

CORRECTION OF EMITTANCE GROWTH DUE TO QUAD COMPONENTS IN SOLENOIDS WITH QUAD CORRECTORS AT AWA

L. Zheng^{†1}, C. Tang, W. Gai, Tsinghua University, Beijing, 100084, China
 J. G. Power, J. Shao, E. E. Wisniewski, W. Liu, M. E. Conde, D.S. Doran, C. Whiteford,
 ANL, Lemont, IL 60439, USA
¹also at ANL, Lemont, IL 60439, USA

Abstract

An asymmetrical electron beam is observed on the drive beamline at Argonne Wakefield Accelerator (AWA) due to the quad components in the solenoids. An ASTRA simulation shows that the emittance will increase when the electron beam passes through solenoids with quad errors. We use two quad correctors to correct this emittance growth. A preliminary emittance correction result is presented in this paper.

INTRODUCTION

Quad components in solenoids have some limitations to the beam quality in photoinjectors. One obvious effect is that quadrupole fields will distort the transverse distribution of electron beams from round to elliptical[1]. Moreover, the transverse beam trajectories are coupled in x and y directions in solenoids. A quadrupole field in this coupled system will result in a growth of the emittances in 2D phase spaces[2], although the 4D emittance remains unchanged.

The drive beamline at Argonne Wakefield Accelerator (AWA) contains a photoinjector (as shown in Fig. 1) that is used to generate high-charge bunches to drive wakefield structures. The photoinjector includes six solenoids, a bucking-focusing solenoid, a matching solenoid and three linac solenoids. Some strong quad components in these solenoids have been observed when we did electron beam experiments. An example is shown in Fig. 2. All six linacs and four quads (Q1 to Q4) are turned off in this operation. A round laser beam illuminates on the Cs₂Te cathode and produces 100-pC electron bunches. The electron bunches pass through all six solenoids, and the beam images at different YAG screens are acquired, as shown in Fig. 2. A round electron beam becomes an ellipse, even a line, after a long drift passing through the solenoids section. It is very difficult to determine the exact position of the quadrupole components based on the electron beam images. In this work, we try to reduce the adverse impacts of the quad components in the solenoids on the beam quality using quad correctors.

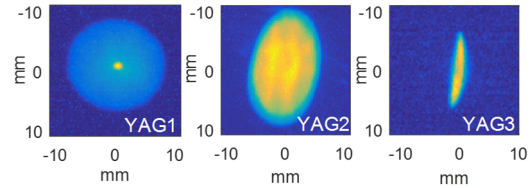


Figure 2: Electron beam images on YAG1 to YAG3. Strong quad components in the solenoids are observed.

QUAD CORRECTORS

A quad corrector consists of a normal quad and a skew quad. Each quad has four air coils. All eight coils are installed on the aluminium frame with the same interval around the tube. We can achieve a quadrupole field with any strength and any skew angle by the strength combination of the normal and skew quads. To get a quadrupole field in the quad corrector with strength k and skew angle θ , the strength settings of the quads should be:

$$k_{normal} = k \cos(2\theta)$$

$$k_{skew} = k \sin(2\theta)$$

As shown in Fig. 3, two quad correctors have been mounted on the beamline. Quad corrector 1 is installed at the exit of the matching solenoid, and quad corrector 2 is installed after the sixth linac.

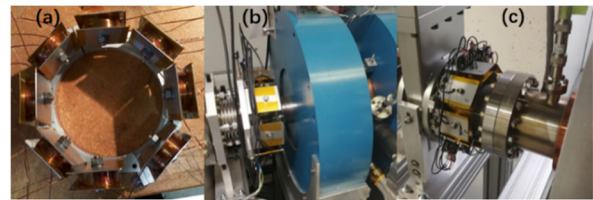


Figure 3: (a) structure of the quad corrector. (b) quad corrector 1 is installed at the exit of the matching solenoid. (c) quad corrector 2 is installed after the sixth linac.

