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NEW SCINTILLATION TYPE BEAM LOSS MONITOR TO DETECT SPOT AREA BEAM LOSSES IN THE J-PARC RCS

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Abstract

In the J-PARC RCS, a large fraction of our effort has been concentrated on reducing and managing beam losses to achieve 1MW high power proton beam operation. Standard beam loss monitor (BLM), which is installed outside of the magnet in every cell of beam optics and detect the beam loss at wide area in each cell, is insufficient to investigate finer beam loss mechanism in the ring. Thus we developed new scintillation type BLM to detect the spot area beam losses on the vacuum chamber inside the magnet. The new BLM isolates a photomultiplier (PMT) from a plastic scintillator, and connects it with optical fibres. Because small plastic scintillator is set on the vacuum chamber directly, it has capability to have high sensitivity for a beam loss at localized spot area. On the other hand, the PMT can precisely be operated without being affected by a magnetic field because it can be kept keeping away from the magnet. In this paper, we report the detail of the performance of the new BLM.

INTRODUCTION

The 3-GeV Rapid Cycling Synchrotron (RCS) of the Japan Proton Accelerator Research Complex (J-PARC) accelerates protons from 400MeV to 3GeV kinetic energy at 25 Hz repetition rate. The average beam current is 0.333 mA and the design beam power is 1 MW. The RCS has two functions as a proton driver for neutron/muon production at the Material and Life science experimental Facility (MLF) and as a booster of the Main Ring synchrotron (MR) for the Hadron experimental facility (HD) and Neutrino experimental facility (NU) [1].

The most important issue in achieving such a MW-class high power routine beam operation is to keep machine activations within a permissible level, that is, to preserve a better hands-on maintenance environment. Therefore we adopt the ring collimator system to remove the beam halo and to localize the beam loss at the collimator area [2]. In addition, a large fraction of our effort has been concentrated on reducing and managing beam losses, in the J-PARC RCS. As a result, we have successfully achieved acceptable low-loss 1-MW beam acceleration [3]. Until now, the highest radio-activation area confines to an injection section, and then the beam loss localization by using the ring collimator is functioned. On the other hand, we surveyed residual doses on the vacuum ducts along the ring and mapped residual dose distributions in detail. The detailed dose distributions give key information about sources and mechanisms of the beam losses [4]. To move on the next step, we developed a new beam loss monitors (BLM) to detect the spot area beam loss, especially in the magnet. This paper presents details of the new BLM.

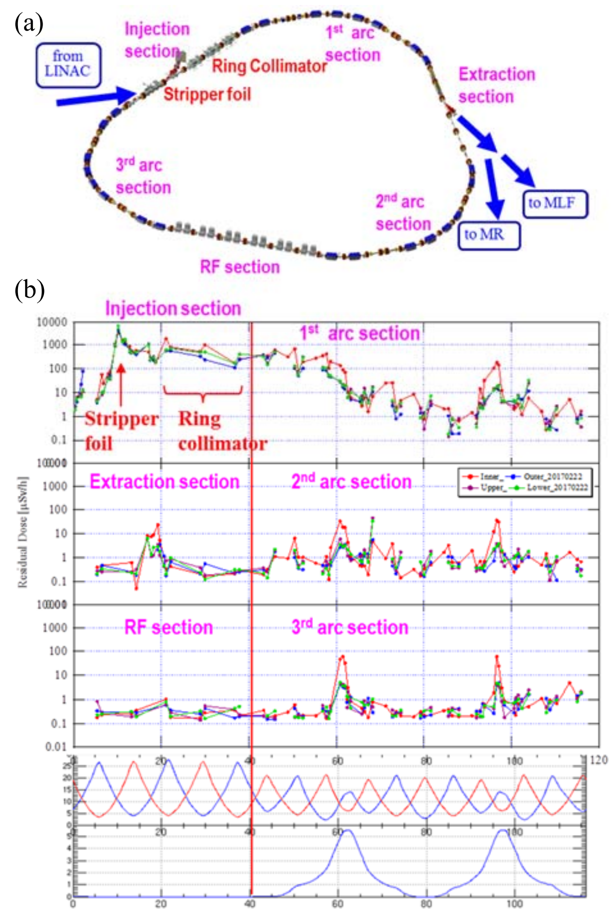

Figure 1: Schematic view of the RCS ring and measured residual dose distributions along the ring.

