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FIRST TESTS USING SIPM BASED BEAM LOSS MONITORS AT THE EUROPEAN XFEL

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Abstract

The European XFEL uTCA based Beam Loss Monitor System (BLM) is composed of about 470 monitors using photomultiplier tubes (PMTs). BLMs installed in the SASE undulator intersections show high signals at electron energy higher 16 GeV or photon energy higher 14 keV due to background synchrotron radiation which directly affects the PMT. The amplitude of this signal can get that high that, also without using any detector material, the BLMs get blind for real losses. Also different lead arrangements did not shield the signal sufficiently.

First tests show that a Silicon photomultiplier (SiPM) is not affected. Also there are several advantages to use SiPM, they are cheaper by factor of 40 and operating voltage is below 35V. First test results will be presented and how it can get implemented in the existing BLMs and BLM system.

DETECTORS

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.

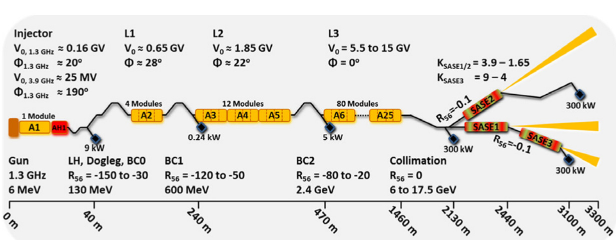

Figure 1: Schematic overview of the European XFEL accelerator [2].

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. The BLM includes either an EJ-200 plastic scintillator or a SQ1 quartz glass rod. The latter are used mainly in the undulator intersection. Scintillators are also sensitive to hard x-rays which are produced within the undulators, whereas quartz rods work with Cherenkov effect, that is sensitive to particle losses only.

Metal Channel type photomultipliers (PMTs) are used for readout. This type of PMTs has excellent immunity to magnetic fields up to 10 mT, what is very important for accelerator measurements.

TASKS

SASE test at 16.5 GeV has shown the following problem:

- at very closed undulator gap (9 keV photon energy) the rear BLMs of SASE1 have shown high signals and turned off the beam. In the setting the magnetic field was very strong and the critical energy was very high.
- at 15 keV and further opening of undulator the problem disappeared

We are dealing here with very hard spontaneous radiation which affects the PMT. Photoeffect produces secondary electrons directly in the PMT, what in turn generates false BLM signals. This fact was proven in BLM without optical radiator (Cherencov or scintillator).

Any attempts to shield PMT area with lead plates gave no significant effect.

Another way to solve the problem is to use another light detector type like SiPMs.

Figure 2 shows the mounting of BLMs in the undulator intersection where the problems appears.

Figure 2: BLMs in undulator intersection.

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SIPM READOUT

Silicon Photomultiplier PM3325-WB-D0 (shown in figure 3) from KETEK with 3x3 mm2 size was chosen for light readout [3].

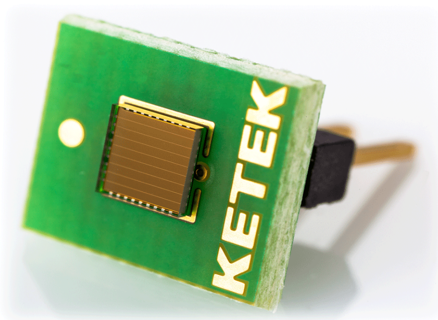

Figure 3: PM3325-WB-D0 from KETEK on PCB with pins.

Silicon Photomultipliers (SiPMs) are novel solid-state silicon detectors with single photon counting capability. SiPMs excel in many applications and feature high gain with very low temperature drift, extremely good timing performance at a low operating voltage. They are also insensitive to magnetic fields and stand out with their mechanical robustness. KETEK provides cost-effective solutions from high volume applications to customized detector solutions. Main SiPM features are:

- Single photon resolution
- High photon detection efficiency
- High gain and high signal to noise ratio
- Low bias voltage (typically about 30 V)
- Insensitive to magnetic fields
- Not damaged by day light
- Low cost

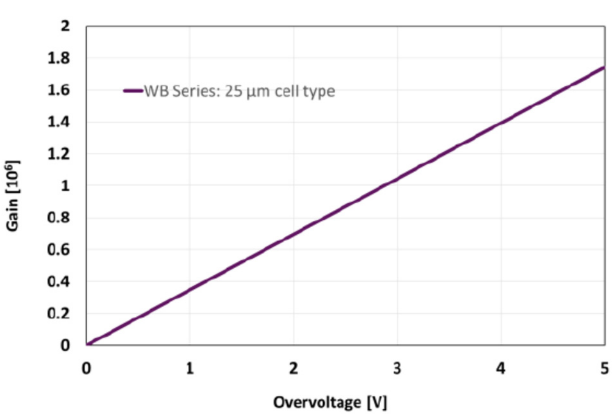

Figure 4: SiPM gain versus bias voltage [3].

