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BEAM LOSS MONITOR FOR POLISH FREE ELECTRON LASER (PolFEL): DESIGN AND TESTS*

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Abstract

The Beam Loss Monitor (BLM) system is primarily used for machine protection and is especially important in the case of high energy density of accelerated beam, when such a beam could cause serious damages due to uncontrolled loss. PolFEL linear accelerator is designed with the beam parameters, which made BLM an essential system for machine protection. The design of BLM system for PolFEL is composed of several scintillation probes placed along and around the accelerator. The paper reports on design and first tests of prototype detector, which is planned to be used for PolFEL project. The prototype was tested in NCBJ and SOLARIS, using radioactive calibration samples and linear electron accelerator as a sources. We also present results of numerical investigation of radiation generated due to interaction of fast electrons with accelerator components.

INTRODUCTION

The motivation for using Beam Loss Monitoring system is the detection of unwanted events of fast charged particles escaping the designated path along the beamline. While not being incorporated directly into the vacuum system and beam instrumentation, the BLM is an important part of the high-energy accelerator, which could generate intense beams of high energies and power. The main role of the BLM is to protect the machine from damages (short- or long-term) caused by energetic particles hitting the vacuum components, and/or escaping vacuum pipe without puncturing them, and damaging sensitive equipment due to excessive radiation. Being important system for large facilities, the working principle of beam loss monitors could also be used for beam controlling and fine-tuning of its position and alignment.

THE PolFEL PROJECT

The PolFEL project, namely the construction of Free Electron Laser in Poland is in the preparation for a few years, and at in the present phase it have main features and components already fixed. It is driven by superconducting linear accelerator, based on TESLA SRF technology, and is designed to operate both in continuous wave (cw) and long pulse (lp) mode. The generation of coherent light is planned in three branches, i.e. in the THz, IR and VUV range. The planned parameters of PolFEL electron beam are listed in Table 1.

Table 1: The Parameters of PolFEL Electron Beam (cw mode) [1-3]

parameter/position	Gun	VUV line	THZ line
Bunch charge [pC]	20-250	<100	250
Repetition rate [kHz]	50	50	50
Bunch length [ps]	2-10	0.1	<10
Beam energy [MeV]	4	<154	<979
Beam current [μA]	12.5	5	12.5
Beam power [W]	-	770	940

BEAM LOSS TYPES

We could highlight two kind of losses, which lead to increased readout in the BLM system, i.e.: regular and irregular ones.

Regular Losses

Regular, controlled, losses are unavoidable part of accelerator operation and, therefore could be used for diagnostics purposes, like injection studies, energy tail measurements, lifetime limitations, etc. They occur usually as an effect of aperture changes or scattering on residual gas.

Irregular Losses

The irregular, uncontrolled, losses are events, which could lead to potentially hazardous situation and damage the equipment or vacuum components. Such losses could resulted from misaligned beam, leaks or obstacles in vacuum system, failures of beam control, or other accelerator parts. The severity of such an event varies from excess irradiation of nearby devices up to puncturing vacuum vessel wall, in case of prolonged exposition to electron beam.

DETECTORS FOR BLMs

Beam Loss Monitor, being in principle a detector of ionizing radiation, could be built using various types of components. The factors, deciding of device selection are, among others: intrinsic sensitivity; calibration procedures; radiation hardness; reliability; dynamic range; time resolution; size limitations; cost; saturation handling.

The BLM used worldwide are constructed using such detectors like: ionization chambers; PIN diodes; secondary emission monitors, scintillation detectors and cherenkov detectors. Each of the detectors have its char-

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acteristics and differences, which make them proper choice for selected requirements [4, 5].

SELECTION AND DESIGN FOR PolFEL

During the selection process of an optimal BLM detector, we have taken into account the aforementioned features of the detector, and also the experience and know-how of our group in NCBJ. The scintillator BLM detector, coupled with miniature PMT module is characterized by:

- high detection efficiency
- high dynamic range
- range variation by selecting PMT gain
- relatively easy calibration
- custom shape and dimensions of detector
- relatively low price
- additional fail-safe feature using side LED

The prototype, meant to test the principles and operation of BLM was build using H11901 photomultiplier and EJ-232 fast plastic scintillator, which match the requirements mentioned earlier [6, 7]. The motivation behind these choices was to find small size PMT with integrated HV supplier and voltage divider, and scintillator, which is easily accessible, relatively cheap, and has high efficiency, and fast timing. The design is presented in Fig. 1.

