

## A CONCEPTUAL DESIGN FOR AN LMF ACCELERATOR MODULE\*

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### ABSTRACT

The U. S. Department of Energy has initiated a design study of a Laboratory Microfusion Facility (LMF) that will be used to develop high-gain ICF targets. A conceptual design for a light ion beam accelerator has been developed for a multimodule LMF system based on technology demonstrated on Sandia's Hermes-III accelerator. The LMF accelerator module incorporates 32 linear induction cavities, each operating at 1 MV, to produce an output voltage pulse that ramps from 27 to 32 MV with a peak current of 1.2 MA. The power for the accelerator module is derived from sixteen Marx generators that drive 128, 4- $\Omega$ , 54-ns pulse forming lines (PFL). Four PFL pulses are combined in each inductive cavity. Nanosecond synchronization of the PFL output pulses is accomplished using KrF laser triggered output gas switches and low jitter, self-breakdown water switches. The outputs of the cavities are added in a magnetically insulated transmission line (MITL) and then delivered to an extraction ion diode. Singly-ionized lithium ions are accelerated in the diode. Voltage ramping is used to achieve power compression of the ion beam when ballistically drifted to the ICF target. An equivalent circuit has been developed to model the module from the Marx generator to the ion diode. The timing performance of the gas and water switches has been included in the model to calculate the resulting output waveform and system jitter.

### INTRODUCTION

The Laboratory Microfusion Facility (LMF) is intended as a facility for developing and using high-gain, high-yield inertial confinement fusion (ICF) targets. The LMF module described in this paper is the result of a study to develop a conceptual design for a reliable multimodule light ion beam system capable of meeting requirements for the LMF.<sup>1</sup> The 40-TW module design is based on an extension of the technology developed for the Hermes-III accelerator shown in Fig. 1.

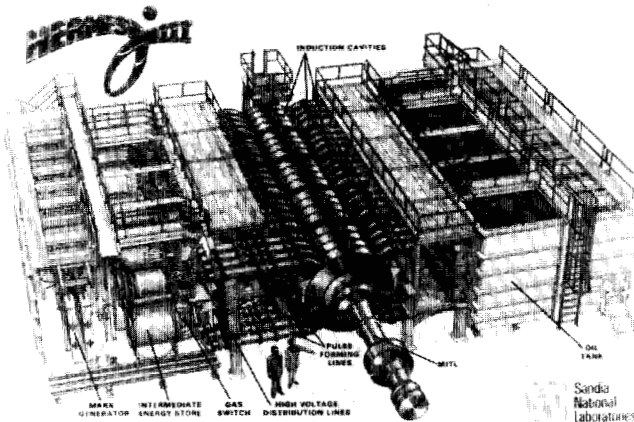


Fig. 1 Hermes-III accelerator

Hermes III is a 16-TW electron beam accelerator designed to produce an intense burst of bremsstrahlung radiation for the simulation of weapons effects.<sup>2</sup> This 22-MV, 730-kA accelerator generates its output pulse by adding the pulses produced by eighty pulse forming lines in a specific parallel/series combination. The eighty individual PFL output pulses are first added in groups of four in the twenty induction accelerator cavities to produce a 1.1-MV, 730-kA output pulse. These single

cavity output pulses are then added in series along the length of a MITL to develop the 22-MV, 730-kA, 40-ns output pulse. The output of this "adder MITL" is delivered to the electron beam diode by an "extension MITL". Figure 2 is a cross-sectional view of the MITL section.

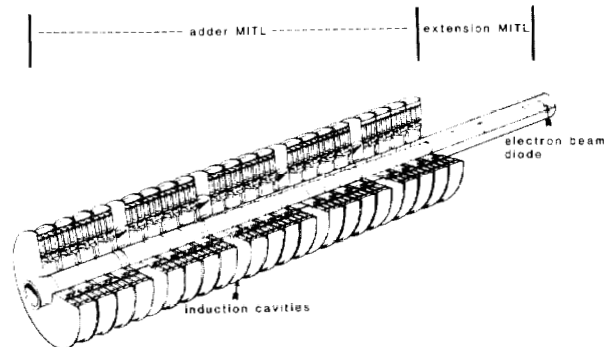


Fig. 2 Cut-away section of the Hermes-III cavity/MITL section.

