BEAM POSITION MONITOR AND ITS CALIBRATION IN J-PARC LINAC

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Abstract

The beam commissioning of J-PARC LINAC has been started in November 2006. Beam Position Monitors (BPM's) which had been calibrated on the bench setup with a scanning wire, take beam-based-calibration method in order to enable the beam to pass at the centre of a quadrupole magnet (Q-magnet). In this presentation, the installed BPM's and their calibration methods are described.

LOCATION AND FUNCTION OF BPM

In the J-PARC LINAC [1], 102 BPM's have been allocated [2]. Figure 1 shows location of different types of monitors, including BPM shown by "red arrow" mark, 38 SCT's (slow current transformer monitors for beam current) by "magenta", 61 FCT's (fast current transformer monitors for beam phase to measure time of flight) by "blue", and 20 WS's (wire scanner monitors for beam profile) by "green". Primary function of BPM is to monitor beam position and to enable the beam to traverse at the field center of a Q-magnet. Other functionality of monitoring the variation of momentum spread is also proposed [3].
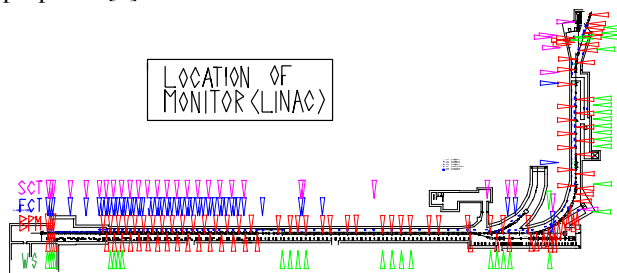

Figure 1: Location of monitors in J-PARC LINAC. Arrow-mark shows monitor location ("Red" = BPM, "Magenta" = SCT, "Blue" = FCT, "Green" = WS). Note that: for easiness of eye guide, each arrow shows only z (beam trajectory axis)-location, but not x, y (transverse to the beam trajectory)-location.

Each BPM in the LINAC section is installed on the Q-magnets yokes. This makes possible to correlate the field center of a Q-magnet and beam position measured by the BPM (as described in latter section).

CALIBRATION AT TEST BENCH

In the offline-calibration test [4], which utilizes a scanning wire to simulate a beam, the provisional positions, x and y, are calculated in the first place by the following formula [5], with $V_{x.diff}$ and $V_{y.diff}$, the difference (between left and right, and between top and bottom) of the output voltage of a logarithmic amplifier for BPM signal in x-direction (horizontal) and in y-direction (vertical), respectively.

$$ x = \frac{1}{S} \bullet V_{x.diff} \, , \quad y = \frac{1}{S} \bullet V_{y.diff} \, , \qquad (1) $$

where S is a geometrical parameter determined from BPM size (r: radius) and from the width of pickup electrode (ϕ: opening angle) by the following formula,

$$ S = \frac{160}{\ln 10} \bullet \frac{sin(\phi/2)}{\phi} \bullet \frac{1}{r} \, . \qquad (2) $$

Then, the calibrated positions are obtained by following formula,

$$ X = \sum_{i=0}^{4} \sum_{j=0}^{(4-i)} a_{ij} \cdot x^i \cdot y^j \, , \qquad (3) $$

$$ Y = \sum_{i=0}^{4} \sum_{j=0}^{(4-i)} b_{ij} \cdot x^i \cdot y^j \, , \qquad (4) $$

where aij and bij are obtained by fitting of the experimental data in the offline calibration.

In the fitting function, there are four dominant parameters. Two of them are scaling factors ($a10$, $b01$), which are close to 1. And remaining two are offset constants ($a00$, $b00$), which are close to 0. These four parameters for BPM (in and after SDTL) are shown in the figures 2 and 3. In figure 3, the unit is arbitral [a.u.] It corresponds to some hundreds micro meters of offset.
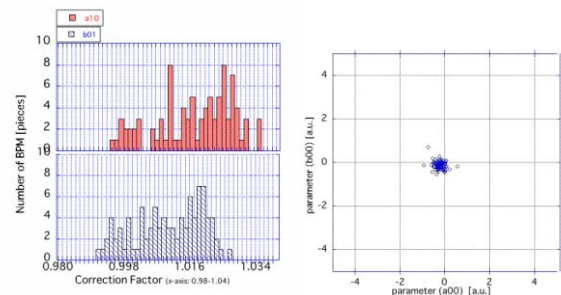

Figure 2(Left), Figure 3(Right): Distribution of four dominant correction factors (Fig2: $a10$, $b01$, which are both close to 1. Fig3: $b00$ vs. $a00$, which are around at origin). See details in the text) for BPM in and after SDTL.

