XFEL BEAM LOSS MONITOR SYSTEM

A. Kaukher, I. Krouptchenkov, B. Michalek, D. Noelle, H. Tiessen, DESY, Hamburg, Germany

Abstract

European XFEL will have a sophisticated Machine Protection System, part of which - Beam Loss Monitors(BLM). The monitors will detect losses of electron beam, in order to protect the components of the XFEL from damage and excessive activation. For protection of undulators, BLMs with a scintillator bar will be used. BLMs at places with high radiation load will be equipped with fused silica rods. Beam dumps of the XFEL will be instrumented with glass-fiber BLMs. The BLMs were tested with an electron test-beam at DESY, as well as at FLASH. Due to large amount of light produced by scintillator and high gain of the used photomultiplier, no optical grease is needed in front of the photomultiplier' window, while typical cathode voltage is only 500-600 volt. The prototype with quartz glass was typically operated at higher cathode voltage. Good operation of all three types of BLMs prototypes was obtained. It is planned to use same monitors also for the FLASH2 project. Current status of the XFEL BLM system development will be presented.

INTRODUCTION

The goal of the Beam Loss Monitor (BLM) system at the XFEL is to detect losses of the electron beam. As a part of the Machine Protection System (MPS) the BLM system will provide an abort signal for the machine operation, in the case losses are too high.

During the commissioning of the XFEL, the BLM system will play a crucial role in reduction of the radio-activation of the tunnel components. As soon as stable operation of the XFEL is achieved, the BLM system will continuously monitor beam losses. It is essential to minimize beam losses in order to reduce risk of a failure of an electronic system and to keep the overall radio-activation level as low as possible. Electron beam parameters relevant to the BLM system can be found in listed in [1].

In the case electrons from the electron beam (or beam halo, or dark current) are escaping from the vacuum chamber of the linac, a number of secondary particles will be produced. These secondary particles can be detected by a beam loss monitor. The key principle is light generation (scintillation, Cherenkov light) by secondary particles in a sensitive medium of the detector and measurement of the produced light with a photo-multiplier tube (PMT). Signal from the PMT is transmitted over twisted pair cable to a micro-TCA crate, where signals processed.

Beam loss monitors are located at injectors, bunch compressors, collimator, undulators sections and electron beam dumps. In order to sustain the quality of the light produced by the XFEL, the permanent magnets of the undulators must be protected from energy deposits in them. For redundancy, two BLMs are placed between the undulators. In total, there will be more than 300 beam loss monitors, most of them in the undulator sections.

DETECTOR DESIGN

There will be three types of Beam Loss Monitors at XFEL. Common to all types is the housing of the BLM. A prototype of the XFEL BLM shown in the Fig. 1.

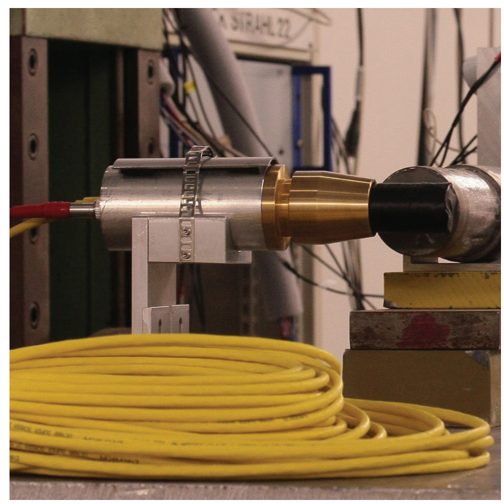

Figure 1: XFEL BLM prototype at DESY test-beam.

The tube-shaped aluminum housing incorporates a PMT base – a circular printed circuit board, where an R5900 Hamamatsu photomultiplier[2] placed on a socket. The voltage potentials for the PMT are prepared with the help of a voltage multiplier directly on the PMT base. A prototype of the PMT base with a Cockroft-Walton type multiplier is currently under test. The PMT base also carries a small LED to produce a test light-pulse.

The unipolar signal from the PMT is converted into a differential signal with the help of a small transformer and transferred via twisted-pair. It is planned to use a cable with 4 twisted pairs, similar to the cables used for networking. Other pairs of the same cable will be used to supply low voltage to the voltage multiplier and the test-pulse signal to the LED.

