

# UPGRADES TO THE INJECTOR CATHODE AND SUPPORTING STRUCTURE OF THE DARHT SECOND AXIS ACCELERATOR \*

R. Mitchell<sup>#</sup>, B. Gardner, T. Ilg, LANL, Los Alamos, NM 87545, U.S.A.  
 M. Leitner, LBNL, Berkeley, CA 94720, U.S.A  
 B. Prichard, SAIC, Los Alamos, NM 87545, U.S.A.

## Abstract

The Dual-Axis Radiographic Hydrodynamic Test Facility (DARHT) at Los Alamos National Laboratory (LANL) consists of two linear induction accelerators oriented at right angles to each other. The DARHT First Axis has been successfully operated since 1999 and produces a 60 ns pulse with beam energy of 20 MeV and beam current of 1.9 kA. The DARHT Second Axis was successfully commissioned in May 2008 and produces a 1600 ns pulse with beam energy of 17.5 MeV and beam current of 2.1 kA. The Second Axis Injector uses a 16.5 cm diameter thermionic cathode with a 10 A/cm<sup>2</sup> required current density to emit electrons into the accelerator. During the early Second Axis commissioning activities in 2006, deficiencies in the DARHT Second Axis Injector were found that prevented the injector cathode from meeting the required 10 A/cm<sup>2</sup> current density. A comprehensive campaign was initiated to solve the injector cathode performance issues. This paper describes the deficiencies found and the solutions used to enable the DARHT Second Axis Injector to meet its requirements.

## INTRODUCTION

The legacy DARHT Second Axis (DARHT-II) cathode was the Os-Ru coated 612-M type manufactured by Spectra-Mat. The cathode was mounted to a stainless steel Cathode Support Spool via a molybdenum Cathode Mounting Plate (see Fig. 1). Surrounding the cathode was a stainless steel/copper Cathode Shroud. The shroud was mounted to the Cathode Support Spool and retained by six Shroud Mounting and six Jacking Screws. The Jacking Screws are similar to the Mounting Screws except that the Jacking Screws have a retainer that does not allow the screws to be fully removed from the shroud. Instead, the Jacking Screws are used to push the shroud off the Shroud Support Spool during disassembly. The cathode heater leads were custom slip-on connectors.

The high temperature thermionic cathode operates at 1120 °C and is susceptible to poisoning from water, oxygen, silicates, chromium, and chromium oxide, among others. As a result, handling during installation must be minimized, the vacuum pressure must be below 1X10<sup>-7</sup> Torr (typical operation is at 2-3x10<sup>-8</sup> Torr), and stainless steel temperature in the cathode region must not be in the 400 to 500 °C region to prevent chromium and chromium oxide diffusion.

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<sup>#</sup>rrm@lanl.gov

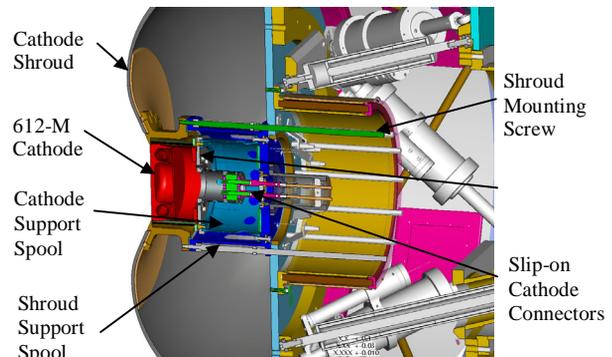


Figure 1: Cross-sectional view of legacy Cathode Assembly.

## DEFICIENCIES DISCOVERED

The investigation found the following deficiencies:

- The 612-M cathode was susceptible to poisoning.
- The anode to cathode (A-K) gap was too large.
- Although the Injector Vacuum Vessel was operating between 2-3x10<sup>-8</sup> Torr, poor pumping conductance in the region behind the cathode produced locally high pressure on the cathode face. The major conductance path from behind the cathode was out the pierce gap along the outside diameter of the cathode.
- Stainless steel components near the cathode were at temperatures where chromium and chromium oxide could diffuse and poison the cathode.
- Broken Macor insulators were a potential poison source from silicates.
- Thermal expansion during operation caused the cathode OD to make contact with the cathode shroud ID, deforming the shroud.
- The cathode did not self-center to the shroud and cathode mounting screws broke due to galling, increasing installation time. The legacy Cathode Support Spool was a stainless steel spool that accepted the cathode's molybdenum mounting plate. To allow for the thermal mismatch between stainless steel and molybdenum, the cathode spool had a series of slots to produce compliant fingers (see Fig. 2). Over time those fingers became distorted due to cyclic heating and over-torque from galled stainless steel screws. It became necessary to align the cathode manually which was time consuming and difficult.
- The shroud's flange deformed around 3 jacking screws from mishandling, and alignment holes were

deformed from the stainless steel pins hitting the soft copper holes during installation.

