BEAM BASED ALIGNMENT OF J-PARC LINAC

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Abstract

During the beam commissioning of J-PARC LINAC, a conventional method for the beam-based alignment is performed to find a relative alignment offset of a quadrupole magnet to a nearby beam-position monitor. It varies the field of a quadrupole magnet field and one of its upstream steering magnets, and measures the responses of downstream BPMs. The offset of magnetic center is extracted by analyzing the deviation of beam orbit. The measurement has been performed for singlet quadrupole magnets. Accuracy within a few 10 micrometers has been achieved. This paper describes a detail procedure and the measurement results.

INTRODUCTION

The beam commissioning of J-PARC (Japan Proton Accelerator Research Complex) LINAC has been started from November 2006. A conventional BBA (Beam-Based Alignment) method is performed to find the relative alignment offset of a quadrupole magnet to a nearby BPM. This method uses a quadrupole magnet and one of its upstream steering magnets as the tuning knobs. The offset of magnetic center is extracted by analyzing the deviation of beam orbit generated by the variation of quadrupole magnet and steering magnet.

The beam orbit is measured using a BPM nearby the quadrupole and a downstream BPM. Practically, to find a BPM with best response, several downstream BPMs are used for the measurement.

An automated application is developed under a XAL [1] framework to aid this procedure. It acquires the data automatically, analyses the orbit deviation, searches the BPM with best response, and gives the evaluation result.

The measurement is performed with 2 iteration loops to improve the accuracy. Typically, the offset can be measured within an accuracy of a few 10-μm [2, 3].

This procedure is performed under the beam condition with 5-mA for the peak current, 20-μs for the pulse width, and 2.5-Hz for the repetition rate.

With this method, the offset of magnet center to the nearby BPM has been found for all singlet quadrupole magnets.

SOFTWARE DEVELOPMENT

To assist the measurement, an automated application called BBC, which respects Beam-Based Calibration, has been developed under the XAL framework.

XAL Overview

The XAL is a Java-based software framework for high-level physics application development. It is developed in the SNS (Spallation Neutron Source) project, and has been used successfully for the beam commissioning in SNS. More than 40 accelerator physics applications have been developed in SNS to satisfy various requirements.

XAL has powerful capability to develop an application for accelerator control system, especially an EPICS-based control system. It assumes the EPICS as underlying control system to communicate with low-level accelerator hardware. Some underlying actions are hidden in the XAL, which are necessary to make connections to EPICS. For an application developer, it is convenient and easy to use.

XAL also provides some templates for application development, and much powerful functionality for GUI design, data analysis, and so on.

Now it is also introduced into the J-PARC project and has been used in the beam commissioning of J-PARC LINAC successfully [4]. Some applications have been developed for the beam commissioning, and more are under development.

The BBC is one of those applications developed by taking the advantage of XAL.

BBA Techniques Overview

Over past decade, a number of different realizations have been developed to measure the offset of magnetic center of quadrupole magnet. All techniques are based on a common approach, which is to change the quadrupole strength and measure the resulting deflection.

The method of BBA used in J-PARC LINAC is also a conventional approach, which has been used widely in many accelerators. It uses a steering magnet to excite the beam. At each steering magnet setting, the strength of quadrupole magnet is adjusted over a desired range. The beam has a different response for different quadrupole magnet strength as Fig. 1 demonstrated.

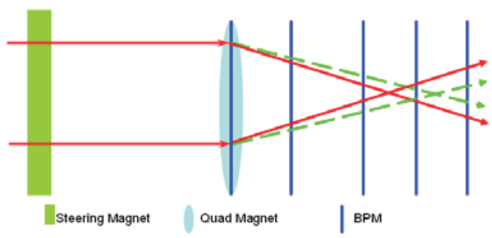

Figure 1: BBA Principle Used in J-PARC LINAC

BBC Software

The detail procedure realized in the BBC application consists of 6 steps, which is almost same with the procedure in the reference [3].

- Step 1: Excite the beam using a steering magnet.
- Step 2: At steering setting, adjust quadrupole field strength for desired interaction times.
- Step 3: At each step of quadrupole field, measure the beam orbit using selected BPMs.
- Step 4: Repeat step 1 ~ 3 for desired interaction times.

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- Step 5: Fit the response of downstream BPMs orbit as a function of quadrupole strength using a linear fitting algorithm, and extracting the slope. In this step, a group slopes can be obtained corresponding to each steering setting.
- Step 6: Fit the orbit response of central BPM, which is inside the quadrupole magnet in Fig. 1, as a function of slopes obtained in step 5 using a linear fitting algorithm. The magnetic offset can be found at the slope equaling zero.

