

# APPLICATION OF A SINGLE-WIRE PROPORTIONAL COUNTER TO THE BEAM LOSS MONITORING AT J-PARC MR

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## Abstract

A single-wire proportional counter which has the maximum gain of 6E4 is used as a beam loss monitor (p-BLM), thus low-level beam loss can be monitored. However, it involves gain reduction problem by the space charge effect. It is essential to estimate the space charge effect to utilize a proportional counter for beam loss monitoring. The calibration procedure is discussed for the p-BLMs for 3-50BT and MR.

Measurements of residual dose were made and some nuclei were identified. Radiation from the short-life nucleus, Fe53 ( $T_{1/2}=8.51\text{m}$ ), may be a good index to predict a residual dose after a long term beam operation.

## INTRODUCTION

A single-wire proportional counter is adopted as a beam loss monitor at RCS and MR of J-PARC. The counter is called p-BLM. As for the MR, we have installed 316 p-BLMs at each Q-magnet and around some other components like collimators, kickers, and beam dumps. The details of the p-BLM are described in [1][2][3], and study about the radiation is described in elsewhere [4].

After discussions of the space charge effect, we describe how to calibrate the p-BLM. And then we introduce an application to the residual dose measurement.

## GAIN FUNCTION

To obtain the gain function of the p-BLM, we have used cosmic rays. The measured gains are shown in figure 5 of ref. [2]. It shows the maximum gain of 6E4 when bias is 2kV. The fitting function for the gain (G) is,

$$G = Q(V_b)/Q_0 = Q_0' \exp(KV_b)/Q_0 \quad (1).$$

Here,  $Q(V_b)$  is the output charge,  $V_b$  the bias voltage,  $Q_0$  the output charge on the ion mode ( $G=1$ ),  $Q_0'$  and  $K$  the free parameters. This relation means that the first Townsend's coefficient  $\alpha/p$  is constant [5] for a bias range of interest, from 700 to 2kV. This also means that the total electron cross section for ionizing process to the gas components is independent upon impact energy of an electron as pointed out in ref. [6]. Using the equation (1) is likely to be physically incorrect, thus we use it as a proper fitting function when a bias is from 700 to 2kV.

## SPACE CHARGE EFFECT

The p-BLM shows quite fast signal rise time of about 100ns [2]. However the drift time of an ion from the

anode to the outer shell,  $t_c$ , is 400~600  $\mu\text{s}$  depending on a bias voltage of interest. This means that a series of beam loss events with time spacing of that less than  $t_c$  is affected by residual ions inside the counter which originate from the former events; positive electric field originating from the residual ions deteriorate effectively the bias voltage and thus consequently gain. This effect is so called space charge effect, and studied by R. W. Hendrics. He pointed out in [7] that bias shift due to the residual ions is represented by the formula below,

$$\Delta V_b = \bar{i} \cdot \frac{p \ln(r_b/r_a)}{V_b} \cdot \frac{1}{2\pi\mu} \cdot \frac{er_b^2}{4\pi\epsilon_0} \quad (2).$$

Here  $r_a$  and  $r_b$  are the radii of an anode and a outer shell, respectively,  $\mu$  the mobility of an ion in a gas, and  $\bar{i}$  the averaged output current. This formula is valid when the counter is operated under equilibrium space charge condition, that is, an output current is stable. A p-BLM output current can be changed transitionally every 0.6  $\mu\text{s}$  by the beam loss due to injection and extraction errors, and betatron motions. In this case, the eq. (2) cannot be applied.

## CALIBRATION PROCEDURE

### 3-50BT

For the 3-50 beam transport line (3-50BT), double beam loss with time spacing of 0.6  $\mu\text{s}$  is occurred every 40ms and these are localized at 6 collimators [8]; for MR, 4 batch injections scheme is adopted where 2 bunched beams are included in each batch. To clear the space charge effect, response of a p-BLM output to a beam loss at the collimator named UNIT4 was investigated. An output current was integrated for 40ms. To compare the output charge directly to the number of lost particles at the collimator, a batch beam was hit on the collimator by a horizontal local bump. The intensity was measured by a DCCT of RCS. The measured beam loss intensities were 1.4E12, 6.8E11, 3.7E11, 2.4E11, 9.8E10, and 4.9E10 particles per batch (ppb).

The measured output charges of p-BLM#13 mounted on a Q magnet just downstream of the collimator are shown in fig. 1. Logarithmic plot of the output charges against  $V_b$  still shows same dependence as eq. (1). This means that the effective bias shift is a linear function of  $V_b$ . As can be seen in the figure, the fitting parameter  $K$  decreases with increasing beam loss (induced charge). An induced charge  $Q_0$  and a mode change voltage  $V_0'$  which

is a threshold voltage between the ion-mode and the gas amplification mode, are extracted as shown in the figure.

