FEL PHOTOINJECTOR SIMULATION STUDIES BY COMBINING MAFIA TS2 AND ASTRA*

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Abstract

For the successful FEL operation a high brightness low emittance beam is of crucial importance. For a detailed investigation of the emittance development the simulations should not be restricted to the rf-gun only. That is why the two simulation codes MAFIA TS2 and ASTRA have been combined in order to make use of their individual advantages. The PIC code MAFIA TS2 is used for detailed modelling of the space charge effects inside the rf-gun. By using a data interface the beam dynamics downstreams the rf-gun is simulated by ASTRA which is capable of simulating long accelerator structures efficiently. In this paper we discuss the advantages and limitations of both simulation approaches. Additionally the results of combined simulations using both codes are presented.

1 INTRODUCTION

In this paper the results of detailed beam dynamics simulations for the FEL photoinjector currently being commissioned at DESY Zeuthen [1] combining the PIC code MAFIA TS2 [2] with ASTRA [3] are presented. A low emittance high quality electron beam is generated using a laser driven 1.5 cell rf-gun. To further reduce the achievable transverse emittance a solenoid based compensation scheme is employed [4]. The parameters used for the simulation of the photoinjector are listed in table 1 .

Table 1: Bunch parameters

Bunch charge	1 nC
Bunch radius	1.5 mm
Radial laser profile	Homogeneous
Long. laser profile	Flat-Top, 20 ps FWHM 2 ps rise/fall time
Acc. field at cathode	50 MV/m
Rf frequency	1.3 GHz
Max. solenoid fluxdensity	0.2 T
Location of max. fluxdensity	0.12 m

2 SIMULATION TOOLS

The beam dynamics simulation tool MAFIA TS2 is a 2.5 dimensional PIC code for rotational symmetric problems capable of solving Maxwell‘s equations in the presence of moving charges including space charge and beam induced fields inside the simulated accelerator structure. The electromagnetic fields in the whole geometry are calculated employing a mesh based discretisation scheme. Due to the small electron bunch dimensions a very fine grid has to be used resulting in huge number of mesh points. Because of the high spatial resolution a small integration time step is needed in order to fulfil the stability criterion of the implemented time integration method which also increases the effect of particle induced noise. Therefore this simulation tool can only be applied to a rather small part of the injector efficiently. The three dimensional tracking code ASTRA does not need a geometrical description of the simulated structures, the external fields acting on the beam are introduced with the help of a paraxial approximation. The space charge fields are calculated from the Poisson solution in the rest system of the bunch using a Lorentz transformation. Therefore the interaction between the bunch induced fields and the surrounding structure is not taken into consideration. On the other hand this algorithm is capable of fast simulation of long beam lines allowing efficient parameter optimisation.

3 PARTICLE INTERFACE

It was shown that the main part of the beam emittance arises in the vicinity of the photo cathode where the interaction of the nonlinear beam induced fields with the cavity walls plays a significant role [5]. This effect can only be adequately treated by a self consistent approach as realized in the PIC code MAFIA TS2. A comparison of the transverse emittance development between ASTRA and MAFIA TS2 is shown in fig. 1. In order to combine the advantages

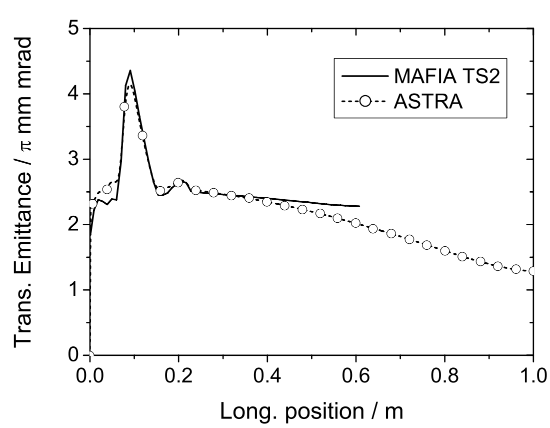

Figure 1: Development of the transverse emittance simulated with MAFIA TS2 and ASTRA starting at the cathode.

