Development of Transverse Modes 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 HEMmn hybrid modes in Dielectric-Loaded Accelerating (DLA) structures) is also very critical for developing dielectric based high energy accelerators. In this paper, we present the design of a 7.8GHz transverse mode damped DLA structure currently under construction, along with plans for the experimental program.

Keywords: Dielectric-Loaded Accelerating (DLA) structures, wakefield, dipole mode.
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INTRODUCTION

The conventional Dielectric-Loaded Accelerating (DLA) structure is very simple - a cylindrical, dielectric tube with an axial vacuum channel is inserted into a conductive sleeve. The dielectric constant and the inner and outer radii of the dielectric tube are chosen to adjust the fundamental monopole mode (TM_{01}) frequency to be synchronized with the passing beam (the phase velocity of the mode will equal the beam velocity ~ c). When electron bunches travel through the vacuum channel of the DLA structure, they can gain energy from fields generated by an external RF source or lose energy due to electromagnetic Cherenkov radiation (wakefields) while propagating down the vacuum channel.

The accelerating mode used in the DLA structure is typically the TM_{01} mode. In the ultrarelativistic limit the axial electric field in the beam channel is independent of the radial coordinate [1]. This implies that there are no focusing and de-focusing forces for a relativistic particle traveling inside the vacuum channel from the Panofsky-Wenzel theorem [2]. However, the particle induced wakefields for the general case of an off axis beam can be decomposed into longitudinal and transverse modes. The transverse modes will produce a nonvanishing deflecting force on the particles inside the leading and trailing bunches and can cause beam breakup in the accelerator if it is too strong. The most harmful transverse modes in dielectric-lined circular waveguides

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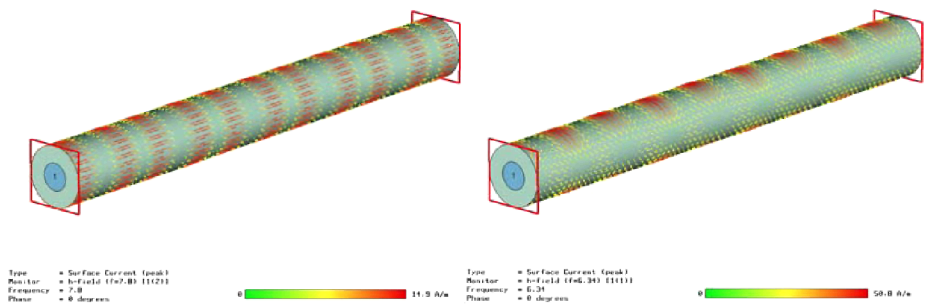
are the hybrid modes (HEM_{mn}, where m and n refer to the azimuthal and radial harmonics respectively). The lowest frequency mode is the HEM_{11}.

In the case of an iris-loaded metal accelerating structure, manifolds can be used to damp the parasitic (dipole) modes [3]. For a DLA structure, the AWA group at Argonne National Laboratory has demonstrated a method to suppress the HEM modes [4]. Segmented conductors were placed around the outside of the dielectric layer (using epoxy to hold the segments in place). These segmented conductors interrupt the azimuthal surface currents needed to support the magnetic components of HEM modes so that the HEM modes will not be confined within the structure. But for TM modes which require only longitudinal currents, these conductors are still capable of confining the wave and thus have no influence on the TM modes.

Figure 1 shows the EM simulation of the surface current distribution of the accelerating and transverse modes for a C-band DLA structure. It clearly shows that the TM_{01} (and all TM_{0n}) mode (left) is supported only by the longitudinally flowing surface current since it has only an azimuthal component of the H-Field, while the surface current of the HEM_{11} (and similarly, HEM_{mn}) mode (right) has strongly transverse component. This fact provides us an approach to damp the hybrid modes without a large perturbation of the propagation of TM_{01} mode.

The major characteristic parameters of the DLA structure shown in Fig.1 are summarized in Table 1 as a comparison with the transverse mode damped DLA structure that we will present in the next section. The parameters of both TM_{01} and HEM_{11} modes are shown. (The Quality factor Q in Table 1 is computed based on the copper wall losses and a dielectric loss factor of 0.5×10^{-4}; the R/Q of the HEM_{11} mode is calculated with 1 mm offset of the beam trajectory from the axis.)



