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EXPERIMENTAL VALIDATION OF THE FIRST 1-MA WATER-INSULATED MYKONOS LTD VOLTAGE ADDER*

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Abstract

The LTD technological approach can result in very compact devices that can deliver fast, high current and high voltage pulses straight out of the cavity without any complicated pulse forming and pulse-compression network. Through multistage inductively insulated voltage adders, the output pulse, increased in voltage amplitude, can be applied directly to the load. Because the output pulse rise time and width can be easily tailored (pulse shaped) to the specific application needs, the load may be a vacuum electron diode, a z-pinch wire array, a gas puff, a liner, an isentropic compression load (ICE) to study material behavior under very high magnetic fields, or a fusion energy (IFE) target. Ten 1-MA LTD cavities were originally designed and built to run in a vacuum or Magnetic Insulated Transmission Line (MITL) voltage adder configuration and, after successful operation in this mode, were modified and made capable to operate assembled in a de-ionized water insulated voltage adder. Special care has been taken to de-aerate the water and eliminate air bubbles. Our motivation is to test the advantages of water insulation compared to the MITL transmission approach. The desired effect is that the vacuum sheath electron current losses and pulse front erosion would be avoided without any new difficulties caused by the de-ionized water insulator. Presently, we have assembled and are testing a two-cavity, water insulated voltage adder with a liquid resistor load. Experimental results of up to 95kV capacitor charging are presented and compared with circuit code simulations.

I. INTRODUCTION

Sandia in collaboration with the High Current Electronic Institute (HCEI) in Tomsk, Russia is developing new, fast, high-current, high-voltage induction accelerators based on the Linear Transformer Driver (LTD) technology [1-2]. LTD based drivers are currently considered for many applications including x-ray radiography, very high current Z-pinch drivers, isentropic compression drivers, and Z-pinch IFE (Inertial Fusion Energy). LTD is a new method for constructing high-current, high-voltage induction pulsed accelerators. The salient feature of the approach is switching and inductively adding the pulses at low voltage straight out of the capacitors through low inductance transfer and soft iron core isolation. The pulse forming capacitors and switches are enclosed inside the accelerating cavity. High currents can be achieved by feeding each cavity core with many capacitors connected in parallel in a circular array.

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High voltage is obtained by inductively adding the output voltage of many cavities in series. Most importantly the LTD drivers can be multi-pulsed with a repetition rate, in principle, up to the capacitor specifications. This makes LTD the driver of choice for Inertial Fusion Energy (IFE) where the required repetition rate is estimated to be 0.1 Hz [3-6].

We have prepared a new LTD laboratory, named MYKONOS, to house our 10, 1-MA, 100-kV LTD cavities constructed and received from the HCEI in Tomsk, Russia. Presently, we have assembled and are testing in the MYKONOS laboratory a two 1-MA LTD cavity, water insulated voltage adder with a liquid resistor load (MYKONOS II). This is the first induction voltage adder ever constructed and operated with a water-filled coaxial transmission line.

In section II we describe the 1-MA, 100-kV LTD cavity and present single cavity results with matched resistive load. In section III we present the MYKONOS II, two-1-MA LTD cavity water insulated voltage adder and the resistive load design. In section IV we describe the up-to-date experimental results and compare them with numerical simulations. In the final section V we summarize our MYKONOS II experimental results, give the status of the 1MV, 1MA, MYKONOS X water insulated voltage adder and present future plans.

II. FAST, 100 NS, 1-MA LTD CAVITY

The LTD cavities enclose the entire pulse-forming network that generates the output pulse. This pulse is applied across the insulator that separates the anode and cathode output electrodes (A-K gap) of the cavity. The cavity shape is similar to a flattened doughnut with the axial A-K gap at the center of the inside cylindrical surface [7]. In Fig. 1 we present the 1-MA LTD cavity and the output pulse on a matched load. In Fig. 1 the top metal cover and the plastic insulator that insulates the charged parts from the cavity top wall are removed.

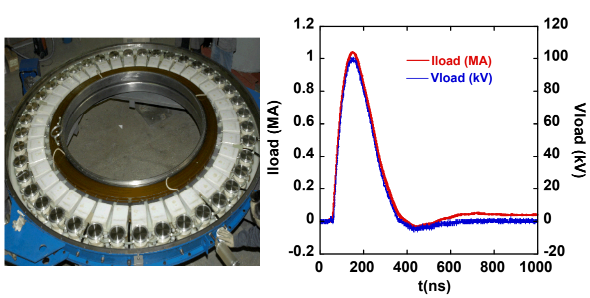

Figure 1. The 1-MA LTD cavity and the output voltage and current pulse at 0.1 Ω load.

