Nuclear Instruments and Methods in Physics Research B 355 (2015) 268–271

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Results of testing the energy dispersive Si detector with large working area

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ARTICLE INFO

Article history:
Received 30 November 2014
Received in revised form 26 February 2015
Accepted 27 February 2015
Available online 17 March 2015

Keywords:
Spectrometer
Crystal
Parametric X-ray radiation
Hadrons
Accelerator

ABSTRACT

In this work the testing results for the spectrometer with a large sensitive area developed for the crystal monitoring station of modern hadron accelerator control systems used for the beam collimation are presented. The investigations were carried out at the XLab Frascati LNF laboratory aiming mostly in studying the detector sensitivity uniformity throughout the sensor area.

1. Introduction

Further development of the modern accelerator physics and applications related, including biomedical technologies, material science, etc..., is mainly connected with novel accelerator techniques providing the high current production devices with the low beam emittance.

The mentioned trends of the modern accelerating technology are restricted to the relevant problem of adequate real-time beam diagnostics. New methods of diagnostics are required for the parameters reached by the time for both maintaining and planing operation (such as power, transverse and linear dimensions of accelerated particles in the beam). New approaches to describe the interaction processes of a beam or its field with a target are necessary for beam diagnostics. The base of these new approaches is the use of screens and thin targets since the essential temperature gradients can occur in a local area of the beams interaction with a target. Because of a short interaction time, the latter effect converts the matter into the extreme state without destroying a target.

One solution of the diagnostics and monitoring problem based on the use of parametric X-ray radiation (PXR) has been recently proposed [1–3] and experimentally investigated [4–5]. In particular, PXR emitted by relativistic protons in crystals was observed in [6–8]. In the works [7,8] the semiconductor silicon detector used for the detection of PXR photons is 380 μm thick with a sensitive surface area of about 13 mm^2 and 25 μm beryllium window. Because of the wide angular distribution of PXR produced by 400 GeV/c protons or lead ions with equivalent energy (see Ref. [2]), in order to increase the accuracy of measurements of the PXR yield the energy dispersive spectrometer having a larger area of the sensitive surface (more than 130 mm^2) developed by Tomsk Polytechnic University jointly with the Petersburg Nuclear Physics Institute is proposed to use.

Recently some papers have discussed the experimental study of PXR generated in a Si crystal by the separated proton beam with energy of 50 GeV at the accelerator U70 and the radiation was observed using the energy dispersive Amptek XR-100CR detector with a sensitive surface area of 6 mm^2 and our detector with a larger area of the sensitive surface [9,10]. However, during

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http://dx.doi.org/10.1016/j.nimb.2015.02.071
0168-583X/

experiments the spectrometer registered problem at each beam/target interaction. The challenge was solved by moving the detector to a considerable distance from the beam. However, even at a large distance the detector was continuously overloaded due to the strong background radiation.

This paper presents results of studying the sensitivity uniformity throughout the sensor area after the detector upgrade.

2. Equipment

Spectrometer consists of a cryostat with 7 L dewars, head part with a preamplifier and spectrometric devices (see. Fig. 1). In the head part the silicon-lithium pin-detector with 5 mm thickness and an area of 130 mm^2 and input cascade of the preamplifier is placed. The distance between the sensor surface and the entrance 25 μm beryllium window is equal to 9 mm. Silicon-lithium detector and input cascade of the preamplifier are cooled by the liquid nitrogen through a copper cold conductor. On the cryostat flange the main section of the preamplifier is fixed. A vacuum in the cryostat is created by the sorption pump. The detection part is connected to a spectrometer device with a connector on the preamplifier. The dependence of the quantum efficiency shown in Fig. 1 is obtained by simulation of the interaction X-rays with 5 and 0.5 mm silicon taking into account absorption in 25 μm beryllium using Geant4 [11]. Simulation results for the thickness sensor 500 μm in a good agreement with the data for Amptek XR-100CR [12]. In this paper, the quantum efficiency is not experimentally determined.

The behavior of the detector in the experiments [9,10] is due to the fact that in the detection part was used preamplifier with pulsed feedback. In this case, the preamplifier provides lower noise compare to preamplifiers using other types of feedback, but can be "locked" due to the overload or if hit by a large amount of charges in the working volume of the detector (for example, from high-energy particles). Based on the analysis of the experimental work results on the accelerator U70, it was decided to upgrade the preamp. To provide the rapid withdrawal of electron–hole pairs created in the working volume of the detector, it is advisable to use the input preamplifier with resistive feedback.

