A PHASE SPACE TOMOGRAPHY DIAGNOSTIC FOR PITZ*

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Abstract

The Photo Injector Test Facility at DESY in Zeuthen (PITZ) is a European collaboration developing RF photocathode electron guns for light source and linear collider projects. As part of the collaborative work being partially funded by the EU's FP6 programme ('EuroFEL', contract number 011935), CCLRC Daresbury Laboratory and DESY are designing and building a phase space tomography diagnostic based on a set of quadrupoles and view screens. In order to measure the beam emittance, four screens with intermediate quadrupole doublets will be used. The equipment will be installed and tested at PITZ as part of the facility upgrade presently ongoing.

Following simulations of the gun using the ASTRA code at a range of energies, simulations of the electron beam parameters through the matching and tomography sections must be undertaken in order to specify the optimum arrangement of magnets and screens.

INTRODUCTION

The photo injector test facility at DESY in Zeuthen (PITZ) is currently being upgraded to operate at higher peak and average gun power. In addition to a normal conducting booster cavity the first diagnostic components that belong to the PITZ2 phase have also been installed. This intermediate phase is called PITZ1.5, and the first results are reported in [1].

For the detailed analysis of the transverse phase spase it is planned to install a tomography section based on multiple quadrupoles and view screens. Together with the future deflecting cavity [2] the tomography section will allow study of transverse emittances along the electron bunch. The development of the tomography section is being undertaken jointly between DESY-Zeuthen and the Accelerator Science and Technology Centre (ASTeC) at CCLRC's Daresbury Laboratory. ASTeC are responsible for beam simulations and the layout of the diagnostic section. DESY-Zeuthen will undertake the construction and installation at PITZ. Fig. 1 shows the initial proposed layout of PITZ2.

METHOD

The diagnostic consists of a quadrupole matching section followed by a number of FODO cells. A screen is placed around each FODO cell. For a measurement at a particular energy the field strength in the FODO quadrupoles remains constant. The beam is matched into the FODO lattice such that the alpha and beta functions are well defined and an emittance measurement can be inferred from the area of the re-constructed phase space. The phase advance between FODO cells is chosen to give results in phase space at different orientations. A four-screen measurement was chosen to provide some redundancy. More could not be used due to space restrictions. The optimum screen to screen phase advance is 180°/n, where n is the number of screens. The resolution of the measurement is approximately proportional to the square root of the number of screens.

To produce the condition of a matched beam in the FODO lattice, matching quadrupoles are required upstream of the tomography measurement diagnostic.

SOLUTION

The tomography diagnostic module is required to operate over the full working energy range proposed for PITZ2, i.e. from 13 to 40 MeV. The constraints imposed on the design by the total space available, including accommodating a deflecting cavity and the matching section, as well as using existing screen modules and practical quadrupoles, meant that there was very little flexibility in what was possible. Despite this, the proposed layout has been demonstrated by simulations to fulfil the performance criteria.

While the initial layout is complete, further work is required to finalise the choice of deflecting cavity, and hence a complete ASTRA model was not possible.

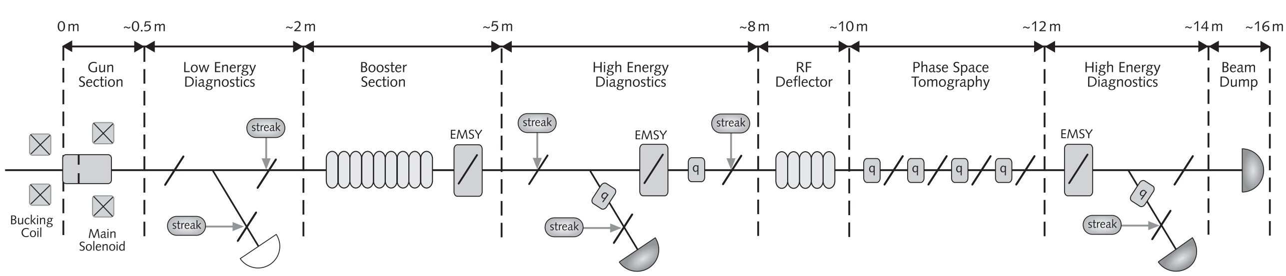

Figure 1: PITZ2 Layout scheme.

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Matching into the tomography section was achieved using MADX and the results are shown in Fig. 2 (for the matching and diagnostic sections) and Figs. 3 and 4 (diagnostic section only). The matching (which is energy dependent) was done at 32 MeV.

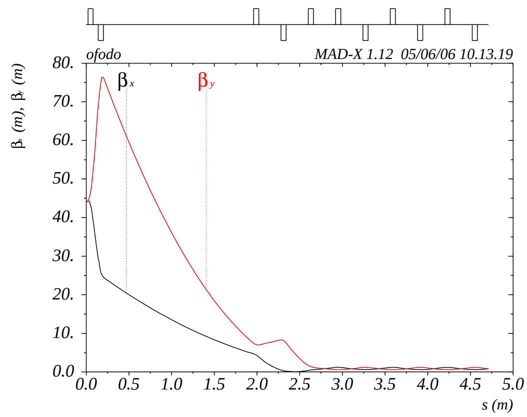

Figure 2: β functions along the five quadrupole matching section and the six quadrupole tomography section.