RESIDUAL DOSE SURVEY AND BEAM LOSS DETECT

Residual Dose Distribution along the Ring

Figure 1 shows the schematic view of the RCS ring and a typical surveying and mapping result of the residual dose distributions along the ring. The residual doses are measured by using the Geiger–Muller (GM) counter. We contact it on a surface of a vacuum duct because the sensitivity to the radio-activation at the contacted local spot can be enhanced drastically. In order to obtain the detailed distribution, we measure the residual dose on inner, .outer, upper, and lower sides of the vacuum duct at upstream and downstream of all magnets.

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At first sight, the highest radio-activation area confines to an injection section, especially, an immediate vicinity of a 1st stripper foil and the ring collimator the ring collimator region. The high radio-activation around the stripper foil is caused secondary particles generated from the foil due to the nuclear reaction by hitting the beam into the foil [5-6]. This cause is not the beam losses in general, and then it cannot be disappeared intrinsically as long as a charge exchange multi turn beam injection scheme with the stripper foil is adopted. But it is possible to reduce the secondary particles from the foil. A key parameter to reduce them is "foil hitting rate [3]" that is defined as a ratio of total number of foil hitting particles to number of injecting particles. From the simulation results, "foil hitting rate" can be reduce drastically by expanding the injection painting area and optimizing the stripper foil width and foil irradiation position. Indeed, we can prove experimentally that the residual dose around the foil decreases corresponding to the "foil hitting rate" [7].

The residual doses at the other section extremely small compared with those at the injection section. However up closer examination, it has some specific structure according the lattice structure. The RCS has a threefold symmetric lattice which partitions into 27 FODO cells. Three cells in each straight section and six cells in each arc section. Measured residual doses are plotted in each symmetric lattice. These arranged and detailed dose distributions give key information about sources and mechanisms of the beam losses as follows: momentum spread at the dispersion peak points, leakage particles which are scattered by the primary collimator but not absorbed by the next secondary collimators, dispersion leakage into the straight section, and so on [4].

Beam Losses Measurement System

The detailed residual dose distribution mapping gives important information about the beam losses. In order to investigate more accurate loss mechanism, the detailed beam losses mapping are also required. That is, we need to detect the spot area beam losses, but it is not that easy.

In the J-PARC RCS, proportional counter-type beam loss monitors (P-BLMs) are adopted to detect ionizing radiations due to the beam losses because they use mainly in the interlock system for machine protection. The 90 units of P-BLMs are installed along the ring and beam lines. Basically, only two are placed for every cell in the ring and are set under the steering magnets or quadrupole magnets. This beam loss measurement system by using the P-BLM works very well with a view of the observation of the significant level of the beam loss at wide area. But, it is unsatisfactory with a view of the detailed beam loss mapping; because number of the measurement point is small and above all it cannot detect the spot area beam loss.

DEVELOPMENT OF NEW S-BLM TO DETECT THE SPOT AREA BEAM LOSS

One of useful methods to detect the spot area beam loss is proposed as follows: a small sensor is adopted and is set on the vacuum duct directly to enhance the sensitivity to the ionizing radiation from generated by the local spot area beam loss [4]. The J-PARC RCS adopted a small scintillator type BLM (small S-BLM) which is simply assembled a small plastic scintillator (EJ212: Eljen Technology [8], 20x20x50mm) and a small PMT (H11934-100-10MD: HAMAMATSU [9]). And we proved experimentally that the small S-BLM can be detected the local spot area beam losses during the beam operation. Moreover, it can detect the gamma ray from the local spot area of the radio-activated vacuum duct after the beam stop. This small S-BLM has a high potential advantage. At the same time but the usage has the following restriction; it cannot be used in a magnetic field because a signal gain of the PMT is drifted by the magnetic field. One solution is isolating the PMT from the small scintillator, and then connecting between them by an optical fibre. Here, it is named "Optical Fibre joined S-BLM (OF-SBLM).

