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Load Line Evaluation of a 1-MV Linear Transformer Driver (LTD)

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***Abstract*— A seven cavity LTD system has been assembled and tested in a voltage adder configuration capable of producing approximately 1-MV into a 7-Ω, critically damped load. Individual cavities have been tested with a resistive load. The seven cavity adder has been tested with a large area electron beam diode. The output pulse when tested into a resistive load is that of an RLC circuit. When tested with a dynamic load impedance, the output voltages of the cavities have an added oscillation. The oscillation affects the output pulse shape but is not harmful to the cavity components.**

I. Introduction

The linear transformer driver (LTD) is a promising new pulsed power technology with applications including high voltage flash x-ray radiography and high current Z-pinch drivers. A LTD cavity is similar to a traditional inductive voltage adder (IVA) cavity, however the primary energy storage is packed inside the cavity. The internal layout of the components in an LTD cavity is shown in Fig. 1. The resulting architecture is more compact than a traditional Marx generator driven IVA.

A 1-MV LTD voltage adder was built at the High Current Electronics Institute in Tomsk, Russia and tested at Sandia National Laboratories [1], [2]. The LTD adder is designed to supply 125 kA in a 100-ns FWHM voltage pulse without the optional peaking capacitors. A single cathode stalk is threaded through the centers of the seven series cavities forming a coaxial vacuum insulated transmission line. The vacuum line is terminated with a large area electron beam diode. Electrons are emitted from the surface of the aluminum cathode, accelerated across a vacuum gap (referred to as the anode-cathode or AK gap), and strike the carbon anode producing an approximately 75-ns FWHM x-ray pulse. The impedance of the electron beam diode is determined by the voltage, length of the AK gap, and the area of electron emission.

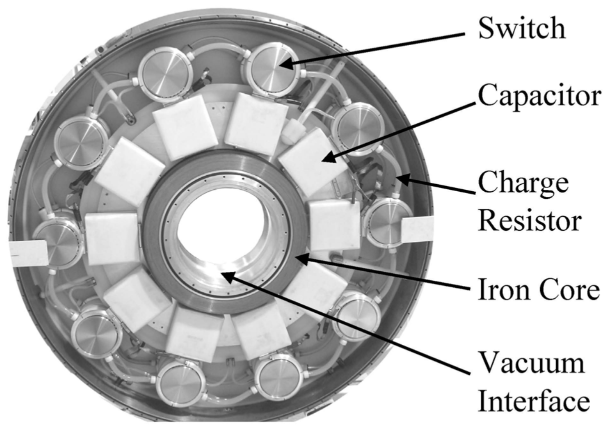

Fig. 1. Photograph of a single LTD Cavity with the side cover removed to show the layout of internal components.

Flash radiography accelerators are typically designed to operate at a single output impedance but are expected to drive various diodes with dispirate impedances. As a result, the diode impedance is not always well matched to the accelerator. The impedance of radiographic diodes can also change significantly during a single pulse. At the start of the pulse, the electric fields in the diode must exceed the electon emission threshold before current is established. This results in a high impedance phase at the start of the pulse. After

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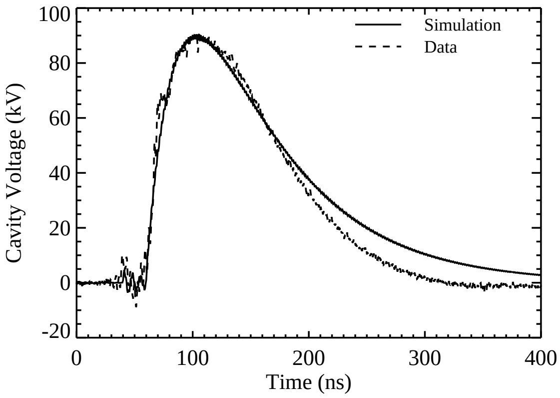

Fig. 2. This plot shows a comparison of experimental data and simulation of a single LTD cavity when tested with a 1.3 Ω resistive load. The simulation has been normalized to the measured data.

