DEVELOPMENT OF THE DIELECTRIC WALL ACCELERATOR

Anthony Zografos, Cameron Hettler, Yoko Parker, Michael Moyers, David Pearson, Vladimir Joshkin, Kevin Leung, Fang Huang, Cecile Cohen-Jonathan, Mario Rougieri, Terrence Brown, Robert Hamm, CPAC, Livermore, CA, USA

Abstract

The Compact Particle Acceleration Corporation has developed the Dielectric Wall Accelerator to produce pulsed proton bunches that will be suitable for proton beam therapy. The Dielectric Wall Accelerator engineering prototype includes a RFQ injection system with a pulsed kicker to select the desired proton bunches and a linear accelerator incorporating a High Gradient Insulator with stacked transmission lines to produce the required voltage. The transmission lines are switched with solid state laser-driven optical switches. A computational model has been developed that is in very good agreement with the experimental results. The system is presently achieving accelerating gradients exceeding 15 MeV/m. The computational model has been used to design the next generation system that will achieve 25 MeV/m in 2013. This paper will discuss the status of the apparatus, the basic elements of the computational model, experimental results, and comparison to the model predictions. In addition, the paper will present a concept for a proton therapy system that incorporates the Dielectric Wall Accelerator and associated shielding requirements.

SYSTEM ARCHITECTURE

A compact accelerator system architecture based on the Dielectric Wall Accelerator (DWA) [1] for medical proton beam therapy has been developed by the Compact Particle Acceleration Corporation (CPAC) [2]. The major subsystems are a Radio Frequency Quadrupole (RFQ) injector linac, a pulsed kicker to select the desired proton bunches, and a DWA linear accelerator incorporating a high gradient insulator (HGI) with stacked Blumleins to produce the required acceleration energy. The Blumleins are switched with solid state laser-driven optical switches integrated into the Blumlein assemblies. Other subsystems include a high power pulsed laser, fiber optic distribution system, electrical charging system, and beam diagnostics. An engineering prototype has been constructed and characterized. This prototype also allows the characterization of alternate architectures. This paper describes the results of the characterization of a “dipole” architecture. The dipole architecture involves a transmission line that consists of a pair of strips where each end of the strip is connected to a switch that is attached to each face of a parallel plate capacitor. As the polarities of the voltages across the switches in this configuration are opposite, we call this structure a dipole. We have studied dipoles for a proton DWA application, starting from single dipole characterization and model validation, and then moving onto a dipole DWA system.

MODELING OF THE DIPOLE BASED SYSTEM

CST Microwave Studio (MWS) was used for modeling the dipole. Figure 1 shows a model of a single dipole that consists of (a) a capacitor made of two parallel plates, (b) photoconductive switches on each side of the capacitor plates, (c) a transmission line (TL) made of two parallel strip lines, and (d) equilibration rings (EQRs) that are used to couple the voltage carried by the TL to the high gradient insulator (HGI) to generate an acceleration field in the bore of HGI. The capacitor was charged to a desired voltage, and the stored charge in the capacitor was delivered to the TL by triggering a laser pulse to close the photoconductive switches. The model does not include the circuitry for charging the capacitor; i.e., the stage of charging the capacitor was excluded from the simulation. In reality, the switch on state resistance depends on the laser energy and the pulse duration. However, the on state resistance in the model is simply determined by the electrical conductivity of the switch material.

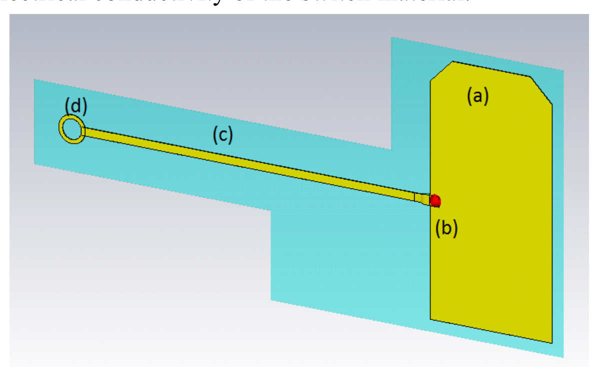

Figure 1: Single dipole model: (a) a capacitor, (b) switches, (c) transmission line, (d) equilibration rings.

Figure 2 shows an example of the output voltage waveforms measured at the EQRs with a fast probe and corresponding simulation result. The simulation result and measurement appear to be in good agreement, which confirms that both the modeling and the experiments were done correctly.

Using the same dipole geometry with some design modifications for integration, a Dielectric Wall Accelerator (DWA) system that consists of 24 dipoles was built to achieve a high electric field in the HGI and also to observe proton acceleration. Figure 3 shows a model of the system; the resistors and electrical connections for charging the capacitors are not shown.

