The Argonne Wakefield Accelerator Facility: Capabilities and Experiments

Manoel E. Conde, Sergey Antipov*, Wei Gai, Chunguang Jing*, Richard Konecny, Wanming Liu, John G. Power, Haitao Wang*, Zikri Yusof

High Energy Physics Division, Argonne National Laboratory, Argonne, IL 60439. USA

**Illinois Institute of Technology, Chicago, IL 60616*

Abstract. A description of the Argonne Wakefield Accelerator is presented, pointing out the unique capabilities of the facility. A photocathode RF gun produces electron bunches with tens of nanocoulombs of charge, which are used to excite wakefields. A second photocathode RF gun generates electron bunches that are used to probe these wakefields. An overview of the experimental program carried out at the facility is also presented.

INTRODUCTION

The Argonne Wakefield Accelerator (AWA) Facility is dedicated to conducting research on fundamental accelerator and beam physics issues associated with future high energy physics machines: high current electron beam generation and propagation, wakefield acceleration in dielectric-based and other advanced structures, high power RF generation, and material breakdown studies under high fields.

The facility is also used to study the production of high brightness electron beams, and the generation of electron beams with very low thermal emittance. New instrumentation and diagnostics are also developed to match the unique needs of this facility. Finally, the facility is also made available to research groups interested in using its capabilities to study other phenomena, such as radiation emitted by cosmic showers propagating through solid matter and through the atmosphere.

FACILITY DESCRIPTION

Two features make the AWA facility very unique and ideally suited for the study of electron beam driven wakefield acceleration: (a) the ability to generate short electron bunches with very high charge (tens of nanocoulombs per bunch), and (b) the existence of two photocathode RF guns capable of sending electron bunches through a single structure (or two separate structures) with precise time separation between them.

CP737, *Advanced Accelerator Concepts: Eleventh Workshop,*
edited by Vitaly Yakimenko

Photocathode RF Guns and Beamlines

Figure 1 shows a schematic of the AWA beamlines. A high charge drive beam is used to excite wakefields, and a low charge witness beam is used to probe the wakefields. These two beams can be made to propagate through the same structure, to study collinear acceleration, or can travel to two separate structures. In the case two separate structures, the so called two beam accelerator configuration, the RF power (wakefield) generated by the drive beam in the first structure is coupled by means of waveguides into the second structure, where the witness beam can be accelerated.

The drive beam is generated by a half-cell photocathode RF gun running at 1.3 GHz. The bunch charge can be varied from 10 to 100 nC, with a bunch length of 15 to 35 ps FWHM. The drive gun is followed by two linac tanks (1.3 GHz) that bring the beam energy up from 2 MeV to 15 MeV. The 4 MeV witness beam is generated by a 6 ½ cell photocathode RF gun. The bunch charge is typically 0.1 nC with a bunch length of 8 ps FWHM.

In order to achieve a higher quality drive beam, a new photocathode RF gun has been built and commissioned [1]. The old gun had been designed and built when only 2 MW of RF power was available. This limited amount of RF power had led to the construction of a half-cell gun, yielding a relatively soft 2 MeV electron beam at the gun exit, with the consequent high emittance and long bunch length. The new 1 ½ cell gun produces a 7.5 MeV beam with 12 MW of RF power. Similar bunch charges (10 – 100 nC) are generated by the new gun, but with shorter bunch lengths (2 – 5 ps rms) and much lower emittances (30 – 200 π mm mrad).

Both drive guns (old and new) have been operated with Magnesium as the photocathode material. The witness gun uses a Copper photocathode. A program to fabricate Cesium Telluride photocathodes is presently underway, and will enable the generation of long bunch trains with high charge per bunch.

The RF guns and the linac structures are powered by a single 30 MW klystron, running at 1.3 GHz, with 8 μs long pulses and a maximum repetition rate of 10 pps. Waveguide power splitters and phase shifters enable precise phase control over the various RF cavities. Also, a common 81 MHz oscillator establishes the phase relationship between the RF power and the laser pulses.

