UPGRADES TO THE DARHT SECOND AXIS INDUCTION CELLS*

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Abstract

The Dual-Axis Radiographic Hydrodynamics Test (DARHT) facility will employ two perpendicular electron Linear Induction Accelerators to produce intense, bremsstrahlung x-ray pulses for flash radiography. The second axis, DARHT II [1], features a 2.5-MeV injector and a 15.5-MeV, 2-kA, 1.6-microsecond accelerator consisting of 74 induction cells and drivers. Major induction cell components include high flux swing magnetic material (Metglas 2605SC) and a Mycalex™ insulator. The cell drivers are pulse forming networks (PFNs). The DARHT II accelerator cells have undergone a series of test and modeling efforts to fully understand their operational parameters. These R&D efforts identified problems in the original cell design and means to upgrade the design, performance and reliability of the linear induction cells [2]. Physical changes in the cell oil region, the cell vacuum region, and the cell drivers, together with different operational and maintenance procedures, have been implemented in the refurbished units resulting in greatly enhanced cell performance and reliability. All 74 cells have now been refurbished and tested for acceptance. This paper gives the results of those tests and the performance of the 26 refurbished cells in the Scaled Accelerator.

CELL AND DRIVER CONFIGURATIONS

The upgraded induction cell is shown in Fig.1. The accelerator is formed by a series of 74 identical cylindrically symmetric shaped cells. The cell accepts a HV pulse from the driver and delivers this pulse to the annular gap in the inner cylindrical surface (beam line). The inner conductor is surrounded by annular ferromagnetic cores to reduce loss current from the HV plate to ground. Each cell is 73” in diameter and weighs 16,000 lbs. Each cell is driven by 4 PFN Marx stages in series, Fig. 2. Between the top stage of the Marx and the grounded lid are a set of diodes and series resistors that clamp voltage reversal at the cell. Reversal occurs due to saturation of the Metglas cores late in the pulse. The flat top on the cell voltage is achieved by varying the number of turns on the inductor between each capacitor, a PFN section.

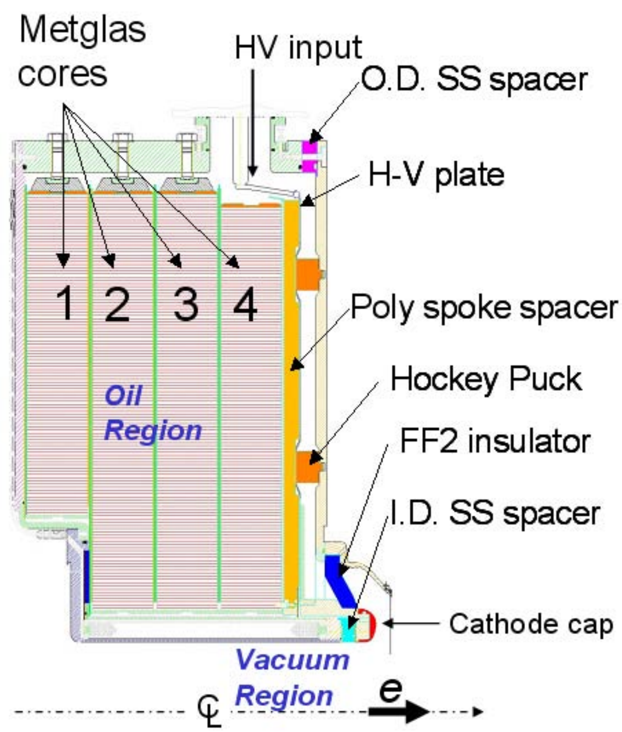

Figure 1. Cross-section of the upgraded DARHT II induction cell.

SCALED ACCELERATOR

The first 26 refurbished cells were assembled in the Scaled Accelerator, Fig.3, to provide the beam needed for a scaled test of the Kicker and multi-pulse Target. The six Injector cells used on the Scaled Accelerator were not

* Work supported by Los Alamos National Laboratory which is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396.
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refurbished. As a result the first 8 cells were operated at a reduced voltage because the gas supply and pressure is common to all 8 PFNs and their Marx spark gaps.

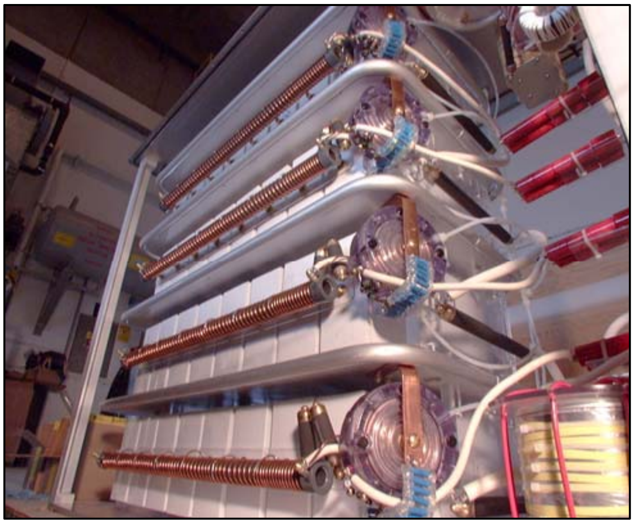

Figure 2. Each cell is driven by an independent PFN/Marx. Each stage is an 8 section PFN.

