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Ranchero Overview and Expectations for Performance at Currents over 50 MA

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Abstract

Ranchero is a coaxial magnetic flux compression generator (FCG) initiated simultaneously on-axis, which is intended to produce currents approaching 100 MA. We continue with both applications and development, striving for both cost effectiveness and high performance. In this paper we discuss on-going work, provide details of the sophisticated detonation system, and show high current predictions from our active modeling effort. We intend further tests that will push the limits of Ranchero performance.

I. INTRODUCTION

Ranchero generators have been used for imploding solid liners on two previous systems [1], [2], and figure 1 shows the configuration for a new series.

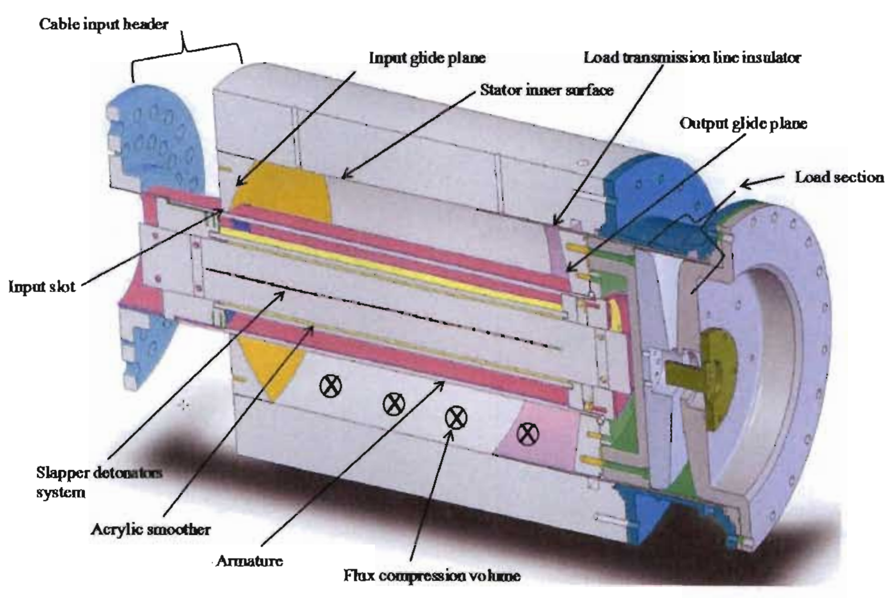

Figure 1. Cutaway of Ranchero experiment with current load design configuration.

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Ranchero FCG modules currently can be available in 0.43, 0.76, 1.0, and 1.37 m lengths. The 1.37 m length generator has 36 kg of high explosive (HE) and the HE weight scales with length. Because most of the generator is fabricated from aluminum, and because the inside-out detonation system requires relatively low HE weight, the destructive forces are smaller than with other designs of comparable capability. As a result, the ability to use complex diagnostics is enhanced. For example, x-ray diagnostics can be fielded with good success in recovering recording films or phosphors. Other critical diagnostics typically used on heavy liner experiments (such as VISAR and PDV velocity sensors) are also routinely fielded without deleterious impact from the HE environment.

One of the most important and critical parts of the Ranchero FCG is the simultaneous axial detonation system, which is annotated as the "slapper detonation system" in fig. 1. The initiation is achieved using series/parallel arrays of slapper detonators, which generate a smooth expansion of the FCG armature. The system detonates HE pellets at discrete points along the axis, and we are currently limited to a point spacing of no less than18 mm by HE sensitivity issues.

Ranchero was designed to be an easy to build and inexpensive 100 MA FCG. So far, however, applications have required loads of considerable inductance. The maximum current on a Ranchero test, thus far, has been a seed current limited 50 MA, achieved with a static load inductance of less than 1 nH. The 12 mF, 20 kV bank in routine use now was being refurbished when that test was performed, and only 1.8 MA initial current was available instead of ~4.5 MA. Otherwise, full current capability would have been demonstrated on that test. A recent test that would have exceeded 50 MA experienced a misfire of the HE, and while interesting data were obtained, high current performance was not demonstrated. Some of the results of that test will be described briefly, and high current tests are still planned. In a resurgent effort, Ranchero generators have become a baseline device for benchmarking new computer codes, and we will discuss some to these efforts as well.

