ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEAD1

COMMISSIONING AND RECENT EXPERIMENTAL RESULTS AT THE ARGONNE WAKEFIELD ACCELERATOR FACILITY (AWA)*

M.E. Conde#, D.S. Doran, W. Gai, W. Liu, J.G. Power, C. Whiteford, E. Wisniewski, ANL, Argonne, IL 60439, USA
S. Antipov, C. Jing, J. Qiu, Euclid Techlabs LLC, Solon, OH 44139, USA
J. Shao, D. Wang, Tsinghua University, Beijing, China
G. Ha, Department of Physics, POSTECH, Pohang, Gyeongbuk 790-784, Korea

Abstract

The commissioning of the upgraded AWA facility has been recently completed. The L-band electron gun has been fully commissioned and has been successfully operated with its Cesium Telluride photocathode at a gradient of 80 MV/m. Single bunches of up to 100 nC, and bunch trains of up to 32 bunches with a maximum total charge in the trains of 600 nC have been generated. Six pi-mode accelerating cavities bring the beam energy to 70 MeV. Initial measurements of the beam parameters have been performed. This intense beam has been used to drive wakefields in several structures, including a 26 GHz dielectric loaded power extractor, an 11.7 GHz photonic-band-gap metallic structure (PBG), and an 11.7 GHz metallic iris loaded power extractor. A second beamline provides electron bunches to probe the wakefields generated by the intense drive beam. A recent experiment has demonstrated acceleration (and deceleration) of the witness beam, in the so-called two-beam-accelerator scheme, with accelerating gradients over 40 MV/m.

AWA FACILITY

The main mission of the Argonne Wakefield Accelerator Facility (AWA) is to develop technology for future accelerator facilities. The AWA facility has been used to study and develop new types of accelerating structures based on electron beam driven wakefields. In order to carry out these studies, the facility employs a photocathode RF gun capable of generating electron beams with high bunch charges and short bunch lengths. This high intensity beam is used to excite wakefields in the structures under investigation, thus being referred to as the Drive Beam. There is a second electron beam that is used to probe the wakefields generated by the Drive Beam, and it is referred to as the Witness Beam.

The facility is also used to investigate the generation and propagation of high brightness electron beams, and to develop novel electron beam diagnostics. More recently, the facility has attracted interest from the broader scientific community, and collaborations on a wider range of topics have been fostered by the DOE-HEP stewardship initiative.

The AWA high intensity drive beam is generated by a photocathode RF gun, operating at 1.3 GHz. This one-and-a-half cell gun typically runs with 12 MW of input power, which generates an 80 MV/m electric field on its Cesium Telluride photocathode surface. Six seven-cell standing-wave π mode accelerating structures increase the energy of the beam produced by the drive gun from 8 MeV to 70 MeV.

The charge of the drive electron bunches can be easily varied from 0.1 to 100 nC, by varying the energy of the laser pulse incident on the photocathode. The high quantum efficiency of the Cs_2Te photocathode – routinely made in house and reaching over 15% QE – makes it possible to generate high charge bunches with laser pulses of relatively low energy. Thus, the laser pulse can be split into a sequence of laser pulses separated in time by one RF period, and this laser pulse train can be used to generate an electron bunch train.

The AWA laser system consists of a Spectra Physics Tsunami oscillator followed by a Spitfire regenerative amplifier and two Ti:Sapphire amplifiers (TSA 50). It produces 1.5 mJ pulses at 248 nm, with a pulse length of 2 to 8 ps FWHM and a repetition rate of up to 10 pps. A final KrF Excimer amplifier is optionally used to increase the energy per pulse to 15 mJ.

The Drive and the Witness beamlines propagate in opposite directions, and come to a common area designated beamline switchyard, where each beamline can branch out into a few beamlines and where experiments are conducted. The beamline switchyard allows wakefield experiments to be performed using either the collinear configuration, in which the drive and witness bunches travel along the same structure, or the two-beam-accelerator configuration, in which RF power is transferred from the drive beam decelerating structure to the witness beam accelerating structure, by means of a waveguide.

COMMISSIONING

The Drive beamline has been commissioned to an energy of 69 MeV, however, after a few weeks of operation, the RF window installed on one of the accelerating cavities showed signs of multipacting at full RF power. Mostly likely this was caused by some defect in the Titanium Nitride coating applied to the ceramic surface of the RF window. A couple of spare RF windows are in hand, and the defective window will be replaced soon. For now, operation of the Drive beamline has continued, but using a slightly reduced RF power level at the mentioned accelerating cavity. As a consequence, the

*Work supported by by the U.S. Department of Energy under contract No. DE-AC02-06CH11357.
#conde@anl.gov

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEAD1

Drive beam energy has been temporarily reduced to about 65 MeV.