ISBN 978-3-95450-122-9

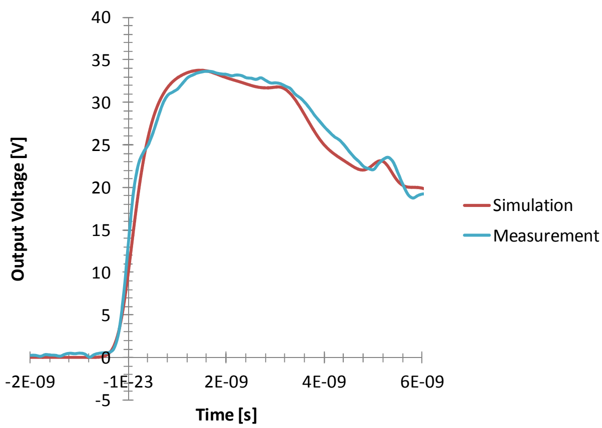

Figure 2: Single dipole output voltage temporal profile.

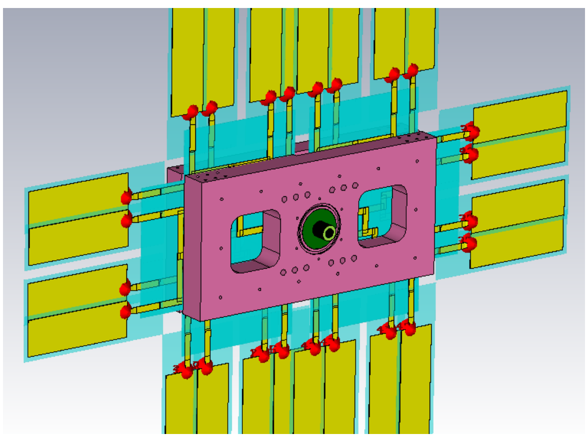

Figure 3: A DWA system model with 24 dipoles.

We have carried out experiments using the same probe method mentioned above in order to validate the model at a low voltage. The probes were connected to the output end of the TL conductors of the first and last dipole layer. The probe measurements and the simulation results are in good agreement. The peak values of the output voltages measured at different switch on state resistance are plotted in Figure 4 together with the simulation result.

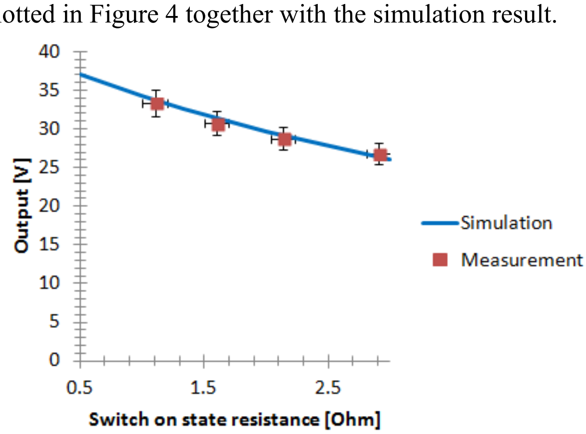

Figure 4: Total output voltage of the 24 dipole system.

The system model was converted to a particle studio (PS) model to run particles in cell (PIC) simulations. An ideal proton beam of 4 mm diameter and with no kinetic beam spread or angular spread was assumed. Simulated output beam energies at the exit of the HGI were compared with measured beam energies and found to mostly agree with each other to within ~10%. Since the proton energy is a function of the integrated electric field along the proton path, this good agreement implies that the model is accurate enough to predict the performance of the entire system, from the voltage coupling into the HGI to the fringe fields produced. Figure 5 shows that there is excellent agreement between the model prediction and the experimental results.

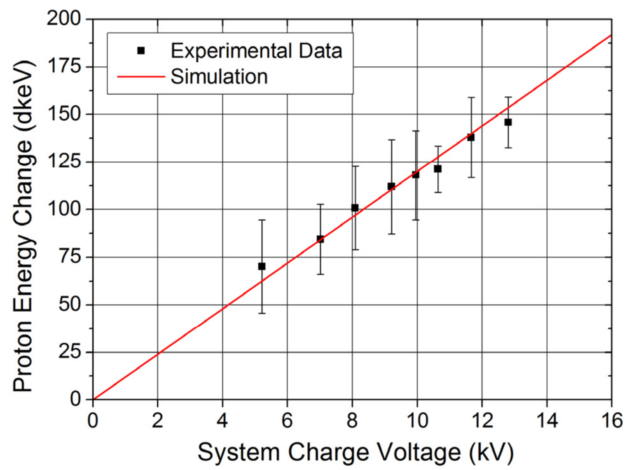

Figure 5: Experimental Data and Simulation Results for proton energy change as a function of system charge voltage for a short accelerator section.

