DEVELOPMENT OF SCREEN BEAM-PROFILE-MONITOR SYSTEM FOR HIGH-ENERGY BEAM-TRANSPORT LINE AT THE HIMAC

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Abstract

A screen monitor system was developed for beam profile monitors at the new High-Energy Beam-Transport (HEBT) section out the HIMAC. This monitor consists of the very thin fluorescent screen and the high-speed CCD camera. In addition to perform high-speed and high-resolution, this monitor does not almost destroy the beam.

INTRODUCTION

The new therapy facility, which is an extension of HIMAC, has been constructed [1]. The three-dimensional rasterscan method is employed for this facility. At the new HEBT section, the Screen Monitor System (SCN) was employed for beam profile monitor, due to the following advantages. The SCN provides high-resolution beam profile. The SCN is provided at a lower cost than conventional profile monitor.

For new facility, the prototype scanning system [2, 3] is installed at HIMAC. In this study, a prototype of the screen monitor system was developed in 2008 to prove fundamental performance. The design and performance of the SCN are described here.

DESIGN OF SCREEN MONITOR SYSTEM

The screen monitor system was designed for not only high-speed and high-spatial-resolution beam profile monitor, but also for semi-non-destructive monitor. In order to achieve these requirements, we employed the high-speed charge-coupled-device (CCD) acquisition system and the very thin fluorescent screen.

It is required to detect effectively the profiles of beams with intensities ranging from 1×10^7 to 1×10^9 carbons per second and with energy ranging from 200 to 400 MeV/u ^{12}C beam. To correspond this wide range, the measurement parameters, which include shutter time and CCD gain, must be changed to matched beam parameters.

The SCN is used for 1) usual beam profile monitor for beam tuning and 2) online monitor during irradiation.

1) For using beam profile monitor, each unit will be in principle located close to a pair of steering magnets or a quadrupole magnet, in order to steer and adjust the beam orbits easily. The beam is steered to be on the centers of the profile monitors within $\pm$ 0.5 mm. Moreover the beam profile is verified and adjusted to be optimum size by quadrupole magnets finally.

2) Some SCNs will be set at the entrance of the irradiation system for dual-purpose. In addition to use for beam profile monitor, these SCNs are used for online-monitor. In order not to disturb the beam so much, we employ the very thin fluorescent screen, thereby, the online monitor enabling us to monitor continuously the beam profiles during irradiation for treatments.

More than 20 SCNs are included in this new HEBT. We designed and made the prototype of two screen monitor systems for previous uses. These are installed in prototype of scanning irradiation system. The distances between the SCN and isocentor are about 9 meter and 6.4 meter, and multi-wire proportional chamber (MWPC) [4] is located 1.2 meter upstream from the downstream SCN. As shown in Fig.1, prototype of the SCN is connected with beam line, and located close to existing beam profile monitor. For the each of the horizontal and vertical of MWPC direction, an anode wire spacing is 2 mm.

Each fluorescent screen was mounted at an angle of 45 degree to beam axis. The CCD camera was installed perpendicular to the beam axis, and the distance from the beam axis was 450 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. The CCD camera is covered with dark box to protect against surrounding light. Maintenance window is located at the side of dark box, to adjust the CCD camera position and focal position easily. In order to reduce the distortion aberration, we employed telephoto lens, and the CCD camera was distanced from the screen.

CCD Acquisition System

Beam position and profile can be measured by compact 8-bit CCD camera (Type XG-H035M, KEYENCE, Japan). This CCD is controlled by special controller (Type XG-7500, KEYENCE, Japan). On the PC, we can make original image-processing application

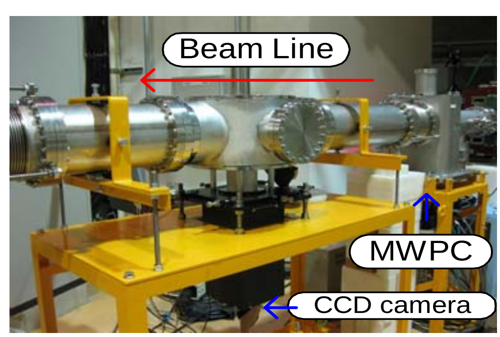

Figure 1: Screen monitor system and MWPC monitor.

including graphical user interface, and upload the application to the CCD controller by using special software XG VisionEditor. Since the CCD camera is controlled and acquisitioned by a CCD controller alone, the less network trouble is achieved.

