

# THE LIGHT-ION PULSED POWER INDUCTION ACCELERATOR FOR THE LABORATORY MICROFUSION FACILITY (LMF)\*

M. G. Mazarakis, D. L. Smith, L. F. Bennett, T. R. Lockner, R. E. Olson, J. W. Poukey, J. Boyes  
Sandia National Laboratories

P. O. Box 5800, Albuquerque, NM 87185-5800 USA

## Abstract

In order to initiate ignition and substantial energy yield from an inertial confinement fusion target (ICF), a light-ion pulse of ~700 TW peak power and 15-20 ns duration is required. The pre-conceptual design presented here provides this power. The HERMES-III technology of linear inductive voltage addition in a self-magnetically insulated transmission line (MITL) is utilized to generate the 25-36 MV peak voltage needed for lithium ion beams. The 15-20 MA ion current is achieved by utilizing many accelerating modules in parallel.

The lithium ion beams are produced in two-stage extraction diodes. To provide the two separate voltage pulses required by the diode, a triaxial adder system is incorporated in each module. The accelerating modules are arranged symmetrically around the fusion chamber in order to provide uniform irradiation onto the ICF target. In addition, the modules are fired in a preprogrammed sequence in order to generate the optimum power pulse shape onto the target.

In this paper we present an outline of the LMF accelerator conceptual design with emphasis on the architecture of the accelerating modules.

## I. INTRODUCTION

The Laboratory Microfusion Facility has both near and long-term goals. The near-term goals are to study high gain Inertial Confinement Fusion (ICF) targets with yields of the order of 500 MJ, to study nuclear weapon physics, and to provide an improved nuclear weapon simulation source. Among the long-term goals, the most important is to provide the technical development necessary to demonstrate scientific feasibility for fusion energy production. To achieve these goals, the LMF driver must deliver to the ICF target energies equal to or higher than 10 MJ with the ability to vary the magnitude and pulse shape of the deposited energy as a function of time.

The light-ion LMF pre-conceptual design is based upon the ion beam input requirements of the 500-MJ yield ICF target. These requirements are established by a combination of numerical calculations and the existing ICF database. The driver design is modular and consists of 24 modules of two different types: A and B. These modules are fired in a two-step sequence to provide the desired power pulse shape on the target (Figure 1). The first pulse to arrive at the target, generated by the 12 A modules, has a 65-TW flat top and a 60-ns duration. The main pulse, delivered by the 12 modules B, arrives at the target 40 ns later. It has higher peak power (650 TW) but shorter duration (20 ns). The pulses overlap during the last 20 ns to provide the target with the required 715 TW peak power.