- The slip-on, spring-loaded cathode heater lead connectors mounted to a Macor insulator deformed during installation and were difficult to replace after damage (see Fig. 2). As the connection to the cathode pin was blind, overloading during assembly occurred which deformed the connector. Upon disassembly, the cathode pin often became stuck to the connector and put large stresses into the Macor insulator, resulting in cracks.

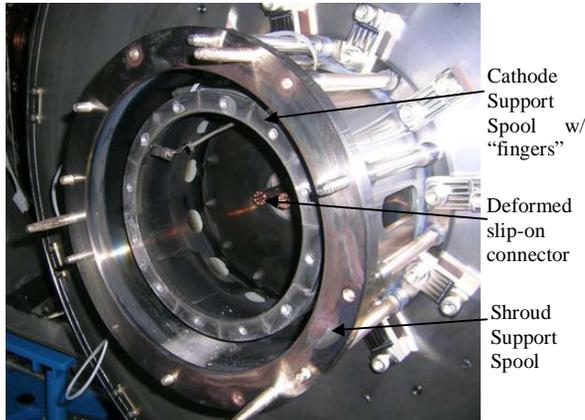


Figure 2: Legacy cathode and shroud mounting spools.

### IMPROVEMENTS TO THE INJECTOR CATHODE ASSEMBLY

The following changes were made to meet injector performance requirements:

- The cathode was changed from a 612-M to a 311-XM formulation that showed more resistance to poisoning [1].
- The A-K gap was shortened by 3”.

- Holes were added to the cathode shroud to improve pumping conductance from the volume behind the cathode (see Fig. 3). The number and size of holes in the Cathode Support Spool were increased, and aligned with holes in the Shroud Support Spool. In addition a flow restriction was added to limit flow near the cathode face.
- To minimize galling and poisoning issues, stainless steel component temperatures were reduced below 400 °C and stainless steel fasteners were replaced by titanium fasteners.
- Alumina replaced the macor insulators due to alumina’s low outgassing properties and improved mechanical strength (see Figs. 3 and 4).
- The cathode to cathode shroud radial gap (pierce gap) was increased to eliminate future contact during thermal cycling.
- The Cathode Support Spool was redesigned to ensure the cathode would self-center to the shroud and not deform from repeated temperature and cathode installation cycles. The new spool is made of solid W-10Cu which matches the thermal expansion properties of the cathode molybdenum mounting plate, lowers the temperature of the cathode mounting structure, and reduces galling (see Figs. 3 and 4).
- To reduce the chance of future shroud damage, the number of shroud jacking screws was reduced from 6 to 2 to eliminate binding, and were differentiated by using different hex sizes. Titanium inserts in the copper flange eliminated distortion from alignment pins.
- Simple heater lead screw terminals replaced the slip-on connectors to ensure a robust electrical contact (see Figs. 3 and 4).

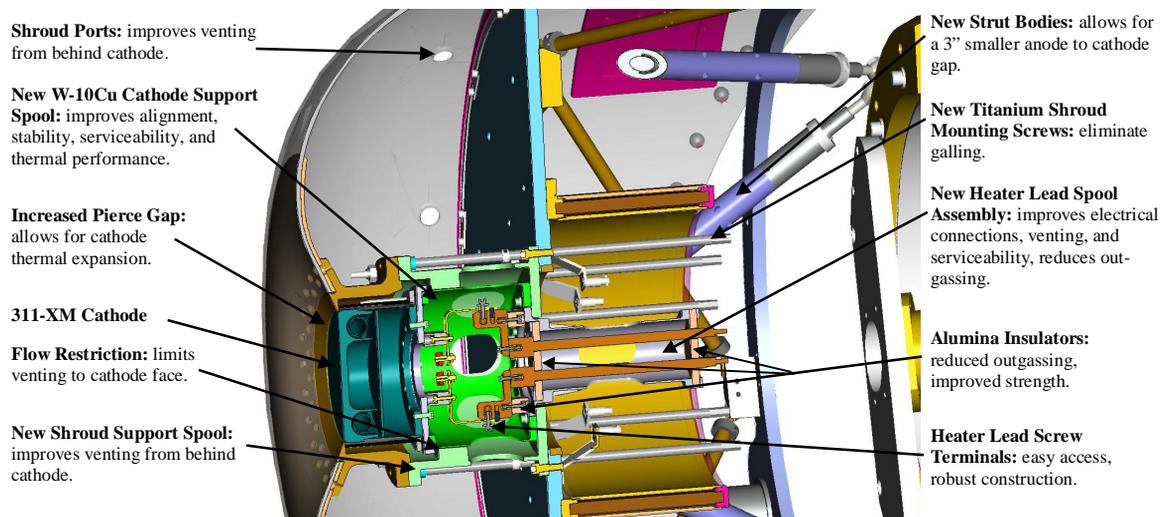


Figure 3: Cross-sectional view of modified Cathode Assembly.

