BEAM HALO MONITOR FOR FLASH AND THE EUROPEAN XFEL

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Abstract

The Beam Halo Monitor for Free-electron Laser in Hamburg (FLASH) based on pCVD diamond and monocrystalline artificial sapphire sensors has been successfully commissioned in September 2009. It is a part of the beam dump diagnostics and ensures safe beam dumping. Its description and the experience gained during its operation are given. The ideas on the design and aspects of operation of the similar systems at FLASH II and the European XFEL are presented.

INTRODUCTION

Detection of the beam halo in particle accelerators can be utilized for beam diagnostics and machine protection. The BHM base on artificial diamond and sapphire sensors [1] has been introduced for FLASH (Free-electron LASer in Hamburg) [2, 3] as a part of the beam dump diagnostics system. It operates in conjunction with the other subsystems. The BHM sensors are able to detect presence even of the well-centered beam in the beam pipe. Their fast response makes it possible to signal on the bunch-by-bunch basis on the beam offsets in a wide range.

The BHM at FLASH has demonstrated successful operation. Similar systems is now being designed for FLASH II (an extension of FLASH) [4] and the European XFEL (E-XFEL) [5, 6].

BHM AT FLASH

Description

Four pCVD diamonds and four artificial monocrystalline sapphires placed inside cups in the last section of the electron beam pipe and uniformly distributed in azimuthal direction has been installed in a module in front of the dump downstream of the vacuum window as shown in Fig. 1. The sensors installed inside the beam pipe have to withstand high radiation doses. Both diamond and sapphire sensors have proven to be tolerant to irradiation with electrons up to the doses of 10-12 MGy with moderate signal degradation [7, 8].

The thickness of the BHM sensors is 300 µm for the diamonds and 500 µm for the sapphires. The sensors are operated as solid state ionization chambers. Bias voltage is feed via central wires of two coaxial cables. Single-ended signal is transmitted via third coaxial cable. The total length of the cables routed from the tunnel to the readout electronics in the counting room is around 60 m. An HV filter and the capacitors to support bias voltage reside 4 m away from the sensors. Signals are shaped and, if necessary, limited and then read out by a 14-bit flash ADC, which captures the signal amplitude with the frequency of 1MHz.

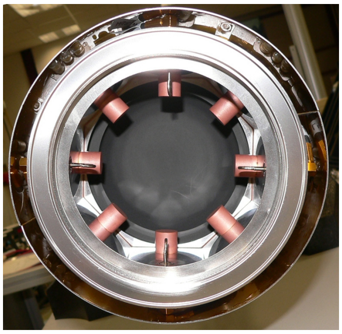

Figure 1: View of the BHM from the dump. The BHM sensors are inside the caps. Four loops of the magnetic-coupled BPM are right in front of the BHM sensors.

Operation Experience

Typical signal shape from a BHM sensor in the counting room without shaping is shown in Fig. 2. The pulse length is 5 ns (FWHM). Fig. 3 represents digital signals from a BHM diamond sensor when as responses 70 bunches with the charge delivered to the dump of 50 pC each in case when the beam is slightly off-centered in the top-left direction. The repetition rate is 200 kHz.

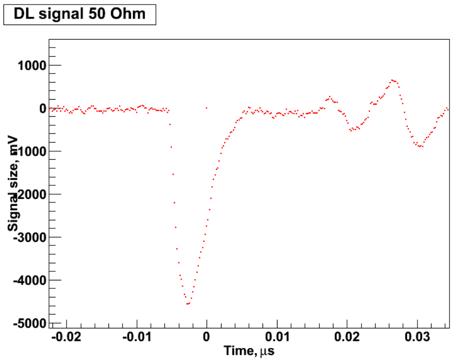

Figure 2: One-short waveform of raw signal from a BHM sensor.

To make correspondence of the signal amplitude to the total charge of the particles hitting the sensor the following procedure is applied. The beam was centered in the dump section of the beam pipe. The rotator magnet (sweeper) utilized to distribute the beam energy deposited inside the vacuum window is set to sweep the beam so that the beam core hits the center of the BHM sensors one by one. In this case the bunch charge hitting the sensor is almost the same as the bunch charge delivered to the dump. Fig. 4 shows the signal from a diamond sensor as a function of the beam position. Beam position is measured by “in-air” BPM. The pick-ups of the BPM are situated very close to the BHM sensors. As the signal from the BPM is saturated when the beam hits its pick-ups directly, it was corrected with the theoretical value for the deflection of the beam by the sweeper magnet.

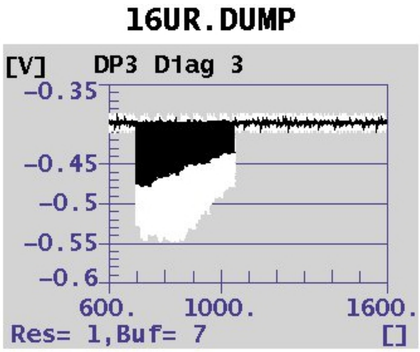

Figure 3: Digital signals from a BHM sensor as a response to 70 bunches. The beam has an offset of around 15 mm in the up-left direction.

