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A PROPOSED ATLAS LINER DESIGN FABRICATED FOR HYDRODYNAMIC EXPERIMENTS ON SHIVA STAR

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Abstract

An entirely new cylindrical liner system has been designed and fabricated for use on the Shiva Star capacitor bank. The design incorporates features expected to be applicable to a future power flow channel of the Atlas capacitor bank with the intention of keeping any required liner design modifications to a minimum when the power flow channel at Atlas is available. Four shots were successfully conducted at Shiva Star that continued a series of hydrodynamics physics experiments started on the Los Alamos Pegasus capacitor bank. Departures from the diagnostic suite that had previously been used at Pegasus required new techniques in the fabrication of the experiment insert package.

We describe new fabrication procedures that were developed by the Polymers and Coatings Group (MST-7) of the Los Alamos Materials Science Division to fabricate the Shiva Star experiment loads. Continuing MST-7 development of interference fit processes for liner experiment applications, current joints at the glide planes were assembled by thermal shrink fit using liquid nitrogen as a coolant [1]. The liner material was low strength, high conductance 1100 series aluminum. The liner glide plane electrodes were machined from full hard copper rod with a 10° ramp to maintain liner to glide plane contact as the liner was imploded. The parts were fabricated with 0.015 mm radial interference fit between the liner inside diameter (ID) and the glide plane outside diameter (OD). to form the static liner current joints. The liner was assembled with some axial clearance at each end to allow slippage if any axial force was generated as the liner assembly cassette was bolted into Shiva Star, a precaution to guard against buckling the liner during installation of the load cassette. Other unique or unusual processes were developed and are described. Minor adaptations of the liner design are now being fabricated for first Atlas experiments.

I. INTRODUCTION

The Los Alamos High Energy Density Hydrodynamics Program (HEDH) Near Term Liner Experiment (NTLX) liner driven series of experiments at the Air Force Research Laboratory (AFRL) Shiva Star pulse power facility offered a maximum of four chances to demonstrate a new liner system. The NTLX liner was designed to operate at nominally 15 MA and with circuit parameters that would be similar to the Los Alamos Atlas facility, then under construction. The design was optimized to insure success of the pulse power flow and liner dynamics, not compromised for either economy or convenience of fabrication. Experimental design criteria, supporting calculations, diagnostic measurements and the hydrodynamic experiments are described elsewhere in this proceedings [2, 3]. Here we describe the fabrication processes of the liner, the associated components of the power flow channel cassette, and the liner driven hydrodynamic experiment inserts.

II. LINER FABRICATION

The liners were fabricated in conjunction with their associated glide planes. Successful machining and assembly of these relatively massive and tight tolerance parts depends upon a combination of adequate tools and careful thought to holding and aligning fixtures and upon good process execution strategies. Most of the machining was done with a Hardinge Conquest T42SP slant bed machining center with several options, all selected to facilitate efficient fabrication of Atlas liners, as that need was understood during Atlas design. The machining center has provision for live spindle tooling which supports cross working operations and contour milling. The machine maintains part roundness to within 0.40 μm, axis repeatability is within 0.76 μm and turret position repeatability is within 1.27 μm. Surface finish is 16 microinch rms (R_q) with carbide inserts, 4 microinch R_q with polycrystalline diamond inserts.

A. Glideplane Fabrication

Glideplanes are machined from full hard oxygen free copper bar stock. The Shiva Star power flow channel hangs below the transmission line deck, lower glideplane corresponds to the outer conductor of the power flow channel and upper glideplane to the inner conductor.

Special fixtures were designed for machining each of these parts as seen in Fig. 1 & Fig. 2. Holes are drilled, tapped, and ¼-28 Helicoil inserts are installed before

finish machining. The 10º glideplane ramps and the 98.00 mm outer diameter are the last surfaces to be finished to
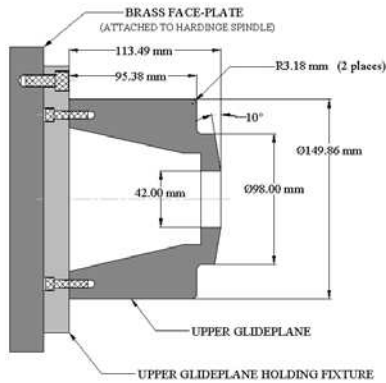

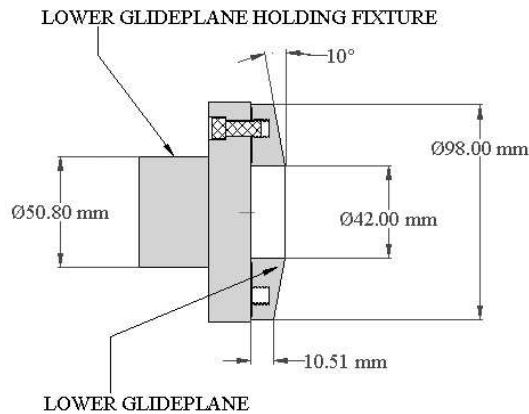**Figure 1**. Inner conductor glideplane.