In the LMF module design the number of cavity stages is increased to 32 and the peak current increased to 1.2 MA. Table I is a comparison of the LMF accelerator module and Hermes III. Stepped-impedance pulse forming lines (PFL) create a ramped 54-ns output pulse that allows for bunching of the ions as the beam is transported from the diode to the target. The key difference between Hermes III and the LMF module is in the design of the MITL. In an ion accelerator, the inner conductor of the coaxial MITL must be positive polarity. Initial calculations indicate that MITL power flow in this configuration is more complex than in the negative polarity. However, preliminary results from a positive polarity experiment performed on Hermes III indicate the efficiency may be greater than calculated. This complex flow may also affect the efficiency of coupling power to the ion diode.

TABLE I. COMPARISON OF THE LMF ACCELERATOR MODULE AND HERMES III

LMF Module	Hermes III
32 Cavities	20 Cavities
128 PFLs, 4 $\Omega$ , 54 ns	80 PFLs, 5 $\Omega$ , 40 ns
0.9 MV to 1.2 MV ramp	1.1 MV
1.5 ns gas switch jitter	same
4.0 ns water switch jitter	same
positive output	negative output
ion diode load	electron diode load

The baseline Li<sup>+</sup> ion diode for the LMF module is an applied magnetic field (applied-B) diode.<sup>3</sup> Although it has many features in common with applied-B ion diodes fielded on past experiments, the extraction applied-B ion diode needed for LMF has several features which distinguish it from the diodes developed on other Sandia accelerators. The operating impedance of the LMF diode, 25-32  $\Omega$ , is higher than that at which other high power diodes have been tested. The LMF diode voltage, 27-32 MV, is beyond the existing experimental data base and will require the use of larger anode-cathode gaps and higher insulating magnetic fields than are presently used. Finally, although many focusing experiments have been performed with radial focusing applied-B ion diodes, few experiments have been performed with applied-B diodes in extraction geometry.

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Many of these gaps in our data base can be filled by several recent advances in diode theory<sup>4</sup> that have made it possible to predict important features of diode performance with reasonable confidence. Among these are diode efficiency with uniform insulation and diode voltage and current at peak power. An extension of the diode operating point theory<sup>5</sup> indicates that the observed decrease in diode impedance after peak power may be due to magnetic field diffusion into the anode plasma. A plasma-free ion source would eliminate this effect, providing a more stable operating impedance. Our present baseline ion source, the electrohydrodynamically driven lithium ion source, will satisfy this requirement if it is successful. This source is expected to have an intrinsic divergence small enough to allow the total beam divergence to satisfy the 6.7 mrad criterion for LMF.

### PULSED POWER SYSTEM

A block diagram of the LMF module pulse power system is shown in Fig. 3. The primary energy storage unit is a 30-stage, 70-nF, 3.0-MV Marx generator. Sixteen Marx generators storing 3.3 MJ are used in the accelerator. Energy is transferred from the Marx generators to 32 water-insulated intermediate storage (IS) capacitors in  $\sim 1 \mu\text{s}$ . Each of these capacitors charges four stepped-impedance pulse forming lines. The coaxial PFL has three impedance sections-- 4  $\Omega$ , 5  $\Omega$ , and 6  $\Omega$ . This design provides the ramped output pulse necessary for bunching the ion beam.

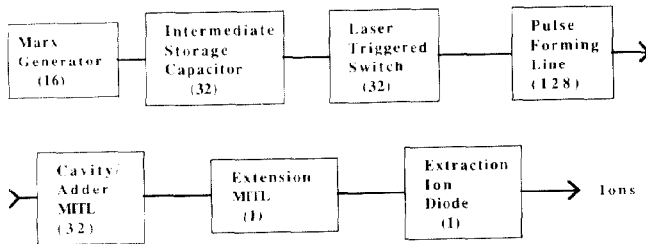


Fig. 3 Block diagram of the LMF pulsed power system. (In parentheses are the numbers of the system components used.)

Energy transfer between the IS and the PFLs is synchronized using KrF laser triggered gas switches.<sup>6</sup> The fast PFL charge time of 200 ns allows for low jitter closure of self-breakdown water switches. Output pulses from four of the PFLs feed into each Metglas<sup>7</sup> isolated linear induction cavity. Output voltages from the 32 cavities are added in series in the adder MITL and transported to the ion diode via the extension MITL.

