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BEAM BASED ALIGNMENT IN A COMPACT THz-FEL FACILITY*

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Abstract

In this paper, we presented the beam based alignment results in a compact THz-FEL facility. The alignment was divided into two sections, the transport line and the optical line. In the transport line, all the five quadrupoles upstream of the undulator were adjusted one by one to fit the electron beam downstream of the traveling wave linac. In the optical line, a set of auxiliary coils were winded on the yokes of the quadrupole downstream of the double bend achromat (DBA) to produce a vertical steering force. Another X-Y combined type steering magnet, together with the auxiliary coils, corrected the beam orbit in the optical line. Dispersion free test demonstrated that after correction the displacement between the magnetic centers of the quads and the beam orbit was less than 0.3 mm.

INTRODUCTION

Huazhong University of Science and Technology has built up a compact terahertz free electron laser (THz-FEL) prototype, and the main beamline elements were installed on a 3 square meters shock isolation baseplate. The compact lattice not only spares very limited space for the diagnostic instruments, but also makes the adjustment of the machine very difficult. Although the first beam of the machine was measured to be larger than 0.7 A (macropulse) in 2014 [1], significant efforts have been made to improve the beam quality to satisfy the FEL conditions ever since [2, 3]. One important factor that deteriorates the beam quality is the orbit deviation, which may be due to the ground settlement after installation. Orbit correction is critically important for making the machine ready for the FEL process. This paper focuses on the orbit correction in the transport line with the beam based alignment (BBA) method.

Different from the steering coil method, BBA adjusts the position of quadrupoles to match the beam trajectory. A widely used BBA method is the dispersion free correction, which can eliminate the installation errors of BPMs [4, 5]. The dispersion free correction can be achieved by scanning the beam energy or the quadrupole current and observing the beam center drift after passing through a quadrupole. However, energy scanning requires changing the accelerating phase in the linac, to which the energy spread is very sensitive, so quadrupole current scanning is applied in our case.

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METHOD

The lattice of the THz-FEL prototype mainly consists of a triplet (Q1+Q2+Q3) and a double bend achromat (DBA, B1+Q4+B2) [6]. The last quadrupole (Q5) was between the DBA and the undulator. The alignment was divided into three steps: (1) alignment of Q1, Q2 and Q3; (2) alignment of the beam line and the optical line; (3) alignment of Q4 and Q5. The three steps were executed in turn.

The alignment method of each quadrupole was relatively straightforward. By scanning the quadrupole current and measuring the corresponding spot drift on the downstream screen, the displacement of the quadrupoles can be calculated as

$$\delta = \frac{p}{eDLk}A, \tag{1}$$

where e is charge of an electron; p is the longitudinal momentum of the beam; D is the drift space between the quadrupole and the screen; L is the effective length of the quadrupole; k is the linear coefficient between the gradient and the current of a quadrupole; A is the linear coefficient after fitting the beam spot variation and the current.

As the quads were not driven by motors, the adjustment of the quadrupole positions had to be done manually after the machine shut down. So the whole process was really time consuming and laborious. Considering the RF phase of the linac was not closed-loop controlled, the BPMs (fluorescent screens) collected ten beam positions for each setting, and then the mean and standard deviation of the data were calculated in the post processor.

RESULTS

Correction of the Triplet

Figure 1 shows how the beam spots vary with the current of the first three quadrupole before and after correction. x and y indicate the horizontal and vertical direction respectively. The improvement was evident. But it should be also noted that the uncertainty (standard deviation) of each position was relatively large. In most cases, the uncertainty was more than 0.2 mm, and it showed no obvious difference before and after correction. This kind of non-stability might be due to the imperfection of the linac system. With the mean and standard value of each setting, the expected value and the corresponding confidence interval of the quadrupole displacement can be calculated.

Correction of the Optical Line

Correction of the optical line was relatively complicated. The aim was to make the beam axis be coaxial with the

