# SYSTEMATIC CALIBRATION OF BEAM POSITION MONITOR IN THE HIGH INTENSITY PROTON ACCELERATOR (J-PARC) LINAC

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*Abstract*

As a joint project of KEK and JAERI, a MW class of high intensity proton accelerator (J-PARC), consisting of Linac, 3 GeV-RCS, 50 GeV-MR, is under construction. For this accelerator, it is required to minimize the beam loss (typically, lower than 0.1~1 W/m at the linac). To achieve the requirement, beam trajectory needs to be controlled with accuracy of some 100 μm. The first stage of the acceleration (up to 181 MeV during the first stage of construction) is done by linac. The beam position monitor (BPM) in the linac utilizes 4 stripline pickups (50 Ω) on the beam transportation chamber. In this paper, systematic calibration of the BPM is described.

## DESIGN OF PICKUP LINE IN BPM

First stage of acceleration (181 MeV in the 1st phase of construction) in J-PARC is done by linac. For the beam position monitoring in the linac, stripline type of pickup electrodes (50 Ω) are placed inside beam transporting chambers. In order to minimize the space and to get the accuracy of the positioning of BPM, each BPM module is supported by pole faces of a quadrupole magnet. For the pickup electrodes it is important to maintain impedance matching, in order to avoid the reflection and to keep the signal balances between the electrodes. In the linac, there are 5 sizes of the beam transporting chamber, namely (from up stream) 37.7, 40, 70, 85, 120 mm in diameters. For BPMs in the 2 smaller types of diameter, flat-shape (in cross section) pickup plates are chosen because the mechanical structure is relatively simpler [1].

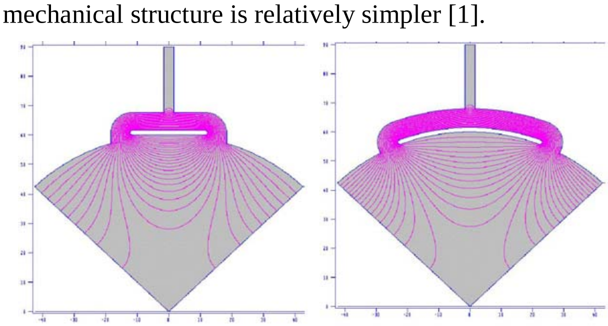

Figure 1: Cross section of the pickup electrode plates in BPM. Left; flat type. Right; round-shape type. (Due to the symmetry in the shape of BPM, only a quarter of BPM is shown.

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For the BPMs in the 3 larger types of diameter, it is designed to use round-shape pickup plate along with the chamber circumference, in order to tale larger width of the electrode to achieve better sensitivity (S/N ratio). Figure 1 shows the two types of cross section of the pickup electrode plate with electric field shape in the BPM. The field shapes are calculated by POISSON [2] code which is used for the impedance optimization. As there are symmetries of the shape in each of 4 (up, down, right, left) electrodes, only a quarter of cross section is shown in the figure. The flat type and the round-shape type of pickups are shown in the left side and the right side, respectively.

## CALIBRATION OF BPM

Calibrations of the BPM take two steps. The first step is taken before installation, and with the dedicated calibration bench which has a stainless wire (100μm) carrying 324 MHz (acceleration frequency) as dummy signal simulating the beam. In this step, an electrical zero point of pickup electrode is calibrated with respect to the mechanical center. The second step is taken after the installation with beam in low intensity, and is called beam based calibration (BBC). Displacement between the electrical center of BPM and the practical field center of the quadrupole magnet is calibrated.

### *Calibration before Installation (Calibration Bench Based)*

Before installation, electrical zero point of pickup electrode for each BPM is calibrated by a calibration bench with a wire which carries 324 MHz simulating beam. Figure 2 shows a schematic (upper) and a photograph (lower) of the calibration bench, looking from the side. The BPM is sustained in the center of the calibration bench. The wire is placed inside the BPM and is straightened from both sides by hinges soldered on core pins of N-type connectors. The wire can be moved inside the BPM in order to simulate possible beam positions. On both edges of the BPM, dummy pipes are attached to simulate beam pipes, and are connected to the outer-line of the N-type connector. One side of the N-type connector is conducted to the 324 MHz generator and the other side is conducted to a terminator. Mechanical test of wire scanning has been already done.

