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TRANSMISSION LINE AND ELECTROMAGNETIC MODELS OF THE MYKONOS-2 ACCELERATOR*

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Abstract

Mykonos is a linear transformer driver (LTD) pulsed power accelerator currently undergoing testing at Sandia National Laboratories. Mykonos-2, the initial configuration, includes two 1-MA, 200-kV LTD cavities driving a water-filled transmission line terminated by a resistive load. Transmission line and 3D electromagnetic (EM) simulation models of high-current LTD cavities have been developed [D.V. Rose *et al*. Phys. Rev. ST Accel. Beams **13**, 90401 (2010)]. These models have been used to develop an equivalent two-cavity transmission line model of Mykonos-2 using the BERTHA transmission line code. The model explicitly includes 40 bricks per cavity and detailed representations of the water-filled transmission line and resistive load. (A brick consists of two capacitors and a switch connected in series.) This model is compared to 3D EM simulations of the entire accelerator including detailed representations of the individual capacitors and switches in each cavity. Good agreement is obtained between the two simulation models and both models are in good agreement with preliminary electrical data from Mykonos-2.

I. INTRODUCTION

Linear transformer drivers (LTDs) are a rapidly growing area of study in pulsed power for applications requiring high-current, high-power, 100-300 ns output pulses in a compact configuration. LTDs are designed to closely combine the primary energy storage and switch hardware within each cavity in order to create a more compact accelerator. Each LTD cavity contains capacitors, switches, and ferromagnetic cores. The combination of two capacitors and the accompanying series-connected switch are referred to as a brick. Individual bricks are arranged azimuthally inside the cavity and are connected in parallel to a parallel plate radial transmission line. This radial transmission line can either be connected directly to a load or can feed a coaxial transmission line that connects multiple LTD cavities to form an inductive voltage adder accelerator.

LTD technology is currently being utilized in several capacities in pulsed power. These modules have been considered for driving x-ray radiography and excimer-laser work and LTD based accelerators are being actively developed for applications including high current Z-pinch loads, internal fusion energy and internal confinement fusion [1-4].

Circuit models of LTDs have been developed, tested, and benchmarked in the past [4-7]. We have expanded on the models developed in Refs. [7,9] to study Mykonos-2, a two-cavity LTD accelerator being developed at Sandia National Laboratories (SNL) [2,3]. We compare the results from the BERTHA [8] circuit model to a 3D-electromagnetic (EM) simulation model of wave generation and propagation through the cavities and transmission line. These simulations use the LSP particle-in-cell (PIC) code [9] to model the main circuit components of the LTD cavities track wave propagation and access self and mutual inductances in the system. Both the circuit and EM simulations models use a recently developed time-dependent core model to accurately represent the small loss currents that flow along interior of the cavities [7]. In Sec. II, we present the BERTHA transmission line model representing a single LTD cavity [6]. A more realistic switch model is now used in the circuit calculations to improve the agreement between the measured and calculated electrical signals. Section III describes the Mykonos-2 accelerator currently being tested at SNL. Section IV shows comparisons between the Mykonos-2 circuit model and experimental data. We

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discuss the 3D-EM model of Mykonos-2 and compare results with circuit model data in Section V. A summary is given in Section VI.

II. LTD SINGLE CAVITY TRANSMISSION LINE MODEL

The BERTHA transmission line code is used to create a circuit model of a single LTD cavity [7]. Figure 1 shows a schematic of an LTD cavity that is comprised of 40 modules, each containing a circuit representing a single brick. Each module is comprised of an equivalent capacitor connected in series to a switch which then connects in parallel to the next module and the core model. Use of a multi-brick circuit model enables individual switch triggering, allowing for simulations including brick-to-brick jitter as well as internal pulse shaping.

To improve the existing model, we refined the way switch resistance is handled. Previously, a step-like function was used to represent the switch resistance. This yielded desired peak load amplitudes, but it could not always yield accurate rise times. This simple function has been replaced by a model developed to calculate a falling switch resistance based on the evolution of expanding ionization channels in the switch gas [10]. We utilize both the time-triggered and voltage-break features of the switch model to ensure that the switch breakdown most accurately reflects experimental performance. Switch parameters include a voltage-breakdown value of 230kV, a switch gap of 3.6cm, and a 45psi gas pressure.

