ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-THCPR04

THE EUROPEAN XFEL BEAM LOSS MONITOR SYSTEM

T. Wamsat*, T. Lensch
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Abstract

The European XFEL MTCA based Beam Loss Monitor System (BLM) is composed of about 470 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 developed for XFEL and tested here, 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) [1] the BLM system delivers a signal which stops the electron beam as fast as possible in case the losses get too high.

In addition there are Beam Halo Monitors (BHM) [2] in front of the beam dumps using the same digital backend as the BLM electronics.

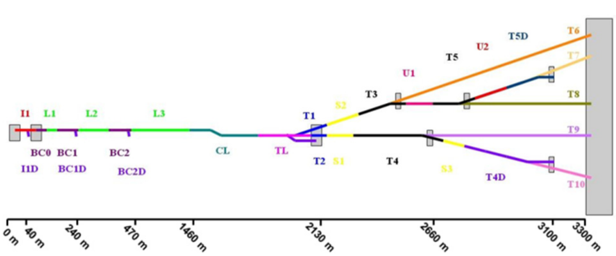

Figure 1: Section overview of the European XFEL accelerator [3].

About 470 BLMs are installed along the XFEL Linac which schematically is shown in Fig. 1. The BLMs are positioned at locations near the beamline, where losses can be expected or where sensitive components are installed, thus most of the BLMs are installed in the undulator area (see table 1). Since even a big number of BLMs cannot provide a complete survey of losses, there is also a toroid based Beam Current Monitor system [4] installed, which provides transmission interlock system to stop the beam if too much charge gets lost along the machine. 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 Distribution

Section	#
I1, BC0	24
BC1	18
BC2	23
L1, L2, L3 (field emission)	98
CL, TL	71
S1, T4	80
S3	48
T4D	10
S2, T3	80
U1, T5, U2, T5D	20

Some selected BLMs are also used as additional detectors for wire scans [5].

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 is required for alarm output collection.

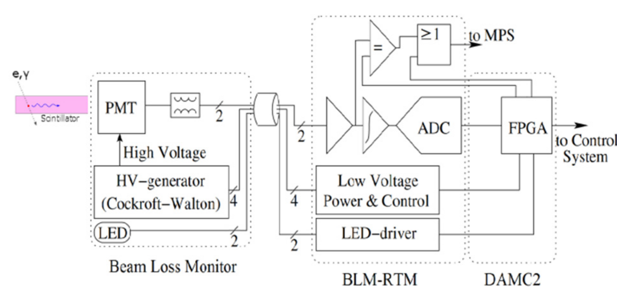

Figure 2: BLM system scheme.

The BLM includes either an EJ-200 plastic scintillator or a SQ1 quartz glass rod. The latter are used mainly in the undulator intersection. In contrast to scintillators, that are also sensitive to hard x-rays, the Quartz rods work with Cherenkov effect, that is sensitive to particle loss only.

The high voltage for the photomultiplier (PMT) is generated within the BLM, so no high voltage cables are needed (see Fig. 2), just a CAT 7 cable with RJ-45 connectors is used. A LED can be switched on within the BLM to provide test pulses to check if the PMT is still working.

* thomas.wamsat@desy.de

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-THCPR04

In addition to the digital processing chain implemented in the FPGA, there is a simple comparator circuit, which is operating completely independent from infrastructure signals like clocks, triggers and even timing.

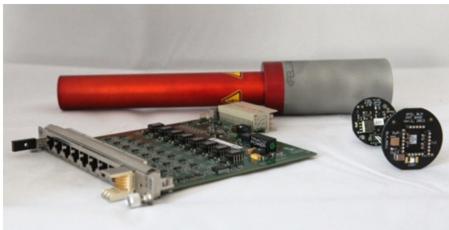

Figure 3: BLM, BLM-RTM and BLM circuit boards, PMT base and high voltage generator.

The BLM-RTM (see Fig. 3) provides 8 channels and includes the analog signal processing plus a 45 MHz 14 bit ADC and also the analog comparator circuit for backup alarm generation. Dedicated servers on each MTCA Crate CPU integrate the firmware into the DESY control system.

Figure 4: MTCA Crate RTM side with BLM-RTMs.

