EMITTANCE INCREASE AND MATCHING ALONG THE TOMOGRAPHY MODULE AT PITZ

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Abstract

The Photo Injector Test facility at DESY, Zeuthen site (PITZ), focuses on testing, characterizing and optimizing high brightness electron sources for free electron lasers. PITZ is equipped with a number of transverse emittance measurement stations, among which is the Phase Space Tomography (PST) module. A PST measurement requires a specific transport along the tomography lattice, which ideally rotates the beam in the normalized transverse phase space by 180° in equidistant steps. A preceding matching section is used to provide an injection scheme that delivers the necessary beam parameters for the design transport along the tomography lattice.

The high charge density and moderate energy of the electron bunch at PITZ contribute to significant space-charge forces which lead to emittance growth and consequent mismatches of the design parameters. This article presents and evaluates measurements of the emittance increase along the matching section of a 1 nC beam at 22 MeV/c under different focusing schemes.

INTRODUCTION

The Photo Injector Test facility at DESY, Zeuthen site (PITZ), can accelerate electron bunches of up to 25 ps FWHM duration, several nC charge and 25 MeV energy [1]. A number of its current and future diagnostics and experiments, like the transverse Phase Space Tomography (PST) [2,3], Transverse Deflecting Structure (TDS) [4] and Plasma Wakefield Acceleration (PWA) [5], require specific beam parameters at certain parts of the beamline in order to achieve their functionality. Therefore, a matching procedure has to be realized for each of these applications, which has to be adjusted to the parameters of the produced electron beam. Particularly for the PST measurement, the Twiss parameters of $\beta_{x,y} \approx 1$ and $\alpha_{x,y} \approx \pm 1$ have to be delivered in front of the tomography lattice, so the beam can be rotated in the normalized phase space by 180° in equidistant steps.

The electron bunches typically produced at PITZ lay in a space-charge dominated regime due to the moderate kinetic energy and the high charge density. When a matching scheme is applied in addition, normally involving transport over long drift spaces under strong focusing, the space-charge effect gets enhanced and leads to transverse emittance growth. The result is mismatched beam parameters apart from the degradation of the emittance.

In order to understand this effect in more details a series of measurements were carried out at PITZ. The transverse projected emittance of a beam with 1 nC charge, 21 ps FWHM flat-top temporal length and 22 MeV/c momentum was measured at three locations along the beamline under different PST matching schemes.

EXPERIMENTAL SETUP

PITZ offers a wide variety of diagnostics across its beamline [1], among which are three stations for the measurement of the transverse projected emittance. The first two, called Emittance Measurement SYstem (EMSY) 1 and 2, are employing the slit-scan technique [6], while the third one is the PST module. The location of these stations together with the seven quadrupole magnets comprising the matching section are shown in Fig. 1.

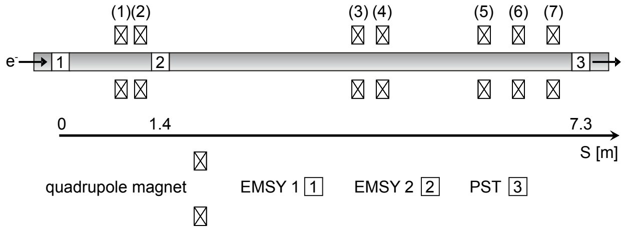

Figure 1: Rough schematic layout of the experimental setup. Seven matching quadrupoles are located between the transverse emittance measurement stations, the position of which is indicated on the coordinate axis with respect to the position of EMSY 1.

After the beam reaches its final acceleration, its transverse trace-space distribution is measured at EMSY 1. Once the Twiss parameters at this location are calculated, the goal is to match the beam to the PST requirements and then measure its transverse emittance at EMSY 2 and PST. The current matching setup allows more than one matching solutions for a specific set of initial (EMSY 1) and target (PST) Twiss parameters. These solutions were obtained using the MAD [7] software.

The directive for the creation of the different matching schemes was the alteration of the focusing strength for each transverse phase space plane. Qualitatively this can be controlled by the phase advance as calculated by MAD. Despite the neglect of the space-charge forces and the irregularity of the lattice, the phase advance gives nevertheless a rough expectation of the frequency of the betatron oscillations in the beam envelope equation and thus the focusing strength [8].

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MEASUREMENT RESULTS

EMSY 1 Measurement and Matching

The result of the EMSY 1 measurement is presented in Table 1. It is important for the interpretation of the upcoming results to point out the asymmetry of the emittance between the two phase space planes.