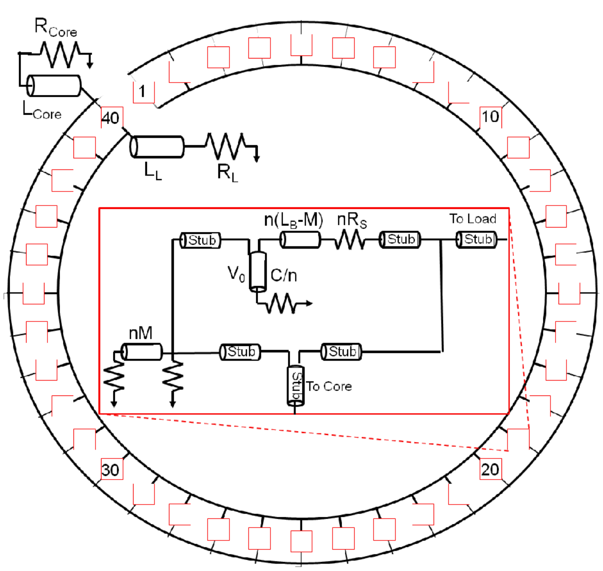

Figure 1. Single cavity LTD schematic in BERTHA. Modules (red boxes) each represent one of the 40 bricks in the cavity. The enlarged module shows a circuit schematic of a brick and associated mutual inductance. "n" is the number of bricks in the LTD cavity, in this case, n = 40.

III. MYKONOS-2 TRANSMISSION LINE MODEL

Mykonos-2 is an accelerator at Sandia National Laboratories currently undergoing testing. It is composed of two 1-MA, 200kV LTD cavities driving a simple resistive load. To model Mykonos-2, we expanded our BERTHA model to include two cavities (each composed of 40 modules modeling individual bricks) driving a common transmission line terminated with a 0.11 Ohm resistive load. Figure 2 shows a schematic of the Mykonos-2 transmission line model.

The transmission line joining the two cavities is comprised of thirty-seven elements and the load region is modeled by 9 elements. Details of the values used can be found in Table I by Rose et al. [6]. Fine-tuning the load resistance value was necessary to model the load utilized on Mykonos-2.

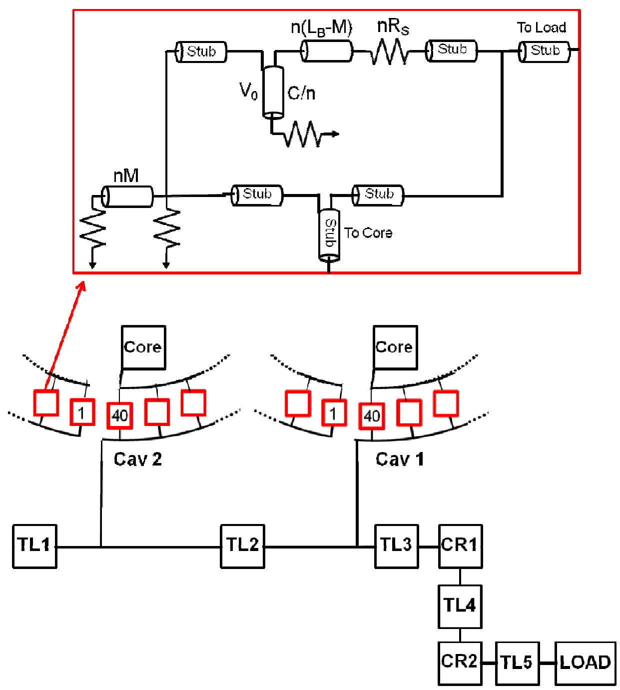

Figure 2. Transmission line model of Mykonos-2. Two LTD cavities drive a common transmission line connected to a simple resistive load.

IV. MODELING RESULTS

The initial transmission line model configuration tested was synchronous, one in which all bricks in both cavities fired simultaneously. The capacitors were charged to 80 kV and the cavities drove a 0.11 Ohm resistive load. The resulting load current had a peak of ~925 kA and a 10-90% rise-time of 67.5 ns. This is in excellent agreement with the experimental load current measured on Mykonos-2 (Figure 3). Load voltage was ~105 MV. A companion paper in these proceedings by Savage et al. provides a more detailed description of Mykonos-2 and a full description of experimental configuration and data.

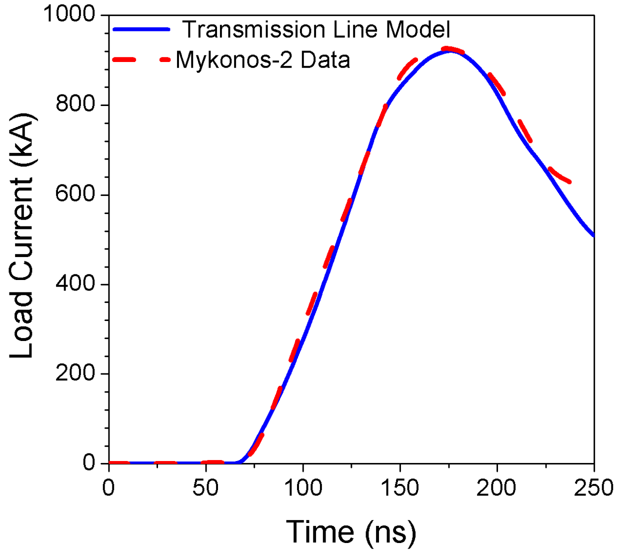

Figure 3. Load current comparison of transmission line model and Mykonos-2 data for a shot with simultaneous switch breakdown.