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of both simulation tools for the calculation of long beam lines a particle interface between MAFIA TS2 and ASTRA has been developed. This interface is capable of converting MAFIA TS2 particles represented in the $\{r, z, p_r, p_\varphi, p_z\}$ phase space to a six dimensional $\{x, y, z, p_x, p_y, p_z\}$ description needed for ATSRA. In order to avoid the introduction of unphysical effects caused by the conversion process, the conservation of first and second order moments as well as the beam emittances has to be ensured. Therefore a single two dimensional MAFIA particle has to be represented by several ASTRA particles with the same radius in three dimensions. Fig. 2 illustrates the conversion process for a single MAFIA particle.

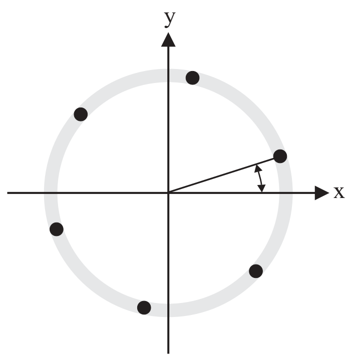

Figure 2: Conversion of a MAFIA particle into several ASTRA particles. The angle θ is chosen randomly.

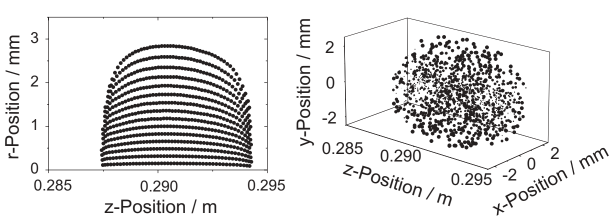

Figure 3: Conversion of a two dimensional MAFIA TS2 bunch into a three dimensional ASTRA particle distribution.

To avoid unwanted correlations the initial azimuthal angle θ is chosen randomly for each MAFIA particle while the angle between single ASTRA particles is kept constant. The complete conversion of a two dimensional MAFIA TS2 located at $z \approx 29$ cm into an ASTRA particle distribution is depicted in fig. 3. By applying this conversion method such important beam parameters as transverse slice emittance and slice energy spread are reproduced precisely in the ASTRA particle distribution as shown in fig. 4.

4 SIMULATION RESULTS

To validate the interface procedure several important beam parameters like bunch sizes and emittances have been calculated by combined simulations. The generation of the ASTRA particle distribution was based on the results of a MAFIA TS2 simulation. In a first approach the phase space information at the end of the rf-gun ($z \approx 29$ cm) was used as the starting distribution for the ASTRA simulation up to z = 1 m. Additionally the results for several intermediate longitudinal starting positions within the range 9 cm $< z < 29$ cm were investigated. Since there was no reasonable difference between the individual simulations, only the results of two starting points, namely z = 9 cm and z = 29 cm, are presented. Fig. 5 shows the results for the longitudinal and transverse beam dimensions which are in perfect agreement. The developments of other important beam parameters like transverse emittance, longitudinal emittance and uncorrelated energy spread are show in fig. 6 - 8. Except for the longitudinal emittance the results of the combined simulations agree very well with the original MAFIA TS2 results. The significant growth of the longitudinal emittance predicted by MAFIA compared to

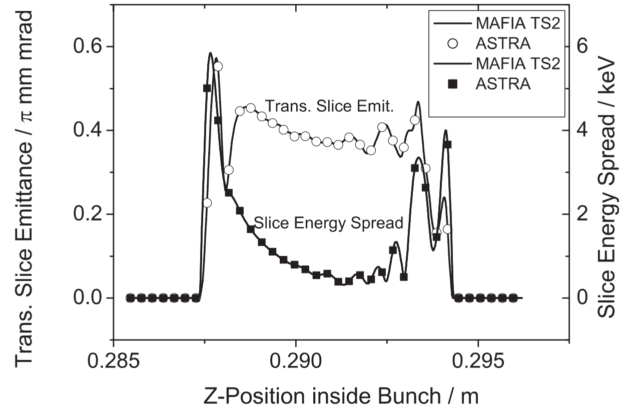

Figure 4: Transverse slice emittance and slice energy spread for a MAFIA TS2 bunch and the corresponding ASTRA particle distribution calculated by the interface at $z \approx 29$ cm.