Change of gain versus bias voltage covers approximately 20dB (see Fig.4).

This corresponds to 150V gap on photocathode of conventional PMT.

SiPMs for beam loss monitors measure as usually high light signals. Many parameters such as single photon counting, temperature stability, noise level are not very critical for these applications [4], [5], [6].

FIRST TESTS AT FLASH AND E-XFEL

Two BLM detectors with usual PMT and SiPM are placed right behind the third bunch compressor of FLASH [7]. This allows comparing bunch signals and different technical solutions.

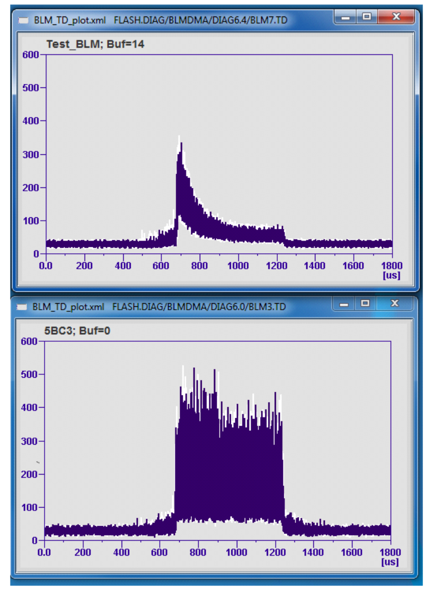

Figure 5: SiPM (top) vs. PMT (down); Darkcurrent signal over pulstrain; SiPM bias voltage drops due to too less bias current.

Figure 5 shows a comparison between a SiPM and a PMT BLM mounted at the same place. The signal of the SiPM decays because bias source delivers too low current.

Next tests in FLASH with adjusted bias source for SiPM showed good stability of the signals.

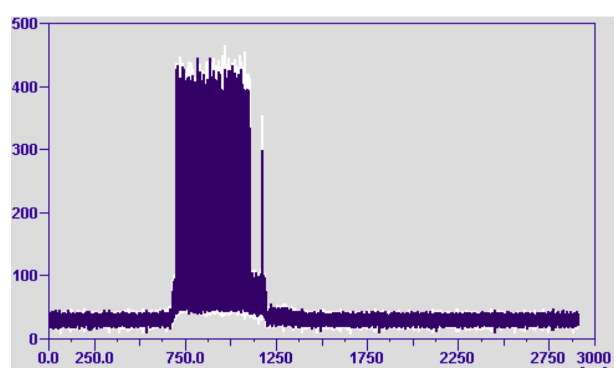

Figure 6: SiPM response, 400 bunches @ 1MHz rep. rate + 1 bunch, scintillator, bias +27V.

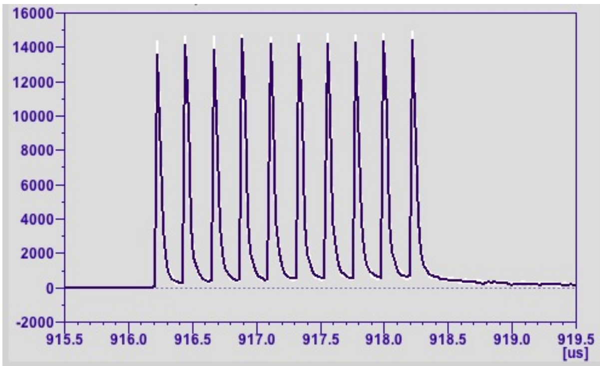

Figure 7: SiPM response, 10 bunches @ 4.5 MHz rep. rate, cherenkov, bias +29V.

Figure 6 and 7 show SiPM response for different bunch numbers, radiators and bias values. The signal stays stable over the hole train, also at 4.5 MHz bunch repetition rate, SiPM does not show any decay.

