RECENT TWO-BEAM ACCELERATION ACTIVITIES AT ARGONNE WAKEFIELD ACCELERATOR FACILITY

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Abstract

The Two-Beam Acceleration (TBA) is a modified approach to the structure-based wakefield acceleration which may meet the luminosity, efficiency, and cost requirement of a future linear collider. Recently, various TBA experiments have been carried out at the Argonne Wakefield Accelerator Facility (AWA). With X-band metallic power extractors and accelerators, a 70 MeV/m average accelerating gradient has been demonstrated in two stages while a 150 MeV/m gradient as well as 300 MW extracted power have been achieved in a single stage. In addition, low cost K-band dielectric power extractor and accelerator have also been developed. The preliminary results show power extraction of 55 MW and an average accelerating gradient of 28 MeV/m.

INTRODUCTION

Accelerating sufficiently large numbers of electrons and positrons at a gradient substantially higher than those achieved in the state-of-art technologies is a key factor for future linear colliders. Among numbers of advanced acceleration concepts, the two-beam acceleration is a promising candidate which may meet all requirements, including high gradient, high efficiency, and low fabrication cost [1]. In TBA technology, a low impedance decelerating structure (a.k.a. power extractor) extracts power from a high-current drive beam and feeds a high impedance accelerating structure to accelerate the main beam. By increasing the ratio of impedances of the two structures, high efficiency energy transfer can be easily implemented [2].

One significant advantage of the TBA technology is the certain flexibility to select the operating frequency, rf pulse length, and particle bunch structure. In the CLIC conceptual design based on TBA, normal conducting X-band metallic structures are proposed to generate a 240 ns rf pulse and accelerate a 312-bunch train (0.6 nC per bunch) with a 100 MV/m gradient [3]. While in the AWA approach, a much shorter rf pulse (<20 ns) is employed to achieve a higher gradient (targeted at 350 MV/m) [2, 4]. Besides, the AWA program is also developing dielectric structures because of their potential to withstand higher accelerating gradients and achieve lower fabrication cost [5, 6]. Some critical questions in the AWA approach are yet to be answered, such as the staged acceleration, the high gradient, the TBA with dielectric structures, etc.. In this paper, the latest progress of the TBA experiments at AWA will be presented.

TWO-BEAM ACCELERATION WITH X-BAND METALLIC STRUCTURES

One of the key technologies in TBA is called staging, where the main beam is accelerated through two or more stages of wakefield acceleration, without indication of beam quality degradation, i.e., the acceleration process does not cause a decrease of bunch charge transmission or an increase in energy spread [2]. Recently, the first demonstration of staging has been performed at AWA with X-band metallic structures.

The experimental setup is illustrated in Fig.1. The 50 MeV drive beam consisted of two 8-bunch trains (DT1 and DT2) and the bunch separation in each train was 0.769 ns (one period of the AWA 1.3 GHz rf system). The drive beam passed through the power extractor and generated wakefield rf power. The single-bunch 8.5 MeV main beam traveled in the opposite direction and gained energy in the accelerators. For synchronization, the spacing between DT1 and DT2 was set to twice of the geometrical distance between the stages. Compared with the full staging, the experiment was a simplified version where both drive trains passed through both power extractors but only rf power from one train was used to accelerate the main bunch in the corresponding accelerator (i.e. DT1 for Stage1 and DT2 for Stage2). Fast kickers would be required in the full staging to direct each bunch train to a single power extractor. Despite of the expense of energy efficiency, the experiment aims to demonstrate that the main beam can be accelerated by the wakefield of two separated drive beam through two stages, when the synchronization condition is satisfied.

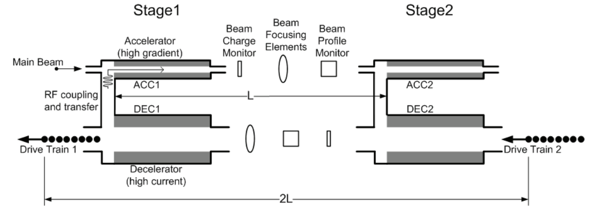

Figure 1: Configuration of the two-beam acceleration staging experiment at AWA.

