MECHANICAL DESIGN AND FABRICATION OF A NEW RF POWER AMPLIFIER FOR LANSCE*

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Abstract

A Full-scale prototype of a new 201.25 MHz RF Final Power Amplifier (FPA) for Los Alamos Neutron Science Center (LANSCE) has been designed, fabricated, assembled and installed in the test facility. This prototype was successfully tested and met the physics and electronics design criteria. The team faced design and manufacturing challenges, having a goal to produce 2 MW peak power at 13% duty factor, at the elevation of over 2 km in Los Alamos. The mechanical design of the final power amplifier was built around a Thales TH628 Diacrode®, a state-of-art tetrode power tube. The main structure includes Input circuit, Output circuit, Grid decoupling circuit, Output coupler, Tuning pistons, and a cooling system. Many types of material were utilized to make this new RF amplifier. The fabrication processes of the key components were completed in the Prototype Fabrication Division shop at Los Alamos National Laboratory. The critical plating procedures were achieved by private industry. The FPA mass is nearly 600 kg and installed in a beam structural support stand. In this paper, we summarize the FPA design basis and fabrication, plating, and assembly process steps with necessary lifting and handling fixtures. In addition, to ensure the quality of the FPA support structure a finite element analysis with seismic design forces has also been carried out.

INTRODUCTION

A new high power FPA has been designed, fabricated, and tested, as a major effort of the LANSCE Risk Mitigation project. The new 201.25MHz cavity amplifier prototype is based on a Thales TH628 Diacrode®, a state-of-art tetrode with a goal to produce over 2 MW peak power at 13% duty factor. The recent (Mark II) design of the amplifier has been improved with a different output circuit and has provisions for cooling and DC bias connections for the tube electrodes. It is designed to reduce the complexity, operating costs and downtime and increase the beam availability at LANSCE. The electrical design, testing and integration of this amplifier are described separately [1] [2] [3].

DESIGN CONFIGURATION

The new FPA was constructed with the input circuit, grid decoupling circuit, output circuit and THALES TH628 Diacrode®. This power tube has wide ceramic seals with anode and screen grid (g2) contact rings on both upper and lower portions. Filament and control grid (g1) contacts are on the lower portion of the tube only. It mounts in a socket made at the upper end of a series of concentric cylinders. These cylinders are the upper ends of the heater cathode line and g1-g2 grid resonators. At the top of the TH628 there is a short λ/4 slave output cavity. All RF connections are made through spring finger contacts. From the mechanical point of view, all sub-systems are installed concentrically from the inside, in order: inner filament/heater, heater cathode, g1, g2, and finally the output resonator with the lower anode DC blocking capacitor fastened to its upper flange. The amplifier was assembled and installed on a removable beam-structural support stand. A cross section view of the FPA with the output power coupler is shown in Figure 1.

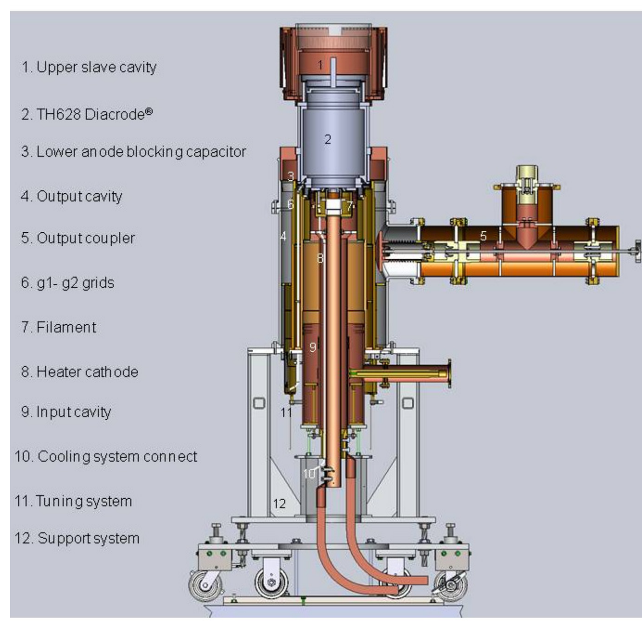

Figure 1: FPA main components assembly overview.

Additional components are designed to provide a safety enclosure around the TH628 tube. Enclosed are anode voltage feedthrough/RF bypass capacitor, air cooling manifolds and a unique air duct that encloses the anode water cooling hoses to provide isolation to reduce DC leakage. These components can be seen around the FPA in Figure 2.

