BEAM BREAKUP IN DIELECTRIC WAKEFIELD ACCELERATING STRUCTURES: MODELING AND EXPERIMENTS*

P. Schoessow#, C. Jing, A. Kanareykin, Euclid Techlabs, 5900 Harper Rd, Solon, OH 44139
A. Kustov, Dynamics Software, Helsinki, Finland
W. Gai, J. G. Power, ANL, Argonne, IL 60439, U.S.A.
Alexander Altmark, LETI, St Petersburg, Russia

Abstract

Beam breakup (BBU) effects resulting from parasitic wakefields limit considerably the intensity of the drive beam that can be transported through a dielectric accelerating structure and hence the accelerating field that can be achieved. We have been developing techniques to control BBU effects using a quadrupole channel or solenoid surrounding the wakefield device. We report here on the status of simulations and experiments on BBU and its mitigation, emphasizing an experiment at the Argonne Wakefield Accelerator facility using a 26 GHz dielectric wakefield device fitted with a solenoid to control BBU. We present calculations based on a particle-Green's function beam dynamics code (BBU-3000) that we are developing. The code allows rapid, efficient simulation of BBU effects in advanced linear accelerators.

INTRODUCTION

Beam breakup phenomena present serious limitations to the performance of dielectric structure based wakefield accelerators and power extractors, even manifesting in preliminary experiments at the ANL wakefield facility [1]. We report here on recent results from a recently concluded experimental and numerical investigation of BBU and its mitigation. The numerical part of this research is based on a particle-Green's function beam breakup code (BBU-3000). The code is a flexible 2D and 3D code based on analytic Green's functions for single particle fields in axisymmetric dielectric loaded structures. BBU-3000 versions are available for both Linux and Windows operating systems. The development and features of the code have been described elsewhere [2, 3, 4]. In this paper we discuss the features most recently added to BBU-3000, including the capability of treating wakefields and beam breakup in 3D rectangular geometries.

The experimental program focuses on BBU measurements at the AWA facility in a number of high gradient and high transformer ratio wakefield devices. We discuss the current plans for an experiment to use an external solenoidal focusing channel to control BBU in a 26 GHz power extraction structure.

26 GHZ DWPE EXPERIMENT

A quadrupole channel around the decelerator of the dielectric power extractor may be the most effective way to control BBU in a high energy machine like a linear collider. However, this technique requires multiple sets of quad triplets that are difficult to implement for the 30 cm devices planned for the AWA experiments. For the relatively soft beams (15 MeV) available at the AWA, a solenoid is a suitable option for controlling BBU. We have done PIC code simulations to verify this approach, both with BBU-3000 and with CST Particle Studio®. Four bunches with 20 nC per bunch are launched at the entrance of the 26 GHz dielectric wakefield power extractor (DWPE) with the beam centroid 0.2 mm off-axis. Energy spread at the entrance is 1%; transverse beam size is 4 mm of diameter; and the angular spread is 0.057 degree (equivalent to 20 mm mrad normalized emittance).

The simulation results are shown in Fig. 1. As a comparison, Fig. 1(a) clearly shows the bunch break-up in the 26 GHz DWPE without the external magnetic field because of the both short range (intra-bunch) and long range (inter-bunch) wakefield. The results in Fig. 1(b) show 100% particle transport for all four bunches due to the presence of the external solenoid field.

A 1-T solenoid has been designed and ordered from Stangenes Industries. The design parameters and the results of a Pandira calculations of the solenoid field are shown in Fig. 2. The I.D. and the length of the solenoid are critical since the solenoid will be placed tightly over the 26 GHz DWPE. A 300 KW power supply to power the solenoid is available at the AWA. The solenoid is under construction at the company. We plan to measure the 26 GHz DWPE at AWA beamline with the solenoid in the late 2011, which will lead to a 150 MW rf output if it is successful.

NEW BBU-3000 CAPABILITIES

Development continued on the BBU-3000 code and on its BOINC-based web implementation, the Beam Dynamics Simulation Platform (BDSP) [4, 5]. (BOINC [6] is an open source software environment for grid computing.) Figure 3 shows a BDSP display of the results of a calculation; the particle positions and longitudinal and transverse wakefields are plotted.

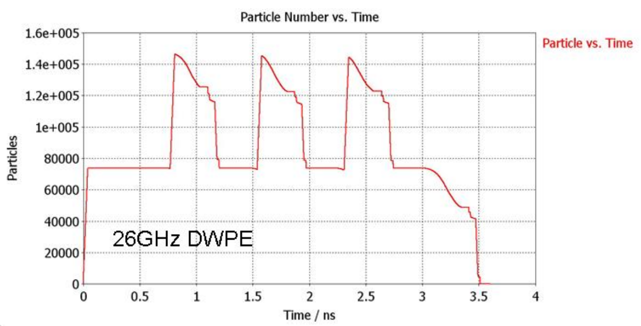
The following key functionalities were implemented and successfully tested:

- Batch mode: allows particle push and force calculation to be called from a shell script or third party software like Matlab. This is useful for automating parameter sweeps, user generated beam phase space, specialized graphics display, etc.