Figure 2. Outer conductor glideplane

minimize distortion of critical dimensions. The specified 98.00 mm diameter is actually finished .03 mm oversize to create an interference fit at the joint with the liner, explained in more detail below.

B. First Liner Fabrication, Lower Glideplane Installation
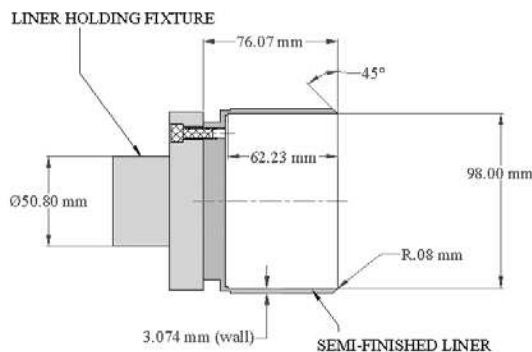

Figure 3. Liner machining holding fixture.

Liners are machined from 1100 Al forgings. The liner is rough cut to near final shape and then annealed to eliminate residual stress. The liner is mounted in a holding fixture shown in Fig. 3. The fixture prevents any forces from being applied to the outer diameter during finish cutting of the liner ID and the free end. The liner is remounted on an alignment fixture in preparation for installation of the lower glideplane and the glideplane is also bolted to a fixture as shown in Fig. 4.
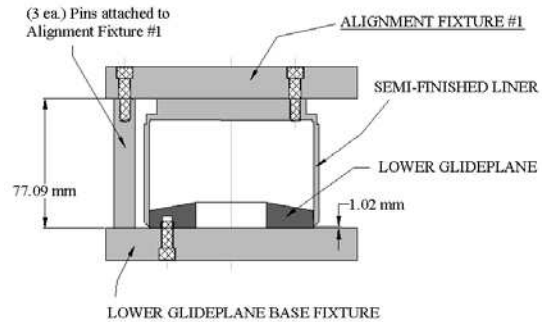

Figure 4. Lower glideplane installation.

The glideplane and baseplate are immersed in LN2 for approximately ten minutes to shrink the diameter of the glideplane. The liner is then slipped onto the glideplane. Three pins attached to the liner fixture establish the axial location of the liner on the glideplane. The parts are carefully cleaned with solvent wetted cloth wipes before the assembly to insure that no cutting fluids from the machining operations are trapped in the interference fit joint.

C. Liner Finishing

The lower glideplane with partially finished liner attached is remounted on the lower glideplane holding fixture of subsection *A*. The interference fit of subsection *B* is protected against cutting fluid penetration during subsequent machining operations by sealing the joint contact lines with a commercial polyether elastomer, Impregum, formulated for taking impressions. The solid end of the liner is then parted and the free end finished to specified figure as shown in Fig.5.
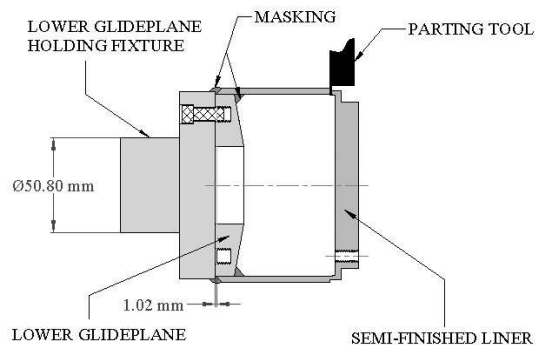

Figure 5. Liner parting.

A liner support fixture is used in conjunction with the lower glideplane holding fixture during final machining of the liner as shown in Fig. 6. The support fixture only contacts the ID of the liner at the free end, where the upper glide plane is to be installed, and is intended to prevent chattering as the liner wall thickness is reduced to the specified 1.00 mm value. After machining, the liner assembly is separated from the fixtures. Cutting fluids are removed from the assembly as described previously, the sealing material is stripped from the joints between liner and glide plane. The finished liner assembly is cleaned again to remove any remaining traces of either cutting fluids or Impregum, now taking care to prevent any fluids from being wicked into the current joint. The importance of excluding dielectric fluids from the liner current joints is to insure initial current connection by compressive pre-stress as explained in Section III.
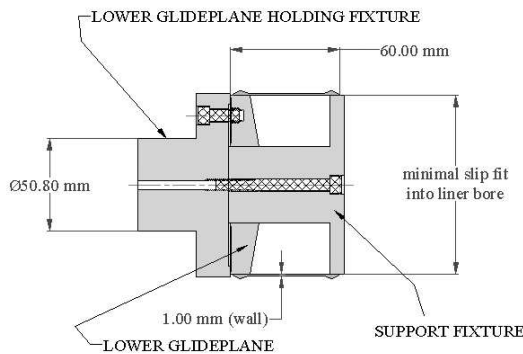

Figure 6. Support fixture for liner finishing.

