COBRA Accelerator for Sandia ICF Diode Research at Cornell University

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I. INTRODUCTION

The new COBRA accelerator is being built in phases at the Laboratory of Plasma Studies in Cornell University where its applications will include extraction diode and ion beam research in support of the light ion inertial confinement fusion (ICF) program at Sandia National Labs. The flexible 4-to 5-MV, 100-to 250-kA accelerator in Fig. 1 is based on a four-cavity inductive voltage adder (IVA) design. In combination with new ferromagnetically-isolated cavities and

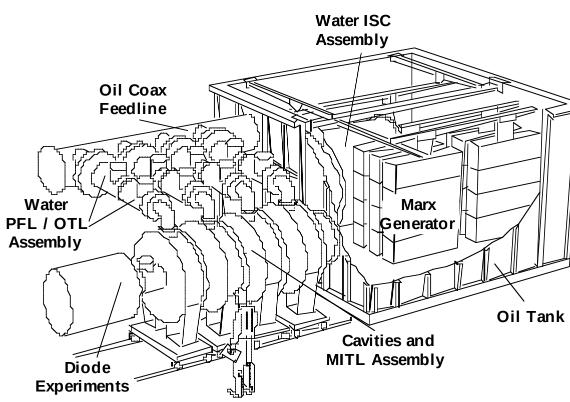

Fig. 1. The 1.3 TW COBRA accelerator at Cornell has a folded overhead pulsed-power geometry for compactness.

self-magnetically insulated transmission line (MITL) hardware, it includes components from existing Sandia and Cornell facilities. Those are the Marx generator capacitors, hardware, and power supply from the DEMON facility; water pulse forming lines (PFL) and gas switch from the Subsystem Test Facility (STF); a HERMES-III intermediate store capacitor (ISC); and a modified ion diode from Cornell's LION. The present accelerator consists of a single modified cavity similar to those of the Sandia SABRE accelerator and will be used to perform the first phase lower voltage tests. Four new cavities will be fabricated and delivered in the first half of FY96 to complete the COBRA accelerator. COBRA is unique in the sense that each cavity is driven by a single pulse forming line, and the IVA output polarity may be reversed by rotating the cavities 180^{o} about their vertical axis. The site preparations, tank construction, and diode design and development are taking place at Cornell with growing enthusiasm as this machine becomes a reality. Preliminary results with the single cavity and short positive inner cylinder MITL configuration will soon be available.

II. RESEARCH PLANS

Ion diode experiments in support of the Sandia ICF program will be the first experimental activity on COBRA. The initial single-cavity COBRA is well matched to the extraction geometry, applied-B diode used on the previous Cornell accelerator, LION (1.2 MV, 4 Ohm, 40 ns), since 1992.[1] Figure 2 shows a sketch of the LION/COBRA diode. We will field this diode on COBRA to continue ion

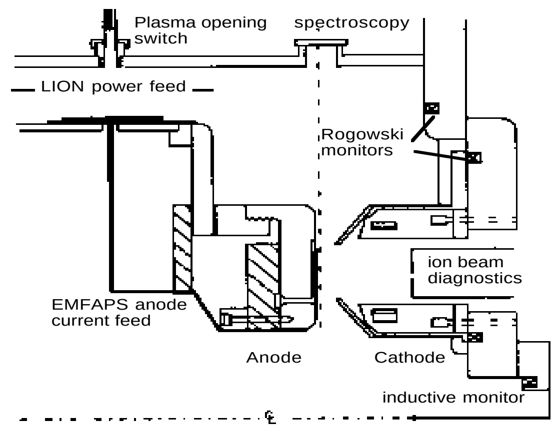

Fig. 2. The modified LION diode produces an ion beam of 10 cm mean radius. This diagram shows 25-cm axial extent.

source studies, particularly addressing the issues of ion species purity and parasitic load with lithium-bearing evaporating metal foil anode plasma source (EMFAPS) active anodes.[2] We will pursue innovations in foil fabrication and in-diode discharge cleaning techniques begun on LION.[3] Diagnostics will include: magnetically-insulated Faraday cups for beam current density; Rutherford-scattering shadowboxes for ion species-resolved beam divergence; Thompson parabola spectrometer and Rutherford-scattering magnetic spectrometer for ion species and energy composition; collimated bremsstrahlung detectors and in-anode collectors for diode voltage and current; and emission spectroscopy and visible light streak photography for in-gap light emission.

