BEAM-BASED ALIGNMENT FOR THE TRANSPORT LINE OF CSNS

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Abstract

Beam-based alignment (BBA) techniques are important tools for beam orbit steering in linear accelerators or transfer lines. In this paper this technique and the control system application programs developed based on XAL platform were applied to the beam commissioning for Medium Energy Beam Transport (MEBT) of CSNS to get the transverse misalignments of beam position monitor (BPM) and quad. The results shows that the absolute values of BPMs offsets are less than 0.6 mm and quads offsets are less than 0.05 mm，that is much smaller than the tolerance of the misalignment.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is a high power proton machine which is composed of accelerator, target and spectrometer [1]. The accelerator mainly contained a linac with a modest but upgradable energy and a rapid cycling synchrotron (RCS) of the fixed energy at 1.6 GeV. The installation and beam commissioning of the front end of linac, MEBT and DTL-1 has been finished. The beam commissioning of DTL2-4 and LRBT is upcoming in September of this year.

The control of beam loss is quite strict for the reason of high power proton. Orbit correction should be done first to decreasing the beam loss. Unfortunately, it can't reach the expected purpose with big errors. One of the strongest error sources of beam orbit distortion is random misalignments of quads and BPMs. The tolerance of the misalignment for magnets, diagnostic instruments in CSNS transmission lines are shown in Table 1. The most advanced approach for distorted beam orbit fine correction is the BBA technique. In this paper, two kinds of approaches and detailed measurement results will be presented.

Table 1: Alignment requirement in Transport line

Device	Dipole	Quadrupole	Corrector	BPM
Δx(mm)	0.2	0.15	0.3	0.15
Δy(mm)	0.2	0.15	0.3	0.15
Δz(mm)	0.2	0.5	1.0	0.5
Δθx(mrad)	0.2	0.5	1.0	0.5
Δθy(mrad)	0.2	0.5	1.0	0.5
Δθz(mrad)	0.1	0.2	0.5	0.5

ALGORITHM OVERVIEW

The study and application of BBA technique can be seen in many laboratories at home and abroad [2-4].

Figure 1 is the principle of BBA technique. The quad is in the position of s_0 with the length of L and the magnet filed of k. When the magnet field of quad has an increment of Δk, the beam will deflect with the angle of $\Delta y'(s_0)$, which is proportional to Δk and $y(s_0)$ (the distance between the beam and the center of quad).The angle of $\Delta y'(s_0)$ will produce a orbital increment Δy(s) in arbitrary position s downstream. The value of Δy(s) can be measured through the auxiliary BPM. Obviously, Δy(s) caused by Δk, at arbitrary position should be zero when the beam passes through the magnetic center of quad by adjusting the corrector upstream. At this time, if the record of measured BPM is not 0, it reflects the transverse misalignments of BPM electrical center with respect to the quad magnetic center. This method using beam to determine the BPM offset is the so-called beam-based alignment (BBA). In most cases, the error of alignment for quad is very small, so the measured offset can be approximately considered the offset of BPM.

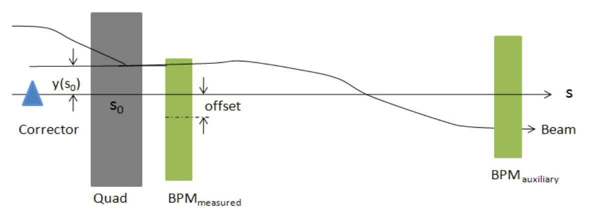

Figure 1: The principle of Beam based alignment.