In this procedure, an important assumption is that the position of magnetic center of quadrupole magnet is constant, and not shifts when its strength is varied. In this case, it would be an importation limitation to the resolution of BBA method because the shift could be caused by many sources such as the thermal effects, mechanical distortion of the magnet, non-uniform coil placement, leakage currents in the coils, and so on. The farther research is not performed in current beam commissioning of J-PARC LINAC. The function is not included in current BBC application also.

The BBC application consists of 3 parts: device selection, scan controller and data acquisition, and analysis.

To find an offset at desired BPM, the user can specify the hardware first from the device selection panel. Fig. 2 demonstrates a selection for BPM04 at MEBT1 section.

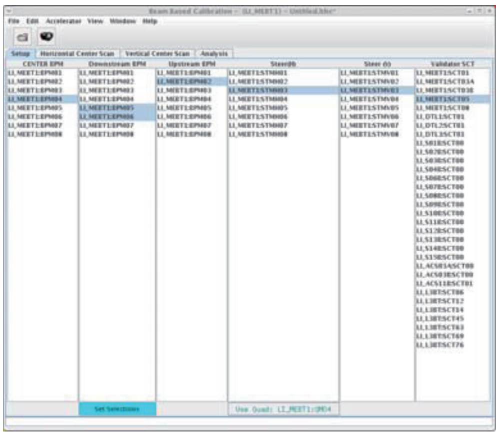

Figure 2: Device Selection of BBC Application

After specifying the central BPM, a quadrupole magnet is selected by the BBC application automatically.

The measurement can be performed using one or a couple of downstream BPMs. The offset will be given by the BPM or that one has a best response if a couple of BPMs are used.

A 2-deminsion scan package is used to adjust the field of steering magnet and quadrupole magnet. Fig. 3 demonstrates an example for scan controller and data acquisition for that BPM04.

The measurement is performed automatically after specifying the parameters of scan controller.

To avoid the system error caused by the measurement, an averaged measurement ca be performed, and the average number can be specified from the scan controller panel. Once the average scheme is used, the fitting algorithm in "Step 5" and "Step 6" will use a weighted linear fitting algorithm, and the average error will be used as the weight.

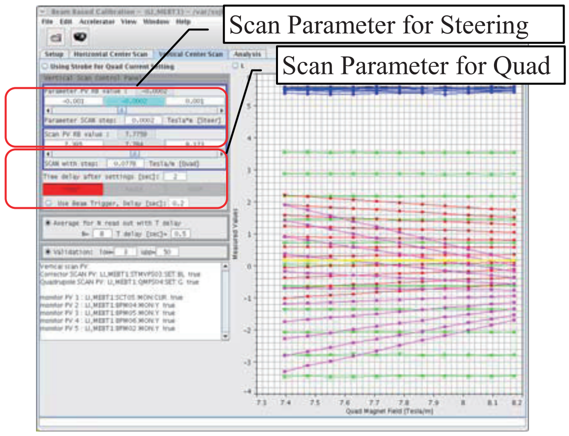

Figure 3: Scan Controller and Data Acquisition

BEAM TEST RESULT

Since the J-PARC is a high intensity accelerator, it is crucial to reduce the beam loss in the beam commissioning in order to avoid the excess machine activation. The field of steering magnet and quadrupole magnet is adjusted manually before starting a real measurement. By monitoring the downstream beam loss, a reasonable regulating range is determined for both steering magnet and quadrupole magnet.

After get the proper range, the measurement is performed with the application. Fig. 3 demonstrates a measurement result in vertical direction for the BPM04 in MEBT1 section. It is a result for the selected devices shown in Fig. 2, and the average number was 8.

The raw data acquired from BPMs are plotted on the right side in Fig. 3. There were 4 BPMs used during that measurement: one central BPM, two downstream BPMs, and one upstream BPM. The upstream is optional, and used to monitor the beam quality. It is necessary to monitor the beam current, which is detected by SCT (Slow Current Transformer) to validate a good measurement.

First Iteration for Rough Measurement

There are 3 EPICS records used to present a BPM position: the first one for the raw value directly calculated using the pick-up signal of BPM, the second one for the result of BBC evaluation, and the third one for the different result of former two.

The BBC application reads the value from the third record. During the first iteration for the rough measurement, the record value of BBC evaluation is set to 0, so the raw value is obtained by the BBC application.

