BEAM LOSS DETECTED BY SCINTILLATION MONITOR

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Abstract

Ar-CO_2 gas proportional beam loss monitors (BLMs) have measured the beam loss through operations, but they are also sensitive to background noise of X-ray emitted from RF cavities. For the future energy upgrade of J-PARC linac, because 21 RF cavities are additionally installed in the beam line, the background noise would be serious problem. We employed the scintillation monitors to measure the beam loss which would bring more accurate beam loss measurements with suppression of X-ray noise. As the measurement results, a good signal to noise ratio is observed for the scintillation monitor with quite low sensitivity to the background X-ray. This paper describes the beam loss measurement system using a scintillation monitor.

INTRODUCTION

The user operation of J-PARC linac was started in December 2008 with the limited beam power of 270 W from the linac. Since then, we have experienced the operational issues including those caused by uncontrolled beam losses. Mechanisms and cures for the uncontrolled beam losses have been identified in the beam studies, and we have succeeded in mitigating them. A beam loss possibly caused by the H^0 particles generated by the interaction between H^- beam and residual gas in the beam line were observed. In the linac operation, Ar-CO_2 gas proportional counters are employed for the measurement of beam loss [1], but they are also sensitive to background noise of X-ray emitted from RF cavities. In the Figure 1, signals from gas proportional counters installed in SDTL section are shown. If the RF supplied though the beam operation is stopped, these signals from the BLS still remain.

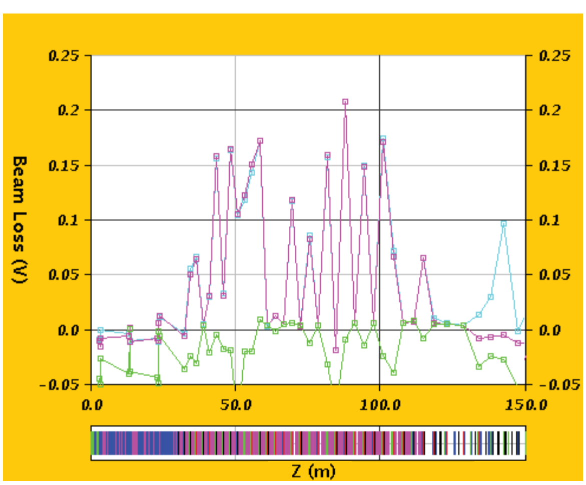

Figure 1: Beam loss around SDTL section. Signals during the operation are indicated in water, an RF without a beam is in pink, and no RF and no beam is in green. This figure shows that the BLM has sensitivity for the X-ray emitted from RF cavities.

In addition, protons, secondary hadrons and gamma-rays would be mainly generated as a beam loss in this section, but it is not easy to estimate real beam loss only using the gas proportional counter.

BEAM LOSS SIMULATION

Simulation Program

In order to develop the new beam loss detecting system for the future energy upgraded linac, the beam loss simulation using the GEANT4 to estimate the particle distribution which is generated by the scattering between the beam particles and the residual gas.

The library which treats a reaction from H^- to H^0 caused by the interaction between the H^- beam particles and the residual gas is newly developed for the GEANT4 [2]. The cross sections of the reaction from H^- to H^0, H^0 to H^+ (proton) and H^- to H^+ are defined by the references [3-4]. Mass of the H^- and H^0 are defined as 939.294 and 938.783 [MeV/c^2] respectively for the mass transport calculation. All RF cavities, the quadrupole magnets and the beam pipes are defined as the boundary conditions. Because the gas pressure inside the beam duct is 1.0e-4 to 1.0e-6 [pa] during the operation and its components are the N_2 and H_2 and hydrocarbon mainly, the nitrogen gas (N_2) with 1.0e-5 [Pa] is assumed in the beam pipe. Twiss parameter at the beginning part of the SDTL section which is employed for the beam dynamics design is assumed for the initial distribution of beam particles. The initial beam energy at the entrance of SDTL section is assumed to be 50 MeV and it is increased up to 181 MeV by the 15 SDTL cavities. All electrical fields generated by the RF and the magnetic fields generated by the quadrupole magnets are taken into consideration, but the space charge effect is ignored. Because the H^- particles are affected by the quite weak magnetic fields by the quadrupole magnets ideally, the Lorentz stripping can be ignored.

Hadrons Generated by Beam Loss

In this simulation, 1.0e+12 H^- particles with the initial momentum are assumed consistently and travel from the SDTL section. H^0 particles are mainly generated by the interaction between H^- particles and residual gas. Because the neutral hydrogen particles are transported to the downstream with the initial momentum, the particles with the imperceptible angles travel ~ 40 m downstream

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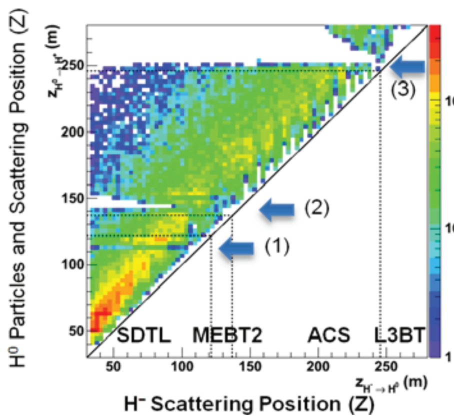

Figure 2: Position and frequency of the scattering between H^0 and beam duct. H^- particles are scattered with residual gas and H^0 particles are generated. Generated particles travel to the downstream and scatter with a beam duct.

