

A TRANSVERSE MODE DAMPED DLA STRUCTURE*

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Abstract

As the dimensions of accelerating structures become smaller and beam intensities higher, the transverse wakefields driven by the beam become quite large with even a slight misalignment of the beam from the geometric axis. These deflection modes can cause inter-bunch beam breakup and intra-bunch head-tail instabilities along the beam path, and thus BBU control becomes a critical issue. All new metal based accelerating structures, like the accelerating structures developed at SLAC or power extractors at CLIC, have designs in which the transverse modes are heavily damped. Similarly, minimizing the transverse wakefield modes (here the HEM_{mn} hybrid modes in Dielectric-Loaded Accelerating (DLA) structures) is also very critical for developing dielectric based high energy accelerators. We have developed a 7.8GHz transverse mode damped DLA structure. The design and bench test results are presented in this paper.

METHOD TO DAMP TRANSVERSE MODES IN A DLA STRUCTURE

Minimizing transverse wakefield effects in high gradient accelerating structures is of critical importance for future high-energy accelerator design. Like a metal accelerating structure, when an off-axis particle travels through a Dielectric-Loaded Accelerating (DLA) structure, parasitic modes (HEM_{mn} for a DLA structure) will be excited which can impart transverse deflection forces to trailing particles and degrade the beam quality if they are not sufficiently suppressed. An rf accelerating structure that has a very low quality factor Q for the deflection modes while maintaining a high Q for the accelerating modes would then be desirable, since the unwanted modes can be selectively damped. The first version of a dielectric based hybrid mode damping device was proposed by Chojnacki [1]. Following a similar principle, we have proposed and developed a new 7.8GHz *Transverse Mode Damped DLA* (TMDDLA) structure. Figure 1 shows its conceptual configuration. In brief, the deflection modes in a DLA structure have all six cylindrical coordinate field components and will require both azimuthal surface currents and axial surface currents; If the conductors are slotted to allow only axial surface currents, the deflection modes will not be confined and will radiate beyond the outer wall, establishing a surface wave, or trapped mode, within an outer uniformly conducting boundary if it exists. If these slots are filled with rf absorbing material, the deflection modes will be highly attenuated.

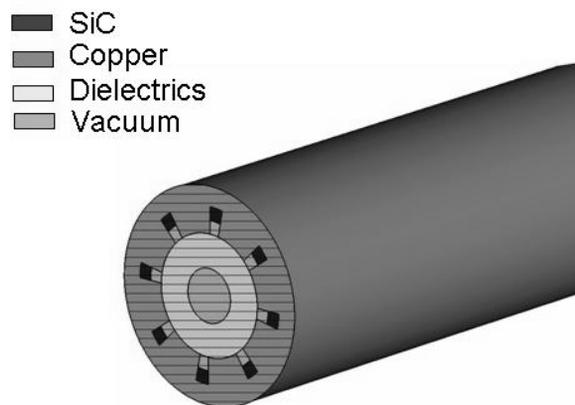


Figure 1: Scheme to damp transverse modes in a dielectric loaded accelerating structure.

A 7.8GHZ TRANSVERSE MODE DAMPED DLA STRUCTURE

We have developed a 7.8GHz TMDDLA structure to demonstrate the method to strongly suppress the hybrid modes (transverse modes) in DLA structures. The major parameters and dimensions of the device are described in [2]. For comparison, Figure 2 and 3 plot the electric fields of the TM_{01} and HEM_{11} modes in both a conventional DLA structure and the transverse mode damped DLA structure. The basic parameters for both structures are the same except that the transverse mode damped structure has eight slots. SiC used in the damping DLA structures is assumed to have a dielectric constant of 13 and loss tangent of 0.22 at C-band. The ratio of total slot width to the circumference is 22%. The uniformity of the accelerating field is not affected by these opening slots since the E_z component across the vacuum channel of the DLA structure is always independent of r .

Simulation shows that the Q of the accelerating mode has only a 3% (from 6964 to 6738) greater loss than the conventional DLA structure due to the slight increase of current density on the copper wall (slot effect). Meanwhile the Q of the transverse mode HEM_{11} is strongly damped in the TMDDLA structure (from 6866 to 23).

