*Experimental Tests of the Power Supply and Prorotype Cell for the 1.5 MeV SLIA Acceleration Unit**

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ABSTRACT

The prototypes for the nominally 300 kV pulsed power supply and acceleration cell were built and tested in order to determine critical design parameters needed for their final designs. The pulsed power supply produced a 73 ns long trapezoidal pulse rising in 3 ns (10-90%) and having high frequency ripple of less than 2%. The power supply's throughput jitter measured 1.5 ns (1σ). The cell was driven by the power supply and had a resistor taking the place of the beam loading. The ferrite core material was CN-20 manufactured by Ceramic Magnetics, Inc. The cell tests showed the ferrites had a useful flux swing of 0.45 T (20.7 mV-sec) before the magnetization current pulled the cell voltage down by more than a few percent. The ferrite impedance (due to both displacement and magnetization currents) stayed in the 200 to 300-ohm range for the first 2/3 of the pulse and then dropped steadily to 60-ohms at the end of the useful pulse. The load voltage had a 5 ns risetime (with the 3 ns driver risetime) due to 550 pF cell capacitance. The prototype test results were similar to original estimates.

INTRODUCTION AND TEST OBJECTIVES

The pulsed power supply and cell were proto- types for one out of five which will comprise each 1.5 MeV SLIA acceleration unit[1]. The objective of these tests was to measure critical design parameters on a prototype system which will, in turn, provide an experimental basis for the final system design. For the power supply, the critical parameters were (1) risetime, (2) pulse length, (3) high frequency ripple (amplitude and frequency), (4) throughput jitter, and (5) high voltage integrity. For the cell, the critical parameters were (1) risetime (due to cell capacitance), (2) ferrite flux swing, (3) ferrite impedance versus time, and (4) high voltage integrity. Although some of these parameters (such as the power supply risetime, pulse length and high voltage integrity) could be accurately estimated using standard pulsed power scaling laws, other parameters (such as the ferrite flux swing and impedance variation) cannot be accurately known except by testing. The ferrite rings presented the greatest unknown since their behavior can depend on details of their fabrication (such as composition, processing and glue joints) and geometry when loaded in the cell as well as the shape and amplitude of the applied voltage pulse. The prototype power supply and cell were both needed to form a test stand for the ferrite rings. The interpretation and application of the test results for the final system design is outside the scope of this paper and will be presented at a later date.

PULSED POWER SUPPLY

The prototype power supply circuit is shown in Figure 1. The Marx was configured to have 62.5 nF and 7.5 μH so the charge time of the single PFL would roughly equal that of a 125 nF, 1.2 μH Marx charging five PFLs. The PFL output switch bias and trigger circuit was configured to mock the effect of the missing switches with its unused cables

