BEAM LOSS MONITORING USING PROPORTIONAL COUNTERS AT J-PARC

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Abstract

Proportional counter used for a beam loss monitor system for the RCS and MR of J-PARC is reported. Main features, signal amplification, radiation hardness, time response and sensitivity are described.

INTRODUCTION

Proportional counter[*] is adopted as a main beam loss monitor system for the RCS and MR of J-PARC. The advantages are signal amplification and radiation hardness. In our case the gas amplification is more than 30000 and the radiation hardness is realized not only in component materials but also its sensitivity which keeps constant upto the charge accumulation of 0.0035 C/mm by Co-60 γ-ray source irradiation. The rise time is less than μs which satisfies the requirement of MPS (Machine Protection System). The system will be overviewed and the performance with radiation sources and beams is reported comparing with the MARS simulation.

USAGE AT THE KEK-PS BOOSTER

As increasing the beam intensity at the KEK PS 500 MeV Booster Synchrotron around 1980's, needs of beam loss monitors had raised. Issues were self-amplification ability, fast time response and radiation hardness. The proportional counter was developed which operates in current mode [1],[2]. The BLM comprised a gold-plated tungsten wire of ϕ30 μm as the anode, a stainless steel tube of ϕ34 mm as the cathod, and Ar (90%) and CH_4 (10%) gass mixture with a pressure of 1atm (Figure 1). Figure 2 shows the example of output signals. Rise time of less than 100 ns was achieved even in the case of Z_{in} = 1 kΩ. This was enough for the Booser synchrotron with the revolution period of 500 - 167 ns. The gain of the BLM was 2 - 100 depending on the loss amount and the beam energy at which operators wanted to observe. Electron tubes were also used to lower the load impedance of the detector. One of the fluitfull aplication was efficiency watching of H⁻ charge exchange injection. Once carbon foil became damaged, unstriped H⁻ hit the BLMs and operator could stop the beam to change the C foil. Foil positioning and geometries were also examined using this BLMs. Besides these contributions foundamental properties as radiation hardness, linearity were postponed as the future study.
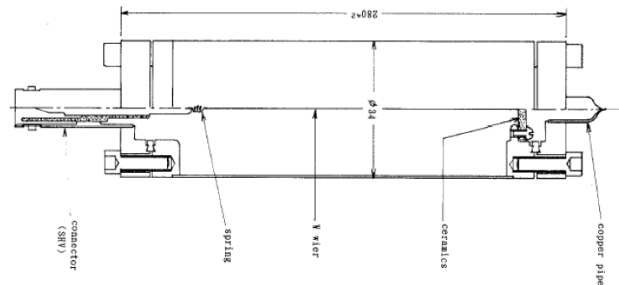
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[*] The name, proportional counter, is used here because this seems better to indicate the object itself, although the actual performance is rather in current mode than in counting mode.

Figure 1: Proportional counter type detector for the KEK-PS Booster Synchrotron.
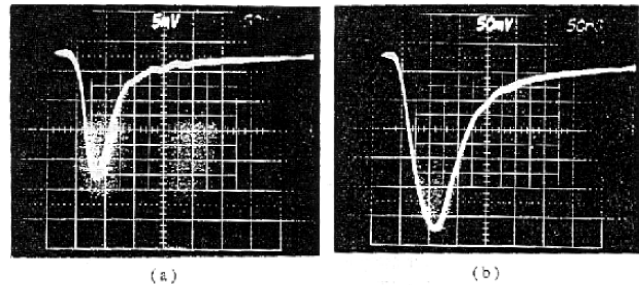

Figure 2: Signals from the BLM.

IMPROVEMENTS TO USE IN J-PARC

Preliminary irradiation test with Co-60 of ~ 0.2 k - 10 kGray/h revealed that the original gas mixturte, Ar 99% and CH_4 1%, lost gain with increasing accumurated dose (Fig. 3.a). A pure Ar gas kept gain but became unstable near 2 kV due to discharge, which suggests neccesity of quench gas. The final gas mixture for J-PARC has been Ar 99% and CO_2 1%. This mixture survives against radiation far better than the original one (Fig. 3.b) [3].

