DESIGN AND POWER FLOW STUDIES OF A 500-TW INDUCTIVE VOLTAGE ADDER (IVA) ACCELERATOR

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ABSTRACT

We present a preconceptual design for a 500-TW pulsed power accelerator capable of delivering 15-MJ kinetic energy into an imploding plasma radiation source (PRS). The HERMES-III technology of linear inductive voltage addition in a self-magnetically insulated transmission line (MITL) is utilized to generate the 8-10 MV peak voltage required for an efficient plasma implosion. The 50- to 60-MA current is achieved by utilizing many accelerating modules in parallel. The modules are connected to a common circular convolute electrode system in the center of which is located an imploding foil plasma radiation source. This accelerator produces no electron beam since the total current from the voltage adders (IVAs) to the inductive load flows on the surface of metallic conductors or nearby in the form of electron sheath.

In this paper we outline the accelerator's conceptual design with emphasis on the power flow and coupling to the inductive load of the center section of the device.

INTRODUCTION

The proposed pulsed power accelerator (Fig. 1) is based on the successful HERMES-III [1] technology developed at Sandia during the last ten years in collaboration with Pulse Sciences Inc. Each of the 30 modules of Figure 1 are similar to HERMES III. This technology is fairly simple and couples the self-magnetically insulated transmission line (MITL) [2] principle with that of the induction linac [3] to generate a new family of linear induction accelerators, which we call linear inductive voltage adders. In these accelerators, the particle beam which drifts through the multiple cavities of conventional induction linacs is replaced by a metal conductor which extends along the entire length of the device and effectuates the voltage addition of the accelerating cavities. These devices can operate in either polarity to produce negative or positive voltage pulses. In a negative polarity voltage adder (Fig. 2), the center conductor is negatively charged relative to the outer conductor which is interrupted at regular intervals by the cavity gaps. The PRS accelerator voltage adder is negative polarity.

The selected number of modules, 30, is a trade-off between cost, manufacturing capabilities, and operatons flexibility. An inductive voltage adder coupling more than ~ 2.5-MA can be very large and cumbersome, requiring special and expensive manufacturing tools to machine the various components. In addition, the radial gaps of the self-magnetically insulated voltage adder become very small, which in turn increases the probability for fast neutral atom closure [4], for the desired 100-ns FWHM pulses.

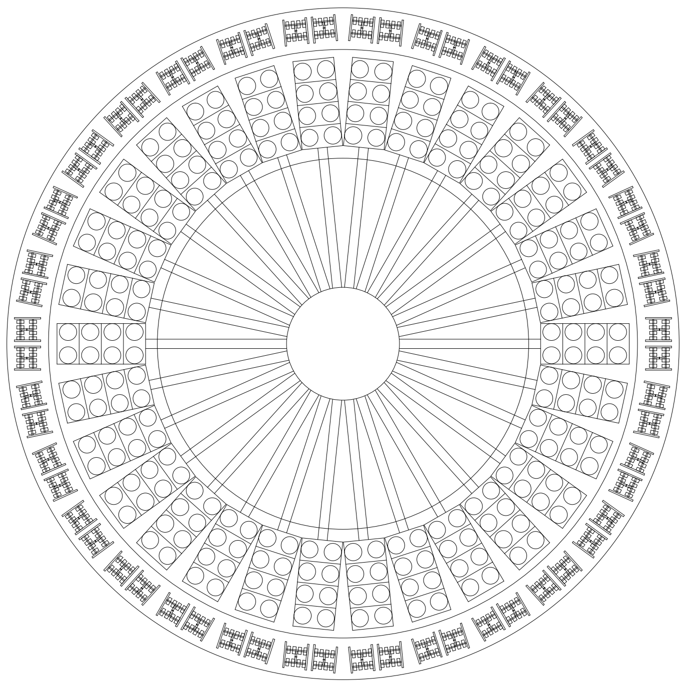

Figure 1. Top view of the PRS multimodular accelerator

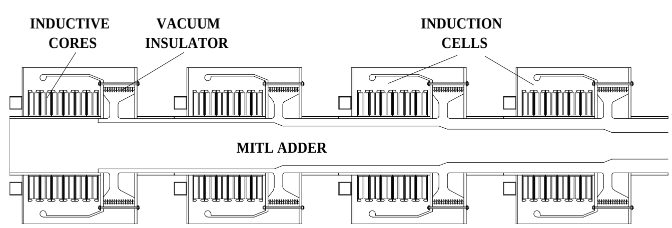

Figure 2. Schematic diagram of the PRS accelerator voltage adder. It is of negative polarity. There is a total of 30 voltage adders in the device.

