ELECTRON BEAM EXCITATION OF A SURFACE WAVE IN MM-WAVE OPEN ACCELERATING STRUCTURES*

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Abstract

As part of research on the physics of rf breakdowns we performed experiments with high gradient traveling-wave mm-wave accelerating structures. The accelerating structures are open, composed of two identical halves separated by an adjustable gap. The electromagnetic fields are excited by an ultra-relativistic electron beam. We observed that a confined travelling-wave mode exists in half of the accelerating structure. The experiments were conducted at FACET facility at SLAC National Accelerator Laboratory. Depending on the gap width, the accelerating structure had beam-synchronous frequencies that vary from 90 to 140 GHz. When we opened the gap by more than half wavelength the synchronous wave remains trapped. Its behavior is consistent with the so called "surface wave". We characterized this beam-wave interaction by several methods: measurement of the radiated rf energy with the pyrodetector, measurement of the spectrum with an interferometer, measurement of the beam deflection by using the beam position monitors and profile monitor.

INTRODUCTION

We studied physics of rf breakdown in open mm-wave accelerating structures [1]. The picture of one side of the accelerating structure is shown in Fig. 1 The fields were excited by an ultra-relativistic electron beam. We changed the interaction with the beam by changing the gap width. By opening the gap, the number of trapped modes is reduced. When the gap is opened beyond half wavelength the synchronous wave remains trapped. With larger gaps the parameters of the wave such as frequency and group velocity are less dependent on gap width. By increasing the gap, the rf power is guided by the corrugations with no radiation, behavior consistent with the so called "surface wave".

Surface waves were studied for applications to communications by [2], showing that guided waves do not necessesarly need to be confined within physical boundaries. G.Goubau [3, 4, 5] presented single conductor surface wave transmission lines. W. Rotman studied a single surface corrugated waveguide [6]. A review of surface waves is presented by G. John [7]. H. M. Barlow [8] discussed the different forms of surface waves, behavior and applications. This effect was also studied by Smith-Purcell [9] and used to make high power Terahertz sources [10]. In this paper we present experimental results of interactions of surface wave with an ultra-relativistic electron beam.

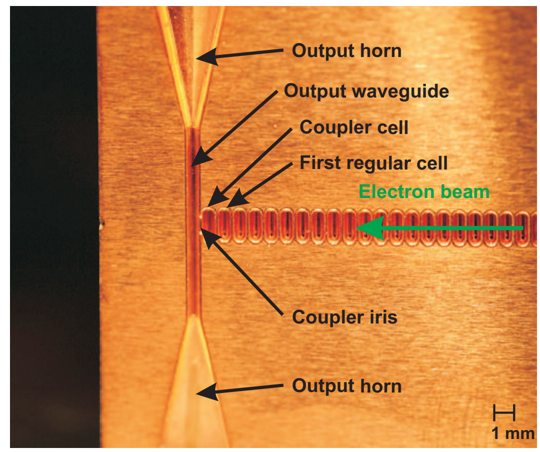

Figure 1: Picture of the output part of one half of the mm-wave accelerating structure, including coupler, output waveguides and horns.

SIMULATION OF SURFACE WAVE

We calculated the parameters of open travelling wave accelerating structures with HFSS [11]. We simulated the periodic structure by using one regular cell. We calculated the rf parameters for different gap sizes starting from 0.2 mm.

We observed that when we opened the gap, with a distance between the two halves larger than half wavelength, the fundamental accelerating mode remains trapped. Figure 2 shows the simulation of the synchronous wave in one period of the accelerating structure: (a) gap = 0.5 mm, gap/λ = 0.217 (f = 130 GHz); (b) gap = 1.3 mm, gap/λ = 0.52 (f = 118 GHz); gap = 4 mm, gap/λ = 1.4 (f = 105 GHz); in all three cases the mode is trapped. The surface wave is guided by one half of the accelerating structure and it has no radiation losses, while it has wall losses. We tested several structures and dedicated two shifts for the study of surface waves, on Nov 21 and Nov 30 2015.

