WAKE FIELD COMPUTATIONS FOR THE PITZ PHOTOINJECTOR*

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Abstract

The computation of wake fields excited by ultrashort electrons bunches in accelerator components with geometrical discontinuities is a challenging problem, as an accurate resolution for both the small bunch and the large model geometry are needed. Several computational codes (PBCI, ROCOCO, CST PARTICLE STUDIO™) have been developed to deal with this type of problems. Wake field simulations of the RF electron gun of the Photoninjector Test Facility at DESY Zeuthen (PITZ) are performed with different specialized codes. Here we present a comparison of the wake potentials calculated numerically obtained from the different codes. Several structures of the photoinjector are considered.

INTRODUCTION

The electromagnetic interaction of an intense charged particle beam with its vacuum chamber surroundings in an accelerator plays an important role for the study of beam dynamics and collective beam instabilities [1]. The so-called wake fields generated by particles moving through an accelerator components affect the motion of the following particles in the beam, and may cause the loss of particles, beam energy spread, and instabilities. In order to avoid collective beam instabilities that limit the accelerator performance, an accurate numerical description of the effect of wake fields on the beam is necessary.

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 usually is assumed to be Gaussian not only in the longitudinal direction but also in the transverse ones.

We note also that wake fields from short bunches of particles in accelerators are difficult to calculate numerically since they excite high frequency fields which require high computational resolution. So, for long accelerator structures huge amount of memory is needed in order to perform numerical calculations. This fact limits the abilities of codes such as MAFIA to calculate wake fields in large structures. For that reason, especialized codes have been developed to deal with the calculation of wake fields excited by very short bunches in large accelerator structures. Here we present results from wake field simulations with the recent developed codes Parallel Beam Cavity Interaction (PBCI) [2] and rotated mesh and conformal code (ROCOCO) [3]. In particular we concern with the numerical calculation of longitudinal wake potentials and their comparison with results from the commercial software CST PARTICLE STUDIO™ (CST-PS) [4].

CODES

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 ROCOCO code uses a discretization scheme based in a rotated mesh. This scheme takes advantage of the properties of the well-known leap-frog update scheme for Cartesian mesh, where the directions aligned with the diagonals of the mesh are dispersion-less. So, in the ROCOCO code the bunch direction is aligned with one of the dispersion-less directions of the mesh by rotating the mesh an angle of 45^0. The ROCOCO code in its present stage computes only cylindrically symmetric structures [3].

Due to the no dispersion in the longitudinal direction of both, PBCI and ROCOCO codes, the numerical phase velocity of longitudinal waves match exactly the speed of the light in the vacuum [7]. This property allows the use of numerical windows moving together with the bunch of particles at ultrarelativistic velocity, i.e. velocity equal to the light velocity. The use of this moving window technique enormously reduces the amount of memory needed for computing wake fields.

In the PBCI code the bunch of particles is modeled as a three-dimensional Gaussian distribution, while in the ROCOCO code as well as in the CST-PS software it is one-dimensional along the propagation direction.

In general the framework used here for the spatial discretization of the wake fields is the Finite Integration Technique (FIT) [5, 6].

LONGITUDINAL WAKE POTENTIAL

For particle beams the wake field generated by the geometrical discontinuities of the accelerator walls can be characterized by the so called wake potentials. These potentials describe the momentum change of a test charge particle when interacting with the wake fields. This interaction depends on the distance s to the bunch head. Here, we concern in particular with the longitudinal wake potential

