REAL-TIME BEAM PROFILE MEASUREMNT SYSTEM USING FLUORESCENT SCREENS

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Abstract

An irradiation technique of a large-area uniform ion beam formed by multipole magnets is developed at the TIARA azimuthally-varying-field (AVF) cyclotron facility in Japan Atomic Energy Agency (JAEA). It is indispensable to perform uniform-beam tuning in real time for efficient operation. Therefore, we developed a real-time beam profile measurement system, composed of CCD cameras, fluorescent screens and an image analysis program based on LabVIEW. In order to measure the transverse intensity distribution of the beam through the fluorescence map converted from a camera image, the irradiation response of two fluorescent screens, DRZ-High (Gd_2O_2S:Tb) and AF995R (Al_2O_3:Cr), were investigated using several species of ion beams. The available fluence rate of the screens was found in the present system. The relative transverse intensity distribution could be obtained from the fluorescence in real time. It was also confirmed that the intensity distribution measured in this system agreed well with the relative intensity distribution obtained with a Gafchromic radiochromic film.

INTRODUCTION

The JAEA AVF cyclotron with a *K* number of 110 MeV accelerates and provides various species of ion beams at different energies for researches in the fields of biological and materials science, such as plant breeding, production of functional polymers and radiation hardness tests of space-use devices [1]. Various irradiation techniques have been developed for providing useful beams. In recent years, a large-area uniform beam irradiation technique using the nonlinear focusing force of octupole magnets has been developed [2]. In the technique, a Gaussian-like beam, obtained by multiple Coulomb scattering through a thin metallic foil, is transformed into a uniform beam on the target by folding the beam tail the by the nonlinear magnetic field. It is possible to irradiate the whole of a large-area sample uniformly at a constant fluence rate.

It is indispensable to form and evaluate the beam quickly for the efficient utilization of the uniform beam. The real-time measurement system of the beam profile based on the beam fluorescence was, therefore, configured and tested.

Table 1: Main Components of the Real-time Beam Profile Measurement System

Image analysis PC (PXI)	Chassis	PXI-1031	National Instruments Co.
	CPU	PXI-8106	
	Image capture device	PXI-1411	
	Chassis	PXI-1042Q	
	CPU	PXI-8106	
	Image capture device	PXIe-8234	
Fluorescent screen	Al2O3:Cr	AF995R	Desmarquest Co.
	Gd2O2S:Tb	DRZ-high	Mitsubishi chemical Co.
Measurement hardware	Horizontal camera	ICD42VP	Ikegami tsushinki Co.
	Vertical camera	scA1390-17gc	BASLER AG

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SYSTEM CONFIGURATION

The real-time beam profile measurement system is composed of CCD cameras and fluorescent screens. The fluorescent data is processed using a computer (PXI, National Instruments) with LabVIEW. Two different types of fluorescent screens, DRZ-High (Gd_2O_2S:Tb, 0.5 mm thick, Mitsubishi chemical) and AF995R (Al_2O_3:Cr, 1 mm thick, Desmarquest) have been chosen. The active layer (310 μm thick) of DRZ-High is put on a 190-μm plastic base. The DRZ-High screen is more sensitive and has lower afterglow as compared with AF995R. The main devices used in the present system and their layout are shown in Table 1 and Fig. 1, respectively.

The fluorescent screen is mounted on the target in a vacuum chamber where the large-area uniform intensity distribution of the beam is formed by octupole magnets. The target size is as large as 20 cm square at the maximum. When the large-area screen is monitored diagonally using a camera, the distortion of the fluorescent image is inevitable. As shown in Fig. 1, the camera A (B), therefore, monitors the screen from the below (from the right side) diagonally for the horizontal

