RITS-6, A 10-MV Inductive Voltage Adder Accelerator[1]

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Abstract – The three-stage Radiographic Integrated Test Stand (RITS-3) has completed its purpose of characterizing the integrated pulsed power driver and high intensity electron beam diode systems at 4- to 5-MV, and is being upgraded to a six-stage version to access the 10-MV regime. RITS-3 pulsed power performance data, issues requiring development and modifications, and scaling implications to a larger accelerator system will be presented and discussed. The design improvements incorporated into RITS-6 will be shown, as well as performance predictions for a variety of load configurations.

1. Introduction

Inductive Voltage Adder (IVA) accelerators with a magnetically insulated transmission line (MITL) have been used at Sandia National Laboratories to study accelerators and diodes for radiographic applications. Experiments [1] on the Hermes-III and SABRE accelerators have demonstrated the ability to produce electron beams suitable for radiographic applications.

A flexible accelerator system called RITS [2] was designed to provide a platform to specifically study pulsed power issues of IVA accelerators for radiographic applications and to study the physics issues of radiographic diodes. The RITS system can be fielded with varying numbers of adder sections to provide voltages up to 16 MV. The output voltage pulse duration (70 ns) was intentionally made longer than desirable for most radiographic applications to allow examination of diode closure effects over extended time periods. A three cell system, RITS-3, has been tested from 4 to 5.4 MV. An expansion to a six stage system, RITS-6, will start this year with an output of > 10 MV at currents of 125 kA.

2. RITS-3 Design

The RITS-3 accelerator [3], shown in Fig. 1, consists of a 36-stage, 20-nF Marx generator that drives a 13 nF, water insulated intermediate storage capacitor. This intermediate storage capacitor transfers its energy through an SF6 insulated gas switch to three water-insulated, 7.8-Ohm pulse forming lines (PFL), shown in Fig. 2, with self-closing water output switches.

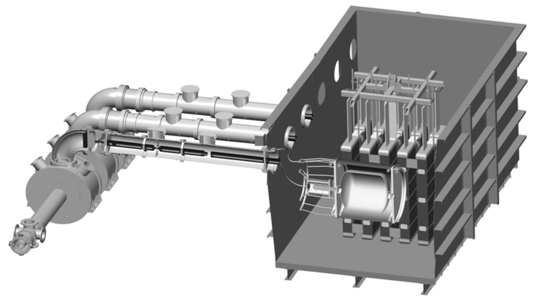

Fig. 1. Drawing of the RITS-3 accelerator with a cut away view of the PFL and intermediate store

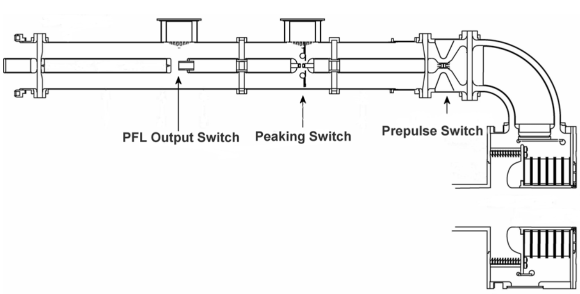

Fig. 2. Cross-section of the PFL and cavity

Pulses from each PFL are delivered through the water insulated output transmission lines to three IVA, Metglas-isolated cavities where they are added on a MITL.

[1] Work supported by Sandia National Laboratories a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94-AL85000.

Two prepulse reduction switches are located in each of the PFLs. The first is water insulated and also acts as a peaking switch to sharpen the output pulse risetime. The second switch is a self-closing, oil-insulated gap.

Essential to the operation of the accelerator is low jitter in the self-closing PFL output switches. A jitter of < 4 ns is achieved [4] when the PFLs are pulse charged in less than 200 ns. Nearly simultaneous voltage pulse arrival times in the MITL is desirable in achieving fast risetime pulses. Abnormally large differences in PFL timing can cause the voltage across one or two of the cavities to have a positive polarity pulse prior to arrival of their PFL pulse.

The radiographic diodes of interest require <150 kA of current so only one PFL per cavity was necessary to supply this current. However, with only a single feed to the cavity, an azimuthal transmission line, shown in Fig. 3, was included in the design to symmeterize the current at the output of the cavity. By varying the connections between the azimuthal transmission line and the cathode side of the cavity, a variation of less than 10% can be achieved [5]. A single point connection produced azimuthal variations in the current of ±50%.

