

# The Ranchito Helical Magnetic Flux Compression Generator

**J. H. Goforth, C. M. Fowler, D. H. Herrera, E. A. Lopez, H. Oona, D. G. Tasker,  
D. T. Torres**

*Los Alamos National Laboratory  
Los Alamos, New Mexico*

*And*

**R. A. Anderson, E. V Baluyot, T. J. Clancy, D. P. Milhous, D. B. Reisman,  
A. D. White**

*Lawrence Livermore National Laboratory  
Livermore, California*

## *Abstract*

The Ranchito helical flux compression generator (HFCG) was designed at Los Alamos in the mid 1990s by Max Fowler. The intent was to supply a few megamperes as the initial current for a fast high current FCG in situations where large capacitor banks were not available. A complete characterization of Ranchito has never been published. However, a recent experiment was conducted that provides data suitable for publication. In the test a Ranchito generator was used to feed current into a simulated plate generator. In the test, we supplied 17.24 kA initial current to the 125  $\mu$ H Ranchito from a capacitor bank, and a 2.75 MA current was subsequently delivered to a load of 287 nH. Full details of the generator design and experimental results are presented in the paper. Our analysis makes use of an inductance ( $L(t)$ ) curve taken from paper copies in Max Fowler's original notes, and follows the approach used by Fowler and Caird<sup>1</sup> to characterize the MK-IX HFCG. A complete working model of Ranchito results, although newer computer codes may now provide a better approach. The data presented are useful for comparing results from newer models.

## **I. Introduction**

The Los Alamos Ranchito HFCG was designed to allow high current high explosive pulsed power (HEPP) tests to be conducted in remote areas where there are no permanently installed capacitor bank facilities. 50 MA imploding liner experiments

could be performed with an HFCG to deliver  $\sim$ 4 MA as seed current to a 300 nH Ranchero coaxial FCG. The original programmatic need was short lived, and Ranchito was never used as a booster for Ranchero. It has been used in other applications. Conservative features in the stator and armature designs allow more current than the 4 MA design goal, and we have generated as high as 7.6 MA. The winding pattern and a scaled current pulse were included in a paper by Parkinson and others in the 12<sup>th</sup> IEEE Pulsed Power Conference<sup>2</sup>. Only this limited amount of Ranchito information has been published and notes still available from early experiments are incomplete. Recently, however, a Ranchito generator was available for a facility check-out experiment, having been built for a plate generator test 7-8 years ago and never used. For the test we used a simulated plate generator as a load. The test was a complete success, and since our plate generators are well characterized, the data set allows us to benchmark Ranchito performance and publish the results. This not only makes the design and performance available, but provides data on an unusual design feature in Ranchito that interests HFCG code designers.

## **II. The Ranchito Design**

Figure 1 is a cross section of Ranchito connected to a plate generator. Ranchito has a 6061-T0 aluminum armature 10.06 cm in diameter and 0.635 cm thick. The active length of the flux compression volume is 152.65 cm, including the input and output cones. The stator has a 22.96 cm inner diameter and has five segments of different

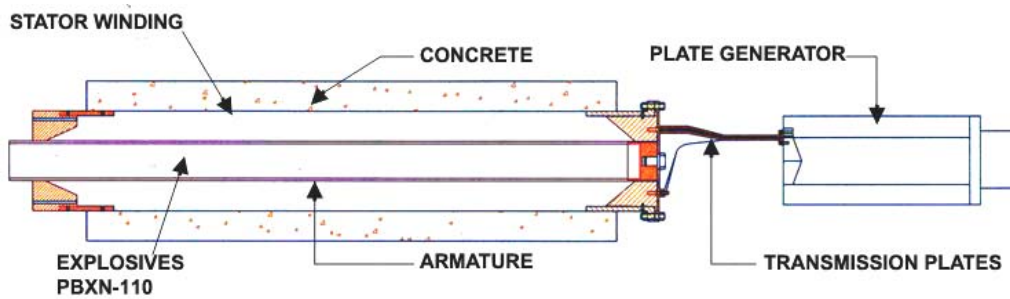
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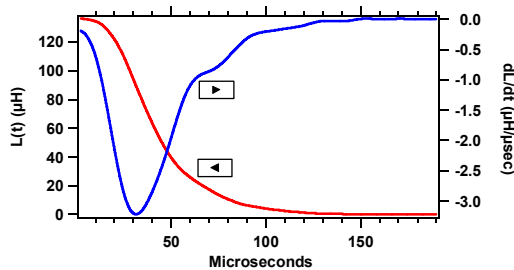
**Figure 1. Cross-section of Ranchito connected to a plate generator. Stator windings do not show, but connect to the two copper rings at the ends.**

pitch, as described in table 1. Each segment consists of two parallel conductors which start as single 0.411 cm diameter Formvar-insulated wires. At the pitch change, additional 0.411 cm wires are silver soldered to existing wires. The joints are