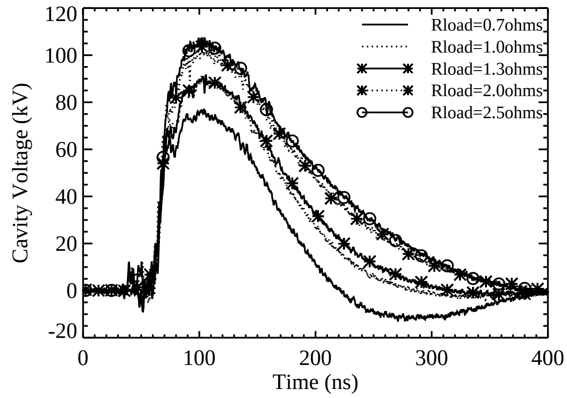

Fig. 3. This plot shows the output voltage of a single LTD cavity when tested with different load resistance values.

current is established, the impedance drops to a steady state impedance. Plasma formation in the diode often leads to a collapsing impedance late in the pulse ending in a nearly short circuited gap. Experiments with resistive loads and large area electron beam diodes of varying impedance can be used to evaluate the performance of a pulsed power driver under loads similar to radiographic diodes.

II. Single Cavity Tests

Individual cavities are tested with a resistive load installed in the center of the cavity. Tests of individual cavities are used to verify that all of the components are functioning properly and also to evaluate the performance of a cavity with different load impedances. The resistor can be filled with different liquid solutions to vary the load resistance. A total of over 1000 shots have been fired with single cavities into a resistive load.

Circuit simulations have been compared to tests of a single cavity and full system tests [3], [4]. Fig. 2 shows a comparison of simulation with the measured cavity voltage for a single cavity tested with a 1.3-Ω load. The simulation has been normalized to the peak measured voltage to give a qualitative comparison. The peak voltage predicted by the simulation is about 30% higher than the measured voltage, but the shape of the waveforms are similar. The faster decay of the measured voltage indicates that the total circuit resistance is lower in the experiment than in the simulation. In the future we plan to perform careful calibration of our voltage monitors as well as analyze uncertainty in the load parameters to improve the agreement of the simulation and data. Work on testing individual LTD switches will also help improve the circuit model by providing more accurate values of switch inductance and switch resistance [5].

A single cavity was tested with different load impedances ranging from 0.7 Ω to 2.5 Ω as shown if Fig. 3. The LTD cavity was charged to ±80 kV for this series of shots. A matched RLC circuit should produce a peak voltage of about one half of the total charge voltage, or 80 kV for this experiment. Fig. 3 shows that the circuit is approximately matched when the load resistance is 0.7 Ω.

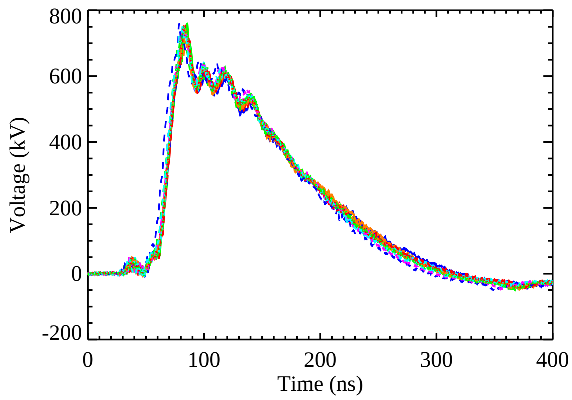

Fig. 4. The output pulse of the LTD is very repeatable. This plot shows the load voltage for 15 consecutive shots into a LAD load.

III. Full System Tests with Large Area Diode

The seven cavities are stacked in series to form a voltage adder and compressed to form a vacuum seal. A constant diameter cylindrical metal stalk is threaded through the centers of the cavities to form a coaxial vacuum line. The outer conductor diameter is 29 cm and the center stalk diameter is 21.5 cm The coaxial line is terminated with a large area electron beam diode (LAD). The anode is a 1.3-cm thick carbon target mounted to a 1.9-cm thick aluminum plate.

Over 400 full system shots have been fired into electron beam loads with different AK gaps. The individual cavity one-sigma jitters during these tests range from 1.4-2.7 ns. The jitter of the series cavities adds in quadrature, so the total load jitter is similar to the average individual cavity jitter. Over the series of 15 consecutive shots plotted in Fig. 4, the one-sigma load jitter is 1.9 ns. The jitter is reported here from a small series of shots because we typically only fire about 15 consecutive shots in any one configuration before changing the charge voltage

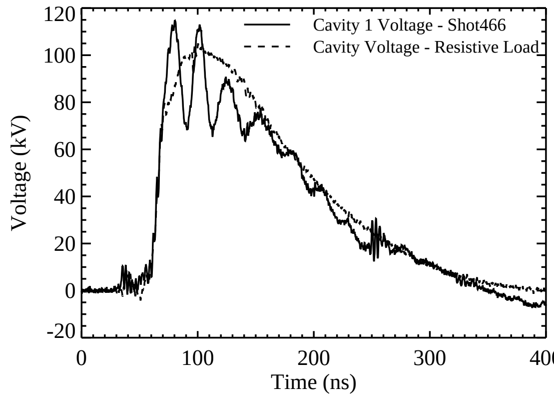

Fig. 5. The output voltage of a single cavity is very different when tested into a constant impedance resistive load compared to testing as part of the seven cavity system into a dynamic impedance LAD load.

