BEAM SPOT MEASUREMENT USING A PHOSPHOR SCREEN FOR CARBON-ION THERAPY AT NIRS

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Abstract

A two-dimensional beam imaging system with a terbium-doped gadolinium oxysulfide (Gd2O2S:Tb) phosphor screen and high-speed charge coupled device (CCD) camera has been used to measure the beam spot for scanned carbon-ion therapy. The system can take the image of the beam spot with the frequency of 50 Hz. Using this system, the time stability of the unscanned-beam spot size and position was verified in the isocenter. This system was also used to check a beam alignment by observing a shadow, which appears on the beam spot image, of the steel sphere located on the reference axis.

INTRODUCTION

In charged particle cancer therapy with pencil beam scanning, the time stability of the beam position and size is important factor to provide the prescribed dose distribution. The large fluctuations of them are capable of increasing damage to normal tissues in the vicinity of the tumor and producing a hot or cold dose region in the target volume. To verify their stability at the isocenter in the treatment room, National Institute of Radiological Sciences (NIRS) [1] in Japan developed a two-dimensional (2D) beam imaging system.

NIRS has performed the three-dimensional scanning irradiation with a carbon-ion pencil beam [2] since May 2011. The carbon-ion beam is provided from the Heavy Ion Medical Accelerator in Chiba (HIMAC) synchrotron using the RF-knockout slow extraction method [3]. The beam energy is changed from 430 MeV/u to 140 MeV/u stepwise by the multiple-energy synchrotron operation [4], and small changes of the beam range are controlled by inserting the PMMA plates with various thicknesses. In the HIMAC synchrotron, the flattop is extended in order to extract the beam for a long time. The beam size variation due to emittance growth, therefore, should be cared during a long extraction period. The beam position drift is also cared although the beam position is controlled with the feedback system integrated into the control system of the scanning magnet power supply.

The 2D beam imaging system developed at NIRS can obtain the 2D beam profiles with the frequency of 50 Hz and observe the stability of the beam position and size at the isocenter in the treatment room. This system consists of a phosphor screen and high-speed charge coupled device (CCD) camera. This system construction is identical to that of the beam monitor system installed in the high-energy beam transport line at HIMAC [5]. The 2D beam imaging system also functions as a beam alignment adjustment system by setting a steel sphere on the reference axis. The beam alignment can be checked by observing a shadow of the steel sphere on the beam spot image.

Using the 2D beam imaging system, the fluctuations of the unscanned-beam spot position and size were observed in the isocenter to verify the time stability of the delivered beam for scanning irradiation. On the other hand, the misalignment of the beam has been routinely checked for quality assurance. In this paper, we describe the 2D beam imaging system and the measurement results using it.

2D BEAM IMAGING SYSTEM

System Configuration

A schematic drawing of the 2D beam imaging system is shown in Fig. 1. A terbium-doped gadolinium oxysulfide (Gd2O2S:Tb) phosphor screen is mounted at an entrance surface of the beam inside the dark box. The light radiated from the phosphor screen is carried to the high-speed 8-bit CCD camera (Type XG-H035M, KEYENCE, Japan), for protecting the camera from the radiation damage, via a mirror placed at a 45 degree to the beam direction. The typical observed image of the beam spot is shown in Fig. 2. The spatial resolution in this system is about 0.2 mm/pixels.

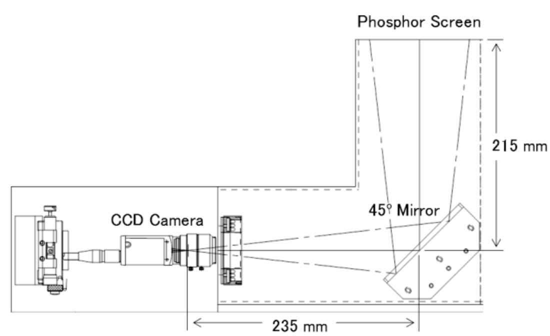

Figure 1: Schematic drawing of the 2D beam imaging system.

