ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-WEPSC44

BEAM LOSS MONITORING SYSTEM FOR THE SKIF SYNCHROTRON LIGHT SOURCE

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Abstract

The Siberian ring source of photons (SKIF) is a new 3 GeV fourth-generation synchrotron light source being developed by the Budker Institute of Nuclear Physics (BINP). In order to ensure its reliable operation, beam loss diagnostics system is required. Two types of beam loss monitors will be installed at the SKIF: 5 fiber-based Cherenkov Beam Loss Monitors (CBLM) for the linac and transfer lines and 128 Scintillator-based Beam Loss Monitors (SBLM) for the storage ring. Sophisticated electronic equipment are employed to use these monitors at different SKIF operating modes. The article describes the design of the SKIF beam loss diagnostics system based on numerical simulations and experimental studies.

INTRODUCTION

The SKIF is the 4th generation synchrotron light source with 3 GeV energy and emittance of 75 pm rad, that is under construction in Novosibirsk, Russia [1]. The SKIF consists of 200 MeV electron linac, linac-to-booster transfer line (LBT), booster synchrotron with maximum energy of 3 GeV and circumference of 158.7 m, booster-to-storage ring transfer line (BST) and storage ring with 16-fold symmetry and 476 m circumference. The storage ring is designed to operate at top-up injection with up to 400 mA beam current. Current stability of 1% is required. The layout of the SKIF accelerator facility is shown in Fig. 1.

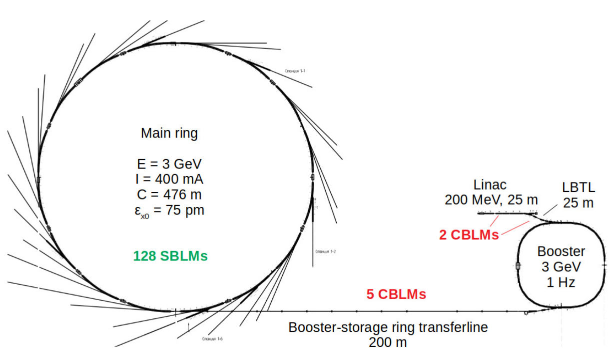

Figure 1: The SKIF layout.

The SKIF is aimed to provide users with syncrotron radiation (SR) almost in 24/7 operation. Therefore, strict requirements on the electron beam stability are imposed. In order to achieve effective SKIF commissioning in the future and its reliable operation and performance in various modes, beam loss diagnostics system is required. This system is an essential tool for real time monitoring of beam losses usually caused by misaligned beam during the machine commissioning or faulty condition of accelerator subsystems or related with beam lifetime [2].

For the linac, LBT and BST where single-bunch mode is available, we proposed to use the CBLMs. For the storage ring in order to control beam losses during machine tuning and operation at top-up mode, the SBLMs were proposed.

CHERENKOV BEAM LOSS MONITOR

The operation principle of the CBLM is based on the registration of the Cherenkov radiation generated by secondary charged particles in the optical fiber attached to the vacuum pipe [3]. The Cherenkov light propagates upstream and downstream along the optical fiber and can be detected usually by a photomultiplier (PMT) at either one or both ends of the fiber. Timing of the PMT signal gives the location of the beam loss and signal intensity is proportional to the number of lost particles.

Simulations and Experimental Studies

The CBLM prototype tests were performed at the operating BINP accelerator [4] with beam parameters similar to the SKIF. As an optimal fiber type in terms of sensitivity, radiation hardness and cost effectiveness, multimode silica fiber with step-index profile FG550UEC by Thorlabs was selected. It has 550 μm core diameter, high OH–, F-doped silica cladding. Measured light dispersion was obtained to be 0.17±0.01 ns/m. In order to achieve desired CBLM spatial resolution of 1 m due to the SKIF magnet spacing, maximum fiber length should be about 40 m.

As a photodetector microchannel plate PMT (MCP-PMT) was selected, with gain over 10^6, dark current less than 1 nA, front rise time of 0.5 ns and the duration (FWHM) of the anode current pulse of at least 1.5 ns. It allows detecting beam losses of ~1 pC corresponding to 1% of the total bunch charge.

The experimental results of 500 MeV beam loss distribution at the downstream and upstream fiber ends are shown in Fig. 2. The upstream signal has 4.2 times better spatial resolution than the downstream one. Taking into account the difference in PMT gains, the downstream signal sensitivity

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is about 10 times higher than the upstream one, which is consistent with the numerical simulations [5].

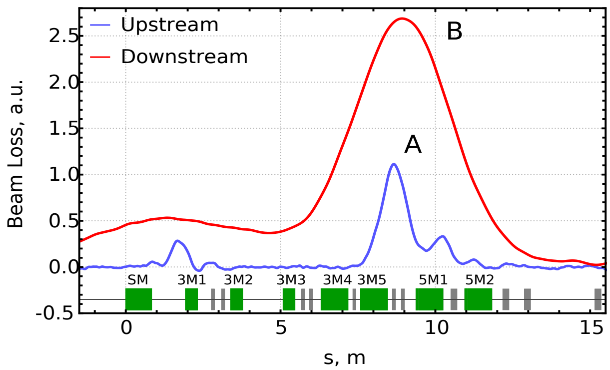

Figure 2: Beam loss distributions of the 500 MeV electron beam at both fiber ends. FWHM of the peak A is 4.2 times smaller than the peak B.

