FEASIBILITY TESTS OF THE BEAM HALO MONITORING SYSTEM FOR PROTECTING UNDULATOR PERMANENT MAGNETS AGAINST RADIATION DAMAGE AT XFEL/SPring-8*

H. Aoyagi#, T. Bizen, N. Nariyama, JASRI/SPring-8, Hyogo-ken, JAPAN
Y. Asano, T. Itoga, H. Kitamura, T. Tanaka, RIKEN/SPring-8, Hyogo-ken, JAPAN

Abstract

A beam halo region of an electron beam at a linear accelerator might hit the undulator magnets and degrade undulator permanent magnets. An interlock sensor is indispensable to protect the magnets against radiation damage. We have been developing an electron beam halo monitor using diamond detectors for an interlock sensor at the X-ray free electron laser facility at SPring-8 (XFEL/SPring-8). The diamond detectors are operated in photoconductive mode. Pulse-by-pulse measurements are adopted to suppress the background noise efficiently. The feasibility tests of this monitor have been performed at the SPring-8 compact SASE source (SCSS) test accelerator for XFEL/SPring-8. We have prepared the pre-amplifier and used the synchronous data acquisition system in order to confirm the stability.

INTRODUCTION

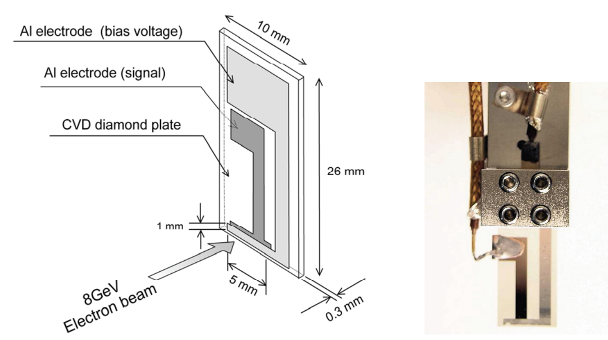
X-ray free electron laser facility at SPring-8 (XFEL/SPring-8) is in the final phase of construction. The XFEL machine is composed of a low emittance electron beam injector, a high gradient C-band accelerator, and in-vacuum undulators. The charge of electron beam is designed to be 1 nC/pulse with the repetition rate of 60Hz. For the oscillation of the X-ray free electron laser, the periodic uniformity of the strength of the permanent magnets of undulators is crucially important. However, the demagnetization of the permanent magnets will be occurred under the electron irradiation, even the small amount [1]. The magnets are not to be irradiated with the core part of the electron beam directly, because the position of core part of the electron beam should be controlled accurately. The halo of the electron beam, however, may be broadened by the slight changes of the beam conditions, and may hit the magnets. The intensity of the halo of the electron beam must be monitored during machine operation, and an electron injector must be halted immediately, when the intensity of the halo exceeds a threshold.

BEAM HALO MONITOR

We have been developing a beam halo monitor for the interlock sensor of the machine protection, which is equipped with diamond detectors to measure directly electron intensity of the halo part of the electron beam. Diamond detector, which operates in photoconductive mode, is good candidate for electron beam sensor, because diamond has excellent physical properties, such as high radiation hardness, high insulation resistance and sufficient heat resistance. This diamond detector is based on the technique of X-ray beam position monitors for the SPring-8 X-ray beamlines [2]. We adopted a pulse-by-pulse measurement for the halo monitor, because it suppresses the background noise efficiently, especially in the facilities having extremely high intense beam with low repetition rate, such as XFEL machines.

Diamond Detector

The detector head of the beam halo monitor is made of CVD diamond [3]. The structure of the diamond detector, which was fabricated by Kobe Steel, Ltd., is shown in Figure 1. One electrode is for signal reading and the other is for applying bias voltage. The active area is the bottom part of the plate between electrodes. In the case of pulse mode measurements, the dark current does not have effects on the output signal, because the charge from dark current is negligibly small in one pulse.



(a) (b)

Figure 1: (a) Structure of the diamond detector. (b) Mounted on the holder

Structure of Beam Halo Monitor

We have designed and made a beam halo monitor to measure the beam halo at the 250 MeV SCSS test accelerator for XFEL/SPring-8 [4,5]. Figure 2 (a) shows the beam halo monitor installed in front of the permanent magnets array of the undulators at the SCSS test accelerator. A pair of detectors is mounted on the upper and lower side of the beam center as shown in Figure 2 (b). Each detector can be changed independently. The core of the electron beam passes through between both detectors.