(Figure 2). In the figure, the color contour indicates the frequency compared with the assumed particle number. After the travel to the downstream, they have the collision with a beam duct and the structural materials, and they are transported to the other hadrons. Scattering occurred frequently at the low energy part of the linac (~ 50 m), because the cross section of the reaction from H^- to H^0 is getting larger with the smaller momentum. And there are three points where the less events of the collision occur due to the increasing the diameter of the beam duct.

Candidate Device for Beam Loss Measurement

Hadrons are estimated to be produced by the collision between H^0 and beam duct (Figure 3). Because the scattered hadrons are mainly consists the gamma-ray, neutron or proton, the beam loss can be detected by the measurement of them.

Because the current gas proportional counter is sensitive for the X-ray emitted from RF cavities, the sensors which are sensitive for the gamma-ray, neutron or proton are the candidate devices for the beam loss measurement. It is thought that the combination of the gamma-ray sensitive scintillation monitor and the neutron sensitive gas monitor is one of the suitable beam loss detectors and we fabricated the scintillation monitor to confirm the performance.

BEAM LOSS MEASURMENT WITH SCINTILLATION MONITOR

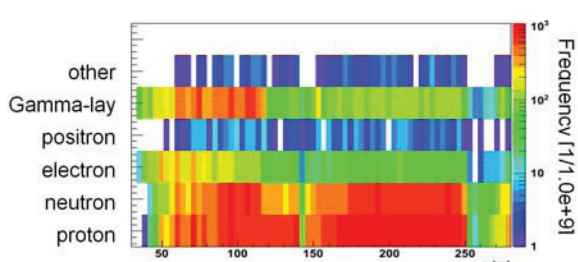

Figure 3: Generated hadrons by the interaction between H^0 and the beam duct.

Plastic Scintillation Monitor

Plastic scintillation monitors with less X-ray sensitivity are employed and installed to measure the beam loss. We used photo-multipliers of Hamamatsu H3164-10 with the gain of 1.1 x 10^6, the peak wavelength of 420 nm, and the rise time of 0.8 nsec (Figure 4). The plastic scintillator is Saint-Gobain BC-408 with the peak emission wavelength of 425 nm and rise time of 0.9 nsec, which matches the photomultiplier.

Three plastic scintillation monitors are employed and installed to measure the beam loss. One of them is installed in the SDTL section to compare the signals obtained from both the gas proportional counter and the plastic scintillation monitor. Others are installed in the part of A0BT and L3BT section where the high residual radioactivity is usually measured. Each monitor is set just behind the proportional counter (Figure 5).

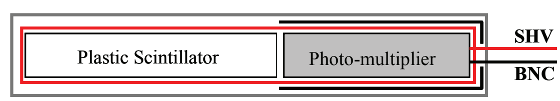

Figure 4: Plastic scintillation monitor.

Beam Loss Measurement with Scintillation Monitor

We measured beam loss in the downstream part of SDTL section (SDTL13 or SDTL16), the upstream part of ACS section (ACS03), and around the first arc in L3BT section (L3BT21). We operated the photomultipliers with the high voltage at -600 ~ -700V. The raw signal is amplified by 1~10 times with a pre-amplifier (Giga G5106). We measured the counts of particles which deposit a high energy loss in the scintillation monitors. We collected waveform data of macro pulses using a 12.5-GHz Tektronix oscilloscope DPO71254-R3.

As the result, only the signal from gas proportional counters is observed, even the no beam current (Figure 6). Because the gas proportional counter recieved the high background of X-ray emitted from RF cavities, the essential beam loss cannot be detcted by the gas proportional counter. Therefore we measured beam loss with a plastic scintillation monitors. Figure 7 shows the beam loss signals obtained from a gas proportional counter

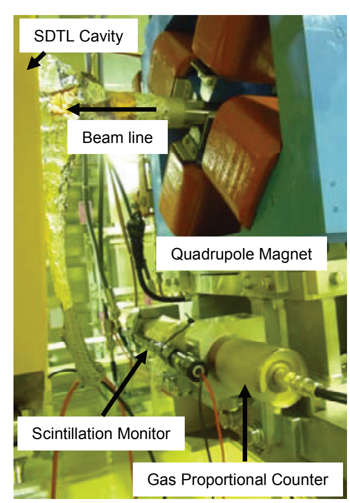

Figure 5: Installation of BLM (Plastic scintillation monitor and gas proportional counter).