These 30 parameters are extracted for each BPM, and stored in EPICS IOC (Input Output Controller).

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Calibrated beam positions (X, Y) are calculated in the IOC automatically.

BEAM-BASED CALIBRATION

During the beam commissioning of LINAC front end (up to DTL1) in 2003 and 2004 at KEK, the principle of a beam based calibration (called "BBC") of BPM had been demonstrated [6]. The beam commissioning at Tokai-site has started since 2006, and the beam based calibration has been conducted. Figure 4 shows schematics of the calibration.
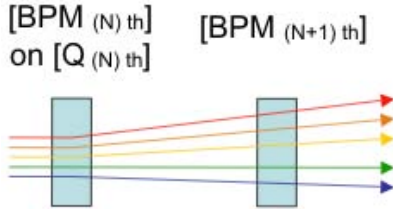

Figure 4: Schematics of the beam based calibration. In this schematics, BPM (N)th is under calibration. Steering magnet located upstream (not shown here) is used to change beam position entering in BPM(N)th.

[Step-1] Move the beam by an steering magnet located in upstream (not shown in figure 4) Different color in the figure 4, represents the steered beam.

[Step-2] For each steered beam, vary the Q-Magnet field (in the figure 4, vary field of Q(N)th).

[Step-3] Monitor whether downstream beam position (BPM(N+1)th) is varying or not. If varying, measure the dependence (namely, slope defined by the following formula (5).

$$slope \equiv \frac{d\left(BPM_{(N+1)th}\right)}{d\left(Q_{(N)th}\right)} \tag{5}$$

[Step-4] Interpolate the beam position by BPM(N)th, where the slope is zero. The obtained position is the offset parameter by the beam based calibration for the BPM(N)th.

Interpolation of offset parameter in the first iteration.

By following the above step-1 to step-5, the interpolation of offset parameter is performed, for the BPMs after singlet Q-magnet. The offset of some hundreds micro meters is calibrated. Figure 5 shows an example in MEBT1. BPM(N)th = BPM5(y-direction), Q(N)th = Q5, and BPM(N+1)th = BPM6. For the steering magnet, STR4(y-direction) is used.

Figure 5: Example of the beam based calibration. This measurement gives -563 micro-meter (pointed by red arrow sign) for the offset parameter for BPM-5th-y in MEBT1. Horizontal-axis [a.u.] or [mm/Ampere]: slope defined by formula-(5) (see explanation in the text). Vertical-axis [mm]: "BPM (N) position"

Fine tuning in the second iteration.

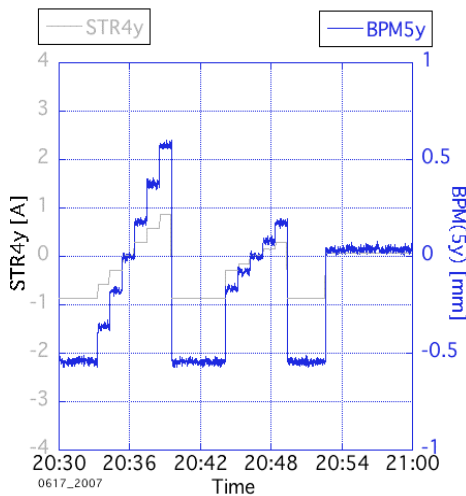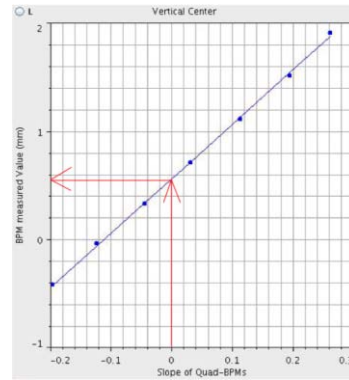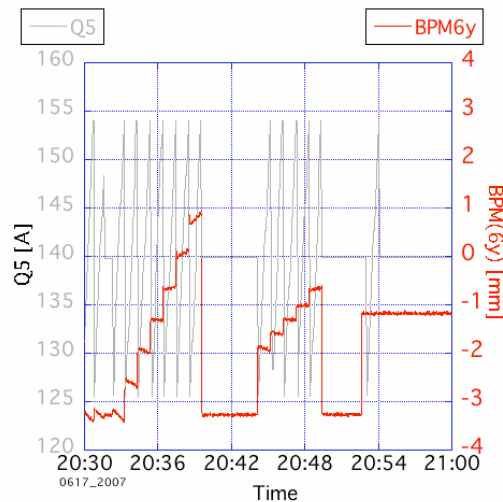After first extrapolation, fine tuning of offset is performed in MEBT1 [7] section.