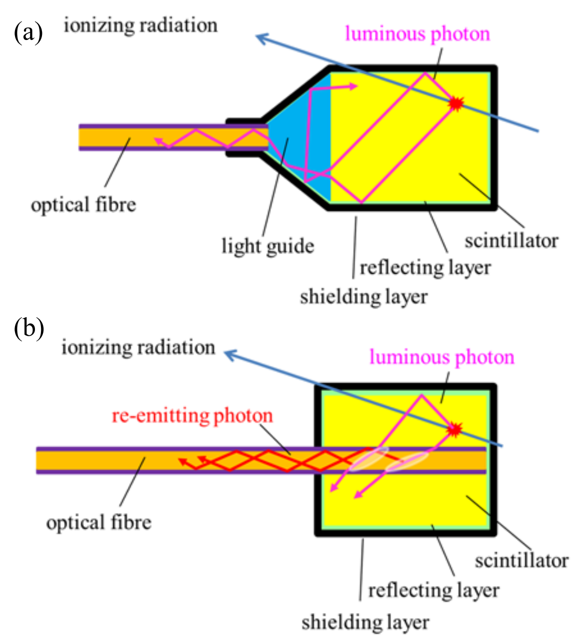

Figure 2: Schematic diagram of the two types design structure for the optical fibre joined S-BLM.

Design of Optical Fibre Joined S-BLM

A most important issue of the OF-SBLM is how to improve photon transmission efficiency from the scintillator to the optical fibre. Thus following two connection and transmission methods (see in Figure 2) were reviewed at the start of the design of the OF-SBLM. In generally, when the ionizing radiation irradiate into the plastic scintillator, that luminescent materials absorb the radiation energy and re-emit the absorbed energy in the form of light. One method is for this luminous photon to transport into the optical fibre directly by using the light guide as shown in Figure 2(a). The tapered light guide concentrates and leads the photo into the edge face of the optical fibre. However the

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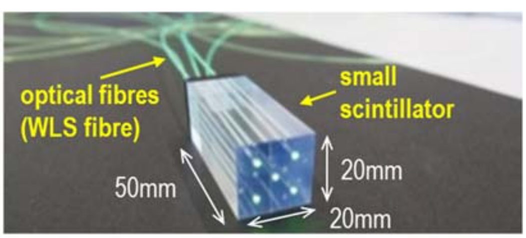
photon transmission efficiency is not be expected to improve because of low photo-condensing efficiency and transmission loss at the boundary surface between the light guide and optical fibre. The other method is for photons to transport indirectly by using a wavelength shifting type optical fibre (WLS fibre) as shown in Figure 2(b). The WLS fibre absorbs the luminous photons, re-emits new photos with shifted wavelength, and finally transmits the re-emitting photons pass through the fibre. Emission peak wavelength of the EJ212 plastic scintillator is 423nm. Thus we adopt Y11 Kuraray [10] WLS fibre which works as a blue to green shifter (emission peak: 476nm, absorption peak: 430nm). In order to increase the number of the incoming luminous photons into the WLS fibre, we made five holes in the plastic scintillator and stuck the five fibres into the holes as shown in Figure 3(a). Diameter of the Y-11 fibre is 1mm and fibre length is 3.5m. After sticking, the scintillator is wrapped by aluminium foil for reflecting layer and over-wrapped by black tape for shielding layer. Five WLS fibres are bundled into a shielding tube together.

On the other hand, the Y-11 fibre also emits a scintillation photon by the incoming ionizing radiation. This dark photon works as an offset noise to the PMT. In order to cancel an influence of the dark photons, a pair of the OF-SBLMs, where one has the scintillator head and the other does not have the scintillator, are assembled as shown in Figure 3(b). A correct value of the local spot area beam loss is obtained by taking a difference between the two PMT signals.

(a)



(b)

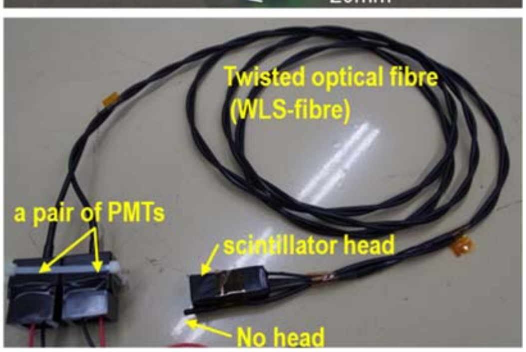


Figure 3: Assembly work of the optical fibre joined S-BLM.