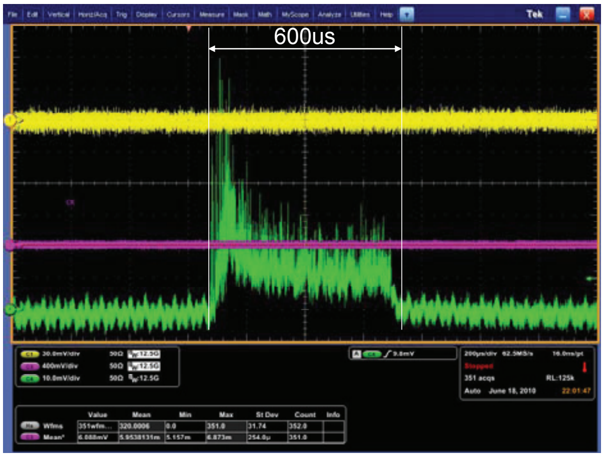

Figure 6: Signals from a gas proportional monitor (green) and a plastic scintillation monitor (magenta) at SDTL13 section, during no beam operation. The beam current signal with a current transformer is also shown (yellow).

and a scintillation monitor. Signals from a gas proportional counter has an RF pulse width (600us), but a signal from scintillation monitor indicates the signal with the width (200us) of an actual beam pulse. A good signal to noise ratio is observed for the plastic scintillation monitor (in Figure 7), with almost no sensitivity of the background X-ray.

Time resolution of the scintillation monitor is good enough to measure beam loss caused by the chopped pulse (Figure 8). Width of the scintillation signal by one event is several tens order nsec. Time delay of the scintillation signal is almost 160 nsec and this delay is corresponding to the time constant of the pre amplifier. Delay of the measured beam current is within 1 nsec.

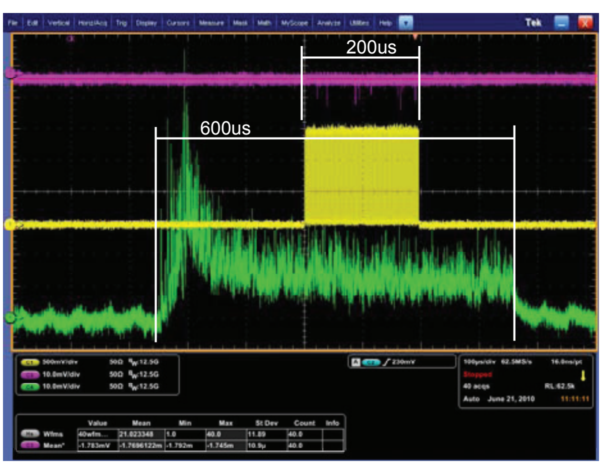

Figure 7: Signals from a gas proportional monitor (green) and plastic scintillation monitor (magenta) at SDTL13 section, during beam operation with chopped beam. The beam current signal with a current transformer is also shown (yellow).

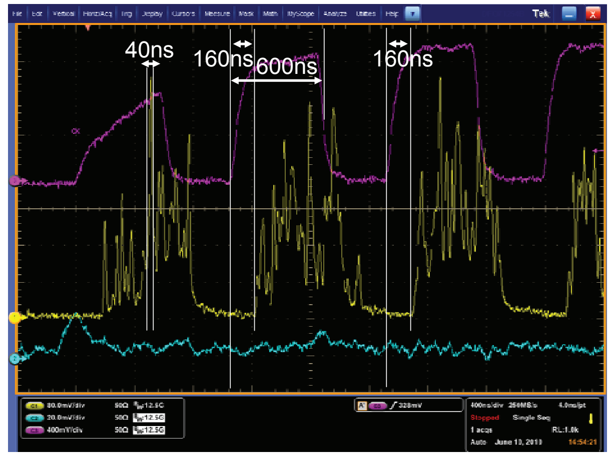

Figure 8: Signals from a gas proportional monitor (blue) and plastic scintillation monitor (yellow) at SDTL13 section, during beam operation with chopped beam. Time scale is extended to 400nsec/div. The beam current signal with a current transformer is also shown (magenta).

In test measurements with plastic scintillation monitor, we successfully measured clear beam loss signals with low noise. And the time resolution of the scintillation monitor is high enough. We will employ the scintillation monitor combined with gas proportional counter in the future beam loss measurement system.

SUMMARY

Because the Ar-CO_2 gas proportional counter is sensitive to background noise of X-ray emitted from RF cavities, the plastic scintillation counter with less X-ray sensitivity is employed to measure the beam loss. We successfully measured clear beam loss signals with low noise and confirmed the high time resolution. This result agrees with the simulation result which estimated the secondary hadrons generated from the interaction between the H0 particles and the beam pipe. Based on the simulation technology, we can also optimize the detecting position and the shape of the scintillation head. Then, a measurement of the emission position and the angle distributions of protons due to the beam loss are being planned. This plan is introduced and this result would lead to clarify the source of beam loss and verify the optimized position [1]. Furthermore, the He-3 proportional counter as the neutron detector will be tested to confirm the detection of the estimated hadrons.

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