LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-JRNL-422822

The Full Function Test Explosive Generator

D. B. Reisman, J. B. Javedani, L. V. Griffith, G. F. Ellsworth, R. M. Kuklo, D. A. Goerz, A. D. White, L. J. Tallerico, D. A. Gidding, M. J. Murphy, J. B. Chase

January 25, 2010

Review of Scientific Instruments

Disclaimer

The Full Function Test Explosive Generator

D.B. Reisman*, J.B. Javedani, L.V. Griffith, G.F. Ellsworth, R.M. Kuklo, D.A. Goerz, A.D. White, L.J. Tallerico, D.A. Gidding, M.J. Murphy

Lawrence Livermore National Laboratory, Livermore, CA 94550

J.B. Chase

Jay B. Chase Consulting, Livermore, CA 94550

*E-mail: reisman1@llnl.gov

PACS numbers: 84.70.+p, 47.65.-d

Abstract

We have conducted three tests of a new pulsed power device called the Full Function Test (FFT). These tests represented the culmination of an effort to establish a high energy pulsed power capability based on high explosive pulsed power (HEPP) technology. This involved an extensive computational modeling, engineering, fabrication, and fielding effort. The experiments were highly successful and a new US record for magnetic energy was obtained.

The FFT device is a HEPP generator capable of delivering many tens of Mega-Joules (MJ) of energy and hundreds of Mega-Amperes (MA) of current to inductive loads. Invented by Andre Sakharov[1,2] (and independently by several others including Shearer[3] and Fowler[4]) in the 1950's, HEPP devices have been used to reach energy and current outputs unobtainable by conventional capacitor bank systems. The FFT is a two-stage magnetic flux compression system consisting of a helical generator coupled to a coaxial

generator (Figure 1). The first stage is the Advanced Helical Generator[5] (AHG) which operates by expanding a metal armature onto a helical coil stator. Placed inside the generator is an explosive system consisting of a cylindrical high explosive (HE) rod initiated at one end. As the aluminum cylinder expands, it makes a rotating contact with helical coil that moves from one end of the generator to the other. This motion pushes flux out of the coil and into the subsequent stage. The second stage is the coaxial generator[3] (COAX) that operates by imploding a cylindrical armature onto a contoured stator. This contour is designed to accept the stator at a small phasing angle which rapidly sweeps flux into the load (Figure 2). The explosive system for this stage is a cylindrical shell of HE initiated with a ring of detonators. The total HE weight of the entire device is 900 lbs and it measures over 10 feet in length.

During the experiment, the device is seeded with a small capacitor bank that provides the initial flux. As the armatures expand (helical stage) and implode (coax stage) during the explosive process, inductance is rapidly reduced. To conserve flux ($\phi = LI$) the current correspondingly rises with decreasing inductance. Flux is transferred to the load as current is amplified nearly a thousand times. The output current is delivered to the load via a low inductance (5.4 nH) gas-to-vacuum insulator interface designed to withstand a voltage of up to 200 kV (Figure 3). The insulator is an angular design to manage electrical fields at the triple point junctions and prevent electrical breakdown in the presence of UV radiation[6,7].

The experiments were conducted at the Big Explosives Experimental Facility (BEEF) at the Nevada Test Site (Figure 4). A 1.3 mF capacitor developed the initial generator flux by delivering 110 kA over 300 μs. At peak capacitor current the helical

generator was crow barred by the action of the explosive armature making contact with two wedge-shaped conductors that connect to the helical coil. At this point the AHG has approximately 27 μH of inductance and 3.0 Webers of flux. During the AHG operation, current is amplified to 17 MA with characteristic e-folding time of 20 μs. At the end of the AHG operation the COAX generator is crow barred by the imploding armature making first contact with the stator. At crow bar time the inductance of the COAX is approximately 85 nH. During the COAX operation phase, the current is amplified into the load region with a final e-folding time of 8 μs. The FFT 2, FFT 3, and FFT 4 peak currents were 98, 98, and 74 MA, respectively (Figure 5)[†]. Current was measured using inductive Bdot probes and Faraday rotation optical fiber probes placed in the load region. It should be noted that FFT4 achieved lower peak current as it had a dynamic load designed to operate earlier in the final current amplification phase.

