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DIAGNOSES AND REPAIR OF A CRACK IN THE DRIFT TUBE LINAC ACCELERATING STRUCTURE AT LANSCE*

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Abstract

Many were perplexed at the inability of Module 3 at LANSCE to maintain full power and duty factor while running production beam. First occurring during the 2018 production run, the Drift Tube LINAC module began to intermittently trip off, leading to a series of root cause investigations. These analyses included eliminating the usual suspects: vacuum leak, debris in tank, drive line window, amplifier tube degradation, etc…The throttling back of repetition rate from 120 to 60 Hz allowed continued production with a diminished beam, one that reduced neutron flux to three experimental areas. During the annual long shutdown in 2019, a more thorough investigation involving the use of x-ray detection, high resolution camera and borescope was performed. Although x-ray detection was able to broadly indicate areas of arcing, the best diagnostics turned out to be the high resolution camera and borescope. After a tenacious search, a 30 cm long crack in a weld was discovered at one of the ion port grates. Because this area was inaccessible from the outside for welding and in a confined space, non-intrusive repairs were unsuccessfully tried first. Ultimately, an expert welder had to enter the tank under high-level institutional management scrutiny to perform a weld on copper with very unfamiliar welding conditions. This paper describes the diagnoses, discovery, unsuccessful solutions and ultimate repair of the crack in the accelerating structure.

INTRODUCTION

The Drift Tube LINAC (DTL) at LANSCE accelerates two species of proton beam from 750 keV to 100 MeV energy through a set of four accelerating structures (Fig. 1). The four modules accomplish this acceleration when driven with 201.25 MHz RF power that generates electrical fields in the regions between the noses of each drift tube. The beams experience nearly zero fields while inside the drift tubes.

Arcing may occur when initiated by a vacuum leak, debris, compromised vacuum window or other initiating mechanism. When excessive arcing in Module 3 occurred during the middle of the 2018 run cycle, the usual causes were investigated and eliminated. As the staff pursued the problem further, a work around was construed whereby the machine could be operated at reduced repetition rate (60 vs. 120 Hz, Table 1) to preserve run cycle availability rather than taking the downtime hit and its unpredictable duration. Although neutron experiments are accomplished more efficiently with greater flux, the experimental areas at LANSCE are not all dependent on repetition rate.

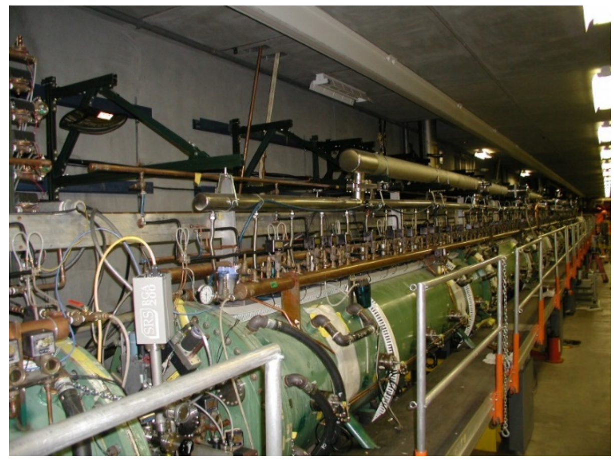

Figure 1: LANSCE DTL modules.

Table 1: History of Stable RF, Module 3

Date	PRF	RF Gate Length	Beam Pulse	Average RF Power
	Hz	usec	usec	kW
7/16/2017	120	1010	625	153.75
11/16/2017	120	810	475	116.85
11/17/2017	120	830	525	129.15
11/27/2017	120	830	565	138.99
6/28/2018	120	880	625	153.75
9/18/2018	120	760	520	127.92
9/20/2018	120	700	400	98.4
9/24/2018	60	1010	625	76.875
9/24/2018	60	1060	625	76.875
9/26/2018	60	1060	725	89.175
10/9/2018	60	1040	725	89.175

A more disciplined and thorough diagnosis for the arc down phenomenon could be accomplished during the long outage, scheduled for a few months away. Resources were dedicated to this vital task and it was performed systematically such that the likely causes could be entertained and accepted or eliminated.

Diagnosis

Any tests to diagnose the Module 3 arcing issue with RF on would need to be performed at the end of the run cycle

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where maintenance tasks such as cooling tower cleaning could be delayed a short time. One such test, as designed by the RF Team, would involve the detection of x-rays, indicators of excess electron activity, byproducts of arcing [1]. A row of shielded x-ray detectors were set up in the aisle at prescribed distances from both the module and each other. As RF power was ramped up and arcs occurred, these detectors would pinpoint or reduce the area to search for the arc initiation site in the 15 meter long module. As this diagnostic experiment revealed, the area in the tank to search was near the RF window, approximately 6 meters from the upstream end. Although not precisely pinpointed, the experiment narrowed down the area to search, saving time for further examination.

Since thorough cleaning, verifying window integrity and vacuum leak reduction did not affect the arcing, it was decided to shut down power, open up the vacuum system and look more closely at the module's copper surfaces with cameras. Although this task seems relatively simple and straightforward, it required the design and fabrication of special tooling to feed the cameras through the small ports and grates available to access the tank. A borescope was supplemented by a special, high-resolution camera, purchased specifically for the job. These cameras allowed close-up viewing and photography of geometric features that could be compared against previous photos to distinguish changes revealing the cause. After much time and effort, the RF Team discovered a crack in the ion pump grate at one of the transverse copper welds. The crack was approximately 30 cm long and 3 mm wide (Fig. 2). This feature was in the region identified by the x-ray detectors.

