RESEARCH PROGRAM AND RECENT RESULTS AT THE ARGONNE WAKEFIELD ACCELERATOR FACILITY (AWA)*

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Abstract

We give an overview of the research program at the Argonne Wakefield Accelerator Facility (AWA), including some highlights of recent experiments. The AWA facility is dedicated to the study of beam physics and the development of technology for future particle accelerators. Two independent electron linacs are used to study wakefield acceleration: 70 MeV high charge electron bunches of up to 100 nC are used to drive wakefields, which can be probed by bunches originating from the same linac or from the 15 MeV linac. Recent Two-Beam-Acceleration (TBA) experiments reached accelerating gradients of up to 150 MV/m. The wakefields were generated by the passage of the 15 – 45 nC drive bunches through iris-loaded metallic structures operating at 11.7 GHz. No indication of witness beam quality degradation was observed, and bunch charge was preserved during the acceleration process. Another series of experiments was conducted using two TBA stages, demonstrating acceleration of the witness beam in these two subsequent stages by means of two independent drive bunch trains. Dielectric loaded structures operating at 26 GHz are also used in TBA experiments. Another main thrust of the research program consists of exploring and developing techniques to manipulate the phase space of electron bunches. These efforts include bunch shaping and the exchange of emittances in the transverse and the longitudinal phase spaces.

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. The recent installation of a beamline to perform Emittance Exchange between the transverse and longitudinal phase spaces has attracted great interest from the broader accelerator community.

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 (Fig.1). 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

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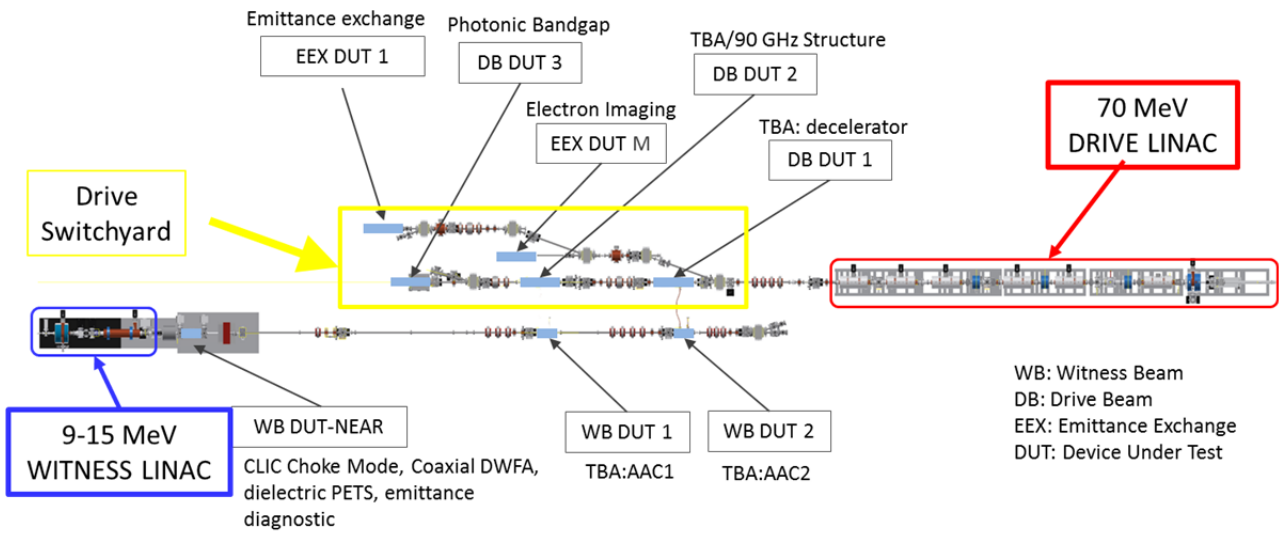
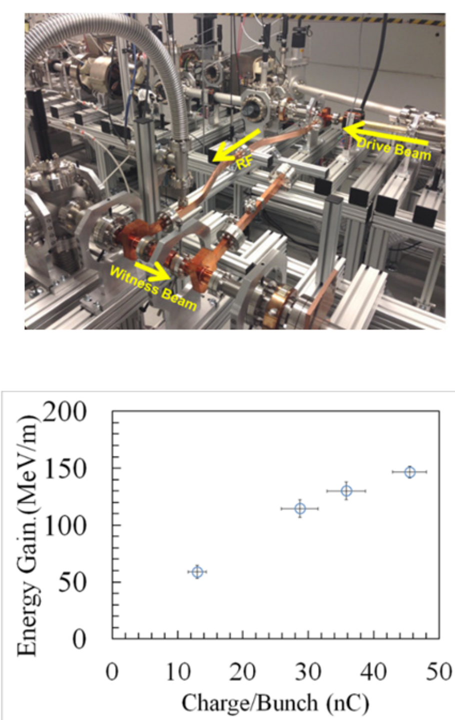


Figure 1: Schematic of the AWA beamlines, showing the two independent linacs and the experimental area where a large number of experiments have been carried out recently.

witness beam accelerating structure, by means of a waveguide.

RECENT EXPERIMENTS

A two-beam-accelerator (TBA) experiment was conducted employing metallic iris loaded structures operating at 11.7 GHz [1]. Figure 2 shows the experimental setup, depicting the two rf structures and the waveguide connecting them. Drive electron bunches of up to 45 nC generated 300 MW of rf power, yielding an accelerating gradient of 144 MV/m (Fig. 2b).