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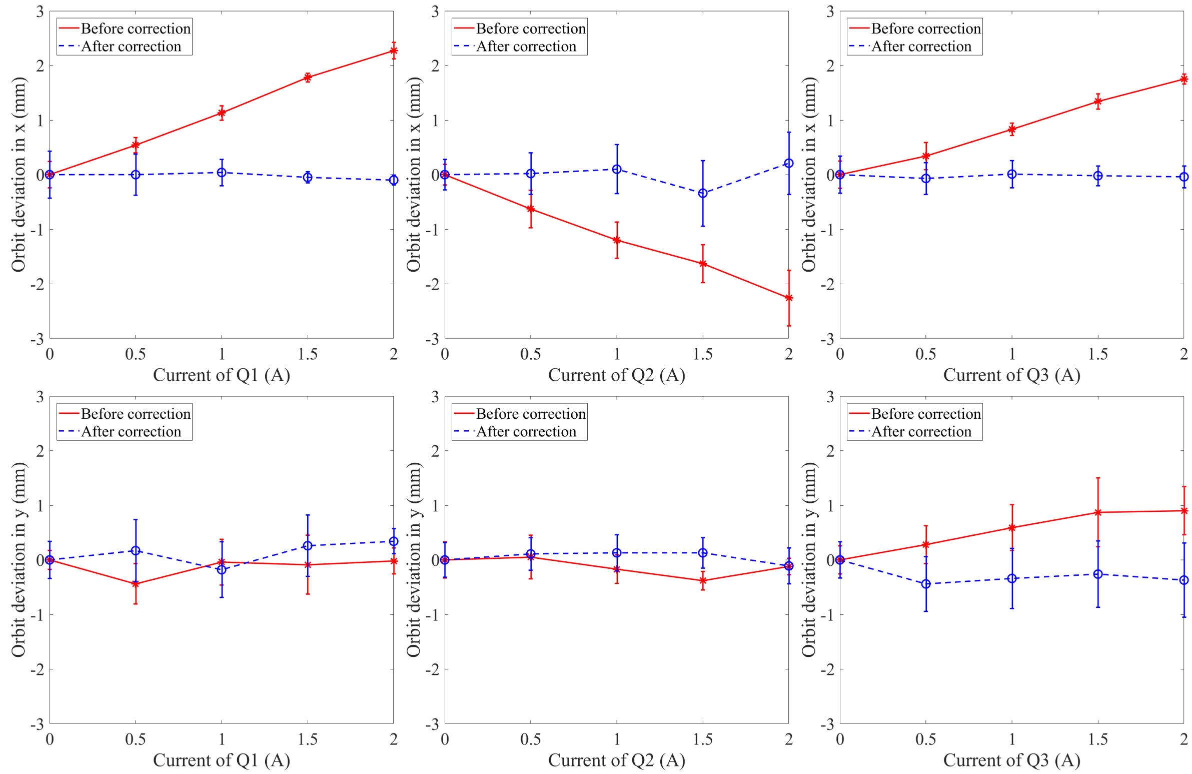

Figure 1: Beam spot drift corresponding to Q1, Q2 and Q3 before and after correction when scanning the quadrupole current.

optical axis, which was determined by the two mirrors of the optical cavity [7]. In this case, steering coils must be used to adjust the beam orbit. Figure 2 demonstrates the correction procedure of the optical line. There are two vertical steering coils (S2 and S3) and two BPMs (fluorescent screen, F2 and F3). Because of the limited space, S3 is a set of coils manually winded on Q5, as shown in Fig. 3. It is a pity that there is no tool to correct the horizontal orbit, and we are trying to do the upgrade in the future.

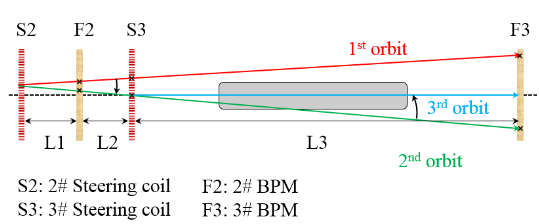

Figure 2: Correction scheme of the optical line. The black dash line in the center represents the reference optical axis.

Before the correction of the beam orbit, it is necessary to identify the reference optical axis, as indicated by the black dash line in Fig. 2. Assuming the uncorrected orbit is the red one in Fig. 2, the first step is using S2 to adjust the orbit to pass the center of S3. Then S3 is used to adjust the orbit to be coaxial with the optical axis. The optical axis is identified by the two laser spots on F2 and F3, then quantitative analysis of the deviation can be done by measuring the

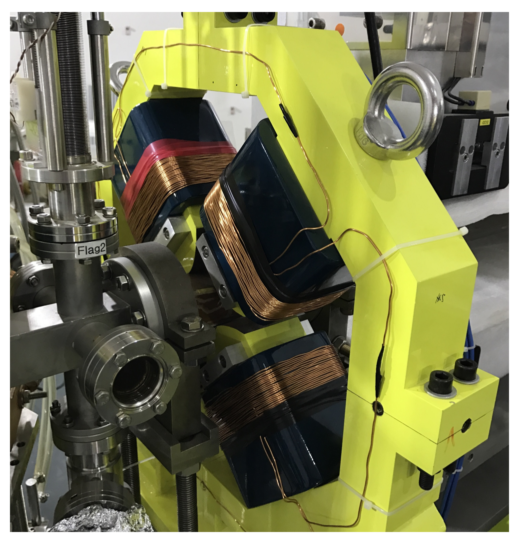

Figure 3: Vertical steering coil S3 winded on Q5.

displacement between the laser spot and the beam spot. Table 1 displays the deviation of the beam orbit relative to the optical axis before and after correction. Because of the lack of horizontal steering magnet, the vertical orbit correction has better performance than the horizontal orbit.