The linearity is another issue to be checked for J-PARC application. In the arcs of the MR (Main Ring Synchrotron), allowed beam loss is less than 0.5 W/m. On the other hand several areas as collimator sections, injection area and extraction area are expected to suffer from large beam loss. To estimate radiation level and BLM signal level, radiation fluence was calculated with the MARS [4]. The geometry used for calculation was the 3-50 BT collimator (Fig. 4).
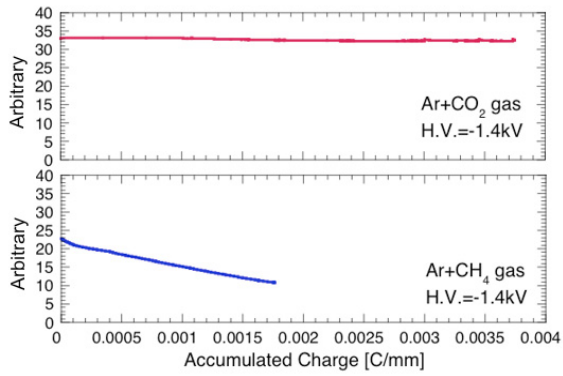
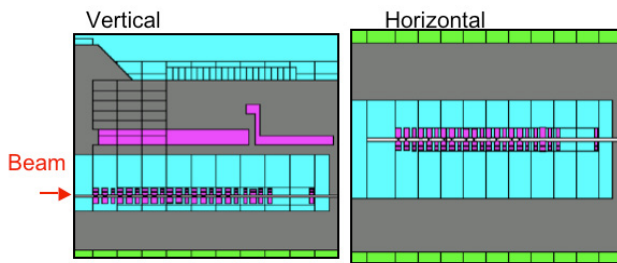Figure 3: Degradation of the gas amplification factor caused by Co-60 irradiation.

Figure 4: 3-50BT collimator.

MARS outputs were normalized by single proton loss. This results was transfered to the case of 450 W loss with the assumption of 4000-hour operation per a year and $\sim 8.5 \times 10^{11}$ proton loss / shot. Expected dose for the BLM was 0.15 Gy/shot for point loss and 0.012 Gy/shot for almost uniform loss. Using the BLM gas amplification factor (Fig. 5) measued with the cosmic ray and the suturation curve [5] (Fig. 6), the use of this type of BLM for the collimator sections seems to be difficult due to large saturation.

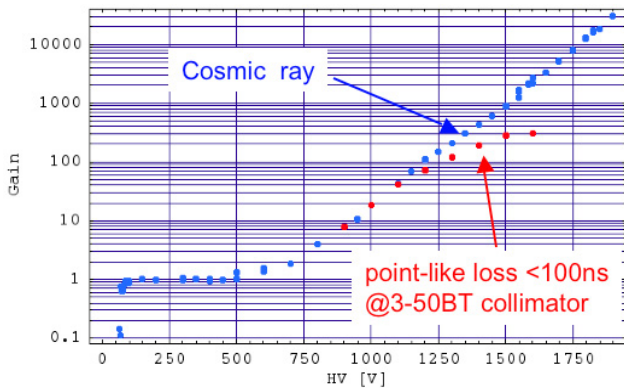Ar gas ionization chamber has been prepared for such high radiation regions.
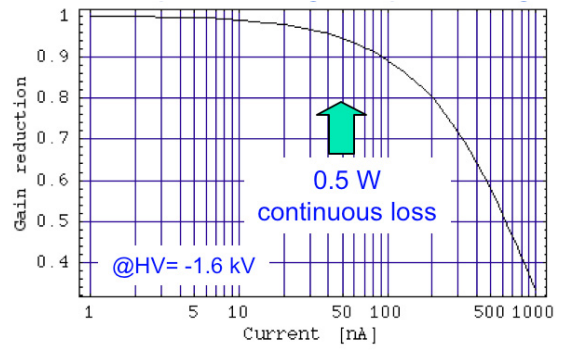

Figure 5: Gas amplification measued with the cosmic ray.