Simplicity of making a dielectric based accelerator is always pointed out as one of its advantages over metal based accelerating structures. This criterion is maintained for the transverse mode damped DLA structure as well although it is slightly more complicated than the fabrication of a conventional DLA structure. The key part

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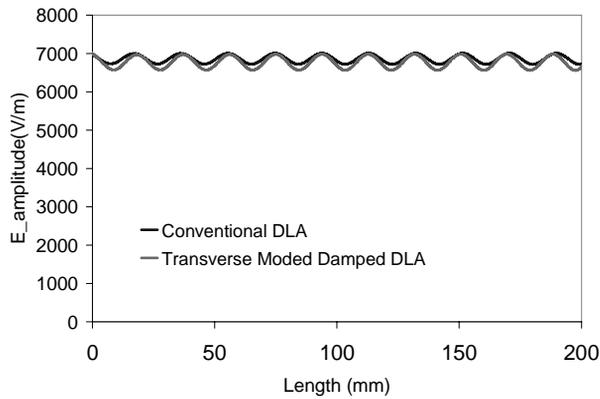


Figure 2: Comparison of the amplitude of the accelerating field on axis (E_z , TM_{01} mode) in both a conventional and transverse mode damped DLA structure. The field strength is valued per half watt input power.

of the TMDDLA is a slotted copper jacket which is to house a dielectric tube so that only the boundary conditions of the longitudinal modes (TM modes) can be maintained. These slots are also used to house the rf absorbing material. Due to the slot openings, the transverse modes cannot be confined inside the tube. The leaked energy needs to be absorbed by a microwave lossy material. Some microwave absorbing material is also vacuum friendly, like SiC. Moreover, it can be brazed to the copper jacket so that the best thermal contact can be maintained in order to transfer the thermal heating from the leaked transverse modes to the outside (or through cooling channels if necessary in a high current beam situation). The rf absorbing material we used is an AlN-SiC compound (Ceralloy 13740Y) provided by Ceradyne Inc.

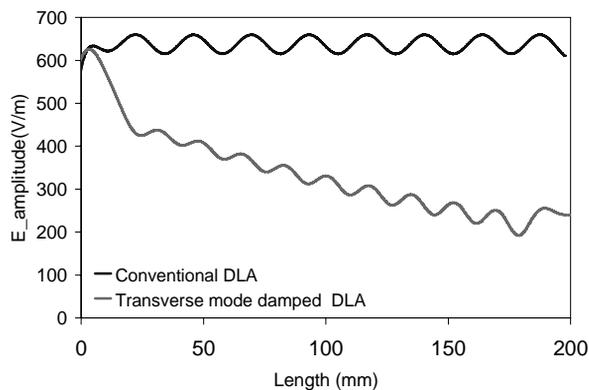


Figure 3: Comparison of the strength of the transverse field for a 1mm off-axis beam (E_z , HEM_{11} mode) in both conventional and transverse mode damped DLA structures.

The whole structure will slide into a vacuum pipe, which can form a metal boundary for the leaked transverse mode (although this boundary may not entirely contain the modes synchronized to the passing beam). The more rf absorber in the slots, the less transverse wave

energy can be leaked into the vacuum pipe. The finished structure and vacuum pipe are shown in Fig. 4. Also, in Fig. 4, note that there is a small hole at roughly the center of the structure which is for a probe. We plan to use a high frequency rf probe to detect the excited wakefield signal in the structure. The probe has a 1.33" CF flange to seal the vacuum. The pin tip and part of the outer conductor will be inserted into the hole on the TMDDLA (or the conventional DLA) structure so as to minimize the interference from other microwave radiation noise inside the beamline. The rf probe uses a 3.5mm connector and 'air' (no dielectric) coaxial line at the vacuum side which make it perform well in the microwave region.



Figure 4: The 7.8GHz transverse mode damped DLA structure and the customized vacuum pipe with a vacuum sealed rf probe.

To evaluate the performance of the 7.8 GHz TMDDLA structure after the machining and assembling process was complete we have performed a series of RF bench measurements. The first measurements were mode excitation tests where we used the network analyzer to measure the transmission coefficients (S_{21}) of the device for both the longitudinal and transverse mode. During the measurement a pair of TM_{01} or HEM_{11} mode launchers was used to drive and receive either the fundamental monopole mode (TM_{01}) or transverse mode (HEM_{11}) at the ends of the structure. In order to help accurately identify the different modes, we used two end plugs to build up standing wave in the structure. Pin probes in the launcher can be centered or offset to excite either the TM_{01n} or HEM_{11n} modes in the structure.

