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Abstract

The goal of the Photo Injector Test Facility at DESY, Zeuthen site (PITZ) is to develop sources of high phase-space density electron beams that are required for the successful operation of SASE FELs. This requires detailed characterisation of the sources and therefore the development of suitable advanced diagnostics.

As part of the ongoing upgrade towards higher beam energies, new diagnostics components are being installed. An example is a tomography module for transverse phase space reconstruction which is designed to operate in the energy range between 15 and 40 MeV. The module consists of four observation screens with three FODO cells between them. A number of upstream quadrupoles are used to match the beam envelope parameters to the optics of the FODO lattice.

This contribution presents the final design of the tomography module. Data from numerical simulations are used to illustrate the expected performance and to compare it to a simplified setup of two quadrupoles. The quality of the reconstruction is revised with the help of different algorithms.

INTRODUCTION

Successful operation of SASE FELs requires the use of high-quality electron sources and thus a better understanding of the processes that contribute to emittance and emittance growth in injectors. For these reasons the **P**hoto-**I**njector **T**est **F**acility at DESY, Zeuthen site (PITZ) is currently extending its diagnostics instrumentation with a module for transverse phase-space tomography [1, 2, 3].

The PITZ accelerating sections consists of a 1.5 cell RF gun and a booster cavity. Together with the installation of the tomography section, the booster cavity will be exchanged which will allow the beam momentum to reach 30 MeV/c. Low-energy diagnostics components, situated between the gun and the booster, and high-energy ones, downstream of the booster, are used for the characterisation of the electron beam. Some other new additional elements are described in [1]. In this paper the tomography section is presented. The first part reviews the final design layout while the second part is a comparison between such a set up and a simplified version consisting of two quadrupoles and an observation screen. The final part shows the expected performance using numerically simulated distributions. Earlier design iterations can be found in [2, 3].

PHASE-SPACE TOMOGRAPHY SETUP

The main components of the module are four observation screens with three FODO cells between them. In [4] it has already been shown that the phase advance that delivers the smallest emittance measurement error for such a setup is 45°. This requirement, together with the layout of the section and the beam parameters, means that it is necessary to have an upstream matching section. The full assembly is shown in Fig. 1. As it can be seen there, the beamline section surrounded by the first two screen stations, also forms one of the several identical FODO cells. These five cells extend over 3.04 m. Four additional quadrupole magnets, not shown in Fig. 1, located upstream, are available for matching.

Quadrupole magnets

All the quadrupoles in the straight section are identical, produced and measured by DANFYSIK [5]. In one of the first design iterations a quadrupole effective length of 0.06 m was assumed [2] but, due to stringent space limitations, this is now the allowed geometrical length of a magnet. Basic parameters of the quadrupoles used are given in Table 1 and the magnetic field necessary for nominal gradient of 5.6 T/m, as a function of the longitudinal position, is shown in Fig 2.

Table 1: Main parameters of the quadrupole magnets. Effective length and required current are measured at nominal gradient of 5.6 T/m

Average effective length	0.043	m
Average required current	7.3	A
Physical length	0.063	m
Maximum gradient	7.5	T/m
Bore radius	0.04	m
Weight	9	kg

From the hysteresis curve shown in Fig. 3 it can be demonstrated that the magnetic field stays linear below 7 T/m. For that reason the quadrupoles should be operated below this value. From ASTRA [6] numerical simulations

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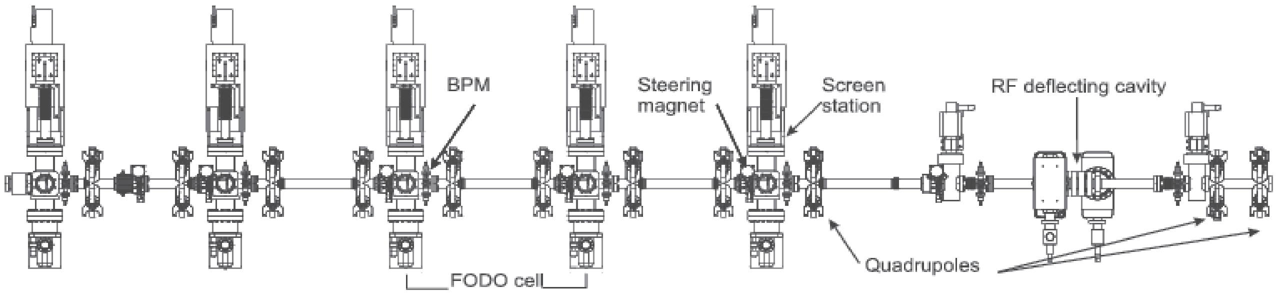


Figure 1: Tomography and matching section top view. The electron beam propagates from right to left.

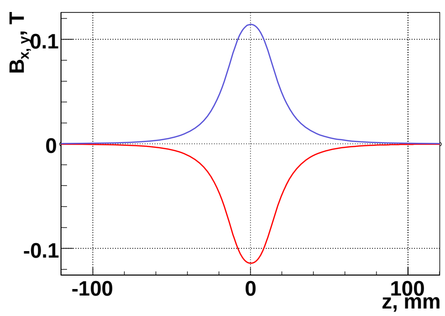


Figure 2: Magnetic field mapping as a function of the longitudinal position along the quadrupole for the nominal gradient of 5.6 T/m. The data were taken from quadrupole measurements done by DANFYSIK.

it can be seen that for some beam energies better matching is obtained when some of the quadrupoles have gradients close to or above 7 T/m. Such a conflict can be resolved if the drift space between two of the matching quadrupoles is increased by 0.08 m.