The BBA method mentioned above is a tradition approach, which can give the value of BPM offset conveniently and accurately. However, scanning over all BPMs is time consuming procedure. A modification of BBA algorithm presented here looked more promising, which can get the quad and BPM transverse misalignments simultaneously. This algorithm is based on difference orbit multiple measurements. Meanwhile, the liner optics between all beam line elements must be known. Based on the beam transfer equation, we can write a set of equations of each of BPM trajectory with different quad strength settings and different incoming launch conditions. We can use the matrix equation to express as follows:

$$\begin{bmatrix} m_1 \\ m_2 \\ m_3 \end{bmatrix} = \begin{bmatrix} QR_1 & -I & LR_1 \\ QR_2 & -I & LR_2 \\ QR_3 & -I & LR_3 \end{bmatrix} * \begin{bmatrix} \Delta q \\ \Delta b \\ x_{init} \end{bmatrix} \quad (1)$$

Where m is the BPM readings, the subscript number corresponds to different measurement conditions; QR is the response matrix which maps the quad offset to the BPM readings downstream, LR is the response matrix of initial conditions to each BPM. The Eq. (1) can be solved with the singular value decomposition (SVD) method

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when we get all the BPM readings under different conditions. But unfortunately, Eq. (1) is ill-conditioned; the solution of the whole equation will be infinite. The reason in physics is that we didn't know the reference line and the launch condition is so sensitive to the beam orbit. To stabilize the system and get the most close results, two 'soft-constraints' was added.

$$\sum_i \Delta q_i = 0 \qquad \sum_i s_i . \Delta q_i = 0 \qquad (2)$$

Where s_i is the quad location. After adding the two constraints, the input error is quite close to the fitted error by many tests [5].

APPLICATION DEVELOPMENT

This BBA application is developed based on the SNS/XAL [6], which is an open source development environment used for creating accelerator physics applications, scripts and services. Additionally, XAL use JCA to realize interaction control with EPICS system interface, greatly simplifying the programs of the bottom work. There are many applications for beam commissioning like orbit correction, lattice calculation, energy manager and so on [7-8]. The application of virtual accelerator in XAL is specifically designed for the test of other application. It is actually a soft IOC, which uses the online model to produce realistic signals for common beamline elements (e.g. BPMs) and accepts signals to modify magnets and RF. By virtual accelerator application, a series beam orbits can be produced with arbitrarily incident position, angle and the offsets of BPMs and quads. The value of offsets can be solved with linear fitting or SVD method. The control software design process is shown in Fig. 2.

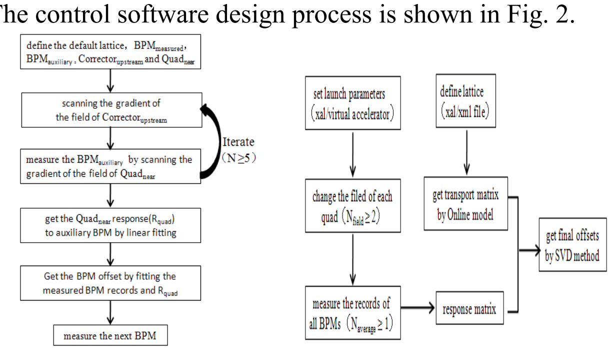

Figure 2: The design process of BBA control software (left is the tradition approach, right is the modified approach).

EXPERIMENT RESULTS

The beam commissioning for MEBT and DTL-1 has been finished last year. There is no BPM in DTL-1 sequence, BBA application was firstly applied in MEBT sequence during the beam commissioning. Figure 3 is the layout of MEBT. There are totally 10 quads, 6 correctors and 7 BPMs. The BPMs and correctors are installed in the center of the quad, i.e. the same position with the quads.

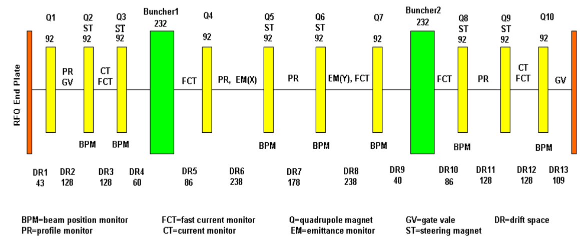

Figure 3: The layout of MEBT.

