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ESTIMATION OF THE WAKEFIELD RESONANT FREQUENCY USING DIFFERENT SIMULATION TOOLS *

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Abstract

Reliable and fast wakefield calculations are important for beam dynamics and THz generation in accelerators. We compare approaches and limitations with different available simulation tools and compare results. As an example, we analyse a cylindrical corrugated waveguide with narrower and wider radii of 5 and 6 mm, and aperture width and periodicity of 1 and 2 mm using ABCI by KEK and ANSYS HFSS simulation software. First, ABCI was used to determine the resonant frequency of the cylindrical corrugated waveguide with different lengths. The corresponding results were taken as a reference to examine the simulation method in the ANSYS HFSS environment. The eigenmode solver of ANSYS HFSS was used to determine different resonant frequencies. This was followed by examining a cylindrical corrugated waveguide that was implemented having a length of 17 mm for different conductor settings. The corresponding waveguide was fed by a plane wave having a resonant frequency that satisfies the intersection of the light line and dispersion curve of the corresponding mode. The analysis showed that the maximum loss factor was achieved at 39.20 and 40.07 GHz using ANSYS HFSS simulation data for different conductors, whereas ABCI resulted in 38.50 GHz. The talk will present the results gathered by different simulation setups implemented in ANSYS HFSS.

INTRODUCTION

Terahertz technology has become increasingly important for accelerators, charged particle beam manipulation and the measurement of relativistic electron beam properties. Terahertz structures can be operated at much higher gradients than conventional RF accelerating structures, reaching GeV/m, and they are well-matched to operating with extremely short bunches, and can be built in compact size [1]. Likewise, extremely short bunches generate wakefields at THz frequencies, which can either be disruptive to the beam propagation if not taken into proper consideration or can be exploited as a powerful diagnostic tool for measuring the longitudinal distribution of the ultrashort bunches [2].

The dimensions of the accelerating structures scale with wavelength, so that in many cases the structures resemble corrugated waveguides. We seek new computational tools to analyse the properties and performance of these structures.

When comparing different numerical tools, we take the generalized case of a corrugated cylindrical waveguide with a standard set of dimensions. The solutions are complex as the waveguide can be excited by a large number of waveguide modes over a range of frequencies limited only by the cutoff frequencies of the pipe. These modes may have both longitudinal and transverse field components that can interact with the beam.

A powerful tool exists in the ABCI program [3] for calculating the wakefields excited by an electron bunch in a cylindrical waveguide. Since we are also interested in rectangular and parallel plate structures, we have also investigated 3D numerical software such as ANSYS HFSS.

However, HFSS calculates the electromagnetic field propagation in waveguides and does not implicitly include the field from a relativistic bunch. Nonetheless, the resonant eigenmodes calculated by HFSS can all be excited by the relativistic bunch. The challenge investigated in this paper is to identify which eigenmodes can interact with the electron bunch and are therefore generated as wakefields in the structure. The electron bunch will couple its energy into those waveguide modes with the greatest loss factor. Secondly, the field will only couple to the bunch if the phase velocity of the waveguide mode satisfies the v=c condition.

We also take the opportunity to examine the influence of different material properties on the numerical calculations, such as the conductivity and the surface roughness of the waveguide.

METHOLOGY AND RESULTS

A 2-dimensional wakefield simulation software, ABCI [3], was used to figure out the resonant frequency of the strongest wakefield of a corrugated cylindrical waveguide. The structure of the waveguide was selected to have a narrower and wider radii of 5 and 6 mm, respectively. The period and aperture width of the corrugations were set as 2 and 1 mm, respectively. The waveguide was analysed for different lengths in ABCI environment. The resonant frequency of the wakefield was determined to be 38.50 GHz by using ABCI. By taking ABCI solution as reference, the same waveguide was examined in commercially available ANSYS HFSS environment using a similar methodology to one that is presented in [4]. The simulations were done for perfect electric conductor (PEC) and a finite conductivity boundary with Huray model surface rough model [5]. First, ANSYS HFSS eigenmode solver was utilized to determine the possible resonant frequencies of wakefields that can be generated by a travelling electron bunch. A single period of the corrugated waveguide was implemented to collect dispersion curves of both PEC- and Huray surface roughness model-implemented waveguides. The dispersion curves of both PEC and Huray surface roughness model cases are given in Fig. 1. The eigenmode solver was set to solve the first twenty modes. The results show that both eigenmode solver simulations setups result in very close dispersion curves. Hence, the intersections of the

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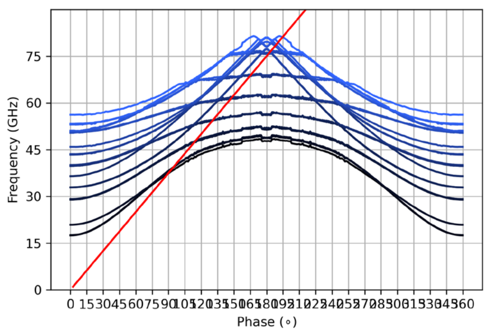
light line with dispersion curves collected from different simulations are very close to each other, whereas the intersections did not occur at exactly the same frequencies.

