

# THE BEAM LOSS MONITOR SYSTEM OF THE J-PARC LINAC, 3GEV RCS AND 50GEV MR

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## Abstract

The beam loss monitor (BLM) system has been developed to provide quantitative loss data and investigate the loss mechanism in the J-PARC linac, 3 GeV rapid cycling synchrotron (RCS) and 50GeV MR. It is necessary to measure wide dynamic range of loss intensity for various beam energies. To prevent the activation and heat load by intense beam loss, fast time response of loss signals is required. In this paper, construction and application of BLM system are described in detail. Preliminary result of demonstration in the KEK-PS and KEK-DTL1 (20MeV) are discussed. Calibration results with cobalt 60  $\gamma$ -ray radiation source are also reported.

## INTRODUCTION

The J-PARC (Japan Proton Accelerator Research Complex) project aims to provide the highest beam intensity among the accelerators of such energies in the world [1]. The 3 GeV and the 50 GeV proton synchrotron ring is designed to provide high intensity beams of 333 $\mu$ A (1MW) and 15 $\mu$ A (0.75MW), respectively. The high intensity beam accelerator complex itself requires the significant progress of design study and hardware R&D. Operational beam intensity should be limited by the beam loss and activation level of the equipment. Once the beam loss exceeds a criterion at outer environment, beam intensity has to be decreased to prevent the further activation. The BLM system will be essential component for beam commissioning, tuning and machine protection system (MPS) in high intensity beam accelerators. The loss monitor system is composed of the scintillator and photomultiplier tube (S-BLM), gas filled proportional counters (P-BLM) and coaxial cable ionization chamber (AIC-BLM), which detect  $\gamma$ -ray, neutron and charged particles induced by lost particles [2-4].

## THE BLM SYSTEM IN THE J-PARC

The distribution of loss monitors planned in the J-PARC linac, 3 GeV RCS and 50 GeV MR is described in Figure 1 [5]. Protection and prevention of magnet, RF cavity and other equipment against the damage by dump of the beam, should be guaranteed before thresholds are exceeded. The permitted delay time depends critically on the beam energy. The RFQ must be turned off within several  $\mu$ sec for low energy beams (up to DTL), which contain delay time in transfer cable and interlock modules. Thus, fast time response of less than a few  $\mu$ sec is required. Although damage threshold is not so serious

in RCS, high time resolution is also required to avoid the activation at injection and/or extraction.

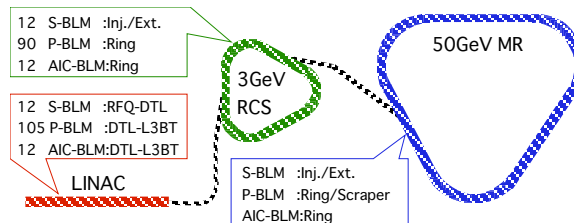
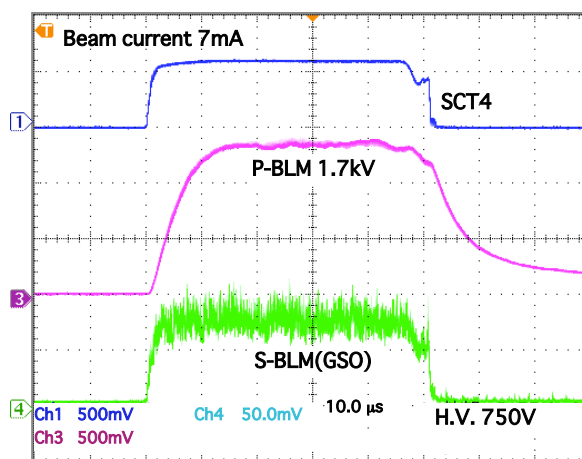


Figure 1: Designed BLM system in the J-PARC linac, 3 GeV RCS and 50 GeV MR.

