IMPROVEMENT IN HIGH-FREQUENCY PROPERTIES OF BEAM HALO MONITOR USING DIMOND DETECTORS FOR XFEL/SPring-8*

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Abstract

The beam halo monitor using diamond detectors, which are operated in photoconductive mode, has been developed for the X-ray free electron laser facility at SPring-8 (XFEL/SPring-8) to protect the undulator magnets against radiation damage. Pulse-by-pulse measurements are adopted to suppress the background noise efficiently, and to improve the detection sensitivity. The feasibility tests of the prototype of this monitor have been carried out at the SPring-8 compact SASE source (SCSS) test accelerator for SPring-8 XFEL. As the next step, we are trying to improve the high-frequency properties: (a) dimension of diamond detectors is newly designed, (b) microstripline structure is applied in the vacuum chamber to improve the high-frequency property, (c) RF fingers are also applied to suppress the effect of the wake field from intense electron beam. The mechanical design of the monitor that will be installed in XFEL/SPring-8 has been done.

INTRODUCTION

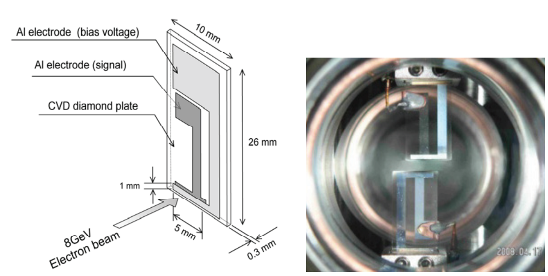
X-ray free electron laser facility at SPring-8 (XFEL/SPring-8) is in the final phase of construction. The charge of electron beam in the undulators is designed to be 0.3nC/pulse with the repetition rate of 60Hz. For the oscillation of the X-ray free electron laser, the magnetic strength with the periodic uniformity by the permanent magnets of the undulators is crucially important. However, the demagnetization of the permanent magnets will be occurred under the electron irradiation [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 when the intensity of the halo exceeds a threshold.

We have developed the prototype of the 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 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.

Prototype of the Beam Halo Monitor

The schematic view of the diamond detector of the prototype is shown in Fig. 1 (a). One electrode is for reading out signal (front side) and the other (rear side) is for supplying bias voltage. The active area is the bottom part of the plate between electrodes. A pair of detectors is mounted on the upper and lower side of the beam center (Fig. 1 (b)). Each detector can be operated independently. The core of the electron beam passes through between both the detectors.

The feasibility of the prototype of the beam halo monitor has been demonstrated at the beam dump of the 8GeV SPring-8 booster synchrotron and the 250 MeV SCSS test accelerator for XFEL/SPring-8 [2-7]. 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 detection limit is 2×10^3 electrons /pulse. The influence of an environmental noise in the klystron gallery is not observed. The influence of induction current that is caused by wake fields 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 is no influence on the free electron laser oscillation during user operation. The stability in a mid/long term of the monitor has been also confirmed. All these results suggest that the electron beam halo monitoring is feasible for XFEL/SPring-8.



(a) (b)

Figure 1: (a) The diamond detector of the prototype, (d) The detectors are set on the upper and lower side of the beam axis.

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IMPROVEMENTS IN HIGH FREQUENCY PROPERTIES

New designs have been applied to improve the high-frequency properties. The following three items are adopted for the new monitor: (a) miniaturizing of diamond detectors, (b) microstripline structure, (c) RF fingers.

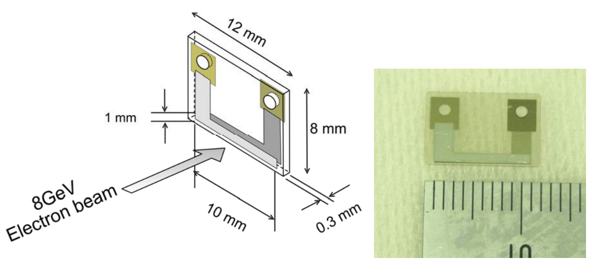
Miniaturizing of Diamond Detectors

The diamond detectors were newly designed. The dimension of diamond detectors was miniaturized from 26 mm × 10 mm to 12 mm × 8 mm in order to adopt microstripline structure and RF fingers easily (Fig. 2). The width of active layer is chosen to be 1mm. By having this narrow active area, this monitor can be used for profile measurements of the beam halo.