V. 3D MYKONOS-2 EM SIMULATION MODEL

The previously developed 3D EM Lsp model of a 2-cavity LTD accelerator is used [11]. We briefly summarize the model that has previously been benchmarked against circuit equations and theory. All components mentioned above, e.g. capacitors and switches, are included for each of the 40 bricks per cavity in this 3D model.

Lsp simulations described here are carried out in 3D cylindrical coordinates (r, theta, z) which utilize the symmetry inherent in the individual LTD cavities. The simulation grid is nonuniformly zoned in all coordinate directions in order to properly resolve small components of the cavities such as the switch breakdown channels. Figure 4 shows a cross-section view through the two cavities and transmission line of the model.

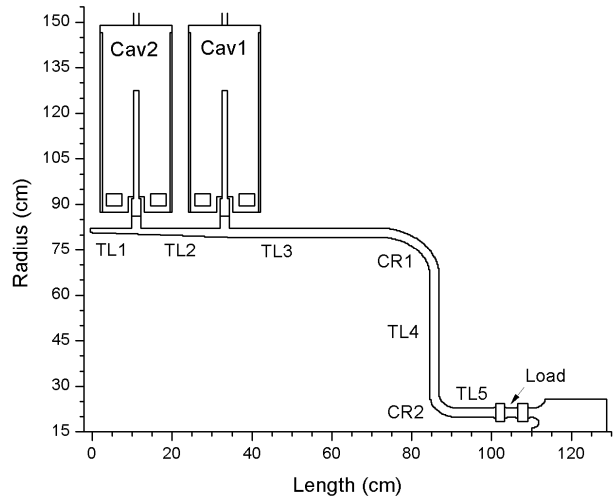

Figure 4. Cross-sectional view of 2-cavity system with transmission line and saltwater load.

To demonstrate the accuracy of the 3D EM model, figure 5 depicts a load power comparison between the 3D EM model and a transmission line model with matched impedance outlets [6]. These idealized models show that the 3D model represents the accelerator as well as a transmission line model. One would benefit from the use of such a 3D EM model to study field stresses on the switches and cores in cases with varied switch break-down times such as jitter or internal pulse shaping delays. Examining these stresses is beyond the scope of this paper but it is worth noting that a reliable model with such a capability has already been created and benchmarked against circuit models and theory.

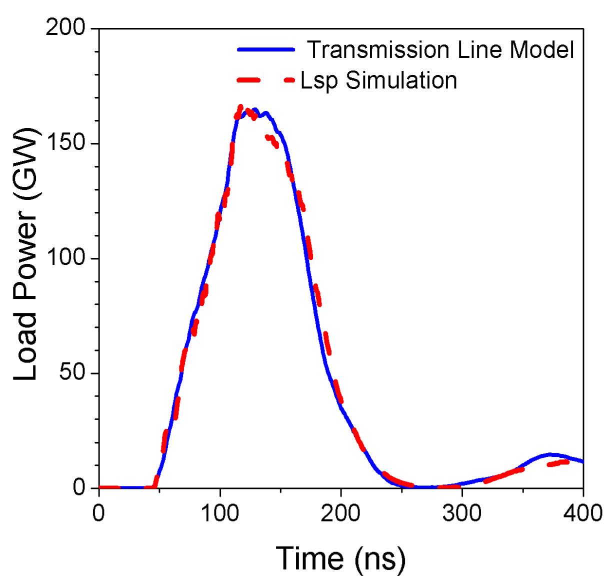

Figure 5. Load power model benchmark for 3D EM Lsp model and Bertha transmission line model.

VI. SUMMARY

An existing transmission line model of an LTD cavity has been improved to better represent switch breakdown. Breakdown voltage and breakdown time are both defined to optimize switch performance. This change in switch resistance representation yields more accurate rise times in load-end data.

A transmission line model of two LTD cavities connected by a coaxial transmission line has been used to model an experimental shot with simultaneous switch breakdown times in both cavities. The resulting load current agrees with experimental data through peak levels.

VII. REFERENCES

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