SIMULATION OF SYNCHROTRON RADIATION AT THE FIRST BUNCH COMPRESSOR OF FLASH*

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Abstract

One method to measure the bunch shape at the free electron laser at DESY Hamburg (FLASH) is to use the synchrotron radiation (SR) emitted from charged particles traveling through the first bunch compressor. For the numerical simulation of the generated high frequency synchrotron radiation the uniform theory of diffraction (UTD) is employed. In this paper a new promising comparison of measured and simulated fields is shown. Furthermore, the applicability and limitations of the method are discussed.

INTRODUCTION

At the first bunch compressor of FLASH, as illustrated in Figure 1, the measured spectrum of the generated coherent far infrared synchrotron radiation is used to reconstruct information about the actual bunch shape [1, 2, 3]. For the correct interpretation of the results it is however necessary to know how several aspects of the real setup influence the measured spectrum. The effects of the horizontal chamber walls are for example not included in the theoretical considerations.

For this purpose it is desired to investigate such effects by means of numerical simulations. Since the wavelengths under consideration (10mm . . . 10μm) are very small compared to the size of the vacuum chamber ($\approx$ 2m), well known discretizing methods like the finite integration technique (FIT), finite element methods (FEM), etc. cannot be effectively used. Therefor the uniform theory of diffraction (UTD) is employed for this task [4, 5]. The UTD is a geometrical optics based method that also takes diffraction effects into account.

COMPARISON WITH NEW MEASUREMENTS

The radiation emitted from the vacuum chamber has been measured at DESY for several frequencies and is compared to simulation results in Figure 2 and 3. The radiation intensity is measured with the help of a pyroelectric detector and several optical filters in a 2D scan transversal to the emission direction. As can be seen from the plots the intensity patterns are in a very good agreement.

In contrast to previous measurements [5] the new measurements are performed at a larger distance of 220mm in front of the chamber window and with a higher spacial sampling. Additionally, the metal parts around the chamber exit and detector have been covered with an radiation absorbing material to suppress multiple reflections between the detector and chamber exit.

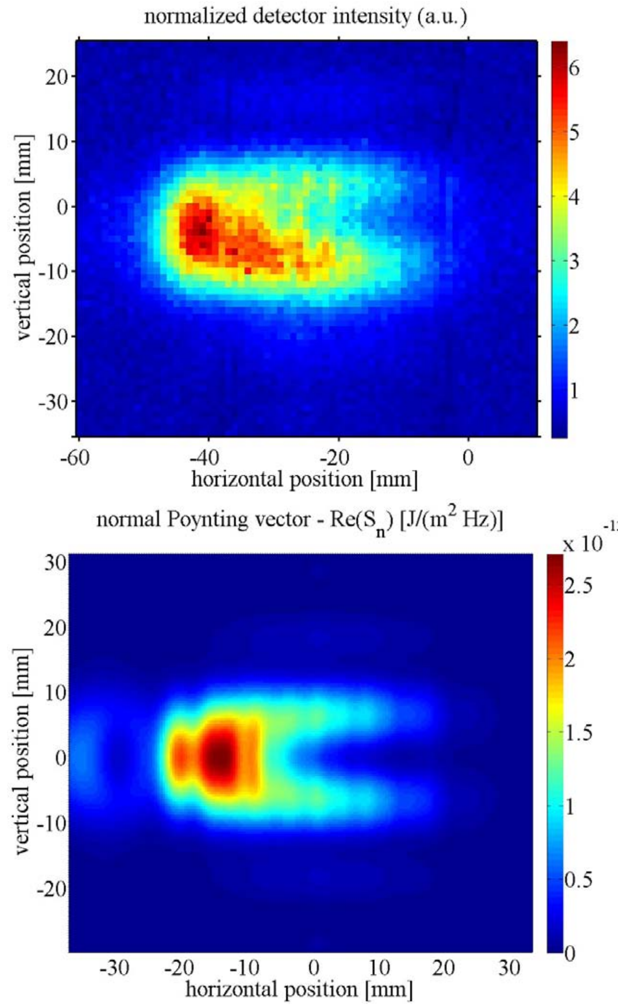

Figure 2: Comparison of measurement (top) and simulation (bottom) for the synchrotron radiation intensity at a distance of 220mm in front of the waveguide exit as seen from inside the vacuum chamber at $\lambda = 350\mu$m.