Flux was fully transferred across the gas-to-vacuum insulator interface. The power and energy delivered to the load were calculated with the following relations for flux (ϕ_{GEN}), voltage (V_{LOAD}), power (P_{LOAD}), and total electrical energy (E_{TOT}).

$$\phi_{GEN} = L_{GEN} I$$

$$V_{LOAD} = -\dot{\phi}_{GEN} - IR_{GEN}$$

$$P_{LOAD} = IV_{LOAD}$$

$$E_{TOT} = \int P_{LOAD} dt$$

[†] FFT1 was a test of the COAX generator with a smaller (10 MA) two-stage helical generator. It achieved a peak current of 67 MA.

L_{GEN} and R_{GEN}, the generator inductance and resistance, respectively, were computed using a magnetohydrodynamic code. Current I is the measured value from the experiment. Current, power and energy for FFT experiments are summarized in Table 1. The highest energy of the series was obtained on FFT 2 which delivered 66 MJ with a peak power of 10 TW.

These HEPP results for energy and power exceed those of previous U.S. experiments[3] and are near the Russian record achieved by A.I. Pavlovski in 1967 (100 MJ, 10 TW)[8,9]. Future FFT experiments will be used to explore high energy density physics.

The authors would like to thank the support of Bruce Goodwin and Charlie Verdon. The authors would also like to acknowledge program manager Scott McAllister. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

References

1) A.D. Sakharov, R.Z. Lyudaev, E.N. Smirnov, Y.I. Plyushev, A.I. Pavlovskii, V.K. Chernyshev, E.A. Feoktistova, E.I. Zharinov, Y.A. Zysin, Sov. Phys.-Doklady **10**, 1045 (1966).

2) A.D. Sakharov, Sov. Phys.-Usp. **9**,294 (1966).

3) J.W. Shearer, F.F. Abraham, C.M. Aplin, B.P. Benham, J.E. Faulkner, F.C. Ford, M.M. Hill, C.A. McDonald, W.H. Stephens, D.J. Steinberg, J.R. Wilson, J. Appl. Phys. **39**, 2102 (1968).

4) C.M. Fowler, W.B. Garn, and R.S. Caird, J. Appl. Phys. **31**, 588 (1960).

5) D.B. Reisman, J.B. Javedani, G.F. Ellsworth, R.M. Kuklo, D.A. Goerz, A.D. White, L.J. Tallerico, D.A. Gidding, M.J. Murphy, J.B. Chase, Rev. Sci. Instr. XX, XXXX (2010).

6) C.L. Enloe and R.M. Gilgenbach, Plasma Chemistry and Plasma Processing **7**, 89 (1987).

7) J.B. Javedani, T.L. Houck, D.A. Lahowe, G.E. Vogtlin, D.A. Goerz, " Insulator Surface Flashover Due to UV Illumination", 17th IEEE International Pulsed Power Conference, 2009.

8) A.I. Pavlovskii in *Megagauss Magnetic Field Generation and Pulsed Power Applications*, edited by M. Cowan and R.A Spielman, (Nova Science Publishers, 1994), p. 9.

9) Magnetocumulative Generators, Larry L. Altgilbers, M.D..J. Brown, I. Grishnaev, B.M. Novac, I.R. Smith, I. Tkach, Y. Tkach, (Springer-Verlag New York, 2000).

Figure and Table Captions

Figure 1: FFT assembly consisting of Advanced Helical Generator and COAX generator.

Figure 2: Two-dimensional magnetohydrodynamic calculation of the imploding COAX generator.

Figure 3: The experimental apparatus at BEEF before the shot.

Figure 4: Gas-to-vacuum powerflow section.

Figure 5: Current waveforms as reported by integrated B-dot probes for the FFT experiments.

Table 1: Summary of peak current (I), power (P), and total electrical energy (E) for the FFT experiments.