The fields of the quad correctors are measured by a gaussmeter. The fields of normal and skew quads for quad corrector 1 are 0.04 T/m for 8-Amps coil current, as shown in Fig. 4.

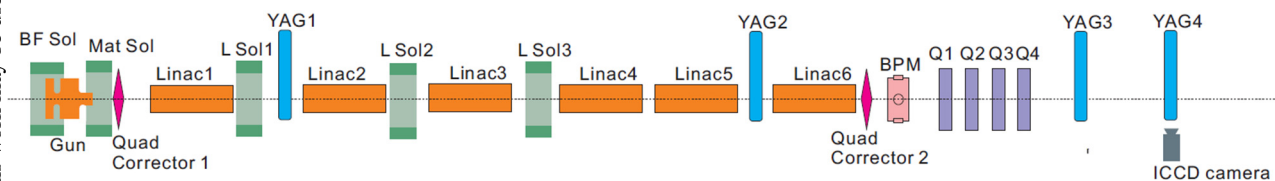


Figure 1: Schematic layout of AWA drive beamline photoinjector (not to scale).

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

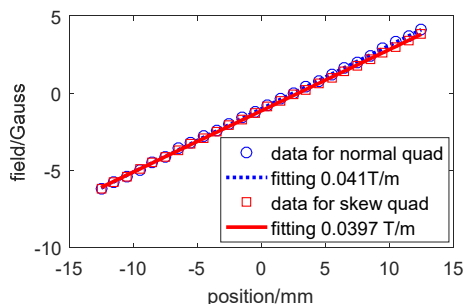


Figure 4: Field measurement for quad corrector 1, which shows a good linear relation between the field and the position.

EMITTANCE CORRECTION WITH QUAD CORRECTOR 1

Quad corrector 1 is installed at the exit of the matching solenoid. We tried to verify the effect of this quad corrector when we measured thermal emittance using the matching solenoid scan. The bunch charge in this measurement is below 1 pC to reduce the space charge effect. The bunch energy is ~ 3.2 MeV after gun acceleration. The laser beam diameter is 2.2 mm. The rms beamsizes at YAG1 that change with the matching solenoid field are shown in Fig. 5. The waist in the scan is not in the same position when the quad corrector is off, which means that there is a quad component in the solenoid. The beam becomes more round when the corrector is on, but the thermal emittance measurement result has no significant change. An ASTRA[3] simulation based on the experimental parameters is done, showing that the beamsize in the solenoid is small and the quad component in the solenoid is not strong enough to result in an emittance growth. An ASTRA simulation shows that an obvious emittance growth will be observed when the laser beam diameter is larger. We plan to use a laser beam with a 12-mm diameter to repeat this experiment in the next step, and the corrector will be used to correct the emittance growth.

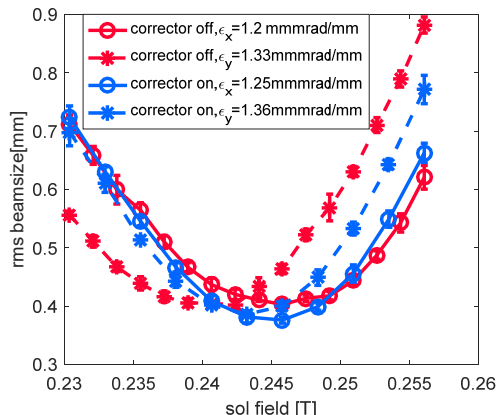


Figure 5: Thermal emittance measurement with and without quad corrector. The beam becomes more round when the corrector is on.

† email address: zhenglm14@mails.tsinghua.edu.cn

EMITTANCE CORRECTION WITH QUAD CORRECTOR 2

Dowell's work has verified the emittance correction with a quad corrector for one solenoid through analytical theory, simulations, and experiments[2]. In this part we will show that a quad corrector can be used to correct the emittance growths induced by quad errors in multiple solenoids at the same time. An ASTRA simulation is used to explain our theory. The parameters used in the simulation are listed in Table 1. All the quad errors are assumed to be normal quads ($\theta = 0$). The space charge force is excluded in the simulation. The simulation result is shown in Fig. 6.