The substantial data base from the performance of this diode on LION will be compared to results on COBRA to illuminate issues of power coupling to the diode load on the new accelerator. In particular, the diode will first be mounted on COBRA with a very short (75 cm from cavity gap to diode gap) vacuum MITL. It is expected that with the single-point (azimuthal) power feed to the cavity, power flow in the MITL will be significantly azimuthally asymmetric. We will diagnose effects of this asymmetry on diode performance. Our aim is to explore the tradeoff between diode performance degradation by power flow asymmetry for a short MITL and degradation by the delay between the vacuum-wave prepulse and the main power pulse at the diode with a long MITL.

After the full four-cavity COBRA is in place, the Cornell experimental program will make a transition from the long-standing emphasis on ion diode physics toward a more integrated development of the diode as part of a beam generation, transport, and focusing system. We will design a system using an extraction diode, a gas-filled transport region, and asolenoidal focusing lens to produce a small analog to a module of a large ICF driver such as the Laboratory Microfusion Facility (LMF).[4] Our aim is to diagnose and develop the accelerator, diode, beam transport, and lens as integrated, interacting components of the beam driver system to provide an overview of the issues involved and to investigate tradeoffs and optimization for LMF.

III. ACCELERATOR DESCRIPTION

The requirement for a 4-to 5-MV pulsed power driver led naturally to four 1.0-to 1.25-MV cavities that nearly duplicate the IVA technology presently used in the HERMES-III and SABRE machines at Sandia.[5] The cavity-to-cavity inductive isolation, performed by ribbon-wound annular cores of type 2605CO METGLAS[6] ferromagnetic material, and the vacuum MITL allow us the most compact machine design to maximize the available experimental area. As shown in Fig. 3, the inner cylinder of the MITL is tapered at each cavity output feed gap according to the impedance requirements to best couple to the diode load. Our choice foa a single overhead water line to charge

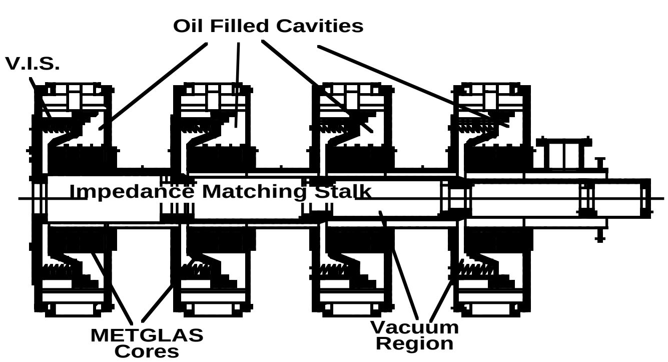

Fig. 3. The COBRA IVA consists of four radial cavities that deliver power to the coaxial vacuum MITL.

each cavity was influenced by cost and space limitations, but we did confirm that the MITL current flow (for negative polarity operation) was azimuthally symmetric within about 2 ns along the vacuum coaxial line from the cavity output gap. These tests were performed at the Sandia STF using the same water lines and cavity that are installed for the initial COBRA experimental series. Larger diameter cavities may need two or more equally spaced feeds to optimize the flow symmetry.

The basic pulsed-power source for the IVA consists of one oil-insulated Marx generator, a water-dielectric ISC or transfer capacitor, a self-breaking multi-stage SF_6 gas switch, and water-dielectric coaxial PFLs with self-closing output water switches. The tools we used to iteratively design and model COBRA include the STF experiments, the SCREAMER circuit simulation code[7] and electrostatic field solvers like JASON[8] and ELECTRO[9] along with dielectric breakdown and flashover criteria like that originated by J.C. Martin.[10] The following Table I is a summary of the accelerator design parameters, peak values generated by the circuit models, and some of the hardware dimensions. Negative high voltage is assumed for the inner conductors of the coaxial lines. Note that the subscripts 'in' and 'out' typically refer to the inner and outer coaxial radii,