The diamond detectors have been evaluated with 8GeV electrons of the SPring-8 booster synchrotron. The linearity of charge signal of the detector against the number of incident electron was confirmed (Fig. 3).

Microstripline Structure

The microstripline structure is applied in the vacuum chamber to improve the high-frequency property (Fig. 4). The impedance is designed to be 50Ω. The demonstration of pulse measurement using the microstripline structure has been described in reference [8].



(a) (b)

Figure 2: (a) The dimension of the diamond detectors. (b) The photograph of the diamond detectors.

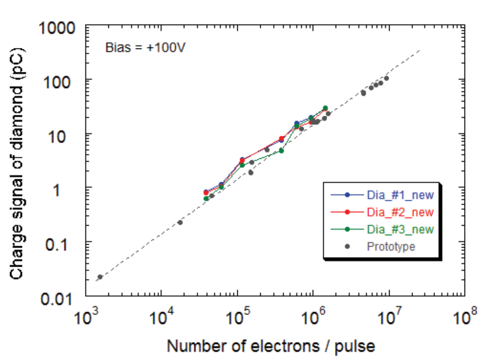


Figure 3: The linearity of charge signal of the detectors on the number of incident electron. Black dots indicate the diamond detector for the prototype.

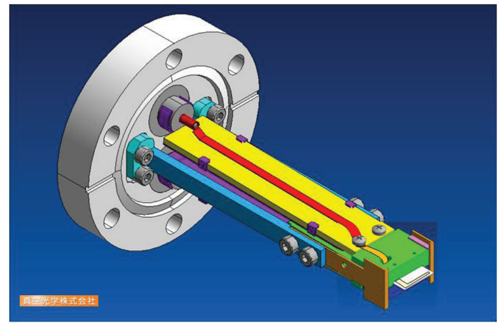
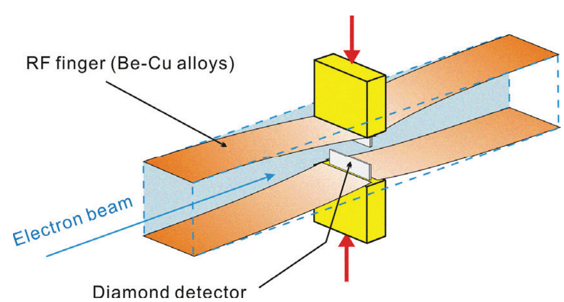


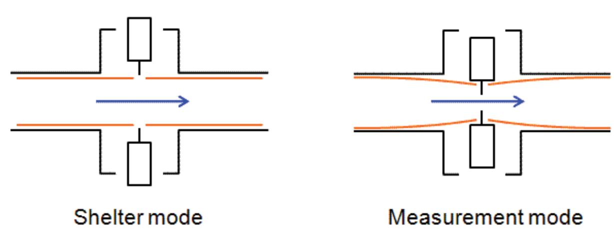
Figure 4: The microstripline structure with SMA feedthrough connectors on the ICF70 flange. The diamond detector is clamped on the ceramic holder.

RF Fingers

The RF fingers are also applied to suppress the effect of the wake field from intense electron beam. Figure 5 shows the schematic view of movable RF fingers. The ceramic holders push edges of the rectangular RF finger inside and the fingers are bended, as the actuators of diamond detectors are trimmed. There are two modes of the movable RF fingers. The RF finger flattens when the diamond detectors are pulled out, and the impedance of the electron beam can be lowered (shelter mode). If the diamond detectors are driven to near the beam core to measure the beam halo, the RF fingers bend moderately and bumps of inner wall of a beam route is minimized (measurement mode).

