SEMI-NONDESTRUCTIVE MONITORING SYSTEM FOR HIGH-ENERGY BEAM TRANSPORT LINE AT HIMAC

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Abstract

The development of a screen monitor (SCN) system for the surveillance of scanned carbon therapy beams at the Heavy Ion Medical Accelerator in Chiba (HIMAC) is presented. The monitoring of the beam properties is achieved by a newly designed semi-nondestructive monitoring system, located at the High-Energy Beam Transport (HEBT) line, consisting of a thin fluorescent screen and a high-speed charged-couple device. The properties of a prototype SCN were successfully investigated at HIMAC with a ^{12}C beam at 350 MeV/nucleon.

INTRODUCTION

The quality of a beam, i.e., its position, size and intensity, plays a significant role for the patient's treatment in the three-dimensional (3D) scanning system for carbon therapy. Comparing with the irradiation with the broad beams, the scanning irradiation is much more demanding, as any change of the scanned beam would result in a significant impact on the irradiation dose of the patient. To investigate the beam quality during the therapeutic irradiation by the semi-nondestructive monitor, the material of the monitor needs to be as thin as possible because the effect of the beam expansion for the therapy should be prevented. As the therapeutic irradiation keep to go on safety and smoothly, the measurement cycle should be kept to be enough at some level and the whole system should be set up in the most stable manner.

New particle-therapy research facilities are being constructed at HIMAC [1] for which the 3D scanning technique will be employed [2]. A semi-nondestructive monitoring system has been developed by using a thin fluorescent screen and a high-speed charge-coupled device for the HEBT line. In this paper, we present details of the automatic beam tuning before starting the treatment and the interlock system during therapy and report on initial results.

DESIGN OF SCN

The SCN system consists of the fluorescent screen and the charge-coupled-device (CCD) camera. The beam position and profile were obtained from the distribution of the fluorescent light, as produced by beam. The schematic layout of the scanning port is shown in Fig. 1. One of SCN will be located before the scanning magnet as the semi-nondestructive monitor. Other SCN will be set and used after the scanning magnet for using the Beam Auto Centering (BAC) sequence as usual beam profile monitor. To

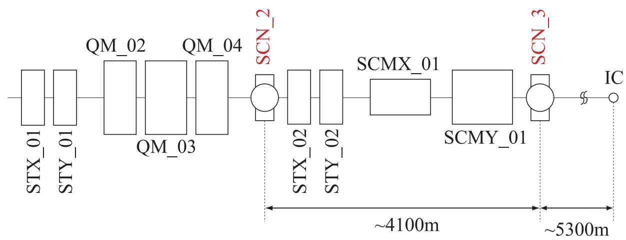

Figure 1: A layout of the scanning port.

monitor position and size of the beam during therapy, it is required to detect the trend data with the highest possible speed. This is achieved by changing the shutter speed of the camera and the CCD gain because the energy and the intensity of the beam during therapy are changed for each slice.

Beam Auto Centering

In the BAC sequence, the beam axis is automatically tuned by the two steering magnets with the measurement for the beam positions at two SCN as shown in the following equations

$$\mathrm{Mesposi}_2 - \Delta\mathrm{posi}_2(\mathrm{ST1}) = \mathrm{Refposi}_2$$

and

$$\mathrm{Mesposi}_3 - \Delta\mathrm{posi}_3(\mathrm{ST1}) - \Delta\mathrm{posi}_3(\mathrm{ST2}) = \mathrm{Refposi}_3.$$

In these equations, $Mesposi$ denote the position measured by SCN, $\Delta posi(ST)$ shows that the response of the steering magnet (α) times the variation of the current value on the steering magnet ($\Delta \mathrm{I}_{\mathrm{ST}}$), $Refposi$ denotes the reference position due to a miss alignment of each monitor and the subscripts indicate ID number of SCN. The α values are measured in advance and the $\Delta\mathrm{I}_{\mathrm{ST1}}$ and $\Delta\mathrm{I}_{\mathrm{ST2}}$ can be determine by the simultaneous equations. The BAC sequence has an effect before treatment represented by the simulation results as shown Fig. 2. When the multiple-energy of the beam [3] will be applied, the size of the beam at isocenter will be changed because of the energy dependence on the emittance. Therefore, the triplet quadrupole magnets (see Fig. 1) should be adjusted for each energy. As the k-values of each quadrupole magnet are changed, we plan to measure the α values for each energy in the commissioning experiment.