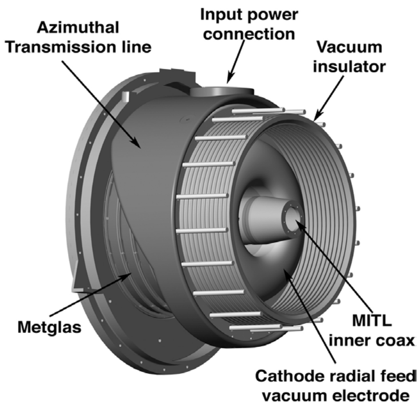

Fig. 3. RITS cavity showing the essential components

Two different MITLs have been tested on RITS-3. The first had three sections: 8 Ohms, 16 Ohms, and 24 Ohms system output impedance when operating at the Creedon [6] minimum current. The second [7] had the impedance increased to 14.2 Ohms per cavity, 42.6 Ohms output impedance. Output voltages of ~ 4.3 MV were achieved with the first MITL and ~5.4 MV with the second. Fig. 4 shows a cross section view of the cavities and MITL.

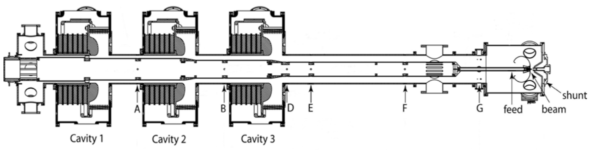

Fig. 4. RITS-3 cavity and 24 Ohm MITL cross section view terminated with a paraxial diode. Diagnostic ports are located at positions A through G on both the inner and outer conductors of the MITL

3. Pulsed Power Results

Because some of the radiographic diodes of interest have highly field enhanced cathodes, a low prepulse voltage is desirable to prevent plasma formation on the cathode prior to the main voltage pulse. Fig. 5 shows calculated and measured prepulse voltage on the MITL. The ~ 6 kV negative prepulse was felt to be low enough so further prepulse reduction methods such as biasing the cathode or inserting a flashover switch in the MITL stalk were not necessary.

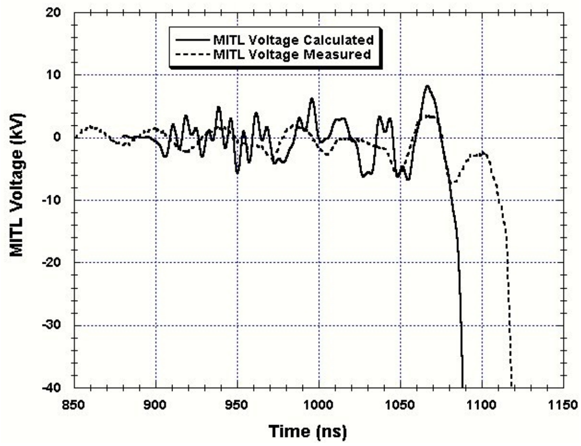

Fig. 5. MITL prepulse voltage after the third cavity

The single point feed combined with an azimuthal transmission line in the cavities can provide adequate symmetry to the current injected into the MITL so that the current is not lost in the power feed from the cavities to the load. Fig. 6 shows the total currents at positions A through F.

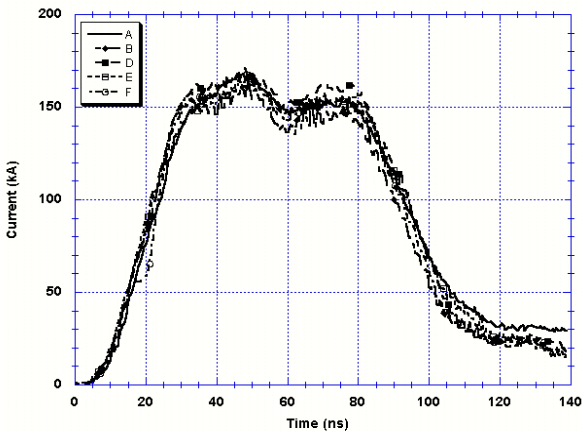

Fig. 6. Azimuthally averaged anode currents throughout the length of the MITL show no loss

The MITL voltages calculated using eq. (1) based Mendel's pressure balance theory [8] agree with the predictions by Bailey [7]. Fig. 7 shows the voltages for both the matched and high impedance MITLs.

$$V \cong Z_o(I_a^2 - I_c^2)^{1/2} - 0.511(I_a/I_c - 1)\{[2(I_a/I_c + 1)]^{1/2} - 1\}. \quad (1)$$

The ratio of the anode current to the cathode current, I_a/I_c, varies from 1.8 to 2.2 for the RITS-3 voltage range. So about half of the total current flows in a sheath in the gap between the cathode and anode. When the MITL is terminated in a high impedance diode, it operates in a self limited mode. The current carried by the sheath electrons is simply lost at the end of the MITL. However, when the MITL is terminated with a diode of less than the MITL operating impedance, some of the sheath current is retrapped on the cathode stalk and a new operating impedance of the MITL is established.