Table 1: Parameters Used in ASTRA Simulation

Parameters	Value
Matching solenoid	0.2 T
Linac solenoid 1	0.02 T
Linac solenoid 2	0.02 T
Linac solenoid 3	0.02 T
Quad error in Matching solenoid	160 G/m
Quad error in Linac solenoid 1	16 G/m
Quad error in Linac solenoid 2	16 G/m
Quad error in Linac solenoid 3	16 G/m
Gun gradient	38.5 MV/m
Gun phase	43 deg
Laser diameter	2.71 mm

We assume that the quad error exists in the solenoid and the longitudinal field profile of the quad error is same as the solenoid field. The positions of the solenoids and the quad corrector are shown in Fig. 6, and the strengths of all the fields are normalized to 1.

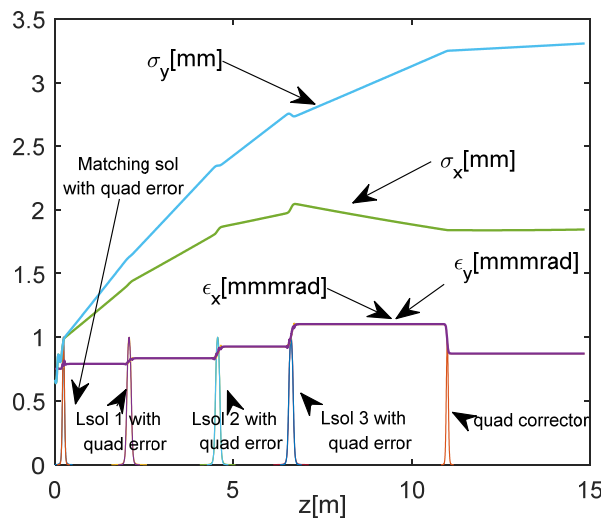


Figure 6: An ASTRA simulation to show the emittance correction with the quad corrector. The beamsizes and emittances along the beamline are presented.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

The beamsizes in x and y directions are different due to the quad errors in the solenoids. An emittance growth is observed when the beam passes through every solenoid. The quad corrector is placed at 11 m downstream the cathode, which is the same position as quad corrector 2 in Fig. 1. We scan the strength and the skew angle of this quad corrector to optimize the emittance. The emittance will oscillate with the skew angle, which is presented in Fig. 7. The emittance will be reduced by choosing an appropriate strength and skew angle of the corrector. The final emittance is reduced to close to the cathode emittance in Fig. 6 in the case of the quad corrector with a gradient of 70 Gauss/m and a skew angle of 1.732 rad. This simulation shows that we can use one quad corrector to correct all the emittance growths from quad errors of matching solenoid and three linac solenoids at the same time.

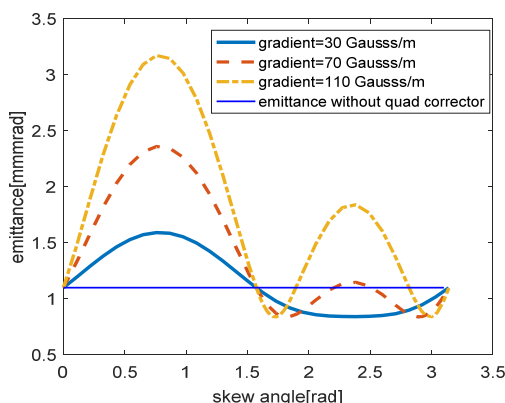


Figure 7: Scan the strength and skew angle of the quad corrector to optimize the emittance in the simulation.