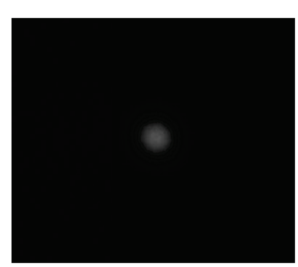

Figure 2: Typical image of the beam spot measured by the 2D beam imaging system.

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The CCD camera is controlled by the special controller (Type XG-7500, KEYENCE, Japan). It employs three processors for a fast image processing, and it is operated through the Programmable Logic Controller.

Beam Alignment Adjustment

The 2D beam imaging system is also utilized for the alignment adjustment of the beam by using an acrylic phantom. The setup for adjusting the beam alignment is shown in Fig. 3. A steel sphere is embedded in the surface of this phantom, and its position is on the axis of the reference coordinate system. The misalignment of the beam can be measured by taking an image of the beam spot while setting this phantom.

The steel sphere generates a shadow, as shown in Fig.4, on the beam spot image. The beam misalignment is calculated by deriving the centres of the beam spot and the steel sphere. The algorism to obtain the two centres is indicated in Fig. 5. At first, the standard deviations of the beam image including the shadow are calculated from the horizontal and vertical projection profiles. In the next step, the difference map is created by subtracting the pixel values of the original image from the 2D Gaussian distribution, which is derived from the above standard deviations. After that the negative values in the difference map are replaced zero, the centre of the beam spot is obtained from the addition map of the original image and the difference map. This addition map is the anticipated image map in the case of without the steel sphere. The centre of the steel sphere is also calculated by subtracting the original pixel values from the addition map.

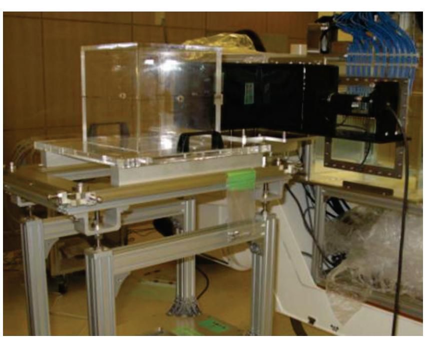

Figure 3: Photograph of the 2D beam imaging system with a steel-sphere-mounted acrylic phantom. This is the setup for the beam alignment adjustment.

Figure 4: Typical image of the shadow on the 2D beam spot profile. It is created by the steel sphere located on the reference axis.

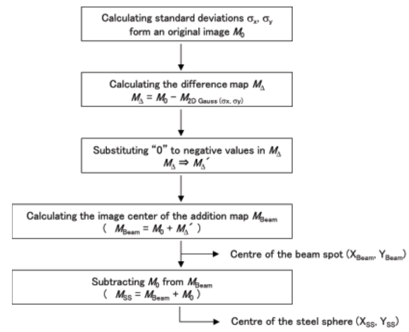

Figure 5: Algorism to calculate the beam misalignment.

MEASUREMENT RESULTS

The measurement of the time stability of the unscanned-beam position and size was carried out at a scanning beam course in the HIMAC treatment room. The 2D beam imaging system was set so that the phosphor screen corresponded with the isocenter. The carbon-ion beam was provided from the HIMAC synchrotron using the multiple-energy operation with extended flattops. The beam-energies were 430, 400, 380, 350, 320, 290, 260, 230, 200, 170 and 140 MeV/u. The rate of the extracted beam was 1×10^8 particles per second.

The beam was extracted for 20 seconds on each energy-flattop, and its position and size were measured with the frequency of 50 Hz all the time. The result of the time stability measurement is shown in Fig. 6. The fluctuation of the beam position was observed during extraction. The horizontal and vertical position fluctuations were in the range of 0.4 mm and 0.2 mm, respectively. The horizontal fluctuation was larger than the vertical one, and this is because the horizontal beam position is strongly affected by the current fluctuation of the synchrotron magnets due to the extraction mechanism. On the other hand, the slow drift of the beam position was not observed owing to the feedback control system of the scanning magnets. The measurements of the unscanned-beam position and size stability were carried out at other three courses. Their results were equal to that indicated in Fig. 6.