The following upgrades have been carried out:

- changes in the preamplifier work mode to resistive feedback in order to remove "locking" effects as well as to increase its dynamic range in the feedback loop on the maximum allowable counting current;
- replacement of the input stage of field-effect transistor with a resistor feedback considering the increment of the maximum allowable counting current (count rate multiplied by the energy);
- development of preamplifier power cord with additional output for a constant voltage control of feedback by an external DC voltmeter;
- realization and testing of the detector using sources of ionizing radiation – Fe-55 (energy is 5.9 keV, photon energy of the investigated PXR is from 4.5 keV to 25 keV) and Co-57 (energy is 122 keV, the equivalent energy of ionization losses of particles background radiation in silicon with 500 μm thickness is about 150 keV [9,10]).

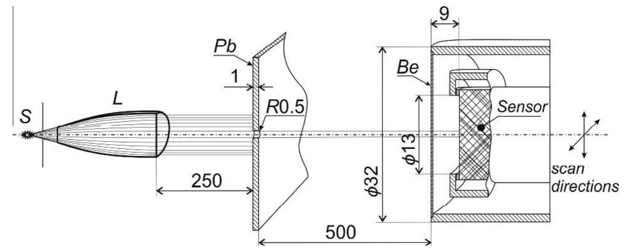

Fig. 2. A schematic view of the experiment layout (S – source, L – polycapillary X-ray semilens).

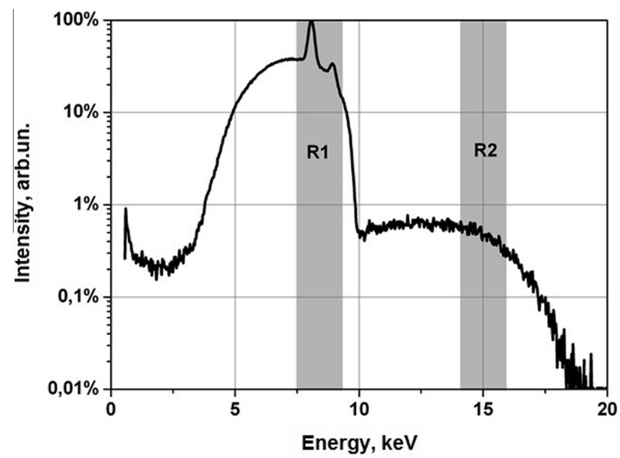

Fig. 3. The spectrum registered by the detector from X-ray Cu tube.

The voltage adjustment range of feedback ranged from −1.7 to +16 V. At loading of the detector X-rays with energy of 5.9 keV to 100,000 counts/s the feedback voltage was +7 V, and when loading X-rays with an energy of 122 keV to 5200 counts/s the feedback voltage was +2.1 V, consequently, the detector was able to record up to 50,000 counts/s of photons with energy of 122 keV. In

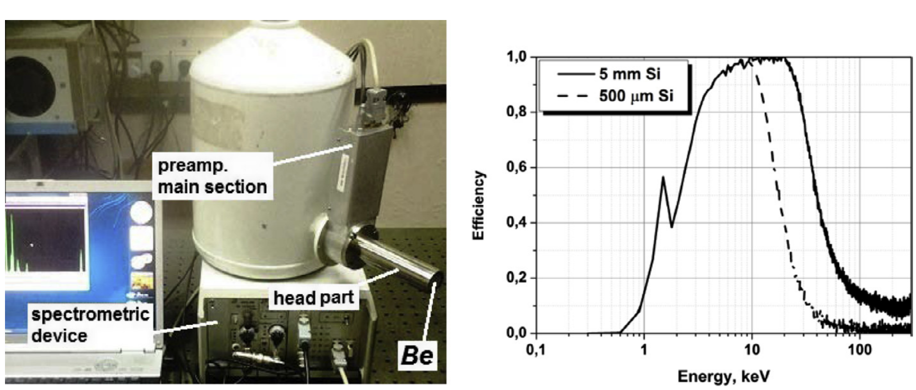

Fig. 1. Photo of the spectrometer (left) and theoretical quantum efficiency of the SSD (right).