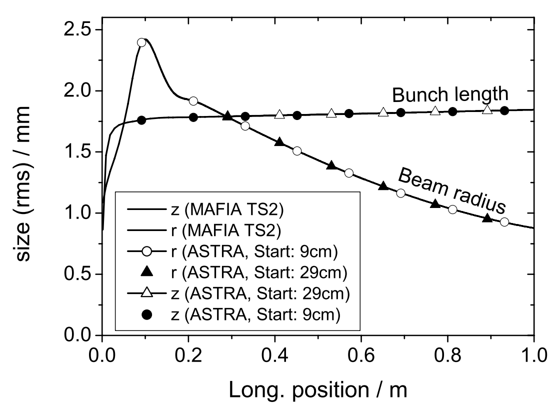

Figure 5: Longitudinal and transverse beam sizes (rms) for two different ASTRA starting points compared to the MAFIA TS2 results.

the ASTRA results can be explained by the growing influence of particle induced noise which has a major impact on the longitudinal phase space while the transverse phase space is only slightly perturbed by this effect (as can be concluded from fig. 6).

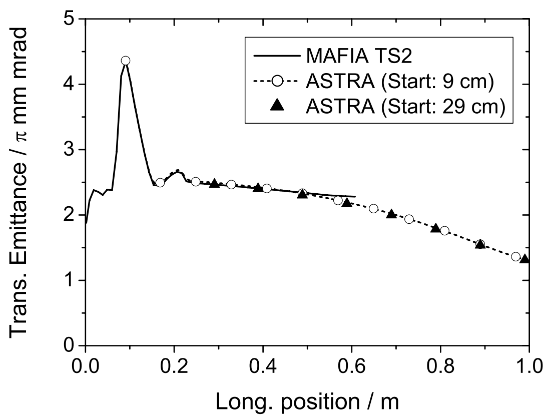

Figure 6: Development of the transverse emittance for two different ASTRA starting points compared to the MAFIA TS2 results.

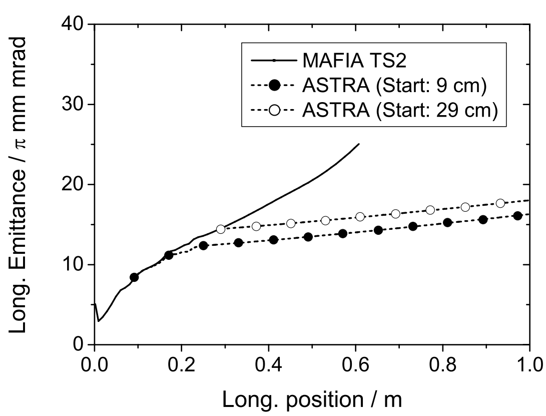

Figure 7: Development of the longitudinal emittance for two different ASTRA starting points compared to the MAFIA TS2 results.

5 CONCLUSION

In this paper the results of beam dynamics simulations by combining MAFIA TS2 with ASTRA with the help of a particle interface were presented. The investigation of the combined simulations concerning the main beam parameters like sizes and emittances yielded very good agreement. By applying this interface it is possible to make use of the advantages of both simulation tools namely the accurate treatment of space charge induced effects in the vicinity of

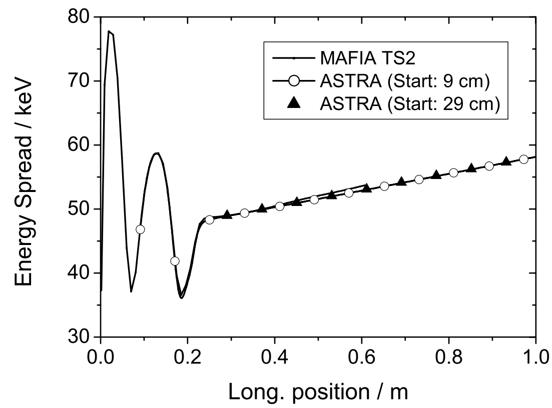

Figure 8: Development of the energy spread for two different ASTRA starting points compared to the MAFIA TS2 results.

the cathode (PIC code MAFIA TS2) with the long beam line simulation capability of ASTRA which makes such a combination useful for accurate and efficient machine optimisation.

6 REFERENCES

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