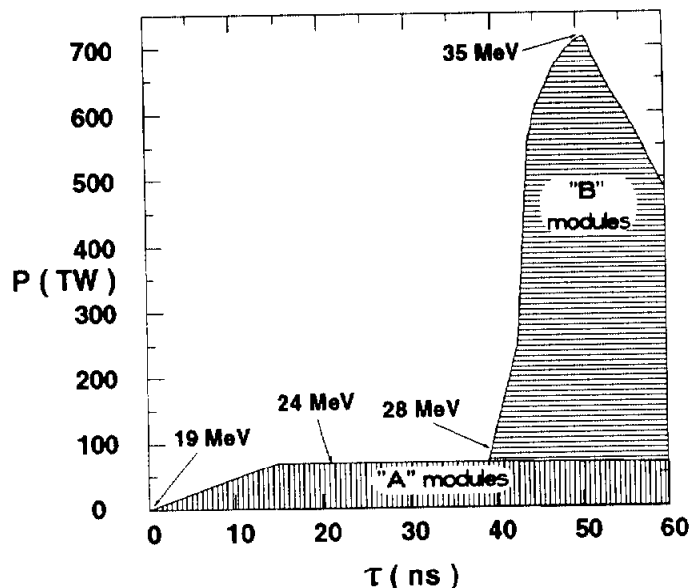


Figure 1. ICF Target Power Requirement for a 500-MJ Yield

## II. THE LMF ACCELERATOR

The LMF pulsed power accelerator (Figure 2) is based on the successful HERMES-III<sup>1</sup> (Figure 3) technology developed in Sandia during the last ten years in collaboration with Pulsed Science Inc. Each of the 24 modules of Figure 2 are similar or identical to HERMES III. This technology is fairly simple and couples the self-magnetically insulated transmission line (MITL)<sup>2</sup> principle with the N. Christophilos invention of the induction linac<sup>3</sup> to generate a new family of linear induction accelerators, such as HELIA,<sup>4</sup> HERMES III, RADLAC/SMILE,<sup>5</sup> and SABRE,<sup>6</sup> which we call linear inductive voltage adders. In these accelerators there is no beam drifting through the multiple cavities as is the case with conventional induction linacs. The place of the beam is taken by a central conductor which extends along the entire length of the device and effectuates the voltage addition of the accelerating cavities. The beam is produced at the end of the voltage adder in a single or multistage diode. These devices can operate in either polarity to produce negatively or positively charged particle beams. In a positive polarity voltage adder (Figure 4), the center conductor is positively charged relative to the outer conductor which is interrupted at regular intervals by the cavity gaps. The HERMES-III voltage adder is of negative polarity. A linear inductive voltage adder can be converted from negative to positive polarity and vice versa by a rotation of 180° around a vertical axis of the center conductor or equivalently of each of the accelerating cavities. This was

\*This work was performed under U.S. Dept. of Energy Contract No. DE-AC04-76DP00789.

demonstrated on HERMES-III which operated with equal success in positive and negative polarity.<sup>7</sup> SABRE has a positive polarity inductive voltage adder. The LMF voltage adders also are of positive polarity, and the beam particles produced by the diodes are singly charged positive lithium ions.

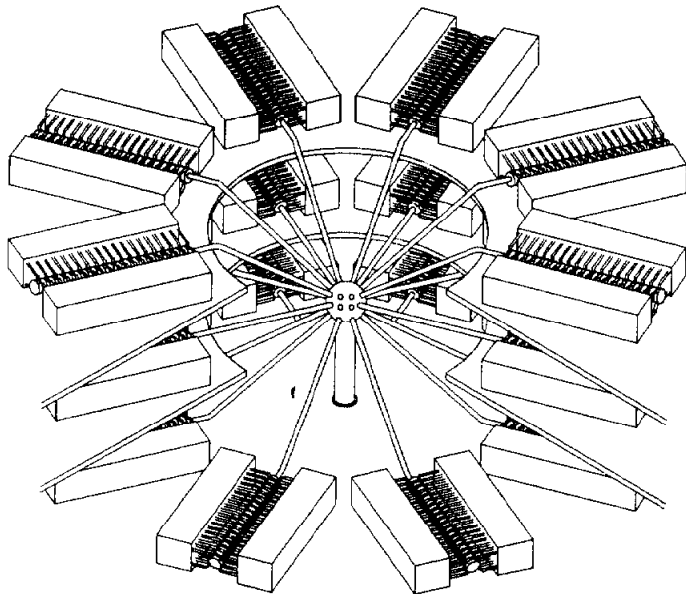


Figure 2. Cutaway View of the Light-Ion Microfusion Accelerator

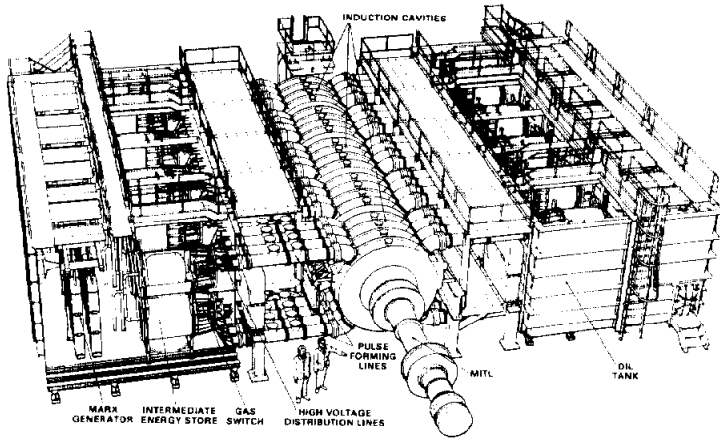


Figure 3. The HERMES III Accelerator

The selected number of modules, 24, is a trade-off between cost, pulse uniformity on the target, and number of diodes that can be fit at the 4 m radius outside wall of the interaction chamber. Each module has its own diode, producing the 24 separate ion beams focused on the ICF target. The beams propagate fully space charged and current neutralized in a 1 Torr helium atmosphere. In the first 3 meters of transport the beam annular cross section remains constant with the particle trajectories being slightly divergent. The principal focusing occurs in a main solenoidal lens 1 meter from the 1 cm radius ICF target. The beam transport system is achromatic.<sup>8</sup> The achromaticity is achieved by combining the final focusing solenoid with the self-