Laser System

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. The timing stability is better than 1 ps rms, and the amplitude stability is ± 3% rms at high energy, and ±1% at lower energy.

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 one RF period, thus ensuring that the electron bunches have the same launch phase.

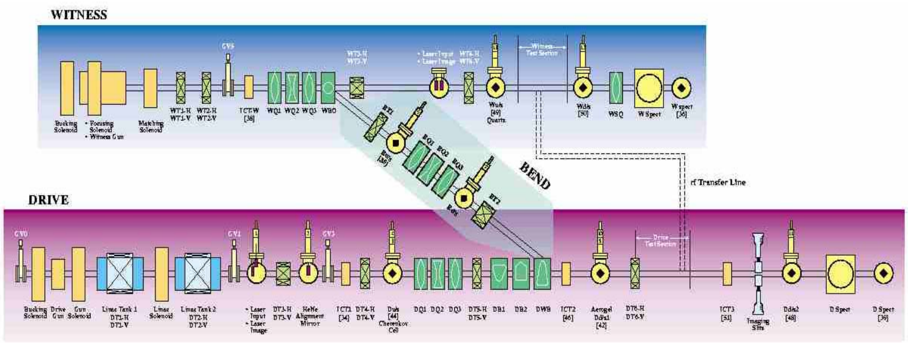

FIGURE 1. Schematic of the AWA beamlines.

Instrumentation and Diagnostics

The AWA beamlines are equipped with numerous beam diagnostics. They include: Integrating Current Transformers (ICTs), Faraday-Cups, Cerium doped YAG crystals for beam profile measurements (and emittance measurements when used in conjunction with quadrupole scans), aerogel and Cerenkov radiators for bunch length measurements with a streak camera, pepper pot plates and ICCD cameras for emittance measurements, and magnetic dipole spectrometers.

Novel beam diagnostics are also under development. In collaboration with R. Fiorito and A. Shkvarunets, we are developing a modified optical transition radiation interference diagnostic (OTRI), that uses a fine metallic mesh as the first radiator and a transparent dielectric foil as the second radiator. This ameliorates the scattering on the first foil and allows for the spacing between the two foils to be very small.

EXPERIMENTAL PROGRAM

The main research focus of the Argonne Wakefield Accelerator Facility is on electron beam driven wakefield acceleration. This includes issues related to high current electron beam generation and propagation, and the development of accelerating structures that support high accelerating gradients [2].

Other research goals of the facility include the generation of high brightness electron beams, the fundamental physics of photoemission processes and its relationship to the thermal emittance of beams.

The facility has also been made available to the Astrophysics community, which has used its electron beam to study the properties of the radiation emitted by cosmic showers propagating through solid matter and through the atmosphere.

Electron Beam Driven Wakefield Acceleration in Structures

Over the past few years, several wakefield acceleration experiments have been successfully carried out at the AWA facility in both the collinear and the two beam accelerator configurations. These experiments used dielectric loaded cylindrical waveguides, with operating frequencies ranging from 7 to 20 GHz. The dielectric materials are typically Magnesium-Calcium-Titanate based ceramics (MCT), with dielectric constants spanning from 4 to 40. Accelerating fields of about 15 MV/m have been measured in collinear acceleration experiments. A two beam accelerator experiment operating at 7.8 GHz demonstrated that more than 90% of the RF power generated by the drive beam (4 MW) was coupled into the second structure, yielding an accelerating field of 7 MV/m.

A new dielectric structure is currently under testing. It is expected to be installed in the beamline in the near future. The near term goal is the operation in a multi-bunch mode to generate wakefields in the dielectric structure with gradients of the order of 100 MV/m.

High Brightness Beam Generation

The high-brightness beam study has centered on the emittance measurement of a 1 nC electron beam. The normalized emittance measurement was done using a modified three-screen technique and measuring the transverse beam profile at three different locations along the beamline (Fig. 2). The preliminary results indicated that an emittance between 8 and 12 mm-mrad was obtained, consistent with PARMELA simulations. Further studies to verify and improve emittance measurements will soon be done using a series of pepper-pot plates.