D. *Final Liner Assembly, Lower Glideplane Installation*

Another set of alignment fixtures is used for installation of the lower glideplane as shown in Fig. 7. Three pins contact a reference land machined on the upper glideplane to establish the axial position of the liner at the current joint on the glideplane OD. Note that the plane of the bolted current joint face of the lower glideplane is the corresponding reference surface of the gauge pins. This assembly fixturing establishes the stack height of the
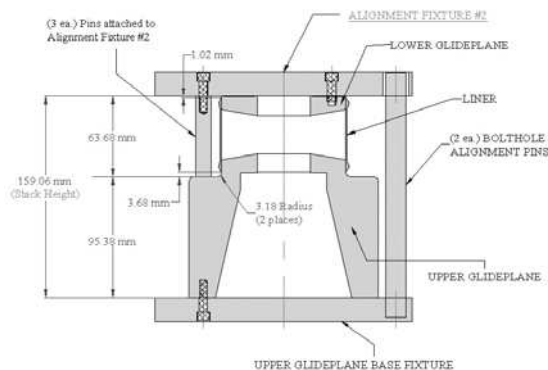

Figure 7. Final assembly.

complete liner and glideplane assembly.

The upper glideplane to liner joint is also based on an interference fit. The lower glideplane is immersed in LN2 following the procedure of subsection *B* for installing the lower glideplane. The final assembly fixturing includes long pins to index the current joint boltholes of the upper glideplane with those of the lower glideplane.

Upon completion of this assembly, neither end of the liner is against a hard constraint at the corresponding glide plane. The liner is designed to axially slip on the glideplanes, rather than be forced to deviate from cylindrical figure as the glideplane attachment bolts are tightened, should the transmission plate separation at Shiva Star deviate from the designed stack height of the liner/glideplane assembly.

III. LINER CURRENT JOINTS

For a peak current of 16 MA, connection of the liner to the glide-plane/electrodes occurs at a magnetic field of 64 T. The magnetic pressure associated with this field is over 240 kpsi, and the skin-current will heat the aluminum surface to well over its melting point. Mechanical pre-stressing of the contacts, used elsewhere in the liner cassette, is quite insufficient here. Very early in the current rise, liner connection to the copper surface is maintained only by the dynamic behavior of the aluminum. The pre-stress provided by the thermal-interference technique must hold the current connection until compression waves from the outer surface of the aluminum can be experienced at the contact region. By tapering the liner thickness toward the end of the liner, we reduce the transit time for sound waves from the outer surface of the liner. A finite thickness must remain, however, at the end of the liner in order to have any compressive pre-stress at the contact. In the present design, this required tapering the liner thickness down to a radius of curvature of less than a few mils.

IV. LINER CASSETTE

In addition to the liner and glideplane assembly described above, a complete NTLX experiment includes a 6061 aluminum return current conductor, polyethylene insulator in the power flow channel and an experiment insert which is the subject of a liner driven hydrodynamics experiment. All of these parts with the exception of the insert are assembled as a cassette prior to being installed in the Shiva Star facility. A holding fixture is installed in the cassette during transport and insertion at Shiva Star to prevent damage to the liner during these operations.

The power flow channel dielectric is machined from a block of polyethylene using a large manual lathe. The return current conductor is machined by a commercial vendor on a CNC lathe that is larger than available in our facility. The part is specified with standard commercial

high precision ± 0.005" tolerances. That tolerance is not sufficient to insure assembled specifications of the cassette. Return current conductors are individually gauged by MST-7 and adjustments are made to dimensions of mating parts fabricated by MST-7.

V. HYDRODYNAMIC EXPERIMENT INSERTS

All inserts fabricated for the NTLX experiments consisted of an acrylic cylinder contained within a metal cylinder. The example in Fig. 8 shows an acrylic cylinder offset within a 40 mm diameter Sn cylinder.

Figure 8. NTLX experiment insert.

An end cap was machined as an integral piece of each of the acrylic fabrications. O-rings in machined groves were used to position the insert in the cassette and were expected to decouple shocks propagating in the glide planes. Acrylic cylinder ends were diamond turned to address optical diagnostics requirements [3]. The large end cap was coated with 2500 Å Al over a 50 Å Ti flash by thermal evaporation to form an efficient 532 nm reflector.

VI. CONCLUSIONS

The NTLX design was optimized to insure success of the pulse power flow and liner dynamics. The liner design was not compromised for either economy or for the convenience of fabrication. All four of the experiments at Shiva Star were successful.

Successful machining and assembly of the relatively massive and tight tolerance NTLX liner parts depended upon a combination of adequate tools and good process execution strategies. Fabrication innovations included the interference fit, magnetically compressed liner current joints. Acrylic was machined to be an optical element of laser shadowgraphy and was coated with an efficient 532 nm back surface reflector.

The NTLX liner design will be used for the initial series of Atlas experiments.

VII. REFERENCES

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