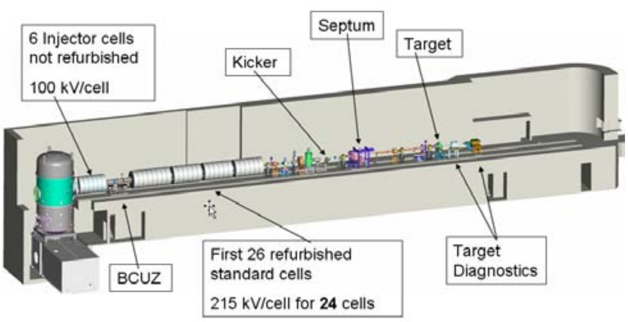

Figure 3. Configuration of the Scaled Accelerator.

The 24 refurbished cells in the Scaled Accelerator have performed flawlessly for > 2000 shots at 200 – 230 kV and beams > 1 kA. Concerns about good finger stock contacts in the return current path and possible UV were not experienced. At no time did any cell experience a voltage breakdown, neither in the oil nor the vacuum regions. The one exception was in the vacuum region on cell position 32, at the end of the accelerator, on Shot 4874. Debris and a pressure burst resulted from inserting a downstream aperture on the 3 preceding shots. The fourth such shot, #4874, resulted in a breakdown. The voltage on this cell was reduced by 15 kV and it was successful for all 650 subsequent shots.

Figure 4 shows a typical average waveform for the refurbished cells on the Scaled Accelerator. The waveforms are a result of adding together the voltages on the 24 refurbished cells and then dividing by 24 to give the average cell voltage.

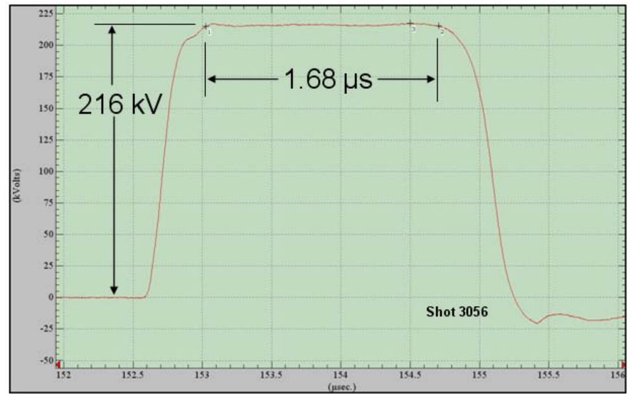

Figure 4a. The average cell voltage on the Scaled Accelerator Test exceeded the design goal of 200 kV per cell.

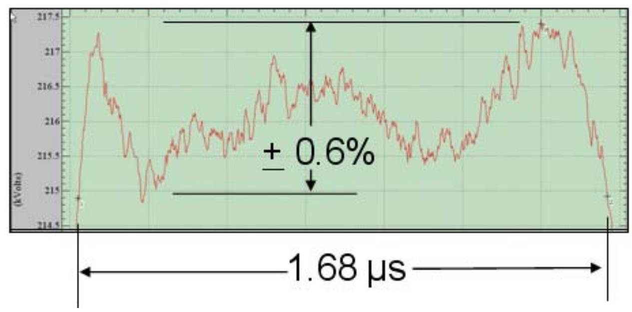

Figure 4b. The average cell voltage on the Scaled Accelerator Test exceeded the design goal of flatness to ±1.0%.

Displayed in Fig. 5 are the last 24 shots in the Scaled Accelerator Test series on the next to last cell in the accelerator. This is an example of the data demonstrating that jitter and flat top are consistently good on the individual cells as well as on the average cell voltage. The individual waveform on the cells for the last shot of the test series are shown in Fig. 6. A spread of voltages is used to achieve the flat tops, because the amount of Metglas in the cells varied from 480- to 515 mVs. In an effort to identify the status of cells 9 – 31 after completion of the Scaled Accelerator Tests, we fired 200 shots at 250 kV on these cells, Fig 7. The conclusion was that the cells had not degraded in spite of the large number of shots or debris in the vacuum regions.

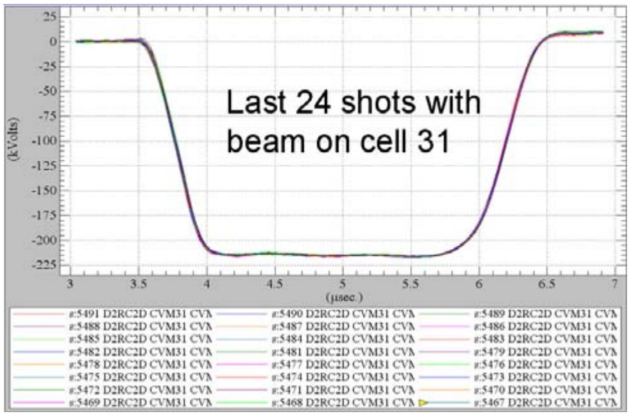

Figure 5. The spread in PFN erection was less than 30ns and the voltage top flat to ± 1% for each cell.