Section	Length (cm)	No. turns	Wires/turn
1	29.2	28	2
2	29.2	14	4
3	25.4	6	8
4	19.1	2.5	14
5	19.3	1.5	24

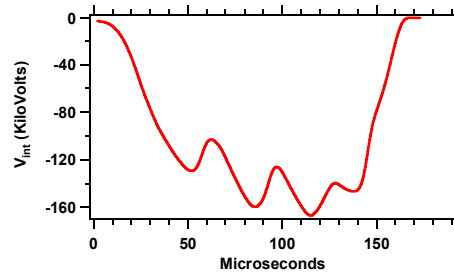
**Table 1. Winding pattern of the Ranchito generator**

insulated with heat shrinkable tubing. An unusual feature of the last two pitch changes is that only some of the wires are bifurcated. The generator was originally designed using our Scat 95 code and the calculated  $L(t)$ , and resulting derivative are given in figure 2 (this curve has been digitized from an original plot from Max's notes). Changes in pitch were required for additional current capacity



**Figure 2. Ranchito  $L(t)$  and  $dL/dt$  as calculated by Scat 95. Zero time is when flux compression begins.**

and to prevent internal voltage ( $dL/dt \times I$ ) from getting too large. The bifurcation scheme chosen gave the internal voltage shown in figure 3, which varies between 130 and 170 kV prior to pitch changes. This profile resulted from a calculation in which the initial current was 21 kA and the load was 370 nH, and it gave a peak current of 6.1 MA.



**Figure 3. Ranchito internal voltage from Scat 95 calculation.**

### III. Experimental Results

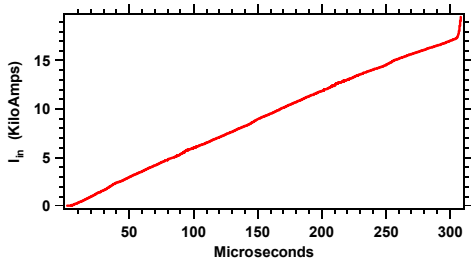
Figure 4 is a photograph of the Ranchito assembly ready to fire at the Los Alamos TA-39 facility. Cable inputs shown on the left bring initial current to the generator from the capacitor bank. The Ranchito stator is encased in concrete for



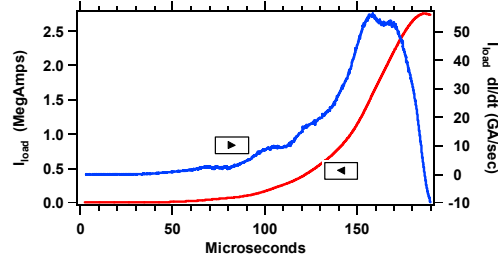
**Figure 4. Photograph of Ranchito generator with simulated plate generator load.**

inertia. A simulated plate generator is on the right, and consisted of actual plate generator parts with 2.54 cm thick brass replacing the explosive for inertial ballast.

The actual purpose of this experiment was to exercise our facility for subsequent use in a specific configuration and we used two modules of our main capacitor bank to supply the initial current. Our goal was to get 15 kA into Ranchito in 300 $\mu$ s, which is normally accomplished using a 300  $\mu$ F portable bank. To achieve these parameters with 6 mF, we charged the bank to 8.5 kV, and fired the Ranchito to crowbar at 300  $\mu$ s, even though the quarter cycle time in the circuit was  $\sim$  1000  $\mu$ s. The principal generator diagnostics were Faraday rotation sensors and Rogowski coils. An 83 turn Faraday probe was on the Ranchito input, and there was a pair of four turn fibers in the simulated generator. Two counter-wound Rogowski coils monitored dI/dt in both the Ranchito input and the simulated generator. A ground loop that occurred  $\sim$ 50  $\mu$ s after current start limited the value of the Rogowski coils. However, with verification of values from the Faraday probes and eliminating the common mode signal from the counter-wound coils, useful information was obtained. Figure 5 shows the initial current obtained from averaging both Faraday rotation sensors and the sensitive Rogowski coils. This figure is zeroed  $\sim$ 5 $\mu$ s prior to initial current from the capacitor bank. The Ranchito generator crowbars at  $\sim$ 308  $\mu$ s in this figure, and all the other waveforms in this paper are zeroed at that time. The current at crowbar time is 17.24 kA with a range over all the probes of plus and minus 1.25 kA. Our original estimates were based on old notes suggesting the initial inductance was  $\sim$ 130  $\mu$ H and the initial generator resistance was  $\sim$ 200 m $\Omega$ . The measured current and time are more consistent with 125  $\mu$ H initial inductance, and 150 m $\Omega$ . The two values are not unique solutions to the RLC circuit, but further credence is given to these values because initial values of dI/dt indicate that  $L_0$  is  $\sim$ 125  $\mu$ H. The current and dI/dt measured in the plate generator with Faraday probes are shown in figure 6.