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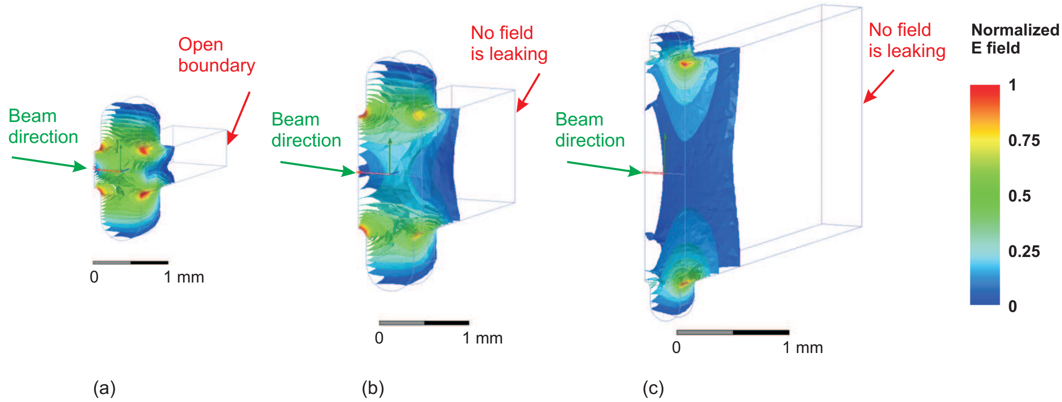

Figure 2: Simulation of the synchronous wave in one period of the accelerating structure (half accelerating structure is shown): (a) gap = 0.5 mm, gap/λ = 0.217 (f = 130 GHz); (b) gap = 1.3 mm, gap/λ = 0.52 (f = 118 GHz); gap = 4 mm, gap/λ = 1.4 (f = 105 GHz); in all three cases the mode is trapped.

EXPERIMENTAL RESULTS

The travelling wave accelerating structure was installed in the vacuum chamber at the end of the FACET [12] linac. The experiment setup is illustrated in Fig. 3. The electromagnetic fields in the structure are excited by the FACET electron beam. The electron beam has 3.2 nC of bunch charge and a 50 μm of bunch length. The power is radiated through the output horns towards pyro-detectors, part of the mm-wave interferometers. A reference pyro-detector detects the magnitude of the radiated power, while the interferometer measures the frequency spectrum of the signal.

Our setup allowed a gap opening up to 7.5 mm. With this gap, gap/λ = 2.4 and the surface waves of the two halves are practically independent. The picture of the half accelerating structure is shown in Fig. 1. To study the surface wave, at this gap we excited it by moving one half structure close to the electron beam, as shown in Fig. 4.

The measurement of the surface wave properties relied from the energy radiated by the horns. The structure couplers were designed to be matched for gap = 0.3 mm [1]. With any other gap the coupler are mismatched but we are still able to detect the energy excited by the beam even at the maximum gap. With the the pyro-detector we observed that the generated power increases when the beam gets close to the structure half (See Fig. 5).

We measured the spectrum of the radiated signal with the interferometer. With gaps larger or equal to 0.9 mm, we observed only one strong peak (See Fig. 6). The measured frequency was 123.6 GHz.

We measured the frequency at different gaps. When the gap gets larger, the fundamental mode becomes the surface wave. The plot of the simulated (blue) and measured (red) frequency of the fundamental mode is in Fig. 7, with 3.2 nC of bunch charge and a 50 μm of bunch length as a function of the gap. We have good agreement between simulations and measurements.