Drive bunch charge during operation with single bunches has reached values as high as 100 nC. Operation with bunch trains of up to 32 bunches spaced by one RF period of the 1.3 GHz RF power, has reached total charge in the trains of up to 600 nC. This limit was set by the degradation of the vacuum that occurred due to some beam scraping along the accelerating cavities, forcing the reduction of the repetition rate of the machine. It is hoped that with more careful beam transport, and with the addition of some getter pumps, an even higher value for total train charge will be reached, or, at least, operation will be allowed to remain at the nominal repetition rates of 2 or 5 pulses per second.

WAKEFIELD ACCELERATION

The use of electron beam driven wakefields to achieve high gradient acceleration has received considerable attention. It offers the advantage of using a relativistic beam to transport the energy to the accelerating structures, decreasing the difficulties of generating and distributing RF power by conventional means; wakefields naturally constitute RF pulses that are of short duration and high peak intensity [1].

Research at the AWA facility has been exploring various types of wakefield structures, including photonic band gap structures, metallic iris loaded structures, and also more exotic schemes using metamaterials. The main focus of the facility, however, has clearly been the development of dielectric loaded structures. They offer the advantage of simple geometry and easy fabrication with accelerating properties that compare favourably with conventional iris loaded metallic structures: the axial electric field is uniform across the transverse cross section of cylindrical structures, and the uniform cross section of the structures presents no geometric features to cause field enhancement. The damping of the undesirable deflecting dipole modes seems to be more easily accomplished in dielectric loaded structures as well; past experiments have used longitudinal slots on the metallic outer shell of dielectric structures, as a means to damp dipole modes. Dielectric structures also hold the promise of withstanding higher electric fields without material breakdown. A significant advantage offered by wakefield structures, in comparison with other wakefield schemes, is the ability to accelerate positron bunches or electron bunches in basically identical fashion.

In the past few years AWA has demonstrated high gradient fields (100 MV/m) in dielectric based wakefield structures [2]. Generation and extraction of RF power using beam driven dielectric structures has also been demonstrated [3 - 5]. Several experiments exploring new designs and new features of dielectric based wakefield structures will be conducted in the near future.

Some of the long term goals of the AWA facility are the demonstration of: accelerating gradients of hundreds of MV/m, net acceleration of the witness beam by ~ 100 MeV, RF power extraction in the GW level, and staging.

RECENT EXPERIMENTS

Initial measurements on a two-beam-accelerator experiment (TBA) showed promising results and demonstrated the great potential that the AWA facility has in carrying out its research program. An 11.7 GHz wakefield structure was installed in the drive beamline and used as a power extractor. The generated RF pulse was coupled out of the structure and sent by means of a waveguide into a structure in the witness beamline. Figure 1 shows a picture of the setup. In this first TBA experiment at the newly upgraded facility, the two structures were $2\pi/3$ travelling wave iris loaded structures, fabricated with brazed copper cells. The decelerating structure had 35 cells and a group velocity of 0.22 c. The accelerating structure had only three cells (plus two coupling cells) and a group velocity of 0.016 c.

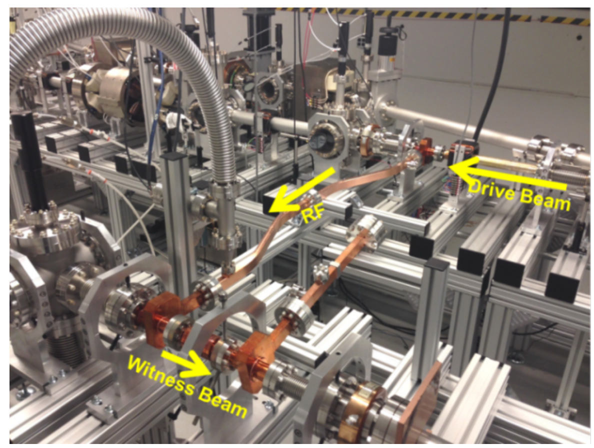

Figure 1: Two-beam-accelerator setup at AWA. The yellow arrows near the wakefield structures indicate the direction of propagation of the drive and witness beams. The third yellow arrow is placed near the waveguide that takes the RF pulse from the decelerating structure to the accelerating one. Also seen in the picture is the RF load connected to the output coupler of the accelerating structure.

Preliminary measurements clearly showed acceleration and deceleration of the witness beam, according to the timing between the two electron beams. Thus, as the arrival time of the witness bunch was varied along the phase of the RF pulse, its energy increased and decreased following the period of the 11.7 GHz travelling wave. The number of bunches in the drive bunch train was also varied between 1, 2, 4, and 8, and that, obviously, changed the duration and amplitude of the RF pulse, and, consequently, the witness bunch energy. Using 8 drive bunches with a total charge of 90 nC, the energy of the witness bunch varied by ± 1.4 MeV with respect to its original value of 8.5 MeV. This is illustrated in Fig. 2. It should be noted that there is some ambiguity in the definition of the accelerating gradient. In such a short accelerating structure, the two coupling cells (one at each end of the structure) make a small contribution to the net acceleration of the witness bunch. Thus, the observed

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEAD1

structure gradient can be justifiably quoted as a value between 40 MV/m and 55 MV/m.

