STUDY OF DIAMOND DETECTOR APPLICATION AT THE FRONT END OF A HIGH INTENSITY HADRON ACCELERATOR*

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Abstract

Diamond detectors function as beam loss or luminosity monitors for high energy accelerators, such as LHC, Babar, etc. Because of regular detectors insufficient protection of the front end, diamond detectors owning significant characteristics, like time resolution in the nanosecond range, radiation hardness and negligible temperature dependence. Thus, diamond detectors have been becoming promising candidates for detecting BLMs of fully super-conducting hadron accelerator, such as C-ADS, FRIB. In this paper, the sensitivity of diamond detectors was simulated by Monte Carlo program FLUKA and GEAN4. Meanwhile, we tested the performance of a new prototype of CVD diamond detector, and compared it with Si-PIN and Bergoz detectors at the storage ring of the HLS II. The results of the diamond detector were consistent with other two detectors well. More evaluation of diamond detectors in low energy radiation field are ongoing.

INTRODUCTION

Beam loss monitors (BLMs) are common devices usedin hadron and lepton accelerators. Depending on accelerator specifies, BLMs could be just diagnostics or could play an essential role in the machine protection system (MPS). Beam loss control is one of the bottlenecks for beam power increasing for high intensity machine. Some new hadron accelerators, like the Chinese Accelerator-Driven System (C-ADS) and the Facility for Rare Isotope Beams (FRIB), are full superconducting accelerator[1][2]. The sc cavity is more sensitive to beam loss than roomtem perature accelerating section. Thus, it's necessary to provide a high level beam loss monitor system. A widely accepted rule of thumb is to limit the beam loss to 1 W/m to keep the radioactivation levels low enough for hands-on maintenance. As beam powers grow ever higher, the corresponding fraction of the allowable beam loss necessarily becomes smaller and thus more challenging.

There are some ordinary BLM detectors such as Bergoz in NSRL and ionization chamber in SNS[3]. The Bergoz detector is based on Si-PIN sensor, in many similar applications, the Si-PIN BLM detector encountered the radiation damage problem and had limited lifetime[4]. That's why the Si-PIN sensor is not enough for a high intensity accelerator. In SNS, The ionization chamber (IC) is the main detector type in the BLM system due to its simple design and immunity to radiation damage. The biggest problem is significant background from the X-ray radiation produced by the RF cavities. And it's not sensitive enough at lower energy. Thus, it's necessary to design new type BLM detector to meet the high intensity hadron accelerator at the low energy section.

RADIATION FIELD SIMULATION

High Intensity Hadron Accelerator

Different from the room temperature accelerating section at the front-end of SNS or J-PARC, C-ADS or FRIB will accelerate the heavy ion by sc section from RFQ. In this paper, radiation field caused by beam loss of C-ADS injector will be fully discussed as a representative of new type accelerator.

Injector II, as a possible front-end of C-ADS linear accelerator, consisting of an ECR ion source, a 2.1 MeV room temperature RFQ and superconducting half wave resonator (HWR) cavities[5]. The sc accelerating section will stimulate the proton from 2.1MeV to 10 MeV. Figure 1 depicts the sc HWR cavity and the FLUKA simulation model. In the sc HWR cavity, the white structure is niobium cavity and the green one is titanium as insulation and support. Liquid helium fill the gap between niobium and titanium to keep low temperature.
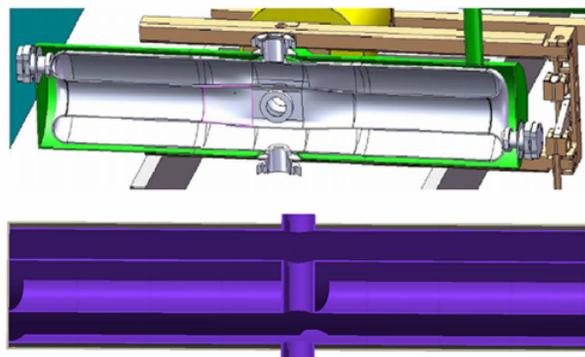

Figure 1: The upper one is the left view of HWR cavity and the lower one is the top view of FLUKA model.

Analyze of the Simulation

The secondary particles that hit the BLM detector may be electron, photon and neutron. Thay come from three mechanisms: prime proton loss, field emission and delayed process by activated materials. The sc accelerator

may produce cavity X-ray when it operates on high accelerating gradient. Acknowledgedly, these cavity X-rays are caused by field emission (FE) [6]. FE is due to quantum tunneling of electrons from microscopic defects on the RF surface, assisted by the cavity's electric field. Materials activation is inevitable for any particle accelerator. For the simulation purpose, the normal loss which is homogeneously distributed along the HWR cavity inner surface should be taken into consideration. The accepted average beam loss limitation is 1 W/m.