LEAKAGE RADIATION

The dielectric wall accelerator (DWA) has the potential to decrease the size and cost of light ion treatment facilities [3,4]. Before designing the shielding for a DWA-based facility, the radiation leakage pattern around the accelerator should be established. Unlike cyclical accelerators such as cyclotrons and synchrotrons that emit leakage radiation in all directions within the plane of the accelerator, the radiation emanating from a DWA is expected to be peaked in the forward direction, thereby reducing the required shielding thickness for most barriers.

The Monte Carlo program MCNPX [5] was used to simulate the leakage pattern around a 225 MeV proton DWA. The accelerator geometry was modeled as several concentric layers with the materials of the layers being vacuum, high gradient insulating (HGI) material, and epoxy with increasing radius from the beam axis [6]. At selected locations along the length of the accelerator, the HGI material was replaced with a stainless steel tube to accommodate vacuum system attachments and focusing magnets and the epoxy replaced with air. An accelerating gradient of 50 MV/m was assumed for all accelerating sections. To simulate the grazing loss of protons on the

ISBN 978-3-95450-122-9

accelerator wall, protons were impinged onto the cylindrical HGI cylinders surrounding the accelerated beam axis with the directions of the protons being parallel to the beam axis. The energy of the impinging protons upon each cylinder was successively increased along the length of the accelerator.

The required barrier thickness (ceiling or wall) varied with position around the accelerator. Lateral to the distal end of the accelerator, approximately 1 m of concrete was required. Lateral to the proximal end of the accelerator, approximately 0 .5 m of concrete was required. Upstream of the accelerator, the required wall thickness was only 0.3 m of concrete. Mesh tally planes are shown in Fig. 6.

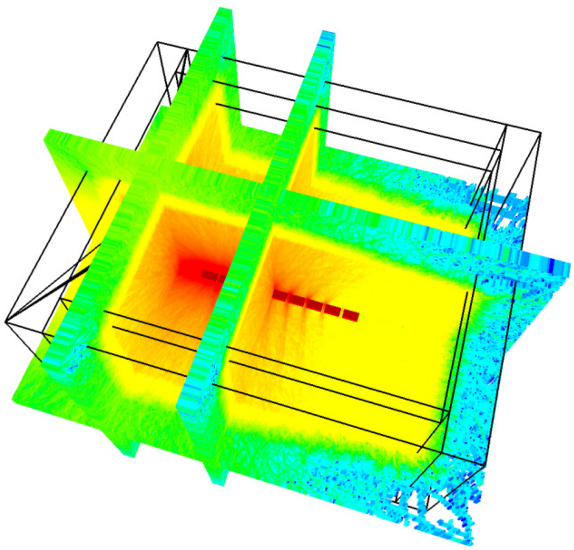

Figure 6: Perspective view of mesh tally planes. Total DE from simulation is superimposed onto mesh planes.

CONCLUSION

CPAC has developed the capability to model various Dielectric Wall Accelerator configurations. The DWA engineering prototype system has been a valuable tool in validating the simulation results. The presented dipole configuration produced an accelerating gradient approaching 20 MeV/m and it is one of the alternatives that were considered for the DWA based proton beam therapy system. Monte Carlo based shielding calculations showed that such a system will have relatively simple shielding requirements thus making it a good alternative for installation in existing radiation oncology facilities.

REFERENCES

[1] G. J. Caporaso et al., “Compact accelerator for medical therapy,” *U.S. Patent* US 7,710,051 B2.

[2] A. Zografos et al., “Engineering Prototype for a Compact Medical Dielectric Wall Accelerator,” IPAC2011, San Sebastian, September 2011, Vol. 8, p.3636, 2011; http://www.JACoW.org

[3] Y.-J.Chen, “Dielectric wall accelerator for proton therapy,” presented at the Photo-Medical Research Center, Japan Atomic Energy Agency, May 31, 2010.

[4] M.F. Moyers, “Proton Therapy” in *The Modern Technology of Radiation Oncology: A Compendium for Medical Physicists and Radiation Oncologists*, ed. J. van Dyk, pp. 823–869 (Wisconsin: Medical Physics Publishing, 1999).

[5] D. Pelowitz ed., “MCNPX User’s Manual Version 2.5.0,” LA-CP-05-0369 (Los Alamos National Laboratory, Los Alamos, New Mexico, 2005).

[6] M. F. Moyers et al., “Leakage Radiation from a dielectric wall accelerator,” to be published.

ISBN 978-3-95450-122-9