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STANDING WAVE DIELECTRIC DISK ACCELERATING STRUCTURE DESIGN AND FABRICATION

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Abstract

A Dielectric Disk Accelerator (DDA) is a metallic accelerating structure loaded with dielectric disks to increase coupling between cells, thus high group velocity, while still maintaining a high shunt impedance. This is crucial for achieving high efficiency high gradient acceleration in the short rf pulse acceleration regime. Research of these structures has produced traveling wave structures that are powered by very short (~ 9 ns), very high power (400 MW) RF pulses using two beam acceleration to produce these pulses. In testing, these structures have withstood more than 320 MW of power and produced accelerating gradients of over 100 MV/m. The next step of testing these structures will use a more conventional, klystron power source. A new standing wave DDA structure is being fabricated for testing on the Nextef2 test stand at KEK. Simulation results of this structure show that at 50 MW of input power, the DDA produces a 457 MV/m gradient. It also has a large shunt impedance of 160 MΩ/m and an r/Q of 21.6 kΩ/m. Cold testing of this structure will be conducted late summer 2024 with high power testing to be done in the fall.

INTRODUCTION

The future path for accelerators are compact, high energy linear machines. In order to minimize the footprint, high gradient accelerating cavities need to be developed. Dielectric Disk Accelerators (DDA) researched here are X-band dielectric disk loaded metallic structures are a promising candidate to be used in future accelerators. These structures have high shunt impedances and high accelerating gradients [1].

To produce high accelerating gradients, high peak input RF power are required and to limit the risk of breakdown, short RF pulses are used [2]. These pulses are created using Two Beam Acceleration (TBA). A high charge drive beam is produced and sent through a Power Extractor and Transfer Structure (PETS) [3]. This decelerates the drive bunch and transfers the created RF power packet to the DDA that accelerates a witness beam. The RF pulse length produced by the PETS in this research is ~9 ns.

In this paper we will review the outcomes of previous DDA experiments and discuss plans to test a new standing wave DDA on a klystron test stand at KEK.

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PREVIOUS DDA PROTOTYPES

Initially, two single cell DDA structures were designed and high power tested [4, 5]. A clamped design was selected for new designs due to difficulties with brazing on previous prototypes. During high power testing, the clamped single cell DDA withstood 321 MW of input power and achieved an accelerating gradient of 102 MV/m [6]. The test ran up to the amount of available RF power. During the experiment there were no optical signs of breakdown and in review of the recorded RF pulses during data processing there were also no signs of breakdown. After testing, the single cell clamped DDA was disassembled and visually inspected. Damage was found where the faces of the copper components meet when clamped. Figure 1 shows the damage. Since the damage was located outside the RF volume it was likely caused by uneven and insufficient clamping during assembly.

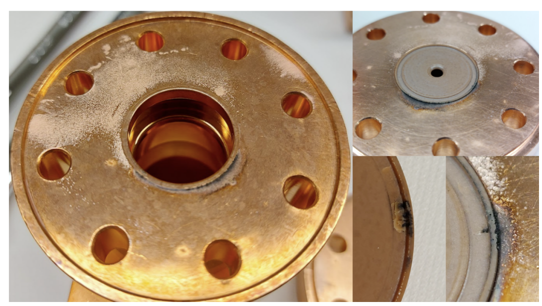

Figure 1: Damage seen on the copper and ceramics from the single cell DDA high power experiment.

Multicell DDA Structure

Following the success of the single cell clamped structure, a multicell clamped structure was designed and tested. The fabricated and assembled structure is seen in Fig. 2.

Structure Simulation The original design of the multicell DDA involved seven dielectric disks that made up six cells. The design emphasized maximizing the shunt impedance of the structure while also keeping the accelerating gradient as high as possible. Simulations were done in both CST and COMSOL [7, 8]. Table 1 summarises the simulation results for the six cell structure.

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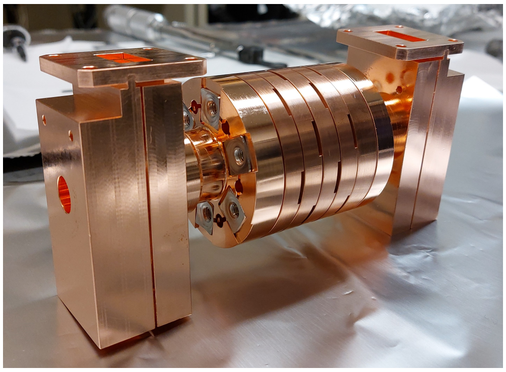

Figure 2: Assembled 5 cell DDA prototype.