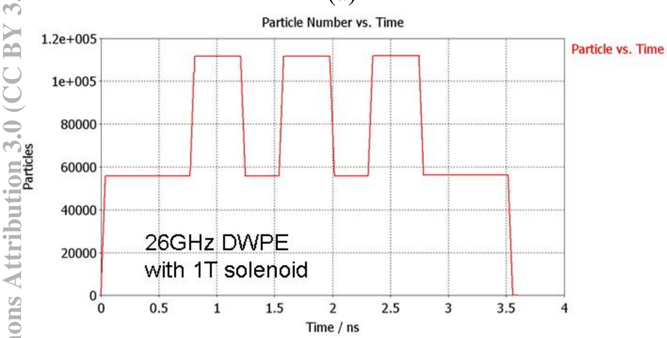
*Work supported by US DoE SBIR Grant, Contract #DE-FG02-07ER84823.
#paul.schoessow@euclidtechlabs.com

Copyright © 2011 by PAC'11 OC/IEEE — cc Creative Commons Attribution 3.0 (CC BY 3.0)

- Full-fledged multitasking in BOINC: multiple users/ experiments/projects;
- New project creation on the base of an existing one – a "Sandbox" for the users to independently work on different tasks in the same Web GUI;
- Web GUI reworked for all operations with experiments and projects;
- Graphics fully ported from Windows client to the BOINC Web GUI;
- Experiment data input was ported from windows client to the BOINC Web GUI;
- Windows client stand-alone functionality was elaborated;
- Windows client was elaborated to seamlessly support all the aforementioned Web GUI functionality.



(a)



(b)

Figure 1: The PIC code simulation of the 4-bunch train passing through the existing 26 GHz DWPE: (a) without solenoid (b) with a 1 Tesla solenoid.

RECTANGULAR STRUCTURES

Rectangular waveguides provide a number of technological and fabrication advantages in comparison with a traditional cylindrical DLA structure. Beam dynamics simulations are critical in accelerating structure design and also for the design of dielectric collimating structures for linear colliders [7]. We have developed a module for BBU-3000 (formerly limited to cylindrical geometries) that allows rapid, efficient simulation of beam breakup effects in rectangular DLA structures.

For a bunch propagating in a rectangular waveguide the particles which are placed in the tail of bunch experience the strongest deflecting force. Our simulations showed that the bunch with a significant offset of 3 mm propagated only 4 cm in the waveguide (Fig.4a) before its tail began to scrape on the dielectric wall. The cross-section of the waveguide in the X-Y plane clearly shows that the particles located around the center of the bunch experience the main deflecting force (Fig.4b).

At the same time, decreasing the offset to 800 μm would only increase the interception distance by 10 cm. These test simulations show that the focusing is critical for a rectangular DLA structure the same way as it is required for cylindrical DLAs that have been studied previously [2, 8], and it will be necessary to design an external FODO channel for the control of the beam in the presence of strong transverse wakefields.

SUMMARY

We have described here an ongoing project to study beam breakup in dielectric structures. In this project we extensively studied BBU physics, and developed software that allows us now to design focusing techniques to control BBU in dielectric structures.

The project comprises both software and hardware aspects. The software effort is based on development of the BBU-3000 code. Currently beam dynamics simulation tasks are rather CPU intensive. We have implemented a solution based on the Boinc software environment. Boinc is an established framework that we are using to specify beams and simulation parameters, and also beam and EM field visualization, and to allow multiple users and projects to access the BBU-3000 software via the web and perform simulations on a cluster of machines. The current software incorporates a "sandbox" feature for easy addition of new projects on the fly, such as trying new waveguide geometries or introducing a user-supplied particle-particle force algorithm.

We studied BBU effects in the 26 GHz power extractor. With thorough simulations, we refined our methods (using a FODO lattice or solenoid around the structure) for suppressing the effects of BBU. We studied the possibility of using a commercially available 1 Tesla solenoid to minimize the BBU for the 26 GHz power extractor; the solenoid has been designed and ordered. According to the PIC code simulation, a 1 T solenoid around the power extractor (assuming a 15 MeV AWA beam) is able to prevent BBU for a bunch train with 20 nC per bunch, which can extract ~150 MW rf power at 26 GHz from the beam. This experiment will be performed at the AWA facility in late 2011 upon completion of the current facility upgrade.

Copyright © 2011 by PAC'11 OC/IEEE — cc Creative Commons Attribution 3.0 (CC BY 3.0)

