THE BEAM DIAGNOSTICS SYSTEM IN THE J-PARC LINAC

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Abstract

The beam diagnostics system has been developed to tune and investigate the high intensity proton beam in the J-PARC linac. Beam monitors are required to measure wide dynamic range of beam intensities and energies in linac. In this paper, construction and application of beam monitor system are described. Preliminary results of demonstration of beam position monitor (BPM), fast/slow current transformer (FCT/SCT), wire scanner (WS) and beam loss monitor (BLM) in the KEK-DTL1 (20MeV) are also discussed.

INTRODUCTION

The J-PARC (Japan Proton Accelerator Research Complex) linac aims to provide high intensity beams of peak current 50mA, kinetic energy 181/400MeV, pulse width 0.5mA and repetition rate 25Hz [1]. The goal of 133 kW beam power and hand-on maintenance will place significant demands on the performance and operational reliability of accelerator diagnostics systems. Beam diagnostics system is required to verify proper transverse focusing and matching of the magnetic focusing lattice of the linac. Large number of beam monitors will be installed in MEBT, DTL, SDTL, ACS and L3BT (Fig. 1). Progress and R&D results of beam monitors are evaluated in detail.

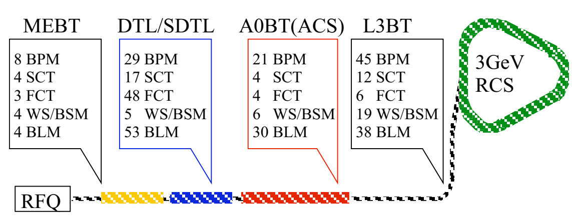

Figure 1: Designed beam monitor system in the J-PARC linac.

BEAM MONITORS IN THE J-PARC LINAC

Beam Position Monitor

Beam position monitors (BPM) have about 40mm-130mm bore and 4-stripline electrodes with one end shorted by 50 Ω terminations (Fig. 2) [2]. Electrostatic computations are used to adjust the BPM cross-section parameters to obtaine 50 Ω transmission lines. BPMs are sustained by pole edge of quadrupole magnet, and designed to reduce the offset between quadrupole magnet and BPM electrical centers of less than 0.1mm. A procedure of beam based calibration/alignment (BBC/BBA) method to evaluate the displacement of linac BPMs are examined [3]. The BPM electronics uses both amplitude-modulation-to-phase-modulation (AM-PM) method and conventional log-ratio method [4]. Prototype of BPM system with log-ration electronics have been constructed and examined in KEK MEBT1 and DTL1.

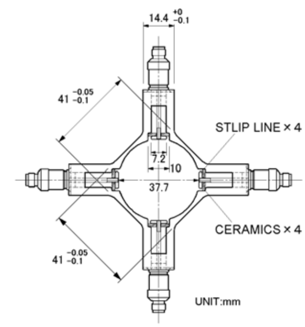

Figure 2: Schematic of beam position monitor in MEBT1.

Slow/Fast Current Transformer

Two types of current transformers have been developed to measure beam intensity and bunch phase (Fig. 3). The slow current transformer (SCT) have dynamic renge of 0.1-80 mA, a droop of 3% for a pulse width of 500 μs and time response of <50ns. The SCT has been chosen with 50 turns and additional winding to provide a calibration/test input capability. The fast current transformer (FCT) have response of relative bunch phase <1%. To measure the beam energy at every accelerator tank and injection point of 3GeV RCS, phase differences of two FCTs are used (time-of-flight: TOF), and 10^{-4} order energy resolutions can be expected. The SCT will also contribute to personal-protection-system (PPS). Integrated current signal will be evaluated to guarantee the normal operation of beam dumps.

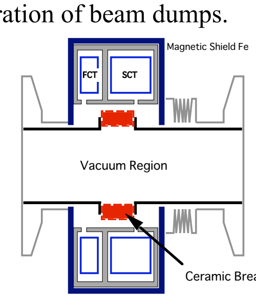

Figure 3: Cross sectional view of slow/fast combined type current transformer. FINEMET core is placed at outside the vaccum chamber to avoide the out gas. Outer wall is composed of iron to reduce the noise level.

Beam Loss Monitor

To prevent the activation and heat load by intense beam loss, fast time response of loss signals is required. The beam loss monitor (BLM) system is composed of scintillator (S-BLM) and Ar+CO_2 gas filled proportional counter (P-BLM, Fig. 4), which detect γ-ray, neutron and charged particles induced by lost particle [5-7]. It is necessary to measure wide dynamic range of loss intensity for various beam energies.