* Work supported by the United States Department of Energy, National Nuclear Security Agency, under contract DE-AC52-06NA25396
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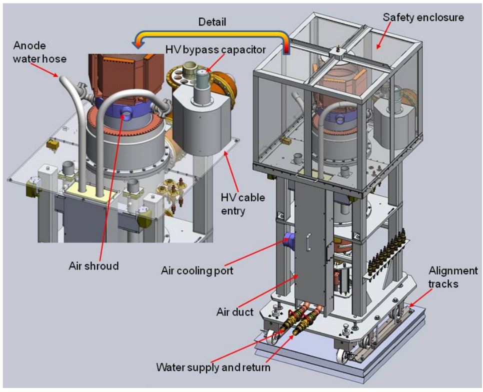

Figure 2: FPA final installation in the test station.

MANUFACTURING OVERVIEW

In meeting the RF design requirements of the new amplifier, mechanical design and fabrication faced challenges with material selections, machining processes and procedures, plating sequences and building of several critical assemblies. Material selection focused on the electrical and mechanical properties, and the ease of fabrication. The design approach required that the fabricators use different diameter tubes, rod or plates during precision machining steps. These shaped raw materials are easily held in machine tools (lathe and mill) accurately with minimal clamping force distortion. To ensure the plating quality from various sources, we used the services of the Metallurgy Characterization Team of the laboratories Materials Science and Technology division for the evaluation of nickel and silver plating on a 6061 aluminum cylinder and plate test coupons. Specifically, adhesion of the electroless Ni to the base Al surface, adhesion between the Ni and Ag plating, and Ni and Ag plating thickness were of primary interest. Ag surface hardness was also investigated. The FPA prototype team performed the critical assemblies of the filament bypass capacitor and g1 and g2 DC blocking capacitors according to detailed procedures based on calculations. Special devices were used including a kiln for heating parts, alignment fixtures for pressing, turntables for uniform heat shrinking of dielectric sleeves, and vacuum chambers for removal of air in HV capacitor assemblies during potting/sealing operations. The largest DC blocking capacitor, for the anode, was machined and fabricated by a reputable RF amplifier manufacturer qualified for such large assemblies.

Grid Circuits with Blocking Capacitors

The g1 and g2 lines were each made from two cylinders, which used forged C10100 OFE copper. This was selected due to availability from the supplier, although Electrolytic-Tough-Pitch (ETP) copper was adequate. The cylinders (flanged base cylinder and inner contact ring) were machined to precise dimensions with groove features designed to retain the contact fingers. Then they were electroplated with 15-25 µm of silver before being pressed together. A 0.5 mm thick sleeve of Fluorinated Ethylene Propylene (FEP) thermoplastic surrounded the inner cylinder and was heated to shrink tightly with minimal entrapped air. The long outer line (base cylinder) was then heated to 177^{0}C to create the required clearance, allowing the subassembly of inner cylinder with FEP to be installed into the outer cylinder. At room temperature there was an interference fit, which was determined using class 2 fitting force to compress the FEP dielectric and make a high quality blocking capacitor for 5 kV DC. The same process was used for g1 and g2, with different sized parts and fixtures.

The heater cathode contact cup had a similarly constructed RF bypass capacitor assembly which was much less critical, operating at 20 V DC. The lower and upper anode blocking capacitor assemblies used similar techniques. For these the voltage standoff is high (30 kV DC). Requiring the edges were specifically radiused and then capsulated with silicone elastomer to reduce electric field enhancement.

Aluminum Output Cavity and Plating Test

The outer conductor of the lower output resonator for the prototype was constructed from a solid billet of aluminum 6061-T6. Material was cut away to produce the desired interior geometry with air-cooling ports and 22.8 cm diameter output feeder without weld or braze joints. The entire piece was coated with electroless nickel, and then electroplated with no less than 25 µm of silver on the interior surfaces to stabilize RF conductivity. An alternative approach of using a copper cylinder was eliminated due to cost and weight.

The production design of the output circuit may utilize a weldment assembly requiring multiple technological processes. This design approach required a plating test coupon of welded aluminum plate to be analyzed. The results on coated material thickness, Ag surface hardness and adhesive stability between the various materials demonstrated high plating quality from one source. Figure 3 presents some plating test results included successful and failed samples.