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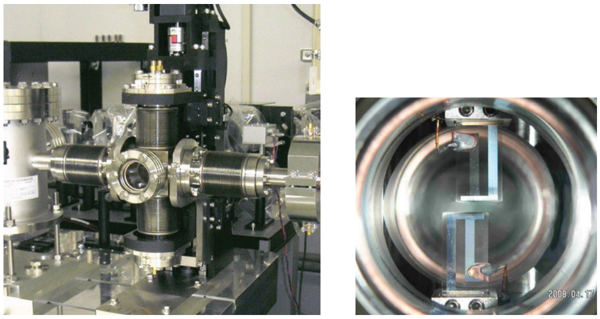
#aoyagi@spring8.or.jp



(a) (b)

Figure 2: (a) The beam halo monitor installed at the SCSS test accelerator, (d) The detectors are set on the upper and lower side of the beam axis.

FEASIBILITY TESTS

The following feasibility tests had been performed at the beam dump of the 8 GeV SPring-8 booster synchrotron and the 250 MeV SCSS test accelerator [6]. We demonstrated that the output charge of the diamond detector is proportional to the number of incident electrons in one pulse in the range of around 10^3 to 10^7 electrons/pulse. The incident electron of 1.5 x 10^3 /pulse results in the charge signal of about 25fC, when the bias voltage is +100V. The influence of an environmental noise in the klystron gallery is suppressed so that it is not to be observed. The influence of induction current can be controlled by using low pass filters. The influence of the secondary electrons and the radiation was not observed in the test at the SCSS test accelerator. There was no influence on the free electron laser oscillation, even though the diamond detectors were adjoined to the beam axis by a few mm.

Instrumentation for Stability Measurement

We have prepared the pre-amplifier for the beam halo monitor and used the synchronous data acquisition system in order to confirm the stability in a mid/long term of the monitoring as shown in Figure 3.

This pre-amplifier was originally developed for the current transformer (CT) in the SCSS test accelerator in order to measure the beam current correctly [7]. It suppresses a few mega-hertz noise emitted from the thyratron of a klystron modulator and a ringing noise caused by the wake field of the electron beam. The time constant of the amplifier is adjusted to about a few tens of nsec for this purpose. The input terminals are modified to match the single-ended output of the beam halo monitor.

The event-synchronized data-acquisition system has been introduced to the control system of the SCSS test accelerator [8]. This system can take a set of data from RF signals and beam monitor signals synchronizing with the same electron beam shots. In the case of beam halo monitor, the waveform data with 238MS/sec and the integral value (charge) data of all shots are continuously stored in the data base.

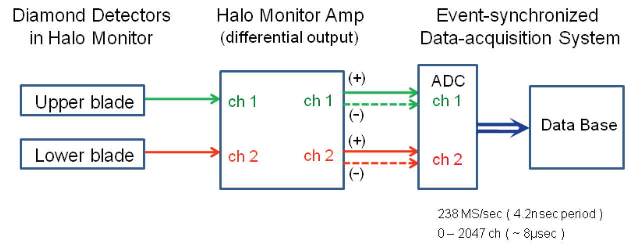
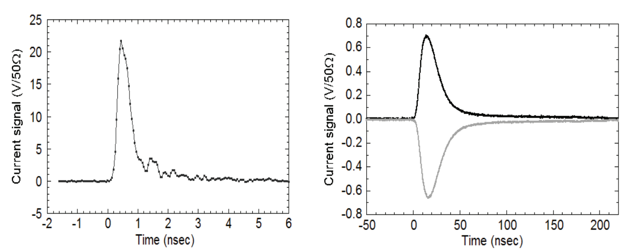


Figure 3: Schematic diagram of the beam halo monitor system.

Experiments

Figure 4 (a) shows the output signal from the upper blade of the diamond detector. The pulse width of the current signal is about 0.4 nsec FWHM against the weak incidence of the electron beam. In this measurement, the pulse width gets slightly longer, because the intense beam is introduced on the diamond detector. Figure 4 (b) shows the same output signal after the pre-amplifier. The pulse is extended to the pulse width of about 20 nsec FWHM, therefore the pulse shape can be stored in the data base as it is. The gain of the amplifier is selected to be ± 0 dB in this case, therefore the charge of output signal is conserved. Figure 5 shows the typical waveform stored at data base during the normal user time. The distance between the electron beam center and the diamond detector is 2.5 mm.



(a) (b)

Figure 4: (a) The output signal from the diamond detector. (b) The output signal from the pre-amplifier.

