Liner Performance of Ranchero-S Experiments

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Abstract

A new high energy imploding liner effort is beginning at Los Alamos, and the “Ranchero-S” flux compression generator (FCG) has been chosen to perform these tests. The first liner experiment has not been conducted at the time of this conference, but performance characteristics have been verified using the Los Alamos Roxane 2-D MHD code and preparations are being finalized. The test uses the Los Alamos Point 88 capacitor bank to supply 3.5 MA of seed current to the 87 nH FCG. Peak current is predicted to be 42 MA into the imploding liner load which has an initial inductance of 2.5 nH and increases to 3.5 nH by current peak. The 7.85 cm OD and 0.35 cm thick aluminum liner is expected to exceed 1 cm/µs. The liner is 4 cm tall initially (182 g), 2 cm tall at full implosion, and at 1.5 cm/µs will have 20.5 MJ kinetic energy. This presentation gives an overview of the program, and describes the expected performance of the FCG and liner. In addition, scaling Ranchero FCGs for pursuing high energy liners into the 100s of megajoule implosion regime is discussed. Separate papers in the conference provide further descriptions of subsystem tests and the suite of diagnostics being used to characterize both the generator and liner performance.
Plans For High Current Imploding Liner Experiments Led To A New Iteration On the Original Ranchero FCG Design

- Initial (Standard) module has circumference, C = 96 cm and we estimated would be capable of 96 MA current output
- To date, the capacitor bank is used for initial current
- High current mark from a standard module is 76 MA, as published in MG XIV
  - Smallest Ranchero module was used for this test
  - Smallest achievable load was used
  - 76 MA out from 3.76 MA in. **Losses were higher than 42 MA tests.**
  - ~16 MJ armature Kinetic energy gave ~8 MJ magnetic energy (+losses)

Post shot analysis picked up a manufacturing flaw, which led to an aneurism in simulations
* There is an intentional lag at the output glide plane.
* The armature is just coasting at this time.

Even without flaw an aneurism was beginning to form in these simulations.
* Ranchero needed to be “fixed” for high current applications

Roxanne simulations account for some additional losses
Ranchero “S” Design Came From Iterating Contours With Hydrocode

- In the first iteration, the output glide plane was eliminated and replaced with a cone.
- The “swoop” was required to provide good zippering
- Advertised current capability had to be reduced due to reduced output diameter
  - 83 cm circumference at output transmission line reduces expectation from 96 MA to 83 MA at the 1 MA/cm rule of thumb limit
  - “swoop” puts detonation front near output for extra help at high current
  - Detonation front near output doesn’t help as much as expected
  - Still have the same slapper line detonator
  - Ranchero S uses PBX 9501 (see Haroz Wed.)

Preliminary MESA calculations were used to determine stator and armature contours.
Renewed Heavy Liner Program Has Begun

First test will use Ranchero 43-S and is predicted to produce a 20.5 MJ implosion.

- Cable input from capacitor bank
- Ranchero 43-S FCG
- 182 g. Aluminum Liner
- Lower Glide plane
- Central Measuring Unit (CMU)
- Experiment will be fired vertically with load at bottom
- Anodized Stator
- HE charge
First Liner Test Has Been Preceded By A Number of Subsystem Tests

- Glue Joint Tests (Goforth IEEE Pulsed Power paper 2015)
- Full Scale Armature test (Haroz – this conference)
- Multiple Static Load Bank tests to “recertify operation”
  - Had not Fired the full bank in five years previous to these tests
  - Facilitated diagnostic development by new LANL team
    - Gunderson, this conference
    - New Detonator Switch configuration
- New slapper firing system to assure no ground problems

Static load test uses same shot stand as liner test

New detonator switches located inside bunker
Choice of First Liner Balances Between “Stable” and “Fast”

Initial survey of velocities vs thickness showed 1 mm thick liner broke up, and 5 mm and greater liners were slower than desired. Both Roxane (2-D) and Raven (1-D) results are given.

We made a conservative “fast” choice, and the details are on the next view graph.
Pre-shot Report\textsuperscript{1} Gives a Summary of System Parameters

- Liner is 3.5 mm thick
- Material is “Alcon” (near Al 1100 grade)
- 4 cm tall initially
- 2 cm tall at implosion

<table>
<thead>
<tr>
<th>Designation</th>
<th>LA-43S-1</th>
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<tbody>
<tr>
<td>Stator</td>
<td>6061 T6 Al, 22.86 cm OR, 81 cm long</td>
</tr>
<tr>
<td>Stator (input IR, break IR, TL OR)</td>
<td>16.88 cm / 17.48 cm / 13.5128 cm</td>
</tr>
<tr>
<td>Armature, dets &amp; length</td>
<td>24x2 dets at 18mm spacing, 43 cm uniform radius section</td>
</tr>
<tr>
<td>Armature radii</td>
<td>8.22/7.62 cm uniform section, 35 cm swoop to 13.218 cm OR (TL IR)</td>
</tr>
<tr>
<td>HE</td>
<td>PBX 9501</td>
</tr>
<tr>
<td>TL output radii, length to C</td>
<td>13.5128/13.218, 6.65 cm</td>
</tr>
<tr>
<td>Insulator</td>
<td>Delrin</td>
</tr>
<tr>
<td>FCG Input Glide plane</td>
<td>Naval Brass, uniform 20.79\degree off normal</td>
</tr>
<tr>
<td>Liner</td>
<td>ALCON (near Al 1100 grade)</td>
</tr>
</tbody>
</table>