Table 1: Simulation Results for 6 Cell DDA

Parameter	Simulated Values
Accelerating Gradient at 400 MW	108 MV/m
Group Velocity	0.24 c
Working Frequency	11.7 GHz
Cell Phase Advance	120 deg
Cell Length	8.541 mm
Quality Factor	9,612
r	184 MΩ/m
r/Q	19.2 kΩ/m

Fabrication and Assembly During fabrication, two issues were encountered. The original design of the multicell DDA included six dielectric cells that used seven ceramics but only 6 of the 15 ceramics sent to be fabricated could be used. An example of a damaged ceramic can be seen in Fig. 3. Because of this, the structure was assembled with only five cells. Additionally, the couplers were incorrectly brazed with a seven degree angle between the two rectangular waveguide flanges, which is discussed in [9].

Figure 3: Example of damaged ceramic that could not be used for assembly.

Cold Test Low power tests were done to measure the S parameters and on axis electric field of the five cell structure. Table 2 summarizes the results of the S parameter cold test. Both S_{11} and S_{21} bandwidths are sufficient for the high power test to be conducted. At the working frequency, the expected transmission of the structure is 76%, not considering waveguide losses. Figure 4 shows what the simulated electric field for the five cell DDA looks like compared to the measured beadpull, which is detailed in in [9].

Table 2: Simulated and Measured Values for the 5 Cell DDA

Parameter	5 Cell Simulated	Measured
S_{11} at 11.7 GHz	–22.25 dB	–21.52 dB
S_{21} at 11.7 GHz	–0.090 dB	–1.18 dB
S_{11} 10 dB Bandwidth	> 600 MHz	~ 600 MHz
S_{21} 3 dB Bandwidth	> 700 MHz	> 650 MHz

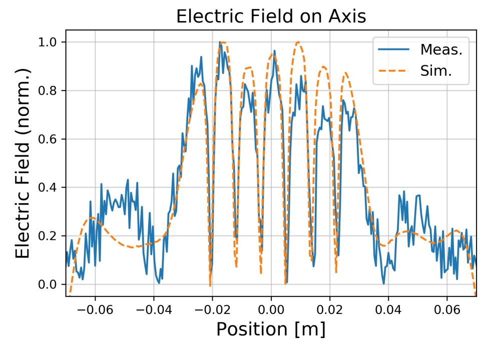

Figure 4: Measured and simulated E_z of the 5 cell DDA.

High Power Test High Power tests for the multicell DDA began November 2023 at AWA. The high power is produced using Two Beam Acceleration (TBA). Conditioning is an important part of the process to limit breakdown. If breakdown were to occur, testing would have to be stopped because the ceramic is likely damaged. When conditioning, the drive beam starts at a low value and is slowly increased to make sure that the structure can handle the increase in field. Figure 5 shows the charge that was recorded for each of the approximately 7000 pulses recorded.

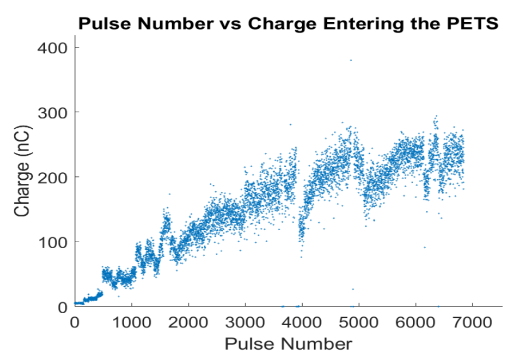

Figure 5: The charge of drive beam for each pulse.

The data collected for each pulse was the power going into, through, and reflected back from the DDA, charge of the drive beam before and after the PETS, and signals from the Faraday cup and ICT located in the vacuum chamber with the DDA. Results of the power into the DDA vs the power that passed through the DDA are seen in Fig. 6.

