TWO BEAM WAKEFIELD ACCELERATION AT ARGONNE WAKEFIELD ACCELERATOR FACILITY

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Abstract

Structure based wakefield acceleration provides a viable approach capable of accelerating a sufficient electrons and positrons in a substantially high graident needed to meet the luminosity, efficiency, and cost requirements of a future linear collider. The short pulse Two Beam wakefield Acceleration (TBA) studied at the Argonne Wakefield Accelerator Facility is aimed to pave the way toward the next linear collider. Here we present the latest results including the 100MeV/m of the single stage TBA and the staged TBA in which a 0.5nC bunch gained equal amount of energy in two stages (~2.4 MeV per stage, corresponding to an average acceleration gradient ~70 MeV/m). The technique is scalable to a staged-acceleration at 200-300MeV/m by using a GeV-scale drive beam. Such a development will considerably reduce both cost and footprint of a future high-energy physics collider as well as future X-Ray light source.

INTRODUCTION

Charged particle acceleration at substantially higher gradients than in today's conventional accelerators is necessary to open new possibilities in fundamental research. The enabling acceleration technology for a large scale accelerator facility must be featured with a high effective gradient, high efficiency, and inexpensive fabrication cost. A number of advanced accelerator concepts have been studied as the cadidate of this kind. Among them the structure-based wakefield acceleration scheme called two-beam acceleration (TBA) has a potential to meet all of the requirements. TBA is a technique that harnesses the wakefields from a high-current drive beam passing through a low-gradient decelerating structure (decelerator) to accelerate a low-current main beam in a high-gradient accelerating structure (i.e. accelerator) [1]. One advantage of TBA technology is its certain flexbility to select the operational frequency and rf pulse length. For example, the choice of 26GHz operational frequency and 20ns pulse length in one linear collider design has the potential to reach ~300MV/m of gradient with a comparable rf-to-beam efficiency [2]. However many critical technology elements of short pulse TBA still need to be demonstrated [3]. In this paper, we report on the progress on the short pulse TBA development at Argonne Wakefield Accelerator (AWA) facility [4] including the successful demonstration of one of key technologies called staging, where a beam is accelerated through two or more units of wakefield acceleration while preserving the beam quality.

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THE 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 Cs2Te 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

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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.

EXPERIMENT

The first demonstration of short pulse TBA staging was performed at the AWA facility. The beamline layout for staging, shown in Fig. 1, contains two decelerator–accelerator pairs (Stage1 and Stage2). The drive beam consisting of two drive bunch trains (DT1 and DT2, each one contains 8 high-charge bunches separated by 0.769 ns) traverses two decelerators producing rf pusles and feeding the paired accerlators through the connected RF waveguides. The main beam propagating in opposite direction gains energy through two accelerators (ACC1 and ACC2). Spacing between the drive beams, L_b, relates to the geometrical spacing between stages, L (L_b=2L) for synchronization to occur. For this simplified staging experiment, both drive trains passed through both stages but only the RF energy from one train was used to accelerate the main bunch in each stage (i.e. DT1 for Stage1 and DT2 for Stage2). This demonstration considerably simplifies the experimental requirements but at cost of efficiency. Nevertheless, it demonstrates that the main beam can be accelerated by the wakes of two separate drive beams through two modules thus satisfying the staging synchronization condition.

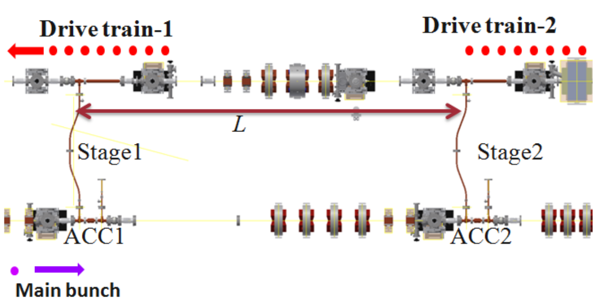

Figure 1: Configuration of Two-beam acceleration staging experiment at AWA.

Both the decelerators and accelerators are conventional 2π/3 mode to obtain a high R/Q. The AWA beam is produced by a 1.3 GHz photoinjector so that the TBA operating frequency is chosen to be 11.7 GHz, the ninth harmonic of 1.3 GHz. The power extractors are 30 cm long and with an aperture of 17.6 mm which is fairly large in order to pass a reasonable amount of charge without requiring a built-in complicated transverse mode damping feature. The group velocity in the structure is 0.22c, resulting in the structure of the RF pulse is such that the first five pulses in the train stack to give maximum gradient while subsequent pulses maintain the flat-top and add to the pulse width. The pulse generated by the 8 bunch train measured at the power extractor was FWHM=9 ns. The RF pulse is stretched to 14 ns during transmission through the couplers and waveguide, filling the accelerator structure. The accelerator structures are about 10 cm in length and have a much smaller 6 mm aperture, comprising 3 cells plus 2 matching cells. These traveling wave structures have a group velocity of 0.016c.

PROGRESS TO DATE

During the experiment, coarse timing between the drive and main beam was first set to a particular delay and then the X-band phase (fine timing) was scanned about this coarse delay. The coarse delay was controlled by moving the main beam delay stage by a fixed amount so as to completely scan the duration of the RF pulse (about 20 ns). Fine timing was controlled by sweeping the main beam L-band cavity phase. At each coarse delay position, the on-crest X-band phase (largest energy gain) and the 20 degrees off-crest phase (minimum energy spread) were found and recorded. The gradient was ~100MeV/m inside the accelerator powered by ~80MW RF pulse from the drive train of 8 bunches with average charge of 25nC/bunch.

The image of the main beam at the energy spectrometer is taken under four conditions: with no drive trains, with DT1, with DT2 and with both trains. The incoming energy of the witness bunch is ~ 8.5 MeV (centroid) with FWHM energy~ 0.3 MeV. Its energy became ~10.9 MeV after the first stage with FWHM~0.1 MeV. This corresponds to an effective accelerating gradient of ~70 MeV/m. When the drive train 2 alone is on, the witness bunch energy is increased to ~10.8 MeV with FWHM~0.5 MeV. This corresponds to ~68 MeV/m accelerating gradient. In the case of both drive train 1 and 2 are on, the centroid energy of witenss bunch is ~13.4 MeV, with FWHM~0.1 MeV. Total energy gain using both stages is 4.9 MeV which is ~70MeV/m of effective gradient in the structures.

The energy gain from the two stages together equalled the sum of the individual energy gains. The main beam gains energy from DT1and DT2 with ~2.4MeV each and 4.9 MeV total. This is the same as the sum of the energy gain from the two drive bunch trains measured separately to within experimental error, thus indicating successful staged acceleration. The gradient in the accelerating structure calculated from the ratio of the measured energy gain in MeV and the measured length of the structure averaged 70 MeV/m.

THE NEXT

With the success of demonstration of this simplified staging expriment we will move to the experiment of the full staging experiment which includes two stages with two TBA units in each stage. Two additional key components will be introduced in the next staging expeiment, beam kicker and high power rf delay line. The details refer to [5].

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