The results are demonstrated in Fig. 4 and Fig. 5. Fig. 4 is a result for the BPM04 in MEBT1 section that the device selection is shown in Fig. 2. The beam energy in MEBT1 section is about 3-MeV. The offset is -2.085 mm (millimetre) and -0.098 mm for horizontal and vertical respectively.

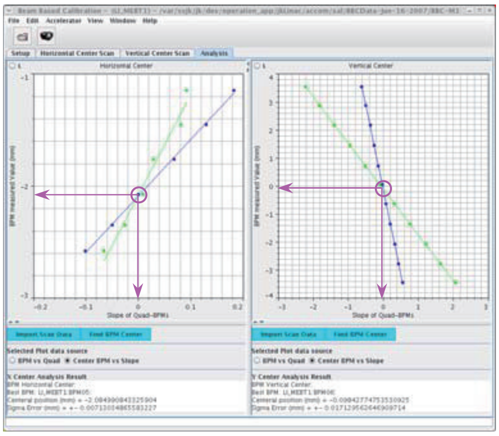

Figure 4: Result of first iteration for BPM04 in MEBT1

Fig. 5 is a result for the BPM19 in L3BT section. The L3BT is a beam transport line from LINAC to 3-GeV RCS ring. The beam energy in L3BT section is about 181-MeV. For this BPM, one downstream BPM is used to measure the beam response excited by selected quadrupole magnet. The offset is -0.644 mm and -0.092 mm for horizontal and vertical respectively.

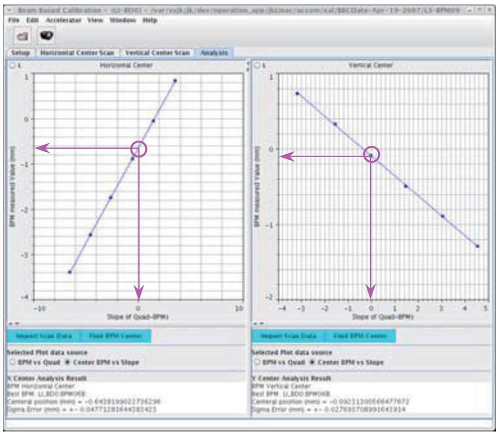

Figure 5: Result of first iteration for BPM19 in L3BT

The evaluation result is set to the second record after finishing the first iteration. With the first iteration, the measurement can achieved within an accuracy of mm.

Second Iteration for Fine Measurement

To improve the measuring accuracy, a second iteration is performed. The procedure is almost same with the first iteration, except that the value of second record is the result of first iteration, not zero.

Figure 6 demonstrates a result for the second iteration. It shows a result after performing the second iteration measurement for BPM02 ~ BPM04 in the MEBT1 section. The lines without any markers are results after performing the first iteration, and the lines with markers are results after performing the second iteration. There are 2 lines in each case, which present the position for horizontal and vertical respectively. With the second iteration, the measurement can achieved within accuracy of a few 10-µm (micro-meter).

SUMMARY

A conventional beam-based alignment method has been performed for singlet quadrupole magnets, which varies the field of a steering magnet and a quadrupole magnet. An automated application is developed under XAL framework to assist the measurement. By performing a second iteration, the accuracy within a few 10 micrometers has been achieved.

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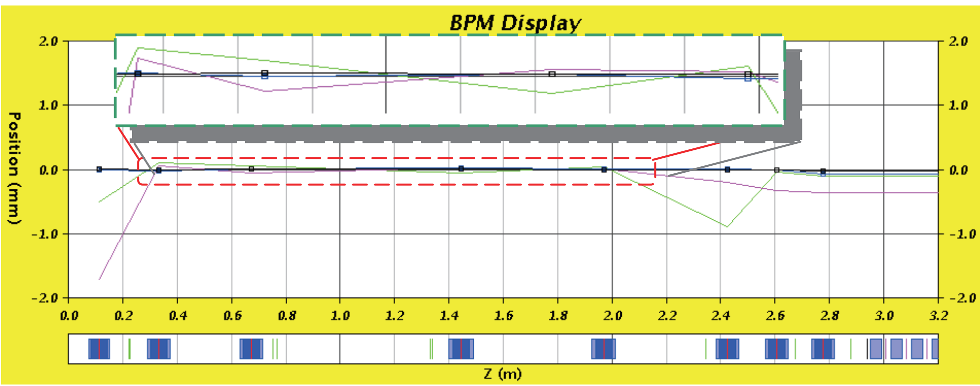

Figure 6: BBC Result for BPM02 ~ 04 in MEBT1 with Second Iteration Measurement.