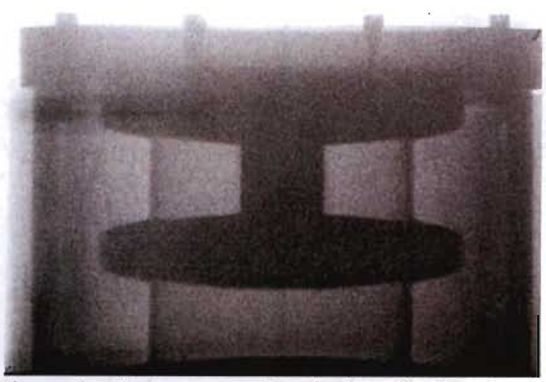

Figure 2 1 Mev x rays of a dual cavity liner load from recent Ranchero tests. The bottom liner could be diagnosed with PDV probes, but the upper liner was not visible from the axis because of the load.

II. IMPLOSION DIAGNOSTICS

All Ranchero systems fielded to date have obtained successful implosion radiographs, and figure 2 shows an example from a recent dual cavity implosion load. The dual liner design allowed liner performance to be measured in the lower cavity, and an impact measurement to be made in the upper cavity. Figure 3 shows the PDV velocity measurement made in the lower cavity. The velocity trace in figure 3 was obtained using a fiber on axis, with a 90 degree prism to view the implosion. The dual cavity load allowed the liner to be observed in the lower cavity, and the velocity of the liner at impact in the upper cavity could be inferred from the performance of the lower

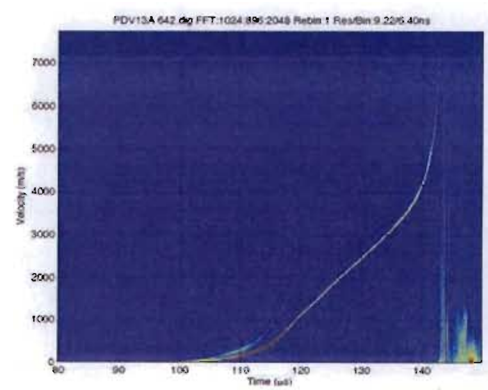

Figure 3. Velocity of the bottom liner (see fig. 2) of a dual cavity experiment. Higher resolution traces showed final velocity at over 9 km/sec.

liner. This comes with a great penalty in inductance, and resulting decrease in applied current. With opaque targets, as is the case in the upper cavity in figure 2, it is still desirable to make a direct measurement of the liner. A recent test was mentioned in which the HE failed to detonate, but a new diagnostic was fielded on the test that gave good, and interesting, results. In the recent test, both on-axis measurements (like figure 3) and measurements from recessed probes in the implosion glide plane were attempted. The liner slowly moved under the action of the 3.7 MA initial field current, and both sets of probes gave very good data, as seen in figures 4 and 5. We are currently evaluating possible reasons for the dual nature of the signals seen in the figures, but probes buried in the glide planes gave results equivalent to the on-axis probe, so that this technique appears to be useful for the future.

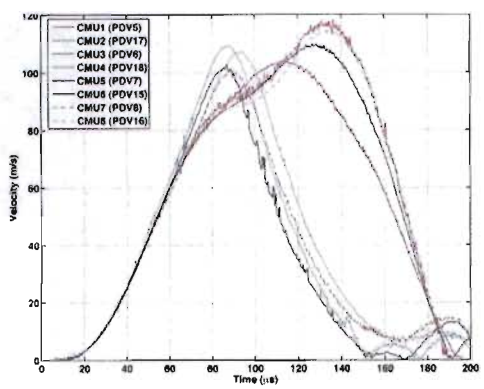

Figure 4. Velocities measured at different azimuths by PDV probes located on-axis in between the glide planes.

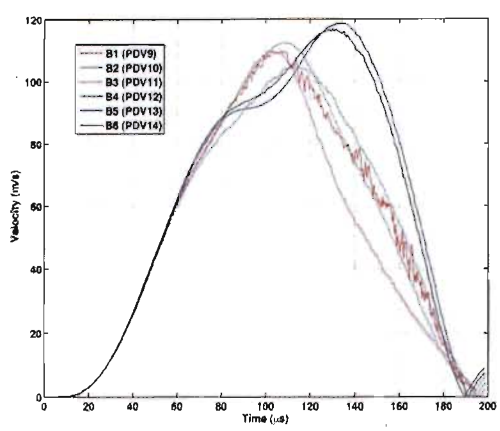

Figure 5. Velocities measured at different azimuth and radius by PDV probes imbedded in the liner glide plane.