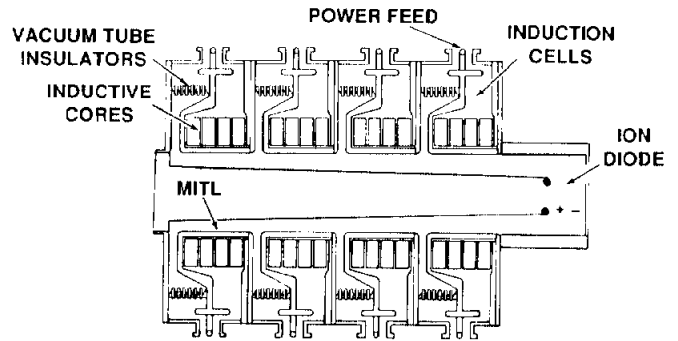


Figure 4. A Simple Positive Voltage Adder of the SABRE Type Providing Power to a Single Stage Ion Diode

filled focusing effect at the ion diode. The ion trajectories are ballistic between the diode and the lens and between the lens and the target.

The power and kinetic energy of the ions delivered to the target are shown in Figure 1. The electrical power delivered by the voltage adders to the diodes is somewhat higher due to certain inefficiencies in the diode and in the transport system. We assume a 70% peak power efficiency from the diode to the target. Hence, the modules A deliver to the diodes at total peak electrical power of 91 TW and the modules B of 457 TW. Table 1 summarizes the electrical output parameters for both types of modules.

The beams from the modules B are bunched by a factor of 2 during transport to the target, driven by a ramped voltage pulse provided to the second stage gap by the inductive voltage adders. Bunching doubles the peak ion power delivered to the target and shortens the pulse duration from 40 ns (Table 1) to 20 ns (Figure 1).

Table 1  
Electrical Output Parameters per Module

	Module A	Module B
P(TW)	7.6	38
V(MV)	24.7	36
I(MA)	0.31	1.06
$\tau$ (ns)	60	40
W(MJ)	0.46	0.83

### III. ACCELERATING MODULE DESIGN

The accelerating voltage of the first stage for both A and B diodes is a constant 10 MV (not ramped). The second stage voltage for the modules A is a constant 15 MV while the modules B voltage is ramped from 18 to 26 MV. A triaxial adder system is designed for each module (Figure 5) to provide the two separate voltage pulses to the diode. The cavities of each module are grouped into two stages, and the voltage addition occurs in two separate MITLs nested one inside the other. The center hollow cylinder (anode) of the second MITL also serves as the outer cathode electrode for the extension of the first voltage adder MITL.