In most cases, parameters of a traveling wave accelerating structure can be obtained from standing wave measurements [3]. The values of r/Q for the traveling wave case are simply twice those for the standing wave case. The values of Q are the same for the SW and the TW cases. In the bench test, we measured the Q of TM and HEM modes of the structure in the standing wave case, which can be easily and accurately obtained. Figure 5 shows the measurement of the TMDDLA structure using the N5230C network analyzer. Note that the length of the loaded quartz tube has been reduced to 150mm in the bench test to accommodate the end plugs and mode

launchers. In the future beam test, we will use a 200mm long quartz tube, since no end plugs are required in that case. We use two techniques to measure Q of the structure, the reflection type method (using S_{11}) and the transmission type method (using S_{21}). Both methods obtained Q ~800 for the TM_{01} mode in the transverse mode damped DLA structure. This value is far below the result from the simulation. The dominant reason for this is the field leak at the both ends of the structure. If the end plugs are brazed to the copper wall, the Q will be close to the ideal case in the simulation.

Figure 5 shows the mode excitation in the transmission

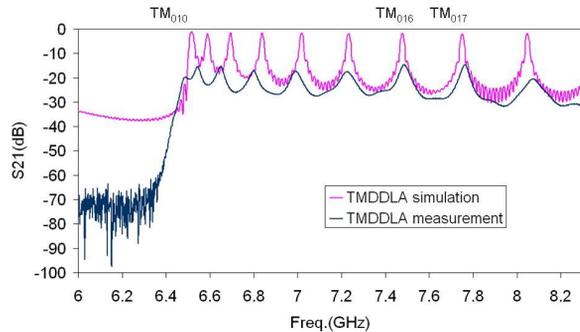


Figure 5: Comparison of the simulation and measurement of the transmission response of the 7.8GHz TMDDL structure in the standing wave case while using an offset excitation to attempt to drive the transverse modes.

response of the TMDDL structure while using an offset excitation. Both the measurement and simulation show the pure TM_{01n} modes excitation. No transverse mode (HEM mode) can be build up to a steady state in the structure. In other word, Q of the transverse mode in a TMDDL structure is too low to be measured in the frequency domain (measurement of the S-parameters using a network analyzer is a steady state measurement). A time domain measurement may capture the transient response of the transverse mode. Note that the structure is designed to have a synchronized frequency at 7.8GHz (phase velocity of TM_{01} mode at this frequency is the speed of light). In the standing wave case, the TM_{017} mode has a similar field distribution to the traveling wave case although its frequency may be a slightly away from 7.8GHz (This can be corrected by tuning the structure length in a real standing wave accelerating structure design). Meanwhile, the fundamental transverse mode, HEM_{11} , has a synchronized frequency of 6.34GHz. In the standing wave case, the HEM_{116} mode has a similar field distribution to the traveling wave case.

In order to have a better understanding of the measurement of the transverse mode damped DLA structure, we built a 7.8GHz conventional DLA structure as a comparison which shares the same parameters as the TMDDL structure. We also used the offset pin probe to excite the transverse modes. Figure 6 shows clearly that

the dominant transverse mode, HEM_{11} is excited and builds up the HEM_{11n} standing wave modes along with

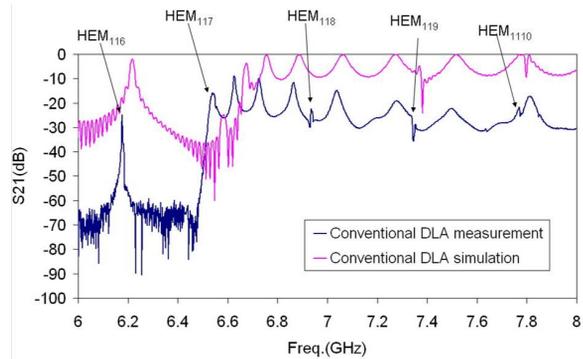


Figure 6: Comparison of the simulation and measurement of the transmission response of the 7.8GHz conventional (undamped) DLA structure in the standing wave case while using an offset excitation to excite the transverse modes.

the longitudinal modes TM_{01n} . Q of the TM_{017} mode, which is equivalent to the synchronized TM_{01} mode in the traveling wave case, was measured to be ~1000. The Q measurement was done by using center excitation to avoid the interference from the neighboring HEM_{11} mode. Frequencies of the standing wave TM_{01} modes for each structure are not overlapped. This may be caused by slight dimensional differences in the fabrication of the two structures and differences in the perturbation from the mode launcher when performing the measurements.

NEXT STEP

The main objective of the project is to perform a number of proof-of-principle experiments to demonstrate the feasibility of using the new transverse mode damping scheme to suppress the transverse modes in a dielectric-based accelerator. The experiments include the beam tests of a transverse mode damped DLA structure and a conventional DLA structure so that we can obtain a direct comparison. These experiments will establish a baseline for characterization of the proposed transverse mode damping methods and technology and will lead to a full featured high gradient dielectric loaded accelerating structure and/or a full featured dielectric-based wakefield power extractor for a two beam acceleration scheme.

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