The simulation procedure is basically the same as described in [5]. First the generation and propagation of the fields inside the vacuum chamber are calculated by the UTD. In a second step the propagation of the fields from the chamber exit to the detector is calculated by Fourier

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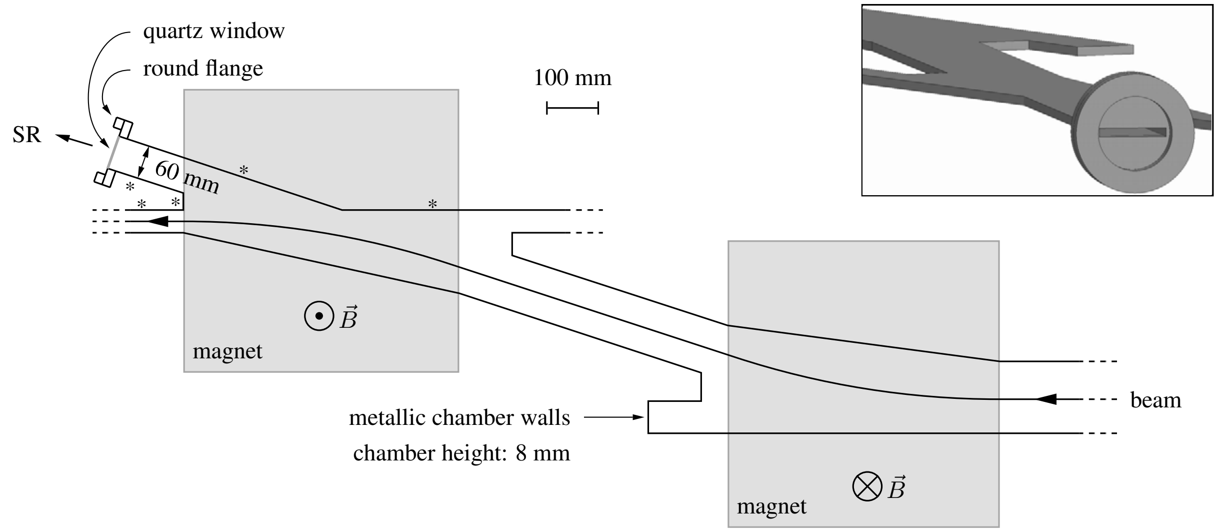

Figure 1: Top view of the beam path and the vacuum chamber it is passing through. The radiation leaving the quartz window is guided through an optical beam line to the diagnostic equipment. The symbol * indicates chamber walls which have been taken into account in the simulation. In the upper right a 3D model of the chamber, looking at the quartz window, is shown.

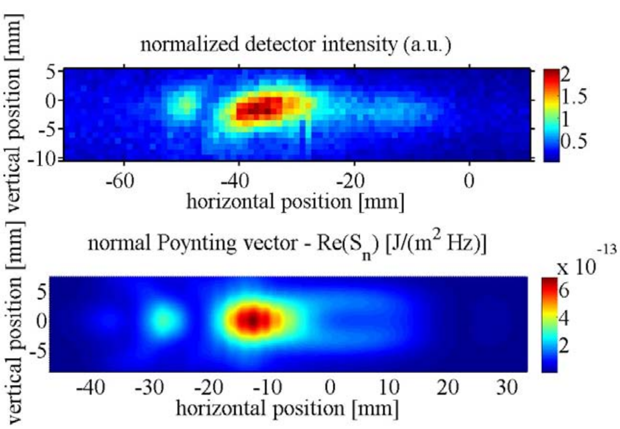

Figure 3: Comparison of measurement (top) and simulation (bottom) at $\lambda = 155\mu$m.

optical methods.

For a better comparison to the measurements results, the simulation results have now additionally been spatially filtered by an averaging over an circular area of 6mm diameter. This way finer details as can be seen in the unfiltered simulation results in Figure 4, but not resolved by the measurements, are smoothed out.

The filtering is motivated by two reasons. On one hand the pyroelectric detector only has a limited resolution caused by the sensor size of $5\text{mm} \times 5\text{mm}$. On the other hand the optical bandpass filters used in the measurement setup have a finite bandwidth whereas the simulations here have only been carried out for the nominal frequency. It has been observed during investigations, that for slight changes in frequency the fundamental intensity distribution remains rather unchanged but the interference pattern shifts slightly. So when the filter integrates over a small frequency band, the interference patterns are smeared and the effect is roughly the same as of the spacial filtering.

Two more simplifications which have already been used in the previous simulations [5] have to be mentioned. First only a point charge is considered. Transversal bunch size effects are assumed to be negligible and longitudinal effects are considered by the bunch form factor [3]. Secondly, only the walls marked with * in Figure 1 are considered in the simulation. Taking all the walls into consideration is numerically very expensive, and will be investigated in more detail in the future.