III. DETONATION SYSTEM

For Ranchero FCGs to function properly, a detonation system that produces a near-perfect cylindrical expansion of the armature is required. The slapper systems used are capable of this, but must be fabricated with extreme care and undergo rigorous testing to verify sufficient precision and consistency of manufacture. Figure 6 shows a close up view of one segment of a Ranchero slapper system. The systems are made up of series parallel arrays of discrete slapper detonators. Each slapper has an electrically exploded foil element that drives a thin layer of Kapton to sufficient velocity to detonate an HE pellet. The number of segments in series and the number of parallel bridges in each segment is determined by the total length desired and the spacing of the individual slappers. The cable shown in fig. 6 has a point spacing of 18 mm, there are four exploding elements in each segment, and there are six segments

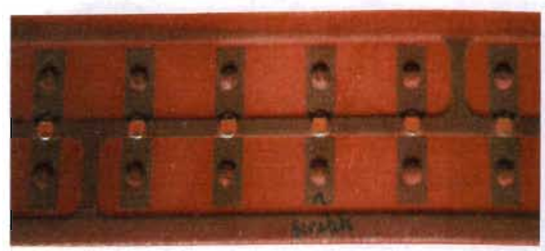

Figure 6. Segment of slapper array showing four bridges in parallel, and one bridge of adjoining series segments.

in series. Aluminum cups, such as those shown, without explosive in figure 7, are centered on each bridge and attached. Two of these cables are placed back to back to make up a complete system, and the two cables are initiated by a single capacitive discharge firing unit that powers the 48 slappers; eight in parallel and six in series. This is a complete slapper system for a 43 cm Ranchero module. Currently, detonators with 18 mm spacing are available in 0.43, 0.76, and 1 m lengths. A cable 1.37 m in length is also available with a 24.5 mm point spacing.

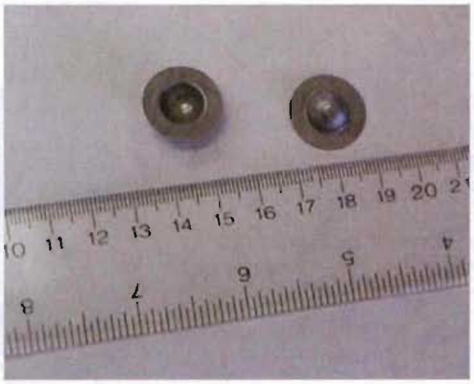

Figure 7. Hemispherical aluminum cups are filled with an HE sensitive to slapper initiation, and one is centered on each slapper. The smallest HE cups that can be used for 18 mm point spacing slappers are 12 mm diameter.

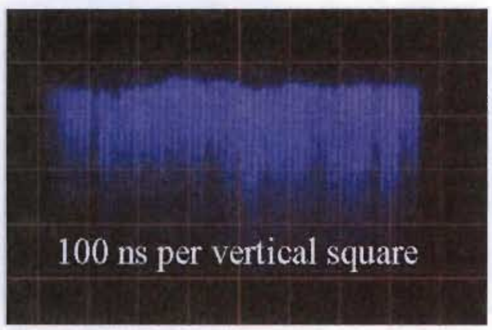

Figure 8. Streak record of 56 point, 1m long slapper array. All pellets are seen to fire, and total spread is approximately 50 ns.

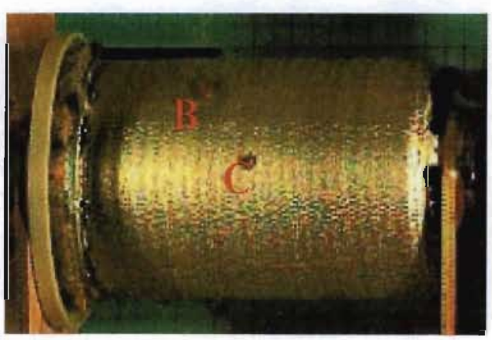

Figure 9. Armature expanded by ~2x. Blowouts at B and C were due to bubbles in the cast explosive, which were detected by x-ray inspection.

