ARGONNE WAKEFIELD ACCELERATOR: A FACILITY FOR THE DEVELOPMENT OF HIGH GRADIENT ACCELERATING STRUCTURES AND WAKEFIELD MEASUREMENTS*

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Abstract

The recently upgraded Argonne Wakefield Accelerator (AWA) facility is being commissioned. Operation of the new L-Band RF gun with a Caesium Telluride photocathode will generate long electron bunch trains, with high charge per bunch (up to 100 nC). The six new linac tanks will boost the beam energy to 75 MeV, making it an extremely well suited drive beam to excite wakefields in structures. One of the main goals of the facility is to generate RF pulses with GW power levels, corresponding to accelerating gradients of hundreds of MV/m and energy gains on the order of 100 MeV per structure. A key aspect of the studies and experiments carried out at the AWA facility is the use of relatively short RF pulses (15 – 25 ns), which is believed to mitigate the risk of breakdown and structure damage.

AWA FACILITY

The mission of the Argonne Wakefield Accelerator Facility is to develop technology for future accelerator facilities. In this role, the AWA facility has been used to study and develop new types of accelerating structures based on electron beam driven wakefields. The facility is also used to investigate the generation and propagation of high brightness electron beams, and to develop novel electron beam diagnostics.

The facility has recently undergone several major upgrades, and it is presently being re-commissioned. A new one-and-a-half cell RF gun has been commissioned, and it will replace the former RF gun as the source of drive bunches. The new RF gun operates with a Caesium Telluride (Cs_2Te) photocathode, and thus, due to the high quantum efficiency of Cs_2Te, it will be able to generate long bunch trains with high charge per bunch. We plan to generate trains with up to 32 electron bunches, each separated by one L-band RF period, and with up to 100 nC per bunch. (It should be noted that the two upper limits, i.e. 32 bunches and 100 nC per bunch, cannot be reached simultaneously, since this would load the accelerating fields in the RF gun to an unacceptable level.) These long bunch trains will, of course, generate long RF pulses when traversing the wakefield structures.

Besides the original 30 MW Thales klystron, three additional L-band RF power stations, consisting of one 30 MW Litton klystron and two 25 MW Thales klystrons, and their respective modulators, will power six new linac tanks in the drive beamline. These new klystrons have been commissioned, reaching full power.

The new linac tanks (Fig. 1) are seven-cell standing-wave π mode structures [1], designed to operate with 10 MW of input power and 11.2 MeV energy gain. Thus, the operation of the six new linac tanks will increase the energy of the beam produced by the drive gun from 8 MeV to 75 MeV. This will, of course, allow significantly more energy to be extracted from the drive beam as it drives wakefields in the structures under test. The higher beam energy also implies a smaller physical transverse emittance of the bunches, facilitating their propagation through smaller aperture wakefield structures, and generating even higher wakefield amplitudes.

The former drive gun and its linac tank, capable of generating 15 MeV electron bunches, will be used to provide a witness beam to probe the wakefields produced by the drive bunches. A new beamline switchyard (Fig. 2) will be constructed to allow concomitant experiments using the two electron beams: (a) collinear wakefield acceleration; (b) RF power generation and two beam acceleration; (c) phase space manipulation (emittance exchange, etc); (d) high brightness beam generation; (e) beam diagnostic development. This flexible beamline switchyard will allow a quicker and more efficient transition among several concurrent experimental setups.

Figure 1: The new linac tanks installed in the AWA bunker. The RF conditioning of these structures will be initiated shortly (June 2013).