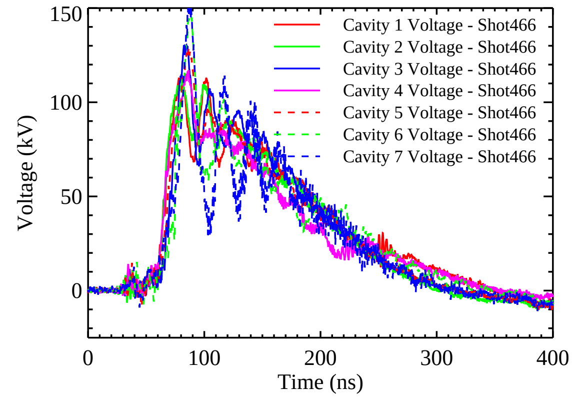

Fig. 6. This plot shows the differences in cavity output voltages when tested as a full system into a LAD load. The sum of these seven voltages produces a plot similar to Fig. 4.

or the diode AK gap. Over a series of 75 shots with varying voltage and diode configurations the one-sigma load jitter is 7.7 ns. As shown in Fig. 4, the timing, peak voltage, and pulse shape is very repeatable.

Large area electron beam diodes have relatively constant impedance through the duration of the pulse compared to a radiographic diode load. However, at the start of the pulse, the electric fields in the diode must exceed the electon emission threshold before current is established. This results in a high impedance phase at the start of the pulse. After current is established, the impedance drops to a relatively constant steady state impedance. The diode impedance remains constant through the pulse as long as the current density on the target is not sufficient to heat the target beyond the threshold for ion emission. If ions are emitted from the anode, the diode impedance will decrease and the beam will begin to pinch. As the beam pinches, the current density increases, which can increase ion production. In extreme cases, the ion production is sufficient to short circuit the AK gap. The diode used in the testing of the seven cavity LTD is designed to deposit the electron current over a sufficiently large area to prevent significant ion production.

Testing a multi-cavity system with a dynamic impedance load is essential for predicting how a large accelerator will perform. The LTD output pulse when tested with a resistor load, has the shape of a simple RLC circuit, as shown in Fig. 5. When tested with a dynamic impedance which is a near open circuit for the first few nanoseconds, the load voltage briefly spikes up higher than when tested with a constant load impedance. The spike at the beginning of the pulse is very noticable in the load voltage shown in Fig. 4. After the diode impedance reaches a steady state value, the load voltage more closely resembles the simple RLC pulse shape. The output voltages of the individual cavities also have a spike at the beginning of the pulse, followed by an oscillation that is slowly damped as the pulse continues. The difference between a cavity tested with a load resistor and when tested in the voltage adder configuration with a LAD load is shown in Fig. 5. The cavity output voltage oscillations are different for each cavity and are determined by the cavity position in the adder, as shown in Fig. 6. The large cavity oscillations vary in amplitude and shape and so the superposition of these voltages results in only a small voltage oscillation at the load, as shown in Fig. 4.

A previous paper analyzed the effects of various faults on the components in an LTD cavity [6]. The cavity oscillations do not pose a significant problem for the components in the cavity. Even the largest oscillations seen in this system, do not cause the cavity voltage to reverse, which could increase the probability of insulator flashover. Based on circuit simulations, these oscillations have very little effect on the voltage across the capacitors. A large capaictor voltage reversal could reduce the capacitor life. The peak voltage on the oscillations briefly raises the electric field stress on the vacuum insulators and results in a marginal increase in the probability of insulator flashover.

IV. Conclusions

We have performed preliminary experiments of individual cavities and of the seven cavity LTD system. Tests of the full seven cavity adder with a LAD load show that there are output voltage features that are not seen when testing with a constant impedance load. Further experimentation and simulation will help us gain a better understanding of the actual circuit parameters and develop a more accurate model of the system.

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