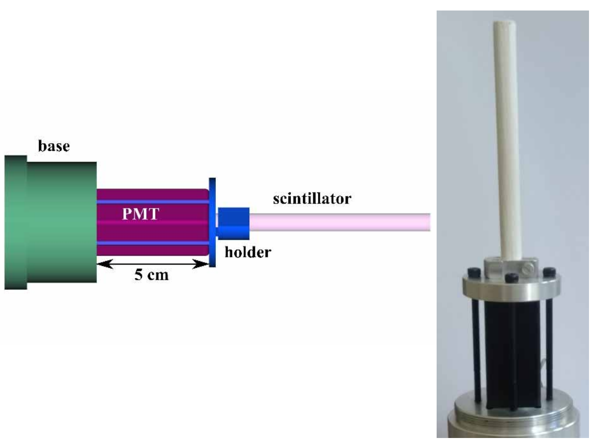

Figure 1: Design of the BLM detector (left) and photo of an actual prototype (right).

The BLM detector consists of scintillator rod (8 mm in diameter, 100 mm in length) coupled with PMT using special holder. Small size of scintillator was chosen on the basis of calculations and maximum electron energy. While in the GeV energy range, 8-millimeter scintillator could have too small efficiency, in the range up to 300 MeV, such detector is sufficiently large. The PMT is then encased in Al, light-proof case. Whole detector is only 6- by 21-centimeters, therefore it could be easily placed nearby various accelerator components.

MONTE CARLO CALCULATIONS

The expected performance and efficiency of BLM design was investigated using Monte Carlo simulations using FLUKA and GEANT4 codes. The calculations were performed in a few steps. The first approximation included cylindrical vacuum pipe and cylindrical scintillator placed at side of the pipe. Next, we added some steel obstacles between beam interaction point and the detector, in order to estimate shielding by accelerator components. The second part of calculations was to reconstruct design of one of the beamline fragments. This was done using GDML readout functionality of GEANT4, which allowed us to relatively easy translate CAD geometry into GEANT4 one. In order to assess the required computing power, the simulations using GEANT4 were performed with increasing similarity to the CAD model. The geometries used during calculations are presented in Fig. 2 [8].

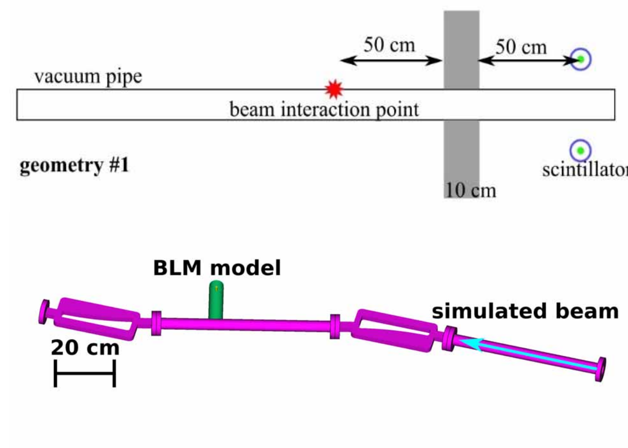

Figure 2: Geometries used during MC calculations: geometry used for preliminary calculations (top), simplified reconstruction of beamline fragment (bottom).

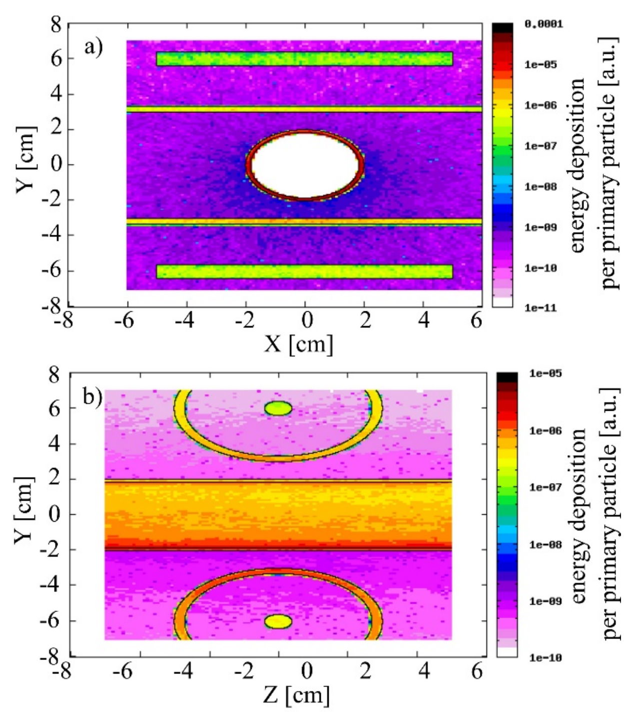

Figure 3: Energy deposition on Cartesian grid: XY plane (top), YZ plane (bottom).

For illustration purposes, and to better understand distribution of radiation generated during “beam loss

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event", we plotted energy deposition on Cartesian grid. The XY an YZ projections, calculated for the simplified geometry are shown in Fig. 3.