Test at XFEL with BLMs mounted like shown in Figure 2 show following:

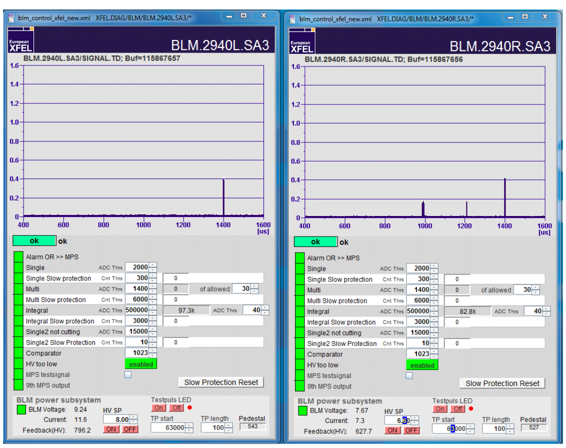

Figure 8: SiPM (left) and PMT (right), no radiator installed, Test LED signal at 1400 us

Figure 8 proves that we can rid of the hard x-ray signals in the undulator area. Two BLMs without scintillator or cherenkov radiator were installed in one undulator intersection. Where the PMT shows signal from the beam at 1000 us and 1200 us, the SiPM is not affected. For comparison the test LED signal was set to 1400 us.

HARDWARE CHANGES

The hardware consists of the BLM detectors, a dedicated Rear Transition Module (RTM) in combination with the DESY Advanced Mezzanine Card DAMC2 [8]. Furthermore a MPS card is required for alarm output collection.

Low bias voltage of SiPM can be taken from the first or second stage of the Cockroft-Walton PMT base. This decision allows to combine usual BLMs and SiPM BLMs in one RTM.

Another way is to develop new RTM with higher output

bias voltages. High voltage OpAmp converts DAC values into pre-selected bias voltage. In this case BLMs with SiPM readout can be connected only (for safety reason). This RTM is under development. It will be used with AMC board from Struck, SIS8300-L2.

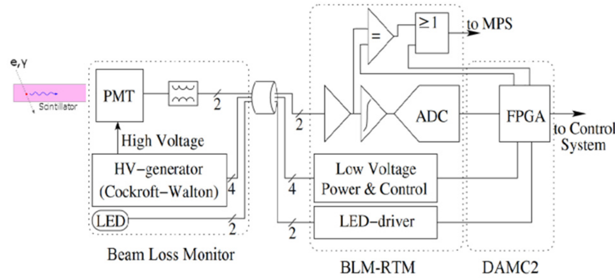

Figure 9: Present BLM system scheme.

Figure 9 shows present BLM system scheme. Detector part for SiPM readout will contain similar oscillator and

voltage doubler or even tripler to guarantee full range of bias voltages and high currents to avoid bias drop at high rates.

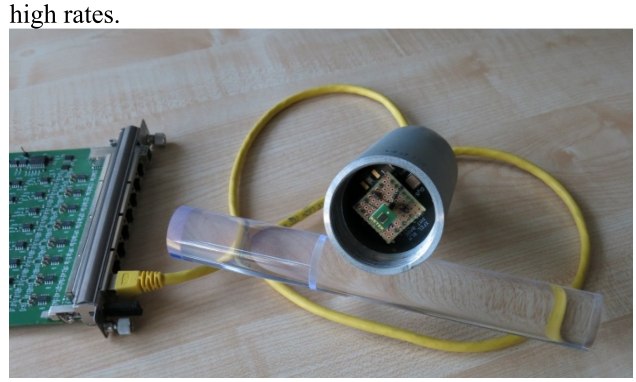

Figure 10: RTM and BLM with SiPM readout (prototype).

Figure 10 shows a reconstructed BLM with SiPM, scintillator and RTM.

NEXT STEPS

New base for SiPM in old mechanics will be constructed and optimized for high currents.

New RTM will be developed (for Struck SIS8300 AMC). Powerful high voltage BIAS outputs needed.

New base design for new RTM (maybe even some different constructions)

Tests of different bases and radiators on FLASH and XFEL.

CONCLUSION

Silicon Photomultipliers from KETEK are tested as readout devices for BLM system of XFEL.

Powerful bias source is needed to keep gain values during long bunch train.

Small radiation damages do not affect functionality of the BLM with SiPM readout.

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Compared to a conventional PMT, SiPMs are cheaper by a factor of 40.

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