BLM with a Scintillator Bar

Due to large light-yield of BLMs with a scintillator, they will be used in undulators sections, so that they can have

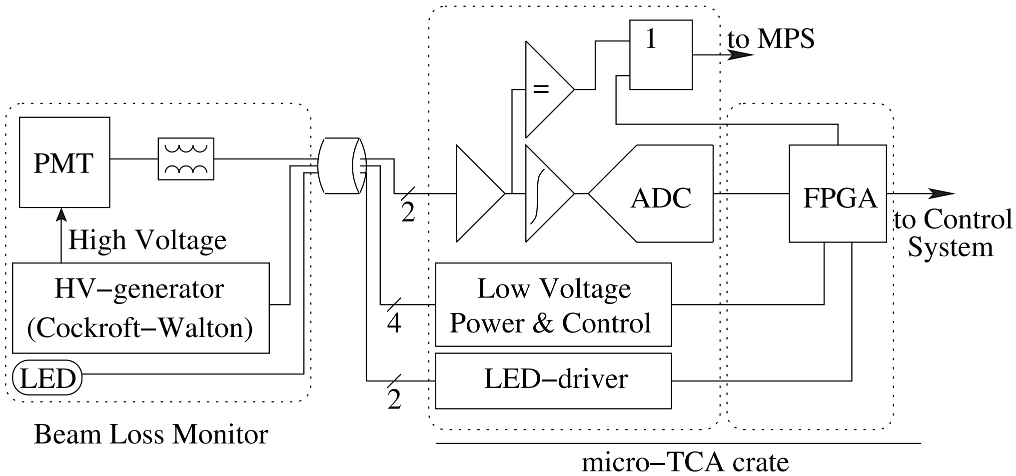

Figure 2: BLM signal processing chain.

high sensitivity to beam losses. The light-guide holder, as shown in Fig. 1, provides opto-mechanical contact of the light-guide (the scintillator is glued to the light-guide) to the photomultiplier. The scintillator and the light-guide are wrapped in an aluminum foil and then in a black tape. The sizes of the scintillator bar are not yet fixed. The diameter of the light guide is 30 mm. Currently, a round shaped light-guide and scintillator(BC-408) with diameter of 30 mm are used for tests.

BLM with a Fused Silica Rod

In the XFEL sections with large radiation load (bunch compressors, collimator) BLMs with a fused silica rod will be used. The rod will be placed directly to the PMT window(without a light-guide). It is considered to use the same light-guide holder for the fused silica rods. Cherenkov light generated in the fused silica rod will be readout directly by the PMT, so that the near ultraviolet component of the light can be detected. Convolution of light transmission of a typical fused silica material with the spectrum of Cherenkov light yields maximum of the light output at ∼330 nm, where the quantum efficiency of the PMT is still more than 10 %.

BLMs at XFEL Dumps

Each dump of the XFEL will be instrumented with 4 BLMs (two in X plane and two in Y plane). Instead of scintillator/light-guide, these BLMs will have a special opto-mechanical interface to a bundle of quartz-glass fibers.

BLM SIGNAL PROCESSING CHAIN

The BLM signal processing chain is shown in Fig. 2. The intrinsic signal width from the R5900 PMT is as short as 20 ns, even after 50 m twisted pair cable. In order to obtain at least 3 data samples with a 50 MSPS 14-bit ADC, an active signal shaper will be used. The data from the ADC are read out and processed by an FPGA. The signal from the BLM is also fed into an analog comparator(to avoid the delay due to the processing in the ADC/FPGA), where the signal is compared with some predefined threshold potential. The analog comparator is supposed to be used only with relatively high thresholds, relevant for loss of a single (usually first) bunch. Upon crossing the threshold, an alarm signal is sent to the Machine Protection System via a digital link. Data from the ADC is processed in real time with several algorithms in the FPGA and alarm signals are sent over the same link to the MPS.

All control tasks are performed by the FPGA: ADC read out, data processing, BLM's test-pulse LED signal timing, threshold update, etc. Three "alarm-algorithms" of data processing in the FPGA will be implemented:

- "Single bunch": an alarm signal is produced upon detection of data above a predefined value(Threshold #1).
- "Multiple bunches": upon detection of data above predefined value(Threshold #2) this event is counted, and if the count result exceeds some predefined value(Threshold #3) – an alarm signal will be produced.
- "Integral over bunch train": the current sum (at a certain moment during the bunch train) of all ADC samples has to be compared with a predefined value(Threshold #4), if larger – an alarm signal will be produced. The correct pedestal of the ADC has to be taken into account.

Two modes of data transfer from the FPGA are possible:

- transfer of raw data samples for the duration of the XFEL bunch train
- bunch-by-bunch loss measurements based on a signal feature extraction

The transfer of raw data will be limited only for the case of system commissioning/debugging and is not intended to be used during normal operation. A “post-mortem” analysis requires that the raw data from, at least, one last bunch train stored in the memory of the FPGA. In normal operation losses will be represented by only some extracted features of the signal from a BLM: pulse amplitude, number of pulses above threshold, etc.

