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ELECTRON BEAM ASYMMETRY COMPENSATION WITH GUN QUADRUPOLES AT PITZ

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Abstract

The electron beam asymmetry observed at the Photo Injector Test Facility at DESY in Zeuthen (PITZ) was traced back to multipole kicks in the gun section, namely around the location of the coaxial power coupler and the main solenoid. Several dedicated studies have been performed to quantify the kick location and strength. Based on these studies, two designs of correction quadrupole coils were proposed. The coils were fabricated and tested with an electron beam. The second updated design implies a two-quadrupole setup on a frame installed around the gun coaxial coupler close to the main solenoid centre location. Skew and normal quadrupole magnets are powered independently, enabling flexibility in electron beam manipulations. By means of this setup, a more symmetric beam was obtained at several screens. This led also to more equal measured horizontal and vertical phase spaces and to even smaller overall emittance values. Some details of the gun quadrupole designs, magnetic measurements, and results of electron beam measurements including emittance optimization will be reported.

INTRODUCTION

Several dedicated experiments to investigate the observed asymmetry in the transverse distribution of electron beams in the rotationally symmetric PITZ photo injector have been performed. One of them, the so-called “Larmor angle experiment” [1] yielded a possible location of the kick onto the transverse phase space at the longitudinal position of ~0.2 m from the photocathode. A 45° orientation of the kick corresponds to a skew quadrupole-like impact. Additional studies were performed in order to characterize this source considering RF gun power coupler [2] and main solenoid aberrations due to anomalous quadrupole fields [3] as major candidates responsible for the observed distortions in the transverse electron beam shape. These studies yielded also the second location of the possible kick – namely around z~0.4 m from the cathode [3].

In order to compensate the assumed kick integrally by a static quadrupole field, two sets of gun quadrupoles were designed and fabricated. The first are quadrupole air coils on an aluminium frame, tested at PITZ for both orientations – normal and skew. No universal settings of these coils were found to compensate the beam asymmetry for both solenoid polarities. The second design consists of a pair of quadrupoles – normal and skew on the same frame. They were connected to two independent power supplies and were able to deliver symmetric beams for both solenoid polarities. Two parameter scans of the beam images at YAG screens as functions of the normal and skew gun quadrupoles currents were performed resulting in slightly different settings for various screens. Emittance measurements were performed for 0.5 nC beams without and with found settings of gun quadrupoles.

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GUN QUADRUPOLES

The gun quadrupole design is based on an air coil concept, consisting of eight individual coils that form two separate quadrupoles: normal (Gun.Quad1) and skew (Gun.Quad2). Such combination of the skew and normal quadrupole fields provides an opportunity to perform a virtual rotation of the quadrupole field. Both quadrupole magnets are placed on the same aluminium frame of 108 mm inner diameter and 36 mm width. Each of eight air coils consists of 140 windings of 0.56 mm copper wire. The coils are powered independently by currents $I_{Gun,Quad1}$ and $I_{Gun,Quad2}$, respectively, with up to ±3 A.

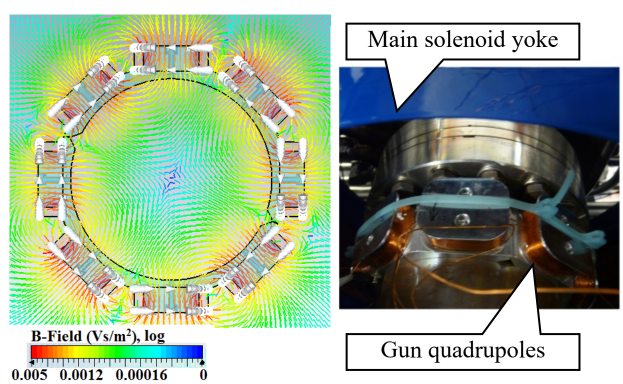

Figure 1: Compensating gun quadrupoles consisting of two air quadrupole coils: normal and skew. Magnetic field simulated with CST EM Studio for $I_{Gun,Quad1}$ = -0.5A and $I_{Gun,Quad2}$ = -0.6A (left). Photo of the quadrupole installed in the PITZ injector (right).

Before quadrupoles fabrication magnetic simulations using the CST EM Studio [4] were performed (Fig. 1, left). Thermal load for the maximum currents was estimated as well resulting in a maximum temperature of 75-

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79°C. Two thermal switchers are installed with 80°C threshold. The simulated gradient of a single quadrupole is 0.012 T/m/A, the effective length is 0.0627 m. The gun quadrupoles were fabricated and installed in the PITZ beamline at the longitudinal position of ~0.32 m from the photocathode. This location is determined by very strong space constraints in the gun area. The frame is mounted around the gun coaxial coupler inside the main solenoid (Fig. 1, right)

It should be noticed that the first design of the gun quadrupole had a similar geometry but consists of only one quadrupole. Tests with this gun quadrupole option have revealed that the beam asymmetry can be compensated only for a one solenoid polarity. Other polarity case needed the quadrupole orientation change (from normal to skew).