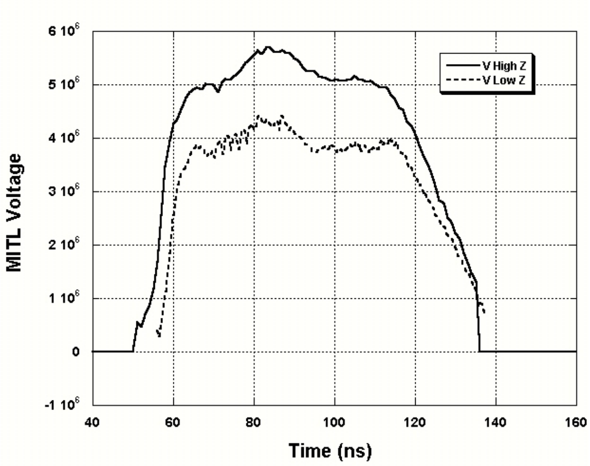

Fig. 7. Voltages calculated from currents at position F for low and high impedance MITLs

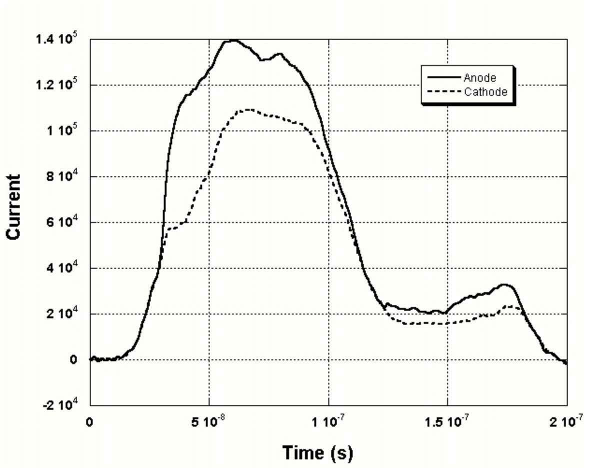

Fig. 8. MITL anode and cathode currents measured 1.2 meters before the end of the MITL

Figure 8 shows the MITL currents for a shot with a load impedance of 35 Ohms. The cathode current increased from the self limited current of 60 kA to 110 kA while the anode current only increased 135 kA to 140 kA. The voltage in the line was only reduced from 5.7 MV to 4.9 MV while the cathode current was nearly doubled.

4. RITS-6 Upgrade

In the RITS-6 system (Fig. 9), the number of cavities, PFLs, gas switches, intermediate storage capacitors will be doubled. A single 61 nF Marx generator will be used to charge the two intermediate storage (IS) capacitors. To synchronize their output the two gas switches (Fig. 10) will be laser triggered. A quadrupled Nd:YAG laser (266 nm) with 30 mJ of energy will be used to trigger switches. A delay of ~ 15 ns between switching times of the two switches will allow propagation of the pulses from the rear three cavities to reach the forward three cavities.

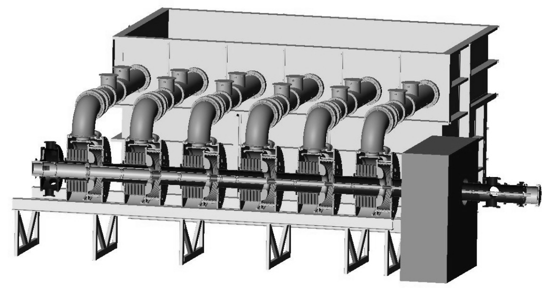

Fig. 9. Drawing of the RITS-6 accelerator

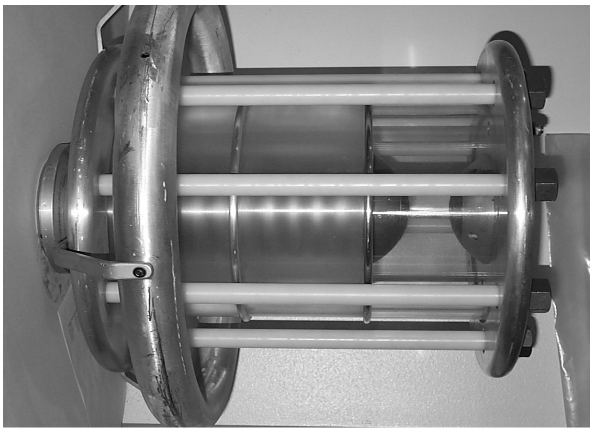

Fig. 10. Laser triggered gas switch. The large gap is trig gered and the remaining (smaller) gaps are over volted