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Table I

R_{anode} = 38 cm

voltage adder segment i	distance from ground plate z [m]	segment voltage V_i [MV]	cathode radius r_i [cm]	operating impedance Z_i [Ω]	vacuum impedance Z_i [Ω]
1	0.30 - 1.98	2 - 2.5	37.0	1.11 - 1.16	1.6
2	1.98 - 3.65	4 - 5	36.1	2.22 - 2.28	3.08
3	3.65 - 5.33	6 - 7.5	35.3	3.33 - 3.41	4.42
4	5.33 - 7.00	8 - 10	34.6	4.44 - 4.54	5.62

ACCELERATOR DESIGN

All the 30 modules in the accelerator are identically composed of a four-stage voltage adder and an extension MITL. The voltage adder is 5.6-m long and contains 4 inductively isolated cavities. Each cavity can withstand ~ 2.5 MV for a 100-ns FWHM sine squared pulse shape. Table I summarizes the axial and radial dimensions of the voltage adder as well as the vacuum and operating impedances for two cavity operating points: 2 MV and 2.5 MV. Those correspond respectively to 430-TW and 660-TW total accelerator power. Each module delivers approximately the same power as HERMES III (16 TW); however, the voltage is half as large and the current more than double.

Due to their radial dimensions, the voltage adders cannot be brought close to the load; therefore, long extension self-magnetically insulated transmission lines (MITLs) are required to transfer and converge the power to the load. In the present design this length is 11.3 m. There are advantages and disadvantages to the utilization of long MITLs. It is our belief that the advantages outweigh the disadvantages. For instance, the erosion energy losses are compensated for by the flexibility of the voltage adder time isolation from the load. For most of the pulse duration, the load impedance seen by the voltage adder equals its self-limited operating impedance despite the fact that the actual load impedance can be up to ten times higher.

POWER FLOW STUDIES

Figure 3 shows one of the TWOQUICK [5] PIC code simulations used to validate the design, modeling one module with a six-meter long MITL. The accelerator center section (transition convolute and imploding plasma) is simulated by a coaxial cylindrical box whose inductance is 30 times larger than the actual inductance seen by the 30 parallel modules. The end plate of the coaxial line simulates the imploding cylindrical foil. The electron map is for 180 ns after the beginning of the pulse, coincident with the 2.1-MA maximum current through the load. The energy coupled into the inductive load is $L\, I^2_{max}/2$ = 630 kJ out of a total of 1,090 kJ energy input into the voltage adder, yielding a system efficiency of 58%. The simulation in Fig. 4 was performed to find the total energy loss in the 11.3 MITL. The voltage adder is not included; however, its voltage output (Fig. 5) was used as input. The output voltage pulse is shown in Fig. 6. The 60-ns erosion of the leading edge corresponds to 92-kJ lost. Besides the pulse shortening by ~ 60 ns, there is a small energy loss (20 kJ) in the main body of the pulse. Together this gives an average erosion rate of 10 kJ/m. Hence, if all the MITL length had been included in the simulation of Fig. 3, the energy efficiency would have been ~ 50%.

Precise energy balance using TWOQUICK suggests the missing 50% of the input energy is distributed between reflections at the load (3%), erosion (10%), losses at the beginning of the inductor early in the pulse (10%), sheath electron losses at the load (20%), and field energy remaining inside the MITL (10%).

To calculate the overall accelerator efficiency driving an imploding plasma radiation source we used the SCREAMER [6] circuit code which gave an energy efficiency of 17%. That is, for a total of 90 MJ stored in the Marx generators of the 30 modules, 15 MJ is delivered to the imploding plasma.

CONCLUSION

The presented PRS accelerator design is based on the HERMES-III technology of inductively insulated voltage adders (IVA). It has 30 parallel modules and can deliver the required 15-MJ kinetic energy to an imploding plasma radiation load. The total energy erosion in the thirty 11-m long MITLs is of the order of 3.3 MJ and the overall energy efficiency of the accelerator is 17%. The modular configuration offers flexibility and risk mitigation by an anticipated staged construction. Components of the first test module are currently under construction.