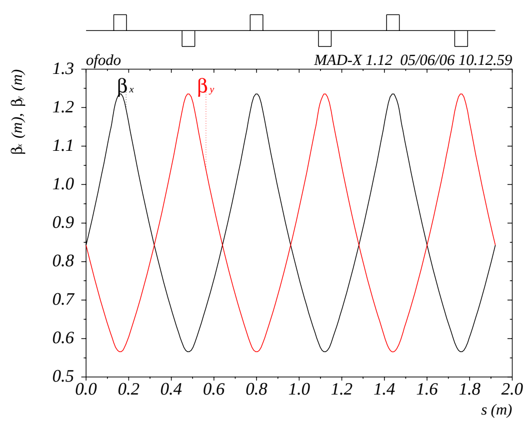

Figure 3: β functions along the tomography section only.

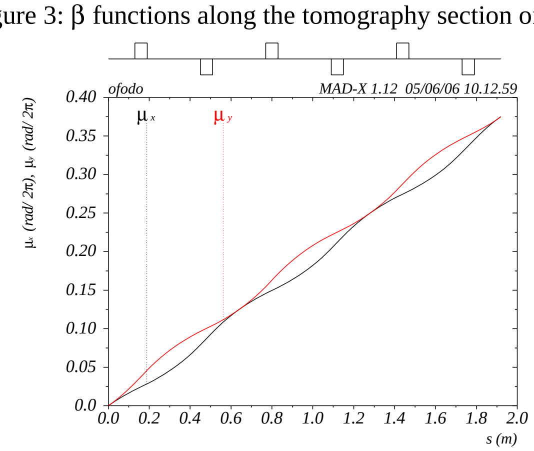

Figure 4: Phase advance in the tomography section only.

It can be seen that the phase advance between FODO cells is 45°, which is correct for a four-screen set-up.

Adjusting the accelerating gradient and the RF phase in the booster and the gun changes the electron energy at the diagnostic section. A smaller gradient leads to less transverse focusing from the RF field and thus the beam properties change. The quadrupole gradients in the matching section prior to the tomography module have to be re-adjusted to match into the FODO lattice. Particle tracking through the injector was performed using ASTRA for several different energies to estimate the beam properties, based on an initial tracking at 32 MeV [3]. The main effect is a scaling of the Twiss parameters with energy, lower energy giving larger β and α values at the end of the injector (at 7.5 m). The results are shown in Fig. 5 and Fig. 6 for the β and α functions respectively. It can be seen that, at low energies the beam rapidly diverges and as a result, it is essential to apply quadrupole focusing to it as soon as possible.

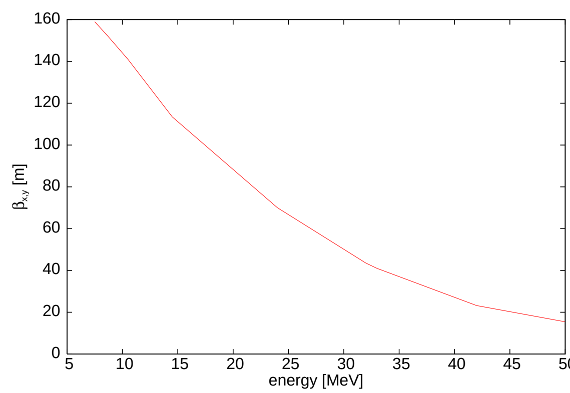

Figure 5: β function estimates at different energies, 7.5 m from the gun.

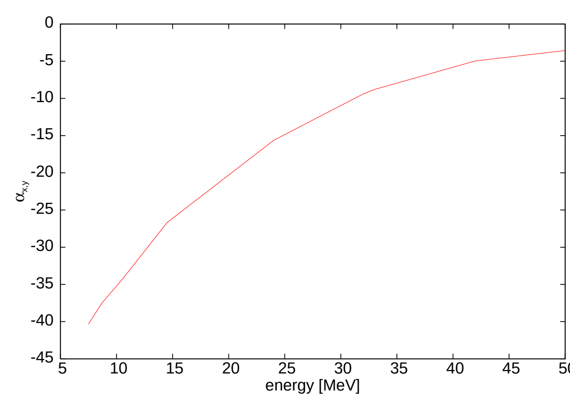

Figure 6: α function estimates at different energies,7.5 m from the gun.

ENERGY SCANNING WITH ASTRA

The low energies involved together with the high bunch charge of 1nC and the relatively short bunch length of 6 ps (RMS) of the PITZ2 diagnostics line mean that space charge could become an issue. The tomography module was tracked with ASTRA, the matching was done with MADX, both with and without space charge over the desired energy range. The results are shown for two extreme cases, one at low energy and the other at high in the figures below. Fig. 7 gives the evolution of beam size for the nominal energy of 32 MeV whereas Fig. 8 shows the same for 14.5 MeV.