Since XG-7500 employs a high-speed three-processer and a high-speed CCD camera, maximum frame rate is 200 Hz without image processing. However, typical monitoring rate is to be around 100 Hz at the beam intensity of 2×10^8 carbons per second, due to following reasons. 1) The image processing takes few milliseconds as will be explained later. 2) Because of low brightness from the fluorescent screen, the shutter speed must be tens of millisecond for low intensity beam. The system can be applied not only for beam profile monitor but also as a tool to monitor the stability of beam position and size during therapeutic irradiation. We call them semi-non-destructive monitor. When the beam center position and size measured by the SCN is inevitably changed over the setting tolerance, the beam is immediately turned off.

This controller can be connected to the programmable logic controller (PLC) by Control & Communication Link (CC-Link) [5]. The devices such as a steering magnet and the SCN are linked together with using CC-Link, high-speed and highly deterministic input-output response are achieved easily. Thus we can make the system simply which monitored and corrected beam position automatically.

Fluorescent Screen

The fluorescent screen should be as thin as possible in order to avoid any expansion of the beam by multiple scattering through the screen. Therefore we chose a very thin (ZnS:Ag 2mg/cm^2) fluorescent screen. The water equivalent thickness of this screen is 46.8 micrometer. Thus this screen scatters particles of 350 MeV/u ^{12}C by an average angle of less than 0.1 mrad, so that the beam is measured with semi-non-destructively. Consequently we can use more than two monitors at the same time and multiple locations.

Since the peak wavelength of ZnS:Ag is 450 nanometer, we chose the CCD camera having a peak response between 500 and 600 nanometer. The scintillation decay time of ZnS:Ag is 70 microsecond, it is sufficiently faster than fluorescent measurement by the CCD camera.

The screen was irradiated 350 MeV/u ^{12}C beam with intensity 2×10^8 carbons per second more than 20 hours. Since there is no variation for the fluorescent screen at present, it is expected that the screen will be free from maintenance.

Image Processing

Although the SCN is used in two way; profile monitor and online monitor, almost same image processing is employed.

The measured image data is processed on the basis of a series of flow charts on the CCD controller. As shown in Fig. 2, (1) the CCD camera takes an image with the conditions such as shutter speed, CCD gain, and shutter

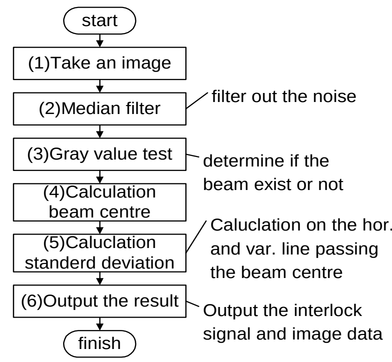

Figure 2: The flow chart of image processing.

timing set by operation file. (2) To decrease the dark noise, the image data pass through the median filter. (3) It is determined that if the beam exist or nonexist by measuring maximum brightness. If the beam does not come, the process is finished. (4) The beam center is calculated from beam profile image. (5) To obtain the beam size standard deviation on the horizontal and vertical line passing the beam center is calculated. (6) For using profile monitor, the taken image data are saved whenever it is needed. For using online monitor, if the calculated result of the beam center position and/ or beam size are changed over the setting tolerance during therapeutic irradiation, an error signal is put out. Then the beam is immediately turned off.

This image processing takes about 10 milliseconds. The interlock signal delay within 15 milliseconds from finishing measurement. The monitor system performs at a rate of 100 Hz, because the system controls acquisition and processing separately.

PERFORMANCE OF SCREEN MONITOR SYSTEM

Beam test was carried out using a physics-general experiment line 1 (PH1) at HIMAC. In the experiment we employed a mono-energetic 350 MeV/u ^{12}C beam. Figure 3 is online display of two beam profiles. From this figure, it shows the rotation of the elliptical beam profile. By using this display, we can verify the beam center position and size not only numerically but also visually. The beam center position and size are judged, and "OK" or "NG" symbol is displayed. The measuring parameter is changed by linked PLC automatically or manually on this display.

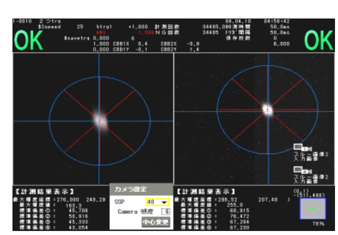

Figure 3: Online display of beam profile when irradiating C350MeV/u with extended flat-top.