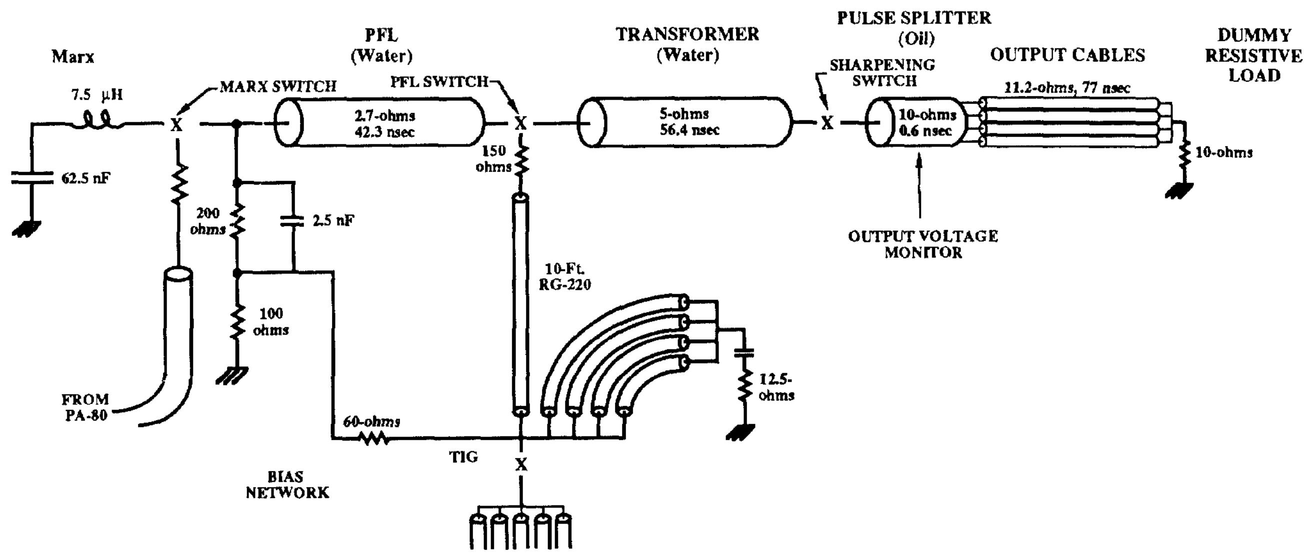

Figure 1. Prototype power supply circuit.

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terminated by an appropriate capacitor and resistor. The prototype PFL was built with a constant impedance along its length. The PFLs for the 1.5 MeV unit will likely have a shaped impedance profile to shape the output pulse and keep the cell voltage constant despite the variation in ferrite magnetization current. (The needed impedance profile can be calculated from the prototype cell measurements, below.)

The output pulse, measured at the entrance to the cables, is shown in Figure 2. When calibrated and corrected for monitor droop, this particular pulse had a 4.5 nsec 10-90% risetime, 306 kV mid-pulse amplitude, and 7% ramp due to PFL switch before peak charge voltage. The ± 2% ripple seen on the pulse top is comparable to the noise in the baseline which suggests that the actual ripple is somewhat less. The spike seen on the fall of the pulse is a reflection from the transition to the dummy load and not part of the forward going pulse.

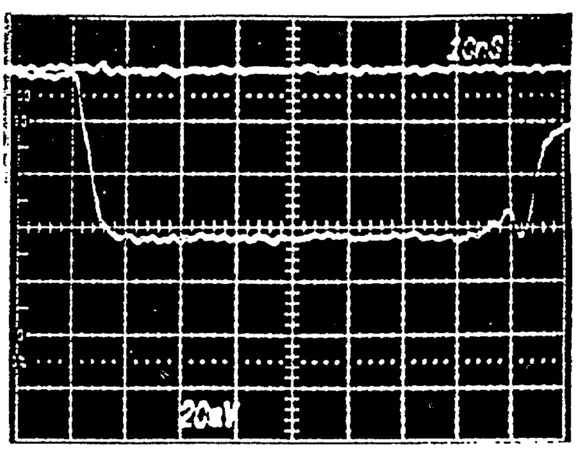

Figure 2. Power supply output voltage, shot 231 (raw).

The power supply test results were similar to the nominal design goals. The output voltage was variable between 170 and 300 kV with a minimum risetime of 3.0 ns (which is controlled by the sharpening switch pressure). The high frequency ripple was less than the ± 2% ripple also seen in the baseline (Figure 2). The pulse length was 73 ns from the beginning of the pulse (leaving the baseline) to the end of the pulse top and the throughput jitter measured 1.5 ns (1σ).

PROTOTYPE CELL

The prototype cell was driven at four (equally spaced) azimuthal locations by the prototype power supply's output cables (11.2-ohm net drive impedance). The cell was assembled in its dummy load configuration, Figure 3, which has one large diameter shielded gap on-axis and a liquid resistor (which was tested at 15 and 25-ohms) to simulate the beam loading. No extra (so-called "compensation") resistors were used in parallel to the load. (The eventual beam loading will be 30-ohms = 300 kV/10 kA.) The cell was tested at voltages ranges from 150 to 340 kV.

The large (1 meter) diameter ferrite core was made of 1.1-inch-thick rings stacked axially, as shown. The large core diameter was selected to accommodate up to seven beamlines as required in future accelerator concepts. The core was pumped down to vacuum with the rest of the cell since relatively small diameter acrylic bushings were incorporated into the drive cable feedthroughs (instead of placing the bushing in the radial waveguide). Each ring was itself made of 12 sections of CN-20 ferrite (manufactured by Ceramic Mangetics, Inc.) joined with epoxy. The 4-7 mil (each) thick joints made the core stack's flux swing dependent on how the rings were loaded in the cell. For example, a 15% larger flux swing was measured with the glue joints staggered and no axial space between the rings than with the glue joints aligned and the rings spaced 1/2-inches apart.