Linac beam of  $8.3 \times 10^{13}$  particles is injected into the RCS during 500  $\mu$ sec. In order to confirm the efficiency of injection process, time resolution of less than several microseconds is also required. The injected beams should be aborted in the 50 GeV MR, when anomalous loss is observed. The P-BLM is prepared for 3GeV RCS and 50GeV MR by reason of fast time response, long lifetime, and feasibility of maintenance. Conventional scintillator and photomultiplier efficiency decrease with irradiation of accelerator operation. It is necessary to evaluate the efficiency of radiation hardness scintillator, and correct with other reliable (even if slow time response) loss monitors. To calibrate the signal level of S-BLM, Ar+CO<sub>2</sub> gas filled P-BLM is examined. Figure 2 shows an example of S-BLM and P-BLM loss signal in KEK-



DTL1.

Figure 2: Beam loss signal of S-BLM and P-BLM at transport line from DTL1 to beam dump. Fast time response of S-BLM is confirmed. Bias voltage were -1.7 kV and -0.75 kV for P-BLM and S-BLM photomultiplier tube (PMT).

Sufficient sensitivity and fast time response of S-BLM  $< 1 \mu$ sec are confirmed for low energy region of linac. P-

BLM also shows the rise time of several  $\mu\text{sec}$  for input impedance of  $10\text{ k}\Omega$  [1,6].

The degradation in gain of  $\text{Ar}+\text{CH}_4$  gas filled P-BLM due to the deposit of polymerized material on wire was reported [5,7]. So that the sensitivity degradation of P-BLM includes other stopping gas ( $\text{Ar}+\text{CO}_2$ ) should be surveyed with  $\text{Co-60}$   $\gamma$ -ray source. As can be seen in Fig. 3, sensitivity reduction of  $\text{Ar}+\text{CO}_2$  P-BLM was not observed up to the charge accumulation of  $0.0035\text{ C/mm}$ , which corresponds to more than several years operation in J-PARC. The constant sensitivity of radiation hardness scintillators and quartz window PMT (GSO, SCSN-81 and H3695-10: Hamamatsu Phot. K.K.) was also examined up to the irradiation of  $7\text{ kGy}$  (Fig. 3). The radiation dose of  $7\text{ kGy}$  is equivalent to about 2 years load in upper stream of linac ( $0.1\text{ W/m}$  loss level). Scintillation efficiency of other samples exposed  $1\text{ MGy}$  radiation will be investigated in beam study.

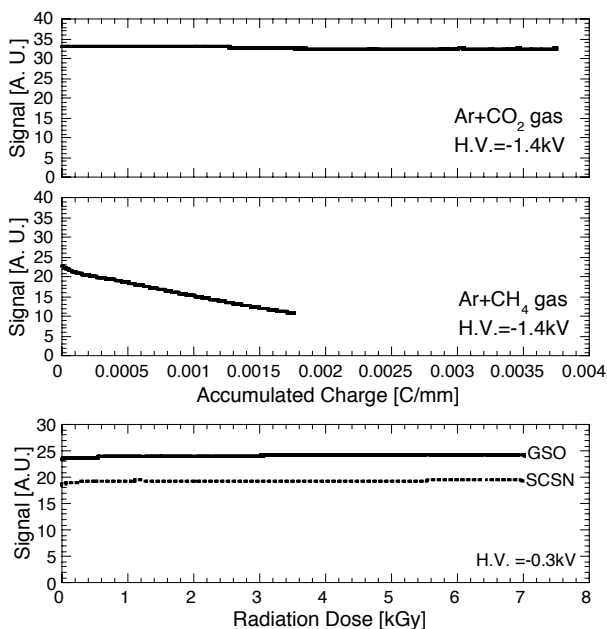


Figure 3: Gain degradation in  $\text{Ar}+\text{CH}_4$  P-BLM under cobalt 60 irradiation. Constant gain property of  $\text{Ar}+\text{CO}_2$  gas filled P-BLM was confirmed. The bias voltage and diameter of anode wire were  $-1.4\text{ kV}$  and  $50\mu\text{m}$ .

### EXPERIMENTAL RESULTS IN THE KEK-PS AND DTL1

The P-BLM and S-BLM (GSO: radiation hardness type) are installed on KEK DTL1. Gas amplifier ratio was evaluated for various beam current of  $5\text{ mA} \sim 24\text{ mA}$ . As shown in Fig. 4, output signal is proportional to bias voltage except the saturation at high voltage operation. Although the signal dependence of  $\text{Ar}+\text{CO}_2$  and  $\text{Ar}+\text{CH}_4$  gas filled P-BLM on bias voltage are similar to each other, the difference of factor 2~3 from Diethorn plot was measured [2]. Figure 5 shows the relation between the P-BLM signal and the relative beam loss at transport line from DTL1 to faraday cup (beam dump). It is assumed that the difference of current transformer (SCT4) and

faraday cup (F. C.) signals represent the relative beam loss at transport line. A large amount of beam loss is intentionally induced by rough RF phase conditioning to evaluate the BLM sensitivity.

