurement system and range verification system has been developed. We have shown the preliminary result for the range measurement for the gantry beam port. We plan to deliver the carbon ion beam to the gantry beam port in September 2015.

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