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RESONANT EXCITATION OF ACCELERATING FIELD IN DIELECTRIC CORRUGATED WAVEGUIDE

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Abstract

Beam driven dielectric wakefield accelerators (DWAs) [1] typically operate in the terahertz frequency range, which pushes the plasma breakdown threshold for surface electric fields into the multi GV/m range. DWA technique allows to accommodate a significant amount of charge per bunch, and opens access to conventional fabrication techniques for the accelerating structures. Resonant excitation of coherent Cerenkov radiation in DWA by a multi-bunch beam was used for selective resonant mode excitation [2] and enhancement of accelerating wakefield [3]. We investigate the resonant excitation of Cerenkov Smith-Purcell radiation [4] in a corrugated cylindrical waveguide by a multi-bunch electron beam. The accelerating field is calculated using Particle in Cell simulations and some basic post-processing is done in order to estimate the possible enhancement of the accelerating field. The aim of this work is to investigate regimes of the resonant excitation that can potentially produce accelerating gradients above 1 GV/m.

INTRODUCTION

Dielectrics are an attractive medium for future accelerators: they can sustain much higher field intensities than conventionally used high conductivity metals, thus opening a door to high gradient acceleration. One possible avenue to creating high accelerating fields in dielectrics is to use so-called drive (or driver) bunches then followed by a witness (or probe) beam, that is then accelerated. With single-bunch drive beams co-linear with the witness bunch, one faces a problem of low transformer ratio: the maximum field created by the drive bunch is limited to twice the self-field. It seems that one way of dealing with this problem is to use tailored charge distributions within driver bunches [5]. Another way is to use multiple bunches for excitation, adding their fields resonantly. In this paper we consider some simulations of resonant excitation in flat and corrugated capillaries with the view of detailed future theoretical and experimental studies.

STRUCTURES

Figure 1 shows the structures considered in our simulations. Both structures are axially symmetric, with a vacuum channel for the beam to pass surrounded by a dielectric pipe, in turn enclosed in a copper pipe, which defines the boundary conditions on the outside of the dielectric layer and provides mechanical stability. The dielectric pipe is composed of discs intended for easy manufacturing, and so provides flexibility in trying various structures within the same setup. Both considered structures are 60 mm long, one is corrugated and the other flat with an internal radius r_1 = 2 mm. The corrugation period d has been increased compared to 1 mm reported in [6] to 5 mm to match to the strongest 50 GHz component of the accelerating field that had been observed in the experimental data and simulations. The corrugation radius r_2 has been kept at 2.2 mm. The drive bunch length assumed in simulation is 300 μm RMS, and the bunch charge corresponds to that availavle in LUCX facility (KEK, Japan), where previous experiment had taken place. All simulated results were produced in CST Particle Studio.

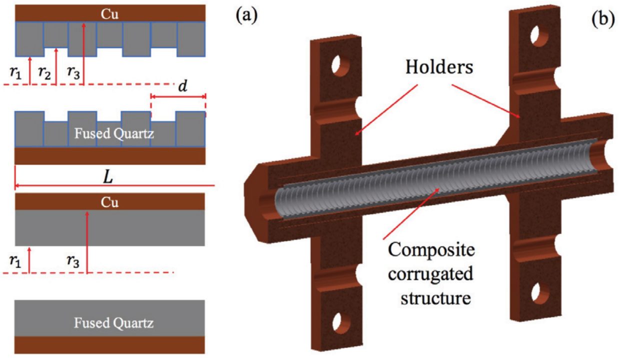

Figure 1: Corrugated and flat capillary geometry: a) in a cross-section along the axis b) in a realistic structure formed of discs in a cylindrical metal holder.