(a)

(b)

Figure 2: The two beamlines where the TBA experiment was carried out. The accelerating gradient measured as a function of the drive bunch charge is shown in 2b.

A second set of structures, constituting another TBA stage was installed in the AWA beamline switchyard, in order to demonstrate the feasibility of having multiple TBA stages as the basis of a larger accelerator concept. Figure 3 shows measurements of the witness beam energy, demonstrating wakefield acceleration in these two subsequent stages [1].

Another TBA experiment was performed using dielectric loaded structures operating at 26 GHz. Preliminary measurements indicated generation of 55 MW and an accelerating gradient of 28 MV/m. This relatively low gradient is attributed to a large frequency detuning of the structures [1].

A series of experiments has explored the capabilities of a beamline (Fig. 4) dedicated to the so-called emittance exchange between the transverse and longitudinal phase spaces [2, 3].

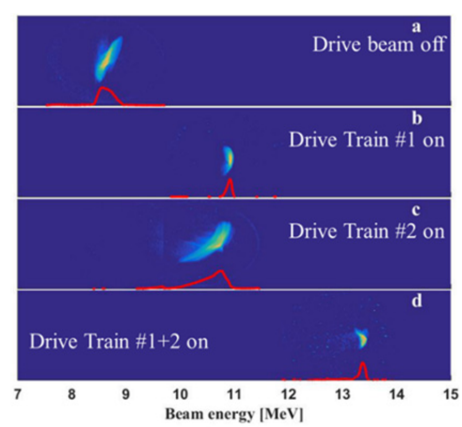


Figure 3: Four images of the spectrometer YAG screen, showing the witness beam energy under four different conditions: (a) without the propagation of any drive beams; (b) with drive bunches propagating through stage I only; (c) with drive bunches propagating through stage II only; (d) with drive bunches propagating through stages I and II.

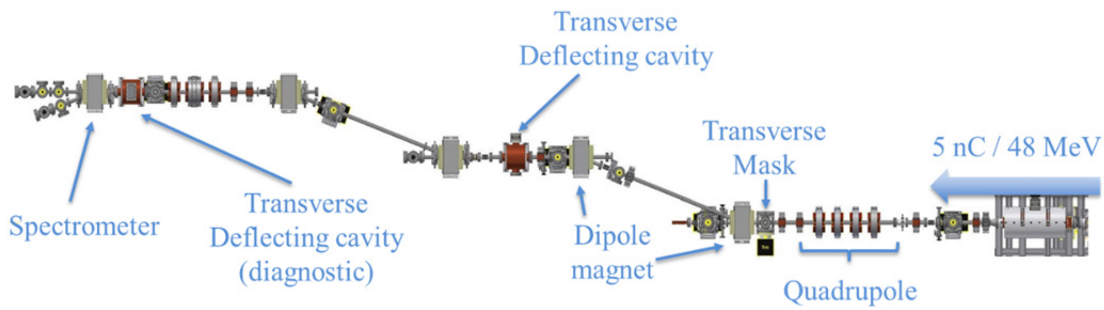


Figure 4: Schematic of the Emittance Exchange beamline, showing the two doglegs, two deflecting cavities, dipole and quadrupole magnets, as well as the position where masks are inserted to shape the transverse profile of the electron bunches. These customized transverse shapes can then create the desired longitudinal charge distributions.

FUTURE EXPERIMENTS

An expansion of the Emittance Exchange beamline is presently under way, with the goal of greatly enhancing its capabilities. Two more doglegs will be added, basically duplicating the present setup, and allowing a second exchange between the transverse and longitudinal phase spaces. Present studies indicate the possibility of bunch compression without the need for an energy chirp in the longitudinal bunch profile [4]. This double emittance exchange beamline also seems to offer robust possibilities for the generation of tailored drive and witness bunches, for collinear wakefield acceleration [5].

The recent effort in designing the double emittance exchange beamline prompted the study of its limitations. Numerical simulations have shown that coherent synchrotron radiation (CSR) generated by the bending magnets can have serious consequences on bunch quality [6]. Space charge effects and second order effects in the beam optics are also being studied.

A more complex demonstration of TBA staging has been designed, and the hardware components are now being procured and fabricated [7]. This new experiment will employ a fast beam kicker and a septum magnet, in order to direct one drive bunch train to stage I, and the second train to stage II bypassing the first stage.

Measurements of the thermal emittance of electron bunches generated at the Cesium Telluride photocathode used in the AWA drive gun have recently been initiated [8]. The development and testing of novel diagnostic methods are also carried out at AWA [9].

Several experiments with collaborators/users from other institutions are planned for the near future, constituting an effective way to enhance and diversify the research program pursued at AWA. Among them, we mention:

- A photonic band-gap (PBG) structure, operating at X-band, in collaboration with E. Simakov and J. Upadhyay (LANL).
- A novel accelerating structure known as “wagon wheel”, in collaboration with X. Lu et al. (MIT).
- A beam driven plasma wakefield experiment using the capabilities of the AWA double-emittance-exchange beamline, in collaboration with J. Rozenzweig et al. (UCLA).
- A novel periodic wakefield structure supporting the propagation of surface waves, in collaboration with G. Shvets and K. Lai (Cornell University).

In conclusion, the AWA facility has unique capabilities that make it an excellent platform for the development of a diverse and vibrant research program in the broad field of accelerator physics and applications.

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