Since the upstream loss measurements provide better monitor spatial resolution and the downstream one – better monitor sensitivity, for the SKIF we decided to perform beam loss measurements from both fiber ends.

Due to the SKIF layout, the designed CBLM system for the linac and LBT consists of a single 30 m long fiber with 2 MCP-PMTs each, 200 m long BST requires 5 fibers of 40 m and 10 MCP-PMTs in total.

SCINTILLATOR BEAM LOSS MONITOR

In its simplest form, the SBLM consists of a plastic scintillator coupled with the PMT [6]. Shower particles e-, e+,γ passing through the scintillator volume excite scintillation. The polystyrene-based SC-205 scintillator manufactured by IHEP was selected. It has a light output equal to 66% of anthracene and decay time of 2.5 ns.

The detector construction has been selected as 10 cm long scintillator rod with 2.5 cm diameter. To maximize light collection the surfaces of the scintillator should be wrapped around with reflective Tyvek paper. The PMT 9107B by ET Enterprises was chosen to match scintillator diameter, moreover, the PMT spectral sensitivity matches the emission spectrum of the scintillator.

The SBLM is placed in a 3 mm steel housing to avoid background signal due to the scattered SR. To perform regular radiation induced calibration of the SBLM signals, a LED is attached to the free end of the scintillator.

SBLM Performance Simulations

Based on FLUKA [7] simulations of the beam loss scenarios we determined optimal amount of the SBLMs and their optimal position at the SKIF storage ring.

Fig. 3 shows an example of simulated distribution of secondary particles caused by the beam loss inside quadrupole. The simulated beam loss scenario is the following: 3 GeV electron beam hits the vacuum pipe with small incident angle relative to equilibrium orbit. Light output is in the range of 10^2-10^4 photons/primary.

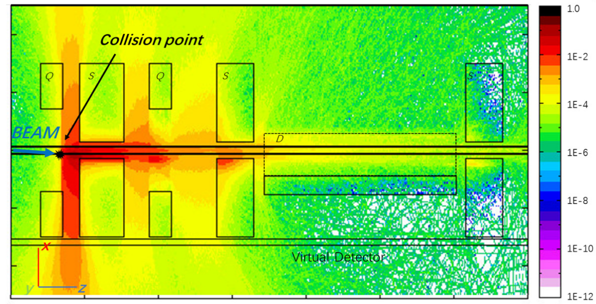

Figure 3: Typical distribution of the secondary charged particles for the beam loss in the SKIF lattice.

Regular losses most likely to occur at the locations with larger beam size which is due to higher beta- or dispersion functions. The simulation result of the SBLM response for a single SKIF superperiod [8] is shown in Fig. 4. 8 SBLMs per superperiod at the locations of the most significant shower peaks to achieve maximum diagnostic efficiency are proposed. Due to the 16-fold symmetry of the ring, a total number of 128 SBLM detectors are planned to be installed around the SKIF storage ring.

BLM ELECTRONICS

CBLM Measuring Module

Measuring modules based on switch capacitor array (SCA) technology are developed to digitize the signal from the PMT. Capacitive storage arrays (such as PSI's DRS4 [9]) are the key elements in such systems. They provide data logging at a sampling rate of several GHz. The following main elements can be distinguished in the developed measurement module for the CBLM (see Fig. 5):

- Programmable gain input amplifiers (PGA);
- DRS4 chip in the configuration with two lines of capacitive storage arrays up to 4096 elementary cells each;
- EA unit that generates signals for carrying out amplitude and time calibration for DRS4 chip;
- Synchronization and timing node, linking DRS4 data recording cycles to external events;
- Digital node based on Intel Cyclone V SoC FPGA.

Bilateral signal registration mode will be organized. The measuring modules placed between the segments of the magnetic structure operate in a two-channel mode. Total amount of 10 modules is required for the SKIF CBLM system.

SBLM Measuring Module

Four-channel measuring modules built on the data recording oscillographic method are proposed to be used for the SBLMs. Each channel of the measuring module will provide data recording with sampling rate of 250 MHz and amplitude resolution of 14 bits. The resources of the Intel Cyclone V FPGA installed on the board of each module will be used for implementing various operation modes of the measuring modules, as well as for receiving, preprocessing and transmitting data via the Ethernet channel. The devel-