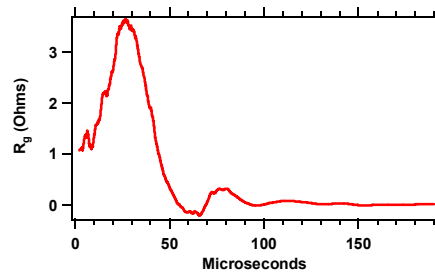
**Figure 5. Initial current for Ranchito test. Zero time is  $\sim$ 5  $\mu$ s before current start.**



**Figure 6. Current (I) and dI/dt as measured on the experiment with Faraday rotation techniques.**

#### IV. Analysis

The same analysis was performed for these results as was for the MK-IX characterization published by Fowler and Caird<sup>1</sup>. A calculated  $L(t)$  and  $dL/dt$  is combined with an experimentally obtained  $I$  and  $dI/dt$  to determine an effective  $R_g(t)$ . Load inductance is also a constant in the equation, and was 287 nH, including 14 nH of residual Ranchito inductance, 10 nH of transmission plates (see fig. 1), and a 263 nH plate generator.  $R_g(t)$ ,  $L(t)$ , and  $dL(t)/dt$  now prescribe an operating model of the generator over a reasonable performance range.  $R_g(t)$  is shown in figure 7. The negative portion of the curve from 55 to 70  $\mu$ s is non



**Figure 7. Derived effective resistance profile for Ranchito test.**

physical, and indicates a minor flaw in the model. The high resistance seen in the first 40  $\mu$ s is real. The driving term for an FCG is  $dL(t)/dt + R_g(t)$ , and the current actually drops 16% in the first 14  $\mu$ s after crowbar showing that  $\bullet R_g(t) \bullet > \bullet dL(t)/dt \bullet$  during that period. In spite of the weak initial performance, 37% of the initial flux remains in the circuit at peak current. This result is based on the 125  $\mu$ H initial inductance determined experimentally, 17.24 kA initial current, and a final inductance of 287 nH carrying 2.75 MA.

## V. Conclusions

A seven or more year old Ranchito was tested and performed nominally. This experiment provided a well defined set of data with which to characterize the generator. The data and unusual winding pattern also provide a useful tool for benchmarking HFCG codes. Based on the results, the Scat 95 prediction of 136  $\mu\text{H}$  initial inductance is 11  $\mu\text{H}$  high. The original purpose for the Ranchito was to provide initial current for Ranchero liner tests in remote locations. We have never used it this way, but the possibility remains. A full scale Ranchero of the type we have tested has an initial inductance of 190 nH. Using total flux and flux loss arguments resulting from the recent test, we could deliver  $\sim 4.2$  MA to a 190 nH Ranchero with an initial current of 17.24 kA. This is  $\sim 30\%$  more current than is available from our full 2.4 MJ capacitor bank, and would allow higher current tests to be performed at our permanent facilities than can be performed with just the bank. This is not an operating limit for Ranchito, and we expect currents as high as 6 MA could be delivered to a 190 nH Ranchero generator, enabling currents into useful loads of over 60 MA. Finally, Ranchito enables plate generator experiments in remote locations. This, for instance, would allow ICE experiments<sup>3</sup> in the two to four megabar range to be conducted in facilities without a large capacitor bank.

## VI. References

1. Fowler, C. M. *et al.*, "The Mark IX Generator," Seventh IEEE Pulsed Power Conference, June 1989, Monterey, CA, p.475, Berstein and Shannon, eds.
2. Parkinson, E. R. *et al.*, "Continued Benchmarking of an FCG Code," 12<sup>th</sup> IEEE Pulsed Power Conference, June 1999, Monterey, CA, p.724, Stallings and Kirbie, eds.
3. Tasker, D. G. *et al.*, "High Accuracy Isentropic Compression Studies With High Explosive Pulsed Power," to be published in this conference.