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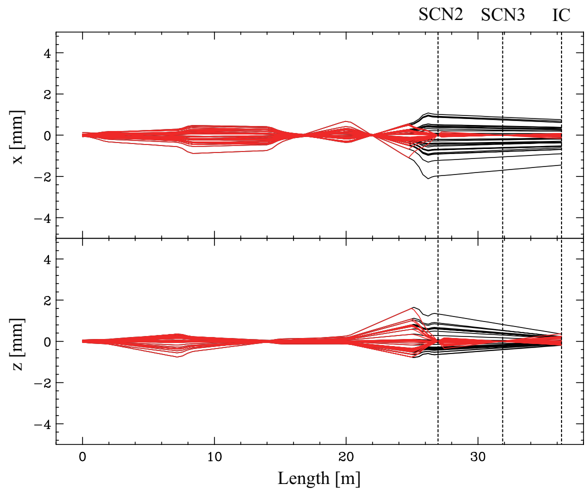

Figure 2: Calculated beam envelopes. The black (red) lines show envelopes before (after) applying the BAC sequence.

Detection Parts

A schematic drawing of the SCN is shown in Fig. 3. Each fluorescent screen is mounted at an angle of 45 degree to the beam axis. The CCD camera is installed parallel to

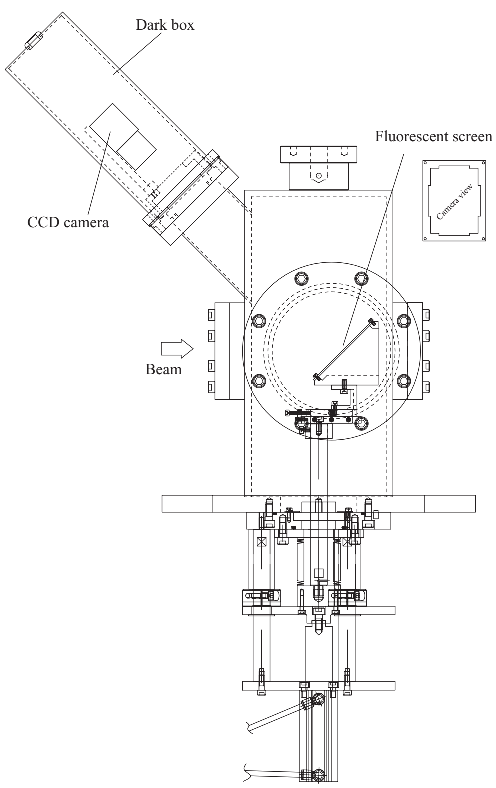

Figure 3: A schematic drawing of the SCN system. It consists of the CCD camera, the fluorescent screen, folder of the screen and the vacuum chamber.

the screen axis and the distance from the screen axis is 250 mm to avoid direct hit of the CCD by the radiation. The spatial-resolution of the SCN is 0.2 mm/pixels in horizontal direction. In order to protect against surrounding light, the CCD camera is covered by a dark box and the inner surface of the chamber is blasted finishing. The support frame of the screen has four reference indentations to calibrate the pixel spacing of CCD. All mechanical resolutions are required to be within ± 0.1 mm and ± 5 mrad.

The high-speed 8-bit CCD camera (Type XG-H035M, KEYENCE, Japan) is selected as the detection device. The special controller (Type XG-7500, KEYENCE, Japan) for this camera employs a highly three-processors and can be operated through the Programmable Logic Controller. These devices are more convenient to construct the whole operation system with, because each part can be linked together by a deterministic input-output response and can also be archived easily.

To prevent beam expansion due to multiple scattering while passing through the screen, a thin ZnS:Ag film of 2 mg/cm^2 thickness is used. The water equivalent thickness of this screen is 47 μm and the average scattering angle is less than 0.1 mrad for a ^{12}C beam with an energy of 350 MeV/nucleon. Thus, the beam is measured in a semi-non-destructively mode.

Image Processing

The measured image data is processed on the basis of a series of flow charts on the CCD controller as shown in Fig. 4. At first, the CCD camera takes an image with the condi-

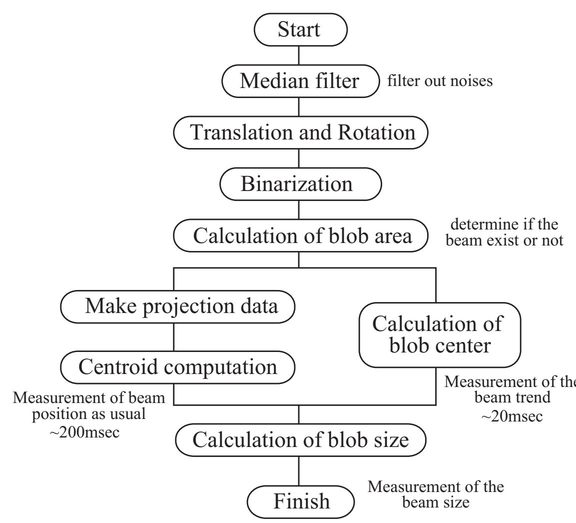

Figure 4: The flow chart of image processing.

tions such as shutter speed and CCD gain. The image data is passed through the median filter to decrease the background noise due to the dark current of CCD. It is determined that if the beam exist or non-exist by the calculation of the blob area. For using profile monitor, the taken image data are saved and the 1D projection data are made from the image data as shown the left-side chart in Fig. 4. The centroid computation is executed about the 1D projection data to obtain the central position of the beam. As select the on-line monitoring mode during the beam irradiation as shown the right-side chart in Fig. 4, if the calculated result of the position or size of the beam will be changed over the preset tolerance during therapeutic irradiation, an error signal is put out for stopping the beam immediately.