Interface to the Machine Protection System

The analog comparator provides fast reaction time of (high) loss detection. Due to the time delay of data processing, an alarm signal from the FPGA will be delayed with respect to the one from the comparator. Alarm signals from the comparator (output pulse width is set to 100 ns) and the FPGA will be OR-ed and the result will be sent to the MPS system. The signal from the “Single bunch” algorithm of the FPGA will be used only as an additional signal for a “post-mortem” analysis.

Reaction time to losses is mainly defined by the propagation time of the signal in the cable. The length of the longest BLM cable is currently defined to be 50 m. The signal propagation time in a twisted pair cable of 50 m is around 200 ns. In the case an alarm is produced, the propagation time via optical fiber varies from $\sim 2\,\mu$s (from the end of the bunch compressor 2 to injector) to $6\,\mu$s (from Dump 1 to the switch yard). Therefore, the data processing time in the FPGA should be only a fraction of this time.

On the MPS side, alarms from BLMs will be gated during the bunch train, thus the “alarms” induced by cosmic particles will be masked. In certain modes of XFEL operation, masking of alarms from the BLMs will be required.

TEST AT FLASH

Three XFEL BLM prototypes have been tested at FLASH. Since the situation concerning beam losses at XFEL and FLASH is expected to be similar, such tests are expected to give representative results. At this stage the data acquisition electronics is not ready yet, therefore a differential signal receiver and a digital oscilloscope were used for data taking. During these tests the PMT’ High Voltage was externally supplied from a High Voltage power supply.

Signals from BLM #1 (inexpensive option: quartz glass instead of synthetic fused silica) and BLM #2 (BC-408 Scintillator + plastic light-guide) were installed before the Bunch Compressor 2, are shown in Fig. 3. Since the end faces of the quartz glass were not polished, an optical grease was applied to the PMT’ window (BLM #1). The signal shape from BLM #1 is presumably due to radio-luminescence in the quartz glass.

No optical grease was used with the BLM #2, still large amplitude signals were observed. Signals have been seen even when no signals were observed with next FLASH BLMs.

The BLM #3 was equipped with a bundle of 7 quartz-glass fibers and installed at FLASH dump. Signal from the BLM can be seen in Fig. 4. Due to long twisted-pair cable used for this BLM (more than 200 m), the signal is broader. Also the HV has to be set higher than for the BLM #1.

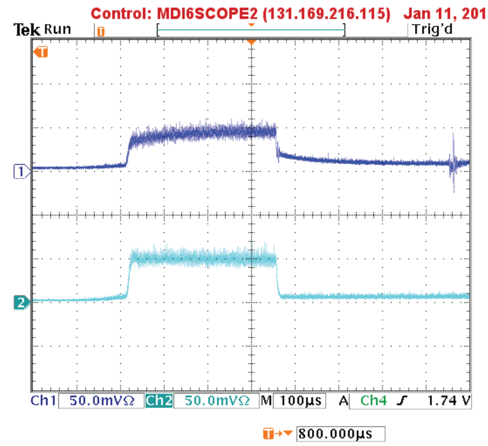

Figure 3: Signals from FLASH dark current: BLM #1 (top, HV=650V) and BLM #2 (HV=550V).

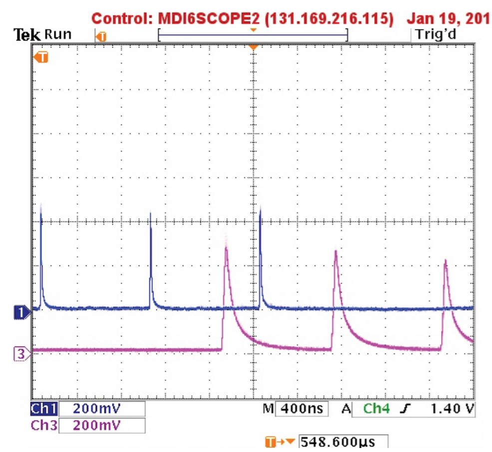

Figure 4: Signals from 3 bunches at FLASH: BLM #1 (top, HV=500V) and BLM #3 (HV=700V).

CONCLUSIONS

Three types of BLMs were tested at FLASH. First tests show promising results – due to high gain of the R5900 PMT, reliable detection of beam losses possible. It is planned not to use optical grease in the XFEL BLMs (except the BLMs at dumps), in order to simplify installation and maintenance.

REFERENCES

[1] M. Altarelli, “General Status of the Project”, talk given at 2011 European XFEL Users’ Meeting, DESY, Hamburg 2011, http://www.xfel.eu/events/users_meetings, accessed 11 May 2011.

[2] Hamamatsu Photonics, R5900U-00-M4 data-sheet, 1999.