(a) (b)

FIGURE 1. Surface currents of the accelerating mode (TM_{01},(a)) and the major transverse mode (HEM11, (b)) of the 7.8 GHz dielectric loaded accelerating structure (dimensions as in Table 1).

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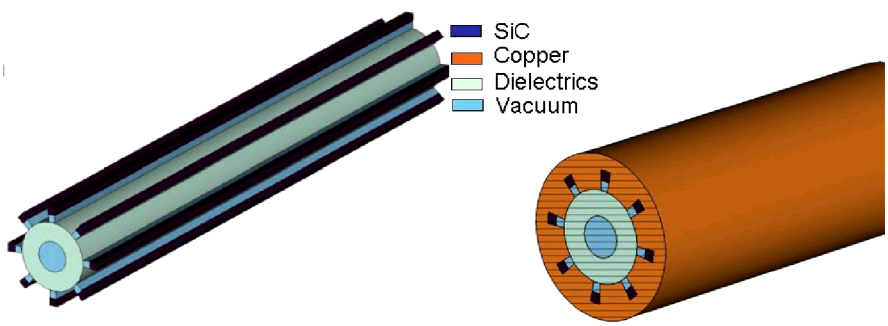
TABLE 1. Parameters of 7.8GHz DLA structure.

Geometric and accelerating parameters	value
ID / OD of dielectric tube	10 mm /11.36 mm
Dielectric constant	3.78
Loss tangent	0.5×10^{-4}
Length of dielectric tubes	200 mm
Synchronous frequency of TM_{01}/HEM_{11} mode	7.8 GHz/6.34 GHz
Group velocity	0.27c/0.36c
R/Q of TM_{01}/HEM_{11} mode	6828(Ω/m)/ 41(Ω/m/mm)
Q of TM_{01}/HEM_{11} mode	6964/6738

DESIGN OF A C-BAND HIYBID MODE DAMPED DLA STRUCTURE

Using a similar concept to that presented in [4], we designed a more vacuum friendly and higher performance transverse mode damped DLA structure. Figure 2 shows a 3-D model, in which the left part is used in the EM simulation where the background is a perfect conductor. Instead of a uniform outer conductor, we cut a number of slots around the copper jacket of the conventional DLA structure so that only axial surface currents are allowed to flow along the copper inner surface. The non-axisymmetric hybrid modes that are comprised of all six cylindrical field components will require azimuthal surface currents on the region of the conductor boundary and thus will leak out past the slots. The inserted SiC slab, which is a very vacuum friendly material and has been used successfully in high power rf loads [5], will heavily attenuate the hybrid modes. Meanwhile, the TM_{01} (or generally TM_{0n}) mode will maintain a good propagation with only a slight sacrifice of Q due to the increased surface current intensity between the slots (compared to a continuous conducting boundary). Since the ratio of total slot width to the overall circumference is small, this perturbation of the TM_{0n} modes can be ignored.



(a) (b)

FIGURE 2. 3-D view of the proposed transverse mode damped DLA structure. (a) model for the CST Microwave Studio ® simulation; (b) artistic view.

Figure 3 and 4 plot the electric fields of the TM_{01} and HEM_{11} modes in both the conventional DLA structure (dimensions shown in Table 1.) and the Transverse Mode

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Damped DLA (TMDDLA) 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 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 [1].

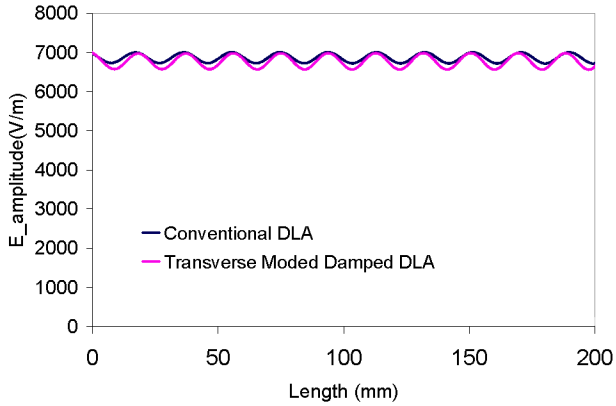

FIGURE 3. Comparison of the amplitude of the accelerating field on axis (Ez, TM_{01} mode) in both the conventional and transverse mode damped DLA structure.