SIMULATIONS

Simulations were done using a PIC code (although in this case a number of techniques are available), the drive beam travelled along the axis of the structure generating a wakefield. Figure 2 shows the longitudinal (accelerating or decelerating) field in a 2D slice of the structure along the axis, the beam propagates from right to left.. One can clearly see several oscillations of the field following the drive bunch in both cases. Figure 3 shows the intensity of the longitudinal component of the field on axis. The location of the beam within the structure is indicated by the initial transient, followed by several oscillations between accelerating and decelerating phases. Hence, the structure

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acts as a relatively narrowband filter. The wavelength is shortened in case of the corrugated structure, which is also reflected in the spectra, Fig. 4. This may, however, be a simple consequence of its dielectric layer being thinner on average. There is also a hint of a sub-harmonic oscillation in case of the corrugated structure, also observed as a hump in the lower part of the spectrum. What's important for our investigation is that about 6 oscillations are clearly present in both cases, hence a resonant excitation can be tried.

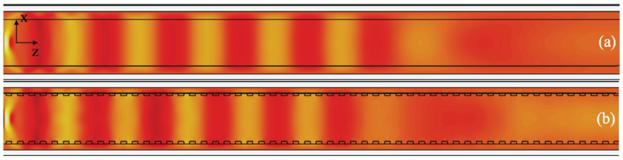

Figure 2: Longitudinal electric field in the wake of the drive bunch for the a) flat and b) corrugated structures as seen in PIC simulations. The beam travels from right to left.

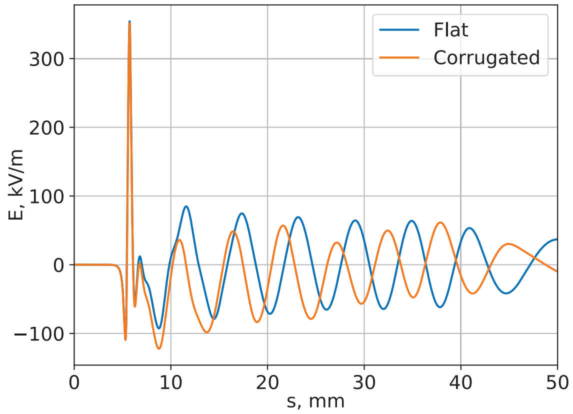

Figure 3: Longitudinal electric field in the wake of the drive bunch for the flat and corrugated structures.

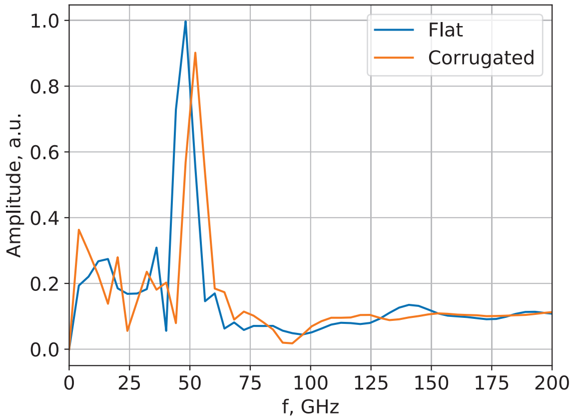

Figure 4: Field spectra.

Further simulations were done for two drive bunches with a varying bunch separation in a flat structure, Fig. 5. As expected, in case the second bunch falls into the accelerating part of the cycle, the resulting field is damped due to the beam loading. In case it arrives at a zero crossing, there is a small gain in amplitude, but the phase of the resulting oscillation it turned by about 45°. Finally, the amplitude of the oscillation is almost doubled in case of the decelerating phase. These results are a consequence of the two excitations adding essentially as harmonic phasors thanks to the narrowband nature of the produced oscillations. Another observation here is that in a real case of beam loading by the witness beam the drive and witness beams may be interleaved, in another words, additional top-up drive bunches can be used within one train, and the distance between the drive bunches can be adjusted to keep them contributing to the net accelerating field. This way, the efficiency of the structure may be increased. Both structures behave similarly when excited with two bunches bar the presence of the sub-harmonic in the corrugated structure, Fig. 6.