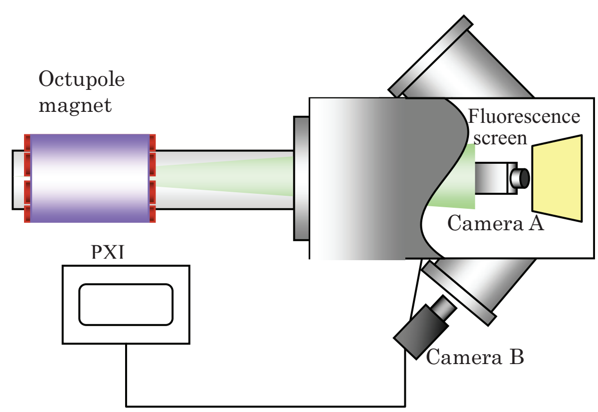

Figure 1: Schematic layout of the main components for the real-time beam profile measurement. The CCD cameras A and B monitor the beam fluorescence vertically and horizontally, respectively.

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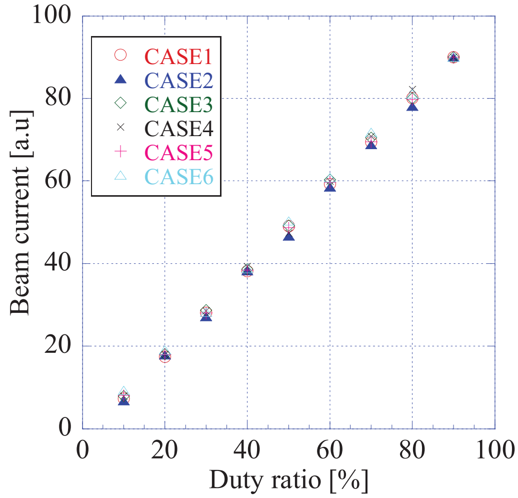

Figure 2: Scaled beam current of 10-MeV proton beams as a function of the duty of the electrostatic beam chopper. The beam current has been scaled by the value at a duty of 90%.

(vertical) profile of the beam.

The fluorescent light from the screen due to ion-beam irradiation is taken as an 8-bit image data of the luminance (fluorescent intensity) and processed in the PXI computer. The image data is analyzed for the evaluation of the beam intensity distribution in real time.

EVALUATION OF THE SYSTEM

In order to explore the available beam intensity i.e., to reveal the dependence of the fluorescent intensity on the fluence rate in this system, the beam irradiation experiment was carried out using 10-MeV proton and 520-MeV argon beams.

Beam Intensity Control Using a Beam Chopper

An electrostatic beam chopper, installed before the cyclotron, was used for the gradual control of the average beam intensity. Figure 2 shows the scaled beam intensity when the beam duty was changed by the beam chopper working at 1 kHz. The beam current of 10-MeV protons was monitored by a Faraday cup near the target. Six different conditions of the beam are plotted. It was found that, using the beam chopper, the beam intensity could be reduced within an error of 1%, independent of beam conditions. Thus, the fluence rate can be controlled in a wide range.

Irradiation Response of the Screen

Using the beam chopper, the fluence-rate dependence of the screens was investigated on the target. The uniform distribution of 40 ~ 50 cm^2 was formed on the target so that the transverse dimension of the beam could be determined easily. The fluence rate was determined from the beam cross-sectional area and current measured by the Faraday cup.

Figure 3(a) shows the dependence of DRZ-High and Desmarquest on the fluence rate of the 10-MeV proton beam. The fluorescent intensity is proportional to the fluence rate of the beam at a low fluence rate and then saturated. DRZ-High is available in the fluence rate on the order of 10^8 cm^{-2} s^{-1}, which is 15 times more sensitive than AF995R.