Figure 6: 3-50BT Saturation of the gain due to space charge.

BEAM LOSS MONITOR SYSTEM AT THE J-PARC MR

Figure 7 summarizes the beam loss monitors in J-PARC. The proportional-counter-type BLM comprised the Pt wire of $\phi 50$ μm, stainless steel tube of $\phi 23$ mm, and Ar (99%) and C02 (1%) gass mixture (Figure 8). The block diagram of signal processing is shown in Fig. 9. Each signal is divided into two parts, one is a fast analog signal and the other is integrated signal. Ether signal is compared to the reference voltage and the alarm voltage level is sent to the MPS system if the condition satisfied. Fast signal processing should be within 10 μs to prevent from the machine damage due to fast beam loss.
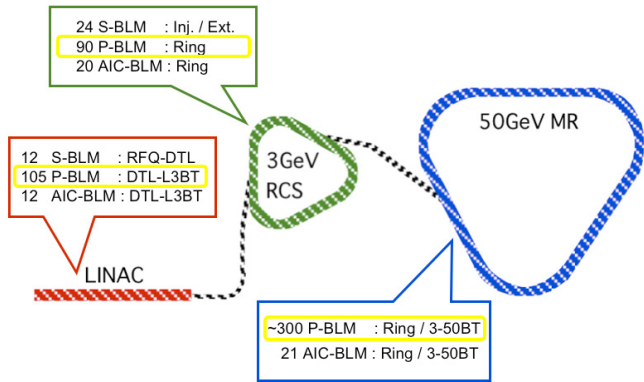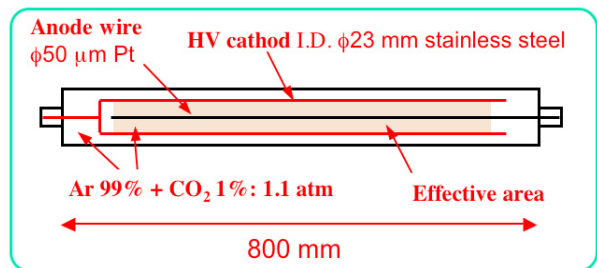

Figure 7: BLM in J-PARC.
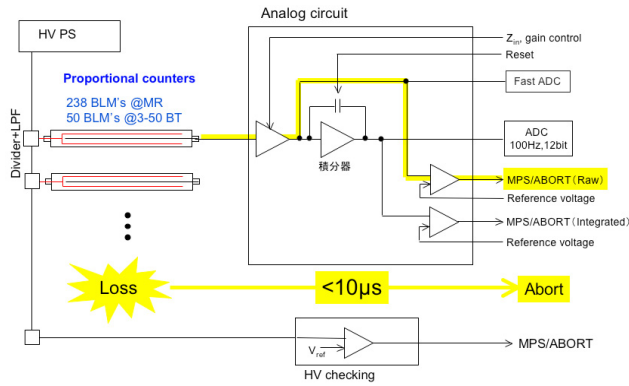

Figure 8: BLM for the MR.

Figure 9: BLM system block diagram.

EXPERIENCE AT THE J-PARC MR

At the "day-one" beam operation several characteristics of the BLM was examined, although the measurement was restricted.

First issue is the fast rise time concerning with the MPS system. The rise time of the loss signals, e.g. from the BLM downstream of the 1st and 3rd collimators, was ~100 ns, satisfying the MPS requirement (Figure 10).