Table I. Cobra Accelerator Design Summary

Marx:		No.Caps = 24 ea	C/Cap = 1350 nF
		V_{ch} = 90 kV	E_{ch} = 131 kJ
		V_{rated} = 100 kV	E_{ch}/E_{max} = 81%
		V_{marx} = 2.2 MV	I_{Marx} = 111 kA
ISC:		R_{out} = 71.8 cm	C_{isc} = 19.5 nF
(HERMES-III)		R_{in} = 53.3 cm	Z_{isc} = 1.98 Ohm
		Length = 130 cm	T_{isc} = 38.6 ns
		V_{isc} = 2.7 MV	T_{eff} = 200 ns
		E_{out} =126kV/cm	E_o/F = 61%
		E_{in} =170kV/cm	E_i/F = 36%
Gas Switch:		Length = 50.6cm	OD = 44.5 cm
		Gap(x18)=16 cm	No.Channels<10
		V_{gas} = 2.7 MV	L_{sw} = 240 nH
		I_{gas} = 405 kA	Q_{gas} > 83 mC
	(@900 ns)	E_{diss} = 9.4 kJ	E_{diss}/E_{out} = 12%
PFLs(4):		R_{out} = 17.8 cm	C_{pfl} = 4.6 nF
		R_{in} = 8.4 cm	Z_{pfl} = 5.0 Ohm
		Length =76.2 cm	T_{pfl} = 22.8 ns
		V_{pfl} = 2.3 MV	T_{eff} = 40 ns
		E_{out}= 172 kV/cm	E_o/F = 47%
		E_{in} = 365 kV/cm	E_i/F = 44%
H_2O Switches(4):		Gap = 4.2 cm	Channels/Sw = 4
		V_{wat} = 2.3 MV	L_{sw} = 66 nH
		I_{wat} = 248 kA	Q_{wat} > 17 mC
	(@1000 ns)	E_{diss} = 2.4 kJ	E_{diss}/E_{out} = 16%
Cavities(4):		ID = 38.1 cm	OD = 150 cm
		Length =41.9 cm	L_{cav} = 20 nH
		Cores/Cav = 4	Wt/Core=51.1kg
		V_{cav} = 1.31 MV	Volt-Sec =0.077
	(Matched Load)	V_{load} = 1.28 MV	T_r(10-90)=23.3ns
		I_{load} = 256 kA	FWHM =49.2 ns
		P_{load} = 328 GW	E_{vis} = 87 kV/cm
	(@1050 ns)	E_{load} = 12.6 kJ	$4E_{load}/E_{ch}$ = 38%

and 'vis' is the oil/vacuum insulator stack. The E/F ratios correspond to the expected electric field stress divided by the calculated breakdown stress.

IV. PREDICTED PERFORMANCE

Our circuit simulation process involved a number of iterations as the COBRA accelerator design evolved and components were modified or better defined. All the feed line lengths, impedance variations, and major component values had to be accurately represented to allow confidence in the model predictions. We used transmission line models in the SCREAMER code to account for the proper physical separations and dimensions of the oil, water, vacuum, and plastic insulated components. These models provide a fixed propagation delay time and either a constant or a linearly tapered line impedance. The switch models are typically represented by a series combination of time-varying resistor and appropriate inductor with both elements shunted by a parallel stray capacitance. The switches are closed by reducing the initial high resistance exponentially to a final low resistance. The exponential time constants were determined from estimates of the resistive and inductive phase contributions to the switching action.[11] The choice for the final resistance is critical for determining the energy dissipated by the gas and water switches, which in turn affects the forward going pulse shape. Figure 4 shows the resulting voltage waveforms of one circuit simulation that corresponds to the parameters listed in Table I. This circuit

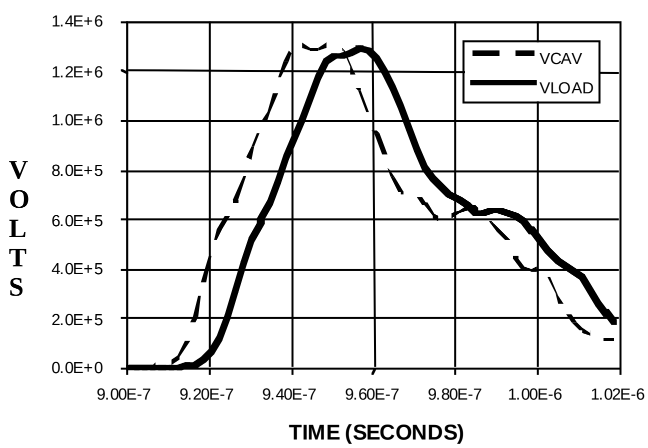

Fig. 4. SCREAMER generated these simulated voltage waveforms at the cavity input and output.

model did not include a "crowbar" switch in the output water transmission line (OTL) nor a saturable magnetic core model which could significantly affect the pulse shape depending on the core material loss properties. Since accurate ion diode models are still being developed for SCREAMER, the only load we have modeled is a constant matched resistance. The load voltage wave shape will definitely be sensitive to the impedance history of dynamic ion diodes.

V. CONCLUSIONS

With this paper we are announcing a new terawatt class accelerator intended to further the light ion ICF program with research and development of diodes, beam transport, and possibly beam focusing. COBRA is the result of a major cooperative effort between a university and a national laboratory (Cornell and Sandia) and, hopefully, may set a precedent for other similar endeavors. It represents technology currently being applied at Sandia and should be a robust, reliable research tool.

VI. ACKNOWLEDGMENTS

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