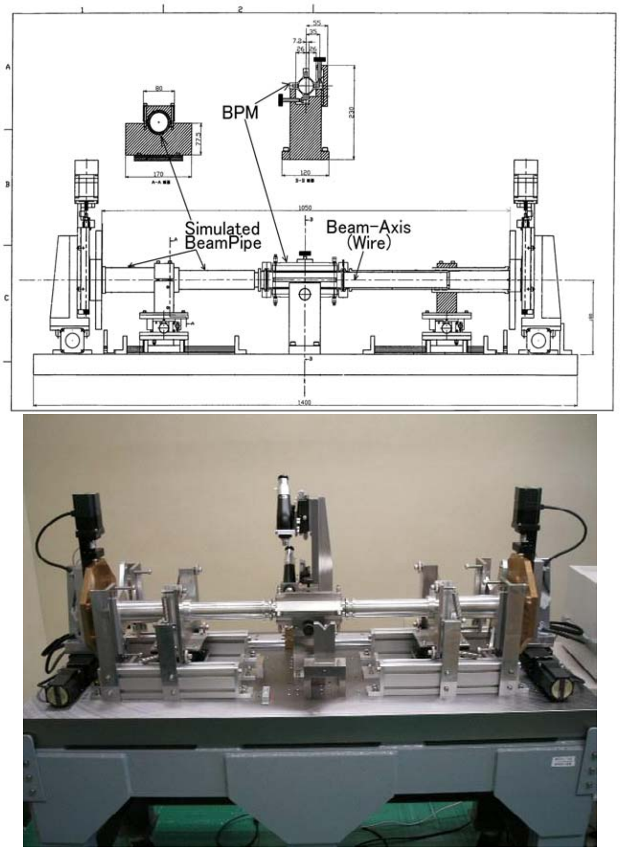


Figure 2: A schematic and photograph of BPM calibrator.

## *Calibration after Installation (Beam Based Calibration; BBC)*

After installation in the quadrupole magnets, when low intensity beam is available, displacement between electrical center of the BPMs and magnetic center of the quadrupole magnet can be calibrated by using the actual beam. To calibrate a BPM mounted in a corresponding quadrupole magnet (called the "*housing quadrupole*" with an "*examined BPM*" here), diagnostic devices are needed both in the upstream side and in the downstream side as follows.

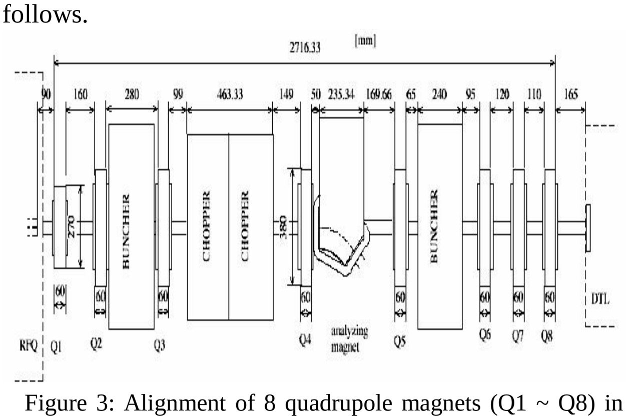


Figure 3: Alignment of 8 quadrupole magnets (Q1 ~ Q8) in the MEBT. In each quadrupole, a BPM is installed (BPM1 ~ BPM8, respectively). Steering coils are installed in Q1, Q2, Q4, Q6, and Q8.

- In the upstream, a magnet to steer the beam is needed (called as a "*steerer*" here). Some of quadrupole magnets in the MEBT have steering coils, which are controllable independently of quadrupole coils.
- In the downstream, another BPM as a probe (called as a "*probing BPM*" here) is needed.