PERFORMANCE OF SCN

The experiment was performed in a physics-general experiment line 1 (PH1) at HIMAC using a mono-energetic 350 MeV/nucleon ^{12}C beam. The on-line display of two beam profiles are shown in Fig. 5. We can verify the condition of the beam not only numerically but also visually with watching the display. The red character A in Fig. 5 shows the size of the blob area within the threshold level of the light output, which is from 30 to 255. It is used for the determination of beam existence or nonexistence. The red character B in Fig. 5 shows the size of the blob area within the threshold level of the light output, which is from 254 to 255. From the measurement of this size, we can find the overflow of light output signal with tuning CCD gain.

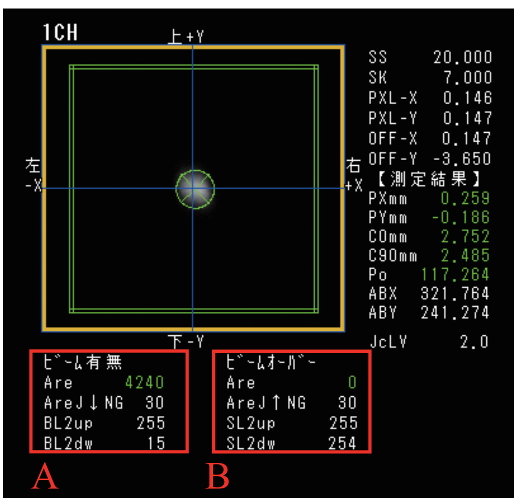

Figure 5: The beam profile image of SCN.

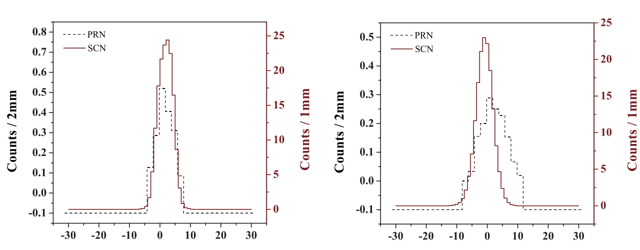

Figure 6: The horizontal (vertical) position was compared with SCN and MWPC as shown in this left (right) figure.

The 1D projection data measured by SCN was compared with the results of the multi-wire proportional chamber (MWPC) [4], which was located on 0.8 m above SCN, as shown in Fig. 6. The position and the size of the beam were observe successfully and we also found that the profile of the beam was Gaussian shape.

For applying the on-line monitoring mode, we can measure the stability of the transverse beam position at a rate of 50 Hz as shown in Fig. 7. The standard deviation (2σ) of the horizontal and vertical positions are 0.1 mm and 0.04 mm, respectively. From these result, regarding spatial-resolution, the SCN satisfy requirement for the on-line monitor.

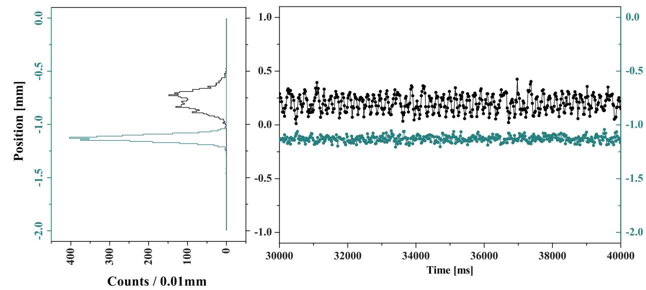

Figure 7: Trend data with the on-line monitoring mode. Black (green) symbols are horizontal (vertical) positions [mm] as a function of the time [msec].

SUMMARY

We have designed the SCN, which consists of the fluorescent screen and the CCD camera, and checked them with prototype scanning system at HIMAC. Since the SCN provide not only 1D but also 2D beam profile data, we obtain the more information of beam, e.g. beam profile incline to the left. The SCN succeeded to monitor the beam real-time in steps of $\sim$ 20 msec, corresponding to a 50 Hz sampling rate. The spacial resolution of the SCN was less than 0.1 mm, which is within tolerance for the on-line monitoring mode and the BAC sequence.

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