Low jitter switch operation is essential in combining the PFL output pulses and in achieving good simultaneity of modules in the multi-module LMF design. An analytical calculation of the LMF module jitter using gas and water switch jitters of 1.5 ns and 4 ns, respectively, (achieved on Hermes III) shows the standard deviation of the output pulse from one module is 0.5 ns. This indicates that adequate synchronization can be achieved with existing switch technology. The high-voltage waveform used in the jitter analysis was calculated using the circuit model described later in this paper. The time at which the voltage pulse reached 26 MV was used as a measure of the module timing. Ions produced at this voltage and time are the first to arrive at the ICF target.

### LMF DIODE PARAMETERS AND DESIGN ISSUES

An applied-B extraction diode geometry that is envisioned for LMF is shown in Fig. 4. There are several constraints on the diode geometry and performance which can be identified.

(1) From Liouville's Theorem, the following relation can be derived<sup>8</sup>:

$$R_{\text{diode}} \Theta_{\text{micro}} \leq R_{\text{target}} \Theta_{\text{incident}}$$

For a 1 cm radius target, a 7 degree angle of incidence, and a 6.7 mrad divergence,  $R_{\text{diode}} \leq 18.2 \text{ cm}$ . We will assume  $R_{\text{diode}} = 16 \text{ cm}$ .

(2) In order to achieve the correct applied magnetic field profile in an extraction geometry,  $R_{\text{outer}}/R_{\text{inner}} \leq 2.0$ , so  $R_i = 8 \text{ cm}$ .

(3) The ratio of the anode-cathode gap to anode emission length,  $d/(R_o - R_i)$  should be small to reduce edge effects. For this study we will assume a limit of 0.4.

(4) The present state-of-the-art for pulsed diode magnetic field coils is 4-5 T. We will assume that a level of 5.3 T can be achieved.

Using these constraints it is possible to define a basic diode configuration. We assume an ion source purity corresponding to a 95% energy coupling efficiency to the  $\text{Li}^+$  beam. Beam divergence from this diode must be  $\leq 6 \text{ mrad}$  in order to satisfy the LMF focusing requirements. The intrinsic divergence of the EHD ion source which is envisioned for this diode is approximately 4 mrad<sup>9</sup> at 30 MV.

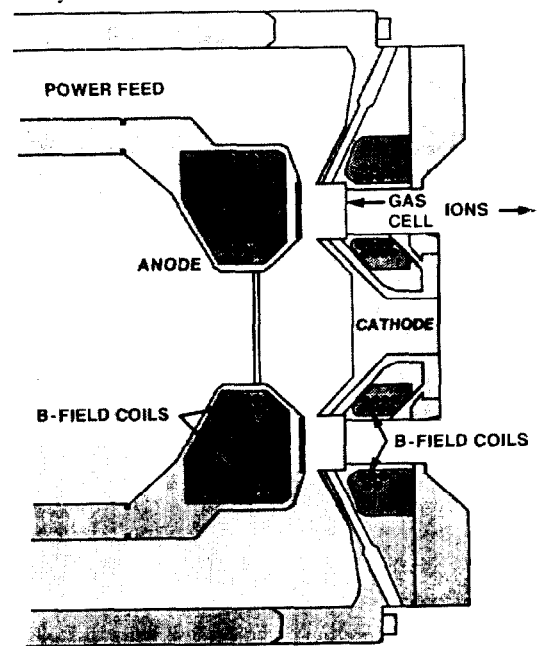


Fig. 4 Applied-B extraction ion diode.

### COMPUTER SIMULATIONS

Circuit code modeling of the Hermes-III accelerator system has shown good agreement with experimental results. The Hermes-III circuit model was modified and used to calculate the performance of the LMF module. Equivalent circuit models of the module were analyzed using the SCREAMER<sup>10</sup> circuit code. The modeling was done in three parts. The first modeled the Marx generator through a single cavity terminated in a matched load. Figure 5 is the calculated single cavity output voltage. The second part of the modeling used 128 randomly time shifted variations of this waveform added in a series/parallel combination to produce the voltage pulse shown in Fig. 6. The random time shifts used were determined by using measured Hermes-III gas and water switch standard deviations and a random normal distribution. In the final part of the modeling, we used the composite voltage pulse as the source voltage for a circuit consisting of a source, a MITL, and the  $V^*$  ion diode model<sup>4</sup> recently developed at Sandia to calculate the expected diode output parameters. The calculated energy efficiency from MITL input to diode energy is 80%, resulting in ion energy at the diode of 1.3 MJ per module. Figure 7 shows the results of the simulation and compares the power pulse at the diode with the beam power pulse after ballistically drifting four meters.