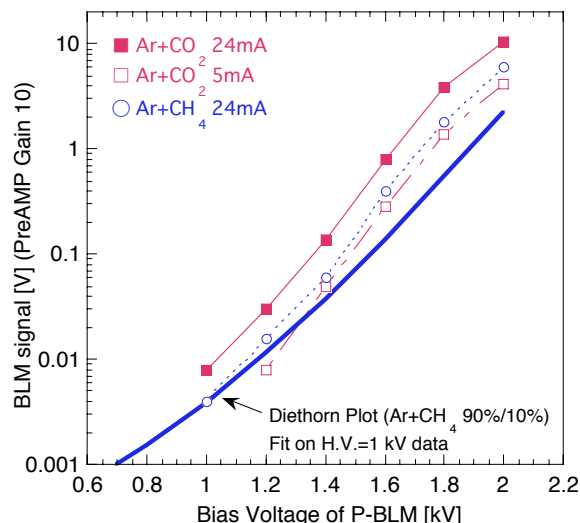


Figure 4: The dependence of the BLM signal on the bias voltage. Quasi-experimental equation Diethorn plot for  $\text{Ar}+\text{CH}_4$  gas is also represented.

The dynamic range of  $10^3$  order was obtained with only gas amplifier. It was confirmed that the BLM signal is proportional to the diminution of beam current. The relation of the loss signal and the scraped beam current have to be surveyed in lower beam loss operation.

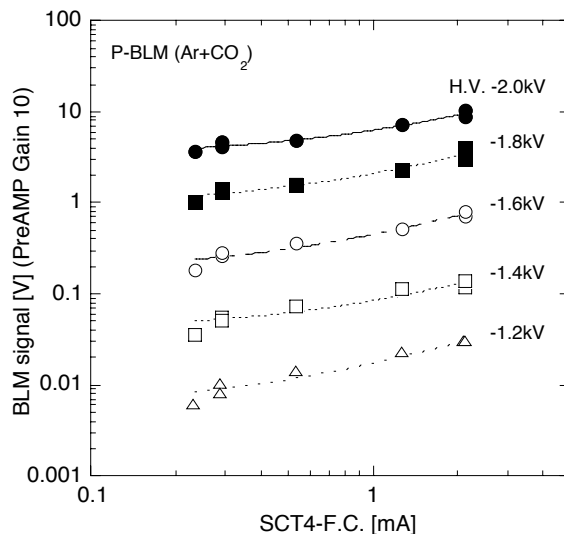


Figure 5: The relation of the BLM signals and relative beam loss level.

The P-BLM was also examined to measure beam loss in the KEK-PS booster ring. Figure 6 (a) shows an example of loss signal during an acceleration period of 25 msec. A large amount of injection and extraction beam loss, and some broad loss signals were observed. Expanded view of the extraction loss signals for S-BLM and P-BLM are shown in Fig. 6 (b). The beam loss oscillation synchronizing with revolution period of  $170\text{ nsec}$  was

measured by the S-BLM, and fast rise time of the P-BLM  $<1\mu\text{sec}$  was confirmed at extraction. However rather slow falling time of  $20\mu\text{sec}$  is appeared for  $10\text{ k}\Omega$  input impedance. The input impedance of pre-amplifier should be optimized both signal level and time response. The extraction beam loss seems to arise during the excitation of bump magnet  $\sim 20\mu\text{sec}$ . The dependence of BLM signals on the absolute beam loss have to be investigated in future.