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The metallic power extractors and accelerators applied in this experiment are conventional disk-loaded traveling-wave structures operated at $2/3\pi$ mode. The frequency is designed to be 11.7 GHz, the 9th harmonic of 1.3 GHz, for coherent wakefield superposition. The parameters of the structures are listed in Table 1.

Table 1: Parameters of the X-band Structures

	power extractor	accelerator
Aperture (mm)	ϕ17.6	ϕ6
Length (mm)	300	100
Normal cells	35	3
Matching cells	4	2
Group velocity	0.22c	0.016c
r/Q (kΩ /m)	3.9	16.5
Q	6370	6760

Given the length and group velocity of the power extractor, each drive train would generate a rf pulse with 3 ns rise-time, 3 ns flattop, and 3 ns fall-time [5]. Because of the finite bandwidth of the output coupler, the rf pulse transferred to the accelerator would be increased to 14 ns including 5.5 ns rise/fall-time. The energy gain of the main beam depended on the accelerating phase as well as the relative position within the rf pulse. Thus, timing precision on the order of a few degrees of the X-band period (picoseconds) was necessary and it was achieved by fine tuning the laser delay between the drive and main beam line.

In the staging experiment, a maximum output power of ~80 MW from the power extractors was obtained when the charge of the drive train was 25 nC per bunch. The energy measurement of the 0.5 nC main beam is illustrated in Fig 2. The results clearly show that the main beam gained energy from each drive train and indicate the successful staged acceleration.

With the same setup, the AWA program continued putting effort to increase the gradient in a single stage of acceleration. Limited by the beam break-up effect, the maximum charge transmitted through a single power extractor was ~45 nC per bunch in a 8-bunch drive train. ~300 MW rf power was produced and an average accelerating gradient as high as 150 MeV/m was obtained.

TWO-BEAM ACCELERATION WITH K-BAND DIELECTRIC STRUCTURES

In addition to the successful TBA using X-band metallic structures, the AWA program is also developing TBA with dielectric structures due to their potential to withstand higher accelerating gradient and achieve lower fabrication cost [5,6]. Recently, this technology has been first demonstrated.

The experiment setup is similar with that in the X-band staging except only one stage is installed, as illustrated in Fig. 3.

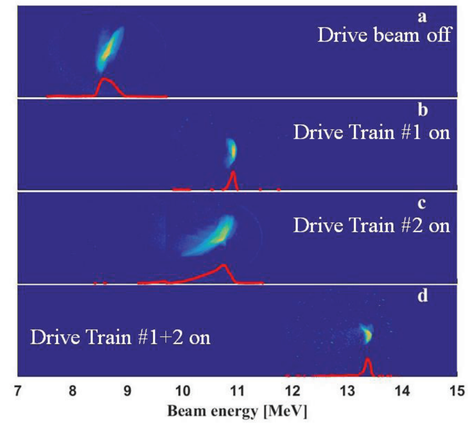

Figure 2: The image of the main beam in the spectrometer screen. The horizontal projection of the profile is plotted below each image (red). (a) No drive trains; (b) DT1 only; (c) DT2 only; (d) Both DT1 and DT2. The total energy gain using both stages is 4.9 MeV and the average graident is 70 MeV/m.

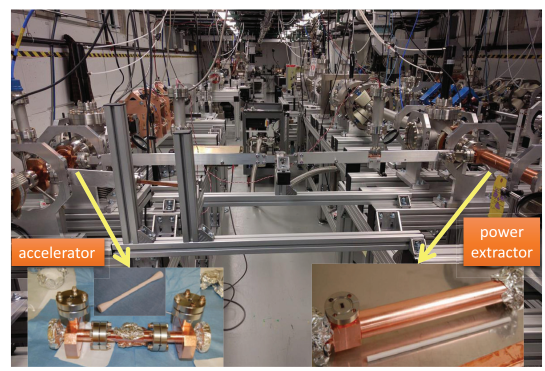

Figure 3: Configuration of the two-beam acceleration experiment with the K-band dielectric structures.

The frequency of the structures is designed to be 26 GHz, the 20th harmonic of the AWA 1.3 GHz rf system. The detailed parameters of the structures are listed in Table 2.

