THE ARGONNE WAKEFIELD ACCELERATOR FACILITY: STATUS AND RECENT ACTIVITIES*

M.E. Conde#, S. Antipov, W. Gai, C. Jing, R. Konecny, W. Liu, J.G. Power, H. Wang, Z. Yusof, ANL, Argonne, IL 60439, U.S.A.

Abstract

We describe the Argonne Wakefield Accelerator Facility (AWA), pointing out its present capabilities and goals. We present recent measurements on beam loading observed in our photocathode RF gun. Wakefield measurements in dielectric loaded structures are also reported. Our most recent wakefield structure operates at 15 GHz, and has been excited by single electron bunches and also by sets of two closely spaced bunches. When driven by 43 nC bunches, the accelerating gradient in this structure reached 23 MV/m. No signs of electric breakdown have been observed. This report ends with a brief discussion on the next activities to take place at the AWA facility.

INTRODUCTION

The Argonne Wakefield Accelerator Facility (AWA) is dedicated to the study of electron beam physics and the development of accelerating structures based on electron beam driven wakefields [1]. In order to carry out these studies, the facility employs a photocathode RF gun capable of generating electron beams with high bunch charges (up to 100 nC) and short bunch lengths. This high intensity beam is used to excite wakefields in the structures under investigation. The wakefield structures presently under development are dielectric loaded cylindrical waveguides with operating frequencies of 7.8 or 15.6 GHz.

The facility is also used to investigate the generation and propagation of high brightness electron beams. Presently under investigation, is the use of photons with energies lower than the work function of the cathode surface (Schottky-enabled photoemission), aimed at generating electron beams with low thermal emittance. Novel electron beam diagnostics are also developed and tested at the facility.

The AWA electron beam is also used in laboratory-based astrophysics experiments; namely, measurements of microwave Cherenkov radiation and beam induced fluorescence of air.

AWA FACILITY

The AWA high intensity electron 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 Magnesium cathode surface. A 1.3 GHz linac structure increases the electron beam energy, from the 7 MeV produced by the RF gun, to 13 MeV. The charge of the electron bunches can be easily varied from 1 to 100 nC, with bunch lengths of 2 to 5 ps rms, and normalized emittances of 30 to 200 π mm mrad.

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 6 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 generation of electron bunch trains (up to 64 bunches) requires each laser pulse to be divided by means of beam splitters into a laser pulse train. The laser pulses in the train arrive at the photocathode surface separated by an integer number of RF periods, thus ensuring that the electron bunches have the same launch phase.

BEAM LOADING MEASUREMENTS

The RF gun has a small loop antenna installed in its vacuum port, on the equator plane of the full cell. This field probe senses the evanescent field that leaks from the gun cavity. Thus, one can easily detect the 1.3 GHz signal from the operating π mode. Furthermore, the antenna signal clearly shows the perturbation caused the electron beam traversing the gun cavity. Figure 1 shows the antenna signal for various electron bunch launch phases, illustrating how the phase of the field perturbation correlates with the bunch launch phase.

Measurements with a time-gated spectrum analyzer (HP8565E) show that the electron beam excites a higher order mode with frequency 2.089 GHz. The frequency of this mode is confirmed with numerical simulations performed with the software package Microwave Studio, and it is listed as the third mode on Table 1. The first mode listed on this table corresponds to the zero mode of the gun cavity. Interestingly, the zero mode is detected by the spectrum analyzer at the very beginning of the klystron pulse; it then quickly decays away. The second mode listed corresponds to the π mode of operation. The fourth mode on the table excites only the half cell of the gun cavity and, therefore, would not be detected by the loop antenna installed on the vacuum port of the full cell. Careful measurements near the frequency of the fifth mode have not been performed yet. Also seen, are several harmonics of the 1.3 GHz frequency. These harmonics could possibly be generated by the dark current emitted in the gun cavity, or might be produced directly by the klystron.