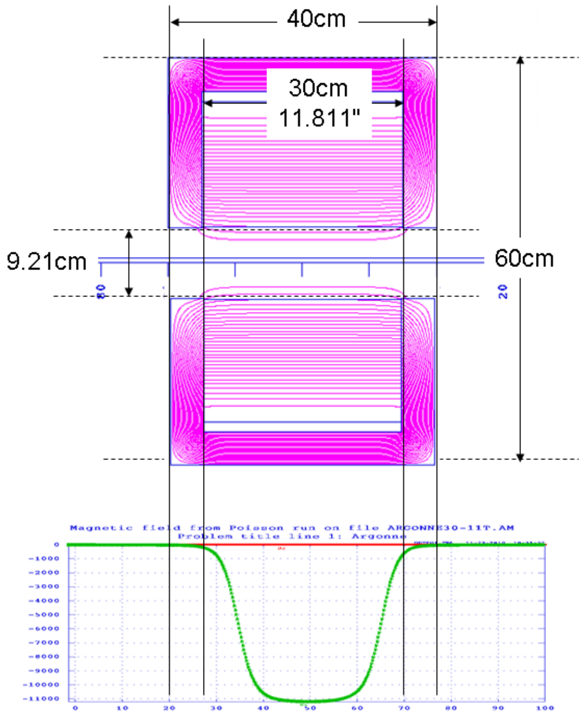


Figure 2: Design for the solenoid to control BBU in the 26 GHz power extractor. The magnet is being fabricated by Stangenes Industries.

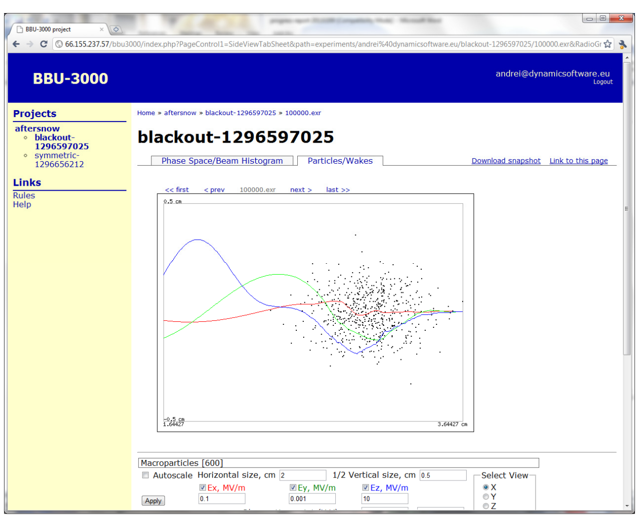


Figure 3: Beam Dynamics Simulation Platform web browser display of particle positions and wakefields.

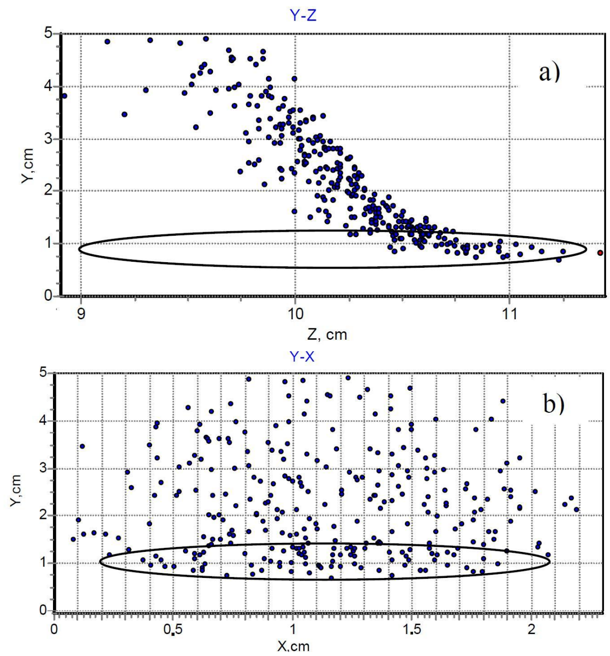


Figure 4: BBU-3000 simulation of beam breakup in a rectangular dielectric loaded accelerating structure. Axial vacuum channel gap = 1.0 cm, dielectric layer thicknesses = 0.5 cm, ε = 10, structure width = 2.3 cm. Beam: Q=100 nC, σ_z=4 mm, σ_x=3 mm, σ_y=0.1 mm, y offset=0.8 mm, W_{beam}=15 MeV. (a) transverse (Y-Z) view; (b) X-Y view. The ellipse shows the initial beam shape in each view.

REFERENCES

[1] C. Jing et al., "The First Experiment of a 26 GHz Dielectric Based Wakefield Power Extractor", Proc. IPAC'10, paper THPD067 .

[2] W. Gai, *et al.*, *Phys. Rev. E*, 55, 3481-3488 (1997).

[3] P. Schoessow et al., Proc. 2009 Particle Accelerator Conference, paper WE6RFP063.

[4] P. Schoessow et al., Proc. IPAC'10, paper TUPEC081.

[5] P. Schoessow et al., "Beam Dynamics Simulation Platform and Studies of Beam Breakup in Dielectric Wakefield Structures", 2010 Advanced Accelerator Concepts Workshop, AIP Conf. Proc. **1299**, 262 (2010).

[6] http://boinc.berkeley.edu.

[7] A. Kanareykin et al., paper THP109, these proceedings.

[8] A.Altmark, P.Schoessow, A.Kanareykin, C.Jing, A.Kustov, J.G.Power, W. Gai, AIP Conf. Proc. **1086**, 404 (2009).

Copyright © 2011 by PAC'11 OC/IEEE — cc Creative Commons Attribution 3.0 (CC BY 3.0)