The tally used during calculations was energy deposition in the scintillator. Results of calculations, in form of histograms of energy deposition events, are presented in Figs. 4-5.

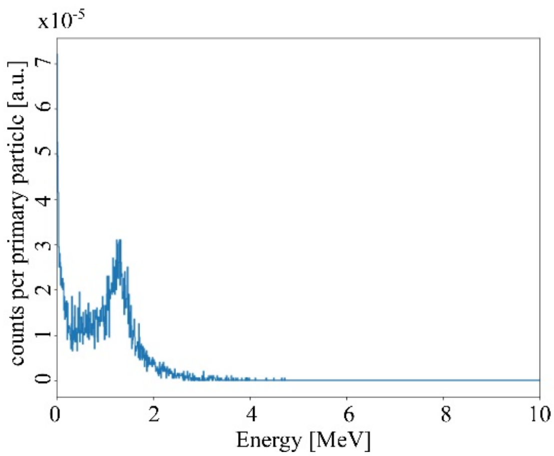

Figure 4: Histogram of energy deposition, calculated for simple geometry using FLUKA code. Electron energies was set to 72 MeV.

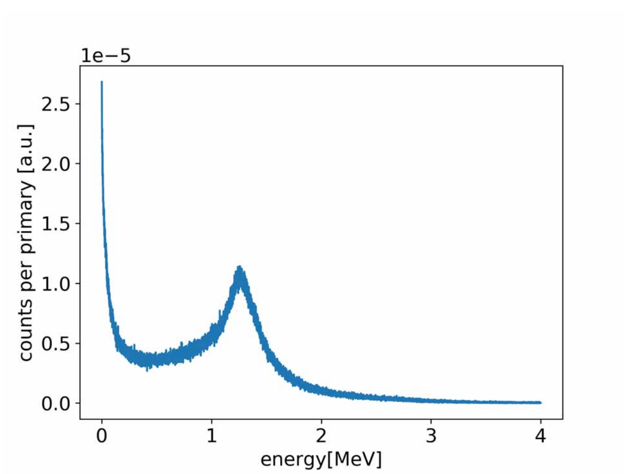

Figure 5: Histogram of energy deposition in scintillator, calculated for simple beamline geometry using GEANT4 workbench. Electron energies was set to 150 MeV.

PROTOTYPE TESTS

The experimental testing of our BLM detector was performed in two phases so far. During the first phase, we have constructed detector using spare parts available in our laboratory. The purpose of such work was to test small plastic scintillator coupled with detector on high-energy linear accelerator. The detector was tested on SOLARIS accelerator, and it showed, that amount of light generated in our system was large enough to further miniaturize the setup.

Based on the preliminary tests and MC simulations, we have decided to design a new setup, which is shown in Fig. 1. The component include small scintillator and PMT photosensitive detector with integrated HV supplier and voltage divider.

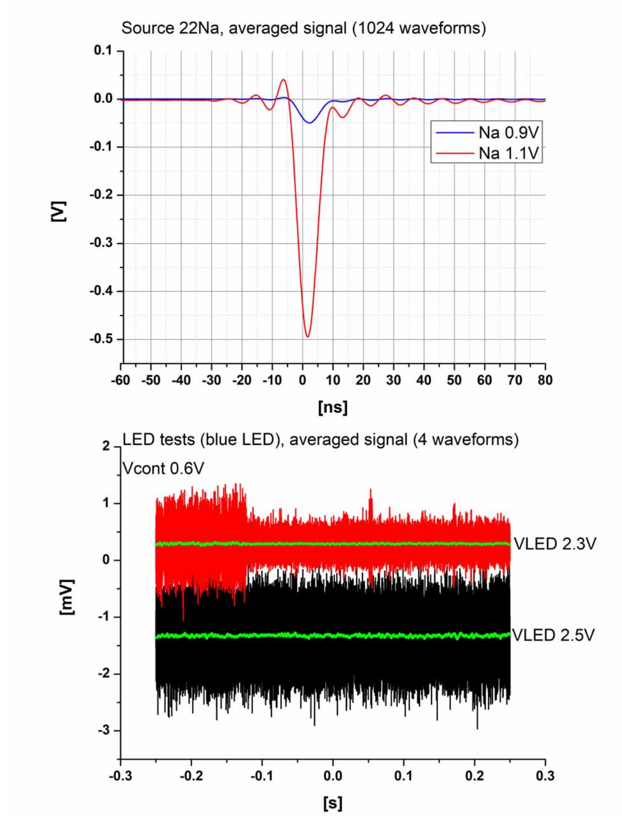

Figure 6: Results of laboratory tests of BLM detector: signals recorded using radioactive 22Na calibration source (top), PMT response to LED placed next to the scintillator (bottom).