*Work supported by the US Department of Energy under contract No. W-31-109-ENG-38.
#conde@anl.gov

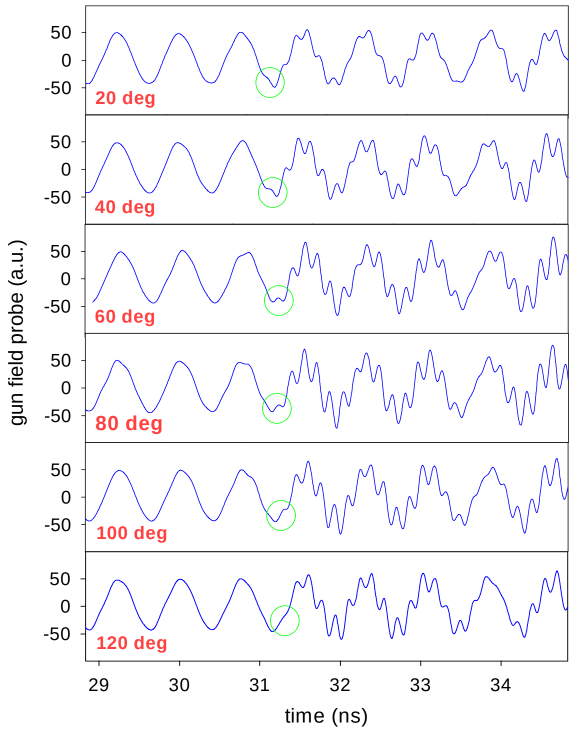

Figure 1: Gun field probe signals showing a couple of periods of the unperturbed 1.3 GHz RF field, followed by cycles that have the higher order mode perturbation superimposed on the fundamental mode. The small circles simply highlight the initial phase of the perturbation and its correlation with the electron beam launch phase (which is written next to each curve).

Table 1: First modes in the Gun cavity, as calculated by the software package Microwave Studio

mode	Frequency (GHz)	comment
1	1.289	Zero mode
2	1.299	π mode
3	2.087	Full cell only
4	2.896	Half cell only
5	2.956	

WAKEFIELD EXPERIMENTS

We have recently built and tested a 15 GHz dielectric loaded wakefield structure. Its cylindrical ceramic tube (cordierite) has inner and outer diameters of 10 and 15 mm, and a dielectric constant of 5. This 102 mm long standing-wave structure has a weakly coupled field probe (-60 dB) to monitor the wakefields generated by the driving electron bunches. An RF mixer circuit is used to convert the signal down to 5 GHz, which is then displayed on a high bandwidth oscilloscope (LeCroy Wavemaster 8600A). Figure 2 shows the output of the mixer circuit for various bunch charges. As expected, the signal is stronger for higher bunch charges. The phase of these signals is arbitrary, since the 10 GHz local oscillator is not phase locked to the klystron that powers the RF gun and linac.

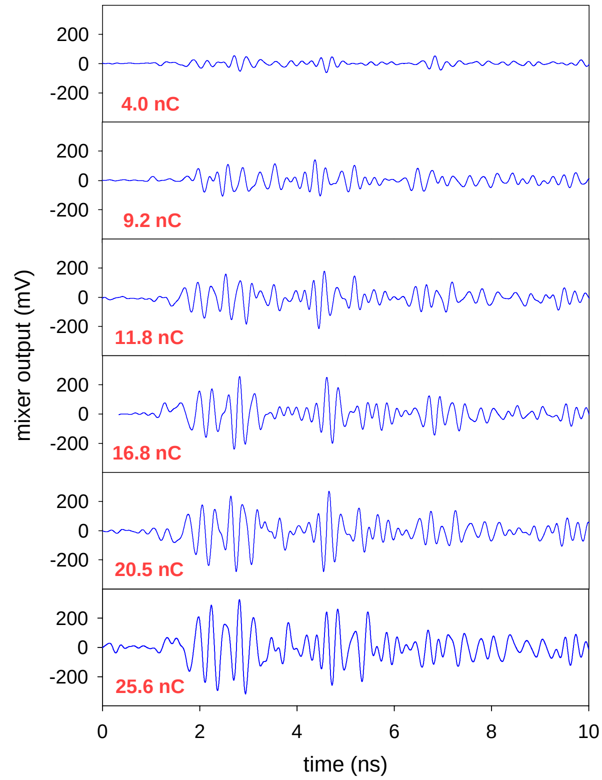

Figure 2: Output of RF mixer for various bunch charges.

Figure 3a shows the output of the mixer for a 43 nC bunch – the highest bunch charge that has traveled through this structure. The amplitude of the wakefields had to be attenuated to avoid damaging the RF mixer circuit; for this reason, the peak values on this graph are smaller than some shown on Fig. 2 for smaller bunch charges. The graph on Fig. 3b shows the peak values (positive and negative) of the wakefields measured for different bunch charges, taking into account the different attenuations added at the input of the RF mixer circuit. As expected, the amplitude of the wakefields rises linearly with bunch charge.

