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Author(s): David A. Clark, P-22,
B.G. Anderson, P-22,
C.A. Ekdahl, NWT-PO,
R.J. Faehl, X-PA,
J.H. Goforth, DX-3,
I.R. Lindemuth, X-PA,
T.L. Peteresen, P-22,
R.E. Reinovsky, DX-DO,
L.J. Tabaka, P-22,
V.K. Cherneshev, VNIIEF,
et al.

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HIGH ENERGY IMPLODING LINER EXPERIMENT HEL-1: EXPERIMENTAL RESULTS

David A. Clark, B. G. Anderson, C. A. Ekdahl, R. J. Faehl, J. H. Goforth,
I. R. Lindemuth, T. L. Petersen, R. E. Reinovsky, and L. J. Tabaka,
Los Alamos National Laboratory, Los Alamos, NM 87545

V. K. Chernyshev, V. N. Mokhov, V. N. Buzin, O. M. Byrenkov, A. M. Bujko,
V. V. Vakhruchev, S. F. Garanin, B. E. Grinevich, Y. N. Gorbachov, E. B. Gubkov,
B. A. Demidov, V. I. Dudoladov, V. V. Zmushko, A. I. Kuzyaev, A. I. Kucherov,
B. M. Lovyagin, Y. I. Matsev, P. N. Nizovtsev, A. A. Petrukhin, A. I. Pishurov,
S. S. Sokolov, V. P. Solovjov, A. I. Startsev, and V. B. Yakubov,
All-Russia Scientific Institute of Experimental Physics,
607200, Sarov (Arzamas-16), Nizhny Novgorod region, Russia.

ABSTRACT

Magnetically driven imploding liner systems can be used as a source of shock energy for materials equation of state studies, implosion driven magnetized plasma fusion experiments, and other similar applications. The imploding liner is a cylinder of conducting material through which a current is passed in the longitudinal direction. Interaction of the current with its own magnetic field causes the liner to implode. Sources of electrical energy for imploding liner systems are capacitor banks or explosive pulse power systems seeded by capacitor banks.

In August, 1996, a high energy liner experiment (HEL-1) was conducted at the All-Russia Scientific Research Institute (VNIIEF) in Sarov, Russia. A 5 tier 1 meter diameter explosive disk generator provided electrical energy to drive a 48 cm outside diameter, 4 mm thick, aluminum alloy liner having a mass of about 1 kg onto an 11 cm diameter diagnostic package. The purpose of the experiment was to measure performance of the explosive pulse power generator and the heavy imploding liner. Electrical performance diagnostics included inductive (B-dot) probes, Faraday Rotation current measurement, Rogowski total current measurement, and voltage probes. Flux loss and conductor motion diagnostics included current-joint voltage measurements and motion sensing contact pins. Optical and electrical impact pins, inductive (B-dot) probes, manganin pressure probes, and continuously recording resistance probes in the Central Measuring Unit (CMU) and Piezo and manganin pressure probes, optical beam breakers, and inductive probes located in the glide planes were used as liner symmetry and velocity diagnostics.

Preliminary analysis of the data indicate that a peak current of more than 100 MA was attained and the liner velocity was between 6.7 km/sec and 7.5 km/sec. Liner kinetic energy was between 22 MJ and 35 MJ.

INTRODUCTION

The highest energy imploding liner experiment ever conducted in which US scientists participated was done in August 1996 at Sarov, Russia. In a joint effort, teams from the All-Russia Scientific Research Institute (VNIIEF) and Los Alamos National Laboratory (LANL) fielded the successful experiment which was the culmination of more than a year of planning and construction activity. The purpose of the experiment was to measure the performance of the helical (HEMG) and disk (DEMG) generators driving a moving load, and to measure the velocity, stability, and symmetry of the imploding liner. The entire generator and load assembly were designed and built by VNIIEF.[1] Diagnostic systems were designed and built by both VNIIEF and LANL. A portable data recording system was brought to Sarov by LANL and used to record all LANL data channels and several VNIIEF data channels. Both teams performed extensive 1D and 2D calculations to predict liner performance.[2] In March, 1997, the teams met in Los Alamos to present findings from post-shot data analysis and to summarize experimental results.[3] We present here a brief description of the experiment and two topics, high current measurement and liner motion.