The calibration and analysis is done in the following 6 procedures with real beam, and one additional procedure to confirm readout electronics

- Procedure 1: Steer the beam by a *steerer* (step by step, of the order of millimeter).
- Procedure 2: For each step of steering beam in the procedure 1, change quadrupole field of the *housing quadrupole* (step by step, of the order of percent off nominal value).
- Procedure 3: For each step of quadrupole field in the procedure 2, read positions measured by a *probing BPM*.
- Procedure 4: Plot the positions measured by the *probing BPM* as a function of field strength of the *housing quadrupole*. And extract the slope of this correlation, assuming a linear correlation.
- Procedure 5: For each step of steering beam in the procedure 1, plot the gradient of the slope in the procedure 4, as a function of the position measured by the *examined BPM*.
- Procedure 6: Interpolate (or extrapolate) linearly the beam position given by the *examined BPM*, by requiring zero slope in the correlation studied in procedure 5. Because the zero slope corresponds to the situation where the beam running at the center of the *housing quadrupole*, the interpolated (or extrapolated) beam position is displacement of the electrical center of the *examined BPM* from the quadrupole's center.
- Additional procedure: Independently of procedures from 1 to 6, measure the output value of readout electronics (a logarithmic ratio amplifier and an ADC), when exchanging the inputs of readout electronics (between up and down, or between right and left). This additional procedure provides an internal offset of the readout electronics.

These procedures are tested at the MEBT (beam transporting line between RFQ and DTL) which is currently being commissioned at KEK. Figure 3 shows the alignments of 8 quadrupole magnets (Q1 ~ Q8) in MEBT [3]. In each quadrupole, a BPM is mounted (BPM1 ~ 8). The steering coils are installed in Q1, Q2, Q4, Q6, and Q8.

The calibration and analysis is done based on the SAD [4] scripts, which is developed for design and commissioning of accelerators. The SAD is chosen for the reason of continuity to the latter stages of accelerators in J-PARC, namely 3-GeV RCS, and 50 GeV-MR synchrotrons, for which the SAD has varieties of tools.

It became possible to measure in some 15 minutes per one BPM by optimizing scanning configuration, for example, concentrating the scanning region and absolute value of the *steerer* strength and the *housing quadrupole* strength during the calibration. These automatic measurements can be viewed also by the existing display tool developed by J-PARC control subgroup [5]. Figure 4 shows one of the examples of the beam based calibration. In this example, a *steerer* is in Q4, an *examined BPM* is BPM6 mounted in its *housing quadruple* Q6, and a *probing BPM* is BPM8. Left side of figure 4 shows the procedures 1 to 4, where horizontal axis is the field strength (unit: percent off nominal value) of the *housing quadrupole*, and vertical axis is measured position (unit: millimeter) by the *probing BPM*. The right side of figure 4 shows the procedure 5 and 6, where horizontal axis is measured position (unit: millimeter) by the examined BPM, and vertical axis is the slope of the left figure (unit: millimeter per percent).

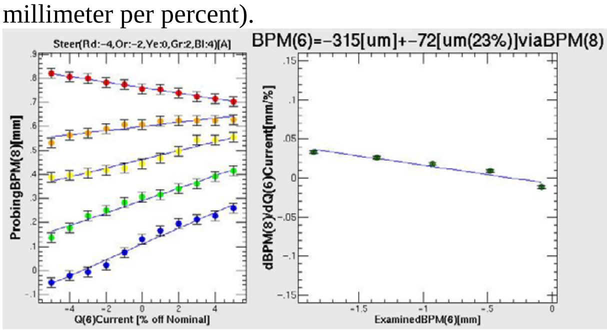


Figure 4: An example of the beam based calibration. (detail in the text). In the left figure, the *steerer* current is set to -4, -2, 0, 2, 4 (Ampere) from the top.

The early stage of experiment of the beam based calibration is done, and the results there are summarized in table 1. It is seen that evaluation with error of the order of some 10 μm is achievable for the displacement between centers of the BPM and the quadrupole, by optimizing the configuration of the BBC.

