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THE TWO BEAM ACCELERATION STAGING EXPERIMENT AT ARGONNE WAKEFIELD ACCELERATOR FACILITY*

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Abstract

Staging, defined as the accelerated bunch in a wakefield accelerator continues to gain energy from sequential drive bunches, is one of the most critical technologies, yet be demonstrated, required to achieve high energy. Using the Two Beam Acceleration (TBA) beamline at Argonne Wakefield Accelerator (AWA) facility, we will perform a staging experiment using two X-band TBA units. The experiment is planned to conduct in steps. We report on the most recent progress.

STAGING EXPERIMENT AT AWA

Linear colliders based on two-beam wakefield acceleration have a modular design [1]. A fundamental requirement of two beam wakefield acceleration that has yet to be demonstrated is the staging of sequential accelerating modules. For a successful staging demonstration two key issues need to be addressed: drive beam separation and the timing between wakefields from different stages and the accelerated (witness) beam.

In many approaches a fast deflector is required to direct beams from a drive bunch train into separate power extractor units feeding sequential accelerating stages for a witness beam. In the case of an L-band driver at the AWA the drive beam spacing is 50 ns. Stripline kickers or RF deflecting cavities can be used as fast deflectors on this time scale. We propose to use a standard strip line kicker for this proposal.

Another important issue for a staging demonstration is ability to synchronize the witness beam with the wakes generated in different stages. The solution considered up to now has been to bend the drive beam, which raised questions about the energy loss and beam degradation caused by coherent synchrotron radiation. Here we propose a new design based on the time delay of RF pulses in different stages with respect to the witness beam. This approach eliminates the need to bend a high charge beam 180 degrees. For the design of the RF delay line one has to consider two factors: line length and attenuation.

Demonstration of wakefield acceleration staging is the next big step towards validation of the approach as a whole. It proves that wakefield acceleration is indeed possible in a modular way. Once staging is demonstrated one can achieve TeV energies by stacking these modules. This approach allows for length reduction of the accelerator, as wakefield acceleration yields a high gradient operation in a short pulse mode.

Technical Approach

Most of wakefield collider concepts relied on bending the drive beams out of the drive train into the power extractor units to catch the appropriate phase of the witness beam. We are trying to avoid the need for a 180° arc in the drive beamline because coherent synchrotron radiation and its effects on the drive beam become a concern. Figure 1 shows a two beam acceleration concept with an RF delay substituting for the 180° bend. There are two types of staging when relevant to this concept.

- Each module is driven by its own drive beam or a drive bunch train. Separate modules need to be synchronized to accelerate the main beam (Figure 1); this process is called inter-module staging. Spacing between the drive beams, L_b, relates to the geometrical spacing between modules, L (L_b=$2L$) for synchronization to occur. A fast kicker is used to direct the drive beam to its respective module.
- There are numbers of power extractor – accelerator pairs inside a single module. This is done to extract as much energy out of the drive beam as possible. These units also have to be synchronized representing an intra-module staging. In our design the drive beam enters the last (from the main (witness, accelerated) beam point of view) power extractor (the m^{th}) in each module. The generated rf is transported through a longer rf waveguide which provides a delay time t_{dm}. The delay time of the rf transport line in the $(m\text{-}1)^{th}$ TBA pair is $t_{d(m\text{-}1)}$. At the exit of the power extractor #1, drive beam is dumped after exhausting most of its energy. At the moment when the rf from the 1st power extractor fills the 1st accelerating structure, the main beam is launched. Because the rf filling time for each accelerating structure is the same, if we assume the rf delay of the transport line in the first TBA pair t_{d1}=0, then t_{d2}=$2L_s/c$, t_{dm}=$2\times(m\text{-}1)\times L_s/c$, where m is the number of structures in each module and L_s is the length of a single structure. Besides the timing in RF delay lines between separate power extractors we need to address the issue of possible RF losses.