EXPERIMENT DESCRIPTION

Figure 1 is a photograph of the HEL-1 device on the firing table. The vertical helical generator can be seen above the five element one meter diameter disk generator which is enclosed in the large diameter cylinder. In the bottom of the cylindrical case is the radial transmission line and liner assembly. The liner was made of aluminum alloy with diameter of 48 cm, thickness of 4 mm, and height 10 cm. Mass of the liner was about 1 kg

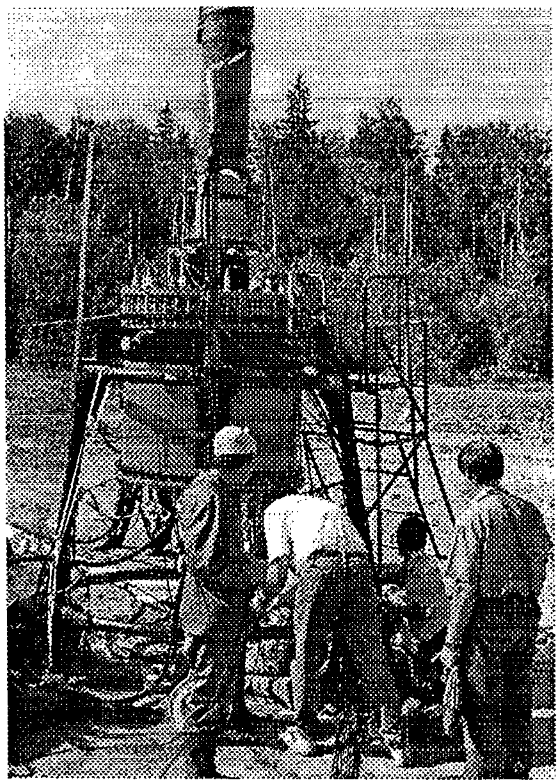

Figure 1. View of the HEL-1 device on the firing table in Sarov, Russia.

A schematic representation of the HEL-1 device is shown in Figure 2 below. The cylindrical device is shown laying on its side with the axis of symmetry at the bottom of the figure. Fundamental elements of the device are the helical explosive flux compression generator (HEMG), crowbar switch, disk explosive flux compression generator (DEMG), coaxial transmission line (CTL), radial transmission line (RTL), imploding liner, glide planes, and diagnostics. Many diagnostics were located in the central cylinder called the central measuring unit (CMU) inside the liner cavity. Other diagnostics were located in the glide planes, RTL, CTL, and outside the assembly to measure case motion. The sequence of events starts by running seed current from a capacitor bank through the helical coils. Explosives located inside the HEMG are detonated and compress flux from the seed current to produce