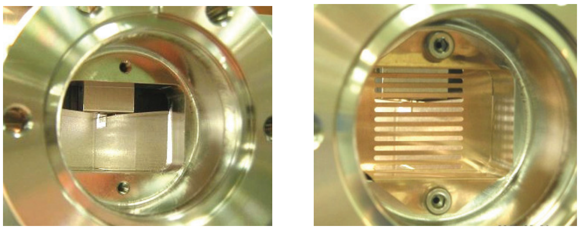


(a) Three dimensional view of the movable RF fingers.



(b) Two modes of the movable RF fingers

Figure 5: The schematic view of the movable RF fingers.

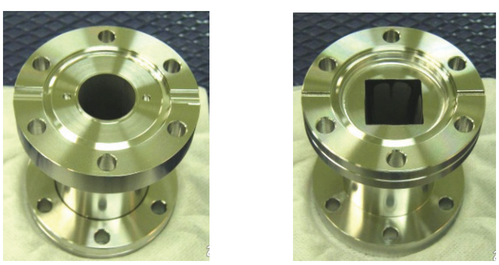


(a) (b)

Figure 6: The photograph seen from the view port. (a) The diamond detector and the movable RF fingers. (b) The screen shield (Be-Cu).

The diamond detectors and the RF fingers can be watched from the viewport, where a screen shield is attached (Fig 6).

Figure 7 shows the beam pipe adaptors, which has a circular section on one side and a square section on the other side. These two sections are connected smooth and continuously. The diameter of the circular section is 22mm, which is the same size as the standard beam pipe. The length of the square section is 22mm, which corresponds to the width of the movable finger. The resonance mode generated in the vacuum chamber of the monitor can be suppressed using the beam pipe adaptor.



(a) (b)

Figure 7: The photograph of the beam pipe adaptor. (a) The circular section of the beam pipe side. (b) The square section of the monitor side.

BEAM TEST

The beam tests of the RF shield evaluation device, which adopts the above-mentioned items, have been performed at 250 MeV SCSS test accelerator. One diamond detector is mounted on the upper port (ICF70) of this device. This device has been installed just upstream of the prototype of the beam halo monitor as shown in Fig. 8. Therefore, it is easy to compare the performances of this device with that of the prototype.

Figure 9 shows the pulse shape of the diamond detector with the RF shield evaluation device. In this measurement, the charge of electron beam was cut down to fC order level by collimators and an OTR screen. No significant ringing or induced current can be seen after the main peak. The small peak after 1.3 nsec of the main peak originates from the reflection at the SMA feedthrough connectors on the ICF70 flange. This small peak can be easily reduced with sophisticated feedthrough connectors. The connectors will be exchanged in the monitor that will be installed in XFEL/Spring-8.

Figure 10 shows that induced current that originates from the wake field is suppressed efficiently. The charge of electron beam was 0.20nC in this measurement. The upper graph is the induced current of the prototype of the beam halo monitor, which has no RF shield. The lower is that of the RF shield evaluation device. We think that the induced current can be reduced further by improving the shape of the movable fingers. We have a plan to cover the diamond detectors fully with the movable RF fingers as the next step.

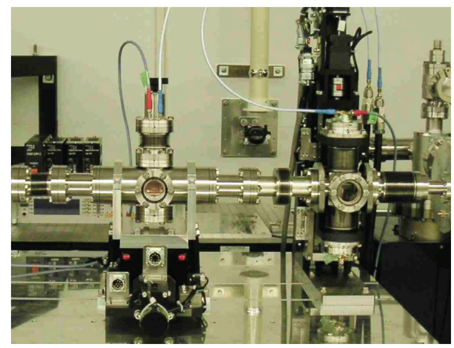


Figure 8: RF shield evaluation device (left), and the prototype of the beam halo monitor (right).

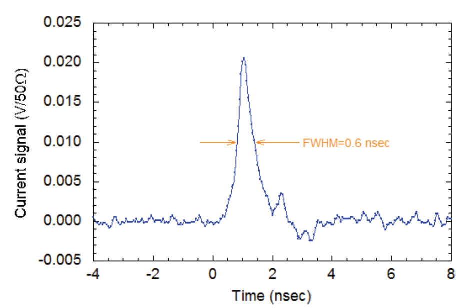


Figure 9: The pulse shape from the newly designed diamond mounted on the RF shield evaluation device.