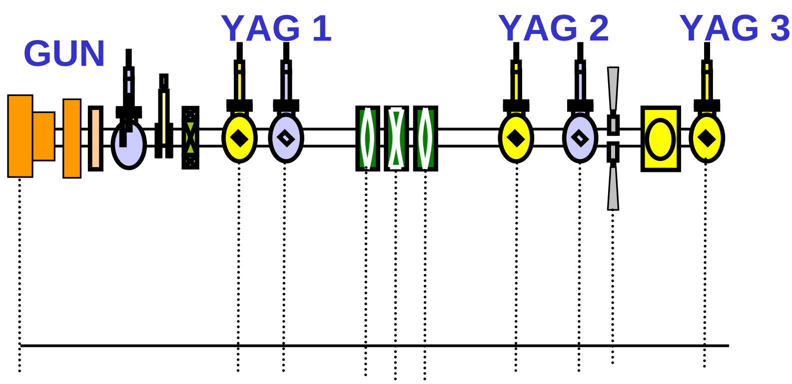

FIGURE 2. Three-screen measurement of the normalized emittance.

Schottky-Enabled Photoemission

The work on the Schottky-enabled photoemission overlaps the study on high-brightness beam. In the Schottky-enabled beam generation, photons with energy (3.3 eV) less than the Mg photocathode's work function (3.7 eV) was used. By increasing the RF power in the photoinjector, thus increasing the amplitude of the electric field in the gun, the effective work function of the photocathode is lowered due to the Schottky effect. At the threshold condition, the effective work function has been sufficiently lowered to match the photon energy, and photoelectrons are then detected. In principle, photoelectrons generated in this manner have extremely small kinetic energy. Consequently, the electron beam generated should have an ultra-low intrinsic emittance. This is a new regime in beam generation for photoinjectors and has important implications in the production of high-brightness electron beams [3].

A "by product" of the Schottky-enabled photoemission is the ability to reasonably estimate the field-enhancement factor of the photocathode. At the threshold condition, regions of the photocathode's surface with high field-enhancement become the sources of the measured photoelectrons. This allows us to determine in a more direct manner the field-enhancement factor on the cathode.

Astrophysics Applications

In collaboration with UCLA and the University of Hawaii, the AWA facility has been used to perform several experiments related to astrophysical applications. An earlier experiment studied the Cerenkov radiation generated via the traversal of an electron beam through silica sand [4]. This study aimed at understanding the Cerenkov radiation formed by charged particles moving through the moon.

In the INCOBREM experiment, the electron beam was used to produce gamma photons that were then passed through an air-filled chamber (Fig. 3). This led to the production of incoherent microwave bremsstrahlung radiation from the ionized air. The project centered on the detection of such microwave signal.

The AIRFLY collaboration will, in the near future, carry out an experiment at AWA. Fluorescence light will be generated as the electron beam traverses a gas-filled chamber, mimicking charged particles traversing the atmosphere.

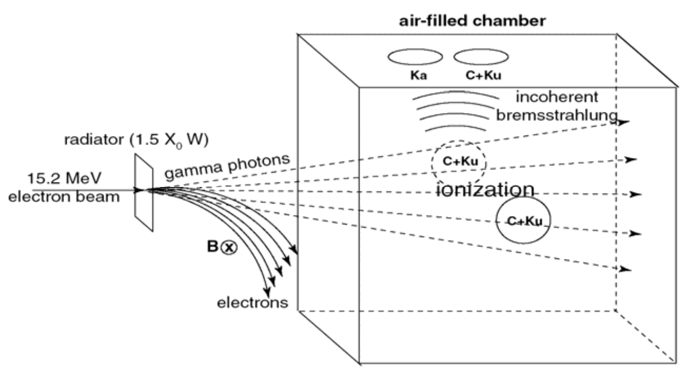

FIGURE 3. Generation of an incoherent bremsstrahlung radiation using the AWA beamline for astrophysical applications.

ACKNOWLEDGMENTS

The AWA group acknowledges invaluable technical support from Felipe Franchini. This work was supported by the US Department of Energy under contract No. W-31-109-ENG-38.

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