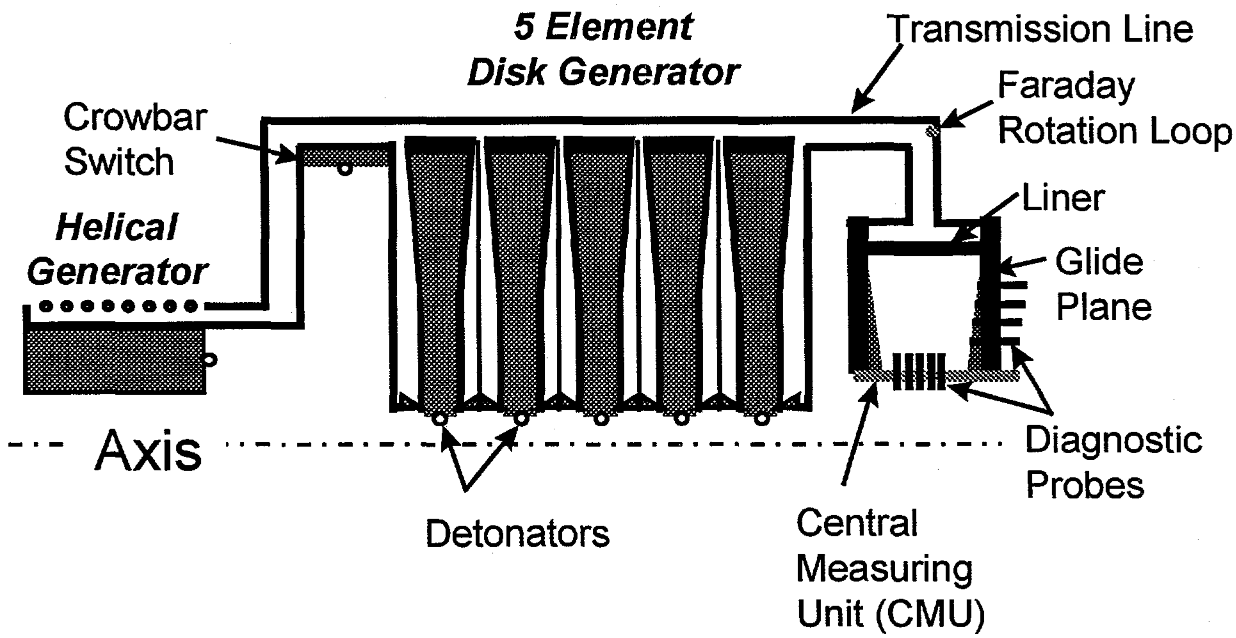

Figure 2. Schematic drawing of the HEL-1 device. The five tier disk generator is seeded by current from the helical generator at the left. In the load assembly at the right, the cylindrical liner implodes when current from the disk generator passes through it. Diagnostics in the CMU and glide planes measure liner motion. Faraday and Rogowski diagnostics measure load current.

higher current. The HEMG current seeds the DEMG which compresses flux in the hollow disk elements producing the highest current. The crowbar switch fires at the same time as the DEMG to short out the HEMG and provide a high current path.

High current flows through the CTL and RTL to the liner which implodes due to the interaction of the current with its own magnetic field. Diagnostics measure current, liner motion and symmetry, case motion, voltage drop across joints, and pressure. A list of diagnostics is given in Table I

Diagnostic recording was provided by both VNIIEF and LANL. Various types of streak cameras, oscilloscope cameras, and Tektronix digitizing oscilloscopes were used for the VNIIEF recording. Forty channels of LeCroy 6841 transient recorders operating at 100 MHz sample rate were used by LANL to record all of the optical pin data and long epoch Faraday rotation traces. Twelve channels of Tektronix TDS544 digitizing oscilloscopes operating at 250 MHz recorded high resolution Faraday rotation data. Common timing for relating data recorded by both teams was done by careful measurement of time delays in individual system components and recording of common signals.

Table I. Diagnostics on HEL-1

Diagnostic Description	Number	Fielded by	Location
Rogowski coil for high current measurement	1	LANL	In CTL at junction with RTL
Faraday rotation high current measurement	2	LANL	In CTL at junction with RTL
Fiber optic impact pins	30	LANL	CMU
Inductive loop (B-dot) current	2	LANL	CMU
Resistive V-gap probes	2	LANL	CTL joint and CTL-RTL joint
Capacitive V-dot probe	1	LANL	RTL
Capacitive V-dot probe	2	LANL	RTL
Piezoelectric pressure probe	4	VNIIEF	Glide Plane
Manganin pressure probe	4	VNIIEF	Glide Plane
Inductive loop (B-dot) current probe	4	VNIIEF	Glide Plane
Inductive loop (B-dot) current probe	12	VNIIEF	CTL and RTL
Optical beam breaker	6	VNIIEF	Glide Plane
Electrical contact pins, Manganin pressure, Resistive pressure	26	VNIIEF	CMU

