EUROFEL-Report-2007-DS1-062

EUROPEAN FEL Design Study

Deliverable N°:	D 1.12
Deliverable Title:	Wake Potential Calculations For The PITZ Photoinjector / Simulations of optimized photo injectors
Task:	DS-1
Authors:	see next page
Contract N°:	011935

Project funded by the European Community
under the "Structuring the European Research Area" Specific Programme
Research Infrastructures action

Wake Potential Calculations For The PITZ Photoinjector

E. Arévalo, W. Ackermann, E. Gjonaj, W.F.O. Müller, S. Schepp, T. Weiland
Technische Universität Darmstadt, Institut für Theorie Elektromagnetischer Felder (TEMF)
Schlossgartenstr. 8, D-64289 Darmstadt, Germany

Abstract

The driving terms of instabilities in particle accelerators depend on the beam surroundings and can be estimated from the wake potentials along the beam path. In order to calculate these potentials an accurate knowledge of the short range wake fields induced in the different accelerator components with geometrical discontinuities is necessary. The computations of these wake fields is a challenging problem, as an accurate resolution for both the small bunch and the large model geometry are needed. Here we report numerical results of wake potentials on different structures of the RF electron gun of the Photoninjector Test Facility at DESY Zeuthen (PITZ). Details of the specialized code developed for the wake field simulations are mentioned.

Introduction

The X-FEL project requires high quality beams with ultra-short electron bunches. In order to predict the energy spread and emittance growth of such bunches, an accurate knowledge of the short range wake fields is necessary. The effect of the wake fields on the bunch of particles can be estimated by calculating the so called wake potentials [1].

Simulations of wake fields from short bunches of particles in accelerators are difficult to perform, since high computational resolution is required due to the high frequency fields excited by the bunches. So, the abilities of codes such as MAFIA are limited due to the huge amount of memory needed. For that reason, especialized codes have been developed to deal with these large wake field simulations [2].

In the following we present results from wake field simulations with the recent developed code Parallel Beam Cavity Interaction (PBCI) [2]. The PBCI code was designed for massively parallel wake field simulations in arbitrary three-dimensional geometry. The algorithms used include a purely explicit and dispersion free split-operator scheme as well as a domain decomposition approach for highly balanced parallel computations [2]. The Finite Integration Technique (FIT) [3, 4] is used for the spatial discretization of the wake fields. In order to reduce the amount of memory needed, and since the PBCI is a dispersion free code in the longitudinal direction, a moving window technique has been successfully implemented.
In our numerical simulations we calculate the longitudinal wake potentials and by applying the Panofsky-Wenzel Theorem [1] we obtain the transverse wake potentials.
Example: the double cross section of the PITZ injector

For very dilute beams, the direct electromagnetic interaction between particles can be neglected against the steering external fields imposed by the accelerator, implying that a bunch of particles can be represented by a simple distribution of charge density moving with ultra-relativistic velocity. This distribution of charge density in our code is assumed to be Gaussian in both the longitudinal and the transverse directions. We note that wake potentials describe the momentum change of a test charge particle when interacting with the wake fields. This interaction depends on a distance s to the bunch head [1, 5, 2].

In Fig. 2 we present an example of the numerical calculation of the longitudinal (W_z) and transverse (W_x) wake potentials for the diagnostics double cross section of the PITZ injector with the mirror included (Fig. 1). Different Beam paths horizontal shifted some distance Δx from the geometrical center are considered in order to estimate and minimize the effects of the mirror. We observe that the effect of the path shift on W_z is small (Fig.2a: different curves are very close to each other). In contrast, the effect on W_x is important (Fig. 2b: W_x amplitudes are well distinguishable from each other). By calculating either the longitudinal loss factor κ_z (Fig. 3a) or the horizontal kick factor κ_x (Fig. 3b) [1] a minimum at $\Delta x \simeq -8mm$ is found (In Fig. 1 the beam path is plotted for this case). This result suggest that in order to minimize the wake field effect due to the mirror a horizontal shift of the beam path can be considered.

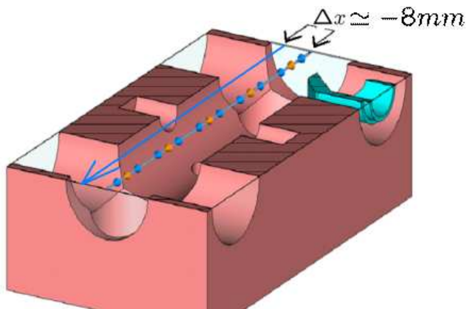

Figure 1: Diagnostics double cross section of the PITZ injector with the mirror. The beam path (blue line) is shifted Δx with respect to geometrical center ($\Delta x = 0$ corresponds to the main axis of the system).

