DESIGN AND NUMERICAL INVESTIGATIONS OF SCINTILLATION BEAM LOSS MONITOR FOR PolFEL*

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Abstract

The Beam Loss Monitor (BLM) system is used mainly for machine protection and is particularly important in the case of high energy density of accelerated beam, when such a beam could lead to serious damages in the case of uncontrolled loss. Operational parameters of PolFEL linear accelerator induced needs to install and operate the BLM system. The BLM concept for PolFEL is based on several scintillation probes placed along the linear accelerator. The paper reports on numerical investigation of electron and X-ray radiation induced during fast electron losses. We also present design of BLM detectors and results of first tests of a prototype on the linear electron accelerator at Solaris research centre.

INTRODUCTION

The main purpose of Beam Loss Monitoring (BLM) system is to detect events of charged particle escaping from its designated path (beam pipe). Such a system, while not being coupled directly with the particle beam, is important from the point of view of machine protection. While above feature is crucial for facilities with high beam current and energy density, ability to detect interaction of particles with accelerator components, could also be used to indirect control of beam position and alignment and fine-tuning these parameters, also for low-power devices.

THE PolFEL PROJECT

The Polish Free Electron Laser, PolFEL, is planned to be operational in the 2024. It is a superconducting FEL, based on the TESLA SRF technology, which could operate in continuous wave (cw) and long pulse (lp) mode. Electron beam, generated in all-superconducting gun will be accelerated by four cavities and then delivered to either THz-undulator, or further accelerated and delivered to VUV-undulator. After passing through undulators, the electron will be used for other experiments (e.g. Inverse Compton Scattering). The maximum electron energies for the beamlines, a THz/IR line and VUV line, are equal to 79 and 154 MeV, respectively. The most important parameters of PolFEL electron accelerator are listed in Table 1 [1, 2].

Table 1: The Parameters of Polfel Electron Beam (Maximal Values, Continues Wave Mode)

	Gun	VUV line	THZ line
Bunch charge [pC]	250	100	250
Repetition rate [kHz]	50	50	50
Bunch length [ps]	10	0.4	10
Beam energy [MeV]	4	154	79
Beam current [μA]	12.5	5	12.5
Beam power [W]	-	770	940

BEAM LOSS AND MACHINE PROTECTION

Beam losses, i.e. deviation of beams from designed path, could be divided into two main classes: regular losses and irregular ones.

Regular Losses

Regular beam loss occurs as a part of normal accelerator operation and are generally unavoidable. However, they are typically localized on the collimator or aperture limits. Such losses could be used for machine diagnostics, e.g. injection studies, tail measurements or lifetime limitations. For further details, see e.g. [3, 4].

Irregular Losses

Irregular or uncontrolled (fast) losses, could happen as a result of misaligned beam, leaks in vacuum system, or other failure of accelerator components. The beam hitting accelerator walls could lead to, e.g.: vacuum lost (in case of melting the vacuum vessel wall), radiation damage of sensitive components (electronics), quench in superconducting circuits (in case of excessive heat deposition by colliding beam). Monitoring of fast losses could also be used to diagnose problems around the machine, like vacuum leaks, obstacles or microparticles in the line.

BEAM LOSS MONITOR TYPES

The Beam Loss Monitor, which in principle is a detector of ionizing radiation, could be built of a different sensor types. The selection of appropriate system is based on several factors, amongst which we can distinguish:

- intrinsic sensitivity
- ease of calibration
- radiation hardness
- reliability, robustness
- dynamic range
- temporal resolution
- shielding properties

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- physical size
- cost
- saturation

There exist several different detector types used for beam loss monitoring, e.g.:

- gas ionization chambers (short- and long-ones)
- solid-state ion chamber (PIN diode)
- secondary emission monitor
- scintillation detectors
- Cherenkov detectors.

Each type of detector is characterized by specific properties, and detailed description of them could be found in the literature [3, 4].

BLM SELECTION AND DESIGN FOR PolFEL

Considering the abovementioned factors and taking into account the experience of various NCBJ groups we have decided to use plastic scintillation detector coupled with photomultiplier as a beam loss monitor detector. The features of such system, which made us choose abovementioned configuration are:

- high detection efficiency compared to other detector types
- high dynamic range and possibility to change it by selecting PMT voltage
- possibility of calibration using standard radiation sources
- availability in custom size and shape
- relatively low price
- additional failsafe checking using built-in LED.