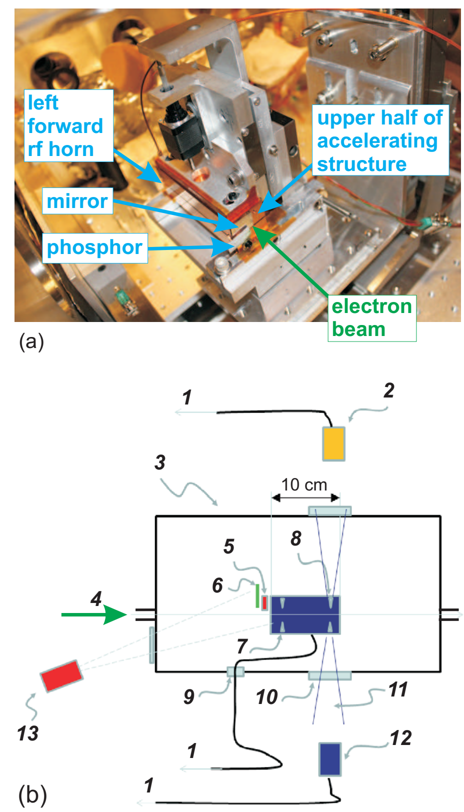

Figure 3: Accelerating structure installed in the vacuum chamber (a). Schematic of the experimental setup (b): signal to scope (1), single shot interferometer (2), vacuum chamber (3), electron beam (4), laser alignment mirror (5), phosphor screen (6), right reflected rf horn (7), left forward rf horn (8), vacuum feed-through (9), rf window (10), output rf beam (11), interferometer - pyrodetector (12), video camera for beam-structure alignment and rf breakdown diagnostic (13).

CONCLUSIONS

We explored physics of rf breakdowns in mm-wave open accelerating structures. In this experiment we studied the

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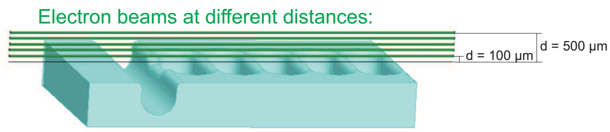

Figure 4: Relative position of the beam with respect to one half of the structure.

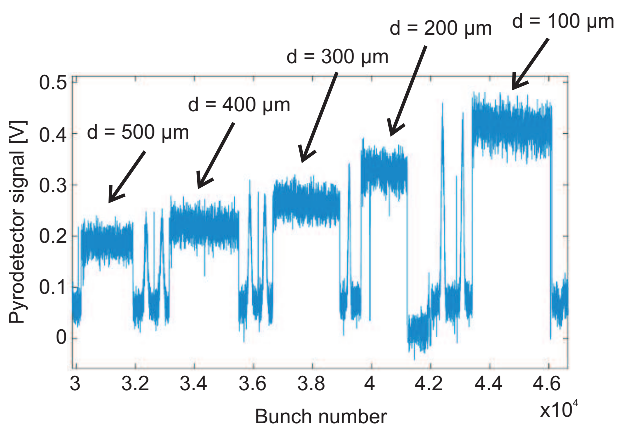

Figure 5: Pyro-detector signals for different distances between the beam trajectory and the half structure. The measured energy increases when the beam gets close to the half structure. The electron beam has 3.2 nC of bunch charge and a 50 μm of bunch length. When the pyro-detector signal is constant (apart from noise) the beam is over the center of the corrugations.

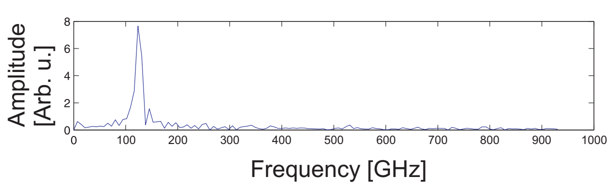

Figure 6: Spectrum of the radiated signal for gap = 0.9 mm.

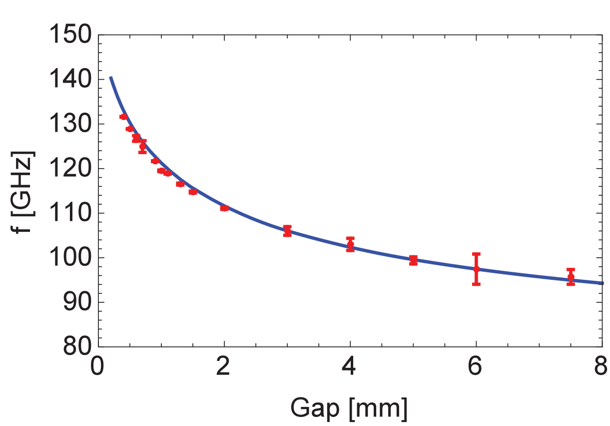

Figure 7: Plot of the simulated (blue) and measured (red) frequency as a function of the gap, with 3.2 nC of bunch charge and a 50 μm of bunch length.

surface wave, by measuring its rf spectrum with the interferometer, showing good agreement with simulations as a function of the gap width. We measured the breakdown rate that we will present in future publications.

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