Figure 6: Beam position (BPM5y) during fine tuning BBC. Beam position at BPM5y is changed by steering magnet STR4y located upstream of BPM5.

Figure 7: Beam position (BPM6y) during fine tuning BBC.

06 Instrumentation, Controls, Feedback & Operational Aspects

T03 Beam Diagnostics and Instrumentation

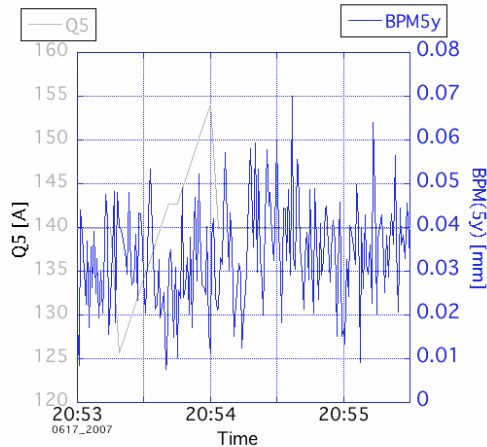Figure 8: Beam position (zoom) of BPM5y during fine BBC.

Figure 9: Beam position (zoom) of BPM6y during fine BBC.

Figure 6 shows beam position measured by the BPM under calibration (BPM5y in MEBT1), shown with axis label on the right side. For reference in Fig 6, the field variation of STR4y-magent during the calibration is also shown (coloured in grey), with axis label on the left side.

Note that: the beam position of BPM5y is changed by a steering magnet STR4y which is located upstream of BPM5.

Figure 7 shows the beam position measured by a monitoring BPM located in downstream (BPM6y in MEBT1), with axis label on the right side. For reference in Fig. 7, the field variation of Q5-magnet is shown (coloured in grey) with axis label on the left side.

By comparing Figs. 6 and 7, Q5 dependences are seen in BPM6y, except for the Q5 swing around at 20:53 (the last Q5 swing in the Figs. 6 and 7). Note that: for the zero [mm] position of BPM in Fig 6 (as well as Fig 7, 8, and 9) the first iteration of calibration (e.g. -563 micro meter for BPM5y) is already taken into account. Namely, around 20:36 or around 20:46 when BPM5y are around zero [mm], BPM6y should show zero-slope but not.

Fine tune of the beam position at BPM5y by STR4y around at 20:53, Q5 dependence of BPM6y is comparable with the background fluctuation of BPM6y.

Figure 9 shows position fluctuation of BPM6y around at 20:53 with enlarged scale (on right hand side). Both in Figs. 8 and 9, the reference (coloured in grey, with axis label on the left hand side) is the field variation of Q5-magnet. Then the residual offset beam position measured by BPM5y (see figure 8, which has enlarged scale (on right hand side)) is calibration parameter by this fine tuning. In this example, +33 micro meter of residual offset is obtained. In this example, total offset in beam based calibration is, therefore, -530 [micro meter] (= -563 + 33 [micro meter]).
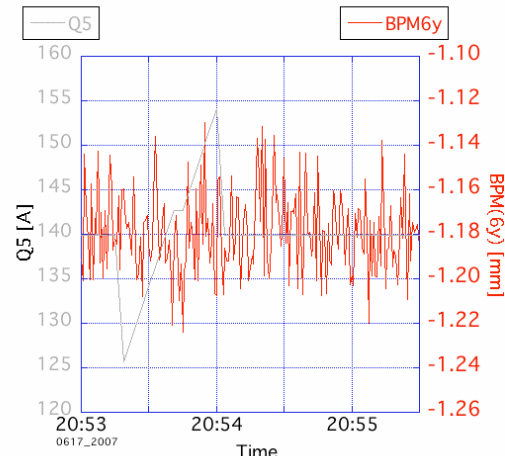
SUMMARY

In the J-PARC LINAC section, 102 beam position monitors are allocated. Calibration with a bench test which utilizes a scanning wire to simulate a beam has been done before installation. During the beam commissioning at Tokai-site since 2006, beam based calibration of BPM has been performed. Several iteration of the calibration gives a fine tuning of BPM with respect to the center of quadrupole magnet, up to a few tens micro meters.

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