Based on the numerical studies and preliminary experimental tests, we have designed BLM detector composed of H11901 miniature photomultiplier [5] and EJ-232 scintillator [6]. The main factors which decided on components choice were small size, fast timing, integrated HV supplier and voltage divider, and relatively low price. The prototype, build using these components, will be constructed and tested thoroughly on the available sources and accelerators at NCBJ and SOLARIS.

NUMERICAL INVESTIGATION

In order to assess the amount of radiation which could be expected during PolFEL operation and/or beam loss event, we have performed numerical studies of chosen design of BLM detector. The studies were performed using FLUKA (version 2021.2.1) Monte Carlo code. During the calculations, we have tested three geometry configurations of the detector vicinity. The detectors (cylinders made of Polyvinyl toluene, 8 mm in diameter and 10 cm in length), parallel to X-axis, were positioned at Z = 0 coordinates. Detectors were placed in Aluminum housing, with 6cm in diameter and 20 cm in length. The steel beam pipe, which represents vacuum pipe, with inner and outer diameters equal to 3.68 and 4.0 cm respectively, was parallel to Z-axis. At chosen position along the beam pipe, we placed solid cylindrical blocks of steel, to imitate magnets put on the beam pipe. The beam interaction point was put 50 cm in front of the magnet

The geometries used during calculations are presented in Fig. 1.

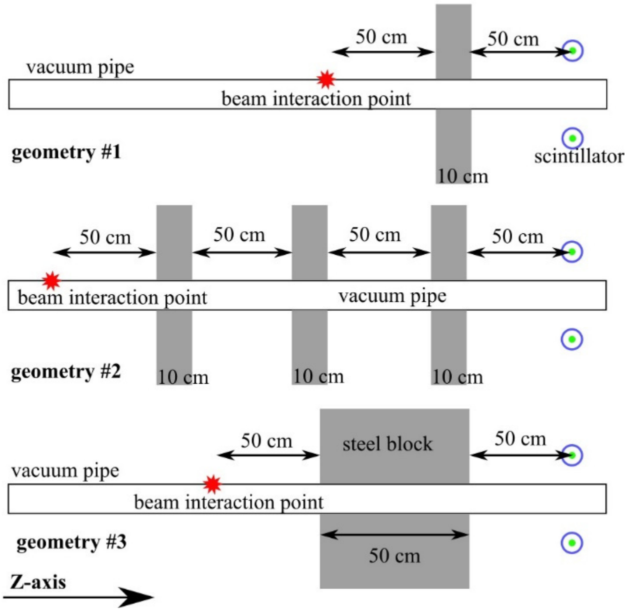

Figure 1: Geometries used during MC calculations. Three configurations of magnets position were used. The detectors, with size according to the design, are placed on the sides of the vacuum tube, parallel to the X-axis. The pipe is parallel with Z-axis. The source is positioned in the position, which ensures hitting the vacuum tube 50 cm in front of the last magnet.

The scored quantity was energy deposition in selected detectors, and energy deposition on the Cartesian grid, around the position of the detectors. The energy deposition spectra, calculated for selected scintillator, are presented in Figs. 2 and 3.

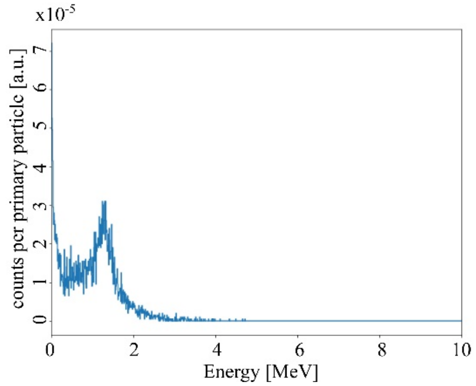

Figure 2: Energy deposition spectrum, calculated for chosen scintillator for geometry #1 and beam angle with respect to Z-axis equal to 10 mrad. Beam interaction point positioned symmetrically between the detectors.