* Glide planes are “Atchison” philosophy
  - Curved to limit vertical component of interaction point to less than 500 m/s

After Liner Parameters Were Chosen, End-to-End Calculations Show Liner and FCG Performance

- Firing point 88 capacitor bank provides seed current of 3.5 MA
- Initial load cavity is 2.5 nH and increases to ~3.5 nH by peak current
- 42 MA peak current
- Liner has moved by ~ 1 cm by peak current (83.5 µs)
- Central Measuring Unit (CMU) has a radius of 1 cm
Liner Velocity Will Be First LANL Experiment to Exceed 1 cm/µs at CMU Impact

Liner is fabricated with a surface of 16 µin (0.4µ) specified, and ~12 µin (0.3µ) was achieved.

CMU contains 12 PDV probes
* Two are recorded in downshifted mode to allow up to 2 cm/µs to be recorded
* Four will observe inward radial motion
* Four will look at angles above and below normal by 10°
Principle Goals for Our Experiments Are Code Verification and Enhanced Liner Design Capability – So diagnostics are critical. CMU is positioned to see “step” in liner surface.

Roxane predictions of velocity observed by PDV probes

Deflection in signal will indicate accurate calculation of glide plane effects.
For Preliminary Liner Tests, Seed Current From Capacitor Bank Will Be Sufficient – “But”

- Current from pt. 88 bank cannot exceed 4 MA
- With this input current, the FCG will not be stressed by a realistic load (at least a few nH)
- Available Helical FCG boosters will allow “Full Current” -- What is that?

Scoping calculations for maximum current performance started with the 43-S configuration and the question; What is the peak current the FCG can put into a 10 nH load?

- Ultimately 1, 5, and 10 nH loads were explored
- Even with the “swoop,” magnetic pressure can get higher than HE pressure as 1 MA/cm is approached near the output

Two Los Alamos booster generators:
- MK-IX could put 18 MA into a 43-S module
- Ranchito could put in 6 MA

Newer Alternatives are also available
Higher Magnetic Pressure at Early Time Limits Peak Current for Larger Inductance Loads

Magnetic flux plots for initial currents:
- 3.5 MA
- 8 MA
- 12 MA

Bottom plot is a density plot corresponding to the 12 MA seed current flux plot

Above 8 MA seed current, and assuming current FCG dimensions, flux is never pocketed, but the armature will never close the gap in the swoop

Even with the detonation front near the output, HE pressure falls off rapidly, and is less than the magnetic pressure by the time final closure should occur.

The main advantage of the “swoop” is to eliminate the lagging armature near the output glideplane, and to provide an extra 30 nH initial inductance without increasing the FCG function time.

Peak current as a function of initial current for 1, 5, and 10 nH loads.

1 MA/cm at the output of the FCG is only exceed in the case of 1 nH loads, and never reached in the case of the 10 nH load
For Future Applications Requiring Higher Currents, There Are Many Ways to Scale Ranchero FCGs to Attain Larger Currents

• Increase the diameter and keep gain fixed:
  • Increased run time
  • Increased HE

• Increase the diameter and keep the run time the same
  • Reduces the gain
  • Extra increase in HE

• Increase the diameter and keep the run time the same, but add length to retain the gain
  • Largest HE increase due to adding length

• Others ..........
A Roxane Study Focused on a 144 S FCG With Incremental Radius Increases

- Generator gap maintained to keep flux compression time constant
- 10 nH static load
- Initial current of 12 MA
- Increase the radius from 26.4 cm to 33.4 cm gives peak I of 118 MA, which would be 1.1 MA/cm
- Simulations at 500 micron resolution appear to predict lower current by ~10% compared to higher resolution calculations that match experimental results well
Conclusions

• The Ranchero 43-S experiment will drive a very interesting experiment with only the Los Alamos point 88 capacitor bank for seed current.
  • Implosion velocity over 1 cm/µs
  • 20.5 MJ implosion energy at 1.5 cm/µs, which is the nominal prediction
  • Diagnostics will provide good code verification results
• Subsystem tests (details in other papers in this conference) are being performed to provide the best assurance of a successful liner implosion test when it is conducted
• All hardware is prepared, and the test is awaiting the completion of subsystem tests.
  • Higher currents will be needed for future higher energy work, and Ranchero can be scaled to higher levels