Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

Optical Design of the Camera Based Beam Viewer for 100 MeV Proton Beam

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Keywords : proton beam, beam viewer, beam diagnostics, beam profile

1. Introduction

The scintillating screens with camera are widely used in accelerator facilities for transverse beam profile monitoring, because that method was simple and precise compare to other beam diagnostics. But the image sensor is sensitive to the secondary radiation, which is induced by the interaction between particle beam and scintillation screen. The radiation damage degrades the performance of the image sensors by increasing the hot-pixels. This problem is the obstacles for camera based beam profile monitoring. Thus, we will prepare the radiation tolerant beam viewer by using the cooled CMOS camera. In this contribution, we would like to introduce the basic optical design for the new radiation tolerant beam viewer system.

2. Methods and Results

2.1 Cooled CMOS camera

When pixels are damaged by radiation, image sensors can suffer the increased dark current and they appear to be much brighter than surrounding pixels. Such pixels are called hot-pixels [1]. But the active cooled image sensor does not show significant production of hot-pixels by radiation damage. The production of hot-pixels is dependent the temperature, they are reduced by a half for a every 6°C drop in temperature. When a 20 °C drop in temperature could reduce the hot-pixels by 10dB.

Thus, we selected the cooled CMOS camera as a beam image observer for the camera based beam viewer system.

Fig. 1. Cooled CMOS camera

2.2 Beam viewer system

The beam viewer system is consisted of as bellows,

- Cooled CMOS camera
- Lens
- Frame grabber
- View port
- Phosphor screen

The camera can be remotely controlled and synchronized with beam trigger. The phosphor screen was chosen with P43 coating, which is cost-effective, high yield of light and its radiation tolerant. And then, phosphor screen can be insert to the beam path by remote control. The Figure 2 shows the schematics of beam viewer system.

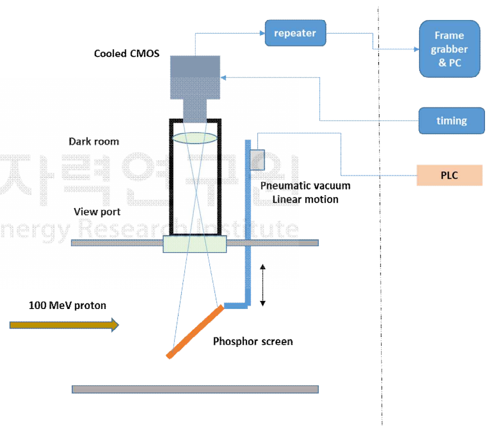

Fig. 2. Schematics of beam viewer system

2.3 Optical design

The phosphor screen is tilted with 45° in the vacuum chamber, the imaging light through the vacuum window. the angle between the proton beam and the observer is the 90 °. This optical set-up does not change the observed beam size. The specification of phosphor screen is described as bellows,

- P43 coated on aluminum substrate
- Size : 100 mm × 100 mm
- P43 coated area : 80 mm × 80 mm
- Thickness of P43 : 50 um

The field of view (FOV) was defined with 80 mm × 56.5 mm, due to 45° tilted in vacuum chamber as shown as figure 3.

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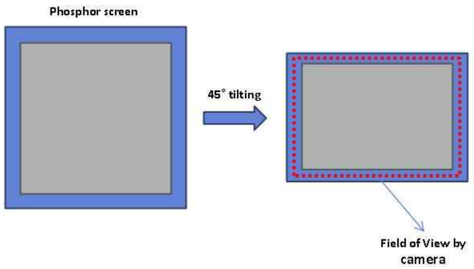
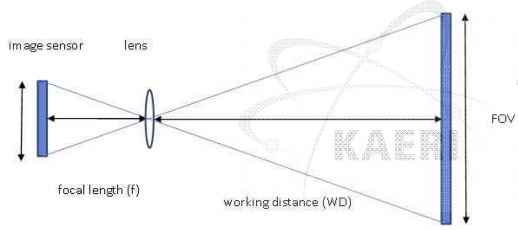


Fig. 3. Target FOV of beam viewer

The CMOS image sensor have the 4.3" optical format, the sensor size was fixed with 18.9 mm(H) and 10.6 mm (V). To obtain the target FOV, the working distance of camera and the focal length of lens have to be determined. When two kinds of lens was considered, the working distance of camera easily determined through the relationship between focal length and working distance as shown as figure 4.



$$\tan(\frac{\theta}{2}) = \frac{Hor\ V/2}{f} = \frac{FOV/2}{WD}$$

Fig. 4. Relationship between the FOV, focal length and working distance.

the focal length of lens was selected with 50 mm and 75 mm, in the two case of the focal length, the calcultion results of the working distance is described as table I. The longer focal length means the longer working distance of camera. the longer working distance of camera have a merit, which can be reduce the radiation damage on camera from the radiation induced by the interaction between proton beam and phosphor screen. but, in the case of the longer focal length, it is required the larger viewing area.

Table I: the calculation of the working distance

	f: 50 mm		f: 75 mm	
WD [mm]	FOV (H) [mm]	FOV (V) [mm]	FOV(H) [mm]	FOV(V) [mm]
200	75.5	42.5	50.3	28.3
250	94.4	53.2	62.9	35.4
270	**101.9**	**57.4**	67.9	38.3
300	**113.2**	**63.8**	75.5	42.5
400	150.9	85.1	**100.6**	**56.7**
450	169.9	95.7	**113.2**	**63.8**

Finaly, the focal length of lens was determined to 75 mm to reduce the radiation damage on the CMOS camera. In this case, the required view area of vacuum window was 68 mm. the defined optical design parameter of the beam viewer system as summarized as Table II.

Table II: Optical design parameters of beam viewer system

optical parameters	
target FOV	80 mm (H) × 56.6 mm (V)
design FOV	113.2 mm (H) × 63.8 mm(V)
focal length	75 mm
working distance	450 mm
view area	68 mm (4.5" CF)
stroke of linear motion	100 mm (1.33 " CF)

3. Conclusions

We have plan to establish the camera based beam viewer system by using the radiation tolerant cooled CMOS camera. In this contribution, the determined optical design parameters of the beam viewer system were described.

Acknowledgement

This research was supported by the National Research Foundation of Korea (NRF-2021M2D1A1045615).

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[1] A. Huber, A. G. Sergienko, D. Kinna, V, Huber, A. Milocco, L. Mercadier and et, al. "Response of the imaging cameras to hard radiation during JET operation", Fusion Engineering and Design, Vol.123, p. 669-673, 2017.