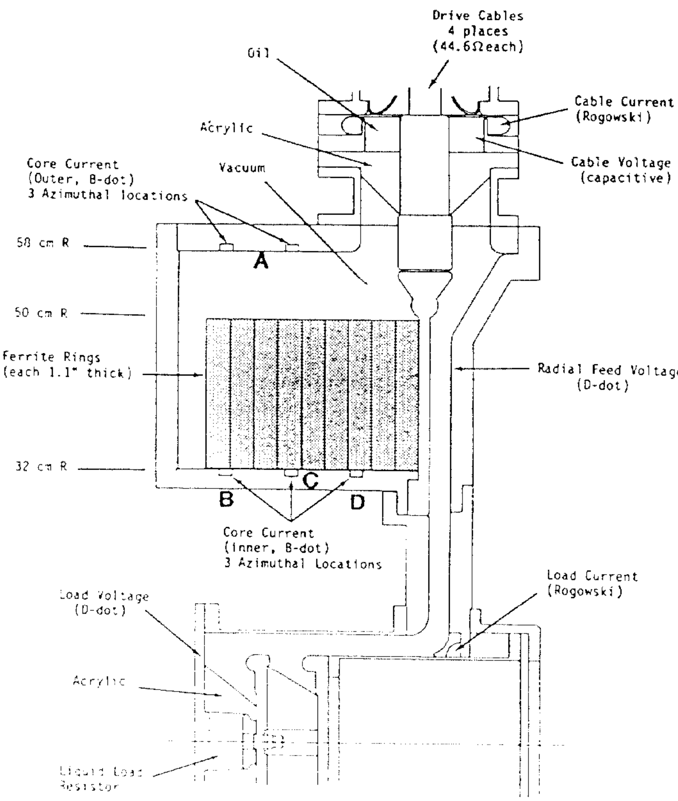

Figure 3. Prototype cell cross-section/diagnostic locations.

With the full 9-core (10.06-inch axial) stack of ferrite, the core flux swing measured 20.7 mV-sec (or 0.45 T) at the end of the useful (top) part of the pulse, shown by cable voltage B in Figure 4. The design goal was 21 mV-sec (= 300 kV x 70 ns). The full flux swing measured 23.3 mV-sec (or 0.51 T) at the zero voltage crossing point. (The cell voltage was raised above the nominal 300 kV for voltage B in order to fully saturate the core before the drive voltage reversed.) With approximately half the ferrite removed (5 cores or 5.54-inch axial remaining), the flux swing was decreased to 54% that of the full load, voltage A in Figure 4. The flux swing was thus shown to be proportional to the cross-sectional area of the ferrite despite the lower voltage of the 5-core tests. In most cases, the cores were reset through the drive cables with a 1 kA peak, 700 μs FWHM pulse which corresponded to 6.2 Oe on the inner and 4.0 Oe on the outer diameters of the ferrite rings. A scan of reset levels showed that currents as low as 250 A peak were equally effective.

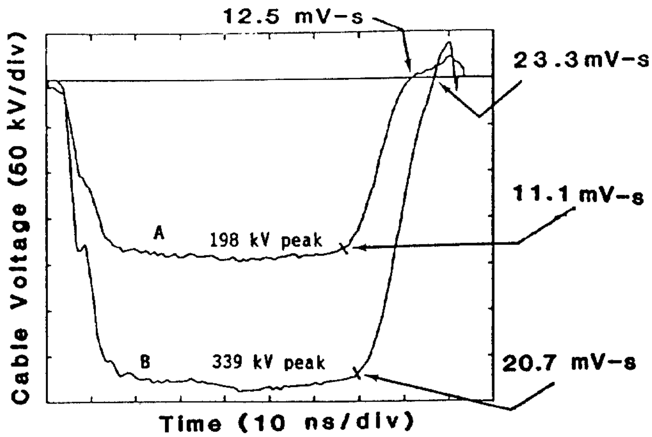

Figure 4. Core flux swing measurements (A = 5 cores, B = 9 cores).