The two approaches above are adopted in MEBT. The first is the traditional BBA method. There is no corrector in the front of BPM01 and no auxiliary BPM for BPM07 either on MEBT. So it can only measure 5 BPMs from the BPM02 to BPM06. Experiment has been carried out for many times when the beam is stable. The result shows that repeatability is quite good and the fitting precision is very high. Figure 4 (top) is an operating interface, which gives a typical example of BPM linear fitting result. Figure 4 (middle) is the horizontal and vertical results of BPM offsets. It shows the second BPM has a large offset in horizontal direction. It was found that the signal is not stable in this direction and speculated that the connection of BPM02 in the tunnel may have a problem, which will be solved when the machine is shut down. While the other BPM offset are less than 0.6 mm, most close to 0. Figure 4 (bottom) is two results measured in different time, which were very repetitive.

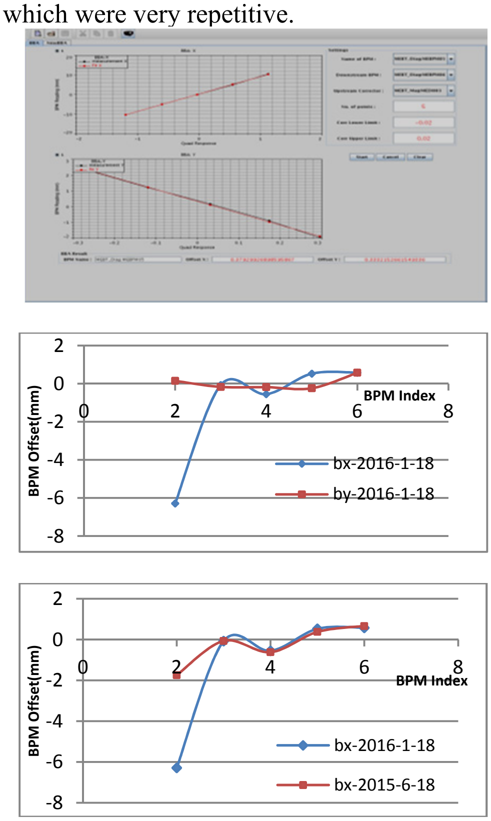

Figure 4: BBA measurement results for the traditional method (top is an example of BPM linear fitting result, middle is the BBA results for MEBT and bottom is repeatability test).

As an exploration of the BBA method, the modification approach was also applied on MEBT. Scanning the gradient of the field of quad one by one and recording all the readings of BPMs, finally getting the BPM and quad offsets by solving the Eq. 1. The total time for measurement was about forty minutes. Figure 5 shows the offsets of all quads and BPMs respectively. The result in horizontal direction was not accurate for the reason of bad signal of BPM02. The results of vertical direction shows that the value of BPM offset is range at ±0.1 mm and quad offset is less than 0.05 mm，that is much smaller than the alignment requirement (0.15 mm).

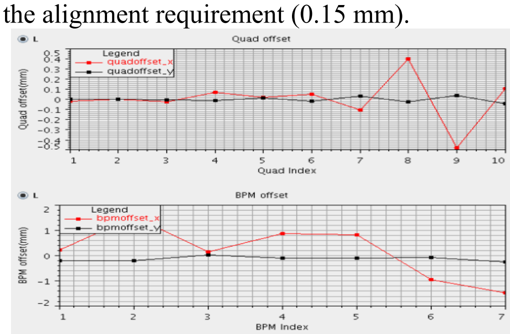

Figure 5: BBA measurement results for the second approach.

The final results of two approaches will be a little different for the reason of heavily dependent on lattice model for the second approach. In addition to alignment error, other errors, such as the magnetic field error are not considered for the model. In the case of beam stability, it is considered that the value of BPM offset obtained by the first approach is more accurate than the second approach. Then the fitting data will be given to the control group for deduction. However the second approach can give the whole situation of quads and BPMs offsets, which is a good supplement for the first approach.

CONCLUSION

Two schemes of BBA for CSNS are proposed in the paper. The simulation control program based on XAL platform is also designed and the offsets of quads and BPMs on MEBT are measured successfully. The results shows that the value of BPMs offsets are range at ± 0.6 mm and quads offsets are less than 0.05 mm，which is much smaller than the tolerance of the misalignment. Through the measurements of the two approaches, we will have a whole understanding of the alignment system in MEBT and prepare for next commissioning cycle.

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