ELECTROMAGNETIC SIMULATIONS OF DIELECTRIC WALL ACCELERATOR STRUCTURES FOR ELECTRON BEAM ACCELERATION*

S. D. Nelson, B. R. Poole, Lawrence Livermore
National Laboratory (LLNL), Livermore, CA 94550, U.S.A.

Abstract

Dielectric Wall Accelerator (DWA) technology incorporates the energy storage mechanism, the switching mechanism, and the acceleration mechanism for electron beams. Electromagnetic simulations of DWA structures includes these effects and also details of the switch configuration and how that switch time affects the electric field pulse which accelerates the particle beam. DWA structures include both bi-linear and bi-spiral configurations with field gradients on the order of 20MV/m and the simulations include the effects of the beampipe, the beampipe walls, and the DWA High Gradient Insulator (HGI) insulating stack. Design trade-offs include the transmission line impedance (typically a few ohms), equilibration ring optimization, driving switch inductances, and layer-to-layer coupling effects and the associated affect on the acceleration pulse's peak value.

INTRODUCTION

DWA structures consist of charged Blumlein stacks which produce an acceleration gradient only during the period of time corresponding to twice the electrical length of the line. Otherwise, there is zero net accelerating gradient and the outer structure of the DWA stack is at ground potential. As such, it is similar in concept to a ferrite-loaded linear induction accelerator cell which is at ground potential except for the period of time corresponding to the Volt-second rating of the ferrite core. In a DWA design, the collapsing field from the blumlien reaches the beampipe wall, produces an accelerating gradient, and accelerates a particle beam (see Figure 1).

The simulations were performed in 4D (x,y,z,t) using finite difference time domain (FDTD) calculations [1]. In addition to discrete wires, switches, resistors, capacitors, and inductors, LLNL supported the addition of static initialization via Poisson solutions of capacitive systems; to the knowledge of the authors, this is unique in FDTD codes. This increased the throughput of simulations by a factor of 20. Discrete switches allowed for detailed simulations of systems common to the accelerator community and other high power stored energy systems.

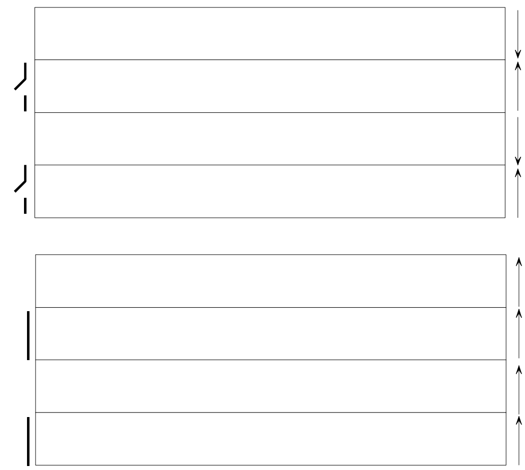

Figure 1: Configuration before and after switch closure showing the electric field direction along the wall.

GEOMETRY

The impedance of each Blumlein corresponds to the parallel-plate transmission line impedance of Z_{0pp} = Sqrt(μ/ε) d / b, where μ and ε are the permeability and permittivity of the dielectric, d is the dielectric thickness, and b is the metallization width. Typically d/b is 1:30 and the parallel-plate equation is valid for slow pulses. Note however, that during the transient switch closure, there is coupling between adjacent layers of the Blumleins. The effective impedance of each pair of Blumleins (a single stack) is $2Z_{0pp}$. Attempts at a single-ended feeds have been unsuccessful to date due to the need to balance the magnetic fields in the beampipe. Single-ended feeds produce a strong dipole H field where as double-ended feeds cancel the H fields in the beampipe. Note that in the double-ended configuration, the beampipe loading is symmetric.

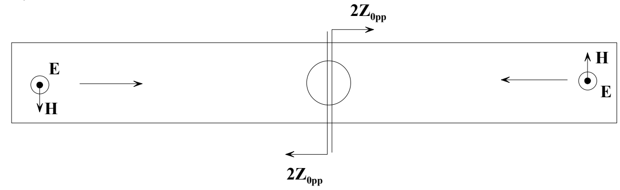

Figure 2: View from above showing the beampipe and the complete double-ended feed configuration.

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Equilibration Ring

Although Figure 2 shows Blumlein strips which are wider than the beampipe, b > 2r, in general Blumlein strips may be of arbitrary size with the inclusion of an equilibration ring around the beampipe to distribute the fields. For very fast pulses, the equilibration ring would need to be impedance matched, however for switch closure times on the order of a few nanoseconds, it is sufficient for the equilibration ring width to be 1/3rd the radius of the beampipe. This is the configuration commonly used with spiral designs (see Figure 3).

