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STATUS AND COMMISIONING OF THE EUROPEAN XFEL BEAM LOSS MONITOR SYSTEM

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Abstract

The European XFEL MTCA based Beam Loss Monitor (BLM) system is composed of about 450 monitors, which are part of the Machine Protection System (MPS). The BLMs detect losses of the electron beam, in order to protect accelerator components from damage and excessive activation, in particular the undulators, since they are made of permanent magnets. Also each cold accelerating module is equipped with a BLM to measure the sudden onset of field emission (dark current) in cavities. In addition some BLMs are used as detectors for wire- scanners.

Experience from the already running BLM system in FLASH2 which is based on the same technology, led to a fast implementation of the system in the XFEL. Further firmware and server developments related to alarm generation and handling are ongoing.

The BLM systems structure, the current status and the different possibilities to trigger alarms which stop the electron beam will be presented.

INTRODUCTION

The Beam Loss Monitor (BLM) system at the European XFEL is the main system to detect losses of the electron beam, thus to protect the machine hardware from radiation damage in particular the permanent magnets of the undulators. As part of the Machine Protection System (MPS) the BLM system delivers a signal which stops the electron beam in case the losses get too high.

In addition there are Beam Halo Monitors (BHM) [1] in front of the beam dumps using the same backend as the BLMs and the toroid based Beam Current Monitor system [2].

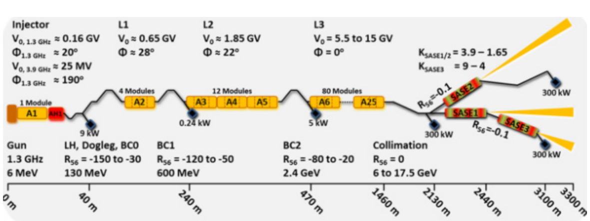

Figure 1: Schematic overview of the European XFEL accelerator [3].

About 470 BLMs are installed along the XFEL Linac which schematic is shown in Fig. 1. Most of the BLMs are installed in the undulator area (see table 1). Also each superconducting accelerating module is equipped with one BLM at the end to detect the field emission produced by cavities (Correlation work still ongoing, no paper available yet).

Table 1: BLM Assignment

Section	#
Injector, dogleg	24
BC1	18
BC2	23
L1, L2, L3 (field emission)	98
Sase1,2 transfer lines	71
Sase1	80
Sase3	48
TL, Dump2	10
Sase2	80
TL, Dump1	20

Some BLMs are also used as additional detectors for wire scans [4].

SYSTEM OVERVIEW

The hardware consists of the BLM devices, a dedicated Rear Transition Module (RTM) in combination with the DESY Advanced Mezzanine Card DAMC2. Furthermore a MPS card [5] is required for alarm output collection.

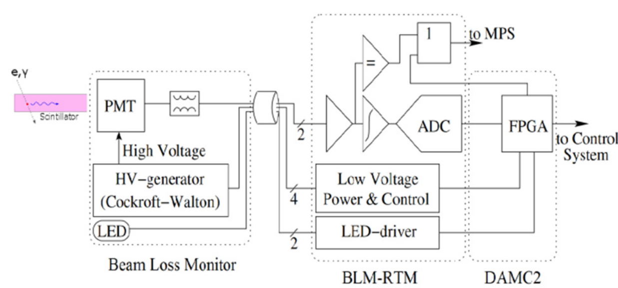

Figure 2: BLM system scheme.

The BLM includes either an EJ-200 scintillator or a SQ1 quartz glass rod. The high voltage for the photomultiplier (PMT) is generated within the BLM, so no high voltage cables are needed (see Fig. 2), a CAT 7 cable with RJ-45 connectors is used. Also a LED can be switched on within the BLM to test if the PMT is still working.

The alarm evaluation and hardware link is implemented in the firmware on the DAMC2 FPGA.

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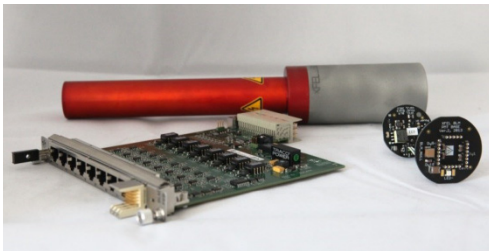

Figure 3: BLM, BLM-RTM and BLM circuit boards, PMT base and high voltage generator.

The BLM-RTM (see Fig. 3) provides 8 channels and includes the analog signal processing plus a 45 MHz 14 bit ADC and also an analog comparator as backup, which is even circa 480 ns faster than the signal processing on the FPGA, that means it stops the bunch train 2 bunches earlier than the FPGA based alarm generation does. Dedicated servers on each MTCA Crate CPU link the firmware with the DESY control system.

There are a lot of uTCA Crates for diagnostics distributed along the machine where 58 are equipped with BLM hardware.

Figure 4: BLMs in undulator section.

The BLMs are mounted as close as possible to the beam pipe like shown in Figure 4.

SYSTEM FEATURES

Each BLM is configurable individually. The control voltage for the PMT, the starting point and length of the test LED signal can be set and switched on or off and a test signal for the MPS can be provided, just by enabling the alarm output to the MPS. Indicated readouts are the set control voltage for the high voltage generator in the BLM, the resultand generated high voltage and its current consumption (see Fig. 5). The number of the pedestal is calculated by the firmware before the bunch train starts and subtracted from the displayed ADC output to remove the analog signal offset at the indicated plot.