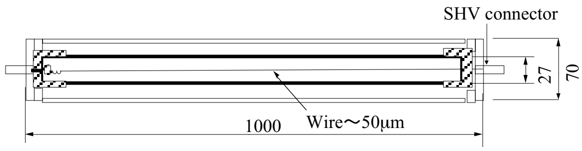

Figure 4: Schematic of proportional counter type beam loss monitor. Dual tube structure was designed to reduce the noise level and measure the residual activation level.

Beam Profile/Size Monitor

Profile measurements are used to determine the beam emittance of a matched beam in a periodic focusing lattice. The thin sensing wire (WS: carbon, diameter 7~100 μm) is scanned to obtain a current density distribution of the beam. Beam size and halo profiles will also be evaluated by movable beam scraper (BSM). The heat flux of single wire and scraper frame have been evaluated to avoid heat damage or thermionic emission.

EXPERIMENTAL RESULTS IN THE KEK MEBT1 AND DTL1

Figure 5 shows the distribution of beam monitor system and an example of BPM out put signal in MEBT1.

BPMs are sustained by pole edges of quadrupole magnets (Q-mag), and the absolute accuracy of beam position monitors were confirmed by beam based calibration method. It has been evaluated that the displacements between magnetic center of Q-mag and electrical center of BPMs are less than 0.2mm [3,8].

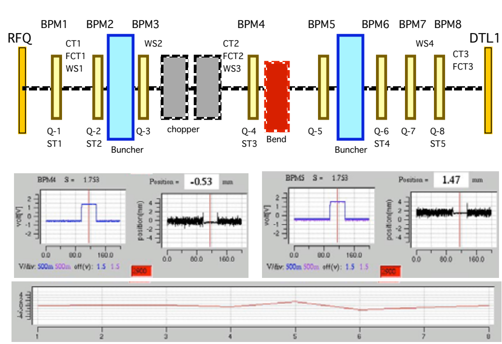

Figure 5: Installed beam monitors in MEBT1 and typical out put signal of BPM by using the Experimental Physics and Industrial Control System (EPICS) software [9].

The P-BLM and S-BLM (GSO: radiation hardness type scintillator) are installed on KEK DTL1. Figure 6 shows an example of SCT, S-BLM and P-BLM signals. Sufficient sensitivity and fast time response of S-BLM <1μsec are confirmed for low energy region of linac (20MeV). P-BLM also shows the rise time of several μsec for input impedance of 10 kΩ [1,10]. Gas amplifier ratio was evaluated for various beam current of 5mA~24mA. Output signal is proportional to bias voltage and agree with Diethorn plot except the saturation at high voltage operation [11,12]. The lineality between the P-BLM signal and the relative beam loss at transport line from DTL1 to faraday cup (beam dump) have been confirmed. It was 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 to evaluate the BLM sensitivity. The dynamic range of 10^3 order was obtained with only gas amplifier. The relation of the loss signal and the scraped beam current have to be surveyed in lower beam loss operation.

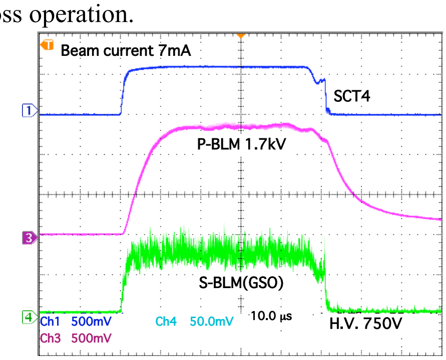

Figure 6: Beam current and loss signals of SCT, S-BLM and P-BLM at transport line from DTL1 to beam dump. Fast time response of S-BLM is confirmed. Bias voltage were -1.7 kV and -0.75 kV for P-BLM and S-BLM photomultiplier tube (PMT).

The degradation in gain of Ar+CH_4 gas filled P-BLM due to the deposit of polymerized material on wire was reported [6]. So that the sensitivity degradation of P-BLM includes other stopping gas (Ar+CO_2) should be surveyed with Co-60 γ-ray source. The sensitivity reduction of Ar+CO_2 P-BLM was not observed up to the charge accumulation of 0.0035 C/mm, which correspondes 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 kGy [13].

