ISBN: 978-3-95450-230-1 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2021-TUPP13

BEAM PROFILE MONITOR DESIGN FOR A MULTIPURPOSE BEAM DIAGNOSTICS SYSTEM

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Abstract

Beam diagnostic tools are the key component of any accelerator. They provide the way to measure beam parameters in order to monitor the accelerator performance. The beam profile is a bridge to other beam parameters such as transverse position, size, divergence and emittance. Depending on the characteristics of the beam, there are different tools and methods for beam profile monitoring. A suitable diagnostic tool for measuring the beam profile with high resolution is scintillator view screens which are the oldest and most precise tools. This paper presents the beam profile monitor design for a multipurpose beam diagnostic system. This system is aimed to measure the beam profile, transverse parameter, momentum spectrum and current. The concerning issues in the beam profile monitor design such as image resolution, radiation damage and scintillator temperature distribution have been discussed.

INTRODUCTION

Diagnostic instruments are a set of equipment used to measure the various parameters of the particle beam in accelerators. A suitable diagnostic tool for high-resolution profile monitoring are scintillation screens that utilize the mechanism of the scintillation phenomenon. In this method, according to Fig. 1, the scintillation light is recorded by an optical system and processed in order to extract the beam parameters. We designed a scintillation screen monitor using YAG for a multipurpose beam diagnostics system that will be able to measure proton beams up to 200 keV energy and electron beams up to 10 MeV.

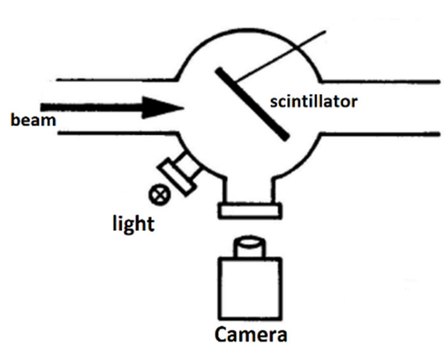

Figure 1: Layout of beam profile diagnostic system.

In this paper, the concerning issues in the beam profile monitor design such as image resolution, radiation damage, temperature distribution and charge accumulation on the scintillator have been discussed. Specially, using the Geant4 Monte Carlo code, we have estimated the resolution of the scintillator view screen and the temperature distribution of the scintillator is simulated using Comsol software and its effect on measured beam profile has been addressed.

PROFILE MONITORING DESIGN

The design procedure includes, scintillator material selection, handling the thermal and charge accumulation issues and estimation and improvement of the measurement resolution.

Selection of Scintillation Material

For the scintillation material high light yield, resistance to radiation damage, vacuum compatibility, linear response and lower temperature sensitivity is demanded, YAG:Ce is a trade-off choice since it presents good scintillation yield and radiation damage resistance and low temperature dependence as discussed below [1].

Radiation Damage

Cavity and atomic displacement are the main types of radiation damage in scintillation crystals [2]. These lattice damage alters the energy of the crystal bond. As a result, optical parameters such as the yield and frequency of scintillation output light change [3]. Radiation damage is directly related to LET (the amount of energy that an ionizing particle transfers to the material per unit distance) of incident radiation, and the LET of each beam is directly related to its mass and charge and inversely related to its energy [4]. Therefore, the damage of the electron beams is generally small compared to the ion beams due to their mass.

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10th Int. Beam Instrum. Conf. IBIC2021, Pohang, Rep. of Korea JACoW Publishing
ISBN: 978-3-95450-230-1 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2021-TUPP13

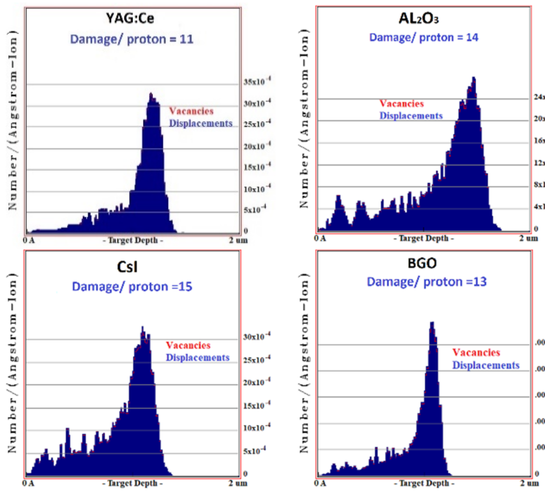

Figure 2: Comparison of radiation damage of scintillators caused by a 200 keV proton.

The scintillation damage caused by a 200 keV proton beam in conventional scintillators are simulated using TRIM software. According to the Fig. 2, the YAG scintillator is the most resistant material to be used as a beam diagnostic tool with the minimum amount of cavities and displacement created (11 damage per collision).