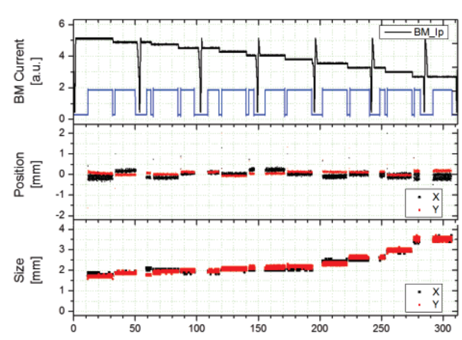

Figure 6: Time stability measurement of the unscanned-beam position and size.

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The beam alignment was checked using the 2D beam imaging system and the steel-sphere-mounted acrylic phantom at the four beam courses. The calculation of the beam misalignment is performed by the beam image analysis program, as shown in Fig. 7. This program derives the centres of the beam spot and the shadow created by the steel sphere from the algorism indicated in Fig. 5. The beam misalignment is calculated from the difference between the two centres. The results of the derived misalignments are shown in Fig. 8. They were measured for the eleven beam-energies as the time stability measurement of the unscanned-beam position and size. The beam misalignments were less than the tolerance of 0.5 mm in all the scanning beam courses.

The beam alignment measurement is routinely carried out at NIRS. If the misalignment is over the tolerance, the current of the steering magnets placed in the upstream of the scanning magnets is adjusted so that the beam spot centre corresponded to that of the steel sphere.

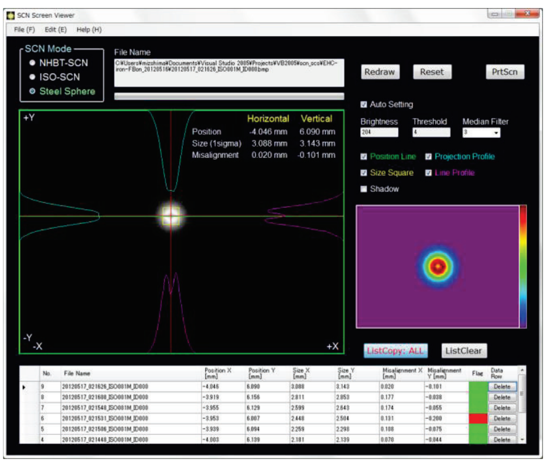

Figure 7: Screenshot of the beam image analysis program.

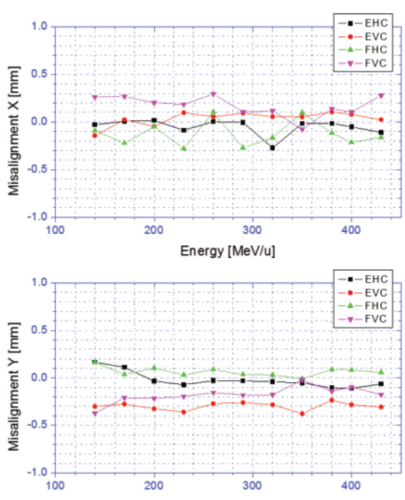

Figure 8: Measurement results of the beam misalignment.

CONCLUSION

A 2D beam imaging system with a terbium-doped gadolinium oxysulfide (Gd2O2S:Tb) phosphor screen and high-speed CCD camera has been used to measure the beam spot for scanned carbon-ion therapy at NIRS. The system enables us to obtain one image of the beam spot every 20 milliseconds. The small fluctuations of the unscanned-beam spot position and size were confirmed in the isocenter to verify the time stability of the delivered beam for scanning irradiation. The beam imaging system also functions as a beam alignment adjustment system by setting a steel sphere at the isocenter. For quality assurance, the beam alignment is routinely checked by observing a shadow of the steel sphere on the beam spot image, and it was confirmed that the misalignment of the beam was smaller than the tolerance of 0.5 mm.

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