We used quad corrector 2 to verify the above theory and simulation. The gun gradient and phase and the laser diameter are same as the simulation (shown in Table 1). The bunch charge is below 1pC to eliminate the space charge effect. The beam with kinetic energy 3.2 MeV passes through all the solenoids and quad corrector 2. Quad corrector 1 is turned off in this experiment. We measure the emittance with quad scan method. Q1~Q4 (see Fig. 1) after quad corrector 2 are scanned, and the beam images are acquired at YAG4. The details of the quad scan method can be found in Ref. [4].

The measurement result is shown in Fig. 8. We scan the skew angle of quad corrector 2 in the range between 0 to π with the gradient of 88 Gauss/m. Some points with different strengths are also presented in Fig. 8. We found that the emittance oscillation with the skew angle in the experiment is very similar to the simulation result in Fig. 7. Furthermore, we have observed an emittance reduction for some settings of the strength and skew angle of quad corrector 2, although this emittance reduction is smaller than what we expected. If the quad corrector can completely correct the emittance, that is, the final emittance is close to the thermal emittance, the minimum emittance should be about 0.83 mmmrad, but the measured minimum emittance after the correction is about 1.4 mmmrad. This discrepancy may

come from the measurement error or an unknown emittance contribution, which will be investigated in the future.

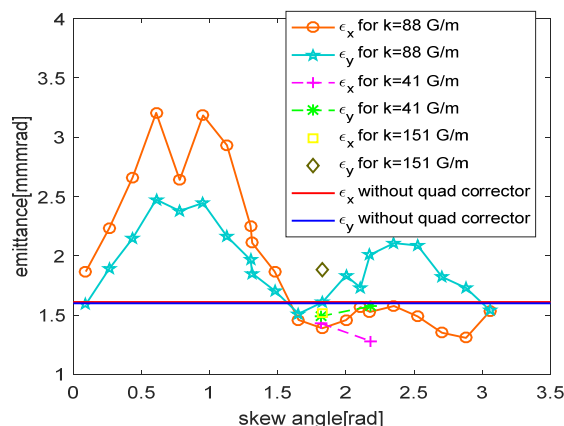


Figure 8: Scan the strength and skew angle of quad corrector 2 to optimize the emittance in the experiment.

CONCLUSION

An asymmetrical electron beam is observed on the drive beamline at AWA, which shows that there are strong quad components in the solenoids. The quad errors in the solenoids will result in emittance growth. In this paper we use quad correctors to correct this emittance growth. Two quad correctors have been made and mounted on the drive beamline. Quad corrector 1 is installed at the exit of the matching solenoid. A quad error in the matching solenoid is observed when we measure thermal emittance using solenoid scan. We can use quad corrector 1 to make the beam round in the experiment. Quad corrector 2 is installed after the sixth linac. Based on ASTRA simulation, we show that a quad corrector can be used to correct the emittance growths induced by quad errors in multiple solenoids at the same time. In the experiment we try to use quad corrector 2 to correct all the emittance growths from quad errors of matching solenoid and three linac solenoids. An emittance oscillation with the skew angle is observed, which is very similar to the simulation, and an emittance reduction is observed for some settings of the strength and skew angle of quad corrector 2.

REFERENCES

- [1] M. Krasilnikov *et al.*, "ELECTRON BEAM ASYMMETRY COMPENSATION WITH GUN QUADRUPOLES AT PITZ", in *Proc. 38th Free-Electron Laser Conf. (FEL'17)*, Santa Fe, NM, USA, Aug. 2017.
- [2] D. Dowell *et al.*, "Exact Cancellation of Emittance Due to Coupled Transverse Dynamics in Solenoids and RF Couplers." *Physical Review Special Topics Accelerators & Beams*, 21, 010101 (2018), doi: 10.1103/PhysRevAccelBeams.21.010101
- [3] K. Flöttmann, A Space Charge Tracking Algorithm (ASTRA), <http://www.desy.de/~mpyflo/>
- [4] L. Zheng *et al.*, "Measurements of Thermal Emittance for Cesium Telluride Photocathodes in an L-Band RF Gun", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May, 2017.