There are different configurable alarms which cut the bunch train. The so called single pulse alarm, multi pulse alarm, integral alarm and comparator alarm. Additional the HV tracing alarm and slow protection alarm which can block the complete bunch train and also following ones as long the alarm is not reset by the operator.

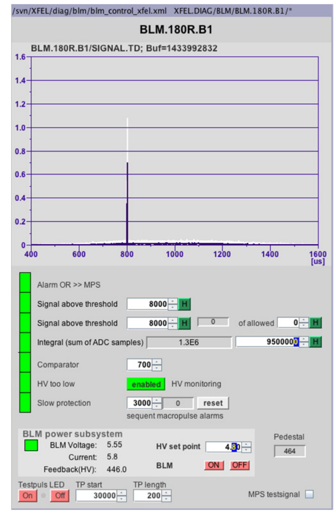

Figure 5: BLM panel in the control system, one bunch; the small hump between 800us and 1200us is darkcurrent.

Kind of Loss Evaluation

Single pulse alarm
Triggers, as soon as the set limit is exceeded
Y-axis scaled to this value → amplitude of 1 → alarm threshold reached
Multi pulse alarm
Needs two terms to trigger:
1. Signal exceeds threshold
2. Number of allowed pulses over threshold reached
Integral alarm
Triggers if the number of integrated samples exceeds threshold
Comparator alarm
Analog backup, threshold is chosen thus it triggers a little bit above single threshold
HV tracing alarm
When the high voltage gets to low so the PMT cannot work properly it causes a permanent alarm, can be disabled
Slow protection alarm
Counts recurrent alarms from macropulse to macropulse, if alarm is gone the counter decreases. When number of recurrent alarms is exceeded it causes a permanent alarm → no beam possible; reset by operator is needed, switches back to single bunch operation

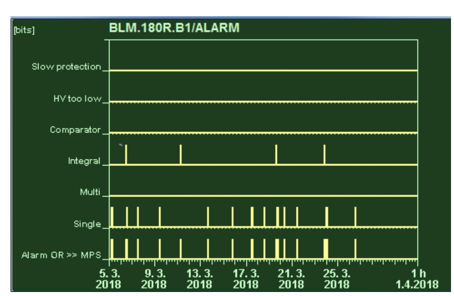

Figure 6: BLM alarm history plot.

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The alarm history of each BLM can be shown by clicking on the left alarm indicator column (see Fig. 6).

The maximum latency of the complete system BLM, MPS and Laser controller to switch off the electron beam is circa 24 us, so at least 108 bunches @ 4.5 MHz bunch repetition rate will be transported through the machine before the bunch train stops.

In case of losses we cannot prevent for example using the Transverse Deflecting Structure [6] or using of axis screens for emittance measurements [7], the BLM system can mask the alarm output for dedicated bunches.

For subsequent investigations the time signal of each BLM is recorded in the Data Acquisition System (DAQ) [8] for each bunch train. Actual 3000 samples @ 1.13 MHz will be saved. In future a sampling rate of 4.5 MHz will be implemented to capture every bunch @ 4.5 MHz bunch repetition rate, but this will increase the CPU load significantly, because to get the same time period the number of samples have to be quadruplicated.

BLM Operating

There are different panels to observe beam losses in the machine. Two main panels are the “BLM & Toroid alarm overview” and the “BLM overview” panel.

Figure 7: BLM and Toroid alarm overview panel.

Figure 7 shows all BLMs and Toroids which can stop the electron beam. By clicking on one BLM the panel shown in Fig. 5 will open. Also the BHMs are included on this panel as for operating they act like a BLM since they even use the same RTM and firmware.

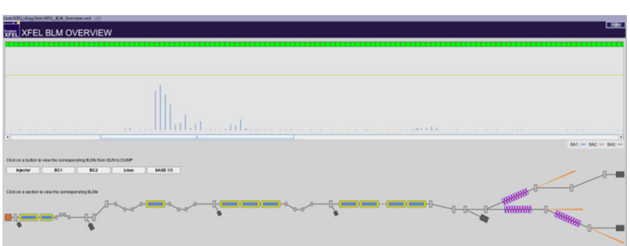

Figure 8: Actual maximum amplitudes of each BLM.

The panel shown in Fig. 8 displays the maximum amplitude of each BLM, this is used during setup to observe the resultand loss change.

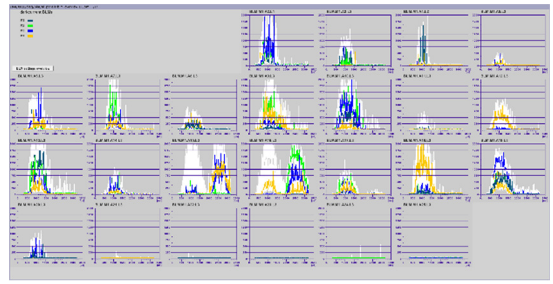

Figure 9: Signals of field emission BLMs, four BLMs concentrated in one plot, in the plot the white persistence is observable, the RF pulse was shifted off beam (delayed).

The goal of the field emission BLMs (plots shown in Fig. 9) are to capture the sudden onset of field emission associated dark current in the XFEL Linac, hence to find adequate thresholds of the BLMs to shut down the RF [9]. This work is still ongoing and not completed yet.

OUTLOOK

A new firmware version development is in progress, which will offer a settable Slow Protection threshold for each single kind of alarm.

CONCLUSION

The BLM system gives a fast feedback in case of too high losses and stops the beam if thresholds are reached. Overview panels show a fast feedback of the loss situation along the machine. Settings of each BLM can be matched to its particular position. Some BLMs are also used as additional detectors for wire scans.

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