There are about 80 uTCA Crates for diagnostics distributed along the machine in the tunnel where 58 of them are equipped with BLM hardware like shown in Figure 4.

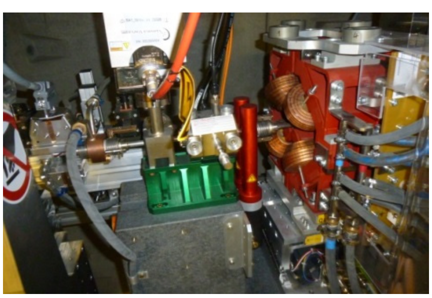

Figure 5: BLMs in undulator section (S1).

The BLMs are mounted as close as possible to the beam pipe like shown in Figure 5.

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. Indicated readouts are the set control voltage for the high voltage generator in the BLM, the result and generated high voltage and its current consumption (see Fig. 6). The value for the PMT 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 can be used to cut the bunch train. The so called single alarm, multi alarm, integral alarm, comparator alarm and additional a not cutting single2 alarm. Each kind of alarm increments a dedicated Slow Protection alarm counter. The alarms are explained in the following.

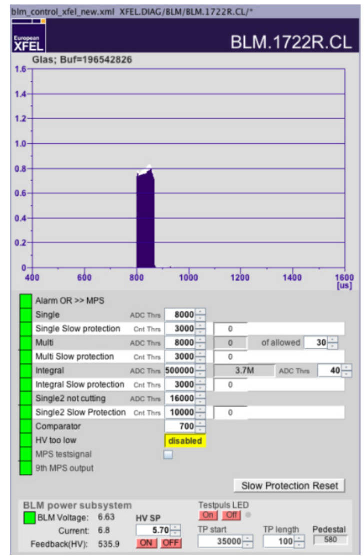

Figure 6: BLM panel in the XFEL control system, 300 bunches @ 4.5 MHz.

Kind of Alarm Generation

Single: Triggers, as soon as the set limit is exceeded Y-axis scaled to this value → amplitude of 1 → alarm threshold reached

Multi: 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

Single2 not cutting: If the Single2 threshold is passed, it does not send an alarm but the Slow Protection Counter increases

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 alarms: 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

Each alarm kind has its own individual Slow Protection counter threshold

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-THCPR04

MPS test signal: Can be activated to test BLM alarm response easily

The 9th MPS output is triggered if a Slow Protection Alarm is generated. This is an additional alarm line which summaries all eight channels of one BLM-RTM.

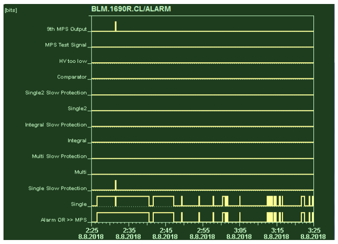

Figure 7: BLM alarm history plot.

The BLM software provides an alarm history of each BLM (see Fig. 7). It can be shown by clicking on the left alarm indicator column.

The maximum latency of the complete system BLM, MPS and Laser controller to switch off the electron beam is about 28 us, so up to 130 bunches at the highest possible bunch repetition rate of 4.5 MHz will be transported through the machine before the laser can stop beam production.

In case of intentional losses, for example using the Transverse Deflecting Structure [6] or of axis screens for emittance measurements [7], the BLM system can mask the alarm output for dedicated bunches [8].

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 8: BLM and Toroid alarm overview panel.

Figure 8 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.

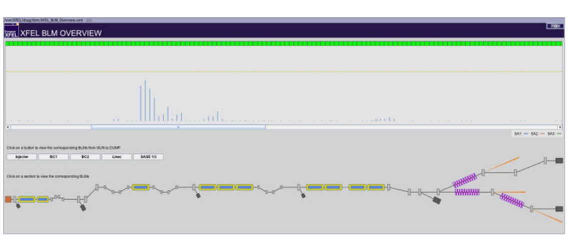

Figure 9: Actual maximum amplitudes of each BLM.

The panel shown in Fig. 9 displays the maximum amplitude of each BLM, this is used during setup to observe the result and loss change. The dotted line indicates the headroom before reaching the most sensitive alarm threshold.

