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

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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 preconceptual 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 programmed 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.

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demonstrated on HERMES-III which operated with equal success in positive and negative polarity. 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.

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. The achromaticity is achieved by combining the final focusing solenoid with the self-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>
<thead>
<tr>
<th>Module A</th>
<th>Module B</th>
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<tbody>
<tr>
<td>P(MW)</td>
<td>7.6</td>
</tr>
<tr>
<td>V(MV)</td>
<td>24.7</td>
</tr>
<tr>
<td>I(MA)</td>
<td>0.31</td>
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<tr>
<td>t(ns)</td>
<td>60</td>
</tr>
<tr>
<td>W(MJ)</td>
<td>0.46</td>
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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 5Ω 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

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<tr>
<th></th>
<th>HERMES-III</th>
<th>2.6 MV Cavity</th>
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<tbody>
<tr>
<td>Cavity Voltage (MV)</td>
<td>1.1</td>
<td>2.6</td>
</tr>
<tr>
<td>Number of CAVITIES</td>
<td>40</td>
<td>17</td>
</tr>
<tr>
<td>PFLs/Cavity</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>PFL Impedance (Ω)</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>I matched (MA)</td>
<td>0.88</td>
<td>1.15</td>
</tr>
</tbody>
</table>

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