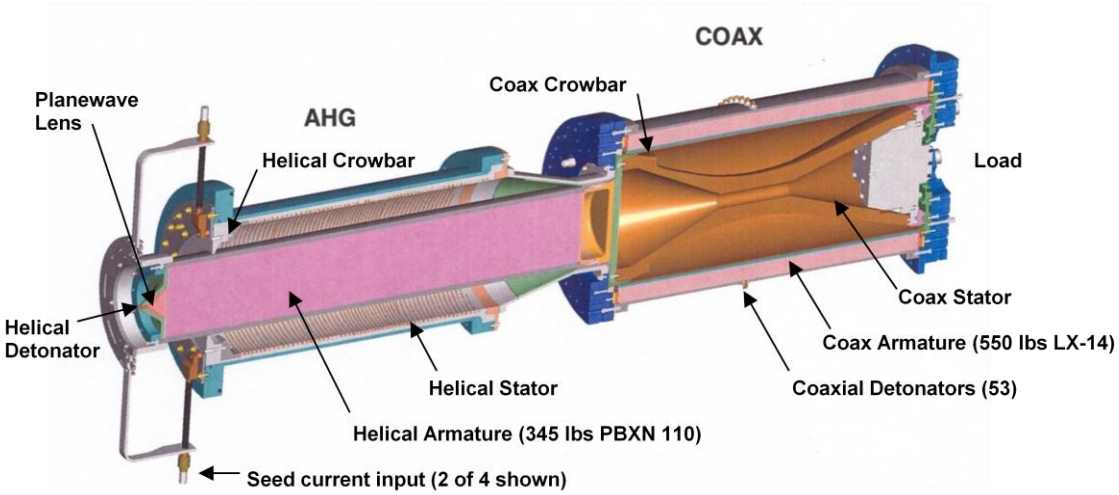
COAX
Planewave Lens
AHG
Coax Crowbar
Helical Crowbar
Load
Coax Stator
Helical Detonator
Coax Armature (550 lbs LX-14)
Helical Stator
Coaxial Detonators (53)
Helical Armature (345 lbs PBXN 110)
Seed current input (2 of 4 shown)

Figure 1

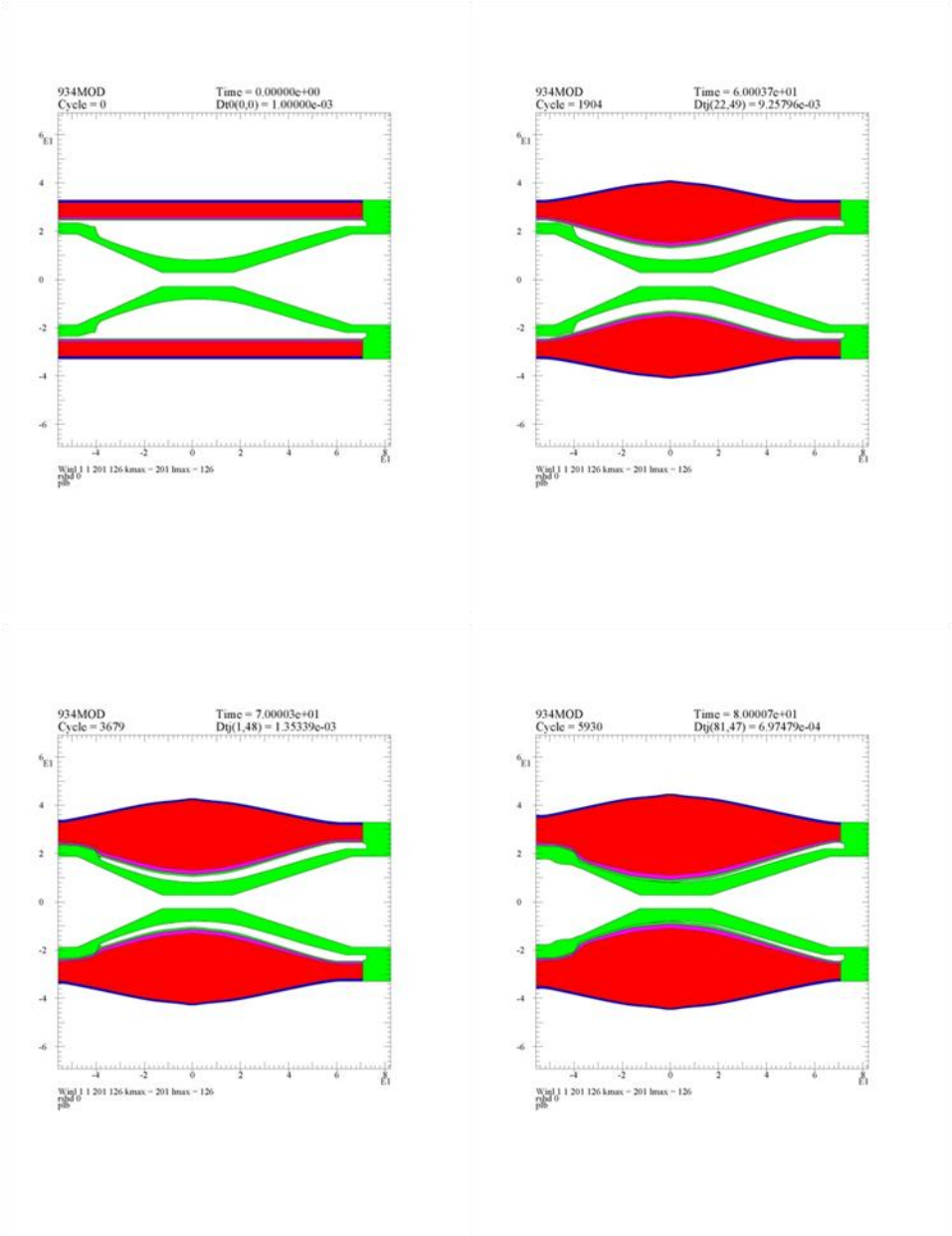
934MOD
Cycle = 0
Time = 0.00000e+00
Dt0(0,0) = 1.00000e-03
934MOD
Cycle = 1904
Time = 6.00037e+01
Dtj(22,49) = 9.25796e-03
934MOD
Cycle = 3679
Time = 7.00003e+01
Dtj(1,48) = 1.35339e-03
934MOD
Cycle = 5930
Time = 8.00007e+01
Dtj(81,47) = 6.97479e-04