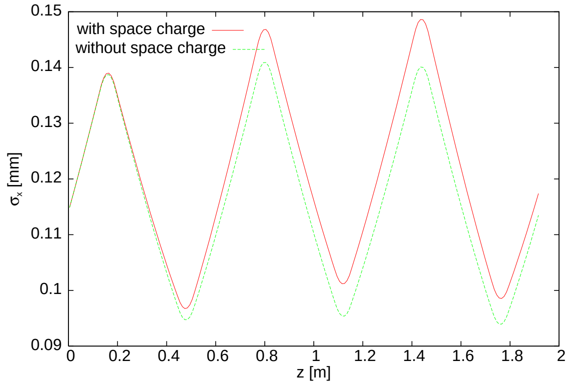

Figure 7: Beam size (x) through the tomography section, with and without space charge, at 32 MeV.

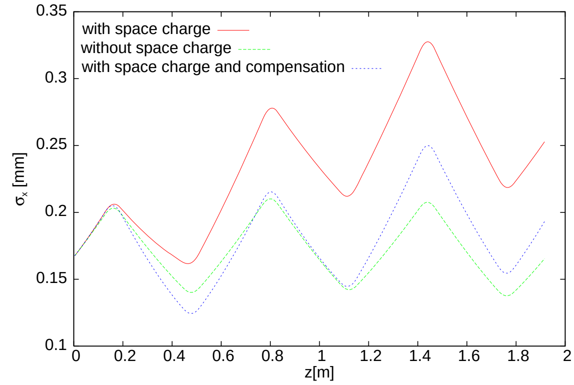

Figure 9: Beam size (x) at 14.5 MeV, with and without space charge and with space charge compensation.

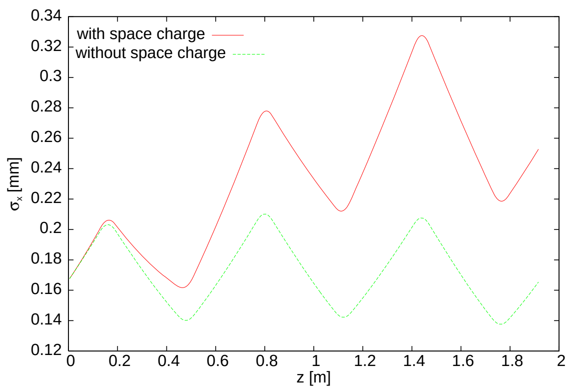

Figure 8: Beam size (x) through the tomography section, with and without space charge, at 14.5 MeV.

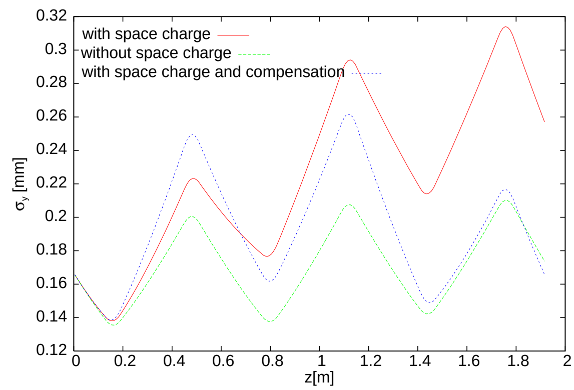

Figure 10: Beam size (y) at 14.5 MeV, with and without space charge and with space charge compensation.

None of the models considered included any kind of previous history of space charge down the injector line because thus far it has not been possible to track the entire line, from gun to tomography module, using ASTRA. Therefore, a Gaussian bunch in all transverse dimensions was used together with a Gaussian energy spread and a uniform bunch length of 8 ps (RMS). The results show that space charge gives rise to a mismatch in the tomography module lattice at low energies.

An attempt at compensating for the mismatch caused by space charge can be done by increasing the overall quadrupole strength in the FODO lattice. This is, of course, not precise as it only takes into account the linear part of space charge. Furthermore, the linear part of space charge is not treated in an adequate way because, though it may be likened to a defocusing quadrupole in both planes, it is unrealistic to expect it to be exactly matched by a series of uni-planar focusing and defocusing elements. However, the results do show an improvement in the way the beam size may be controlled as shown in Fig. 9. for the horizontal plane (x) and in Fig. 10 for the vertical plane (y). This may be of importance at low energies otherwise it is probably better not to try to compensate for space charge but to take the increased beam size into account when making measurements and to compare the results with ASTRA tracking.

NEXT STEPS

After the choice of the deflecting cavity is finalised and further improvements in the design of the magnetic lattice upstream of the tomography module (to increase the operational range of the module towards lower energy) are done, the numerical simulations of the performance of the entire system will be carried out. The design will then be manufactured and installed at PITZ in 2006-07 prior to measurements of the electron beam properties to experimentally confirm the performance of both the diagnostic itself and the PITZ2 gun. In parallel, numerical simulations of the phase-space reconstruction procedure are ongoing [4].

REFERENCES

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