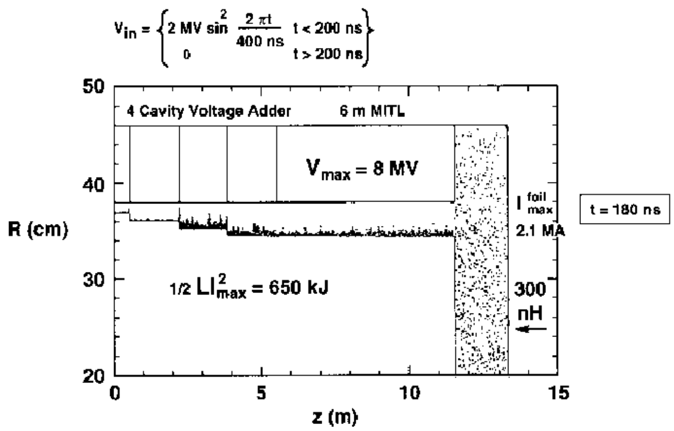

Figure 3. Numerical simulation of the voltage adder connected to a 300-nH inductive load via a 6-m long MITL. The electron map shown is simulated 180 ns later, following the injection of the voltage pulse (V_{in}) at the first cavity.

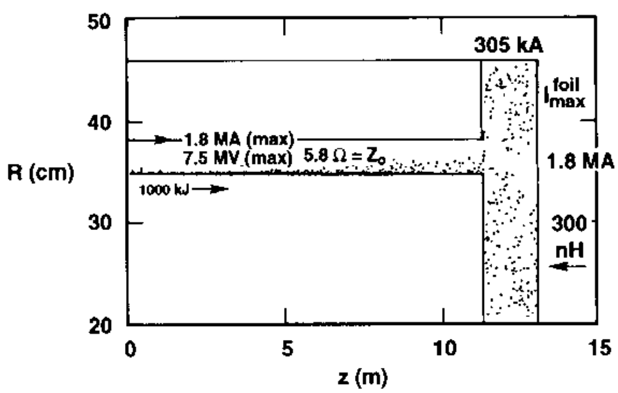

Figure 4. Simulation of the power flow in the 11.3-m long extension MITL of an accelerating module. The electron map is taken at 120 ns following injection.

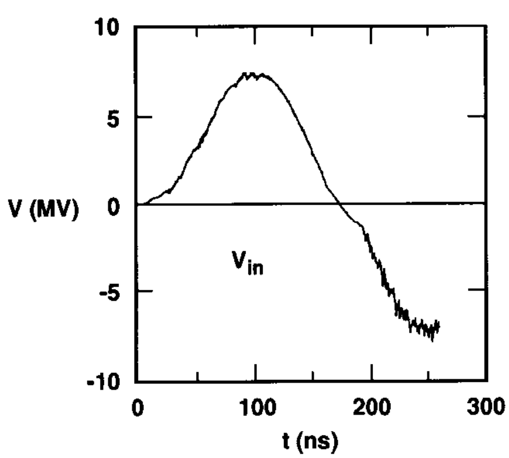

Figure 5. Simulated voltage output at the exit of the voltage adder (Fig. 3).

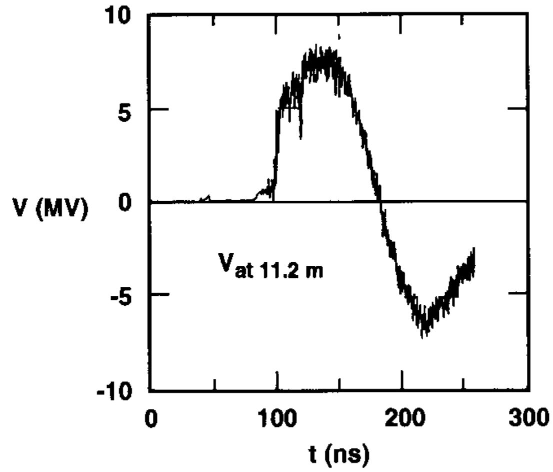

Figure 6. Voltage output pulse at the end of the 11.3-m long extension MITL of Fig. 4. The erosion at the leading edge of the pulse is apparent.

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