Experimental Plan

As the first step towards demonstration of complete staging, a simplified staging experiment was proposed, which includes one power extractor–accelerator pair for

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each of two modules but no kicker is involved. For this simplified staging experiment, two drive trains will go through both modules but only the rf energy from one train will be used to accelerate the witness bunch in each module (i.e. drive train #1 for module#1 and drive train #2 for module #2). It simplifies the experimental requirements at cost of sacrificing the efficiency. Nevertheless it will demonstrate that the main (witness) beam can be accelerated by the wakes of two separate drive beams (bunch trains), i.e. inter-module staging.

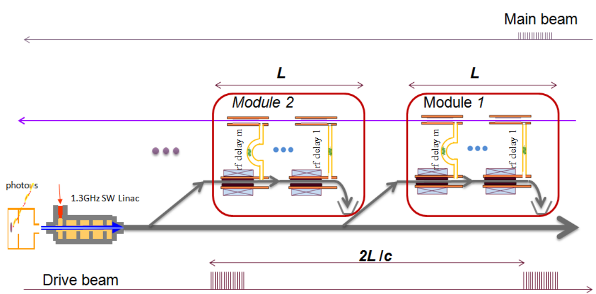

Figure 1: Two-beam acceleration staging using a fast kicker and high power RF delay lines.

Successful demonstration of simplified staging requires accurate timing between the wakes generated by two drive beams (bunch trains) (D_1 and D_2) and the timing of the witness beam entering its respective accelerating structures. This depends on the obvious relationship between module separation, L, and drive beam spacing $L_d = 2 \times L$. We also note that, in the configuration as shown, the drive beam D_1 generates a wake in power extractor in Module #2. However the main beam is not anywhere near the accelerating structure ACS_2 to experience the wake which is dumped into the RF load.

As the 2nd step, we will have two sets of power extractor-accelerator pair in each module. Both the kicker and the RF delay lines will be used as indicated in Fig.1.

PROGRESS TO DATE

Two X-band metallic power extractor-accelerator pairs were fabricated at Tsinghua University. One pair has been installed and tested. The frequency is determined by the drive bunch spacing. The AWA beam is produced by a 1.3 GHz photoinjector so that the operating frequency is chosen to be 11.7 GHz, the ninth harmonic of 1.3 GHz. Both the power extractors and accelerators are the conventional $2\pi/3$ mode to obtain a high R/Q. The effective structure length of power extractor is ~30 cm and the group velocity is 0.22c, resulting in 5 overlapped bunches and a rise time of 3 ns (refer to definition of drain time and T_b=769 ps for the AWA beam). The diameter of the beam opening is 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. 200MW pulsed rf can be reached for a train of 40nC/bunch.

The accelerating structures are five-cell (3cells+2matching cells) travelling wave structure with a 6mm of beam aperture and group velocity of 1.6%c. Under the input of 200MW, it can build up 200MV/m gradient on axis.

The first power extractor-accelerator pair has been installed at AWA beamline (See Fig.2). ~70MeV high charge drive beam passes through the power extractor from right to left shown in the picture. The generated power is delivered to the short accelerator through a bow shaped WR90 waveguide. The other side of accelerator is terminated by a SiC based RF load. RF power can be monitored by field probes located at output of the power extractor and the load. At a synchronized timing, a ~10MeV 1nC witness bunch will be injected to the accelerator from left to right shown in the picture to gain the energy.

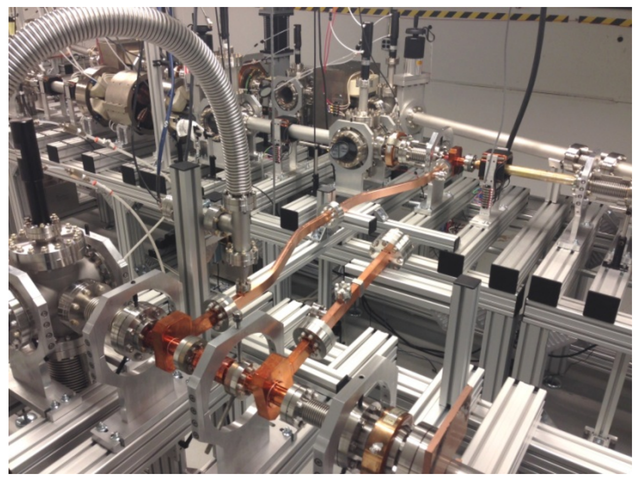

Figure 2: The installed two-beam acceleration pair at AWA facility.