Wakefield measurements were also made using two electron bunches separated by 1.5 ns (two RF periods of the klystron frequency). Figure 4 shows the RF mixer output for each bunch alone and also for the two bunches together.

OTHER ACTIVITIES AND NEXT STEPS

We will proceed with further experiments on Schottky-enabled photoemission [2]; measurements will be made on diamond coated surfaces. We will soon begin fabrication of high quantum efficiency Cs_2Te photocathodes, which will allow us to make long trains of high charge bunches. More measurements of beam parameters will include bunch length and transverse emittance.

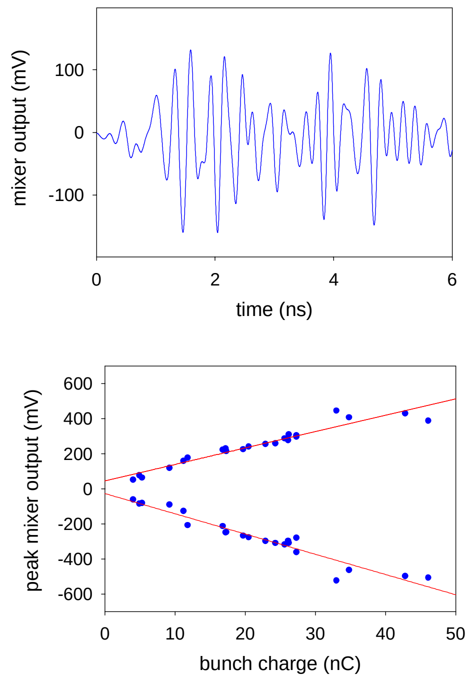

Figure 3: RF mixer output: (a) signal generated by a 43 nC electron bunch; (b) peak value of the wakefield amplitude plotted as a function of the charge in the drive bunch.

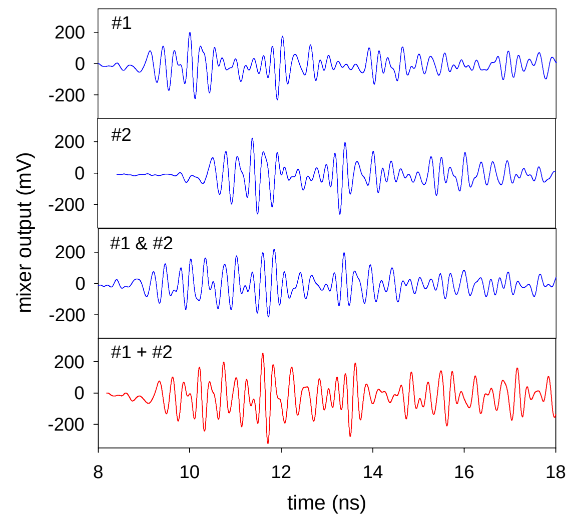

Figure 4: RF mixer output showing the signal from: (a) bunch #1 alone; (b) bunch #2 alone; (c) bunches #1 and #2 separated by 1.5 ns (two RF periods of the klystron frequency); (d) numerical addition of the signals from (a) and (b), which is not strictly the correct approach, since the relative phases of these two signals are arbitrary due to the free running local oscillator in the RF mixer circuit. Another caveat is the fact that the laser intensity of the pulse that generates bunch #2 decreases when pulse #1 is present, due to depletion in the excimer laser amplifier; thus, the charge of bunch #2 is lower when bunch #1 is present.

We will make further wakefield measurements with the present 15 GHz structure; namely, we will vary the spacing between the bunches and also the number of bunches. New dielectric loaded structures are presently under construction, and will be tested shortly. One of them will use a ramped bunch train in order to achieve a transformer ratio higher than two. Another one will be an energy extractor, that is, the RF power source of a two beam accelerator system.

In the next few months we will carry out precise measurements of beam induced air fluorescence, as part of the AIRFLY collaboration. These results will be used in the calibration of instruments employed in the detection of cosmic ray showers [3].

The authors wish to express their deep appreciation for the invaluable technical support provided by Felipe Franchini.

REFERENCES

[1] M.E. Conde et al., “The Argonne Wakefield Accelerator Facility: Capabilities and Experiments,” Proceedings of the 2004 Advanced Accelerator Concepts Workshop, June 2004.

[2] Z. Yusof et al., “Schottky-Enabled Photoemission in a rf Accelerator Photoinjector: Possible Generation of Ultralow Transverse Thermal-Emittance Electron Beam,” Phys. Rev. Lett. 93, 114801.

[3] P. Privitera, private communication.