The overall electrical behavior of the cell is shown by comparing measurements of the cable current flowing into the cell to the current flowing through the load, Figure 5. The cell voltage (not shown) was approximately 300 kV and the load resistor was 25-ohms for this particular shot. The

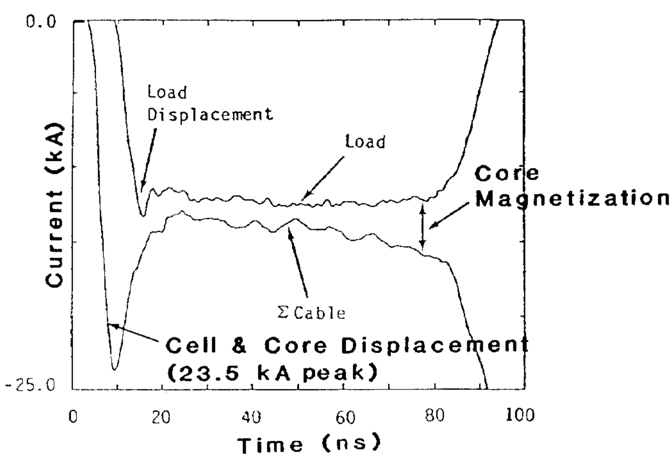

Figure 5. Cable and load current measurements.

load current monitor shows a small spike on its rise as the capcitance downstream charges; otherwise, the load current and voltage were proportional. The load voltage had a 5 ns (10-90%) risetime in response to the 3 ns drive voltage risetime. The higher amplitude, average of the four cable currents shows a 23.5 kA peak at the beginning of the pulse which occurs before the load current begins. The difference between the cable and the load current at the beginning of the pulse corresponds to the displacement current needed to charge the vacuum and ferrite filled regions of the cell between the monitor locations. A capacitance of 550 pF was calculated for the cell from the integral of the displacement current which agreed well with a capacitance value calculated from the geometry assuming a relative permitivity of 12 for the ferrite. The difference between the cable and load current during the rest of the pulse is (primarily) the core magnetization current. Unfortunately, the relatively low amplitude oscillations (a combination of noise and monitor ringing) in the current measurements make calculating the magnetization current imprecise. A better measurement of the core current was made using B-dot probes placed at various positions in the core cavity, Figure 6. The resulting current measurements show an initial displacement current on the upstream monitors which is superimposed on a bilinear magnetization current profile during the useful part of the pulse. The magnetization current has a V/I-dot = 7.3 μH and $L/L_0 = 320$ (= μ_r) from 0 to 55 ns and a V/I-dot = 2.2 μH and $L/L_0 = 97$ from 55 to 80 ns. (The dashed line is the average core current as measured on other shots). The impedance of the cores (including the initial displacement current) goes from 200 to 300 to 200-ohms from 0 to 55 ns, and then ramps from 200 to 60-ohms from 55 to 80 ns. The useful pulse ends at approximately 80 ns (Figure 5) when the drive pulse starts to fall and the core current rises sharply.

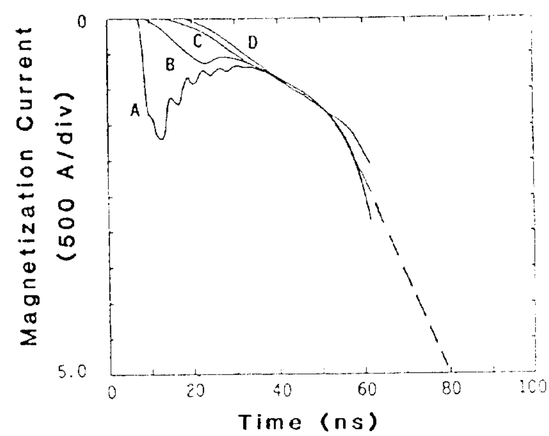

Figure 6. Core region current measurements (refer to Figure 3).

REFERENCE

[1] V. Bailey, et al., *Spiral Line Recirculating Induction Accelerator (SLIA)*, SPIE, Vol. 1061, Microwave and Particle Beam Sources and Directed Energy Concepts (1989).