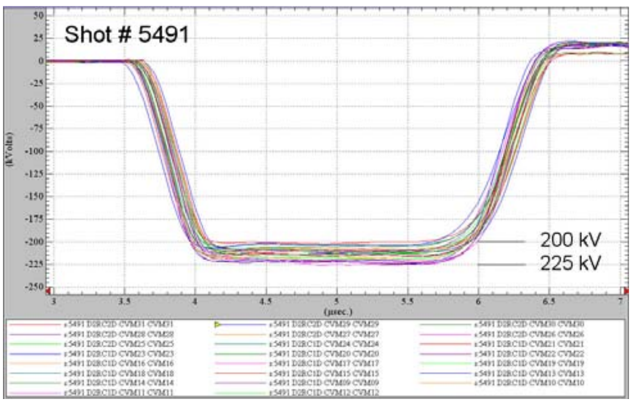

Figure 6. The 24 refurbished cells operated between 200 and 225 kV.

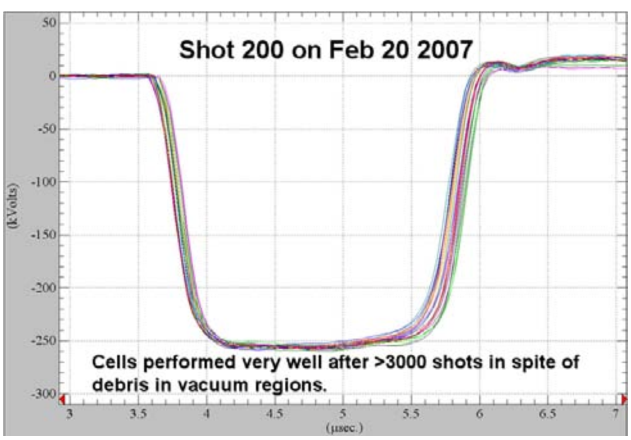

Figure 7. Cells 9-31 were fired at 250 kV for 200 shots at the conclusion of the Scaled Accelerator Tests.

CELL ACCEPTANCE TESTING

All 74 cells in the full up accelerator have passed an acceptance test of at least 1,000 shots at 250 kV before installation in the accelerator. In addition, 24 of these cells were used for over 3,000 shots in the Scaled Accelerator. Breakdowns were experienced in 7 cells during the acceptance tests. Debris in the anode triple point caused breakdowns on reversal on cells A01 and A06, shots # 119 and 54. Procedures were changed to use a borescope to inspect the anode triple point. Subsequently, there were 3 additional cells that broke down in the vacuum, A44 Shot 226, A63 Shot 197 and Injector cell J06 on Shot 55. The later 3 breakdowns are not believed to be associated with triple point. In all cases there was an associated vacuum burst of at least 2 orders of magnitude. After polishing and cleaning the insulator and electrodes, the cells passed the HV acceptance testing.

During acceptance tests cell A08 broke down at the ferrite in the oil volume, 250 kV, Shot 605. This is believed to be a result of an anomaly in the oil region. A29 tracked and cracked the insulator on the oil side at 235 kV, Shot 28. Breakdown resulted from a dent on the end plate or debris in the oil. These cells required complete disassembly and rebuilding.

Aside from A08, all breakdowns, whether in the vacuum or in the oil volumes, were early in the cell's acceptance test series. At all times after cleaning, the cells' vacuum volumes are vented only through a 5 micron filter and room air.

There had been concerns that voids might exist in the Mycalex insulators but these concerns never materialized. Also, using Metglas cores with burned Mylar from earlier breakdowns in the original cells did not compromise the reliability or the initially measured mVs in the cores. The upright cells are twice filled with oil and drained to remove any loose shreds of Metglas or debris. The final fill is with degassed oil and the cell under vacuum. Transport to the accelerator is with the cell upright and at no time is the oil circulated in the cell. We believe that the oil is not carbonized, that circulation would not take place in the desired volumes, and that the possibility of introduction of air is too great.

CONCLUSION

The Scaled Accelerator cells have operated in a very reliable fashion and consistent with meeting the project goals: Injector Cathode at 2.5 MV, 6 Injector Cells and 2 Accelerator Cells at 175 kV for 1.4 MV, 66 Accelerator Cells at 216 kV for 14.25 MV and a total of 18.15 MV.

REFERENCES

[1] M. J. Burns, et. al., "Status of the DARHT Phase 2 Long-Pulse Accelerator," PAC'01, Chicago, June 2001, p.325
[2] B. A. Prichard et. al., "Technological Improvements in the DARHT II Accelerator Cells" PAC'05, Knoxville, May 2005, p. 169.

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