The cavity contains two circular arrays of 40 double-ended capacitors, 40-nF, 15-nH each especially developed for our LTD program. The bottom array is separated from the top by a ~1 cm plastic insulator plate. The top capacitors can be charged up to + 100-kV maximum charge and the bottom ones up to -100kV.

III. MYKONOS II VOLTAGE ADDER

Our ten 1-MA LTD cavities were originally designed and built to run in a vacuum or Magnetic Insulated Transmission Line (MITL) voltage adder configuration. However, later we decided to use de-ionized water as voltage adder insulator. There are a number of advantages in utilizing water insulation. Namely:

1. All the current flows on the surface of the transmission line conductors.
2. There is no sheath current erosion and resulting pulse shortening**.**
3. The transmission line can be terminated with high impedance loads without losing ~1/3 of the total current on the walls, causing substantial wall erosion.
4. The water lengthens the transit time from cavity to cavity by a factor of 9. Many voltage adders can be connected in parallel to a common transmission line without loosing magnetic insulation (magnetic nulls).

However, we must acknowledge certain engineering disadvantages with the use of water. A number of them are;

1. For high voltage adders the water vacuum interface near the load can present some difficulties.
2. The presence of air bubbles in an enclosed water system may cause arcing
3. The de-ionized water can corrode metal surfaces and degrade the water voltage holding strength.
4. Extremely high forces are required to compress the cavity "o" rings in order to make them oil and water tight. We do not have here the advantage of the atmospheric pressure to compress the cavities.
5. With water the voltage adder becomes heavier.

Special care has been taken to address most of the disadvantages. The slant angle of the plastic A-K gap insulator was reduced from 45^0 to 4^0 and cut in the opposite (= 94^0) than the 45^0 direction. The stainless steel surfaces of the cavity exposed to the de-ionized water and the cathode stalk were passivated to avoid corrosion and water resistance degradation. A 6.35-mm diameter channel was drilled on the top side of the A-K gap cathode electrode connecting to the outside of each cavity in order to facilitate the removal of bubbles possibly formed at the A-K gap triple points. The channel is fitted with the same diameter stainless steel tube that extends all the way to the outside top of the cavity. The cavities are hung vertically from the rails as shown in Fig. 2. A small water reservoir is connected at the upper end of the tube which can be pumped if necessary to further force the bubbles to exit the A-K gap region (Fig. 3-4).

Figure 2. The MYKONOS II LTD voltage adder.

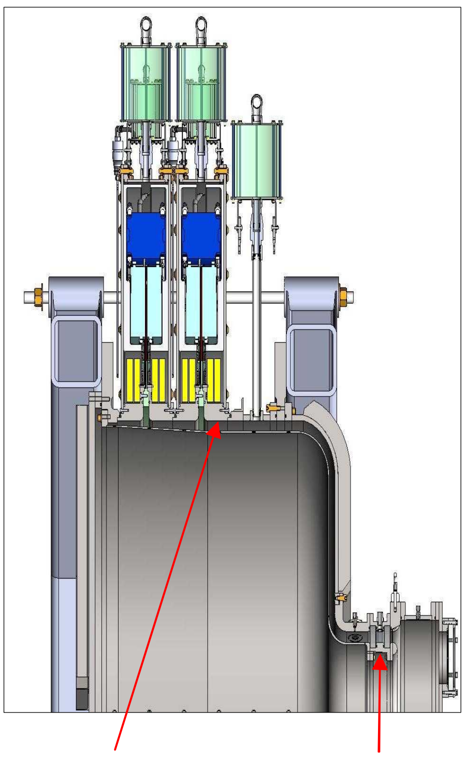

Figure 3.Schematic diagram (side section) of 2 cavities stacked together in a voltage adder configuration. Only the upper half above the axis of the cavity is shown.

A cavity compression system has been built with a strong frond and back frame that compresses the "o" rings of

the cavities with the aid of four rods. The force required to compress the cavities is of the order of 30,000 kg. Presently we have assembled and are testing a two-cavity water insulated voltage adder. This is the first step towards the completion of the 10-cavity, 1-TW module.

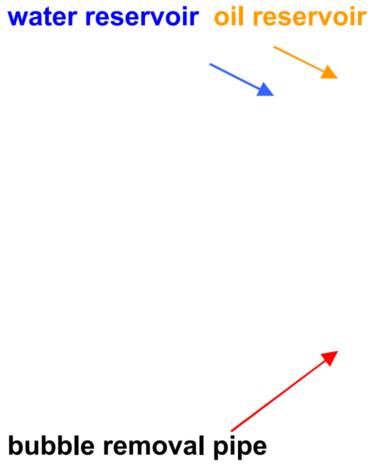

Figure 4. Schematic diagram of a 1-MA LTD cavity section modified in order to operate in a water insulated voltage adder configuration.