Vertical and horizontal beam profiles are measured by 4 wire scanners in MEBT1 [14]. Time averaged (30 μsec) beam pulse signals were processed for each sample positions. Typical out put signal of WS is shown in Fig. 7(a). The measured rms widths of WS4, between Q-mag 7 and Q-mag 8, are 1.45 and 1.04 mm for the horizontal and vertical distributions respectively. The observed results agree with calculated rms widths within 20% differences. The out put signal of WS has been supposed to depend mainly on beam energy, wire diameter and materials. The bias potential should also be determined by measuring the wire signals as a function of bias potential. The resulting data (Fig. 7(b)) shows that the out put signal is saturated in bias potential of higher than 100V. An expected mechanism of interaction between thin wire and H^- beam is that, as the wire is biased positively, the current component due to the intercepted H^- ion are clarified because of a reduction in secondary electron emission.

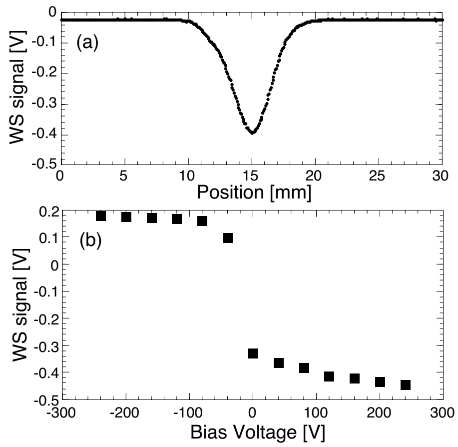

Figure 7: An example of transverse beam profile in MEBT1(a), and net signal during the beam pulse as a function of applied bias potential(b).

Stripline pickups can also be used as a beam width monitors to measure the beam size (quadrupole moment), from which the momentum spread is inferred [15,16].

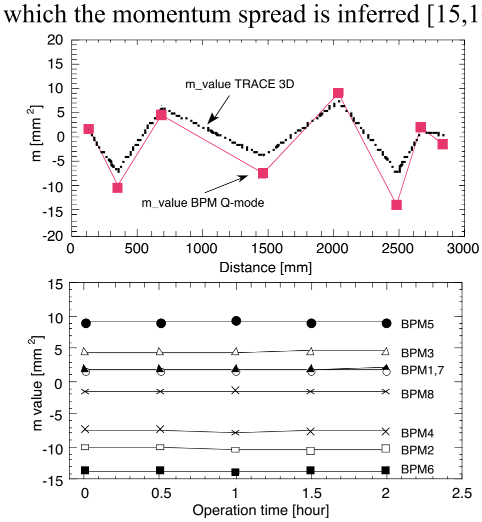

Figure 8: Experimental and calculated results of beam size term (a). Sufficient reliability of beam size measurement during the practical long time period was also confirmed (b).

A non-destructive beam momentum spread measurement using a BPM has been examined in order to investigate and control the momentum spread of J-PARC linac beams. The momentum spread of less than 0.1% is required for 3GeV rapid cycling synchrotron (RCS) injection to avoid uncontrolled beam losses. The 4-stripline monitor has to be mounted on a L3BT beam line of large dispersion to compare the difference of horizontal and vertical beam size. The momentum spread is obtained from following equation as:

$$\frac{\Delta P}{P} = \frac{1}{\eta}\sqrt{m - (\varepsilon_x \beta_x - \varepsilon_y \beta_y)} \qquad (1)$$

$$m = \sigma_x^2 - \sigma_y^2 \qquad (2)$$

The absolute measurement of the beam size term m is also represented as:

$$Q = \frac{(V_1 + V_3) - (V_2 + V_4)}{V_1 + V_2 + V_3 + V_4} = \frac{C}{R^2}(\sigma_x^2 - \sigma_y^2 + x_0^2 - y_0^2) \qquad (3)$$

Figure 8(a) shows a plot of the observed and calculated (TRACE 3D) results of beam size term, good agreements were confirmed in MEBT1. The sufficient accuracy and stability, m<0.5 mm^2 for 2hours, have also be evaluated (Fig. 8(b)) experimentally [17].

SUMMARY

Prototype of beam monitors for J-PARC linac have been performed in KEK MEBT1 and DTL1. BPM pickups and electronics provide a sufficient accuracy and stability (<0.2 mm). A non-destructive beam momentum spread measurement using a 4-stripline pickups was examined. Beam loss signals could also be observed with fast rise time (<1μsec) and very high sensitivities. The wire scanners practically contribute to the beam commissioning in MEBT1 and DTL1. However the interaction mechanism between thin wire and H^- ions for various beam energies have to be investigated in future.

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