Tests with the second design of the gun quadrupoles (Fig. 1) demonstrated a possibility to compensate the electron beam asymmetry by a tuning of the quadrupole currents $I_{Gun,Quad1}$ and $I_{Gun,Quad2}$.

Nevertheless, there is still remaining asymmetry while optimizing the electron beam transverse shape at many screens along the beamline for the same machine settings. One of the reasons for this is the transient character of the RF coupler kick which cannot be fully compensated by a static magnetic field. Another reason could be that fact that two locations of the possible kick (z~0.4 m additionally to z~0.2 m) were found from dedicated studies [3] and the current gun quadrupole is installed between them. Presence of other multipole components (not quadrupole) can be also responsible for the remaining electron beam asymmetry.

EMITTANCE MEASUREMENTS

In order to study the possibility to symmetrize horizontal and vertical phase spaces of electron beams the standard procedure for emittance optimization was used. The projected emittance was measured for the 0.5 nC beam as a function of the main solenoid current which is one of major tuning tool for the PITZ photo injector. The photocathode laser with Gaussian temporal profile of ~11 ps FWHM was used. A quasi-flattop transverse distribution was obtained by applying the beam shaping aperture of 1.2 mm diameter. Figure 2 shows the transverse laser distribution measured with a UV sensitive CCD camera placed at a location which is optically equivalent to the real cathode position. The laser transverse distribution deviates from a homogeneous radial distribution and also contributes to the electron beam asymmetry.

The RF peak power in the gun was tuned to ~6.6 MW yielding a maximum mean momentum of 6.5 MeV/c at the gun exit. The booster was operated on-crest at ~3 MW peak power delivering the final beam mean momentum of 22.3 MeV/c.

The emittance for space charge dominated beams is measured at PITZ using the slit-scan technique [5] at the first measurement station located at z=5.27 m from the photocathode (which is also location of the screen HIGH1.Scr1). The beamlets are collected at the screen HIGH1.Scr4 located 3.133 m downstream the slit mask.

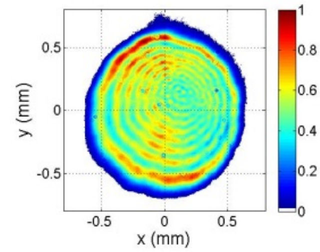

Figure 2: Transverse distribution of the photocathode laser. A beam shaping aperture of 1.2 mm diameter is applied yielding horizontal and vertical rms spot size of 0.29 mm and 0.30 mm, respectively.

Two series of measured emittance data have been taken: first, with no gun quadrupoles applied ($I_{Gun,Quad1,2}$ = 0A) and the second, with gun quadrupoles tuned to $I_{Gun,Quad1}$ = -0.6A and $I_{Gun,Quad2}$ = -0.5A (Corresponding magnetic field distribution is shown in Fig.1, left plot). These gun quadrupole settings were obtained from the two parameter scans ($I_{Gun,Quad1}$,$I_{Gun,Quad2}$) at screens HIGH1.Scr1 and HIGH1.Scr4 compromising a round beam at both screens. Measured rms spot sizes at HIGH1.Scr1 and projected normalized emittance are shown in Figure 3 for both gun quadrupole cases. Such gun quadrupole optimization procedure is rather empirical and needs more systematic studies including four dimensional phase space reconstruction.

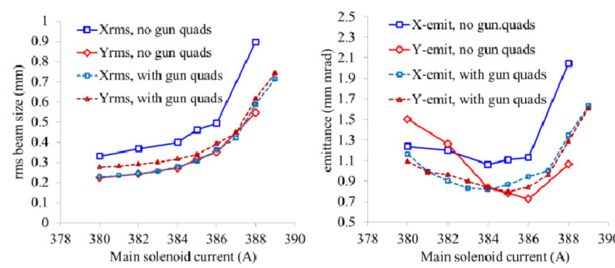

Figure 3: Transverse rms beam size (left) and projected normalized emittance (right) measured for 0.5 nC electron beam as a function of the main solenoid current for the case without gun quadrupoles and with gun quadrupoles tuned to $I_{Gun,Quad1/2}$ = -0.6A/-0.5A, respectively.

Besides more round beam (w.r.t. rms horizontal and vertical beam sizes) more equal horizontal and vertical emittances were obtained. Main results of projected transverse phase space measurements for the main solenoid currents delivering the minimum transverse emittance $(\varepsilon_{x,n}\times\varepsilon_{y,n})^{1/2}$ are summarized in Table 1. Errors of emittance measurements are estimated to be ~0.04 mm mrad. Besides the emittance values also corresponding Twiss parameters for horizontal and vertical planes are getting more equal.