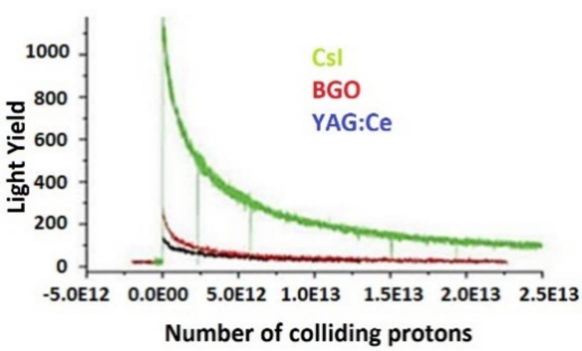

Figure 3: Changes in the optical response of the YAG, BGO and CsI scintillation against radiation damage [5].

This result is consistent with the experimental data obtained by Simon *et al.* (Fig. 3), which emphasizes the high resistance of the YAG scintillation to proton radiation [5]. As shown in Fig. 3, the optical response of CsI and BGO after irradiation of 5,000 billion protons is about 20% and 16% of the initial value, respectively, while for the case of YAG, it is 31%.

Temperature Distribution

As the proton beam strikes the surface of the scintillator, its temperature increases and resulting in degradation of its optical response.

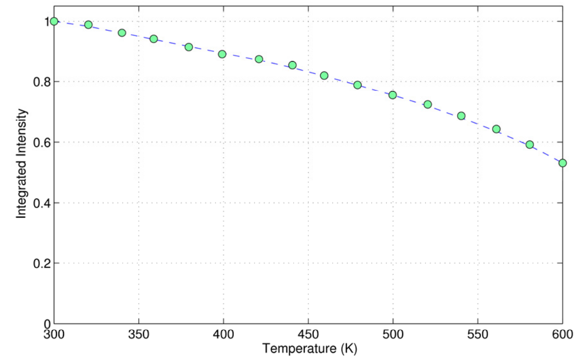

Figure 4: The temperature dependence of YAG yield [3, 6].

Bachmann *et al.* calculated the effect of temperature changes on the intensity of the YAG scintillation yield [3].The results are shown in Fig. 4, where the light intensity of YAG is reduced by about half the maximum value at a temperature of about 600 K ($T_{1/2}$). This temperature is conventionally selected as the maximum allowable temperature of the scintillator. To calculate the final temperature of the scintillator, we simulated the temperature distribution using Comsol software (as shown in Fig. 5) and obtained the final temperature of the YAG: Ce scintillator for different beam powers. Information about the simulated problem is given in Table 1.

Table 1: Simulated Problem Information

YAG (30*30mm*50 um)	scintillator
Al (30*30mm*10 mm)	substrate
Copper cylinder (R=5 m , h=200 mm)	holder
10 mm	Beam radius
From 0.1 to 10 W	Beam power

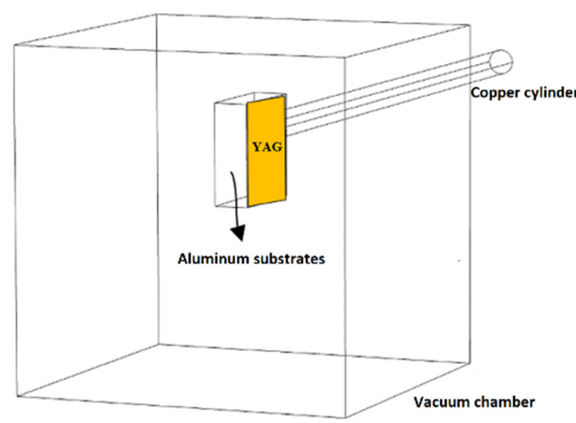

Figure 5: Schematic of the simulated problem.

If the scintillator has no substrate, the scintillator temperature at high powers will reach to 600 K ($T_{1/2}$). The average final scintillation temperature for different beam powers is shown in Fig. 6.

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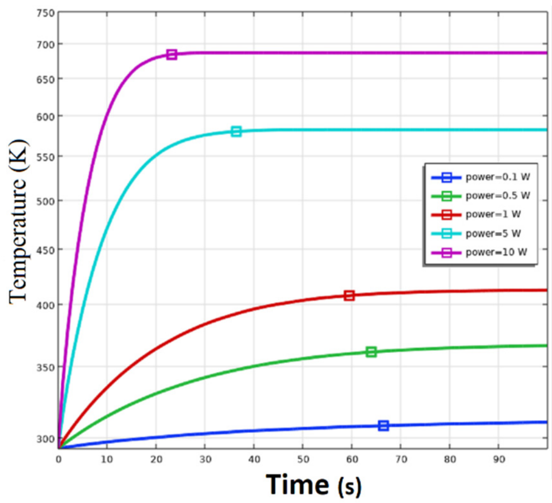

Figure 6: Simulation of the final temperature of the YAG for different beam powers using Comsol software.