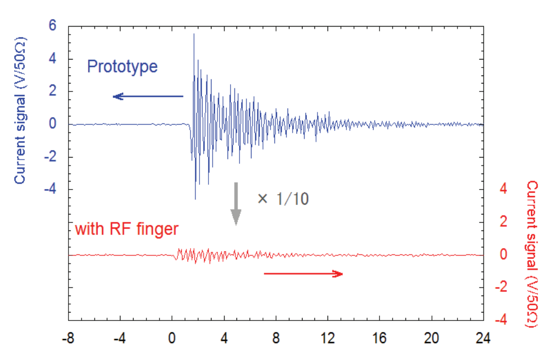


Figure 10: The effect of wake field is reduced to 1/10 by RF fingers.

MECHANICAL DESIGN

The mechanical design of the monitor that will be installed in XFEL/SPring-8 has been done as shown in Fig. 11. The design of the main vacuum chamber follows that of the RF shield evaluation device. The vacuum chamber having RF fingers is fixed to the base plate, so there will be no transverse offset that induces mechanical stress on the bellows joined on the beam pipe adaptor. The both of the diamond detectors on the upper and the lower port can be actuated with stepping motors independently. Basically, the position of the diamond detectors synchronizes with a gap motion of undulators. This monitor will be installed at about 1m upstream of the undulators in order to monitor the intensity of the beam halo.

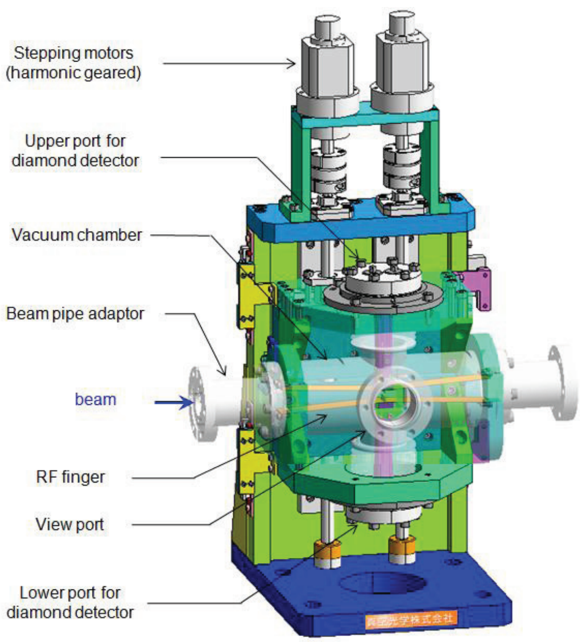


Figure 11: The mechanical design of the halo monitor.

SUMMARY

We have a plan to introduce the beam halo monitor to prevent the demagnetization of ID permanent magnets in XFEL/Spring-8. Electron beam intensity of the halo part is measured directly by using the diamond detectors.

We have improved the high-frequency properties: (a) the size of diamond detectors was miniaturized, (b) microstripline structure was applied in the vacuum chamber to improve the high-frequency property, (c) RF fingers are also applied to suppress the effect of the wake field from intense electron beam. The beam test of the RF shield evaluation device with the new diamond detector has been performed at 250 MeV SCSS test accelerator. We confirmed that in the resonant mode, the effect field is reduced by one order of magnitude.

The mechanical design of the monitor that will be installed in XFEL/SPring-8 has been completed. The improvements mentioned above can be achieved by adopting this design.

As the next step, a further improvement of the movable RF finger will be accomplished, and the beam test will be examined soon.

ACKNOWLEDGEMENTS

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All diamond detectors described here have been fabricated by Kobe Steel, Ltd. The three-dimensional images of the mechanical design have been supplied by Vacuum and Optical Instruments (Shinku-Kogaku, Inc).

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