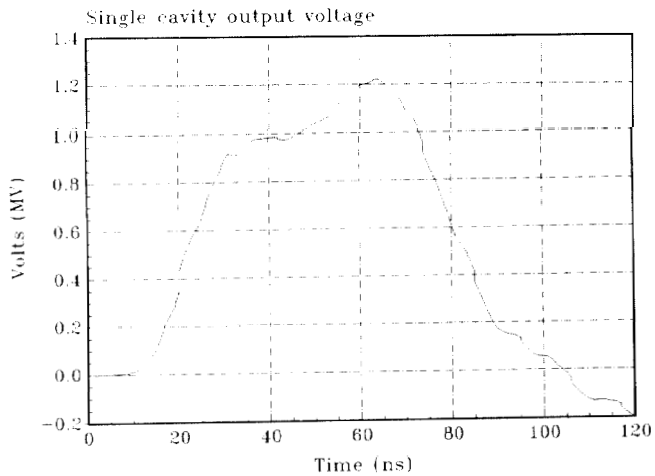


Fig. 5 Calculated output voltage of a single linear induction cavity.

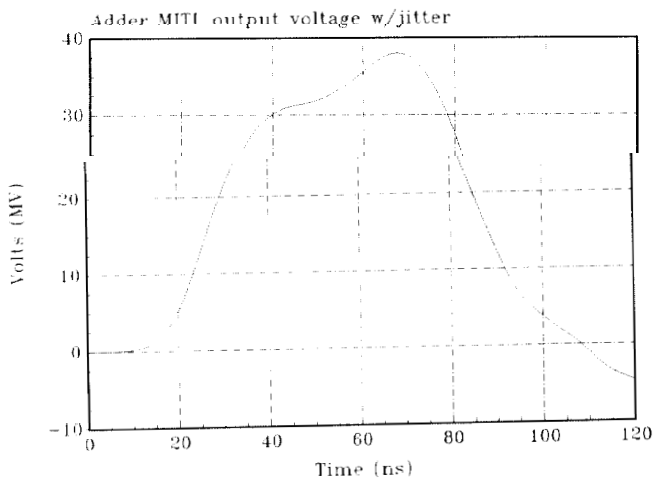


Fig. 6 Calculated 32 cavity voltage that includes gas and water switch jitters.

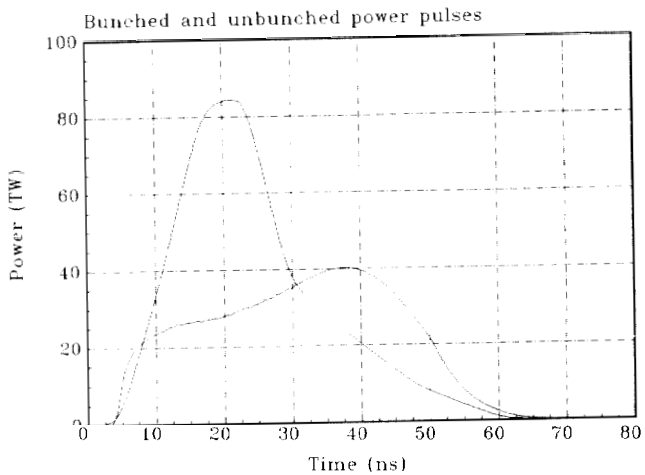


Fig. 7 Bunched and unbunched module output power.

## SUMMARY

A conceptual design for a module for a light ion beam driver for the LMF has been developed. The accelerator module is based on an extrapolation of the Hermes-III technology and delivers to a  $\text{Li}^+$  ion diode  $\sim 3$  times the power that Hermes delivers to an electron beam diode. Presently achieved switching technology is shown to provide adequate accelerator module simultaneity in a multi-module LMF. The major difference in Hermes-III and the LMF module is the positive polarity adder MITL. Key issues in the performance of the LMF module will be efficiency of the adder MITL, energy coupling to the  $\text{Li}^+$  ion diode, and transport and focusing of the ion beam onto the ICF target.

An experimental program is underway to address these issues. An initial experiment was performed in late 1988 that established the feasibility of operating Hermes III in positive polarity. The first ion diode experiment on Hermes III with a positive polarity adder is planned for this coming fall.

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