HIGH CURRENT MEASUREMENT

Several inductive loops (B-dot probes), one Rogowski current coil, and two fiber optic Faraday rotation current sensors were used to measure high current. The Rogowski coil failed to produce reliable data. B-dot and Faraday probes produced excellent results but the Faraday rotation sensors ceased operation a few microseconds before peak current was reached. Figure 3 displays a low time-resolution trace of one of the two Faraday rotation sensors. It can be seen that fringe amplitude begins to roll off at about 260 μsec. The amplitude roll off and destruction of the Faraday sensors are thought to be due to crushing in the transmission line just before peak current was reached.

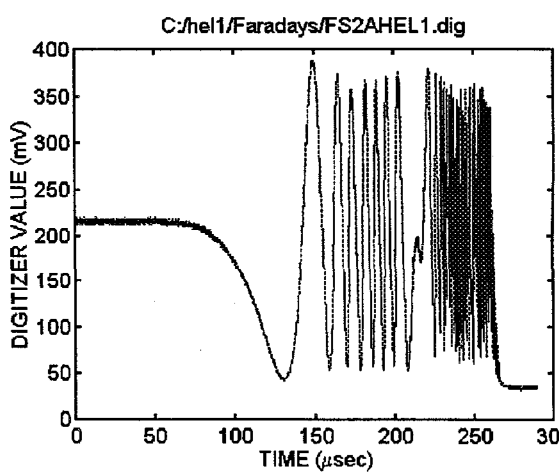

Figure 3. Low time resolution Faraday rotation current measurement data. Fringes are very distinct until 265 μsec when probe was destroyed. Peak current occurred at about 267 μsec.

Several VNIIEF recorded B-dot probes produced very clean traces. A comparison of B-dot probe TL-15 integrated with different baseline offsets and two unfolded Faraday current traces is shown in

Figure 4. It can be seen that Faraday data and B-dot data agree very well up to the time of Faraday sensor destruction. When integrated over the interval [215 300] μsec with a baseline

shift of 0 mV the peak current is about 102 MA. Faraday data was unfolded with a Verdet constant of 2.54 ± 0.2 μrad/Amp and an effective number of fiber turns of 1.01.

LINER MOTION

Performance of the imploding liner was of great interest in the HEL-1 experiment. In particular, diagnostics to detect liner stability (would the liner break up before reaching the target?), symmetry, and velocity were installed. Radiography was not available.

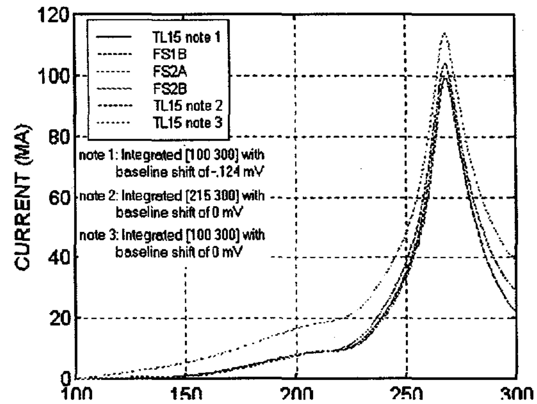

Figure 4. Unfolded LANL Faraday rotation current data compared to current found by integrating VNIIEF B-dot data in several ways. Faraday data matches very well with the early part of integrated B-dot data as described in note 2 and indicates a peak current of about 102 MA.