As you can see in Fig. 7, at a beam power of 5 W, the temperature of the scintillator has reached above the $T_{1/2}$, also the temperature difference between the center of the scintillator and the sides reaches 300 K which affects the linearity of the scintillator response. In fact, the presence of temperature differences leads to changes in the optical efficiency of different points of the scintillator compared to the ideal state and this can disrupt the beam profile [6].

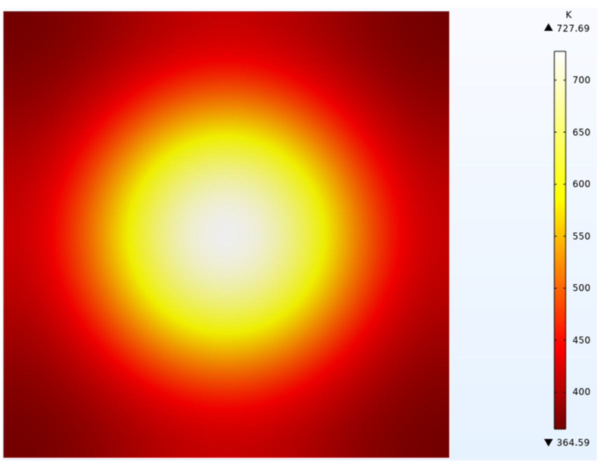

Figure 7: Temperature profile of YAG for 5 W beam power.

Using MATLAB software, we simulated the change of the beam profile for different powers of the input beam. An example of a one-dimensional beam profile for a 5 W beam power is shown in Fig. 8. The presence of a temperature difference of 300 K between the center of the scintillator and the sides increases the width (RMS) of the beam.

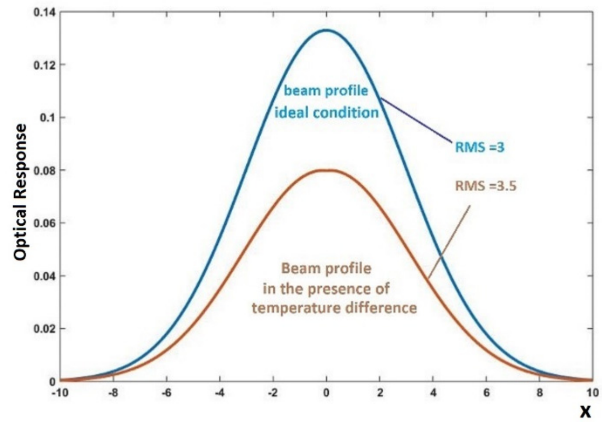

Figure 8: 1D beam profile for 5 W beam power (blue diagram: no temperature difference in scintillation, brown diagram: 300 K temperature difference).

According to Fig. 8, the presence of a temperature difference causes a 17% increase in the width (RMS) of the beam. As a result, the profile of the measured beam has changed and the final shape of the beam has been disturbed. Arrangements must be made to minimize this temperature difference. To do this, we place a 10 mm thick aluminum substrate with a copper holder behind the scintillator. The addition of an aluminum substrate and a copper improves the heat transfer process, thus minimizing the temperature difference of the scintillator at different points.

According to the simulation results shown in Fig. 9, by placing the aluminum substrate and copper holder, better heat transfer has taken place in the scintillator and the temperature of the scintillator has reached below the allowable temperature ($T_{1/2}$) . On the other hand, the temperature difference between the center of the scintillator and the sides is reduced significantly (temperature difference is less than 1 K), and therefore there is no significant change in the ratio of the light output of the scintillator and the width of the beam.

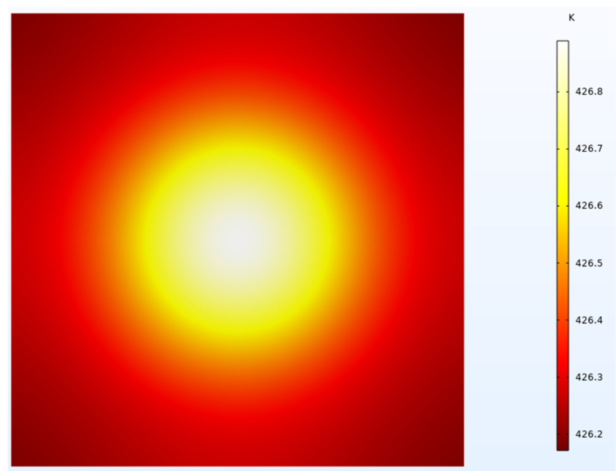

Figure 9: Temperature profile of YAG for 5 W beam power in the presence of aluminum substrate.