Table 2: Parameters of the K-band Structures

	power extractor	accelerator
Aperture (mm)	ϕ7	ϕ3
Material	Forsterite	Alumina
Dielectric constant	6.64	9.7
Loss tangent	1×10^{-4}	1×10^{-4}
Length (mm)	300	100
Group velocity	0.25c	0.011c
r/Q (kΩ /m)	9.8	22.0
Q	2950	2295

According to the length and group velocity of the power extractor, the maximum output power can be obtained with a 4-bunch drive beam [5]. More bunches in the drive train will only increase the flattop of the generated rf power. Based on the typical AWA drive bunch length of 1.5 mm (rms), 160 MW generated power from the power extractor and a 130 MeV/m peak accelerating gradient in the accelerator are expected when the charge of the drive train reaches 20 nC per bunch.

During the experiment, ~250 MHz detuning of the power extractor was discovered from the rf signal directly measured by a scope with 160 GS/s sampling rate, as illustrated in Fig. 4. To compensate this detuning and to achieve coherent wakefield superposition, the space of the bunches in the drive train was adjusted from 0.769 ns to 0.762 ns by launching them at different phases, which on the other hand, caused difficulties in beam transportation. Thus, the maximum charge transmitted through the power extractor was ~20 nC per bunch with a transmission of ~65 %. The maximum transferred rf power to the accelerator was measured to be ~55 MW, much lower than the expected value. One suspicion is that the bandwidth of the power extractor coupler is not wide enough to cover the detuned frequency so a portion of generated rf power was reflected back into the power extractor. The cause of the detuning as well as the coupling will be investigated in the future study.

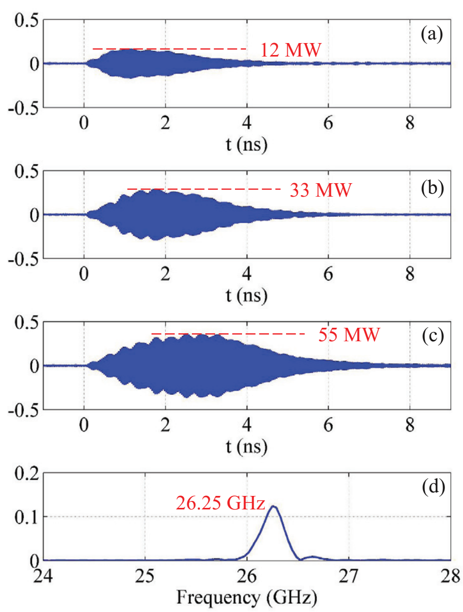

Figure 4: Measured rf signal transferred from the power extractor to the accelerator. (a) Single bunch; (b) 2-bunch train; (c) 4-bunch train; (d) FFT of the 4-bunch train signal, peaked at 26.25 GHz.

With 55 MW input power and a 250 MHz detuned frequency, the peak accelerating gradient in the accelerator is calculated to be 54 MeV/m. Given the shape of the rf pulse, the maximum acceleration can be further deduced as 1.8 MeV, which agrees well with the measured results as illustrated in Fig. 5. As the length of the uniform section in the accelerator is ~65 mm, the corresponding average accelerating gradient is 28 MeV/m.

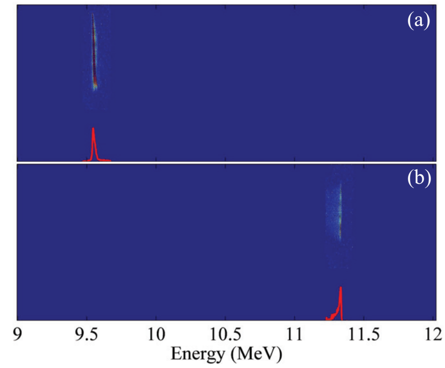

Figure 5: The image of the main beam in the spectrometer screen. The horizontal projection of the profile is plotted below each image (red). (a) Drive beam off, ~0.7 nC; (b) Drive beam on, ~0.2 nC.

CONCLUSION

The AWA program continues to investigate the frontier of the two-beam acceleration technology and has made significant progress during the past years. The staged TBA has been successfully demonstrated using X-band metallic structures, achieving an average accelerating gradient of 70 MeV/m in two stages. Meanwhile, a high accelerating gradient of 150 MeV/m as well as high power of 300 MW has been obtained in a single stage using the same structures. In addition, the first TBA using both dielectric power extractor and accelerator has also been demonstrated recently, in which 55 MW output rf power and a 28 MeV/m avarage accelerating gradient were achieved.

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