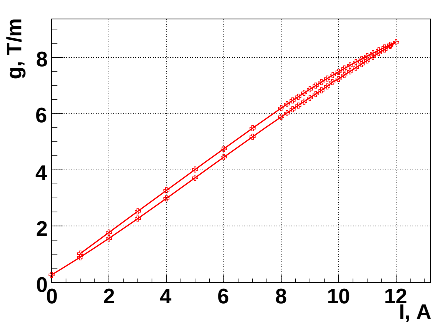


Figure 3: Field gradient as a function of the applied current. The data were taken from the DANFYSIK measurements.

Each quadrupole is to be powered by a separate power supply delivering relative accuracy of the magnetic field of 10^{-3}.

Screen stations

Each of the five screen stations along the section is equipped with a horizontal actuator housing two screens - a YAG and an OTR, planned to be used for different beam energies. The direction of movement of an actuator depends upon the plane of deflection produced by an RF deflecting cavity to be installed later and the necessary resolution - if the beam is going to be streaked vertically, the actuator should be inserted in the beamline in horizontal direction.

As well as the main components described above, each FODO cell is equipped with a BPM and a steering magnet.

The misalignment in the components' mounting should be minimised in order to avoid additional systematic effects. As the error in the emittance is required to be smaller than 10%, the beam size error has to be smaller than 10% [4]. The calculated misalignment tolerances in rms values are as follows: longitudinal misplacement of a screen or a quadrupole maximum 100 μm, quadrupole rotation around the z-axis - 10 μrad, quadrupole rotation around the horizontal and vertical axes - 20 μrad.

A SIMPLIFIED SETUP WITH TWO QUADRUPOLES

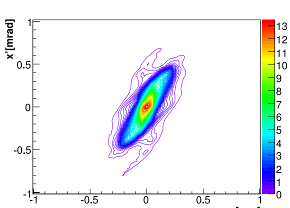
In order to evaluate the performance of the tomography module, the measurement procedure can be compared with a simplified one utilising two quadrupoles and a screen.

As a single projection does not uniquely define the object being imaged, combining information from a number of viewing angles can result in a more accurate description. In medical imaging this number can reach more than several hundred, while in beam physics it is limited by the available setup. Using the design described here, only four projections are available and the reconstruction is beneficial only if the beam is well matched to the optics of the lattice in both transverse planes. If this is not the case, the transfer matrices along the FODO cells do not correctly represent the evolution of the envelope and the phase-space reconstruction is not correct. Such an example is given in [3]. Good matching is hard to achieve since the beam is strongly space-charge dominated over the energy range

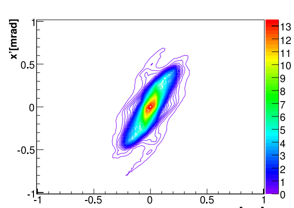
PITZ is operating. It also requires an assumption of a constant emittance value in advance. To overcome these issues, a quadrupole scan with two magnets has proven to be useful. A significant drawback is that full π rotation of the phase-space ellipse cannot be achieved for both transverse planes simultaneously without different drift lengths between the position of reconstruction and the position of observation during a single measurement. In PITZ this option gives the possibility of reconstructing the phase-space density distribution at a z-position closer to the gun and to the position where emittance is being measured using a slit-scan technique. Using ASTRA-generated distributions, including space-charge forces in the tracking, it has been confirmed that 15 phase-space ellipse rotations are sufficient to obtain very good agreement between a generated and a reconstructed distributions for beam momentum of 15 MeV/c. A beam having such a low momentum is hard to match due to space-charge effects. The second transverse plane has to be simulated and consequently measured in addition and therefore a detailed quadrupole scan is desired to be used only as a backup solution and for cross-checking.

TRANSVERSE PHASE-SPACE RECONSTRUCTION FROM NUMERICAL DATA

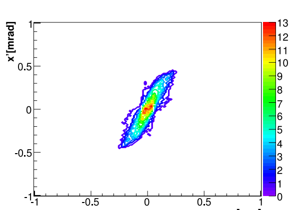
A beam with optimised parameters as required for emittance measurement has been generated at the entrance of the matching section using ASTRA. Furthermore, it has been matched and tracked, including space charge, along the full matching and tomography sections. In Fig. 4, reconstructions of the horizontal trace space using **M**aximum **ENT**ropy [7] and **A**lgebraic **R**econstruction **T**echnique [8] are shown. Both algorithms start with the same input distributions and very good agreement can be seen between them, as well as between the reconstructions and the original distribution, shown at the bottom. The relative errors



(a) MENT reconstruction



(b) ART reconstruction



(c) Original distribution

Figure 4: Reconstructed distributions with MENT (top left) and ART (top right) and the original one (bottom).

in the beam parameters with respect to the original distribution are given in Table 2.

Table 2: Relative errors in % of the reconstruction results with respect to the original distribution

	MENT	**ART**
σ_x	0.21	0.16
$\sigma_{x'}$	2.75	2.74
$\sigma_{xx'}$	0.47	0.57
$\varepsilon_{x,N}$	0.8	0.3

MENT was tested on real data from the FLASH FEL. It shows very good agreement with the results from a multiscreen χ^2-fit technique, provided that robust noise removal, selection of region of interest and spot-centering algorithms are applied in advance.

CONCLUSIONS

The tomography setup is currently undergoing technical implementation. Its performance has been verified for the PITZ working regime using simulations. The requirements for the precision mounting of the components are challenging due to the properties of the space-charge dominated electron beam and the necessity for strong focusing along the matching section and in the FODO lattice. Currently, part of the matching section is already installed and first experience with the module is expected at the beginning of 2009.

Two different reconstruction algorithms have been tested on numerical data - MENT and ART. Both of them perform very well if given correct transfer matrices, i.e. there is good matching of the optical parameters.

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