Fig. 2 shows correlation between the obtained K and  $Q_0$  value. It suggests that the K is linear against the  $\ln(Q_0)$ . To represent the space charge effect, it is reasonable to use an effective output current instead of integrated charge, however, here we adopt the fitting function as,

$$K = 0.00369 - 0.000439 \cdot \ln(Q_0) \quad (3)$$

From these facts, the effective bias shift can be,

$$\Delta V_b \propto (a_1 \ln Q_0 + a_0)(b_1 V_b + b_0) \quad (4),$$

where the  $a_1, a_0, b_1,$  and  $b_0$  are free parameters. At present, a physical meaning of the eq. 4) is unclear.

Fig. 3, the plot of an extracted induced charge on the p-BLM#13 against beam loss, shows good linearity such that  $1.0E12$  protons loss at the collimator induces the charge of  $26nC$ .

The  $Q_0'$  vs. K plot are shown in Fig. 4. The solid circles are data from BLM#3~#19 and open circles are data

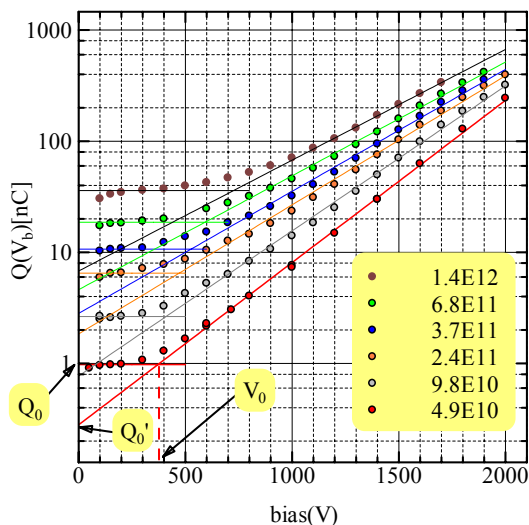


Figure 1: Output charge as a function of a bias voltage. The eq. (1) is used as a fitting function.

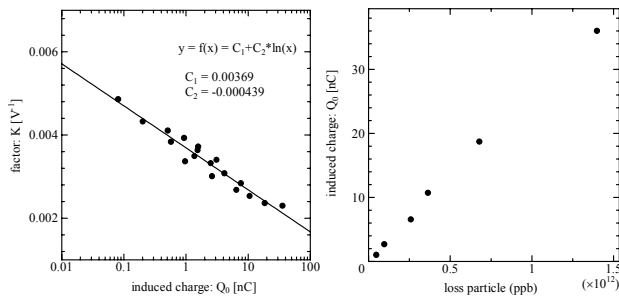


Figure 2 (left): Plot of the extracted K factor as a function of induced charge by a beam loss.

Figure 3 (right): Induced charge  $Q_0$  on p-BLM#13 as a function of the beam loss

from BLM#20~BLM#32. The BLM#20~BLM#32 are mounted downstream of the first vertical bend magnet, and these are separated from BLM#1~#19 and the collimators by a 1.5m concrete shield. Induced charges of the BLM#1~#19 mainly originate from the beam loss at collimators. On the other hands, as for the BLM#20~#32, contributions from the MR's beam loss cannot be negligible. The effective output current of BLM#20~#32 is small when compared to that of BLM#1~#19 even if the integrated output charge is same. These may be one of the reasons why the two sets of data show different tendency as shown in the figure.

Eqs. 1) and 4) suggest that the  $\ln(Q_0')$  is linear against the K factor, however the data shows quadratic expressions rather than a linear as shown in the fig. 4. The best fit to the data of BLM#3~#19 is,

$$\ln Q_0' = 5.30 - 1.38 \cdot 10^3 \cdot K - 1.13 \cdot 10^5 \cdot K^2 \quad (4),$$

here, the standard deviation is 46%.

By using the eqs. 1), 3), 4), and  $Q(V_b)$ , we can extract the  $Q_0$ . Fig. 5-a) shows  $Q(V_b)$  distribution against BLM# and Fig. 5-b) shows the estimated  $Q_0$  values; These are the data when the loss particle was  $3.7E11$  ppb. The estimated  $Q_0$  values of each BLM are agree well within the error of about  $\pm 40\%$ .

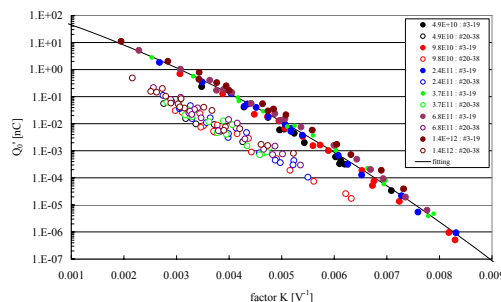


Figure 4: The  $Q_0'$  value against the factor K. The solid circles are from BLM#3~19 and open circles are from BLM#20~32.