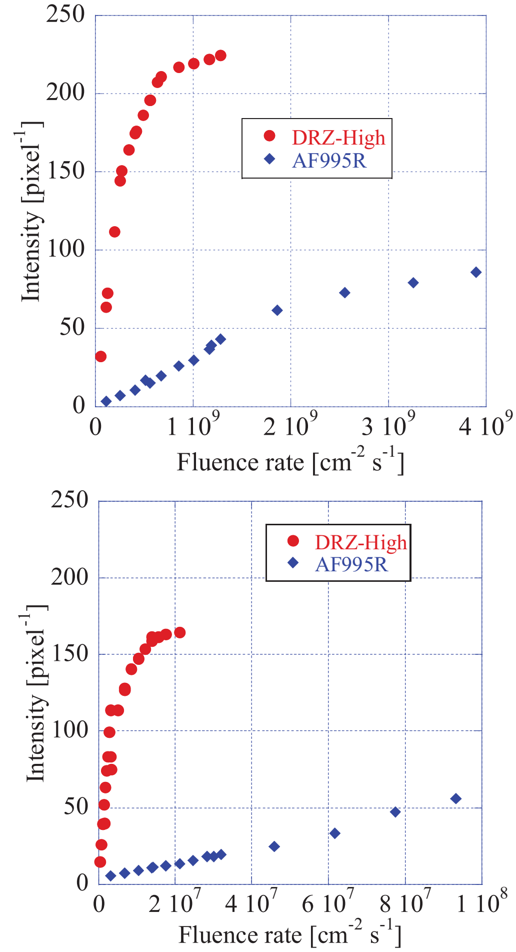

Figure 3: Fluorescent intensity of the two screens on the fluence rate of ion beams. (a) 10-MeV proton beams. (b) 520-MeV argon beams.

The result on the 520-MeV argon beam is shown in Fig. 3(b). The available fluence rate is about one order of magnitude lower than that of 10-MeV protons for each screen. The difference of the sensitivity between the two screens is larger than that in Fig. 3(a). This might be because the argon beam stops fully in the active layer of DRZ-High.

BEAM INTENSITY DISTRIBUTION MEASUREMENT

The present system was applied to beam tuning of the uniform distribution formation using multipole magnets [2]. The transverse intensity distribution of the beam on the target was measured based on the response characteristics of the fluorescent screen The horizontal scaled intensity distribution of the beam is shown as the red line in Fig. 4, which indicates the flat-top intensity distribution of 12-cm wide.

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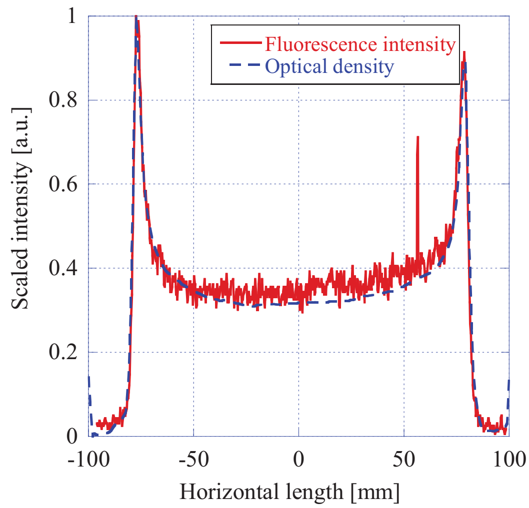

Figure 4: Comparison between the relative horizontal intensity distributions from the DRZ-High fluorescence and the optical density of the HD-810 Gafchromic film. The HD-810 film was irradiated with the 10-MeV proton beam of 15 nA for 10 s.

For the verification of the intensity distribution measured by the beam fluorescent, a Gafchromic radiochromic film was irradiated with the same beam [3]. The scaled intensity distribution obtained from the optical density of the Gafchromic film is given by the blue dashed line in Fig. 4. As clearly seen in the figure, both distributions agree well except for the noise included in the beam fluorescence.

SUMMARY

The real-time beam profile measurement system was developed for the efficient formation of the uniform ion beam. We investigated the beam irradiation response of two fluorescent screens DRZ-High and AF995R for 10-MeV proton and 520-MeV argon beams. The fluorescent intensity was proportional to the fluence rate of the beam at low fluence rates for both screens in the present system. The real-time analysis of the relative intensity distribution of the beam was carried out for the uniform beam formation. It was confirmed that the relative intensity distribution of the beam obtained from the fluorescence agreed well with the relative intensity distribution determined from the Gafchromic film, which verified the measurement system developed.

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