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SIMULATION AND EXPERIMENTAL RESULTS OF DIELECTRIC DISK ACCELERATING STRUCTURES

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Abstract

A method of decreasing the required footprint of linear accelerators and improving their energy efficiency is to employ Dielectric Disk Accelerators (DDAs) with short RF pulses (~ 9 ns). A DDA is an accelerating structure that utilizes dielectric disks to improve the shunt impedance. Two DDA structures have been designed and tested at the Argonne Wakefield Accelerator. A single cell clamped DDA structure recently achieved an accelerating gradient of 102 MV/m. A multi-cell clamped DDA structure has been designed and is being fabricated. Simulation results for this new structure show a 108 MV/m accelerating gradient with 400 MW of input power with a high shunt impedance and group velocity. The engineering design has been improved from the single cell structure to ensure consistent clamping over the entire structure.

INTRODUCTION

To create high power, small footprint linear accelerators, high gradient structures need to be utilized. Dielectric disk loaded accelerating structures can provide large acceleration to beams while being more compact than traditional accelerating structures. Dielectric accelerating cavities were first proposed because of their theorized high shunt impedances and high accelerating gradients [1]. In recent years Dielectric Loaded Accelerators (DLA) have proven more attractive than Dielectric Disk Accelerators (DDA). DLA structures are copper structures that are lined with dielectric tubes. DDA structures are loaded with dielectric disks equally spaced along the copper structure. DDA structures may be better suited for use in a high power, small footprint linear accelerator than a DLA because a DDA structure has a higher shunt impedance and RF to beam efficiency and a smaller input power requirement to achieve the same accelerating gradient [2]. In this paper, the experimental results from a single cell DDA structure will be presented and designs for a multi-cell structure will be shown.

SINGLE CELL DDA STRUCTURE RESULTS

Two single cell DDAs have been tested at high power at the Argonne Wakefield Accelerator (AWA). The first structure experienced problems due to the braze joint design [3]. To avoid these issues, a single cell clamped DDA structure was designed and high power tested.

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Design of a Single Cell Structure

A single dielectric cell is made up of two ceramic disks. The ceramic-copper interface was designed with elliptic rounding to minimize the field enhancement in the triple junction region. The head of the ceramic was designed so that it bit into the copper during assembly and was held securely in place, as seen in Fig. 1.

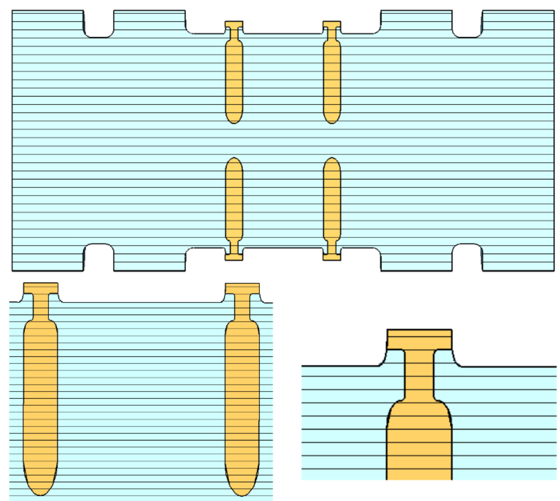

Figure 1: The RF design of the single cell clamped DDA structure. The upper figure shows a cross section of the entire structure. On the bottom left is one dielectric cell and the bottom right shows the detail of the head of the ceramic.

High Power Results

High power testing was conducted at the Argonne Wakefield Accelerator. The goal of high power testing was to determine the maximum accelerating gradient and peak ceramic surface electric field achievable. High power, short RF pulses were produced at the AWA by decelerating high charge bunches and transferring the extracted RF power to the DDA [4].

During testing, the DDA structure withstood up to 320.9 MW of input power and achieved an accelerating gradient of 102 MV/m. The maximum input power was limited by the available drive beam charge at the AWA. During testing and in review of the recorded RF pulses, there was no evidence of breakdown observed. Figure 2 shows the transmitted vs. input power to the DDA structure. The experimental data matches the predicted results well. The

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linearity of the graph also suggests there was no significant breakdown during testing.

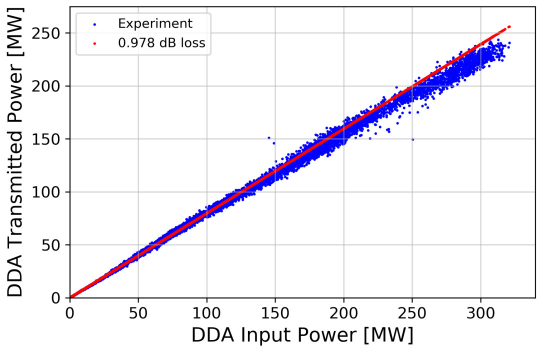

Figure 2: Power transmitted through the clamped DDA structure vs the input power into the structure. The blue dots are experimental data points and the red are the expected value determined from the measured loss of structure.

Visual inspection after high power testing showed some damage outside the expected area where RF power should reach, suggesting that the damage was caused by inadequate clamping. This will be addressed in future clamped designs.

MULTI-CELL STRUCTURE DESIGN

A multi-cell clamped structure has been designed based on the success of the single cell clamped structure.

RF Design of a Multi-Cell Structure

The multi-cell DDA structure is an X-band structure designed to work at 11.7 GHz. The RF design used for this structure is similar to the previously tested single cell clamped DDA structure, with the same head detail and dielectric cell length seen in Fig. 1 but uses seven ceramics to create six dielectric cells. Results were simulated using CST [5] and COMSOL [6].

RF results are seen in Table 1 and the cross section of the electric and magnetic fields are in Fig. 3. With an input power of 400 MW, an accelerating gradient across all dielectric cells is 108 MV/m.

