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Review

Beam monitor detectors for medical applications



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ABSTRACT

Beam monitoring is fundamental for any particle accelerator. In particular, it is a crucial issue in medical applications of particle physics due to the required high precision and reliability. Radioisotope production and cancer radiotherapy require specific beam monitor detectors. In this paper, three recently designed instruments are reviewed. One of them is a newly designed beam monitor detector based on doped silica and optical fibres. It represents a promising solution. This apparatus can be used with various types of beams and for both hadrontherapy and radioisotope production. For this reason, a more detailed description of this multipurpose detector is provided.

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1. Introduction

Beam monitoring is essential for any particle accelerator either for commissioning or during regular operation. The precise control of the beam is crucial in medical applications, radioisotope production and cancer radiotherapy in particular.¹ Diagnostic devices are usually installed to obtain information for an optimal control during the whole irradiation process.

In hadrontherapy, tumours are irradiated with millimetre precision and an accurate beam monitoring allows fulfilling the requirements of the treatment plan. Radioisotope production requires an accurate control of the target bombardment for an efficient, safe and reliable production.

The wide spread of medical accelerators boosted the development of precise, robust and reliable instruments for beam

monitoring. The beam intensities are different in isotope production and hadrontherapy. In the case of hadrontherapy, proton or carbon ion beams are used with currents of the order of 1 nA. For the production of radioisotopes, the beam intensity is much higher and currents in the range of 10–500 μ A are used. Thus, there is a need for both specific detectors and multipurpose instruments.

In the case of hadrontherapy, several detectors have been recently developed.^{2–4} Two of them are reviewed in this paper. They are based on sophisticated technologies, which are here only briefly described. Due to their cost, size and complexity, the number of installed devices is often very limited.

For the realization of a multipurpose, robust and relatively cheap instrument, simple but reliable technological solutions have to be employed. At the Laboratory for High Energy Physics of the University of Bern, a prototype based on doped silica and optical fibres has been recently realized and tested.⁵

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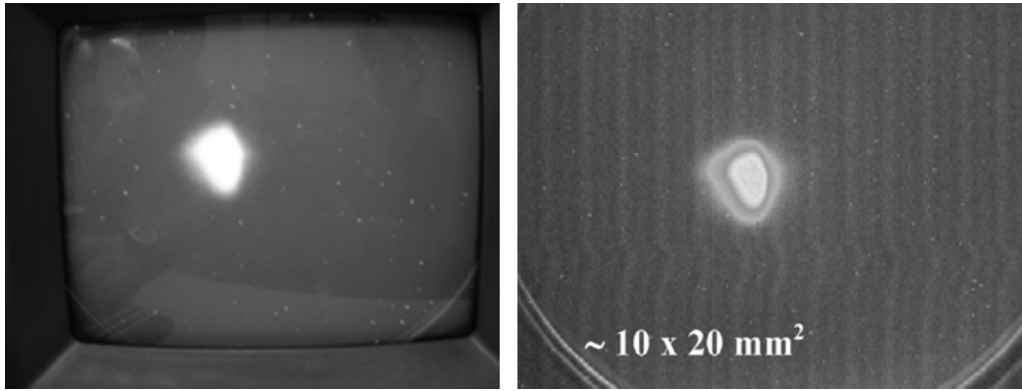


Fig. 1 – Beam profile measured with the beam monitor detector based on secondary electron emission by a thin foil. On the left, the CCD signal on a video monitor is presented. On the right, the signal digitized with a frame grabber is shown.²

The aim of this paper is to give a brief overview of current developments in beam monitoring. Three different detectors are reviewed. One of them represents a multipurpose instrument, and for this reason, a more detailed review is provided.

2. Beam monitor detectors for hadrontherapy

2.1. A real-time beam monitor based on secondary electron emission by a thin foil

This detector is based on secondary electron emission by an ion beam impinging on a metallic foil. The first prototype of this device has been developed by the TERA Foundation.² A thin Al foil is placed in the hadron beam path at 45° with respect to the beam direction. The energy lost by the beam in the foil is transferred to the electrons of the medium. Then, δ -rays are produced together with electrons of the energy below 50 eV that are called secondary electrons (SE). The number of SEs ejected from the foil is proportional to the local beam intensity. The SEs are accelerated to the energy of 20 keV and focused by an electrostatic field towards an imaging device. To measure the two-dimensional profile (Fig. 1) and the intensity of the beam a micro channel plate (MCP) with a phosphor screen have been used. The read-out is provided by a charged coupled device (CCD). In further development, a back-thinned monolithic pixel sensor was used.

The detector is precise and reliable but relatively large and expensive. It is suitable only for beam lines and, being designed for hadrontherapy, cannot be adopted for higher currents without major modifications. New developments are now pursued by the TERA Foundation and the Laboratory of High Energy Physics of the University of Bern.

2.2. MATRIX: a pixel ionization chamber for on-line beam monitoring in hadrontherapy

The MATRIX segmented ionization chamber³ is made of five successive fibreglass frames, as shown in Fig. 2. It has been developed by the TERA Foundation and the INFN in Turin. The sensitive volume corresponds to the air gap between the

cathode and anode foils. The anode foil and the read-out electronics represent the most innovative parts of this instrument.

The detector operates in air and consists of a 21 cm × 21 cm sensitive area divided in 1024 pixels of 6.5 mm × 6.5 mm. The 1024 channels are read out by 8 electronic boards capable of detecting charges down to 100 fC at 5 MHz. Each channel is equipped with a 16-bit digital counter whose output value is proportional to the integrated charge.

Using this detector, it is possible to obtain a two-dimensional map of a clinical beam. It has been successfully tested with a proton beam of 149 MeV at the Loma Linda University Medical Center, the first hospital-based proton therapy centre in the world.

3. A beam monitor detector based on doped silica and optical fibres

Many commonly used particle detectors are based on scintillation. Pure silica and plastic scintillating fibres are used in nuclear and particle physics.^{6,7}

Plastic fibres are inappropriate for the monitoring of high current beams due to their low resistance to heat. They can be used in low current regime, e.g. in hadrontherapy. An array of plastic scintillators has been already developed for the Italian National Centre for Hadrontherapy CNAO.⁸

Contrary to plastic fibres, uncoated doped silica fibres have a very good resistance to heat. The resistance of Ce³⁺ doped quartz surfaces up to temperatures of 1300 °C has been reported.^{9,10} Moreover, their scintillation properties are well suitable for a read-out with photomultiplier tubes (PMT).

Due to the scintillation properties and resistance to heat of uncoated doped silica fibres, they have been used for the construction of a beam monitor detector developed at the Laboratory for High Energy Physics in Bern.⁵ The idea was to develop a universal and cheap detector for the monitoring of beams ranging from fractions of nA to several μ A. The scheme of the designed detector is presented in Fig. 3. It is based on a single doped silica fibre moving transversally through the beam. Since uncoated doped silica fibres are very fragile and have a considerable attenuation length (several dB/m), a scintillating sensing fibre of only about 10 cm in length is used. The

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