Figure 2

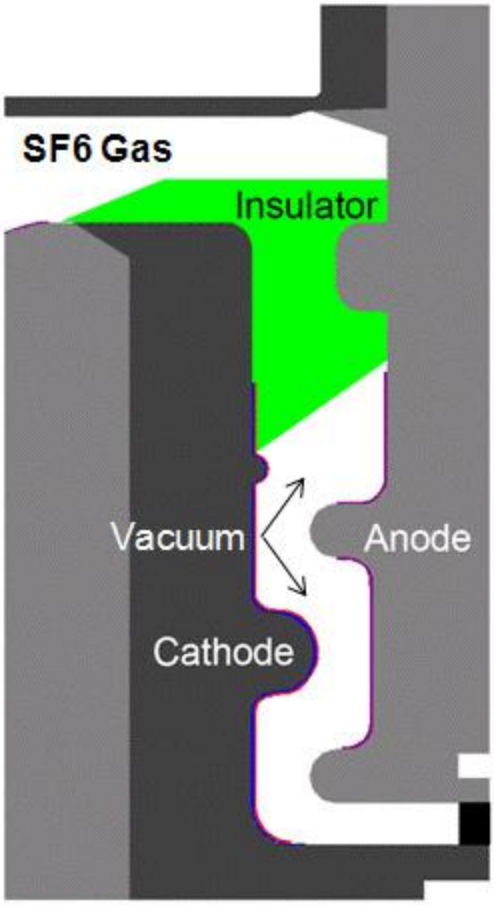

Figure 3

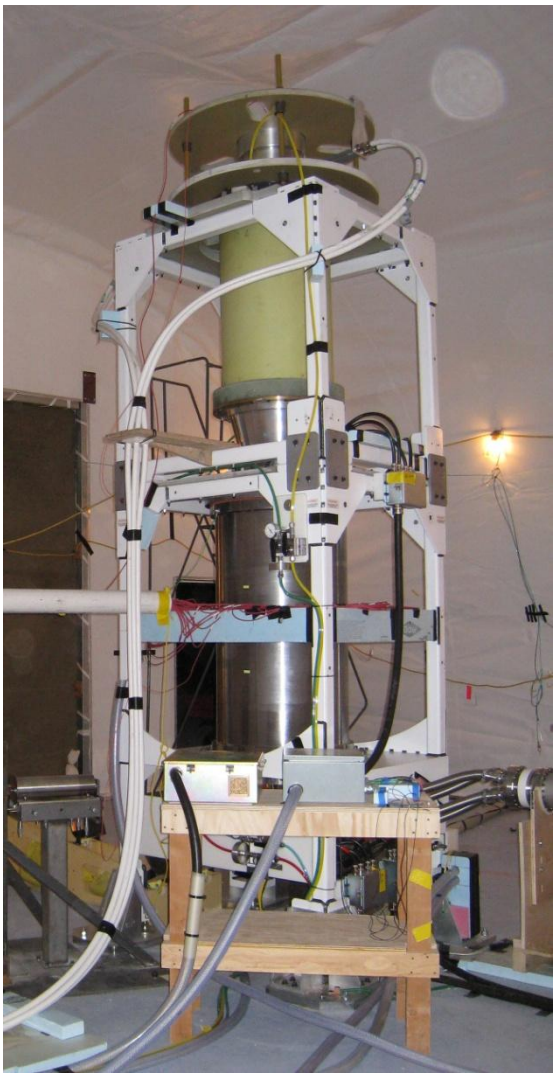

Figure 4

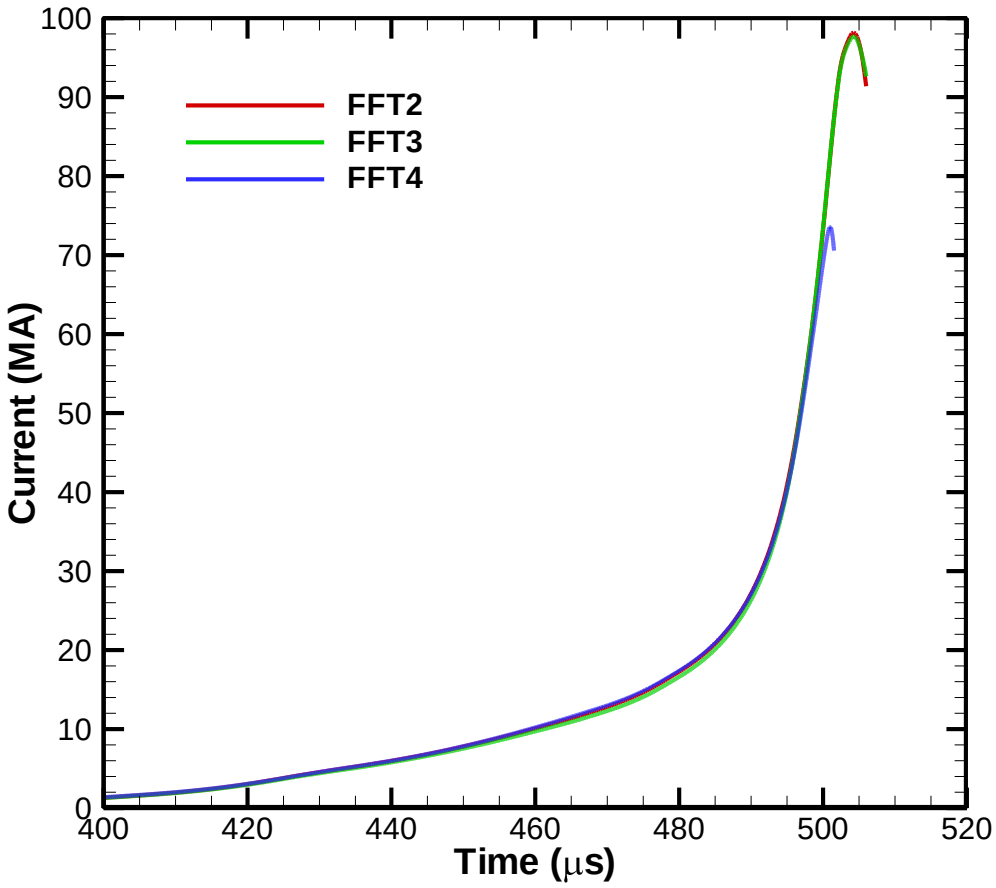
FFT2
FFT3
FFT4
Current (MA)
Time (μs)
0
10
20
30
40
50
60
70
80
90
100
400
420
440
460
480
500
520

Figure 5

Experiment	I (MA)	P (TW)	E (MJ)
FFT2	98	8	60
FFT3	98	10	66
FFT4	74	13	40

Table 1