Performance Confirming Test

To confirm the performance of the OF-SBLM, it was compared with the small S-BLM. The two type BLMs were set in the same place on the vacuum duct, which are located at downstream of the ring collimators and has fully separated distance from the magnets.

Performance confirming test was carried out under following two conditions (a) during the beam operation and (b) after the beam stop. During the beam operation, the beam losses due to the leakage particles from the ring collimator are occurred at the measurement spot. In this case, waveform signals are acquired by the digital oscilloscope with a 50 ohm termination because every turn by turn beam loss signal can be detected. After the beam stop, gamma ray generated at the radio-activate vacuum duct can be detected by the scintillator. Thus relative dose level can be estimated and then its decay curve can be obtained by counting the gamma ray continually. In our case, the PMT signals are measured by the digital oscilloscope with 1 M ohm termination and the acquired data during 20 msec are taken an average. And this evaluation process repeats for every 2 sec to obtain the decay curve.

Experimental results summarized in Figure 4. Red plots indicate the small S-BLM signals and blue ones are the OF-SBLM signals. In both conditions, two BLM signals agree very well with each other. Therefore it can be verify that the OF-SBLM can perform as good as the small S-BLM. Namely, it has high sensitivity of spot area beam loss, finer time structure of the beam loss can be measured, and residual dose at the spot area can be evaluated to detect the gamma ray.

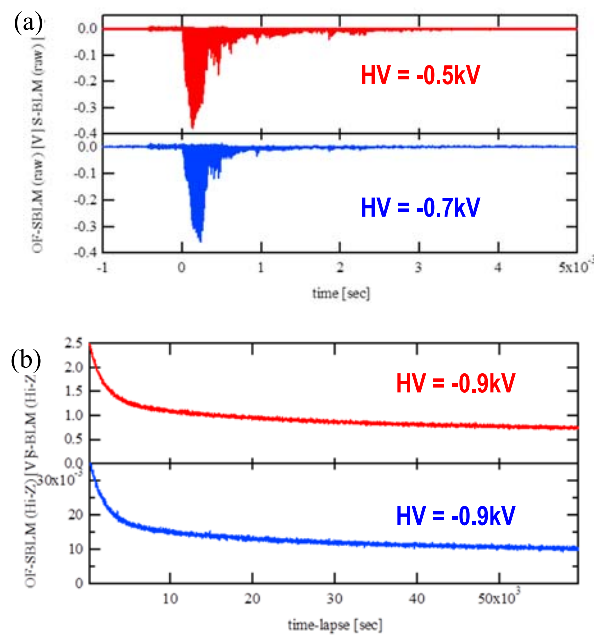


Figure 4: Experimental results to compare the OF-SBLM and small S-BLM. (a) Beam loss waveforms obtained during the beam operation. (b) Relative residual dose decay curves obtained after the beam stop.

Advanced Application of OF-SBLM

In the present, the highest residual doses are observed around the stripper foil. The cause is not the standard beam loss but the secondary particles are produced by nuclear reactions at the stripper foil. Furthermore, it is understand

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that "foil hitting rate" is the key parameter to reduce these highest dose. The OF-SBLM has a great advantage to enhance the sensitivity the secondary particle detection being influenced by the shift bump magnets. Thus we try to measure the secondary particle from the stripper foil and evaluate the "foil hitting rate". The RCS can choose between circulating mode and one path mode by switching the beam extraction magnets. In the one path mode, only injecting beam hits into the foil. On the other hand, both injecting and circulating beam hits during the beam injection period in the circulating mode. The "foil hitting rate" can be evaluated by comparing with both measured signals in two modes. For preparation, the PMT was replaced with a large PMT (H6410: HAMAMATSU [11]) to increase the dynamic range.