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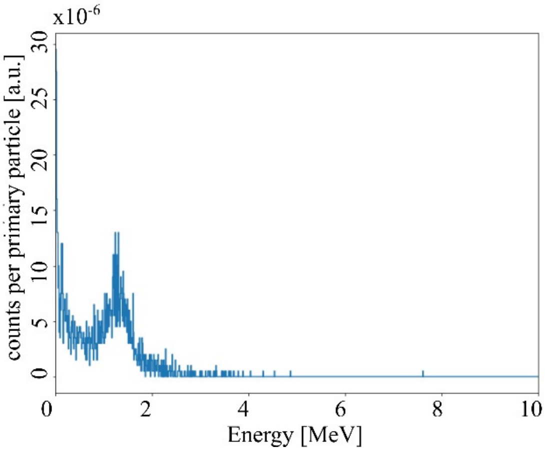

Figure 3: Energy deposition spectrum, calculated for chosen scintillator for geometry #1, beam angle with respect to Z-axis equal to 10mrad. Beam interaction point positioned on the opposite side of the detector.

For better visualization of beam interaction with surrounding, we have calculated energy deposition on Cartesian grid. Results of such calculations are presented on Figs. 4 and 5.

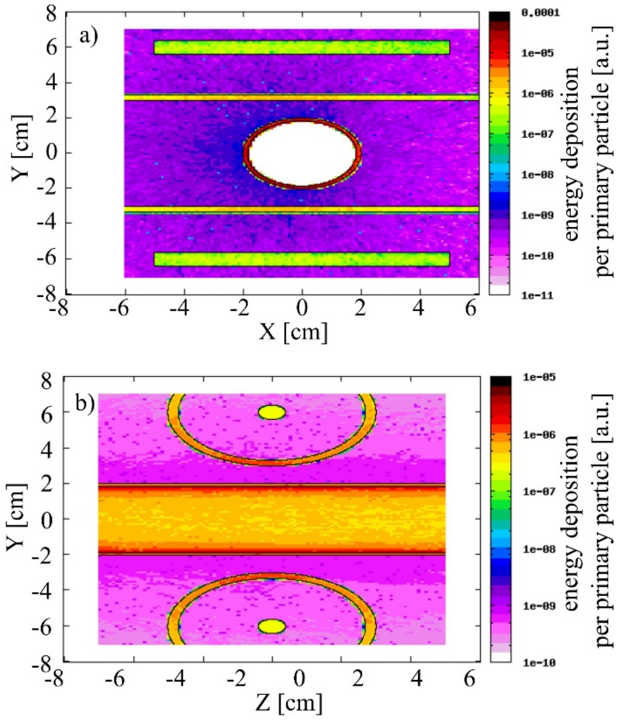

Figure 4: Energy deposition on Cartesian grid (a – XY plane, b – YZ plane). Beam interaction point positioned symmetrically between detectors.

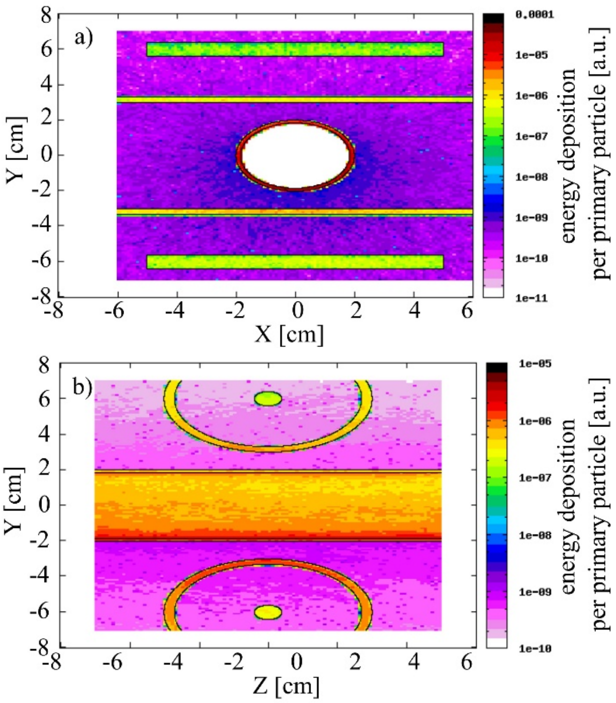

Figure 5: Energy deposition on Cartesian grid (a – XY plane, b – YZ plane). Beam interaction point positioned on the detector side.