Testing was pause in November 2023 due to arcing the in the gun which lead to unstable charge levels and inability to increase the charge any further. Testing resumed early 2024 but faced the same issues. During the experiment, the highest charged reached 293 nC with a measured input power

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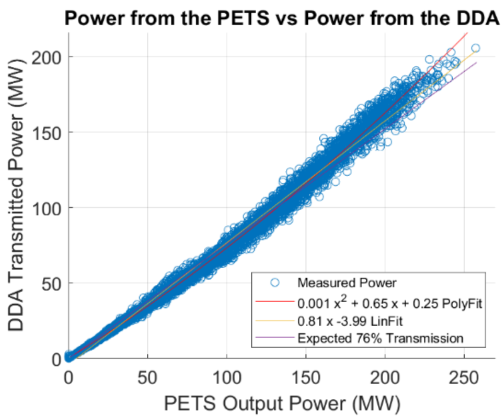

Figure 6: Input vs output power of DDA.

of 222 MW. This power equates to an accelerating gradient of 78 MV/m, according to simulations. During testing and after reviewing the power signals, ICT, and Faraday cup, no signs of breakdown occurred in the structure.

STANDING WAVE DDA STRUCTURE

A new standing wave, single cell DDA structure was fabricated for high power testing. Testing will take place using the Nextef2 test stand at KEK in Tsukuba, Japan. High power testing will be done using a long pulse klystron. This test will provide more information about how the DDA can handle these longer pulses and how it functions as a standing wave structure. Figure 7 shows the engineering design of the structure, featuring the cut off frequency beampipe at the end of the structure.

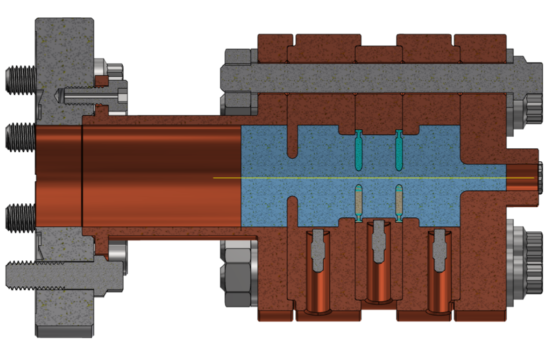

Figure 7: Standing wave DDA structure.

During testing, we can adjust the power level and the pulse length of the pulses going into the DDA. Conditioning will once again be a vital step to the experiment so short, low level pulses will be used at the beginning.

Simulations

Results on the simulations of this structure can be seen in Table 3. The accelerating gradient of this structure is significantly higher than what was seen in the previous structures. This is because this design is a standing wave structure. This change could be made by testing it with a klystron instead of using a PETS. The figure of 50 MW is likely larger than what can be achieved during testing but was used nominally. We expect to reach closer to 30 MW given the capabilities of the klystron.

Table 3: Simulation Results for Standing Wave DDA

Parameter	Simulated Values
Working Frequency	11.424 GHz
Accelerating Gradient at 50 MW	457 MV/m
Cell Phase Advance	120 deg
Cell Length	8.541 mm
Quality Factor	7,399
r	160 MΩ/m
r/Q	21.65 kΩ/m
E field enhancement	2.3

The electric and magnetic fields of the structure can be seen in Fig. 8. The fields of this structure resemble those seen in the previous structures.

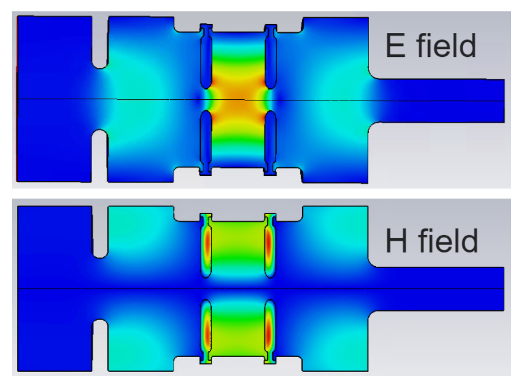

Figure 8: Standing wave DDA structure.

Fabrication

Due to a critical error during fabrication, a portion of the structure was remade. This set back the timeline of the structure several weeks. As of August 16, 2024, the structure has been successfully fabricated and critical dimensions are confirmed. Assembly and tuning will be done at AWA. The structure will then be sent to KEK to be remeasured and then high power tested. Testing will occur later this fall.

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