A number of slapper cables are fabricated using routine circuit-shop etching and laminating techniques. After resistance and inductance are measured, and a visual inspection performed to eliminate cables with obvious flaws, sample cables are selected for test fire. The purpose of the test firing is to verify that manufacturing tolerances are adequate to assure that all bridges will fire, and that they will fire with adequate timing jitter. Figure 8 shows a streak camera record of a typical test firing. An explosive test-fire pellet is placed on each slapper and the system fired. The streak camera senses the light from the detonated test fire pellets, and the spread in timing is recorded. The total spread seen in the figure is on the order of 50 ns, which is adequate for Ranchero performance, and it is seen that all pellets detonate. Slapper detonators are, by nature, low jitter devices because only current pulses of ~200 ns or less will reliably fire them. For this reason, some test firing is performed with "witness plates" which show a dent for each pellet that fires, but cannot be used for timing information. After a sufficient number of cables have been successfully fired, the detonator lot is considered to be qualified, and the next step is to attach hemispherical HE loaded cups to each slapper point. Each cup must be centered on the slapper. After locating the cup, the edge of the cup must be completely sealed to prevent fluid components of the castable explosive from leaking into the slapper/HE region. Once loaded with cups, two slapper cables are placed back to back. The thickness of the cables displace the hemispheres from being exactly on-axis, but the total separation is just over 1 mm, and the two detonation fronts merge well enough at large radius to provide an adequately cylindrical armature. Each pair of cables is then inserted into the armature tube using hardware that keeps the cables as close to the center as possible. If the cable is off-center by 0.5 mm, an asymmetry of ~125 ns occurs. It is the goal to keep all the assembly tolerance inside 0.5 mm. Finally, the armature is cast with PBXN-110, which does not shrink when it cures, and requires only 105 degree F for curing. The final step of the process is to fire a cast and cured system while recording the expansion with a fast framing camera. Figure 9 shows a recent test of such an armature. This casting had bubbles in the HE, observed by x-radiography to be near the armature wall, which are seen to "blow out" through the armature wall in the figure. Such voids are not tolerable in armatures that are to be used in actual Ranchero tests. Modeling with state- of-the-art 3D hydrodynamic codes has begun to allow us to quantify the size of bubble and its proximity to the armature that will lead to failure. At this time we can say that a three mm diameter bubble within three diameters of the armature will lead to a failure as seen in the figure.

Further analysis may lead to a more general statement. As a final note about fig. 9, PDV data taken on this test, which are shown later in the paper, indicate that the peak-to-valley ripple due to the 18 mm discrete point detonation is ~0.8 mm.

IV. HIGH CURRENT EXPECTATIONS

We have previously published our intention to conduct a high current experiment with a 1 m Ranchero module into a very low inductance load [3]. Estimates based on small scale results indicate that 100 MA could be achieved using the seed current available from the capacitor bank at the testing site. A recent calculation, however, suggests that actual results may not reach this level. Figure 10 shows currents for 0.43, 1.0, and 1.4 m long generators powering a 0.5 nH load, all with the same 5 MA initial current. The 1 m system is seen to peak at about 84 MA in this calculation. There are uncertainties in some aspects of the codes, however, and they are best used for guidance, with the answer ultimately determined experimentally. The high current test has been postponed once because inspection showed voids in the HE casting available for that test. A new casting will be attempted soon after this conference, and pending good results, the test will occur within calendar year 2011.

V. BENCHMARKING NEW CODES

The CAD file rendered in fig. 1 can be read directly by some of the LANL ASC codes. In particular, the CAD model shown has been used as the input to Rage, a new 3-D Hydrocode into which MHD is being installed. For now, this code is only used for two or three dimension hydrodynamic problems, but a full up hydro calculation of the performance of the generator in fig. 1 is given in fig. 11. In addition, data from FCG qualification testing can be used to help further improve the quality of the calculations from these new codes. Figure 12 shows data from the same camera test described in figure 9. We monitored the armature motion on that test with an array of PDV probes. The data from five probes positioned to watch the ripple due to one 18 mm pellet inter-space is shown in the figure. Different computer models in use at this time provide different degrees of agreement. None of our codes are able to reproduce in exact detail the profile shown. A variety is issues are being examined to understand what improvements can be made to obtain a better match to the data