## APPLICATION OF CALIBRATION RESULTS

As an application of the beam based calibration results, comparison is performed between measured data by BPM and simulation for MEBT. TRACE3D [6] is used for simulation of beam size (upper figure) and beam centroid (lower figure) as shown in figure 5. For the vertical centroid position, data points measured by the BPM to which the calibration results (BBC only) are applied, are plotted in the lower figure. In the simulation, field strength of quadrupole magnet is based on the measured current to the magnet. Three types of parameters are applied to the simulation, (a) initial beam position, (b) initial beam tilting angle, and (c(1~8)) kick angle for each quadrupole magnet due to e.g. position misalignment of magnet. Development of better optimization procedure is kept going for best parameter set {a, b, c}, as there are some parts which have discrepancies of the order more than some tens μm still (in distance between simulation and data, or in misalignment distance corresponding to kick angle parameter).

Table 1: Results of early stage of experiments of beam based calibrations

| Calibrated BPM (Vertical, Horizontal) | | Steering Magnet(L), Probing BPM (R) | | Center [μm] | error [μm] |
|---|---|---|---|---|---|
| BPM2 | V | 1 | 5 | 29 | 93 |
| | H | 1 | 5 | -265 | 109 |
| BPM3 | V | 2 | 4 | 36 | 32 |
| | H | 2 | 4 | -313 | 222 |
| BPM4 | V | 2 | 6 | 379 | 76 |
| | H | 2 | 6 | -442 | 292 |
| BPM5 | V | 4 | 8 | -371 | 126 |
| | H | 4 | 6 | -185 | - |
| BPM6 | V | 4 | 8 | -315 | 72 |
| | H | 4 | 7 | -46 | - |
| BPM7 | V | 4 | 8 | 100 | 88 |
| | H | 6 | 8 | 17 | - |

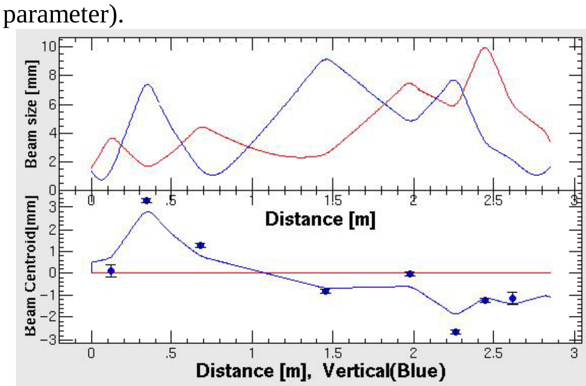


Figure 5: Comparison between measured data (points) and simulation (TRACE3D). Upper is beam size (simulation only), and the lower is beam centroid (vertical only).

## SUMMARY

Beam position monitors (BPMs) for J-PARC LINAC with the stripline type pickup electrode, are calibrated with real beam. It has been understood that evaluation between electrical center and quadrupole center was achievable of the order of some tens μm. Some comparisons between the data applied calibration results and the simulation were done. Calibration with bench setup is under going, and developments to optimize parameters in simulation are kept going.

## REFERENCES

[1] T. Tomisawa, et al., Design of 4-Stripline Beam Position Monitors of the J-PARC LINAC SDTL., Proceeding of 1st Annual Meeting of Particle Accelerator Society of Japan. Aug. 8. 2004.

[2] Poisson Manual, J.Billen, L.Young, LANL, LA-UR-96-1834.

[3] J-Parc Design Report (JAERI-Tech 2003-044, KEK Report 2002-13) from Fig. 3.1.2.3.10

[4] SAD Manual and SAD home page http://acc-physics.kek.jp/SAD/SADTkinter.pdf and sad.html

[5] M. Takagi, et al., Beam-monitor Software at the KEK 60-MeV Proton Linac, (Fig4 during BBC) Proceeding of 1st Annual Meeting of Particle Accelerator Society of Japan.

[6] Trace3D Manual (3rd ed.) K.Crandall, D.Rusthoi, LANL, LA-UR-97-886.