Figure 2: Crack in weld at ion pump grate.

Repair

Evidence collected during the investigation suggested that the crack was the source of the arcing issue but it was not entirely conclusive. Should irreversible damage occur during repair, the mission of LANSCE would suffer, potentially adversely affecting the next run cycle and perhaps beyond. Therefore, the conservative approach had to be a graded one in which the most unintrusive solutions would be tried first.

Copper foil tape was selected based on its composition, conductive adhesive, and thickness (0.066 mm). The tape would be applied over the crack through the ion pump grate but would be visualized for integrity and coverage through one of the frequency tuner ports. Reassembling, cleaning, vacuum pumping and leak checking were performed each time a different approach was tried, a resource intensive operation. The copper tape succeeded to a point in the RF power ramp (RF average power: 7.2 kW of 160 kW needed), then blistered and failed (Fig. 3). The advantage of this approach was that it confirmed the strong suspicion that the crack was the source of the issue.

Figure 3: Blistered copper tape.

A clamped bridge to cover the crack would be tried next (Figs. 4 and 5). In this design, the piece that makes contact with the tank wall would have Ag plated Be-Cu finger stock brazed onto it so that good electrical contact could be obtained while allowing the RF induced current to flow up and over the clamps and bridge. Outgassing of the crack would be preserved due to the gaps and open ends. Although careful thought went into design and implementation of the clamped bridge, it also failed to control arcing (RF average power: 134 kW of 160 kW needed). However, the improvement confirmed that this small crack was the source of breakdowns.

Figure 4: Finger stock brazed to copper bridge.

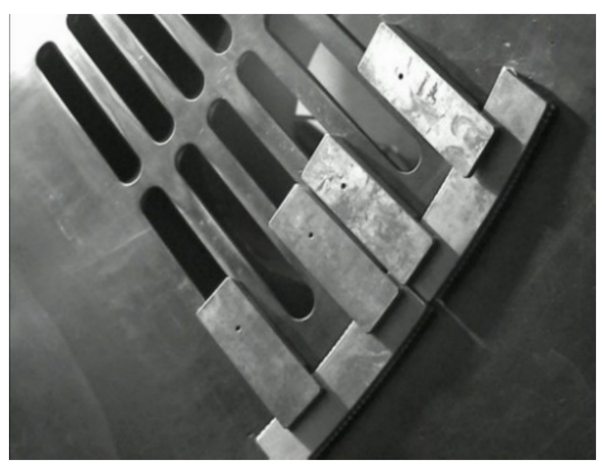

Figure 5: Clamped bridge.

Now, with little time left in the long maintenance outage, the choice had to be made whether to run the machine at a

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reduced repetition rate or take the unprecedented step of entering the module and performing the weld. At LANL, a focus on personnel safety is paramount so the review and approval of such work goes up as a job becomes more hazardous. The hazard screening process assessed this work as a "High Hazard" which garnered the attention and scrutiny of many senior managers. Hazards included working in a confined space, welding on potentially radiologically activated copper, depletion of oxygen while welding, copper vapor inhalation, fire, communication with the Welder while wearing a respirator and donning the vetted Personnel Protective Equipment (PPE) [2]. In addition, an awareness had to be maintained to prevent heat from welding to burn through the tank wall into the water jacket since the cladding was composed of only 3 mm copper clad to 6 mm of steel.

In extensive preparation over the course of several weeks, the Welder specified and purchased a new MIG/TIG welding machine that could be operated with one hand. He practiced welding in a mock module with the PPE on, then became certified for welding copper. Outside resources assisted in these efforts. The weld would need to be tried and adjusted in-situ since the actual conditions could not be simulated exactly. In addition, the Welder would need to maintain a calm disposition in order to prepare appropriately and perform a successful weld.

Although the workers team leaders involved with the job plan the steps, assess the hazards, develop hazard control/mitigation and determine qualifications of workers required, a high-risk job involving multiple disciplines is often formally reviewed in a Rehearsal of Concept (ROC) meeting. Here, the chance for assessment from outside of the organization is exercised. With this additional input adding more time, the actual repair window came near the very end of the maintenance outage.

To begin the repair, communication, air flow, fire watch, confined space attendant and rescue team were all situated and in place in the beam channel. Practice welds were performed outside of the tank with duplicate material and simulated conditions. The Welder shimmied into the tank in the prone position from the removed upstream flange, both with head and feet-first positions relative to the upstream tank opening. Air flow, oxygen level, communication, camera and Welder well-being were all actively monitored. Practice welds were performed inside of the tank to properly adjust welding parameters of current, wire speed and gas flow. Water cooling in the tank channels was initiated to ensure safe temperature for the worker but this added a new variable to the weld settings (needed more current).

After several tank entries, a patch on the crack was successfully welded but this caused an additional perpendicular crack to open up from heat-induced stress (Fig. 6). Welding parameters for patch: current - 250 A, wire speed - 3.7 m/min, Argon shield gas.

Figure 6: Welded patch (left) and heat induced crack (right).

The heat induced crack was also welded (160 A, 2.3 m/min) with better relief this time so new cracks did not occur. Three entries into the tank over a period of two weeks added up to a total of 8 hours to complete the repair. This effort restored the module to normal operating values of 260 kW average power at 120 Hz repetition rate.

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