RELIABILITY AND LIFETIME TESTING OF 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, features a 3 MeV injector and a 15 MeV, 2 kA, 1.5 μs accelerator consisting of 74 induction cells and drivers. High reliability and lifetime of the induction cells are major requirements because of the cost of execution of hydro tests and because the time and effort to remove and refurbish a failed cell is considerable. Research and development efforts have identified problems in the original cell design and means to upgrade the design, performance, and reliability of the linear induction cells. 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 six prototype units. This paper addresses the acceptance criteria and acceptance tests applied to the prototype accelerator cells. These tests validate the upgraded cell design and demonstrate that it meets the essential electrical and reliability requirements prior to committing to refurbishment of the full ensemble of DARHT II cells. The prototype acceptance test results are presented and discussed in terms of the confidence level in which the required cell lifetime and reliability are met by the upgraded design and modified operation and maintenance procedures.

I. INTRODUCTION

A series of tests have identified voltage holding problems in the original design of the DARHT second axis induction cells. Modifications to the design to improve voltage holding have been made in the oil region, the vacuum region, and the cell drivers [1]. The prototype cell design is shown in Fig. 1. Assembly, operation, and maintenance procedures have also been developed to improve the performance of the induction cells. Acceptance criteria for the new design have been developed and a prototype test program has been completed to determine if the prototype cell meets the reliability and lifetime requirements.

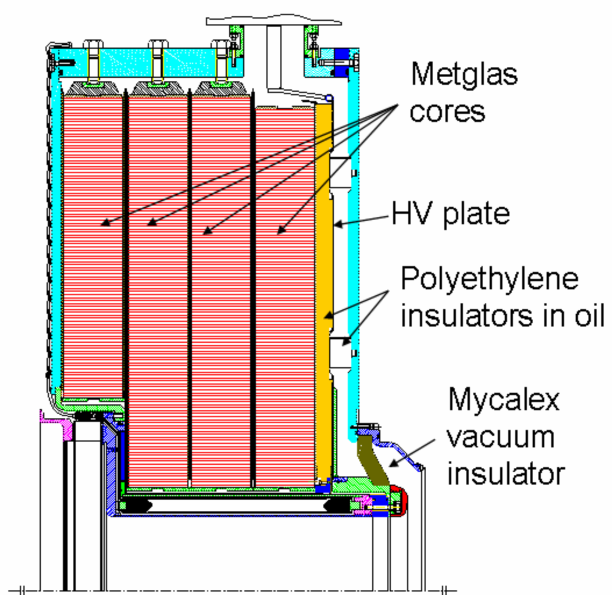

Figure 1. Prototype cell geometry.

II. CELL REQUIREMENTS

Each induction cell is required to provide 200 keV of acceleration to a 2 kA electron beam. The required flattop pulse duration is 1.5 μs with a regulation goal of +/-0.5%. The lifetime of the accelerator is 50k shots. The reliability requirement for the DARHT II facility is less than one failure in 200 shots, where a failure is defined as a failed radiographic shot. The reliability requirement allocated to the ensemble of accelerator cells is less than one cell failure in 800 accelerator shots. There are 68 accelerator cells so 800 accelerator shots corresponds to 54.4k cell shots. In other words, the reliability of each cell must be less than one failure in 54.4k shots. The 6 injector cells which are run at a lower voltage are part of the injector subsystem and were not included in developing the accelerator cell reliability statistics.

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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, features a 3 MeV injector and a 15 MeV, 2 kA, 1.5 ìs accelerator consisting of 74 induction cells and drivers. High reliability and lifetime of the induction cells are major requirements because of the cost of execution of hydro tests and because the time and effort to remove and refurbish a failed cell is considerable. Research and development efforts have identified problems in the original cell design and means to upgrade the design, performance, and reliability of the linear induction cells. 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 six prototype units. This paper addresses the acceptance criteria and acceptance tests applied to the prototype accelerator cells. These tests validate the upgraded cell design and demonstrate that it meets the essential electrical and reliability requirements prior to committing to refurbishment of the full ensemble of DARHT II cells. The prototype acceptance test results are presented and discussed in terms of the confidence level in which the required cell lifetime and reliability are met by the upgraded design and modified operation and maintenance procedure

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III. CELL ACCEPTANCE CRITERIA

From the results of previous tests of the oil and vacuum regions, vacuum flashover across the insulator was assumed to be the dominant cell failure mode. Because of the large number of shots required to demonstrate the required reliability at the nominal voltage of 200 kV, accelerated testing was employed using voltage and pulse width scaling relationships as defined by the semi-empirical expression $F_{BD} = k\ t^{-1/6}\ A^{-1/10}$ where F_{BD} is the electric field on a vacuum insulator (with a constant k) for which there is a 50% probability of breakdown [2]. The time and area scaling exponents of -1/6 and -1/10, respectively, are reasonable for 45 degree plastic insulators and pulse durations up to 100 ns, but are likely to be different for the particular field grading configuration, material, and pulse duration of the DARHT II induction cell insulator. To address this concern, the acceptance tests were designed to include a large number of shots at multiple voltages to generate directly relevant voltage scalings. The tests were also designed to include a significant number of shots so that even without the scaling assumptions, there would be sufficient statistics to indicate whether the reliability requirements had been achieved. From a reliability assurance table in Ref. 3, the values for Table 1 were defined and can be described as the allowed number of failures for multiple 800 accelerator shot tests to have 90% confidence that the inverse failure rate for the ensemble of accelerator cells is at least 800.