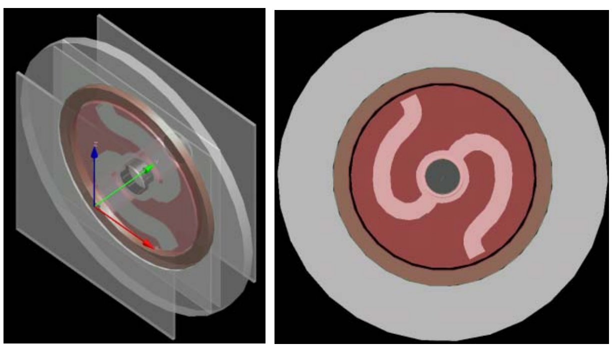

Figure 3: Spiral designs highlight the need for an equilibration ring around the beampipe.

In gauging the effectiveness of the equilibration ring, a series of matched monitoring resistors were placed around the circumference of the beampipe. The overlay of the 8 plots is shown in Figure 4, with the temporal difference caused by the propagation time around one quarter of the ring.

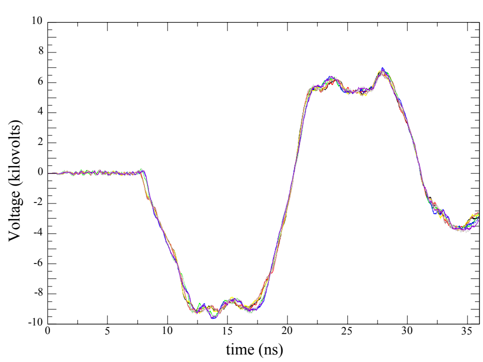

Figure 4: eight waveforms from monitoring resistors placed around the circumference of the equilibration ring.

EXPERIMENTAL DATA

Early experimental data [2] confirming the validity of the various models *in-combination* illustrates the benefits of full wave time domain simulations. These simulations include the switch effects, inductances near the switches, transmission line effects, layer-to-layer coupling, coupling effects around the beampipe, and interactions with the enclosure (see Figure 5). Subsequent comparisons with experimental data [3] also showed excellent agreement with computational models in calculating geometric inductances in the switch region up to the point when the resistive phase of the gas switch dominates, >100ns, which is not included in the computational model yet.

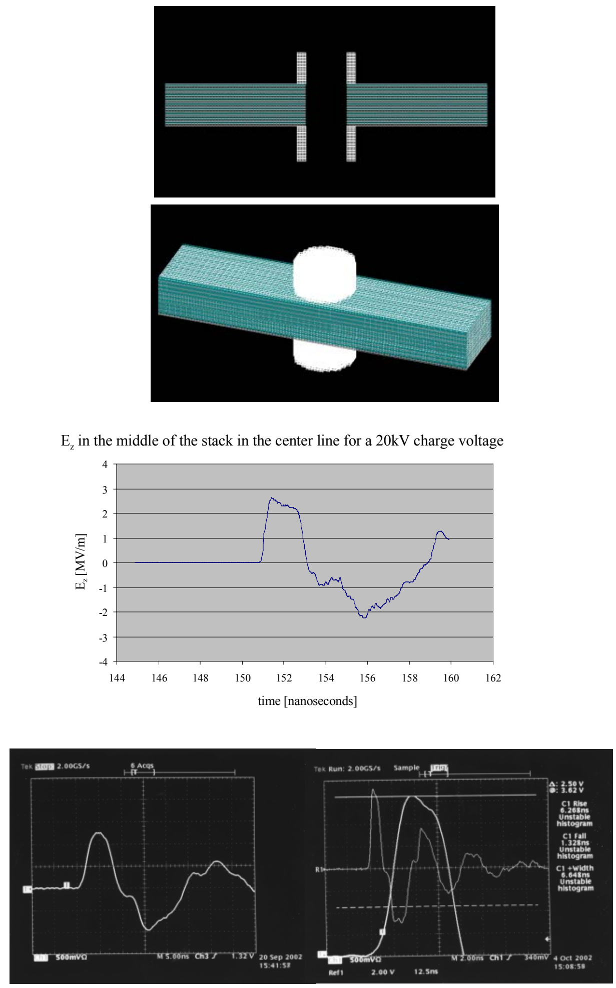

Figure 5: a-d: comparison with experimental data for a 7-stack in an enclosure with beampipe, Sullivan, et. al. [2]

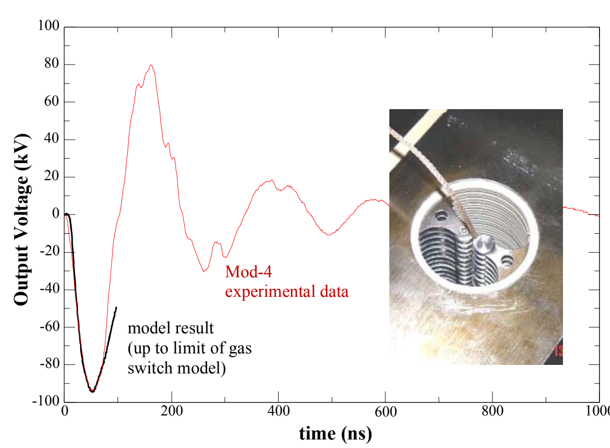

Figure 6: comparison with experimental data for 20-stack with high inductance gas switch configuration shows excellent agreement, Nunnally, et. al. [3]

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SIMULATIONS

As a prelude to pushing particles through the computational grid, the electric (E) and magnetic (H) fields were extracted from the data. In these snapshots (see Figure 7 a-f), the switches were located out of the page and closed at time t=0 ns. The collapsing wavefront in one Blumlein layer in each stack pair approached the beampipe and the electric fields there added. Note that the integral of E along any off-axis line is the same as the integral on axis. The extra beampipe left/right of the stack was needed for computational reasons so that evanescent fields were allowed to decay before interacting with the left/right boundary conditions. Figure 7 shows a short stack.

