BEAM HALO MONITOR USING DIAMOND DETECTOR FOR INTERLOCK SENSOR AT XFEL/SPring-8

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Abstract

An electron beam halo monitor has been developed in order to protect undulator permanent magnets against radiation damage for the X-ray free electron laser facility at SPring-8 (XFEL/SPring-8). The halo monitor will be installed at the upstream of the undulator and detect the electron beam that might hit the undulator magnets. 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. Pulse-by-pulse measurement suppresses the background noise efficiently, especially in the facilities having extremely high intense beam with low repetition rate, such as XFELs. The feasibility study of this monitor was performed at the SPring-8 compact SASE source (SCSS) test accelerator for XFEL/SPring-8. We observed the unipolar pulse signal with the pulse length of 0.4 nsec FWHM. The beam profiles of the halo can be also measured by scanning the sensor of this monitor.

INTRODUCTION

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 (60 Hz). Even if the undulator permanent magnets are irradiated continuously with the small part of the electron beam halo, whose energy is 8 GeV or less, the magnetic field is to be degraded [1]. The intensity of the halo part of the electron beam must be monitored during machine operation, and an electron injector must be halted immediately, when the electron intensity exceeds a threshold. The position of core part of the electron beam is controlled accurately, so usually the magnets are not to be irradiated with the core part directly. The halo part of the beam, however, may be broadened by the slight changes of the beam conditions, and may hit the magnets. Therefore, we are considering the machine protection interlock system, which detects overdose of electrons and send an alarm signal to stop the beam operation.

We have been developing a beam halo monitor for the interlock sensor, 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, 3]. 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.

The detector head of the beam halo monitor is made of CVD diamond [4]. The structure of the diamond detector, which was fabricated by Kobe Steel, Ltd., is shown in Fig. 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. The electron-hole pairs that are created in the active area can be extracted toward the electrodes. The cross section of this active area is designed to have the size of 5 mm by 1 mm. The depletion layer thickness is estimated to 0.3 mm. This detector has a self-sustaining structure, which is not mounted on a package. Therefore the active area of the diamond detector can be put closer to the beam center. The typical dark current is the order of 100 pA at the bias voltage of 100 V. In the case of pulse mode measurements, the dark current does not have effects on the output signal, because the charge from dark current in one pulse is negligibly small.

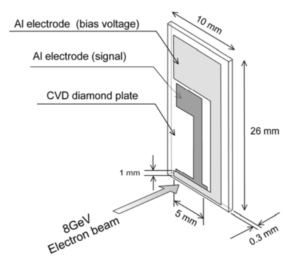

Figure 1: Structure of the diamond detector.

In order to evaluate the basic characteristics of the diamond detectors, such as detection sensitivity against electron beam and linearity, the beam tests have been undertaken at the beam dump of the 8 GeV SPring-8 booster synchrotron [4]. The oscilloscope having the sampling rate of 20 GS/sec and the analogue band width of 4 GHz was used. We prepared low attenuation cables, because the oscilloscope must be set out side of the machine tunnel and the cable length must be long, such as about 20 m. The coaxial cables of 50 Ω are used for impedance matching.

The typical pulse shape of the output signal is shown in Fig. 2 (a). This is one-shot measurement. The bias voltage is +100 V. The number of electron in one pulse is about 10^4. The pulse length of 0.33 nsec FWHM was obtained.

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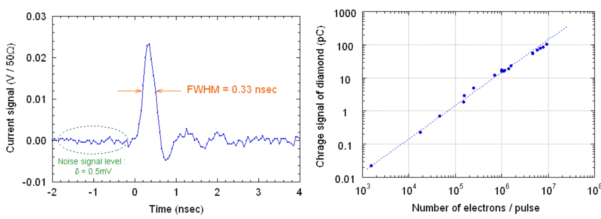
We took great care in cabling between electrodes on the diamond detector and the coaxial cables. We think that the pulse length of the output signal can be shortened farther using the detector having lower electrical capacitances. The RMS noise signal level is suppressed to about 0.5 mV for one-shot measurements.