Fig. 5 represents dependence of this maximal signal averaged over the period of measurement (typically a few minutes) on the bunch charge in the dump section for two diamond and one sapphire sensors. For diamonds the signal has steep rise with the bunch charge and reaches saturation at approximately 70 pC. The slope of the dependence for the sapphire is less steep. This increases the dynamic range of the system and allows it to detect low charges and remain operational at higher ones. For the sapphire the fitting curve represents the dependence. Three points are excluded from the fit as most probably for them the charge of the particles hitting the sensor during the measurement was lower than the bunch charge delivered to the dump because the beam was not well centred in the last section of the beam pipe.

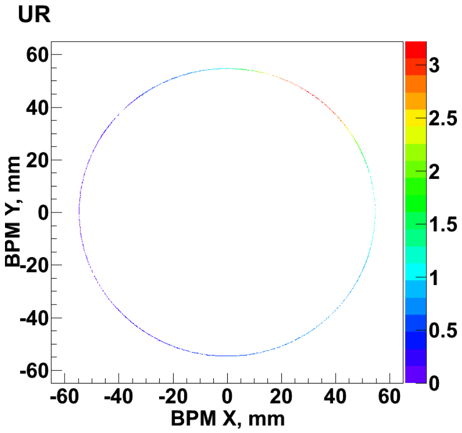

Figure 4: The signal (in V) from a diamond sensor as a function of the beam position.

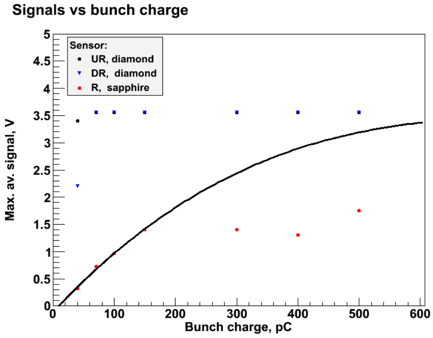

Figure 5: Maximal average signal from two diamond and one sapphire sensors as a function of the bunch charge in the dump.

BHM AT FLASH II AND THE EROPEAN XFEL

The BHM is also foreseen to be installed in the dump of FLASH II and injector and main dumps of the E-XFEL. The design of the mechanical part of the system for FLASH II and its position in the dump will be the same as at FLASH. The main difference of the BHM for the E-XFEL is sensors’ position. The sensors will be placed outside the beam pipe as it is shown in the Fig. 6. Fig. 7 shows position of the BHM in the injector dump of the E-XFEL. The readout electronics with slightly modified schematics made in the µTCA standard will be used both at FLASH II and the E-XFEL.

Unlike at FLASH and FLASH II, where the signals from the BHM sensors are observed by the operators only, the BHM at the E-XFEL will provide alarm signals for the machine protection system. Raw signals from the sensors will be processed and then digitized with 45 MHz sampling ADC. A hardware alarm for raw signals and a few software alarms for digitized signals dependent on the single-bunch or multi-bunch machine operation will be implemented to signal on potentially dangerous conditions.

Direct calibration of the BHM at the E-XFEL will not be possible or at least very difficult as the sensors are positioned outside of the beam pipe. Calibration will be based on the experience at FLASH and GEANT4 simulation of the system operation.

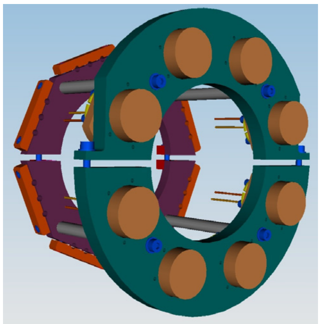

Figure 6: Drawing of the BHM for the E-XFEL.

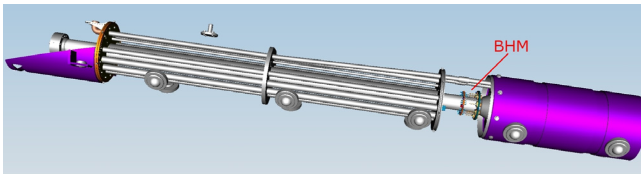

Figure 7: The BHM module in the injector dump of the E-XFEL.

CONCLUSIONS

The BHM based on artificial diamonds and sapphires has been successfully operated at FLASH since September 2009. The system is essential for the beam dump diagnostics. It is able to detect even small beam offsets inside the last section of the beam pipe. Utilization of combination of diamond and sapphire sensors widens the dynamic range of the system. The experience gained at FLASH will be the basis for the design of the BHM at FLASH II and the E-XFEL.

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