Electron beam transverse distributions at screens HIGH1.Scr1 and HIGH1.Scr4 for both cases of the experiment are shown in Figure 4. Whereas the beam asymmetry (tail structure) is almost completely corrected by the gun quadrupoles at HIGH1.Scr1 a remaining structure

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is still observed at HIGH1.Scr4. Besides that also a small tilt is still present in the electron beam transverse distributions. This remaining coupling between x and y planes is most probably due to the rather empirical correction procedure mentioned above. Systematic coupling studies are ongoing now at PITZ and are under preparation at XFEL and FLASH.

Table 1: Transverse Phase-Space Measurements

	No Gun Quadrupoles	With Gun Quadrupoles
I_{main}	386 A	384 A
$I_{gun,quad1}$ (normal)	0 A	-0.5 A
$I_{gun,quad2}$ (skew)	0 A	-0.6 A
σ_x (HIGH1.Scr1)	0.50 mm	0.28 mm
σ_y (HIGH1.Scr1)	0.35 mm	0.32 mm
$\varepsilon_{x,n}$	1.13 mm mrad	0.82 mm mrad
$\varepsilon_{y,n}$	0.73 mm mrad	0.84 mm mrad
β_x	6.53 m	3.18 m
β_y	6.49 m	3.24 m
γ_x	0.56 mrad	0.32 mrad
γ_y	0.16 mrad	0.31 mrad

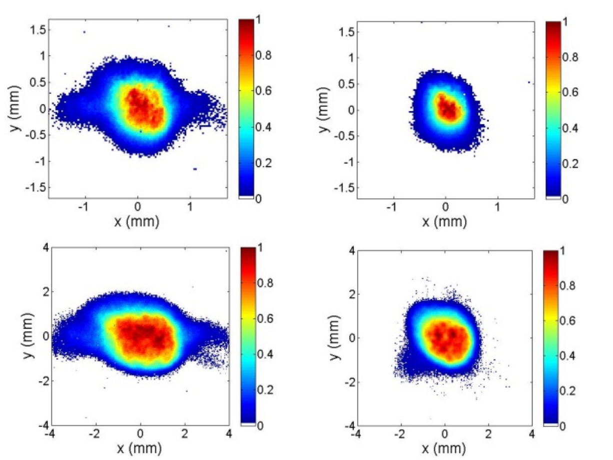

Figure 4: Transverse electron beam distributions at screens HIGH1.Scr1 (upper row) and HIGH1.Scr4 (bottom row) for the case without gun quads (left column) and with applied gun quads (right column).

Corresponding measured transverse phase spaces are shown in Figure 5. It should be noticed that for the case without gun quadrupoles the beam was diverging in the horizontal and converging in the vertical plane. After the application of the gun quadrupoles correction a more similarity is clearly observed between both transverse planes.

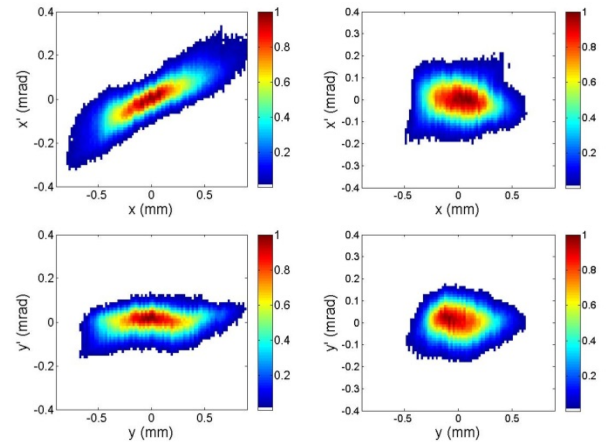

Figure 5: Horizontal (upper row) and vertical (bottom row) phase space measured without gun quadrupoles (left column) and with gun quadrupoles tuned for a symmetric beam (right column).

CONCLUSIONS

Regular (tail) structure in the electron beam transverse distributions observed at PITZ was correlated with the main solenoid polarity. Using the Larmor angle concept and tracking back the tails enabled to localize a location of the kick onto the transverse phase space at the distance of ~0.2 m from the photocathode. Two main factors were considered as reasons of the kick: the RF coupler kick and the main solenoid aberrations due to anomalous quadrupole fields. A single quadrupole installed at this location was not able to compensate the beam asymmetry for both polarities of the main solenoid. The final design of the gun compensating coils consists of two quadrupoles (normal and skew) on the same aluminium frame installed around the coaxial power coupler close to the solenoid centre position. First experiments with applied gun quadrupoles demonstrated the capability to produce a rotationally symmetric 0.5-nC electron beam with almost equalized horizontal and vertical emittances. The mean value of the transverse emittance $(\varepsilon_{x,n}\ \varepsilon_{y,n})^{1/2}$ was reduced from 0.91±0.04 to 0.83±0.04 mm mrad.

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