VI. EXPERIMENTAL RESULTS

MYKONOS II performs as expected. We have fired up to now 1,800 shots between 50 and 95kV in a rep rate mode. Conservatively we fire every 40 seconds. Our first goal was to condition the cavity switches. To that effect we fired in rep rate mode 100 shots per charging voltage in steps of 5kV. The pressure for every setting was the minimum possible without any pre-fire during the 100 shot series. The results are presented in Fig. 5 in absolute pressure units together with a similar work done at HCEI in Tomsk. The Tomsk results are somewhat more conservative.

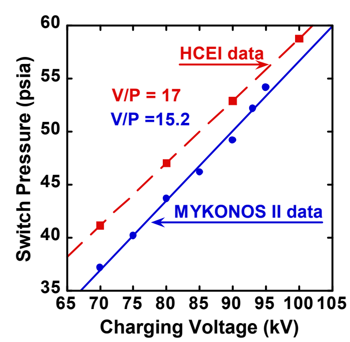

Figure 5. MYKONOS II switch conditioning results. The red points are HCEI results.

Our next step will be to fire 10,000 shots between 90 and 100kV for a life-time measurement. The operating pressure will be selected according to Fig. 5 results with fine pressure adjustments to minimize the FWHM of the output pulse. Figure 6 presents statistics of the 95-kV shots. Although the operating pressure was not optimized for minimum FWHM, the time jitter (4 ns, Figure 6) and peak current spread are reasonable (3.2 kA, Figure 6). Figure 7 compares a typical 95-kV output current pulse at the load with SCREAMER simulations [8]. The results up to the peak of the current agree quite well with the simulation. However, at the fall of the pulse the two traces deviate from each other. We believe that this is due to the difficulty of precisely simulating with SCREAMER the impedance and inductance variation of the curved transmission line connecting the load to the last LTD cavity (Figure 3).

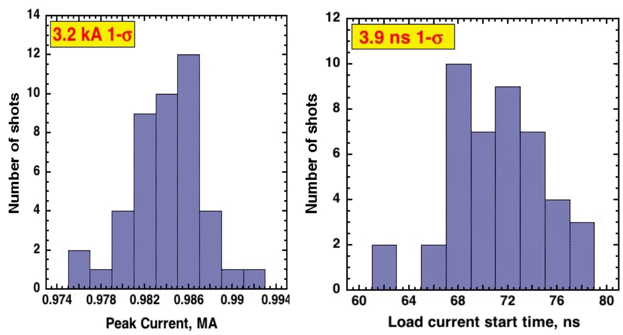

Figure 6. Statistics of 95kV shots.

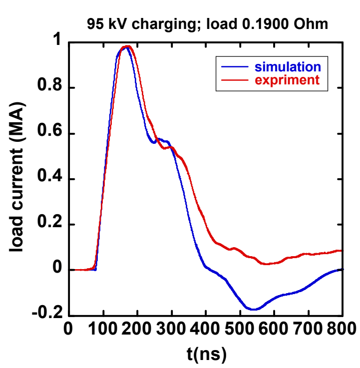

Figure 7. Experimental results of MYKONOS II compared with SCREAMER simulations.

At 80-kV charging we performed pulse-shaping experiments by staggering the firing of the cavities as a whole and also each cavity quadrant separately. The results successfully demonstrated the capability of our MYKONOS to alter the temporal history of the output pulse [9].

VII. SUMMARY

While the MYKONOS laboratory is being readied to receive the 10-cavity voltage adder (MYKONOS X), we are testing a shorter version of two cavity voltage adder (MYKONOS II). The voltage adder is de-ionized water insulated and is terminated with a liquid salt solution resistive load. We have fired already 1,800 shots in rep rate mode, conditioning the switches up to 95 kV charging and performing pulse-shaping experiments.

The current, voltage, power, and energy transmitted into the load is as calculated, and the output pulse shapes are in good agreement with simulations.

Our future plans are first to fire an additional 10,000 shot series with MYKONOS II for life-time measurements and then install the ten cavity 1-MV, 1-MA, 1-TW voltage adder. Following a short conditioning of the other 8 cavities, we will proceed in firing 10,000 shots with the entire device. Pulse shaping experiments will follow with the great flexibility offered by the 10 cavities' staggered firing.

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