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BEAM DRIVEN ACCELERATION AND RF BREAKDOWN IN PHOTONIC BAND GAP TRAVELLING WAVE ACCELERATOR STRUCTURES

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Abstract

We report the results of an experiment to demonstrate excitation of wakefields and wakefield acceleration in a photonic band gap (PBG) accelerating structure. The experiment was conducted at Argonne Wakefield Accelerator (AWA) facility. For modern X-ray Free Electron Lasers (FELs), preservation of the electron beam quality during the beam acceleration is of crucial importance. Therefore, new accelerating structures must be designed with careful attention paid to the suppression of wakefields. PBG structures are widely studied due to their ability to exclude higher order modes. A 16-cell travelling-wave normal conducting PBG structure operating at 11.7 GHz is installed at the AWA beam line. We passed a high-charge single bunch and a multiple bunch train through the structure that generated wakefields and evaluated the effect of these wakefields on a low charge witness beam.

INTRODUCTION

Photonic band gap (PBG) structures are periodic structures (metallic, dielectric or both) which confine the drive mode and damp higher order modes. PBG structures have great potential in reducing higher order modes (HOM) and long range wakefields. The problem associated with the high beam current accelerators needed for the future light sources and high luminosity colliders are the wakefields and HOM related beam breakup instabilities. PBG structures might be the technology needed for a compact and inexpensive high beam current accelerators. This raises the needs for the test of acceleration and wakefield suppression in PBG structures. To date only one test of the acceleration in a PBG structure was performed [1].

TWO-BEAM COLLINEAR WAKEFIELD ACCELERATION EXPERIMENTAL SETUP

The experiment is conducted at Argonne Wakefield Accelerator (AWA) at Argonne National Lab. In AWA facility, an L-band photocathode rf electron gun is used to produce electron beam. The electron gun uses a cesium-telluride photocathode. Six seven-cell accelerating structures are used to raise the electron energy up to 65 MeV. The beam can be split into different bunches and bunch charge of each bunch can be varied. This is achieved by splitting the laser pulse used in electron gun and varying the energy of the laser pulse. In our experiment, a high bunch-charge beam is used to excite the longitudinal wakefield in the PBG structure and hence is referred to as a drive beam, while low charge beam used to probe the field excited by the drive beam is known as a witness beam. When the drive and witness beams travel through the same structure, it is called a collinear configuration. More details of the facility are given in [2].

A normal temperature traveling-wave PBG accelerating structure operating at 11.7 GHz was built and successfully tested for wakefield suppression at Argonne Wakefield Accelerator. This structure has 9 times the operational frequency of the AWA facility. The PBG structure is electroformed and could not be brazed due to internal stresses, a vacuum compatible epoxy was used to attach the components. Due to the use of epoxy. the vacuum chamber containing the PBG structure could not reach ultra-high vacuum to isolate and protect the Cesium telluride photocathode used in the photo injector in AWA facility, the vacuum chamber containing the PBG structure is separated from the beamline with a thin Beryllium (Be) window of the thickness of 178 microns. The experiment on wakefield suppression was conducted at AWA [3].

In the wakefield-suppression experiment [3], a good fraction of electron beam was hitting the front of the PBG structure and not entering the beam pipe of PBG structure due to high thickness of Be window. In order to understand how to send the beam through the PBG structure a series of experiment were done at AWA facility with three different thickness (30, 75, and 127 micron) Be windows. The beam size was measured before and after these windows with different charges and different beam energies. Based on these experiments, a 30-micron Be window was chosen. This 30-micron thick Be window was used during our two-beam collinear wakefield acceleration experiment.

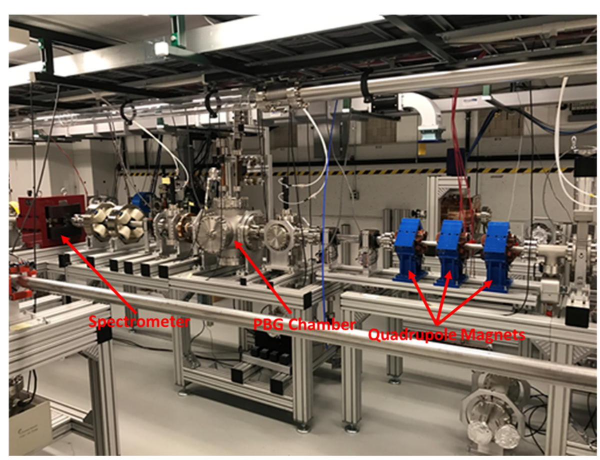

Figure 1: The experimental setup on the beam line at Argonne Wakefield Accelerator (AWA).

