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

E. A. Madrid[ξ], C. L. Miller, D. V. Rose, D. R. Welch, R. E. Clark, C. B. Mostrom
Voss Scientific

W. A. Stygar, M. E. Savage
Sandia National Laboratories

D. D. Hinshelwood
Naval Research Laboratories

K. R. LeChien
National Nuclear Security Administration

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 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 [6].

In Sec. II, we present the transmission line model representing a single Mykonos-2 LTD cavity. A more realistic switch model is now used in the circuit to improve the agreement between the measured and calculated electrical signals. Section III describes the Mykonos-2 accelerator which is currently being tested at SNL and shows comparisons between the circuit model

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ξemail: elizabethm@www.vosssci.com

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and experimental data. We discuss the 3D-EM model of Mykonos-2 and compare results with the circuit model in Sec. IV. A summary is given in Sec. V.

II. LTD SINGLE CAVITY TRANSMISSION LINE MODEL

To illustrate the fundamental features of the LTD equivalent circuit model, we present single LTD cavity calculation results. The BERTHA transmission line code is used to model the LTD cavity [6]. Figure 1 shows a schematic of a circuit representing a Mykonos-2 LTD cavity. It is comprised of n = 40 modules, each containing a sub-circuit (module) 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. The core is modeled as a time-dependent resistive element [6]. Use of a multi-brick circuit model enables individual switch triggering, allowing for simulations that include brick-to-brick jitter as well as internal pulse shaping.

As an improvement over previous models, we have refined the way the switches close. Previously, a step-like function was used to represent the switch resistance [6]. This yielded the desired peak load amplitudes, but it could not always generate accurate rise times for multiple cavity systems. This simple breakdown function has been replaced by an existing BERTHA model developed to represent 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 self-break features of the switch model to ensure that the switch breakdown qualitatively reflects experimental performance. For all calculations presented here a self breakdown voltage of 230 kV is assumed along with a switch gap of 3.6 cm and a 45 psi gas pressure.

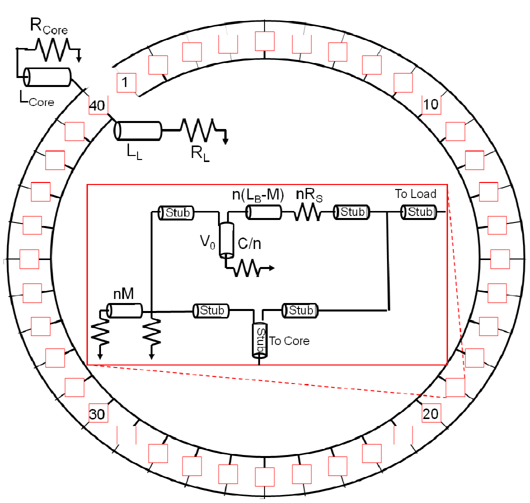

Figure 1. Single cavity LTD circuit schematic. Modules (red boxes) each represent one of the 40 bricks in the cavity. The enlarged module at the center of the figure shows a circuit schematic of a brick and associated mutual inductance [6]. Here "n" is the number of bricks in the LTD cavity.

III. MYKONOS-2 TRANSMISSION LINE MODEL AND RESULTS

To model Mykonos-2, we expand our single cavity model to include two cavities, each composed of 40 bricks, driving a common water-filled coaxial transmission line terminated by a 0.11 Ohm resistive load. Figure 2 shows a schematic of the complete Mykonos-2 transmission line model. The transmission line joining the two cavities to the load is comprised of thirty-seven elements and the load region is modeled by nine elements.

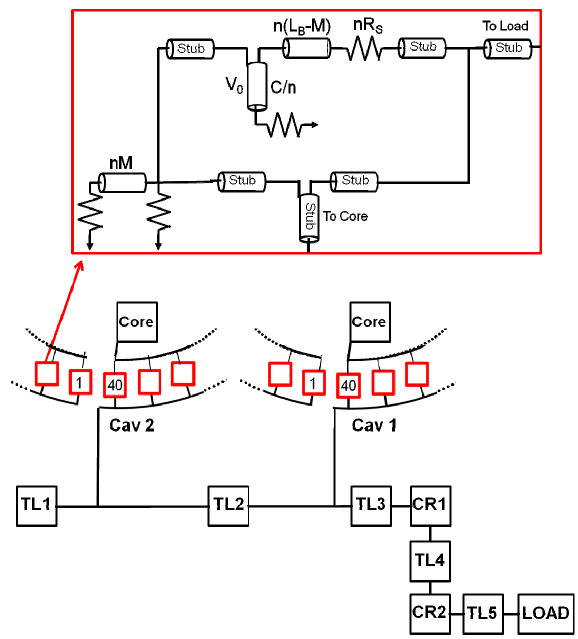

Figure 2. Transmission line model of Mykonos-2. Two LTD cavities drive a common transmission line connected to a simple resistive load.

The transmission line model was tested against a synchronous Mykonos-2 shot, one in which all bricks in both cavities fired simultaneously. The capacitors were charged to 80 kV. The resulting load current has a peak value 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 which is shown in Fig. 3. The model not only captures the rise time and peak value of the load current, but also tracks the falling load current for an additional 50 ns. A key component of these calculation results is the use of the time-dependent core model presented in Ref. 6. Although not shown, the peak calculated load voltage is ~105 kV resulting in a peak load power of ~100 GW. A companion paper in these proceedings by M. Savage *et al*. provides a more detailed description of Mykonos-2.