APPLICABILITY OF UTD TO SR CALCULATION

Long Wavelength Limit

As can be seen from the measurements presented in the previous section, the simulation method gives good results for two sample wavelengths of 350μm and 155μm. Together with the fact, that the UTD is a asymptotic method - it becomes more accurate with increasing frequency - it can be expected that the simulation gives good results for medium and even smaller wavelengths.

However, the method intrinsically becomes more inaccurate for longer wavelengths and the question arises whether it is accurate enough to reachthe lower bound of $\lambda = 10$mm.

Since measurement results are unavailable near the lower bound, for the verification of the UTD other numerical methods have to be employed. The problem, however, is, that even for $\lambda = 10$mm the structure is still electri-

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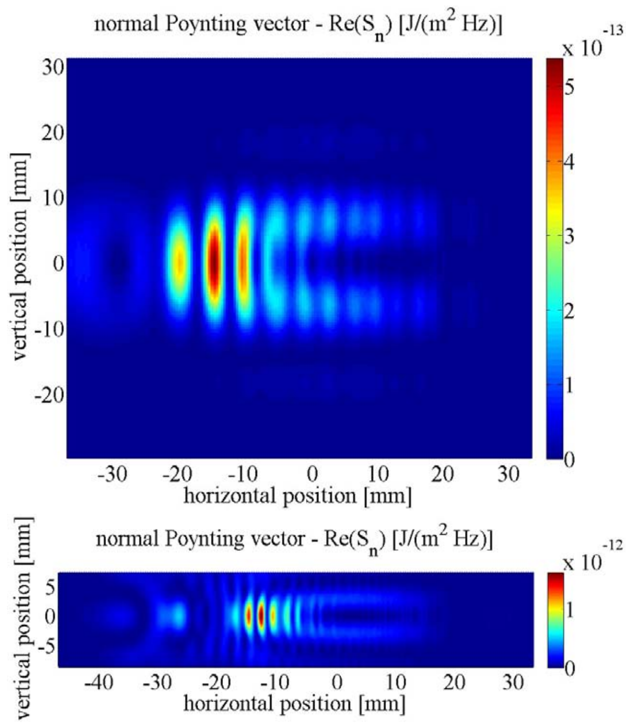

Figure 4: Unfiltered simulation results for the reference frequencies $\lambda = 350\mu$m (top) and 155μm (bottom).

cally very large. For discretizing methods this results in a huge amount of unknowns, quickly reaching current computational limits. Additionally for methods like FIT it is known, that for this kind of problems the dispersion error makes getting accurate results very difficult.

However, from investigations one can conclude, that for the method presented in [5] - from now on called DP-UTD since it uses dipole sources - gives inaccurate results for $\lambda = 10$mm and so it seems that the UTD fails for this long wavelengths. Further investigations though have shown, that it is not the method itself, but rather the special synchrotron radiation setup - the particle beam acts like a huge 2m long antenna - which causes problems to the UTD. Another UTD-formulation, from now on called PW-UTD, that uses a plane wave representation of the synchrotron radiation fields shows, that the UTD is able to give good results for the SR problem at $\lambda = 10$mm.

The drawbacks of the PW-UTD is, however, that it is impossible to include also the walls not marked by * in Figure 1 into the simulation. Also, the computational cost is increasing rapidly with frequency and several more parameters are introduced that have to be chosen carefully to give correct results.

Interesting in this context is the question from which frequency the PW-UTD simulation gives correct results. Preliminary investigations suggest, that the accuracy limit for practical purposes is in the range between $\lambda = 10$mm and $\lambda = 5$mm for the problem at hand. A more precise answer will be obtained in the future.

Challenges of Application

Besides the problems for long wavelength, there are also some other challenges that have to be faced when using UTD for synchrotron radiation computations.

The most challenging one is the big number of parameters that have to be chosen correctly to get good and fast results. These parameters include for the DP-UTD e.g. the number of horizontal and vertical reflections (strongly depending on the wavelength and making the computation very slow for long wavelengths), the discretization of the source and monitor points (more points means better accuracy but longer computations), source path length (computation time), or choosing which reflections and diffractions to include (the number of possible combination increases exponentially). For the PW-UTD there are even more parameters that have to be chosen carefully.

Besides this challenges special attention has to be payed to a correct modeling of the SR sources including source end effects. Furthermore, it has been observed that although in large distances the effect of near field terms (Coulomb terms) are negligible, in the area of the vacuum chamber they have to be taken into account and make the application of the UTD challenging.

CONCLUSION

It has been shown that it is possible to use the uniform theory of diffraction (UTD) for special synchrotron radiation computations inside the first bunch compressor vacuum chamber of FLASH with the idea of including the effects of the horizontal chamber walls.

However the application is not straightforward and attention has to be paid to many details. Also there are still some open questions, that hopefully will be answered in the near future.

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