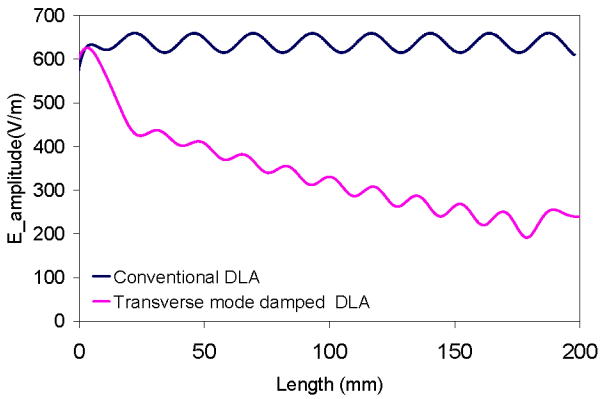

FIGURE 4. Comparison of the strength of the transverse field for a 1mm off-axis beam (Ez, HEM_{11} mode) in both the conventional and transverse mode damped DLA structure.

Table 2 shows the Q of the accelerating mode and transverse modes for both the conventional and TMDDLA structure. The geometry of the TMDDLA structure is the same as that shown in Figure 5 (eight slots). The results are from an EM simulation using CST Microwave Studio®. It clearly shows the transverse modes will be seriously damped in the TMDDLA structure while the accelerating mode has only a 3% greater loss than the conventional DLA structure.

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TABLE 2. Comparison of the 7.8GHz Conventional and the Transverse mode Damped DLA structure.

	Freq.	Q in conventional DLA structure	Q in transverse modes damped DLA structure
Accelerating mode (TM_{01})	7.8GHz	6964	6738
Transverse mode (HEM_{11})	6.34GHz	6866	23

EXPERIMENTAL PLAN

The experiment is planned to be performed at Argonne Wakefield Accelerator facility, where it can provide a 30MeV, 40 nC, short bunch length (2mm rms) bunch train with an upgraded high QE cathode and an additional RF station. Figure 5 shows both the longitudinal and transverse wakefields in the 7.8 GHz conventional DLA structure. A single 30MeV, 40nC electron bunch launched at 1 mm offset from the structure center line is assumed in the calculation. The bunch length used in the calculation is 4 mm (the bunch length at the AWA facility can be elongated from the nominal 2mm by using the laser pulse stacking technique). The mode spectra for both longitudinal and transverse wakefields are plotted in Fig.6. Two major dipole modes (HEM_{11} at 6.34 GHz and HEM_{21} at 11.27 GHz) and two monopole modes (TM_{01} at 7.8 GHz and TM_{02} at 19.9 GHz) contribute to the transverse and longitudinal wakefields respectively.

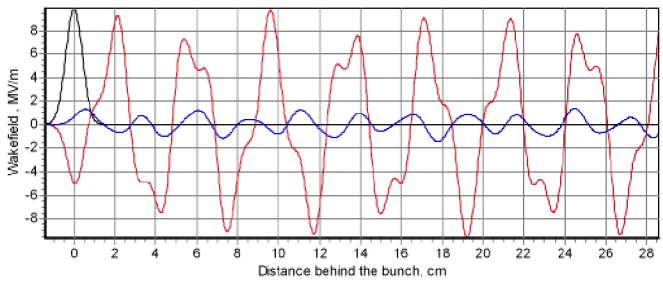

FIGURE 5. The longitudinal (red curve) and transverse (blue curve) wakefields in the 7.8GHz conventional DLA structure. The beam profile is in black.

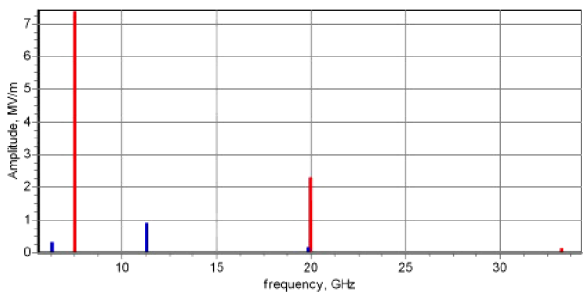

FIGURE 6. Spectrum of the longitudinal (red) and transverse (blue) wakefield modes in the undamped test structure.

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