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We are powering the PBG structure with a drive beam and measuring the beam energies of drive and witness beams after the structure in a spectrometer placed after the PBG structure. The experimental setup is shown in Fig. 1. There are three quadrupole magnets placed before the PBG structure to focus the beam towards PBG structure. As the beam tube diameter of the PBG structure is 6.31 mm while diameter of the Be window is 9.0 mm, we need a strong focusing of beams in order for the beam to pass through the structure. There is an Inductive Current Transformer (ICT) placed after the PBG structure, which measures the beam charge passed through the structure. The beam after the spectrometer is projected on a YAG screen which shows the change in energy. The phase separation between the witness beam and the drive beam is obtained by changing the path length of the laser pulse used to produce the witness beam. As the PBG structure has 9 times frequency of the AWA accelerating structure, 40-degree phase changes in the AWA main Linear Accelerator (linac) amount to 360-degree phase change in the PBG accelerator.

EXPERIMENTAL RESULTS

We optimized for the maximum charge transfer through the PBG structure with the help of quadrupole magnets placed before the PBG chamber. By measuring the charge with the ICT placed after PBG structure we found out that approximately 5-7 nC of charge can be passed through the PBG structure in single bunch. However, for the witness bunch we chose the charge to be 0.1 nC.

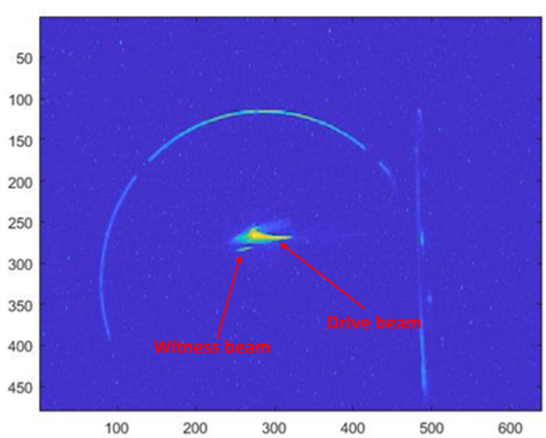

Figure 2: Both the drive and the witness beam energy on the spectrometer placed before the PBG structure.

We also measure the energy of both the beam by a spectrometer placed before the PBG structure and saw that the energy is same as shown in Fig. 2. The horizontal axis displays the energy, if both beams are at the same horizontal positions it means they have the same energy. The shift to the left shows decrease in the energy while shift to the right shows increase in energy. The energy of the electron beams is approximately 65 MeV, and various experimental parameters used during the experiments are given in Table 1.

Table 1: Experimental Parameters at AWA

Frequency of main linac in AWA	1.3 GHz
Frequency of PBG structure	11.7 GHz
Charge in the drive beam bunch	5-7 nC
Charge in the witness beam bunch	0.1 nC
Thickness of Be window	30 micron
Diameter of the Be window	9.0 mm
Diameter of the beam tube of PBG structure	6.31 mm
Energy of the electron beam	65 MeV

Once the drive beam passes through the PBG structure, it creates the longitudinal wakefield. The magnitude of generated power in the PBG structure is proportional to the transmitted charge through the PBG structure. The effect of this generated wakefield is felt by the witness beam depending on the phase of the witness beam. When witness beam is in phase we see maximum deceleration. In Fig. 3, we show the witness beam and the drive beam after the PBG structure. Which shows that witness beam is getting decelerated due to drive beam.