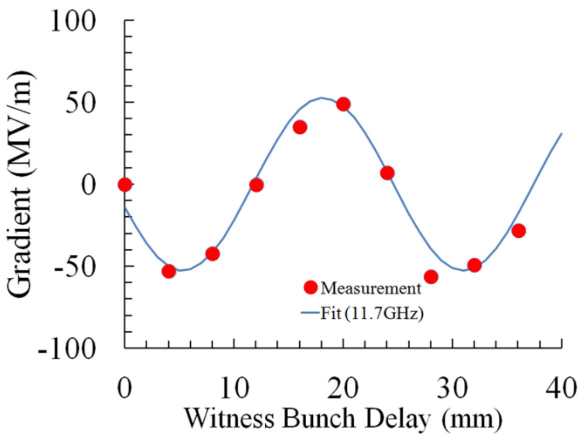

Figure 2: Accelerating gradient seen by the witness bunch as a function of its phase in the 11.7 GHz RF pulse.

The witness beam energy measurements mentioned above refer to the energy of the beam centroid as seen at the spectrometer YAG screen. As shown in Fig. 3, the witness bunch energy spread seemed to decrease slightly after being subject to the wakefield acceleration. The witness bunch charge was approximately 0.5 nC.

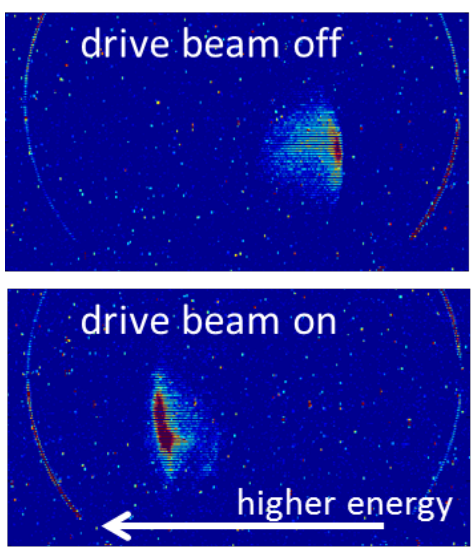

Figure 3: Witness bunch seen at the spectrometer YAG screen, with and without propagation of drive bunches through the decelerating structure.

Besides the TBA experiment just described, three other experiments have been installed in the Drive beamlines and have taken some preliminary data: an Emittance Exchange experiment (Fig. 4) [6], a metallic PBG structure operating at 11.7 GHz [7], and a planar 90 GHz metallic structure [8].

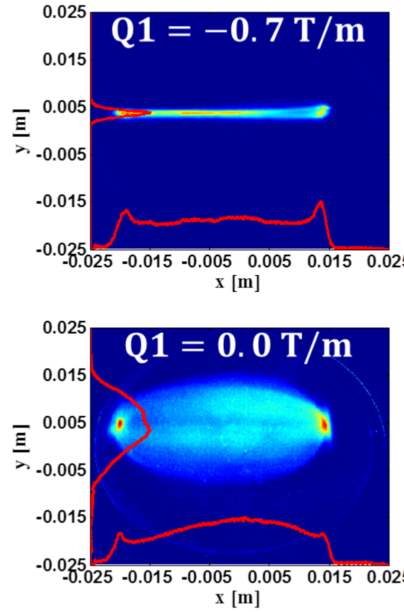

Figure 4: Transverse beam profile downstream of emittance exchange experiment shows clear evidence of the emittance exchange mechanism in the x and z dimensions. The quadrupole setting upstream of the experiment can only affect the y and z profiles of the downstream beam.

REFERENCES

[1] W. Gai et al., "Short-pulse dielectric two-beam acceleration," J. Plasma Physics, **78**, 339 (2012).

[2] M. Conde et al., MOP067, Proc. of LINAC'08, Victoria, BC, Canada (2008); http://www.JACoW.org

[3] F. Gao et al., Phys. Rev. ST Accel. Beams **11**, 041301(2008).

[4] F. Gao et al., IEEE Trans. Nucl. Sci. **56**(3), 1492 (2009).

[5] C.-J. Jing et al., THPD067, Proc. of IPAC 2010, Kyoto, Japan (2010); http://www.JACoW.org

[6] G. Ha et al., "Initial EEX-based Bunch Shaping Experiment Results at the Argonne Wakefield Accelerator Facility," these proceedings, WEPWA035, Proc. of IPAC'15, Richmond, VA, USA (2015); http://www.JACoW.org

[7] E. Simakov et al., "Experimental Study of Wakefields in an X-band Photonic Band Gap Accelerating Structure," these proceedings, WEPJE008, Proc. of IPAC'15, Richmond, VA, USA (2015); http://www.JACoW.org

[8] D. Wang et al., "High Power RF Radiation at W-band based on Wakefields Excited by Intense Electron Beam," these proceedings, WEPMN017, Proc. of IPAC'15, Richmond, VA, USA (2015); http://www.JACoW.org