Table 1: EMSY 1 Measurement Result with Statistical Errors

	***x* plane**	***y* plane**
Normalized emittance [mm·mrad]	2.32 ± 0.02	2.07 ± 0.03
β-value	3.31 ± 0.02	3.66 ± 0.10
α-value	0.11 ± 0.07	0.67 ± 0.07

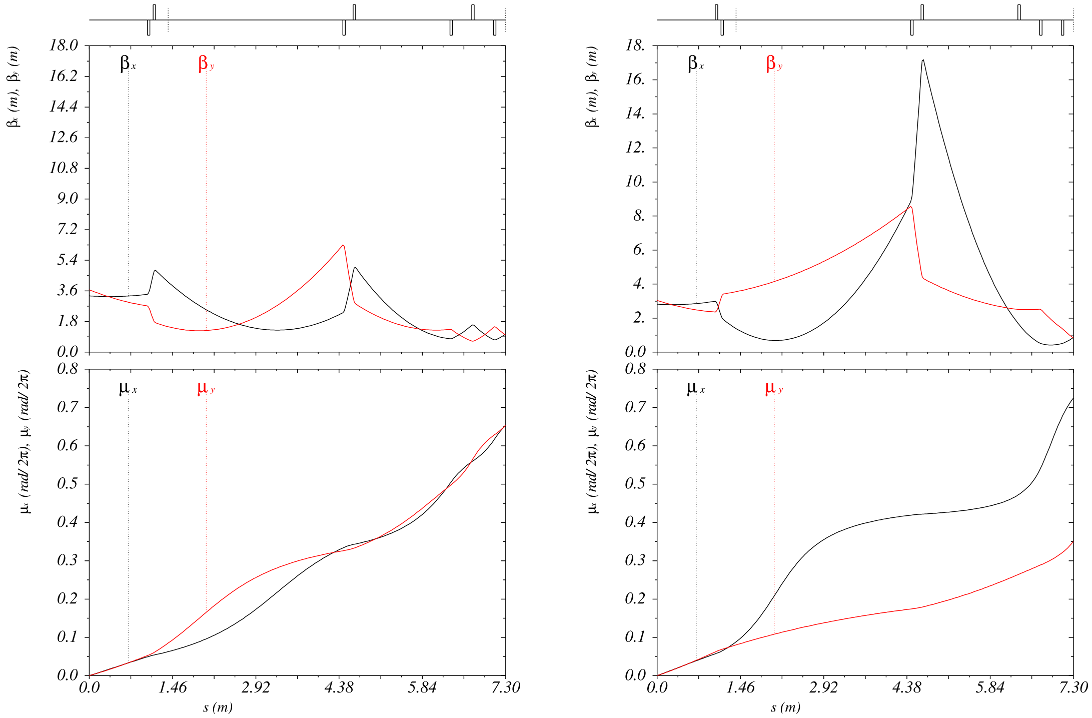
Four matching solutions, referred as m1, m2, m3 and m4, were created for the measured beam by influencing the evolution of the phase advance in MAD, in order to have different focusing strengths for the two transverse planes. The plots from MAD of the β-value and the phase advance along the matching section for m2 and m4 are shown as an example in Fig. 2.

EMSY 2 Measurements

Each of the obtained matching schemes were applied to the machine and the transverse emittance was measured at EMSY 2, yielding the results plotted in Fig. 3a. The effect of the different focusing, represented by the MAD-expected phase advance and the measured beam size at this location (Fig. 3b), is reflected in the emittance value of each phase space plane. By increasing the focusing for one plane, its emittance growth gets reduced and vice versa. Due to the nature of the quadrupole focusing, this leads to an emittance exchange between the two planes. For the case of m4, for which a very strong horizontal focusing was achieved, the vertical emittance overtakes the horizontal. The geometrical mean of the emittance of both planes, indicated as *XY*, does not vary significantly among the different matching schemes and shows an increase of ~25% w.r.t. EMSY 1.

PST Measurements

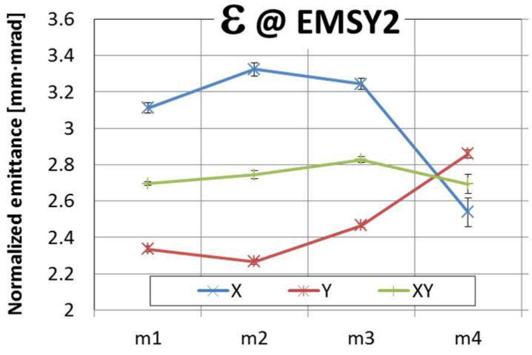
A similar trend is observed at the PST location, as plotted in Fig. 4a together with the results from EMSY 1 and 2. Again, the emittance of each transverse plane follows inversely the MAD-expected phase advance for each applied matching scheme (Fig. 4b), taking into account the initial asymmetry between the two planes. The excessive horizontal emittance, already present since the beginning, evolves downstream and has to be corrected by a stronger x-focusing; a symmetric focusing just propagates it further. Like before, m4 manages to reverse the relation between horizontal and vertical emittance, achieving to deliver a smaller average emittance as well. This could be the result of a better transport that the stronger horizontal focusing yields due to the coupling of the transverse phase space planes. The average emittance increase from EMSY 1 is in the order of 100%.