Further simulations have been done for other parts of the photoinjector, e.g. the rounded shield of the valve and the diagnostics double cross section without considering the mirror [5]. It is alto worth mentioning that we have

(a)

(b)

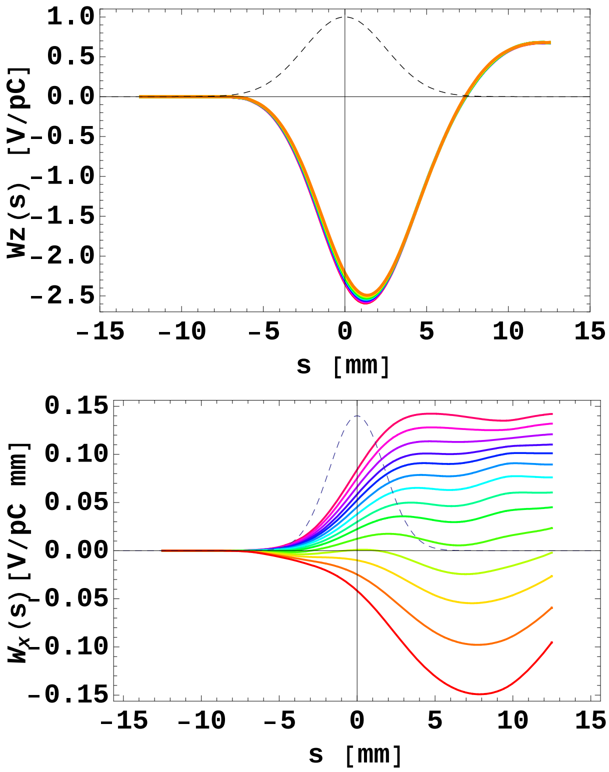

Figure 2: The longitudinal (W_z) and transverse (W_x) wake potentials vs. the distance s for different shifts (curves with different colors) $\Delta x \in$ [-11mm,2mm] (Δx values considered in simulations can be seen in the horizontal axis of Figs. 3). In Fig. (a) the W_z curves are very close to each other. In Fig. (b) bottom-up curves correspond to increasing Δx values starting from the minimum $\Delta x = -11$mm to the maximum $\Delta x = 2$mm. The bunch width in the simulations was 2.5mm.

successfully validate our code [5] against results from the commercial software CST PARTICLE STUDIO™ [6].

Summary and conclusions

We have developed a code which has been succesfully applied in the calculation of wake potentials at different parts of the PITZ photoinjector. We have shown, for example, how a simple transversal shift of the particle path can lead to a minimization of the wake field effects induced by the presence of the mirror at the double cross section. We have succesfully validate our code against available commercial software showing that our results are reliable. Finally, it is worth mentioning that our code is appropriated for large accelerator structures, e.g the PITZ photoinjector, where commercial softwares fail due to the large amount of memory needed. So, possible design and/or operation optimizations can be theoretically studied.

(a)

(b)

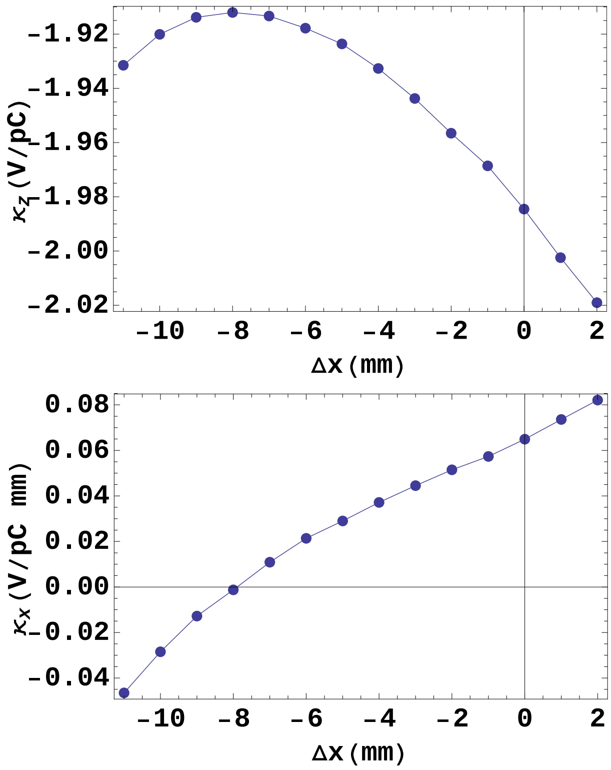

Figure 3: The longitudinal loss factor κ_z (a) and the horizontal kick factor κ_x (b) vs. the shift Δx. The dots in the graphs indicates which values Δx were considered in simulations. The parameters are the same of Fig. 2.

REFERENCES

[1] B. W. Zotter, S. A. Kheifets, " Impedances and Wakes in High Energy Particle Accelerators", World Scientific, Singapore (1998).

[2] E. Gjonaj, X. Dong, R. Hampel, M. Kärkkäinen, T. Lau, W.F.O. Müller, T. Weiland,"Large Scale, Parallel Wake Field Computations for 3D-Accelerator Structures with the PBCI Code" , Proceedings of the 9th International Computational Accelerator Physics Conference (ICAP 2006), p. 29 (2006).

[3] T. Weiland, "Eine Methode zur Lösung der Maxwellschen Gleichungen für sechskomponentige Felder auf diskreter Basis", Electronics and Communication (AEÜ) **31**, 116 (1977).

[4] T. Weiland, "On the Numerical Solution of Maxwell's Equations and Applications in Accelerator Physics" , Particle Accelerators (PAC), **15**, 245 (1984).

[5] E. Arévalo, R. Hampel, W. Ackermann, W.F.O. Müller, T. Weiland, " Wake field computations for the PITZ photoinjector", Proceedings of the 2007 Particle Accelerator Conference (PAC 2007), New Mexico, USA (2007).

[6] CST GmbH. Bad Nauheimer Str. 19, 64289 Darmstadt.