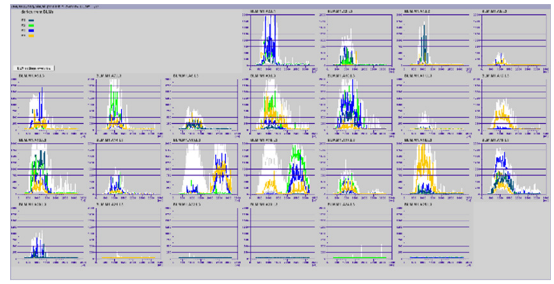

Figure 10: Signals of field emission produced by the RF in the superconducting modules as seen by the BLMs. Four BLM signals are shown in one plot. White areas indicate a kind of signal history: In this case one can see that the RF pulse was shifted off beam (delayed).

The goal of the field emission BLMs (plots shown in Fig. 10) is to capture sudden onset of field emission associated dark current in the XFEL Linac. Adequate thresholds of these BLMs can be used to shut down the RF [9]. This work is still ongoing and not completed yet.

OUTLOOK

Firmware improvements and adjustments are still ongoing. The maximum bunch number in the machine was so far 500 bunches, so settings for long bunch trains up to 2700 bunches per bunch train have to be found.

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 the loss situation along the machine. Settings of each BLM can be matched to its particular position. In summary the BLM system is operating reliable and provides a back bone for save operation of the accelerator. The evaluation of the activation profile during 2017 and 2018 shows that losses and thus activation can be kept on a very low level.

REFERENCES

[1] S. Karstensen, M. E. Castro Carballo, J. M. Jäger, and M. Staack, "XFEL Machine Protection System (MPS) Based on uTCA", in *Proc. ICALEPCS'15*, Melbourne, Australia, Oct. 2015, pp. 82-85. doi:10.18429/JACoW-ICALEPCS2015-MOM308

[2] A. Ignatenko *et al.*, "Beam Halo Monitor for FLASH and the European XFEL", in *Proc. IPAC'12*, New Orleans, LA, USA, May 2012, paper MOPPR018, pp. 816-818.

[3] D. Reschke, W. Decking, N. Walker, and H. Weise, "The Commissioning of the European XFEL Linac and its Performance", in *Proc. SRF'17*, Lanzhou, China, Jul. 2017, pp. 1-5. doi:10.18429/JACoW-SRF2017-MOXA02

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-THCPR04

[4] M. Werner, T. Lensch, J. Lund-Nielsen, Re. Neumann, D. Noelle, and N. Wentowski, "A Toroid Based Bunch Charge Monitor System with Machine Protection Features for FLASH and XFEL", in *Proc. IBIC'14*, Monterey, CA, USA, Sep. 2014, paper WEPF02, pp. 521-524.

[5] T. Lensch and S. Liu, "Status and Commissioning of the Wire Scanner System for the European XFEL", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 1919-1922. doi:10.18429/JACoW-IPAC2018-WEPAF047

[6] A. A. Zavadtsev, "Three Transverse Deflecting Systems for Electron Beam Diagnostics in the European Free-Electron Laser XFEL", in *Proc. RuPAC'16*, Saint Petersburg, Russia, Nov. 2016, pp. 196-200. doi:10.18429/JACoW-RUPAC2016-THXSH02

[7] S. M. Meykopff and B. Beutner, "Emittance Measurement and Optics Matching at the European XFEL", in *Proc. ICALEPCS'17*, Barcelona, Spain, Oct. 2017, pp. 1655-1657. doi:10.18429/JACoW-ICALEPCS2017-THPHA116

[8] T. Lensch and T. Wamsat, "A Fast Wire Scanner System for the European Xfel and Its Impact on Safety Systems", presented at the ICALEPCS'19, New York, NY, USA, Oct. 2019, paper WEPHA086, this conference.

[9] J. Branlard, V. Ayvazyan, O. Hensler, H. Schlarb, Ch. Schmidt, and W. Cichalewski, "Superconducting Cavity Quench Detection and Prevention for the European XFEL", in *Proc. ICALEPCS'13*, San Francisco, CA, USA, Oct. 2013, paper THPPC072, pp. 1239-1241.