Table 1: Secondry Particles Peak Yield Out of SC Cavity (s=second, e=electron, p=proton)

source	photon	neutron	electron
proton loss	3.37E-5 /p	1.43e-5 /p	4.34e-7 /p
FE electron	2.26E-3 /e	non	8.42e-7 /e
nuclide decay	1.81E+3 /s	non	little
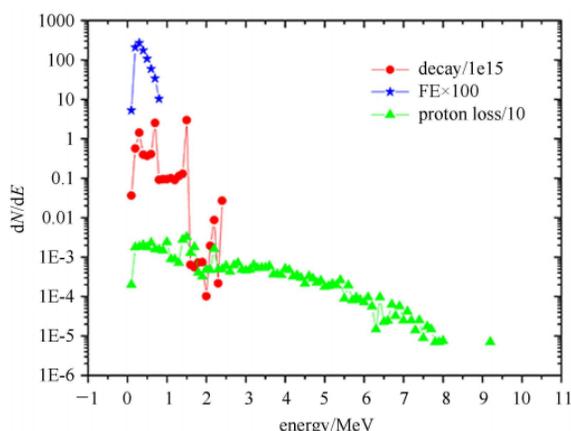
Figure 2: Photon energy spectrum in three loss mechanisms. (The values of longitudinal axis are adjusted).

Table 1 and Fig. 2 give a complex relationship between the three main beam loss mechanisms and their secondary particles peak yield. Neutron detectors are required because of the sole evidence for proton loss. Meanwhile, the amount of photon yield is the largest, but acquiring the right signal is a challenge assignment to perform. For photon detection, the background would contain the photons caused by normal proton loss, γ-rays by residual radiation and X-rays by FE sometimes. The electron yield is small, but it is more easy than the photon to certify the beam loss occurred.

According to the experience of SNS and J-PARC, neutron and photon are the main detecting particles[7]. Traditional BLM system for proton accelerators mainly consists of ionization chambers and scintillation detectors such as neutron detectors. This combination is usually not sufficient to protect low-energy high-intensity hadron machines due to:

1) low radiation level from beam loss,
2) significant X-ray background near high-gradient superconducing RF cavity
3) poor loss localization with neutron detectors.

Because of the sc cavity, the selection of beam loss detector is more difficult for CADS injector. Under such circumstances, an ion chamber is not a good candidate to monitor the beam loss in the cold areas. It is also impossible to place scintillation detector in the cryomodule for its large size and low radiation hardness. Diamond detector has high radiation hardness and can be used at low temperature. So diamond detectors is a promising candidate for BLMs of C-ADS Injector.

DIAMOND DETECTOR TEST

Diamond Detector

Diamond is probably the most versatile, efficient and radiation-tolerant material available for use in beam detectors[8]. Correspondingly, it has a wide range of applications in beam instrumentation and in beam diagnostics. The nanosecond time response in combination with the sensitivity to single particles makes them ideal for use in fast beam loss detection. As shown in Fig. 3, a new prototype of CVD diamond based BLM detector has been designed and under evaluation for the upgrade of existing BLM systems, which can work in either pulse counting mode for fast monitoring, or in charge measurement mode for slow monitoring. The detector is 6mm diameter, thickness 300μm, and leakage current less than 3pA under 800V bias voltage.

Figure 3: Prototype of CVD diamond BLM detector.

To evaluate the performance of the CVD diamond detector, we made several experiments at the storage ring of the HLS II.

Comparison with Si-PIN and Bergoz Detector

We installed one Si-PIN detector, one diamond detector and one Bergoz detector at the same position on the storage ring at the NSRL. The three detectors are placed very close to each other to reduce the influence of installation position. Fig.4 is the layout of detectors.
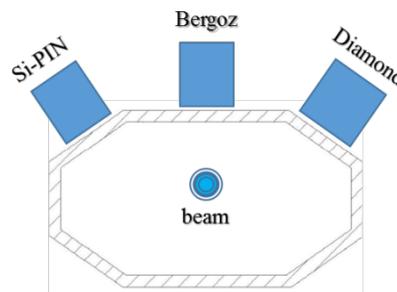

Figure 4: Layout of three detectors.

Both the pulse counts from Si-PIN and CVD diamond detectors and the outputs of the Bergoz BLM detector have been measured during the initial injection and top-up injection of the storage ring. And the outputs of the diamond detector is in accordance with other two detectors well, and the diamond detector proves to be very sensitive to the machine status, as shown in Fig.5.
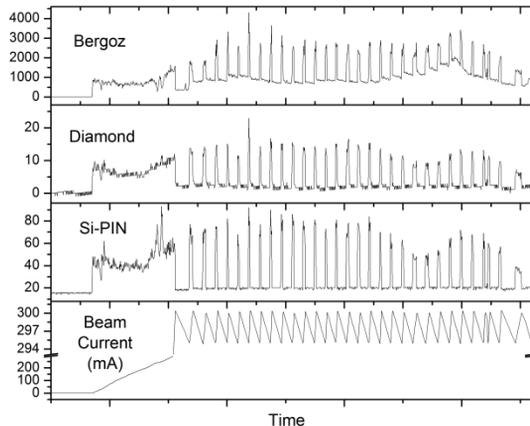

Figure 5: Comparison of Diamond, Si-PIN and Bergoz detector.

CONCLUSION

In short, beam loss is a key challenge for high intensity hadron accelerator. Traditional BLM detectors don't meet the requirements. The inherent properties of diamond make it an ideal material for radiation detectors. A new prototype of CVD diamond detector is tested in NSRL and has a good performance. More quantitative experiments are needed for diamond detector.

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