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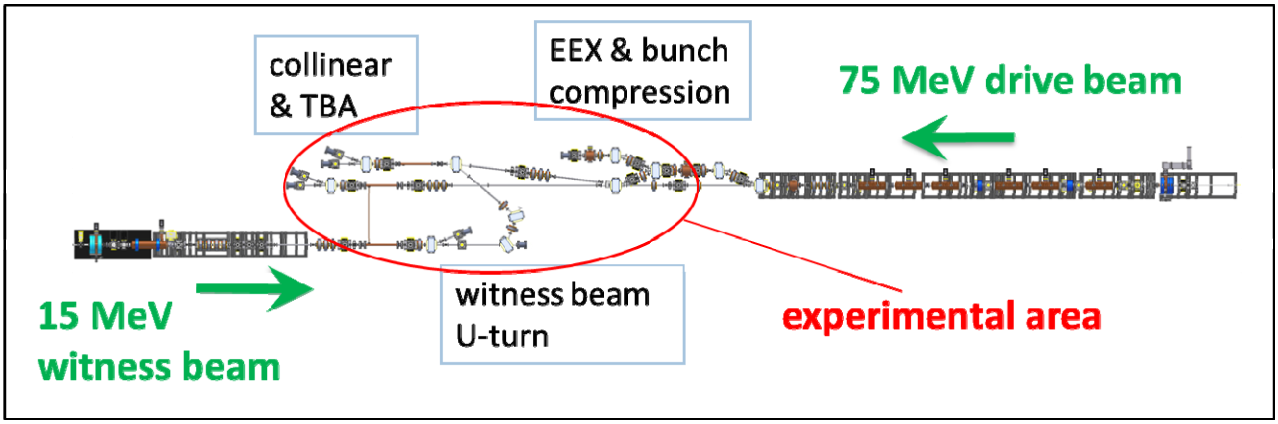

Figure 2: Schematic of the AWA beamlines, showing the Drive Beamline, the Witness Beamline and the beamline switchyard where the various experiments will take place.

.WAKEFIELD ACCELERATION

The use of electron beam driven wakefields to achieve high gradient acceleration has received considerable attention in past years. 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 [2].

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; planned experiments will explore the use of longitudinal slots on the metallic outer shell of dielectric structures, as a possible scheme 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.

WAKEFIELD EXPERIMENTS AT AWA

In the past few years AWA has demonstrated high gradient fields (100 MV/m) in dielectric based wakefield structures [3]. Generation and extraction of RF power using beam driven dielectric structures has also been demonstrated [4 - 6]. Several experiments exploring new designs and new features of dielectric based wakefield structures will be conducted in the near future.

The enhanced capabilities of the upgrade AWA facility will allow the generation of longer bunch trains with high charge per bunch. The higher beam energy will make it possible to excite high gradient wakefields in longer accelerating structures, thus generating hundreds of MV/m over meter scale structures. The second RF gun will provide “witness” bunches to probe the wakefields, demonstrating high gradient acceleration, and a high energy gain.

One of the goals of the facility is to achieve accelerating gradients on the order of 0.5 GV/m in structures with approximately 3 mm apertures. The generation and extraction of RF pulses with power levels on the order of GW shall also be demonstrated. As an example, Table 1 shows the main parameters of a pair of structures that has already been built and that will be tested as soon as the upgraded AWA facility becomes operational.

Table 1: 26 GHz TBA structures

Decelerating structure	**Accelerating structure**
ID / OD / length (mm) 7.0 / 9.068 / 300	ID / OD / length (mm) 3.0 / 5.025 / 300
Dielectric constant 6.64	Dielectric constant 9.70
Group velocity 0.254 c	Group velocity 0.111 c
R/Q 9.79 kΩ/m	R/Q 21.98 kΩ/m
RF Power (50 nC) 1.33 GW	R_{sh} 50.44 MΩ/m
Peak gradient 167 MV/m	E_0 (1.26 GW) 316 MV/m
Energy loss 20.5 MeV	E_{loaded} (1.26 GW) **267 MV/m**

DEMONSTRATION OF STAGING AND OTHER APPLICATIONS

The initial wakefield acceleration experiments at the upgraded AWA facility will be followed by a proof of principle experiment, demonstrating that two stages of

