BEAM HALO MONITOR USING DIAMOND DETECTORS FOR XFEL/SPRING-8

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Abstract

We have been developing an electron beam halo monitor as an interlock device for protection of undulator permanent magnets against radiation damage. When permanent magnets are irradiated with a halo part of 8GeV electron beam, magnetic fields undulators are degraded permanently and laser oscillation is weakened. Therefore, the interlock device is required during machine operation. Diamond detector, which operates in photoconductive mode, is good candidate for electron beam sensor. The excellent feature of this monitor is pulse mode operation to suppress the background noise efficiently. The beam test of the beam halo monitor using the diamond detector heads has been carried out at the beam dump of the SPring-8 booster synchrotron. Minimum number of injected electron was about 10^3/pulse, and we observed the pulse length of 0.33nsec FWHM without a preamplifier. The signal noise level is 0.5mV rms. The linearity of output signal on injected beam was also checked. The feasibility of the beam halo monitor equipped with the diamond detectors is described.

INTRODUCTION

The construction of the SPring-8 X-ray Free Electron Laser (XFEL) has been started. 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 1 nC / pulse (60Hz). 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 electron beam that irradiate on the magnets must be observed during machine operation, and an electron injector must be halted immediately, when the electron intensity excess the threshold. The 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 hits the magnets. Therefore, we are considering the machine protection interlock system, which detects the overdose of electrons and send an alarm signal to stop the beam operation.

We have been developing the beam halo monitor for the interlock device. The monitor is equipped with diamond detectors to measure the electron intensity of the halo part of the electron beam. The diamond detectors are placed close to the magnets in the vacuum chamber. 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]. In order to evaluate the basic characteristics of the diamond detectors, such as detection sensitivity against electron beam and linearity, the beam tests has been undertaken at the beam dump of the SPring-8 booster synchrotron [4].

We adopted a pulse-by-pulse measurement, because it suppresses the background noise efficiently, especially in the facilities having extremely high intense beam but low repetition rate, such as XFEL machines.

STRUCTURE OF THE MONITOR

The detector head of the beam halo monitor is made of CVD diamond. The structure of the diamond detector, which was fabricated by Kobe Steel, Ltd., is shown in Figure 1. The dimension of the diamond plate is 10 mm by 26 mm, and thickness is 0.3 mm. The pair of aluminum electrodes is formed by a lithography technique on both sides of the plate. 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 5mm by 1mm. The depletion layer thickness is estimated at 0.3mm. If an electron having the energy of 8GeV is induced in the diamond, about 0.1 % of its energy is absorbed in the bulk of diamond on the average. 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 order of 100pA at the bias voltage of 100V. 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.

A pair of the diamond detectors is mounted on actuators of the halo monitor as shown in Figure 2. The distance (d) between both the active areas of the detectors can be change by the 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. The RF feedthrough connectors are used on vacuum 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.

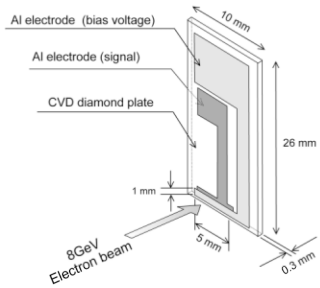

Figure 1: Structure of the diamond detector.

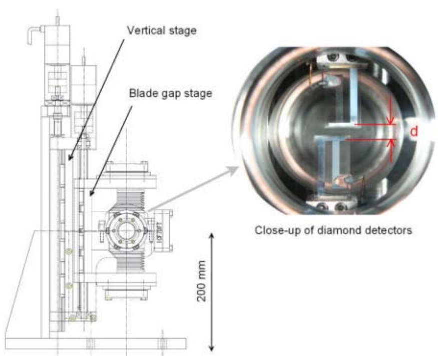

Figure 2: Structure of the beam halo monitor.

EXPERIMENTAL SETUP

The setup of the beam test is shown in Figure 3. The diamond detector is set in the halo monitor. The electron beam size is about 2mm rms in horizontal and about 0.2mm rms. in vertical. The pulse length is about 50psec rms. The repetition rate is 1Hz. The number of the induced electron can be tune from the order of 10^3 to 10^9/pulse. There is an aluminum window (t=1mm) in the end of the dump line. The simulation study demonstrated that the effect of the aluminum window at the 8 GeV beam dump is negligible. The oscilloscope having the sampling rate of 20 GS/sec and the analogue band width of 4GHz was used. The silicon PIN photodiode (HAMAMATSU, S5377-05) was used in order to measure the charge in one pulse at the low charge condition. We used the working function of 3.78V for the photodiode. 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 20m. The coaxial cables of 50 Ω are used for impedance matching. RF combiner is also used.

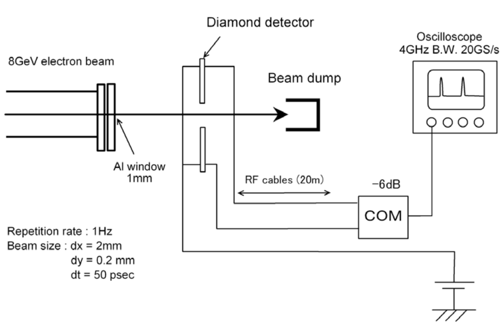

Figure 3: Set up of the electron beam test.

SIGNALS FROM THE MONITOR

The typical pulse shape of the output signal is shown in Figure 4. This is one-shot measurement. The bias voltage is + 100V. The number of electron in one pulse is the order of 10^4. The pulse length of 0.33 nsec FWHM was obtained. 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 0.5mV for one-shot measurements. Therefore the threshold is recommended to be set over 5mV, which is ten times larger than the RMS noise signal level.