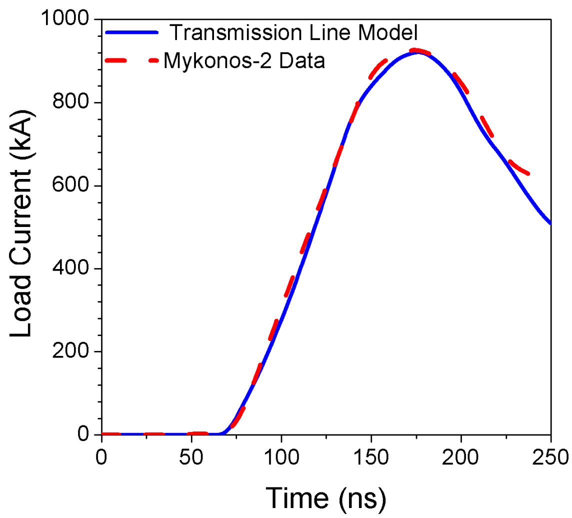

Figure 3. Load current comparison of transmission line model and Mykonos-2 data for a shot with simultaneous switch firing.

IV. 3D MYKONOS-2 EM SIMULATION MODEL

A 3D EM model of an LTD cavity has previously been developed [6]. Here we use the same simulation techniques to model the Mykonos-2 accelerator. A cross-sectional view of the EM simulation model is shown in Fig. 4. All major electrical components discussed above, e.g. capacitors and switches, are included for each of the 40 bricks per cavity in this 3D model.

The EM simulation described here is carried out in 3D cylindrical coordinates (r, θ, z) which utilize the symmetry inherent in the individual LTD cavities and transmission line. 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. One advantage of an EM simulation model is that electric field stresses at individual component connections can be dynamically examined. This is particularly applicable to multiple cavity systems involving pulse shaping.

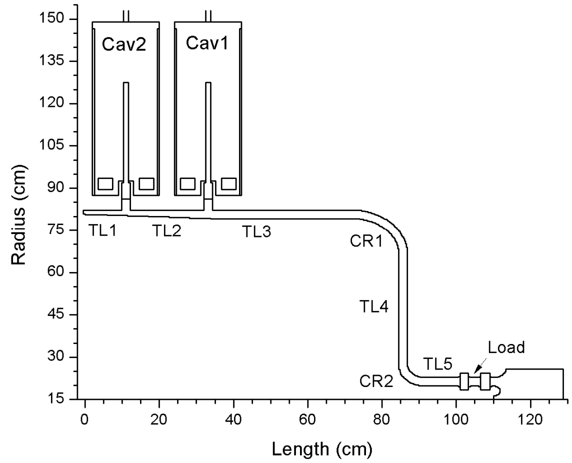

Figure 4. Cross-sectional view of 2-cavity system with transmission line and resistive load.

To demonstrate the accuracy of the 3D EM model, Fig. 5 shows the load power obtained from the 3D EM model compared to a transmission line calculation with matched impedance outlets in place of a resistive load. Both calculations use a 100 kV charging voltage and assume a 6.6 ns delay between switch firing in the two cavities (a 6.6 ns delay is the transit time between the two cavities and ensures optimal power delivery). The two models are in good agreement over all time scales of interest.

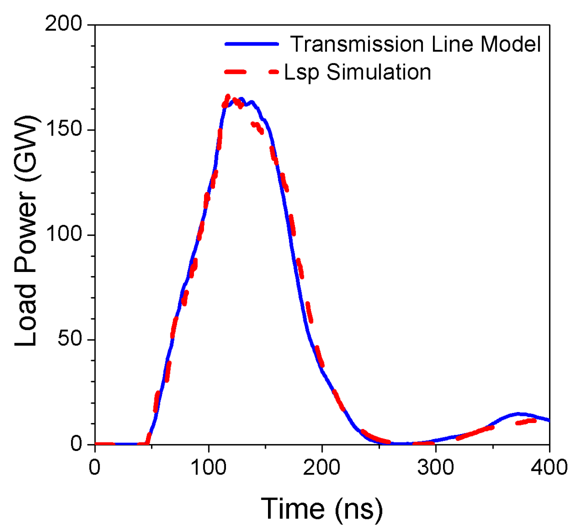

Figure 5. Load power model benchmark for 3D EM Lsp model and Bertha transmission line model.

V. SUMMARY

A detailed transmission line model of the Mykonos-2 accelerator has been developed. The model has been compared with data from Mykonos-2 and good agreement is found for times well past peak load current. In addition a 3D EM model of Mykonos-2 has been developed. The models have been compared to each other and good agreement is found. The utility of these models is enhanced by improved treatments of the switching characteristics and resistive core.

The 3D EM model presented here can also be used to assess field stresses on individual components within an LTD cavity. This should be a critical aspect in the analysis of LTD systems that include pulse shaping. While examination of these stresses is beyond the scope of this paper, it is worth noting that this capability is already available. Both the EM and transmission line models will be applied to the design and validation of future accelerators including the Mykonos-10 facility and next generation Z-pinch drivers [13].

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