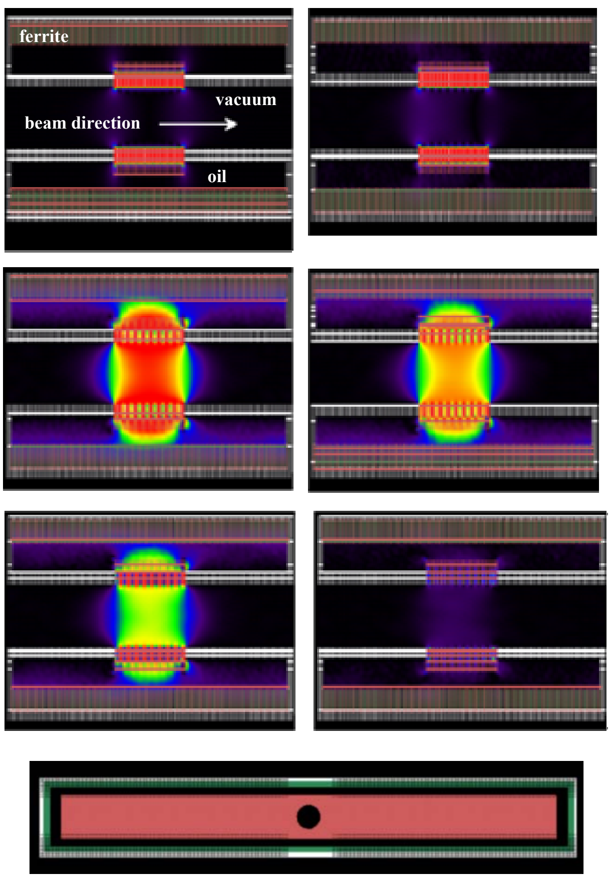

Figure 7 a-f: as the collapsing blumlien wavefront reaches the beampipe, the fields now add thus producing acceleration in the beampipe. The bottom figure (horizontal) shows the view looking down the beampipe.

Pulse fidelity

For this configuration, it is straight forward to achieve rectangular pulses with good fidelity (see Figure 8) as long as the switch closure time is not excessively short. Fast *dV/dt* switch effects couple directly from adjacent layers and degrade the baseline of the pulse since energy is coupled from the switched line to the unswitched line and thus acts as a baseline offset for the fields in the beampipe.

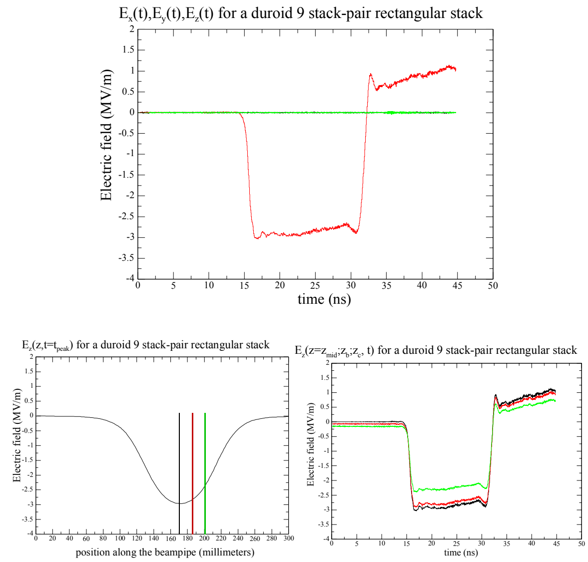

Figure 8: taking cuts across the beampipe at three spatial locations versus time shows excellent pulse stability and fidelity across the beampipe.

CONCLUSIONS

DWA structures have been successfully simulated using finite difference time domain tools which also greatly aid in designing the structures. Double-ended feed configurations allow for balanced bias H fields in the beampipe region. There presence of the equilibration ring allows for energy to be distributed around the beampipe for uniform excitation and avoidance of dipole modes. Since the structure is modular, assembling large stacks is straight forward and 7-, 9-, and 20-stack units have been demonstrated.

ACKNOWLEDGEMENTS

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REFERENCES

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[2] J. S. Sullivan, E. J. Gower, “Compact, Repetitively Pulsed, Stacked Blumlein Pulser,” *Lawrence Livermore National Laboratory*, UCRL-JC-147159, 2002.

[3] W. C. Nunnally, et. al., “Investigation of UV Laser Triggered, Nanosecond, Surface Flashover Switches,” *Lawrence Livermore National Laboratory*, UCRL-JC-151646, 2003.