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which reads

$$W_z(s,z) = -\frac{1}{Q}\int_{-\infty}^{z} dz' E_z\left(x,y,z',t=\frac{z'+s}{c}\right), \quad (1)$$

where E_z is the longitudinal wake field component, and z denotes the travelling distance of the bunch within the structure. In Eq. (1) x and y denote the transverse coordinates, and Q is the charge of the bunch of particles. Notice that in Eq. (1) we integrate E_z along the structure's axis. On the other hand, in order to capture the overall effect of the discontinuities on the test charge particle, one has to calculate Eq. (1) with $z \to \infty$. This implies that the numerical calculation has to be performed till the wake fields have relaxed. Usually this relaxation process takes large distances behind the discontinuities to be completed. Therefore, the direct numerical integration of Eq. (1) requires the use of large amount of computational resources. One possibility to overcome this problem consist in stopping the direct numerical integration at some suitable short distance after the discontinuities and then by using the information stored on the other components of the scattered field to compute the contribution of the rest of the path [7]. This technique is called "indirect integration" and it is available in the ROCOCO code and in the CST-PS software. For the present paper this procedure is not used in the PBCI code. Instead, we integrate long enough till the wake fields have relaxed. Notice that in the case of the PBCI code it is not a problem since it uses the moving window technique, as mentioned above.

EXAMPLES

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 induced in the different accelerator components is necessary. In order to compare the different codes considered here, simulation results of the longitudinal wake potential are presented. In particular we consider the wake field contribution of a rounded shield used at PITZ as well as the contribution of the PITZ diagnostics double cross section. The simulations were performed for a electron bunch of 1 nC and Gaussian distribution with a width $\sigma_z = \sigma_x = \sigma_y = 2.5$mm. Notice that in the ROCOCO code and in the CST-PS software $\sigma_x = \sigma_y = 0$ (one-dimensional bunch of particles).

Rounded shield

In Fig. 1 it is shown a valve which is direct connected at the output of the Antenna of the RF electron gun. The valve is separated from the rest of the PITZ structure by two small steps, one at the entrance and other at the output. In order to shield this valve several possibilities have been considered within the PITZ project. Among these it has been studied the geometrical effect of a rounded shield, as shown in Fig. 1. Here the wake potential of this structure has been numerically calculated by using the three codes above mentioned. We note that due to the shielding the system becomes rotationally symmetric, so it can be studied with the ROCOCO code.

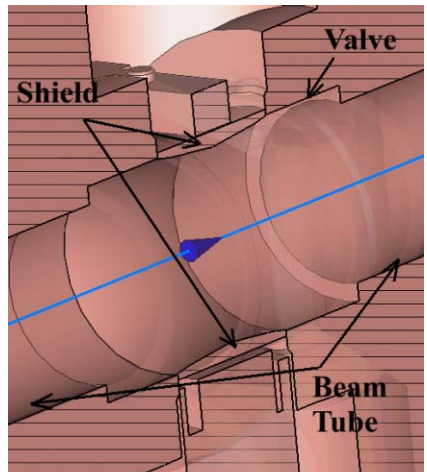

Figure 1: Valve with rounded shield of the PITZ injector. The path of the bunch of particles (blue line) goes along the main axis of the structure.

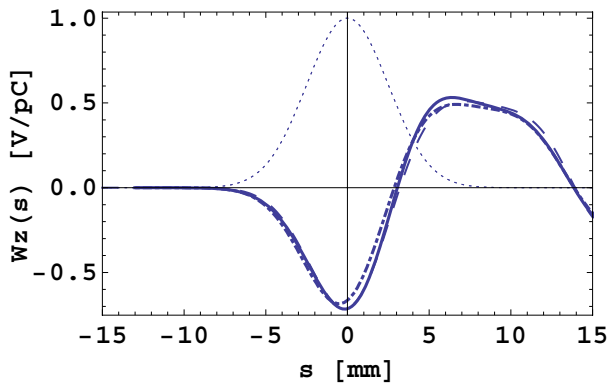

Figure 2: Wake potential of the valve with rounded shield. The longitudinal resolution is 142μm for for the ROCOCO code (dot-dashed line), 166μm for the PBCI code (solid line), and 162μm in average for the CST-PS software (dashed line). The Gaussian bunch is shown for comparison (dotted line).