Diagnostics to measure liner performance included optical and electrical impact pins in the CMU and piezoelectric pressure sensors, manganin gauges, and inductive loops in the lower glide plane. The experimental technique was to measure liner arrival time at different locations and to measure shock speed in the CMU to confirm liner impact velocity. Impact pin data indicates that the liner did not preserve its cylindrical shape during the implosion. However many pin times are consistent with features observed in 2D calculations. Figure 5 characterizes the calculated liner shape from a 2D calculation[4] as the liner approaches the CMU. The liner bulges outward at the center and "run ahead" material exists along the glide planes. Observed times of arrival from the optical pins is consistent with the following course of events. Run ahead material strikes the end of pin E first then hits the CMU at the base of pin E. The shock induced into the edge of the CMU then travels the 11 mm diagonal distance to the end of the buried C pins. A shock velocity of 8.8 km/s is

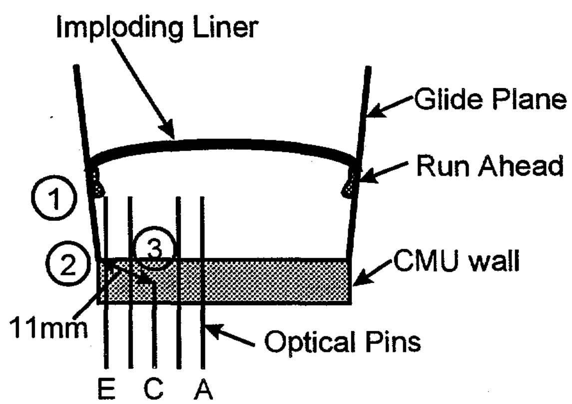

Figure 5. Schematic representation of imploding liner interacting with impact pins and the CMU material.

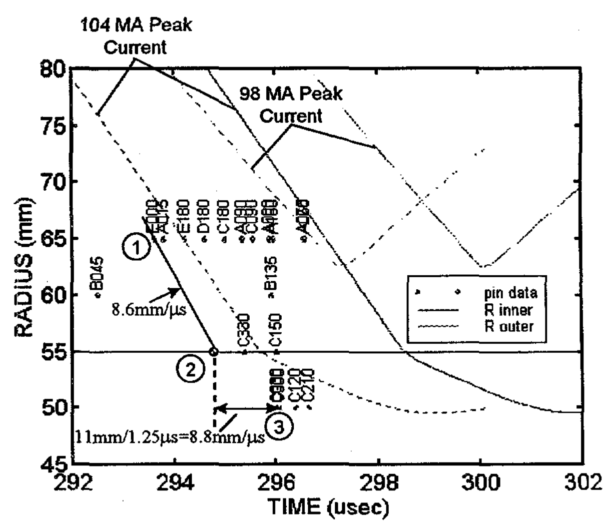

Figure 6. Radius versus time plot for one dimension "CRUNCH" calculations for 104 MA and 18 MA peak currents. Optical pin data is overlaid for comparison.

induced into the stainless steel CMU if the velocity the "run ahead" along the glide plane is about 8.6 km/s.

Pin arrival times are presented in the radius versus time (RT) plot Figure 6 along with the path of events just described. In addition, results of 1D "CRUNCH" calculations are presented for two peak currents. The 1D calculations cannot describe the complicated shape of the liner necessary to describe the pin arrival times. For the most part, the pins were struck in the order E-D-C-A which is indicative of the bowed liner.

CONCLUSION

A collaborative effort between Los Alamos National Laboratory (LANL) and the All-Russia Scientific Research Institute (VNIIEF) built and tested a very large imploding liner driven by a five element, 1 meter diameter, explosive disk generator system. The purpose of the experiment was to test the performance of the generator system driving a dynamic load and to measure the performance of the very large liner. Many diagnostics were fielded by both institutions. Highlights of experimental results are summarized below.

Liner initial diameter, thickness, height, mass: 48 cm, 4 mm, 10 cm
Helical generator peak current: 9.1 MA at 215 μsec
Disk generator peak current: 102 MA at 268 μsec
Liner impact time on CMU: 296-298 μsec
2D interpretation of shock arrival times in LANL CMU arising from early impact near glide plane from "run ahead" liner material leads to a shock speed of 8.8 km/s which implies a velocity for the "run ahead" material of 8.6 km/sec.
One set of VNIIEF CMU impact pins provided a direct measure of the liner velocity of $7.8 \leq V_L \leq 8.4$ km/s.
Liner kinetic energy was between 22 and 35 MJ.

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