Correction of Q4 and Q5

Correction of Q4 and Q5 is the same as that of the triplet. Q4 is in the middle of the DBA section, and the orbit is

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Table 1: Comparison of the Beam Orbit Deviation Relative to the Optical Axis before and after Correction

	Before	After
Δx on F2 (mm)	0.59	0.00
Δy on F2 (mm)	-1.85	-0.79
Δx on F3 (mm)	-3.35	-3.23
Δy on F3 (mm)	1.54	0.00

sensitive to the bend current. Horizontal correction was found to be very difficult in our experiment. So only vertical correction results were presented. Figure 4 shows the vertical spot drift before and after correction when scanning the excitation current. To further test the correction effect, beam profiles on F2 and F3 when scanning the two quadrupoles were recorded, as shown in Figs. 5 and 6. Table 2 is a summary of the correction effects of all the five quadrupoles.

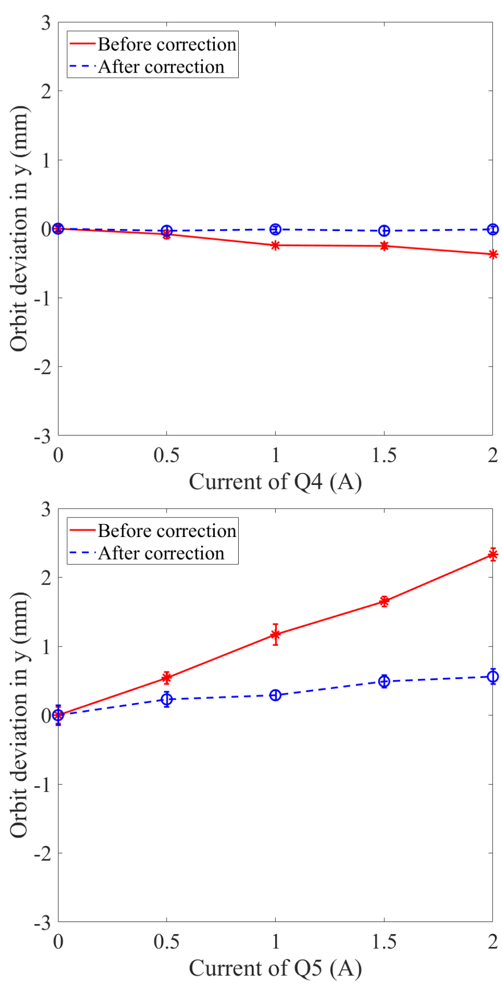

Figure 4: Vertical beam spot drift corresponding to Q4 and Q5 before and after correction when scanning the quadrupole current.

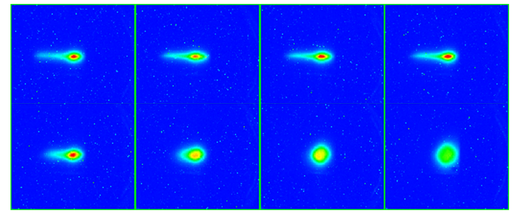

Figure 5: Beam profile on F2 when scanning the current of Q4: 0 A, 1 A, 1.5 A, 2 A, 4 A, 6 A, 8 A, 10 A.

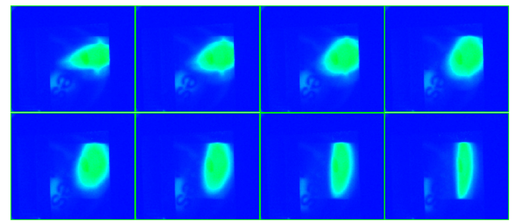

Figure 6: Beam profile on F3 when scanning the current of Q5: 1 A, 1.2 A, 1.4 A, 1.6 A, 1.8 A, 2.0 A, 2.2 A, 2.4 A.

Table 2: Correction Results of the Five Quadrupoles

Quad	Deviation in x (mm)	Deviation in y (mm)
Q1	-0.06(-0.10,-0.04)	0.14(0.05,0.22)
Q2	0.02(-0.18,0.21)	-0.03(-0.15,0.08)
Q3	-0.01(-0.10,0.08)	-0.21(-0.48,0.06)
Q4	No data	-0.01(-0.07,0.03)
Q5	No data	0.27(0.23,0.30)

CONCLUSION

Although the BBA has optimized the orbit deviation, the overall correction is still far from adequate. Especially in the optical line, because of the lack of steering tools, the horizontal orbit deviation is about 2 mrad. Its influence on FEL process should be examined carefully. Also, further upgrade of the machine should be considered.

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