In Fig. 2 we show results of the wake potential for the valve with the rounded shield. In general a good agreement between the three results is observed. In particular there is an excellent agreement between the PBCI and the CST-PS results for negative and small positive values of the distance s. An small discrepancy is observed for large values of s, which is mainly due to the fact that the wake potential in the PBCI code was calculated up to some finite distance. Notice, as mentioned above, the ROCOCO code as well as the CST-PS software use the indirect integration. An small discrepancy of the ROCOCO result with respect to

the PBCI and CST-PS results is observed . This may be an effect of the rotated mesh used in the ROCOCO code.

PITZ Diagnostics Double Cross Section

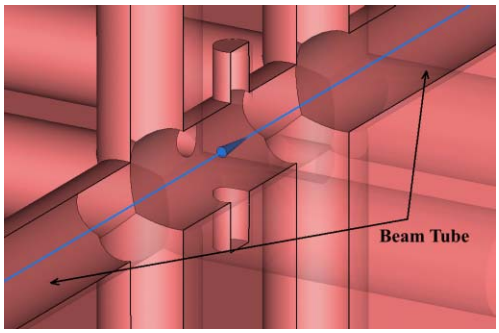

Figure 3: Diagnostics double cross section of the PITZ injector. The path of the bunch of particles (blue line) goes along the main axis of the structure.

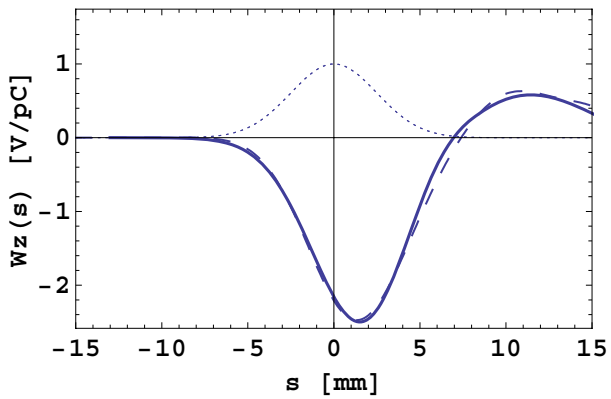

Figure 4: Wake Potential of the Diagnostics double cross section. The longitudinal resolution is 166μm for the PBCI code (solid line), and 154μm in average for the CST-PS software (dashed line). The Gaussian bunch is shown for comparison (dotted line).

In Fig. 3 is shown the PITZ diagnostics double cross section, which is a ten-port structure. This structure is not rotationally symmetric, so the ROCOCO code in its present stage cannot be used here. In Fig 4 we present results only from the PBCI code and the CST-PS software. As in the previous case we observe a very good agreement for negative and small positive values of the distance s. For larger positive values an small discrepancy is observed. Here, it is interesting to notice that apparently there is not mayor effect from the type of bunch considered in the simulations, i.e. three-dimensional in the PBCI code and one-dimensional in the CST-PS software.

It is also worth mentioning that in order to obtain the present results it was needed about 15 million grid points with the PBCI code, while with the CST-PS software we needed about 72 million. This together with the fact that the PBCI is a fully parallelized code makes it suitable for the computation of wake potentials of of large accelerator structures.

CONCLUSIONS

In this paper we have presented numerical calculations of wake potentials using the PBCI and ROCOCO codes. We have compared them with results from the commercial software CST-PS. In general a good agreement between the results of the different codes was observed for the different structures considered here. A small discrepancy observed between the ROCOCO results and the PBCI and CST-PS results may be to the rotate mesh used in the ROCOCO. This is still a point of ongoing investigation. No major differences were observed between results from simulations with one-dimensional bunches (ROCOCO code and CST-PS software) or three-dimensional bunches (PBCI code) for the structures considered here. Finally we point out that the PBCI code needs less grid points to simulate large structures than the CST-PS software, making the former suitable for large structure simulations.

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