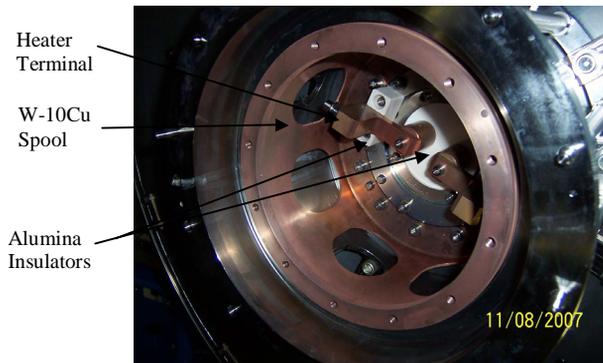


Figure 4: New Cathode Support Spool and heater lead terminal details.

## FINITE ELEMENT THERMAL ANALYSIS

A thermal finite element analysis was performed on the cathode support structure to determine if the new design would lower temperatures behind the cathode, while not overloading the cathode heater. To validate the model, the legacy design was modeled and compared with measured test results. Analysis determined that an additional 100 W out of the original 2.2 kW of power is required with the new W10Cu spool, and will not overload the cathode heater. In addition, the new spool reduces temperatures behind the cathode to approximately 200 °C, well below the 400-500 °C range where stainless steel can diffuse chromium and chromium oxide (see Fig. 5).

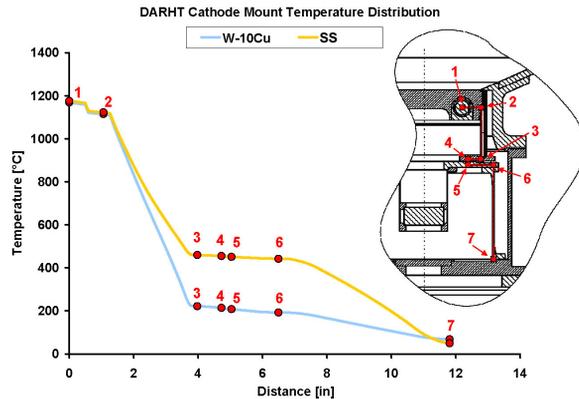


Figure 5: Temperature results of the cathode (points 1 and 2) and support structure for legacy and new designs (points 3-7).

## SUMMARY

### *New Design Improves Cathode Installation*

The legacy Cathode installation times took between 5 to 16 hours to install depending on the number of problems encountered. Those problems included galled threads, broken fasteners, and difficult alignment. The cathode misalignment varied from .005" to .013" and was not repeatable. With the new structure, installations have been consistently less than 2 hours, and centering has typically been within .005" with repeatability within .001". No

problems with galling or distortions have been found after three installations.

### *New Design Improves Cathode Performance*

After installation of the new cathode and modified support structure, the injector exceeded the required 2kA current over the 1600 ns pulse duration (10 A/cm<sup>2</sup> required current density). The injector current changed from 1100 A for the legacy design to 2100 A for the new design, an increase of 1000 A. Figure 6 shows the performance improvement between the legacy design and the new design.

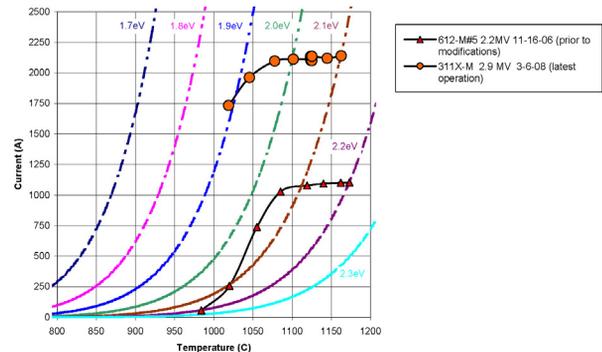


Figure 6: Cathode performance comparison.

## CONCLUSION

Changes to the cathode support structure improved performance by decreasing installation time, reducing localized pressure on cathode face, increasing alignment accuracy, reducing cathode mount temperature, and using materials that avoid poisoning at elevated temperatures. Those changes coupled with the reduced A-K gap and a more robust cathode design allowed the DARHT-II Injector to meet the required 2kA current over the 1600 ns pulse duration (10 A/cm<sup>2</sup> required current density). In March 2008, the project met or exceeded all project requirements.

## REFERENCES

- [1] J. Kwan et al., "Gas Poisoning of 612-M and 311-XM Cathodes", IVEC 2008. IEEE International, April 22-24, 2008, pp. 44 – 45.