The linearity of output signal on injected beam was also demonstrated as shown in Fig. 2 (b). The numbers of incident electron in one pulse were estimated by the output charge from the silicon detector. The output charge from the diamond detector is proportional to the number of incidence electrons in one pulse in the range of around 10^3 to 10^7 electrons/pulse. Minimum number of injected electron beam was nearly 1.5×10^3 /pulse, and we observed typical charge signal of 25 fC, when the bias voltage is +100 V.



(a) pulse shape (b) linearity

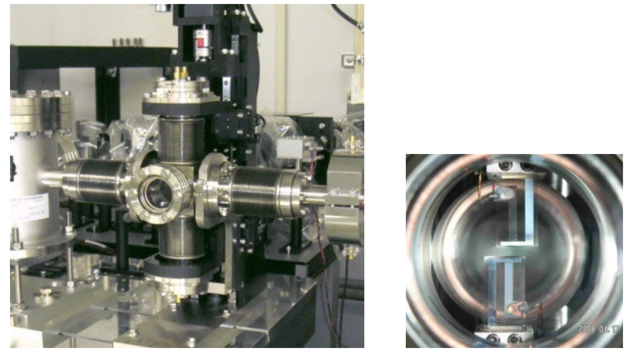
Figure 2: Measured data of the diamond detector.

BEAM HALO MONITOR

Figure 3 shows the diamond detectors which are mounted on the beam halo monitor. Each diamond detector is fixed on ICF70 vacuum flange. The RF feedthrough connectors are used on flanges, and the RF coaxial cables for UHV are connected to the electrodes of the detectors with very short wires. Therefore, the pulse length can be shortened, and the detection efficiency can be enhanced. Coaxial cables are used for impedance matching.

Figure 4 shows the beam halo monitor installed at the 250 MeV SCSS test accelerator for XFEL/SPring-8. A pair of detectors is mounted on the upper and lower side of the beam center. The distance between both the active areas of the detectors can be change by one actuator, and the center position of both detectors can be also change by the other actuator. The beam halo monitor is designed to install in front of the permanent magnets array of the undulators. The core of the electron beam passes through between both detectors.

Figure 3: Photographs of the diamond detectors.



(a) (b)

Figure 4: (a) Photographs of the beam halo monitor (b) Seen from on the beam axis.

Feasibility Test

We have carried out feasibility tests of the beam halo monitor at the SCSS test accelerator. The tests have been demonstrated as follows:

- Observation of the signal shape (check of pulse length, existence of ringing) at very low electron beam intensity.
- Evaluation of effect of noise source caused by such a thyratron.
- Evaluation of induction current (effect of wake field) and their suppression.
- Evaluation of signal cause of bremsstrahlung and secondary electrons produced at vacuum pipes, etc.
- Evaluation of effect on laser oscillation when the sensors get close to the electron beam.

Figure 5 shows the pulse shape of the beam halo monitor. The number of electron in one pulse is estimated to be about 4×10^4. The active area of the diamond detector was irradiated with the core part of the electron beam in this measurement. The output pulse length of 0.4 nsec FWHM was obtained. The pulse length is slightly longer than that measured at the 8 GeV SPring-8 booster synchrotron, as shown in Fig. 2 (a), because the cable length used in this measurements was longer by 5 m. The significant ringing was not observed. Figure 5 also indicates that the effect of noise source caused by such a thyratron can be evaluated to be negligible.

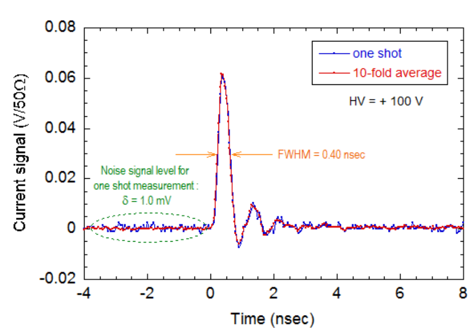


Figure 5: Pulse shape of the beam halo monitor (blue line: 10-fold average, red line: one shot measurement).

We evaluated the effect of induction current, when the electron beam core with high intensity (1.2×10^8 e/pulse) passes through near the detectors. We adopted the low pass filters (LPFs) in order to suppress the effect. Figure 6 shows the effect of induction current and the suppression. The upper part and the lower part show the signal shape without the LPFs and without LPFs, respectively. The effect of induction current can be suppressed by using proper LPFs, and the net signal from e-h pairs, which comes from the halo part of the electron beam, can be measured.