The linearity of output signal on injected beam was also demonstrated as shown in Figure 5. 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 around 1.5 x 10^3 /pulse, and we observed typical charge signal of 25fC, when the bias voltage is +100V. This number is a certain detection limit of this detector. If this detector is used for an interlock sensor, the practical detection limit can be considered about 10^4 /pulse.

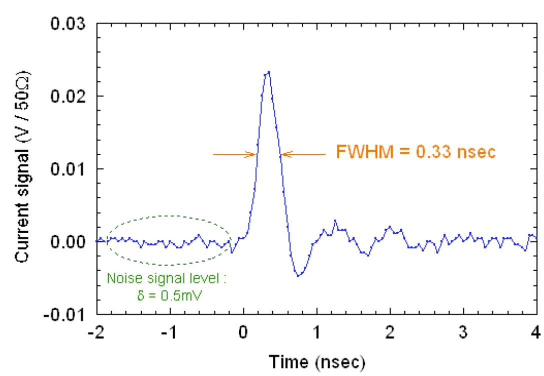

Figure 4: Pulse shape of the output signal.

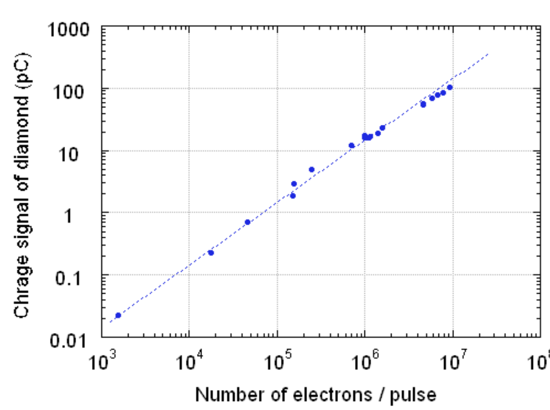

Figure 5: Linearity of the output signal.

The vertical scan measurement was carried out. The distance between the both active areas is constant (d=2mm), and the center of both detectors is scanned in vertical direction. Each signal is shown in Figure 6. This data is the average of ten shots. The signals from the lower blade have a delay of about 12nsec, which corresponds to the cable length of 3m, against the signals from the upper blade. At the vertical position of 0mm, the small signals from both of the blade, which corresponds to the halo part of the beam, can be observed. Figure 7 shows the variation of charge from each detector during this measurement. Charge from the diamond detector is estimated from the time integral of the current signal in Figure 6. At the vertical position of around +/- 1mm, the core part of the beam hits the active area of each detector. These data suggest that this monitor can be operated as an electron beam profiler.

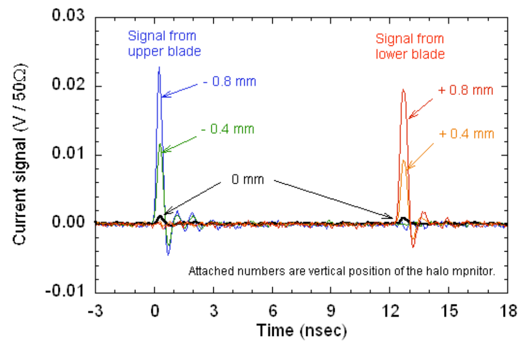

Figure 6: Current signal during vertical scan measurement.

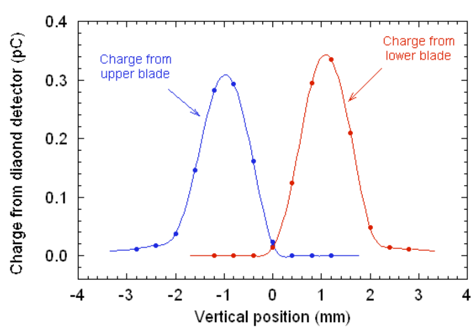

Figure 7: Charge during vertical scan measurement.

We observed the effect of induction current, when the electron beam having high intensity passes through near the detectors. Figure 8 shows the signals from e-h pairs and the signals from induction current. The number of electron is about 10^7 /pulse. The distance of between the active area of the detector and the center of the electron beam is about 1.4mm. The number of electron that hits on the active area of the detector is estimated to be less than 1% of the incident beam. We found that the signal from the induction current dose not change even if the bias voltage is varied. Therefore, we think that the effect of the induction current can be suppressed by subtraction of signals with analogue circuit. The low pass filter is also applicable for suppressing the effect of the induction current.

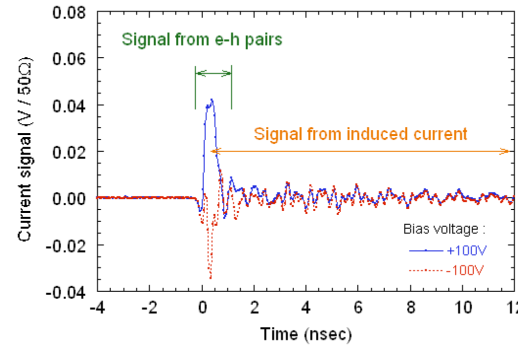

Figure 8: Signal from e-h pairs and induction current.

CONCLUSION

We have designed and fabricated the beam halo monitor using the diamond detectors as the sensor of machine protection interlock system for XFEL/SPring-8. The beam test of the monitor has been carried out at the beam dump of the SPring-8 booster synchrotron. The pulse length of the current signal is 0.33 nsec FWHM. The RMS noise signal level is about 0.5mV rms for one-shot measurements. We demonstrated that the output charge of 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. The incident electron of 1.5 x 10^3 /pulse results in the charge signal of about 25fC, when the bias voltage is +100V. This suggests that the diamond detector is promising for the electron beam halo monitor. The suppression of the effect of the induction current is next step for utilization of the halo monitor.

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