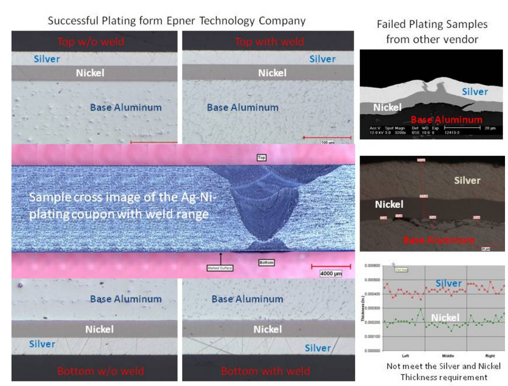

Figure 3: Plating test results of Aluminum coated with Silver and Nickel.

COOLING DESIGN

The requirement for the water cooling temperature rise is 5 to 10^{0}C typical for the multi-phase (Hypervaportron®)

– cooled anode of the TH628. The water flows for the anode and the smaller cooling loops (g2, filament, upper slave circuit) are continuously monitored. The cooling water is carefully filtered to less than 3 PPM-by-weight solids. An eighty mesh filter is utilized to remove any solid particles which might obstruct the flow of water, leading to a drop in cooling efficiency and possibly tube failure. The cooling water is demineralized. A protective device connected to the tube's control system provides a shutdown of the high voltage if the resistivity of the water falls below 2 MΩ-cm. This results in 500 µA of DC leakage current in the water hoses. Sacrificial metal targets are mounted in the hose ends to minimize electrolysis leading to corrosion of the pipe fittings. Resistivity at 20°C is maintained at 2 MΩ-cm or higher by means of a regeneration loop.

In addition to water cooling of the anode, cathode, screen grid connections and the upper slave circuit tuner, the ceramic insulators and electrode terminals must be air cooled. Pressure sensing devices are used to ensure tube protection in case of loss of cooling air. The air is filtered and forced through channeled passages to ensure effective cooling of seals and electrode terminals in such a way that the temperature at any point on the tube envelope (electrode terminals, ceramic insulators and ceramic-metal seals) remains below 150°C. A special air shroud for the upper ceramic/metal seal was fabricated from a 3D printing process.

FINITE ELEMENT ANALYSIS

Finite element analysis was performed for critical mechanical component and lifting fixtures. The structural analysis for the FPA support stand was required to meet engineering standards. As shown in Figure 1, a 600 kg assembly is mounted on the aluminum beam structure. A linear structural FE analysis was carried out using SolidWorks® simulation code to determine the maximum stress, maximum displacement, factors of safety of the entire structure, and the factor of safety of the most critical part. This analysis took into account the seismic design force calculated in compliance with the LANL Engineering Standard Manual for structural design and analysis requirements [4] [5].

The load combination case with longitudinal seismic design forces and the entire weight of the FPA, along with the appropriate boundary conditions, is shown in Figure 4.

The worst case loading was determined to occur when seismic ground motion induced forces were added. The maximum von Mises stress of the structure is about 44.8 MPa and the minimum factor of safety is over 4.0 compared to the yield strength of the aluminum material [6]. The tension and shear stresses of the bolted and welded connections were also evaluated and found to provide a safe and stable installation for the FPA.

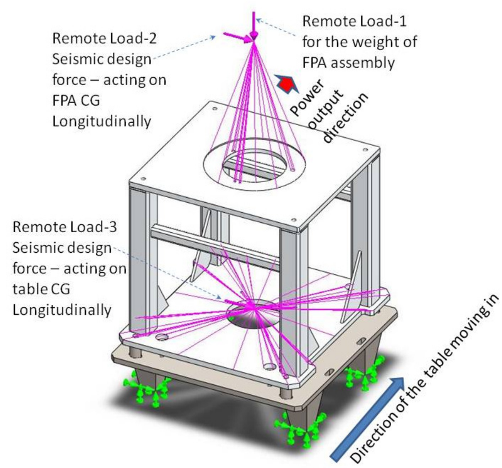

Figure 4: Loading and boundary condition of FPA support stand.

Analysis was performed for the RF contact flange of the upper edge of the output circuit using ABAQUS/Standard™ software code. This helped in assembly of the high current RF joint between the lower anode blocking capacitor flange and the output circuit top flange. The result guided the mechanical design to obtain a uniform contact force along the inner edges of two flanges without any measurable gap.

CONCLUSION

The mechanical design, manufacturing, and assembly steps have been successfully demonstrated on the prototype of the new developed VHF power amplifiers for the DTL at LANSCE. The installation steps as well as the specialized material, tooling and handling fixtures have been improved. These same processes will be incorporated into the contract and work procedures for the production of the six identical FPA's for the LANSCE Risk Mitigation program and operations beginning in 2013.

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