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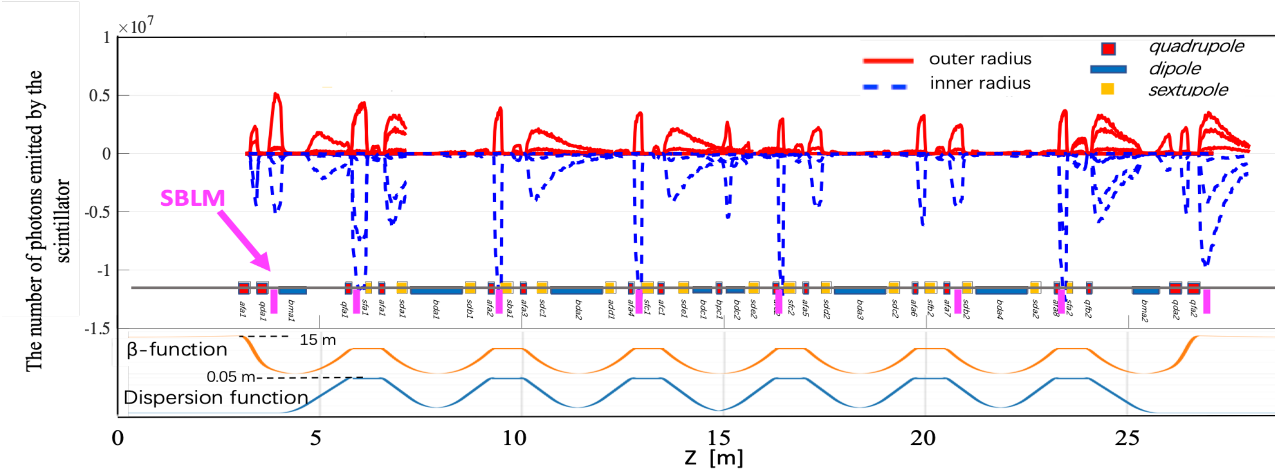

Figure 4: The simulated distribution of optical photons in the scintillator over the SKIF storage ring superperiod. The sign of the vertical axis only has meaning of direction.

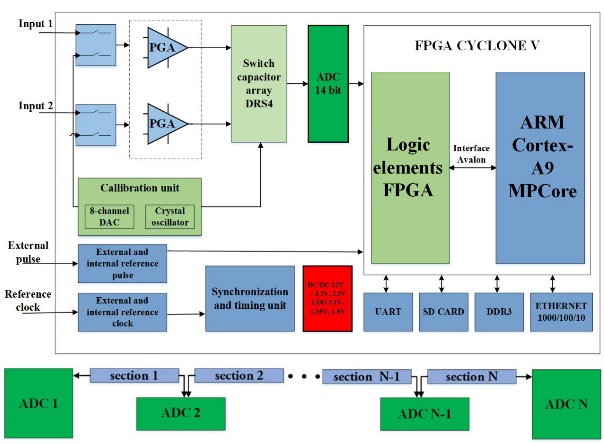

Figure 5: Measuring module for the CBLM (top), scheme of the CBLMs in successive segments of the magnetic structure (bottom).

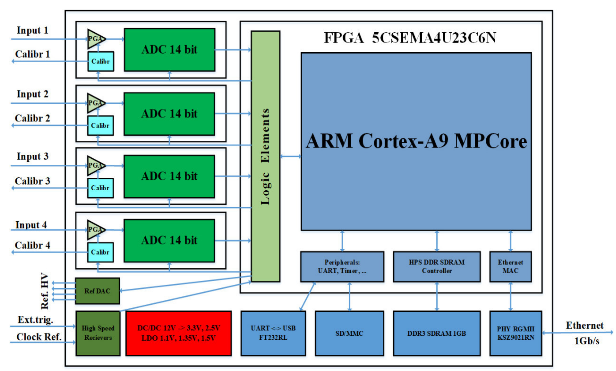

Figure 6: Measuring module for the SBLM.

oped measuring module has four identical measuring tracts (see Fig. 6), each of them includes:

- Wideband input amplifier (0-100MHz) with programmable gain;
- 14-bit ADC with sampling rate up to 250 MHz;
- Synchronization and timing node, built on the basis of PLL (generator with a phase-locked loop) and FPGA elements;
- The generator of the test signal for the SBLM amplitude calibration;

The developed SBLM measuring module will have two operating modes: oscilloscope and counting. Oscilloscope mode allows recording the shape of the detector signals in a sequence of time windows with a duration set by the operator. Counting mode allows fixing signals in a sequence of successive time windows, the duration of which is set in software. For the SKIF storage ring, 32 modules are required.

The CBLM and SBLM measuring modules are combined into the general data acquisition system by the cable synchronization lines that ensure the binding of data acquisition cycles to external events. They interface with a PC-based operator console using a standard switch over Ethernet-1000 communication channels.

CONCLUSION

For the SKIF to achieve effective future commissioning and its reliable operation and performance in various modes, beam loss diagnostics system is critical. The design of the beam loss diagnostics system for the SKIF is completed. The CBLM optimal parameters were selected based on the prototype test results at the operating BINP accelerator. Based on FLUKA simulations, total amount of the SBLMs and their optimal position at the SKIF storage ring were obtained. Further experiments with the SBLM prototype are expected. The measuring modules for the CBLM and the SBLM have been developed. These electronics could be combined into a general data acquisition system and integrated in the SKIF control system for real time operation.

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