Table 1. Allowed number of failures for multiple 800 accelerator shot tests.

Allowed Number of Failures	Number of 800 Accelerator Shot Tests
0	3
1	5
2	7
3	9
4	11
5	13
6	15
7	16
8	18
9	20

IV. ACCEPTANCE TEST RESULTS

The two test sequences used for each of the six prototype cells were an assembly checkout test followed by reliability tests. For the assembly checkout test, a 200 shot run was performed at 250 kV to identify assembly and cleaning problems before commencing the reliability testing. If a breakdown occurred during the assembly checkout test, the problem was identified and corrected. The 200 shots at 250 kV were then repeated. After each cell passed the checkout test, the prescribed reliability acceptance tests were performed. If there was a voltage breakdown on the main pulse, a failure was recorded. A voltage breakdown on reversal was not counted as a failure since it would not lead to a failed radiographic shot. 200 kV shots were defined as having that average voltage over a 2 μs duration, an overtest compared to the 1.5 μs pulse duration requirement. The higher voltages were defined by scaling this voltage up with the corresponding decrease in duration because of a fixed amount of core volt-seconds. It should be noted that the cores are just driven into saturation for this nominal 200 kV, 2 μs test waveform. For example, a 250 kV shot had a 1.6 μs duration and was equivalent to 10.37 200 kV shots with 1.5 μs duration, based on the time and area scaling exponent assumptions described earlier.

After more than 190k shots at voltages ranging from 200 kV to 250 kV, there were no failures (see Table 2). Without any scaling for increased voltage, this test was equivalent to making 800 full accelerator shots 3.5 times. With the previously described scaling assumptions, this test was equivalent to making 800 full accelerator shots 18.6 times. From these results, there is greater than 90% confidence that the cell reliability requirement has been achieved with this set of prototype cells. These conclusions are strictly true only if the area scaling is due to shot-to-shot variations and not sample-to-sample variations. However, the testing of six total cells and the low failure rate give confidence that cell-to-cell variations may be acceptably low in the full accelerator cell ensemble. Because there were no failures, no information was gained on the time and area scaling for voltage breakdown for the DARHT II accelerator cells. Testing at higher voltages could have generated directly relevant voltage scaling information, but because of the limited volt-seconds of the cores, this was impractical in these tests on the fully integrated cells.

Table 2. Prototype acceptance test shots with no failures.

Prototype Cell	Voltage (kV)	Required Shots	Actual Shots	Equiv. 200kV, 1.5μs Shots
1	200	50,000	50,069	80,872
1	250	0	8,700	90,226
2	220	25,000	26,510	94,750
2	250	8,700	12,698	131,689
3	250	8,700	8,772	90,973
4	250	8,700	8,700	90,226
5	220	25,000	25,114	89,761
5	250	8,700	12,288	127,437
6	220	25,000	25,038	89,489
6	250	8,700	12,364	128,225
TOTAL		168,500	190,253	1,013,648

From the results of these acceptance tests, there is confidence that the lifetime requirement of the cells has also been achieved. Without any scaling for increased voltage, one cell was tested for 1.2 lifetimes, 3 cells were tested for 0.8 lifetimes, and 2 cells were tested for 0.2 lifetimes. With the previously described scaling assumptions, three cells were tested for 4.3 lifetimes, one cell was tested for 3.4 lifetimes, and two cells were tested for 1.8 lifetimes at 200 kV and 1.5 μs with no failures or evidence of degradation.

V. COMPONENT TESTS

In addition to the prototype cell acceptance tests, component tests on individual cells were performed to address specific conditions in the accelerator hall. Venting and oil contamination tests were used to develop vacuum region cleaning procedures and accelerator venting procedures. A current contact test was performed to look for degradation from possible arcing and to test for insulator flashover from possible UV light generation at the current contacts. A cathode cap tolerance test was performed to test the robustness of the design to tolerance stackup at the exposed cathode triple point. A transverse impedance measurement of the cell is scheduled for July to evaluate beam breakup instability growth in the accelerator. This measurement has been done with the original design and from modeling, the effects of the design modifications are expected to be minimal. Various tests with the insulator have been performed to test the bulk breakdown and surface flashover strength of the legacy material as well as the newly produced Mycalex material. A mechanical loading test is scheduled for July to test the mechanical strength of the new Mycalex. Various tests have been performed to gain experience with modifications to non-critical components which were not captured in the prototype acceptance test series. There is also one prototype cell which will be installed into the accelerator and tested in July with beam and magnetic field.

VI. PRODUCTION CELL ACCEPTANCE TESTS

Production cell acceptance tests are planned to qualify the cells before they are put into service. All cells must complete 400 shots at 250 kV in the assembly area without any voltage breakdowns. If a voltage breakdown occurs, the cell will be inspected, repaired as necessary, and the 400 shot sequence will be restarted. All cells must also complete 400 shots at 250 kV in the accelerator hall after installation without any voltage breakdowns. If a voltage breakdown occurs, the cell will be inspected, repaired as necessary, and the 400 shot sequence will be restarted.

VII. CONCLUSION

Acceptance criteria have been developed for the prototype cells to ensure that the reliability and lifetime requirements are met. The results from prototype cell acceptance tests, in addition to the results from the completed component tests, indicate the design is robust and meets the reliability and lifetime requirements with greater than 90% confidence level. Assembly, installation, and cleaning procedures used during the prototype cell acceptance tests will be used for the production cells to ensure similar results. Production cell acceptance tests are a planned quality assurance and quality control step to qualify cells for service.

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IX. REFERENCES

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