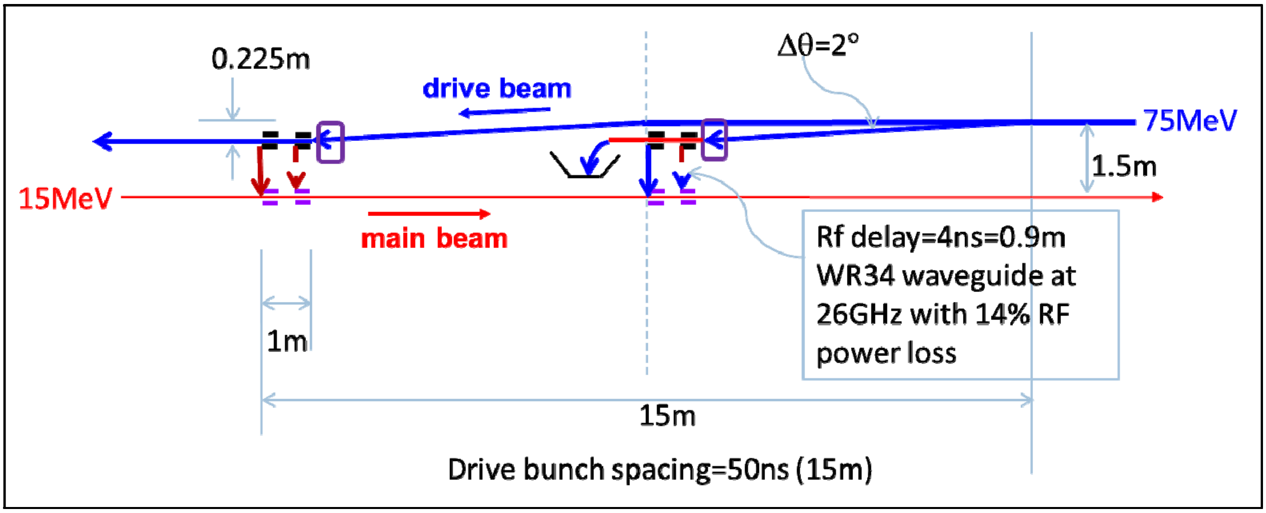

Figure 3: Schematic of the proof of principle experiment to demonstrate staging at AWA. Each stage has two decelerating structures and their corresponding accelerating structures. Correct timing of the RF pulses is obtained by adding appropriate delays to the waveguides connecting the structures

decelerating structures, and their corresponding accelerating structures. Correct timing of the RF pulses is obtained by adding appropriate delays to the waveguides connecting the structures.
wakefield acceleration can be successfully operated in series. Each of these two stages will have two structures, as shown in Fig. 3. It is important to notice that, contrary to the scheme proposed in the past [7], this new design requires no U-turn of the drive beam. The proper timing of the RF pulse that is generated at the decelerating structure and sent into the accelerating structure, is accomplished by adding some length to the waveguide that connects the two structures. The necessary delay in the proposed experiment is only 4 ns, which implies that the extra 0.9 m long section of WR34 waveguide will attenuate the 26 GHz RF pulse by approximately 14%. This is considered acceptable for a proof of principle experiment. Subsequent experiments can easily mitigate the RF losses caused by the extra length of waveguide by using an overmoded circular waveguide, operating in the TE01 mode.

A preliminary design of an FEL user facility that employs collinear wakefield acceleration, based on dielectric loaded structures to accelerate the electron beam has been recently presented [8]. The main features that make dielectric loaded structures particularly well suited for this application are the high gradient capabilities and the high energy efficiency.

CONCLUDING REMARKS

The recent upgrades implemented at the AWA facility make it a truly unique and outstanding facility for the study of beam driven wakefield applications. Following the commissioning of the new beamlines, a series of experiments shall demonstrate the tremendous potential of these technologies, and it will give indications of their likely impact on future accelerator designs.

REFERENCES

[1] J.G. Power et al, "Upgrade of the Drive Linac for the AWA Facility Dielectric Two-Beam Accelerator," in proceedings of IPAC 2010, Kyoto, May 2010.

[2] W.Gai et al, "Short-pulse dielectric two-beam acceleration," J. Plasma Physics, p. 1, Feb. 2012.

[3] M. Conde et al., "High Gradient Excitation and RF Power Generation using Dielectric Loaded Wakefield Structures," in proceedings of LINAC'08, Victoria, September 2008.

[4] F. Gao et al., "Design and Testing of a 7.8 GHz Power Extractor Using a Cylindrical Dielectric-loaded Waveguide," Physical Review ST Accel. Beams 11, 041301(2008).

[5] F. Gao et al., "Multi-Nanosecond High Power Pulse Generation at 7.8GHz with a Dielectric-loaded Power Extractor," IEEE Transactions on Nuclear Science **56** (3), p. 1492 – 1497, (2009).

[6] C. Jing et al., "The First Experiment of a 26 GHz Dielectric Based Wakefield Power Extractor," in proceedings of IPAC 2010, Kyoto, May 2010.

[7] C. Jing et al., "Short RF Pulse Linear Collider," in proceedings of IPAC 2012, New Orleans, May 2012, pp1924-1926.

[8] C. Jing et al., "A Compact Soft X-Ray Free-Electron Laser Facility Based on a Dielectric Wakefield Accelerator," www.osti.gov/servlets/purl/1052039