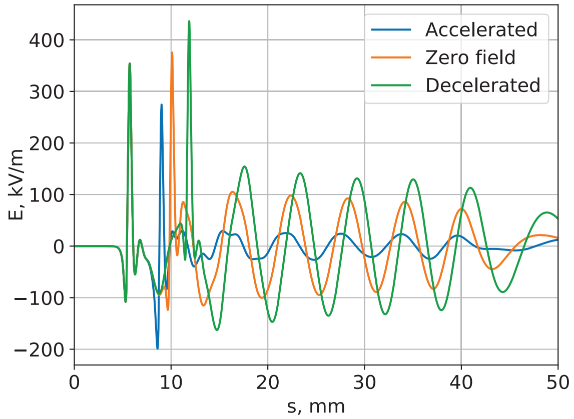

Figure 5: Longitudinal electric field in case of two drive bunches in different phase relations for the flat structure.

With the assumption of the dielectric still working in the linear regime, which is true for our simulated data, one can extend the results to include more bunches by a simple addition. This had been done using the 2-bunch data, which was shifted in time and added to itself 4 times to simulate 10 bunches. The resulting field intensity is shown in Fig. 7. There is clearly a further increase in the amplitude of the accelerating field, which continues for at least the first 6 bunches, and gives at least a 4-fold increase in the field amplitude. With further excitation, the increase seems to settle down, although the figure suggests that some optimisation in the bunch arrival time may be possible. It should be noted, that the simulations so far don't include dielectric losses, which will diminish the increase, but at the short time scale of only a few oscillations the effect is not expected to be significant.

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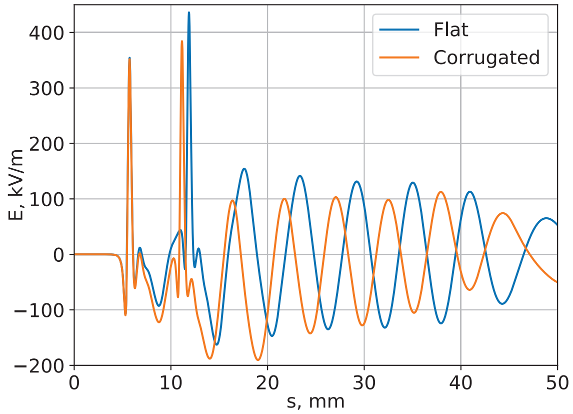

Figure 6: Longitudinal electric field in case of two drive bunches, second bunch in the decelerating phase for the flat and corrugated structures.

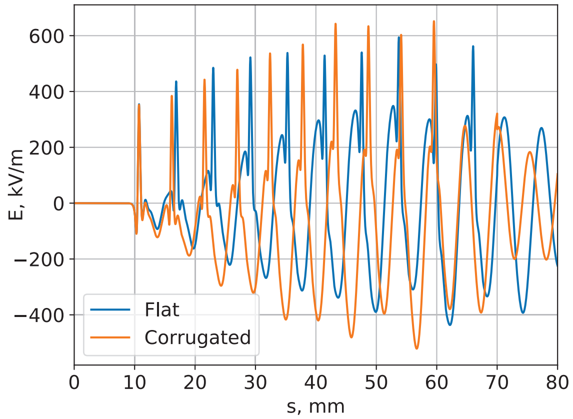

Figure 7: Flat vs corrugated structure when excited with 10 consecutive drive bunches.

DISCUSSION AND OUTOOK

One could argue that the nature of this paper is rather inspirational. Still, this naive exercise gives us an important result for future studies: both flat and corrugated structures can be excited resonantly. An analytical or at least semi-analytical model is desperately needed in order to optimise the corrugated structure and guide the numerical simulations. Dielectric losses must be included in order to understand their effect on the amplitude and phase of the combined excitation. On the experimental front, there is a challenge of producing multiple drive bunches. At LUCX this can already be done with the current splitting system for up to 4 bunches, however, the level of control required for the witness bunch separation, limits the applicability of this system as the laser pulses are controlled in pairs. There is an option of using two different lasers for generating the drive and witness bunches. This could aid increasing the drive bunch charge too. At the same time, the sufficiently powerful laser systems currently available at LUCX would struggle producing short drive bunches, and synchronisation of two separate laser systems to the level required for ensuring a stable bunch distance in the order of a mm is challenging. One possibility is to probe the field within the structure directly, in another words, avoid operating with the witness bunch in the meantime, which could be the near-term aim of our experimental programme.

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