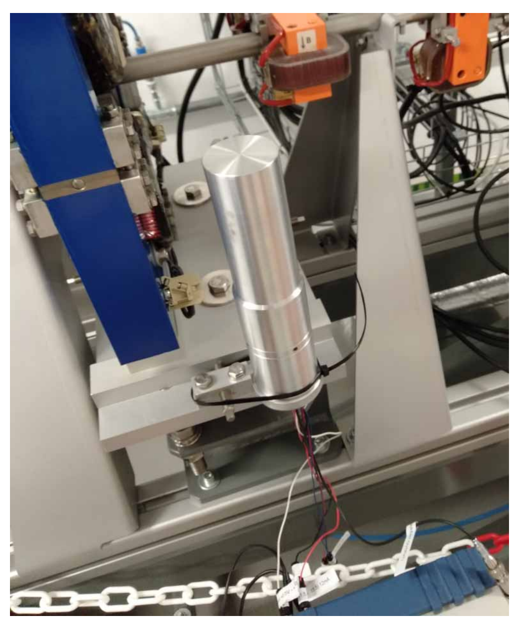

Figure 7: BLM detector placed in the vicinity of SOLARIS linac beamline.

The prototype device was aim to investigate the design behavior in the radiation field of electron accelerator. The first measurements, performed to check the connections

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and operation, was made using radioactive sources. We have observed distinct signals and response to built-in test-LED. Results are shown in Fig.6.

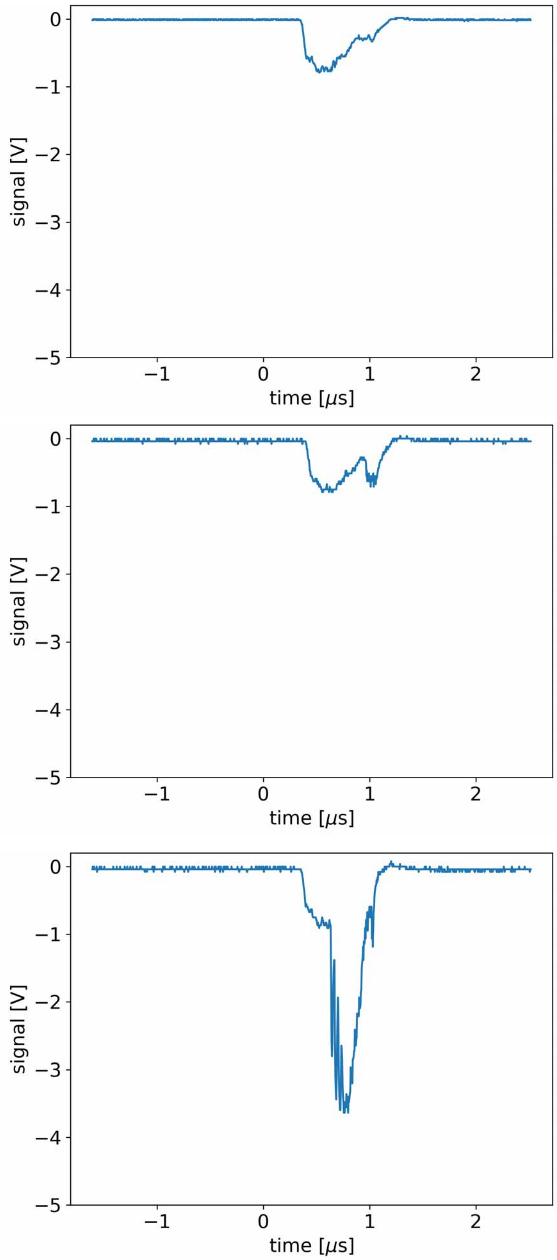

Figure 8: Exemplary signals recorded during tests at SOLARIS accelerator: central beam (top), beam tilted in Y-plane (middle), beam tilted in X-plane (bottom).

Afterward, it was tested on a linear accelerator in SOLARIS facility. During the tests, we have changed position, PMT gain and working conditions of accelerator. The experimental setup is shown in Fig. 7. The results are shown in Fig. 8. Based on the performed prototype tests, we can conclude, that the designed detector could be used for monitoring of beam losses in the electron linear accelerator. The detector, however, needs some additional considerations and testing in order to assess the impact of RF noises and selection of readout electronics.

CONCLUSIONS

The BLM system, which is essential for operation of large-scale facilities, is important also for medium-size ones like PolFEL. While being primary the safety device, BLM could also be used for control and fine-tuning the beam. The beam loss monitor for PolFEL accelerator was designed on the basis of Monte Carlo calculations and preliminary experimental tests. The prototype design was build of small plastic scintillator and miniature PMT module. Both the calculations and measurements showed usability and efficiency of the proposed design. The detector is still under development and numerical, and experimental investigation, to further improve its capabilities.

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