The power extractor was tested before delivery of the witness bunch. Shown in Fig.3, the rf pulse by a train of 8 bunches, 18nC/bunch on average, was measured at output of the power extractor using a 20GHz scope. The measured rf power is 25MW, lower than the prediction, 40MW. The possible reason is the missing of fine tuning of bunch spacing inside the train, which will be corrected in the ongoing experiment.

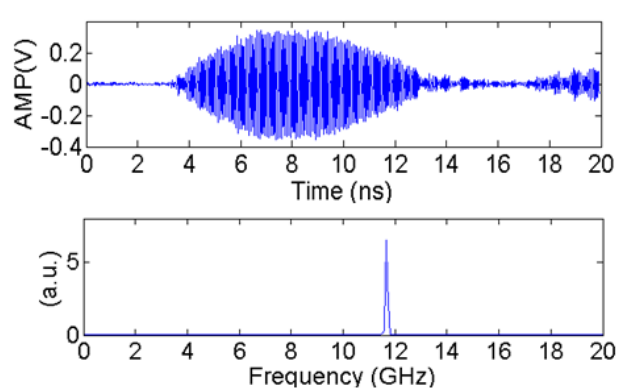

Figure 3: The measured rf pulse and its spectrum at output of the power extractor.

The coarse injection timing of witness bunch is set by the laser delay between the drive and witness

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photoinjectors to ensure that the witness bunch is injected after the accelerator being fully rf filled. The fine timing, i.e. injection phase, is tuned by the mirror mounted on a remotely controlled translation stage, to ensure the maximum energy gain at the downstream energy spectrometer of witness beamline.

The experimental results are shown in Fig.4 and Fig. 5. Figure 4 shows the maximum witness bunch acceleration, ~1.3MeV, by a rf pulse generated from the power extractor driven by a train of 8 bunches with ~12nC per bunch. Through changing of laser delay on the witness bunch side, we scanned its injection phase over the entire period of the incident RF generated from the power extractor. Energy gain and loss of the witness bunch are used to estimate the accelerating gradient as shown in Fig.5.

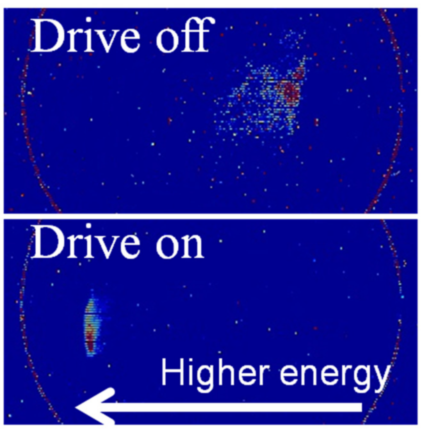

Figure 4: Acceleration of the witness bunch while the drive bunch train is on.

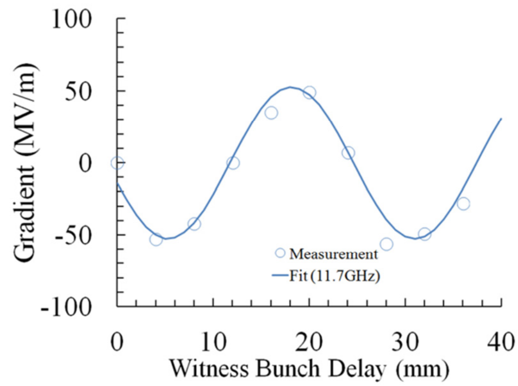

Figure 5: Accelerator gradient mapped out through the energy gain or loss of witness bunch at different delay positions in respect to the incident RF.

THE NEXT

With the success of demonstration of one TBA unit, we will continue efforts to install the second TBA unit and demonstrate the simplified staging within a few months.

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