PRELIMINARY EXPERIMENTAL TESTS

The first device, a so-called concept-prototype, was built to check the principles and operation of plastic scintillation detector at linear accelerator. The scheme of such detector is presented in Fig. 6.

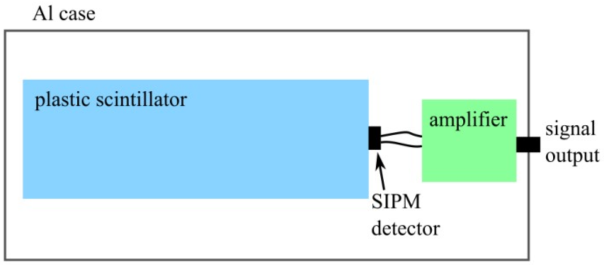

Figure 6: Scheme of concept-prototype version used during first tests at SOLARIS accelerator.

The concept-prototype version was constructed using materials already available in our laboratory, therefore it was considerable different from the prototype design. The device was tested both in our laboratory, using standard radioactive sources, and at SOLARIS linear accelerator. The signals were recorded using digital oscilloscope. Due to the built-in amplifier and fixed operational voltage of the detector, the registered signal was severely clipped. Nevertheless, it was possible to observe changes in signal width, which could be interpreted as an effect of increase in signal amplitude. The exemplary signal, recorded during operation of SOLARIS linear accelerator, is presented on Fig. 7.

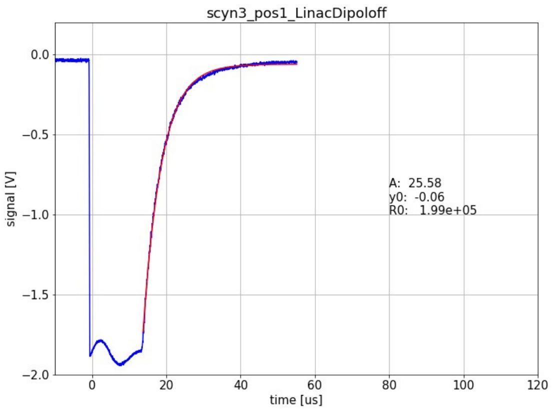

Figure 7: Exemplary signal recorded during tests at SOLARIS accelerator.

Blue line is the recorded signal, and red line represents exponential fitting. Fitting parameters are showed on plot. The results of preliminary tests lead us to conclusions, that we have enough signal and do not need large scintillator for monitoring the beam losses. The high dynamic range of photodetector is also important for the BLMs.

Based on the MC calculations and tests, we decided to build a new prototype, which follow the assumptions:

- small scintillator with length up to about 10 cm
- PMT photosensitive detector with integrated HV supplier
- placement of BLM detectors in several positions along linear accelelator, each of the detector will be calibrated and tested during initial phase of operation.

The new, improved design of BLM detector prototype, based on mentioned in previous section photomultiplier and scintillator (i.e. H11901 and EJ-232), is presented on Fig. 8.

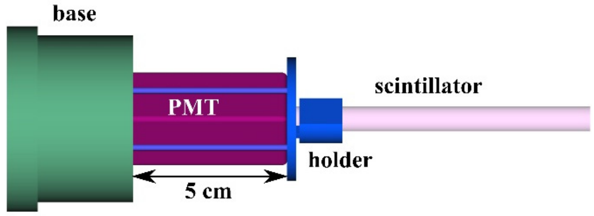

Figure 8: Scheme of new prototype version of BLM detector.

CONCLUSIONS

The Beam Loss Monitor system is important for the machine protection and beam diagnostics and control in large-, as well as small-scale accelerator facilities. The working parameters of PolFEL electron accelerator induce need to install and operate the BLM system. On the basis of numerical (Monte Carlo) calculations and experimental test, we have designed a prototype BLM detector for PolFEL, which uses fast plastic scintillator coupled with miniature photomultiplier. The further investigation, both experimental and numerical, of designed prototype is the next step of BLM system development for PolFEL facility.

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