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Also, by connecting the aluminum substrate to the ground (as shown in Fig. 10), the charge accumulation in the scintillator and damage caused by sparks to the scintillator is prevented.

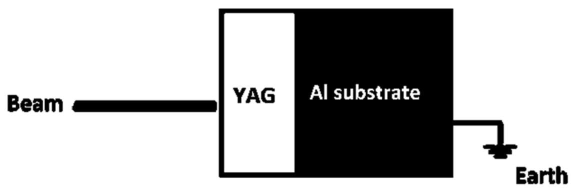

Figure 10: Schematic of the connection of the aluminum substrate to the ground to prevent sparks.

Image Resolution

In order to estimate the image resolution limits due to coulomb scattering, the Geant 4 Monte Carlo code is used. We simulate the collision of an ideal zero-dimensional beam with the YAG scintillator screen. Due to multiple scattering within the scintillator, an area of the scintillator is illuminated. Figure 11 shows the scattering of protons in the YAG scintillator. The dimensions of this area is a measure of the resolution of the scintillator.

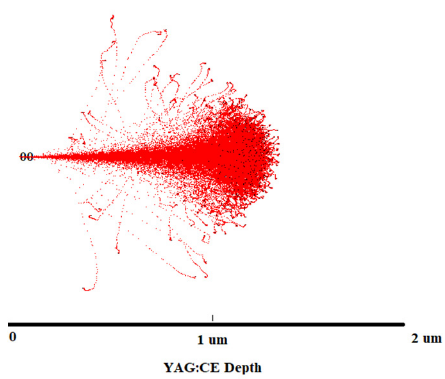

Figure 11: Multiple scattering of proton beam in YAG scintillator (Srim simulation).

Figure 12 shows the transverse distribution of the profile of this ideal beam in both x and y directions with its 2D profile. By calculating the RMS (size) of the beam profile, a measure of the scintillation resolution can be obtained.

As shown in the Fig. 12, the RMS for a 200 keV proton beam is less than 0.1 μm (RMS =72 nm) with an error of less than 2%, which indicates the very high resolution of the YAG scintillator. To benchmark the results, we simulated the problem with the MCNP code, which resulted in a difference of less than 2% compared to the Geant4 code. This difference is due to the different methods of problem solving by the codes.

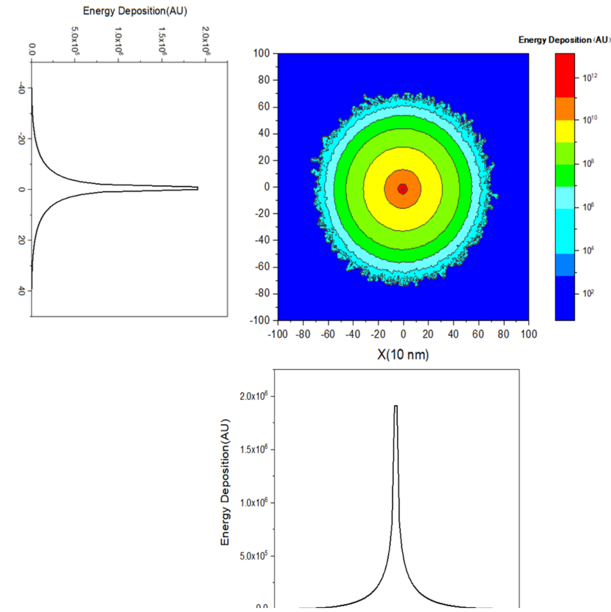

Figure 12: The profile of the 200keV proton beam on the YAG scintillation target.

CONCLUSION

In this paper, the design procedure such as scintillator material selection, handling the thermal and charge accumulation issues and estimation and improvement of the measurement resolution have been studied. In order to select the resistant scintillator material, the scintillation damage caused by a 200 keV proton beam in conventional scintillators are simulated using TRIM software and the YAG scintillator was the most resistant material to be used as a beam diagnostic tool with the minimum amount of cavities and displacement created (11 damage per collision). The effects of scintillation temperature changes on the beam profile were also investigated. At 5 W, the temperature difference between different points of the scintillation, affects the linearity of the scintillator response and causes a 17% increase in the width (RMS) of the beam. To reduce these damaging effects on the beam profile, it was suggested to place an aluminium substrate behind the scintillator. Finally, using Geant 4 Monte Carlo code, we simulated the collision of an ideal 200 kV proton beam with the YAG: Ce scintillator and obtained the beam transverse distribution (beam profile). By calculating the RMS (root mean square) of the beam profile, we obtained a measure of the resolution of the YAG: Ce scintillator, which was less than 0.1 microns, and confirmed the proper resolution of the YAG: Ce scintillator for use as diagnostic tool.

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ISBN: 978-3-95450-230-1 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2021-TUPP13

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