The MITL for RITS-6 is 11.3 meters with a diameter of 6.9 cm at the output end and is cantilevered at the entrance to the 1st cavity. The centering of the cathode throughout the length of the accelerator is kept to less than 4 mm deviation by including tilt adjustments after cavities 3 and 6.

5. RITS-6 Predictions

Pre-assembly of the RITS-6 hardware has begun. RITS-3 is expected to be shut down in mid to late August. At that time, the Marx generator will be rebuilt with the higher energy density capacitors, the addition IS capacitor and gas switch, the three additional IVA cavities, and the new cathode stalk will be installed. The final rebuild and assembly is expected to take four weeks. Pulsed power testing and check out will take an additional three weeks.

The initial diode used in the check out phase will be a blade load. With this diode, multiple shots without venting the MITL to atmospheric pressure can be safely done. By varying the A-K spacing the load can be from the self limited 85 Ohms to a highly undermatched case. Fig. 11 shows LSP [9] calculations of the electron beam trajectories for two different A-K spacings.

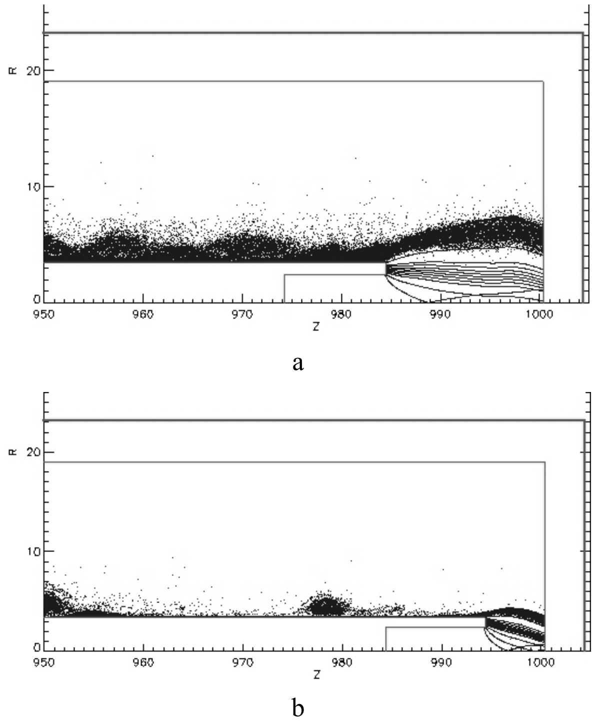

Fig. 11. Self limited case (85 Ohms) with A-K spacing of 16 cm (a). A-K spacing of 6 cm giving an impedance of 56 Ohms (b)

The output voltage and current of RITS-6 will depend on the radiographic diodes under test. An immersed Bz diode has a high impedance (~ 300 Ohms) which will allow the voltage to reach ~ 10.5 MV. A self magnetic pinched beam diode operates at about 50 Ohms. This will result in a voltage of 7 MV and a cathode current of 130 kA. Fig. 12 graphs the operating parameters for RITS-6.

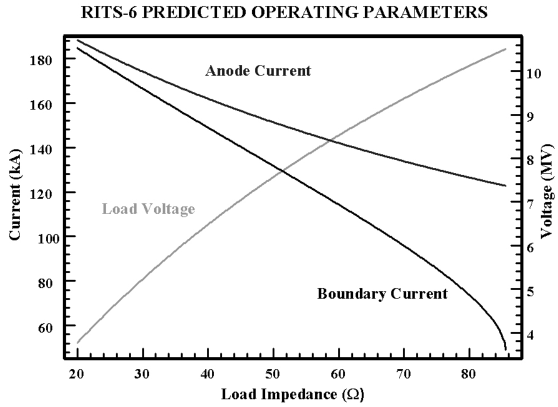

Fig. 12. Calculated operating curves for the RITS-6 high impedance MITL

6. Summary

RITS-3 has provided valuable information on the design and operation of pulsed power driven IVA accelerators. It has also provided a versatile test bed for the study of radiographic diodes. We have high confidence that RITS-6 will be equally valuable in the studies of pulsed power and radiographic diode physics.

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