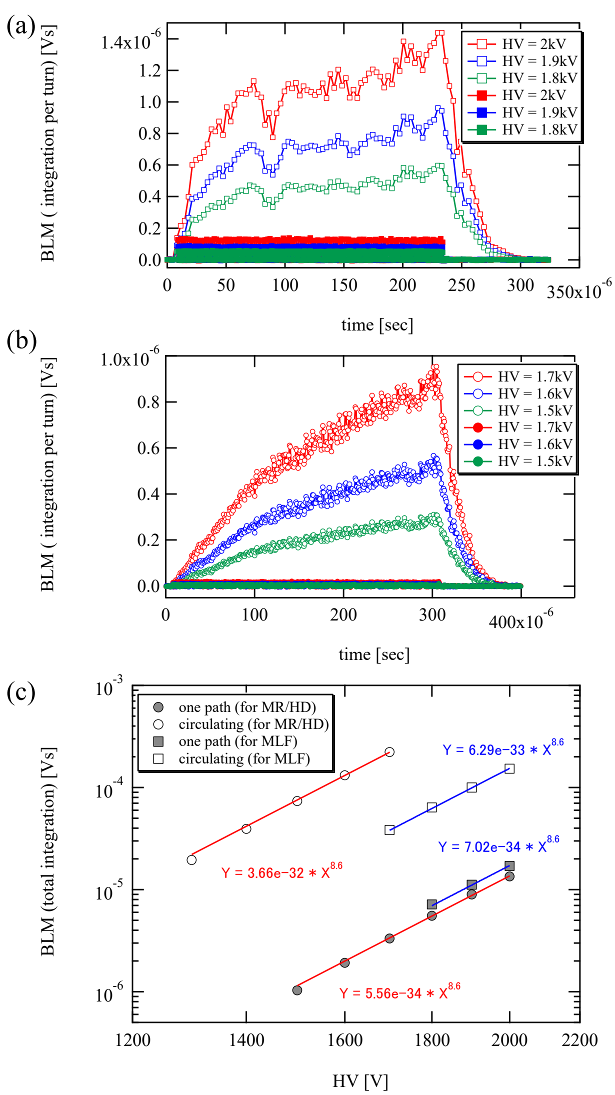

Figure 5: (a) Measurement of the secondary particles from the stripper foil in both one path mode and circulating mode for MLF user operation. (b) Secondary particles measurement for MR/HD user operation. (c) High voltage dependence of the secondary particle measurements.

Beam experiments were carried out in following two user operations; (a) for MLF user (225μs, 200 π/200π-Anti.) and (b) for MR/HD user (300μs, 50 π/50 π-Cor.). Figure 5(a) and (b) shows the turn by turn OF-SBLM signals plots in both one path mode and circulating mode respectively. These signal levels between in one path mode and in circulating mode are markedly different. Thus we have to consider the OF-SBLM (especially the PMT) with saturation in their response or signal buried in a noise, even if the PMT has an enough wide dynamic range. Figure 5(c) shows high voltage dependence of the secondary particle measurements. All plots follow the power-law profile, and each power index obtained by fitting is 8.6 in common. Then it is certain that the OF-SBLM responds without saturation and without being buried in the noise. By comparing the fitting coefficients, the "foil fitting rate" can be estimated directly. It is 8.95 for MLF user operation and 65.8 for MR/HD user operation. Calculating estimation value by using the particle simulation including a space charge effect is 6.3 and 70 respectively. There are a few differences between the measured and calculated values, and it may be caused by slightly varying some conditions. However we can prove the OF-SBLM to have the great advantage for finer tuning to mitigate the beam losses still more.

SUMMARY

Residual dose distributions along the ring are measured by using the GM survey meter, and these detailed dose distributions suggest the various beam loss mechanism. To detect the local spot area beam losses, the optical fibre joined S-BLM is developed. Key technique to improve photon transmission efficiency from the scintillator to the optical fibre is using the wavelength shifting fibre and stricking it into the scintillator. We verify experimentally that OF-SBLM has capability to detect the spot area beam losses without being influenced by the magnetic field. Furthermore, it demonstrates to detect the secondary particles from the stripper foil and evaluate the "foil hitting rate" experimentally.

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