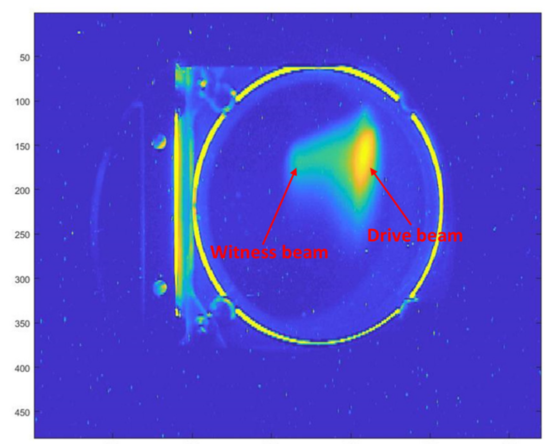

Figure 3: Both the drive and the witness beam energy on the spectrometer placed after the PBG structure.

The charge of the witness beam is small (0.1 nC) compared to the drive beam (5-7 nC). Thus, it is not very visible on the YAG screen. We varied the phase of the witness beam and saw the max deceleration but we could not see the acceleration produced by the wakefield of the drive beam. There may be problem with the phase variation as when we are changing the phase of the witness beam it is getting out of phase with the klystron and that might be creating an error in energy of both beams before the PBG itself or there is a wakefield effect of the 1.3-GHz long linac itself which might be undermining the energy gain in the PBG structure.

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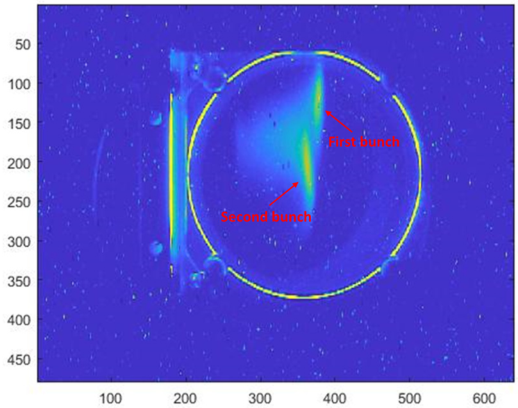

Figure 4: Two-bunch separation on spectrometer placed after the PBG structure.

We also send two and four bunches with charges of 5-7 nC each through the PBG structure and measured their energy afterwards with the spectrometer. There was no phase variation experiment done with these bunch charges. Second bunch of the charge feels the wakefield of the first bunch of the charge. The image on the YAG screen for the two bunches is shown in Fig. 4.

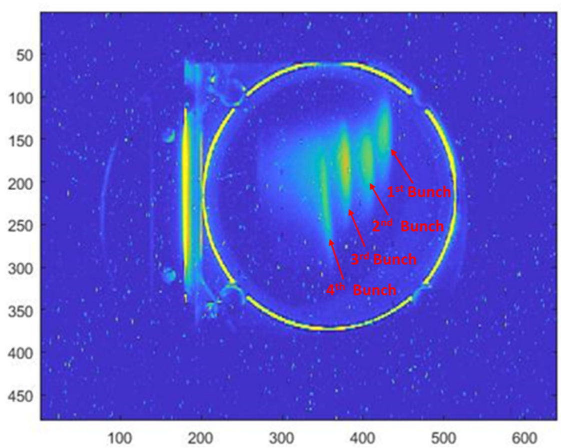

Figure 5: Four-bunch separation on spectrometer placed after the PBG structure.

The result for the four-bunch experiment is shown in Fig. 5. This fits well with the prediction that the last bunch will see the cumulative effect of all the three previous bunches and all the four bunches are equally separated on the energy scale though having the same energy at the beginning. Our future plan is to vary the phase variation more carefully and measure for all bunches energy before and after the PBG structure with the help of the spectrometer.

CONCLUSION

We conducted a collinear wakefield acceleration experiment in a 16-cell travelling wave PBG structure in AWA. We varied the phase of the low charge witness beam with respect to the high charge drive beam. We did experiment with a single bunch high charge drive beam and a multiple bunch high charge drive beam. We measured the energy of beams with a spectrometer placed after the PBG structure. We measured the witness beam energy with the drive beam on and off. We saw clearly the deceleration of the witness beam caused by the drive beam. We did not observe acceleration. A comprehensive computational beam simulation in OPAL for AWA beam line and an experiment with fine phase variation is planned for future. We are also building a normal-conducting PBG structure with reduced magnetic field by improving the design parameters of rods inside the PBG structure and we will test this PBG structure for rf breakdown at SLAC [5].

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