### Main Ring

As for the MR p-BLM, a calibration procedure is not clear like 3-50BT's because an output current will be changed during a MR cycle, and thus it is difficult to estimate the space charge effect from the integrated output charge. Practically we need a beam-based calibration using local bump for each operation parameter. In ref. [3], a calibration results for 3GeV DC mode operation are described.

To estimate a Slow extraction (SX) inefficiency, calibrations of the p-BLMs of the SX straight section were made. The SX involves localized beam losses at an electrostatic septum and at a magnetic septum, and beam

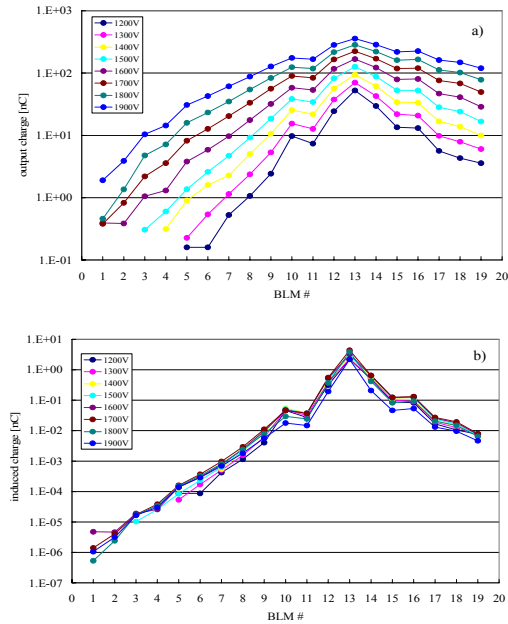


Figure 5: Output charge at each bias voltage a), and extracted induced charge b).

loss signal distribution is peaked at BLM#76 and BLM#82. A local bump was made to reproduce a beam loss at the electrostatic septum and at the magnetic septum. The beam energy was 30GeV and the bias voltage was set to 1.3kV. Output charges are shown in fig. 6 as a function of the beam loss intensity measured by using a MR DCCT. The typical SX inefficiency was estimated to be a several percent.

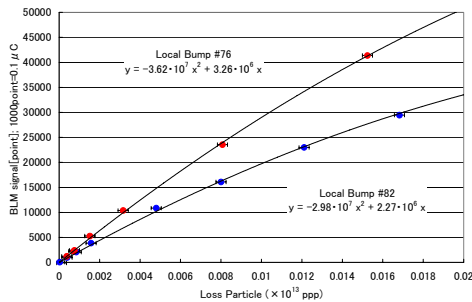


Figure 6: BLM response to the beam loss at the electrostatic septum (local bump #76) and at the magnetic septum (local bump #82).

## RESIDUAL DOSE MEASUREMENT

By using the p-BLM's high gain performance of about  $6 \times E4$  of  $V_b=2kV$ , a trend of the residual dose can be measured from the moment just after a beam stop. The output current was measured by using the shunt impedance of  $10M\Omega$ . The calibration was made by using the calibrated scintillation dosimeter. The output current

of  $0.65nA$  corresponds to  $10 \mu Sv/h$  for  $V_b=2kV$  setting. Fig. 7 shows measured output currents from the p-BLM which was set just under the beam pipe, about 1m from the surface. Contributions from the unstable nuclei, Fe53 ( $T_{1/2}=8.51m$ ), Mn55 ( $T_{1/2}=2.579h$ ), and Co55 ( $T_{1/2}=17.53h$ ) are shown in the figure with the most probable reaction channel. By measuring the contribution from the Fe53, it likely to be possible to predict the residual dose level after a long term beam operation.

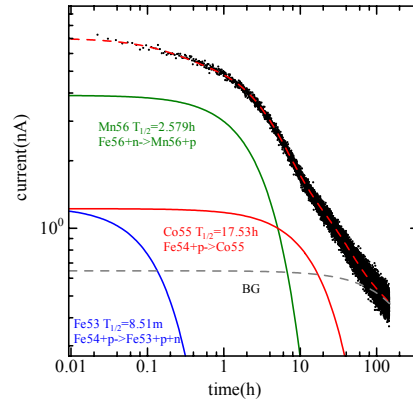


Figure 7: p-BLM output current induced by the residual dose after 18-days beam operation.

## SUMMARY

Single wire proportional counters (p-BLMs) are used for beam loss monitoring. It is essential to estimate the space charge effect to calibrate the p-BLM. As for the 3-50BT p-BLMs, the bias shift due to the space charge effect can be formalized and thus we can deduce the induced charge by the beam loss. The calibration was made by using the extracted induced charge. On the contrary, at present, MR p-BLMs need calibration by using controlled beam losses by a local bump for each beam operation. To clear the space charge effect on the MR p-BLMs, further experimental and theoretical studies are needed.

The residual dose measurement was made and shows clear contribution from the Fe53 ( $T_{1/2}=8.51m$ ). By monitoring the contribution from the Fe53, estimation of the residual dose level after a long term beam operations is likely to be possible.

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