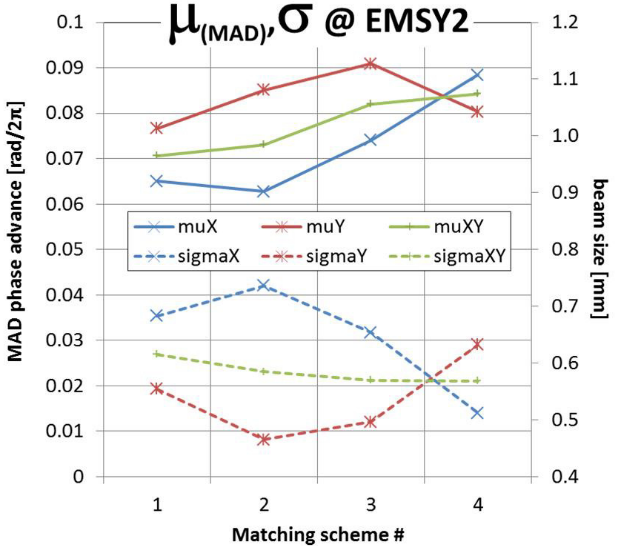
(a) β-value (top) and phase advance (bottom) for m2.

(b) β-value (top) and phase advance (bottom) for m4.

Figure 2: Plots of the β-value and the phase advance from EMSY 1 to PST from MAD. The matching quadrupoles are indicated on the top as white rectangles and EMSY 2 as a dotted black line right after the second quadrupole.



(a) Measured emittance at EMSY 2 for m1, m2, m3 and m4.



(b) MAD-expected phase advance and measured beam size at EMSY 2 for m1, m2, m3 and m4.

Figure 3: Measured emittance and beam parameters at EMSY 2.

OUTCOME

It has been demonstrated that the increase of the transverse projected emittance along the beamline and its relation between the two phase space planes can be influenced by the applied focusing strength. This observation can assist the correction of the beam transport in case of asymmetries and the delivery of a better matching with smaller emittance degradation. A future study should suggest the necessary beamline modifications that will allow a transport with minimum emittance growth.

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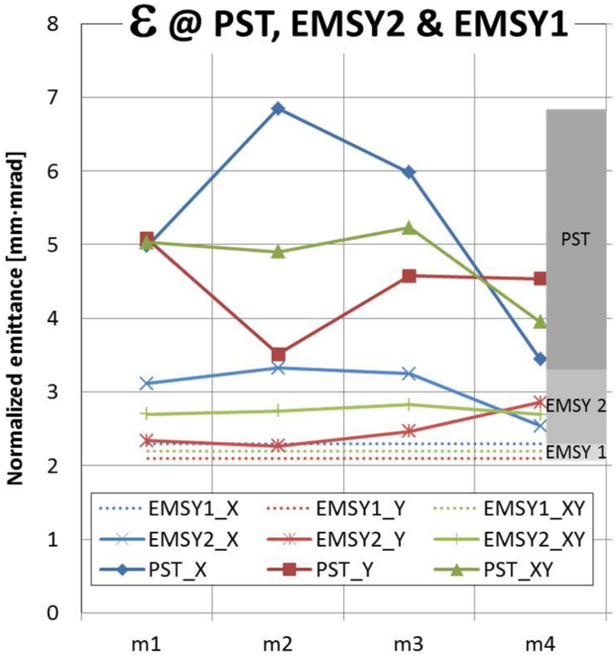
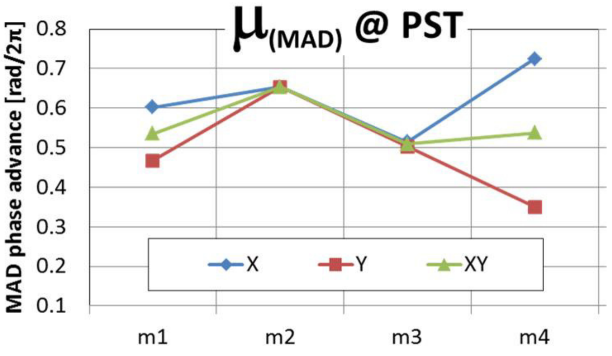


(a) Measured emittance at PST, EMSY 2 and EMSY 1 for m1, m2, m3 and m4.



(b) MAD-expected phase advance at PST for m1, m2, m3 and m4.

Figure 4: Measured emittance and MAD-expected phase advance at PST.

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