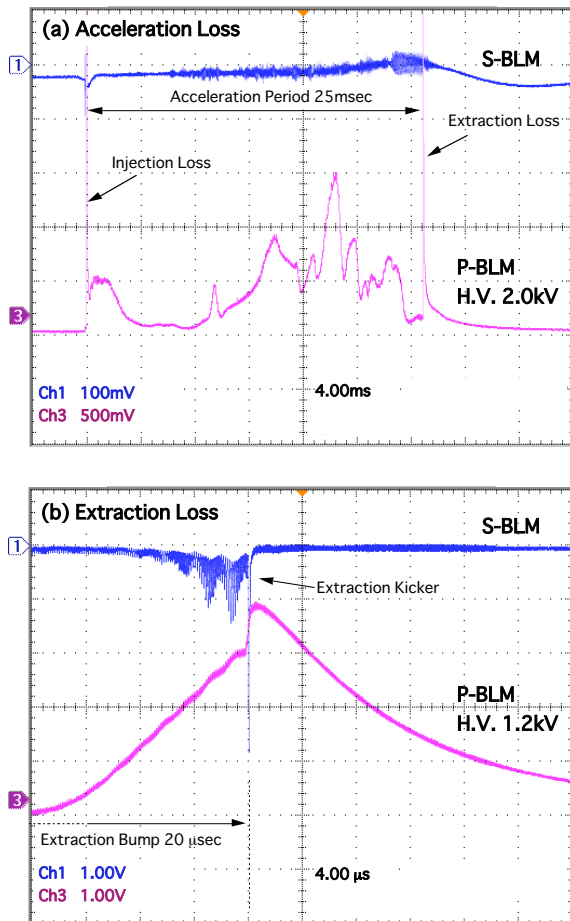


Figure 6: An example of (a)acceleration and (b)extraction loss of KEK-PS booster ring.

Figure 7 shows an application of BLM's in the KEK-PS 40 MeV beam transport line. A huge level of residual activation  $20\sim 30\text{ mSv/h}$  had been observed at a pulse bending dipole and some quadrupole magnets. Although multi-wire profile monitors were used to tune beam positions and profiles, the residual activation level could not be reduced (December 2002). However, S-BLM's have been installed on May 2003 at six positions near quadrupole and bending magnets, and contributed to fine tuning, the residual activation level was drastically suppressed less than  $7\text{ mSv/h}$  on December 2003. This result suggests that the BLM system is indispensable to survey and suppress the actual loss level which includes a neutral beam and/or beam halo.

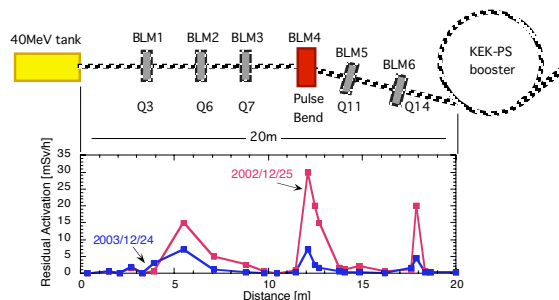


Figure 7: An application of BLM's in KEK-PS. Residual activation level was reduced by using a BLM system.

## SUMMARY AND DISCUSSION

In order to pursue various phenomenon concerning with high intensity beam loss, a diagnostic system has been developed. S-BLM's will be distributed along the upper stream of the linac and injection/extraction areas of the RCS. Ar+CO<sub>2</sub> gas filled P-BLM's will be installed in the linac, and employed to tune and investigate the loss mechanism around the RCS and 50 GeV MR, which will provide alarm signals for an abort system when anomalous loss is observed. Furthermore AIC-BLM's will be also distributed in linac, 3GeV RCS and 50GeV MR to correct the signal level of P-BLM. It will be also used to observe uncontrolled beam losses around the 50 GeV MR[8]. The sensitivity property of prototype of S-BLM and P-BLM was investigated in KEK-PS booster and DTL1. The proportional relation between BLM signal and bias voltage was confirmed. The dependence on the relative beam loss was also surveyed. Constant sensitivity of Ar+CO<sub>2</sub> gas filled P-BLM and radiation hardness scintillator with quartz window PMT were also evaluated with cobalt 60  $\gamma$ -ray radiation source.

In order to obtain the absolute sensitivity of each loss monitors, further experimental studies are required. Especially, the absolute sensitivity of P-BLM have to be found for various energy region up to several tenth GeV to develop the BLM system in the J-PARC linac, 3 GeV RCS and 50 GeV MR.

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