Following the eigenmode solver analysis, the waveguides with PEC and Huray surface roughness model were implemented for Modal analysis. The analysis was based on utilization of a plane wave as an incident wave as the source that illuminated the waveguide. The resonant frequencies of the incident waves were set as the intersection



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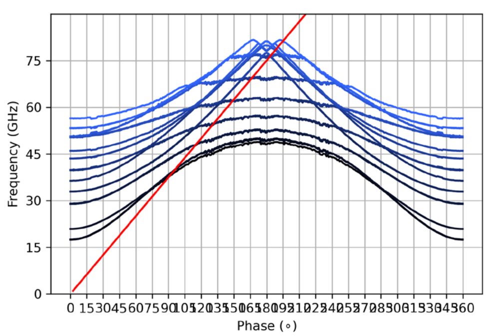

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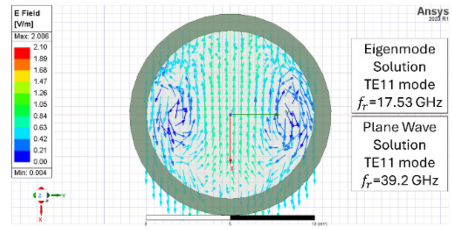
Figure 1: The dispersion curve-light line intersections of a single period of the corrugated cylindrical waveguide implemented by PEC and Huray surface roughness model (a and b). Red curve represents the light line, and the other curves are the dispersion curves of different modes that were calculated by the eigenmode solver.

frequencies that were calculated using eigenmode solver results. The electric field distributions were examined for all forty different simulation scenarios, that were set by material properties and the resulting light line-dispersion curve intersections. The fields distributions that emerged at the frequencies which gave the largest loss factors for both material assignments are given in Fig. 2. The field distributions show a good agreement with early reports presented for dielectric coated waveguides, that support hybrid mode (HEM_{11}) excitation [6]. Because corrugations create an effect similar to the one introduced by the dielectric coating, whereas TM01 mode can be expected to emerge in the case of largest loss factor. While the detail of the parameters that were used to calculate the loss factors for both PEC and Huray surface roughness model cases will be presented in the conference, the calculations led to



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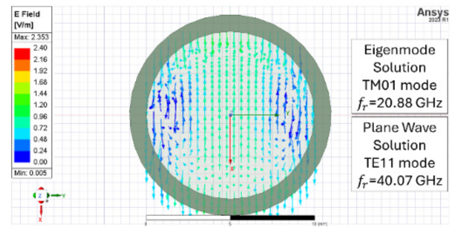

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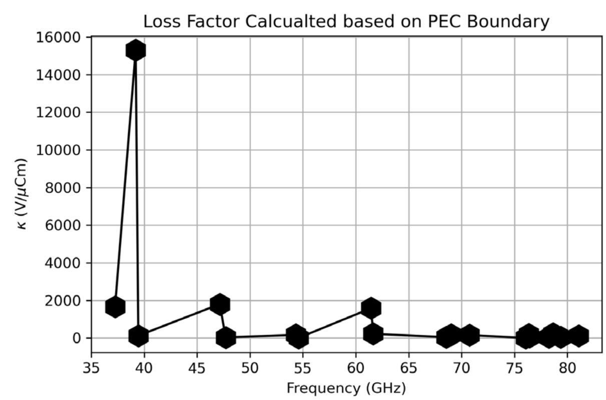
Figure 2: The electric field distributions in cases of PEC and Huray surface roughness model (a and b).



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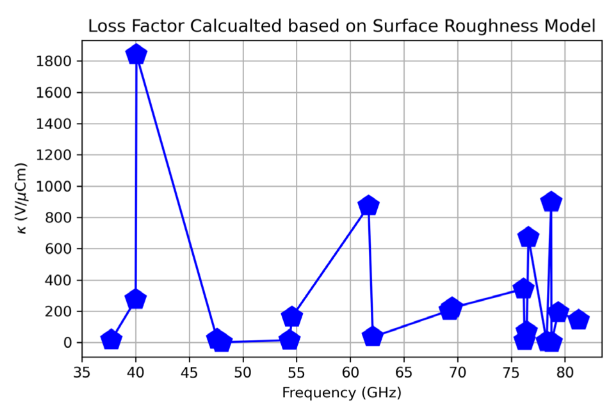

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Figure 3: The loss factors that were calculated using the data collected from PEC and Huray model surface roughness model settings (a and b).

the following loss factors at different frequencies at which the light line intersected the dispersions curves of different modes that were calculated by the eigenmode solver. The corresponding calculations are presented in Fig. 3. The

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results show that PEC and Huray surface roughness model result in loss factors with order of magnitude difference. Nevertheless, the general distribution of the loss factors shows a relatively similar behaviour. While these loss factors were not examined using experiments, the simulation settings led to determination of the frequency at which the largest loss factor might be seen and showed a good agreement with the solution of ABCI.

CONCLUSION

A methodology to determine the loss factors at different frequencies was presented. The results show that ANSYS HFSS can allow a designer to determine different frequencies at which possible strong wakefields may emerge. The analyses were based on different material settings. Consequently, the different material settings led to an order of magnitude difference in the largest loss factors. But the difference is not limited to the scale of the largest loss factor, but the relative loss factors at the other frequencies compared to the largest loss factors showed significant scale differences. This creates a strong motivation for realization of the waveguides to examine the effects of a real conductor under real measurement conditions.

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