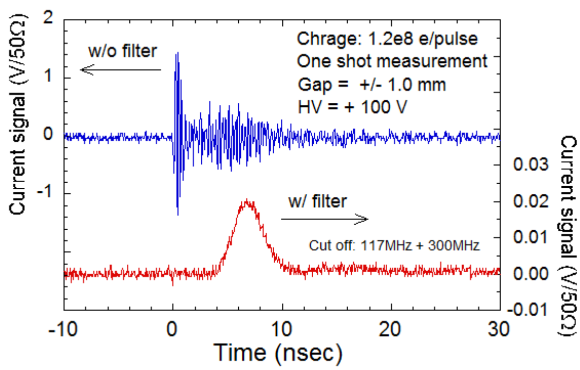


Figure 6: Effect of induction current and the suppression (upper: without LPFs, lower: with LPFs).

We also made an evaluation of signal from the bremsstrahlung and secondary electrons produced at vacuum pipes, etc. Therefore the vertical scanning measurements have been carried out. Figure 7 shows the signal charge as a function of vertical position of the active area of the diamond detector. The aperture of a spatial slit, which is placed just after the end of injector, was varied systematically. The profiles of electron spread by bremsstrahlung and electron scattering is theoretically assumed to be broad. On the contrary, the amount of signal charge at the vertical position over +/-2 mm is lower the detection limit even at the full aperture of the slit. So we think that the signal from the bremsstrahlung and secondary electrons is negligibly small.

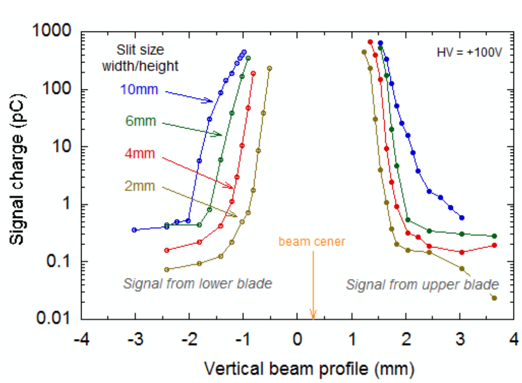


Figure 7: Scanning measurements.

Finally we checked the effect for the laser oscillation when the sensors approach the electron beam as shown in Fig. 8. The intensity of laser oscillation is not to be effected if the distance from the beam center and the diamond detector is more than 1 mm.

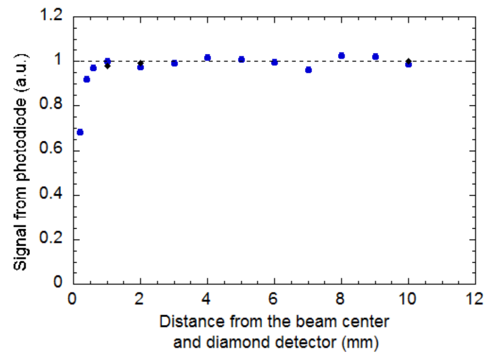


Figure 8: Effect on laser oscillation.

CONCLUSION

We have designed and fabricated the beam halo monitor using the diamond detectors as the sensor of machine protection interlock system at XFEL/SPring-8. The beam test of the monitor has been carried out at the 250 MeV SCSS test accelerator for XFEL/SPring-8. The pulse length of the current signal is 0.4 nsec FWHM. The RMS noise signal level is about 1 mV rms for one-shot measurements. We demonstrated the feasibility of the beam halo monitor. 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.

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REFERENCES

[1] T. Bizen et al., “High-energy electron irradiation of NbFeB permanent magnets: Dependence of radiation damage on the electron energy", Nucl. Instr. Meth. A 574 (2007) 401.

[2] H. Sakae et al., “Diamond Beam-Position Monitor for Undulator Radiation and Tests at the Tristan Super Light Facility", Journal of Synchrotron Radiation, 4 (1997) 204.

[3] H. Aoyagi et al., “New Configuration of Photoconductive Type Diamond Detector Head for X-ray Beam Position Monitors”, AIP Conf. proc. (SRI2003) Vol. 705 (2004) 933.

[4] H. Aoyagi et al., "Beam Halo Monitor using Diamond Detectors for XFEL/SPring-8", THPC146, EPAC 2008, Genoa, Italy.