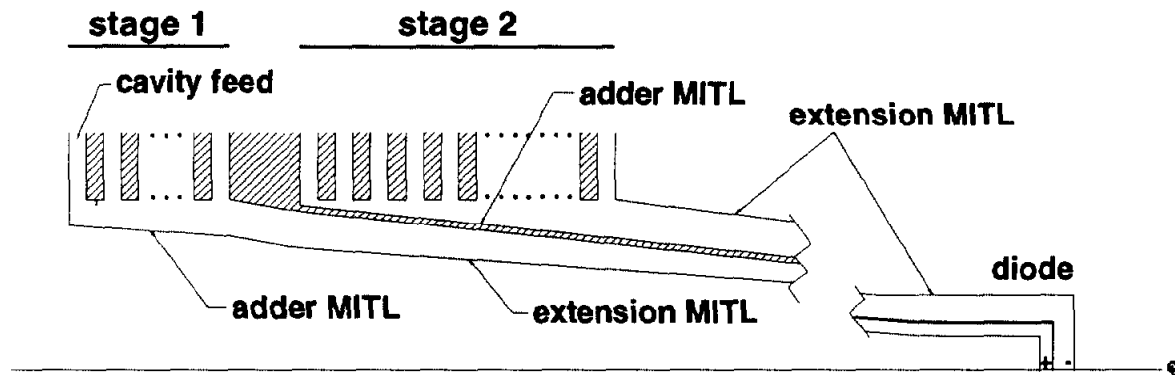


Figure 5. The Triaxial Voltage Adder Configuration for the Two-Stage Extraction Diodes of the LMF Accelerator.

Each voltage adder is connected to the corresponding stage of the diode via a long extension MITL which time-isolates the diode from the voltage adder. Thus the diode can operate at lower impedance than the voltage adder without affecting the voltage adder operation. Undermatching the diode load reduces the sheath electron current in the extension MITL and provides for more efficient pulse power coupling. The power coupling efficiency for this design depends on the final voltage of each adder, typically 80% to 85%.

The LMF driver can be built with components similar or identical to those of HERMES III. The modules A are HERMES-III accelerators with 4 more cavities (24 total) operating at half power, using half of the  $5\Omega$  pulse-forming and transmission lines that power each of the HERMES-III cavities.

There are two design options for the modules B: one that is again composed solely of HERMES-III components and the other made up of 2.6 MV cavities of entirely new design. The modules B can be built by two HERMES-III accelerators connected in series (40 cavities in total) or by seventeen 2.6-MV cavities. Table 2 summarizes the two design options for the B modules.

Table 2  
Design Options for the B Modules

	HERMES-III Option	2.6 MV Cavity Option
Cavity Voltage (MV)	1.1	2.6
Number of Cavities	40	17
PFLs/Cavity	4	4
PFL Impedance ( $\Omega$ )	5	8
I matched (MA)	0.88	1.15

#### IV. CONCLUSION

This LMF accelerator design is based on the HERMES-III robust technology. It has a flexible modular configuration which

offers risk control by an anticipated staged construction. Half of the 24 modules are identical to HERMES III, and the other half can be built with HERMES-III or similar 2.6-MV components. This provides a confident base for realistic cost estimates and offers additional assurance for the success of the project.

#### REFERENCES

- [1] J. J. Ramirez, et al., "HERMES-III—A 16-TW, Short Pulse Gamma Ray Simulator," *Proc. 7th International Conf. on High Power Particle Beams*, Karlsruhe, Germany, July 4-8, 1988, pp. 148-157.
- [2] J. H. Creedon, "Magnetic Cutoff in High-Current Diodes," *J. Appl. Phys.*, **48**, No. 3, 1070 (1977).
- [3] N. Christophilos, et al., "High Current Linear Induction Accelerator for Electrons," *Rev. Scient. Instrum.*, **35**, No. 7, 886 (1964).
- [4] J. J. Ramirez, et al., "The Four Stage HELIA Experiment," *Proc. 5th IEEE Pulsed Power Conf.*, Arlington, Virginia, June 10-12, 1985, p. 143-146, IEEE #85C2121-2.
- [5] M. G. Mazarakis, et al., "SMILE—A New Version for the RADLAC II Linear Accelerator," *Proc. of the 1990 Linear Accelerator Conference*, Albuquerque, New Mexico, September 10-14, 1990, pp. 438-440, LA-12004-C.
- [6] J. Corley, et al., "SABRE, A 10-MV Linear Induction Accelerator," *Proc. 8th IEEE Pulsed Power Conference*, San Diego, California, June 16-19, 1991, pp. 920-923, IEEE #91CH3052-8.
- [7] D. L. Johnson, et al., "Hermes-III Positive Polarity Experiment," *Proc. 7th IEEE Pulsed Power Conference*, Monterey, California, June 11-14, 1989, pp. 32-35, IEEE #89CH2678-2.
- [8] C. L. Olson, "Achromatic Magnetic Lens Systems for High Current Ion Beams," *Proc. of the 1988 Linear Accelerator Conference*, Williamsburg, Virginia, Oct. 3-7, 1989, pp. 34-37, CEBAF Report 89-001.