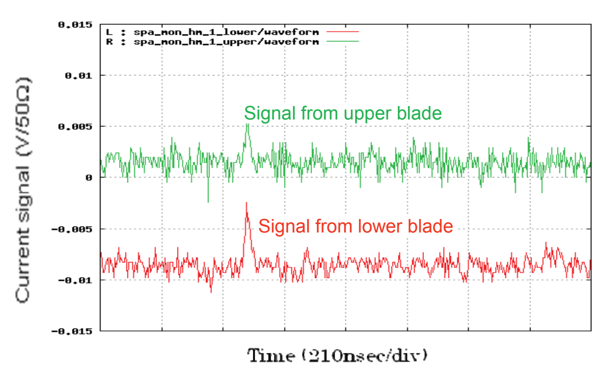


Figure 5: The waveform stored at data base. The upper (green) one is from the upper blade of the diamond detector and the lower (red) is from the lower blade.

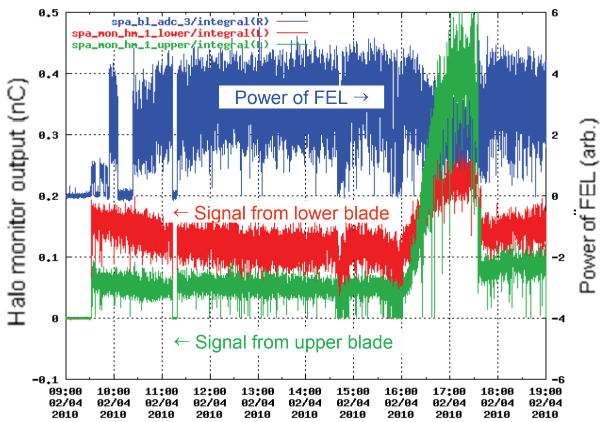


Figure 6: The result of the one-day measurement during machine study. The left axis shows the charge signals from the upper (green) and the lower (red) blades of the beam halo monitor, and the right axis shows the power of the free electron laser (blue).

Figure 6 shows the result of the one-day measurement during the machine study. The charge signal from each blade is calculated from the pulse signal as in Figure 5, and the baseline offset is subtracted from the simple integration of the waveform. During the machine study, machine conditions are changing at all times. In the beginning of the machine study, the power of the free electron laser was optimised, and the charge signal of the beam halo monitor showed the tendency to decrease. In the period of 16:00-17:30, the phase of RF cavity was trimmed, and the integral output signal. We think the halo monitor system operates normally from these observation results.

Figure 7 shows the result of the stability test during user time. Machine operation is usually start-up at 8:30, and is offered to the users soon after a quick beam tuning. The trend of the beam halo monitor outputs are very stable as well as the machine operation for about ten hours.

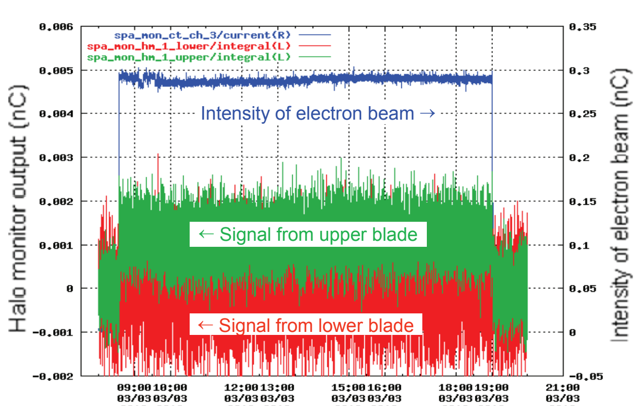


Figure 7: Result of stability test. The left axis shows the integral output signal of the halo monitor, and the right axis shows the intensity of the electron beam.

SUMMARY

We are planning to introduce the beam halo monitor to prevent the demagnetization of ID permanent magnet by the electron beam irradiation. Electron beam intensity of the halo part is measured directly by using the diamond detectors. The feasibility test has been performed at the beam dump of the 8 GeV SPring-8 booster synchrotron and the 250 MeV SCSS test accelerator for XFEL/SPring-8. We have prepared the pre-amplifier for the beam halo monitor and used the synchronous data acquisition system in order to confirm the stability in a mid/long term of the monitoring. During user time, the output of beam halo monitor is very stable. All these results suggest that the electron beam halo monitor is feasible for the interlock sensor to protect the radiation damage of the undulator permanent magnets for XFEL/SPring-8.

For the next step, we have prepared (a) diamond detectors newly designed to optimize to the beam halo monitor for XFEL/SPring-8, (b) detector holders having microstripline structure to improve the high-frequency property and (c) RF fingers to suppress the effect of the wake field from intense electron beam. As for the influence on the output of the diamond detector by an intense wake field of the electron beam, a more detailed examination is necessary.

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