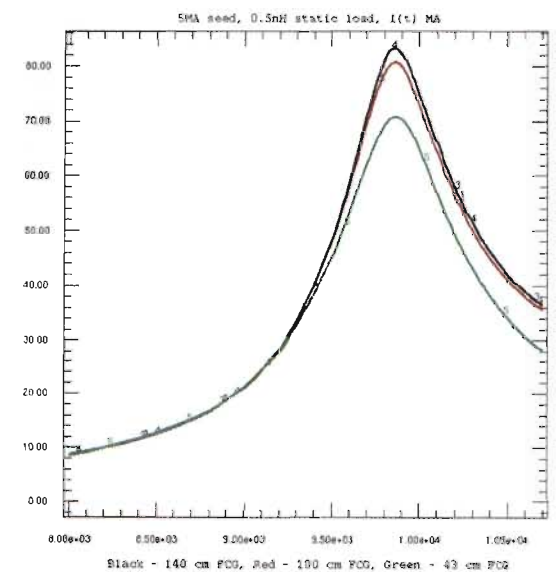

Figure 10. MHD modeling indicates that our high current shot may achieve only 84 MA using the initial current available from our capacitor bank.

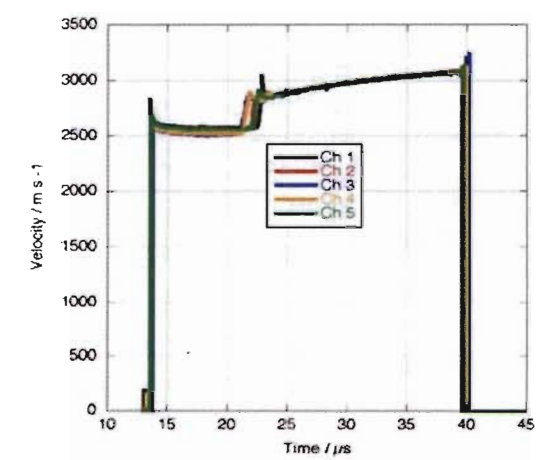

Figure 11. PDV data from an array of five probes viewing one 18 mm pattern. Codes that showed the sharp initial spike rang more than the data. All code showed the step down, then back up. None gave a totally correct profile.

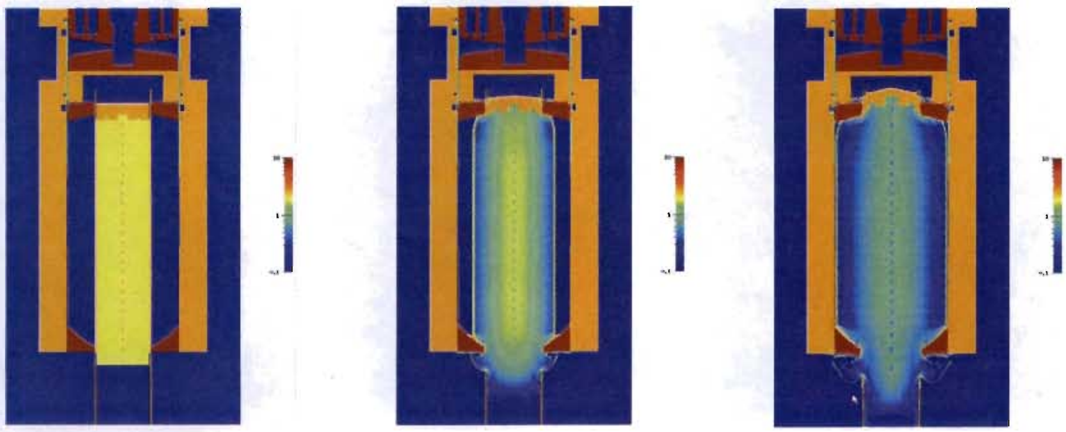

Figure 12. Three frames of a Rage run showing progression from initial condition to near burnout. The input for this run was the same CAD file that is used to fabricate parts.

VI. CONCLUSIONS

Ranchero is a relatively inexpensive platform that allows easy access of most implosion load diagnostics. It has a sophisticated explosive initiation system, with a well specified testing and qualification regimen. We are using increasingly sophisticated codes for modeling this and future work. Present modeling work indicates that a peak current of 84 MA would be achieved on a planned high current test, while extrapolations from small scale results indicate a higher level could be achieved. High current tests are still planned as soon as an acceptable armature can be obtained.

VII. REFERENCES

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