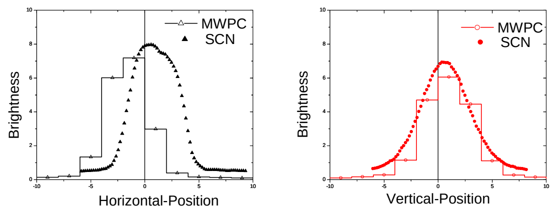

Figure 4: Both horizontal and vertical beam profile measured by the SCN and MWPC.

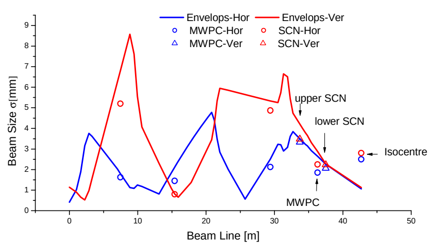

Figure 5: Beam envelopes compared with measured beam size.

Figure 4 shows a comparison between the two transversal beam profiles at the HEBT by the SCN and that of existing MWPC profile monitor in this measurement. The fluorescence was integrated during 20 milliseconds. Since the SCN provided the higher spatial resolution data than MWPC one, we can observe that while the vertical beam-profile was Gaussian shape, the horizontal beam-profile resembles a trapezoid[6]. Figure 5 is beam envelopes compared with measured beam size. From these result, the beam size measured by SCN is substantially agreement with calculated one. Due to scattering in the beam monitor and a ridge filter, the horizontal beam-profile was Gaussian shape and the beam size of both directions was expanded at the isocentor.

Beam Stability Test

Stability checks of the beam profile were also an important part during therapeutic irradiation. For applying this high-speed beam profile system, we can measure stability of the transverse beam position and brightness at a rate of 60 Hz as shown in Fig. 6. In this figure, the green curves show brightness from the fluorescent screen, the blue and red curves show the displacement of the beam position at the horizontal and vertical direction at the start of beam extraction, which is extended the cycle [7]. As shown Fig. 6, at the upstream SCN position, the beam profile swing by 0.5 millimeter in horizontal direction relative to beam intensity at about 1.5 second intervals. Particularly the beam moves left oblique projection.

There are two-tiered synchrotron rings at HIMAC, each of power supply is connected same electric transformer. Therefore the power supply is correlated, when a large amount of power is supplied to another ring.

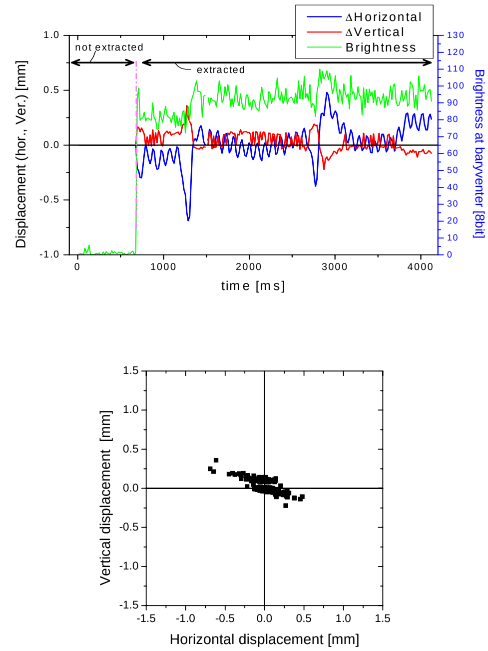

Figure 6: upper: The stricter of displacement of beam position and brightness during 4 second extraction. Lower: relationship of the displacement of beam position.

From these results, regarding spatial-resolution, the SCN satisfy requirement for online monitor.

SUMMARY

We have designed and tested high-speed and high-resolution screen monitor system with prototype scanning system at HIMAC. This system consists of the fluorescent screen and the CCD camera. Since the SCN provide not only 1D but also 2D beam profile data, we can obtain the more information of beam, e.g. beam profile incline to the left.

Beam position and size are calculated with 10 milliseconds in CCD controller. Therefore the SCN can be used for interlock monitor system. If the calculation result of the beam center position and size is reached to tolerance, an error signal is put out with about 100Hz.

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