Table 1: Simulation Results for the Multi-cell DDA Structure

Parameter	Value
Dielectric Constant	47.75
Loss Tangent	0.0002
Accelerating Gradient at 400 MW	108 MV/m
Group Velocity	0.24 c
Quality Factor	9,612
r	184.4 MΩ/m
r/Q	19.18 kΩ/m
Phase Advance	$2\pi/3$
$E_{surface,max}/E_{acc}$	1.44

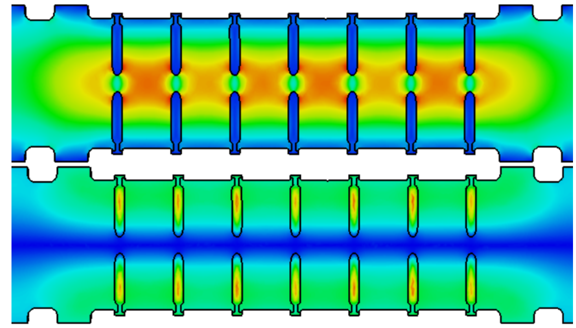

Figure 3: Cross section of the average electric (upper subfigure) and average magentic field (lower subfigure) of the multi-cell DDA structure.

The electric field on-axis is seen in Fig. 4. In Fig. 4, the central six maxima are located in the center of two dielectric disks and the outer maxima points correspond to the matching cells. A design consideration for multi-cell structures is the field balance between the cells. The average electric field for the second and fifth cells are lower than the others by about 8%. Ideally the average field would be closer in value for all the cells but because this structure will be high power tested and not used to accelerate a beam, the balance is not critical. This will be taken into consideration for future full scale structures.

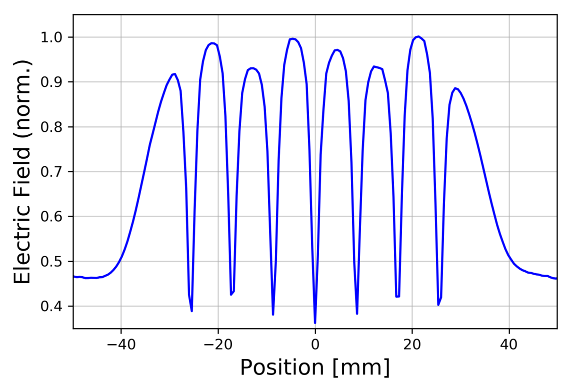

Figure 4: Simulated normalized electric field on-axis for the clamped multi-cell DDA structure.

Engineering Design

Mechanical parameters of the multi-cell structure are summarized in Table 2. This structure uses a clamped assembly. To address the issue of uneven clamping that led to the damage seen in the single cell structure, a more sophisticated clamping mechanism was designed.

The engineering design can be seen in Fig. 5. There are seven ceramics with copper pieces placed between them to create the dielectric cells. During assembly, a ceramic will be placed within a counterbore in one copper piece and then a second copper component will be stacked on top of it and

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clamped securely with six screws. This process is repeated for each cell to ensure each are tightened correctly. The screw positions are rotated for each copper component such that the position is between the screws of the components on either side. During assembly, a torque wrench will be used to ensure an even tightening for every screw.

Table 2: Mechanical Parameters for the Multi-cell DDA Structure

Parameter	**Value**
Disk Outer Diameter	20.48 mm
Dielectric Cell Diameter	2.239 mm
Matching Cell Iris Diameter	18.4 mm
Matching Cell Diameter	22.86 mm
Disk Thickness	1.45 mm
Dielectric Cell Length	8.541 mm
Number of Ceramics	7

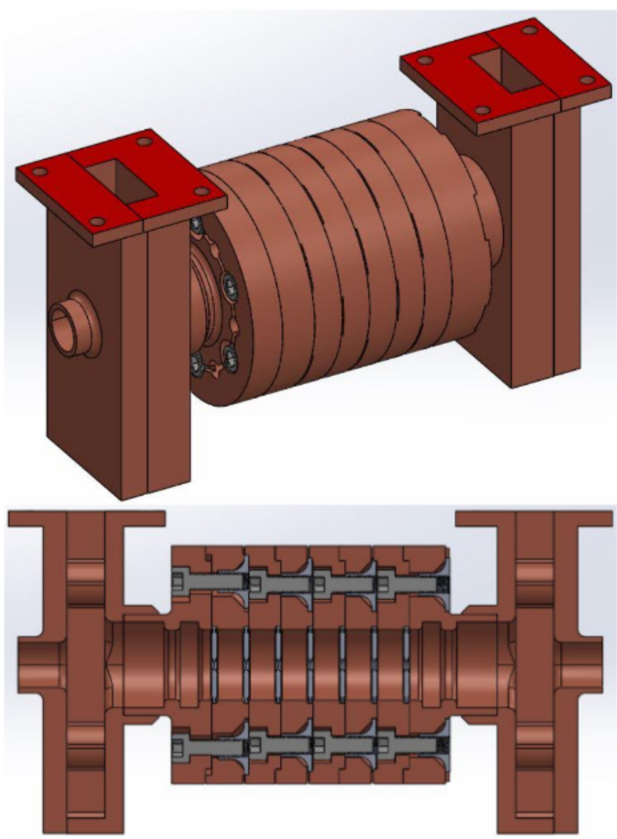

Figure 5: Engineering design of multi-cell DDA structure. Top - isometric view, bottom cutaway view.

CONCLUSION

Dielectric disk accelerating structures are attractive candidates for use in future linear accelerators that require large accelerating gradients. A clamped single cell DDA produced successful results and a clamped multi-cell DDA has been designed. Simulated results from the multi-cell structure are comparable with the single cell. Fabrication has begun, with high power testing to follow.

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