Second issue is the linearity. The integrated signal from 3-50 BT collimator was obtained with variable bias HV. The data is normalized for the gain curve at HV = 1000 V (Fig. 5). At higher HV the signal amplitude was decreasing. In this measurement the beam loss amount varied a lot, and at > 1200 V the maximum amplitude may have exceeded the full scale of the amplifier. This should be confirmed at the next run.

Final issue is the calibration to translate lost number of protons. As a trial, sum of all the BLM in the MR was compared with the proton beam loss (Fig. 11). The sensitivity, BLM signal / lost proton # [count/p] is reduced for each BLM, ~ 7600 count/10^{11} p. One example of beam loss distribution is as Fig. 12. Comparing with the uncontroled loss limit 0.5 W/m which corresponds to 5.7×10^{12} at 3 GeV, and 3.4×10^{11} at 50 GeV, the dynamic range seems to be sufficient. Even the point loss of 0.5 W, 3.7×10^{9} at 3 GeV, and 2.2×10^{8} at 50 GeV, will be detected.

CONCLUSION

"Proportional counters" has been improved as a BLM. The merit is the gas amplification more than ~30000. Long term gain degradation due to center wire contamination was improved using gas mixture of Ar and CO_2. Radiation hardness can be realized. Rise time of ~100 ns which can resolve the loss turn by turn and satisfies the MPS requirement. Sensitivity has been examined with beams and asistance of the MARS calculation. Minimum of dynamic range is estimated as ~10^{8} proton loss equivalent at HV = -1.6kV. Too high dose can cause saturation of the detector itself and the processing circuit and needs complementary detectors.

REFERENCES

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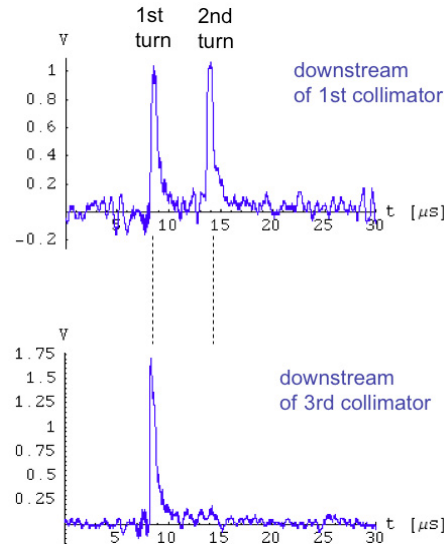
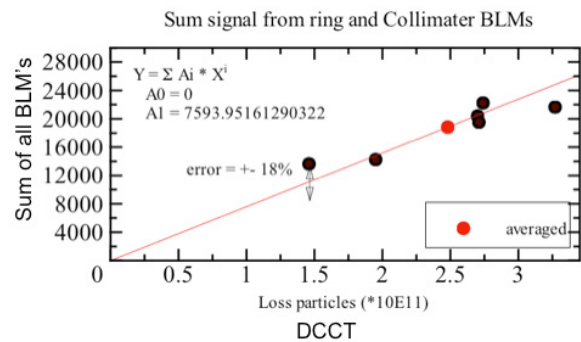Figure 10: Beam loss downstream of the MR collimators.

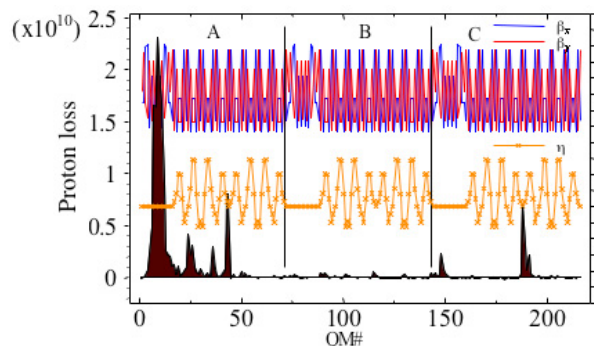Figure 11: Sum of all the BLM in the MR was compared with the proton beam loss measured with the DCCT.

Figure 12: Beam loss distribution, an example.