HIGH-INTENSITY PROTON RFQ ACCELERATOR FABRICATION STATUS FOR PXIE*

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ABSTRACT

PXIE is a prototype front end system [1] for the proposed PIP-II accelerator upgrade at Fermilab. An integral component of the front end is a 162.5 MHz, normal conducting, continuous wave (CW), radio-frequency quadrupole (RFQ) cavity that was designed and is being fabricated by LBNL. This RFQ will accelerate a continuous stream of up to 10mA of H- ions from 30 keV to 2.1 MeV. The four-vane, 4.45 meter long RFQ consists of four modules, each constructed from 2 pairs of identical modulated vanes. Vane modulations are machined using a custom carbide cutter designed at LBNL. Other machined features include ports for slug tuners, pi-mode rods, sensing loops, vacuum pumps and RF couplers. Vanes at the entrance and exit possess cutbacks for RF matching to the end plates. The vanes and pi-mode rods are bonded via hydrogen brazing with Cusil wire alloy. The brazing process mechanically bonds the RFQ vanes together and vacuum seals the module along its length. Vane fabrication is successfully completed, and the braze process has proved successful. Delivery of the full RFQ beam-line is expected in the middle of 2015.

VANE FABRICATION

For details on the PXIE RFQ design, please refer to [2]. Fabrication began with end machining of all vanes, followed by rough machining on all sides. Each vane was then sent out for gun-drilling ~ 1.0 meter long cooling channels. After gun drilling was complete, copper plugs were electron-beam welded to seal the cooling channels at the drilled end. The vanes then returned to LBNL where flow and leak tests were performed to verify the integrity of the e-beam weld, as well as check for any flow blockages in the cooling channels. After this, machining of tuner, pi-mode rod, sensing loop, and vacuum ports began. In addition to port features, several tapped hole patterns were machined in the backside for vane handling and mounting, which proved critical for handling and restraining the vanes later in the fabrication process. Once finished, each vane underwent CMM inspection of the backside to verify tolerances for flatness and port locations, as seen in Figure 1.

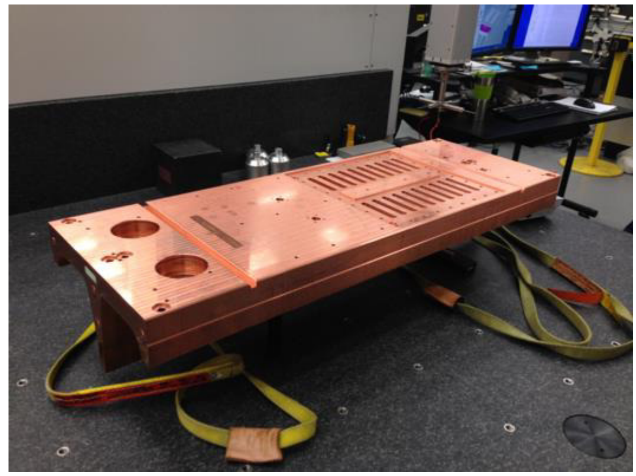

Figure 1: Backside port CMM check.

The vanes were then mounted to 3 in. thick stainless steel plates that restrained the copper during inner cavity rough machining, as well as subsequent final cavity machining. CMM inspection was then performed after rough machining of the cavity, followed by machining of the cavity walls to their final dimension. Vanes for modules 1 and 4 then had their cutbacks machined, as well the radial matcher for module 1 vanes. The cutback machining is initially checked with aluminum blanks to verify the machine program, as seen in Figure 2.

Figure 2: Aluminum test pieces to verify cutback machining program, if acceptable the program is saved on machine to be duplicated on the production part.

The vanes are again submitted to CMM inspection; after which the modulation machining begins. Each modulation program is initially verified using test pieces

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of copper that undergo CMM inspection. The modulation cut programming is saved in the machine and replicated on the real production parts, which is shown in Figure 3.

Figure 3: Vane modulations being cut at LBNL

Modulations are cut with a specially made carbide cutting tool, as described in [2]. After modulations are complete, the vanes were submitted to a final full-CMM inspection. The vanes are then stored and UHV cleaned immediately prior to braze assembly.

BEAD PULL

Module 2 was the selected as the first module to be brazed. In addition to the CMM inspection of the vanes, this module was dry fit assembled and bead pull was performed to very module frequency and field flatness. Adjustable slug tuners and end plates were designed for cavity tuning during bead pull, as well as temporary cutbacks modeled after the module 4 exit cutbacks. Pi-mode rods are also installed in the module to separate quadrupole and dipole modes. The LBNL preparation of module 2 for bead pull is shown in Figure 4.

Figure 4: LBNL module 2 prep for bead pull.

The bead pull system was designed and operated by FNAL colleagues. With all adjustable slug tuners at their nominal intrusion and end tuners fully out, the measured RFQ frequency was 163.02 MHz, which deviates less than 0.1% from simulated frequency. Field flatness was within specification as well. Based on these results, and previous CMM inspection data of other vanes, it was decided that LBNL would move forward with brazing of all modules.

MODULE BRAZING

CuSil [3] braze alloy was selected due to its high reliability in copper to copper brazes and its eutectic nature. Vanes were UHV cleaned immediately prior to the start of module braze assembly, and braze alloy installation and module assembly were performed in a portable cleanroom tent to reduce possible contamination at the braze surfaces. Braze wire was installed in machined grooves at the braze surfaces and "staked" into place to ensure that alloy could not fall out during assembly. Special lifting fixtures were designed and load tested for vane manipulation during the assembly process and a custom assembly fixture utilizing a six-strut system was developed for precision alignment of the vanes. Figure 5 shows module 4 in the assembly fixture. The six strut system kinematically supported the vanes and provided sufficient clearance at the braze surfaces. Vanes were slowly brought together until all braze surfaces were tightly mated.

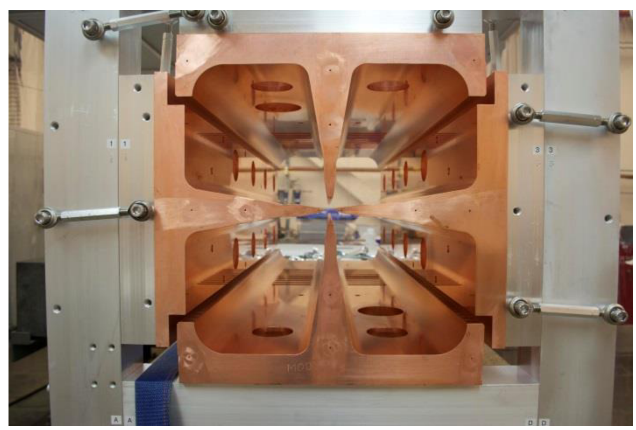

Figure 5: RFQ module in assembly fixture.

After all vanes are aligned and mated, pi-mode rods with brazing fixtures were installed. The module was then clamped together using stainless steel braze clamps and belleville washers were used to provide constant loading at the braze joint during brazing, as well as providing travel for the differential expansion between stainless steel and the copper. Pi-mode rods were also brazed into the structure at this step. Thermocouples were installed along the length of the module for temperature monitoring during the braze cycle. The assembled pre-braze RFQ module in shown in Figure 6.

Figure 6: RFQ module with braze fixtures.

The brazed RFQ structure is shown in Figure 7.

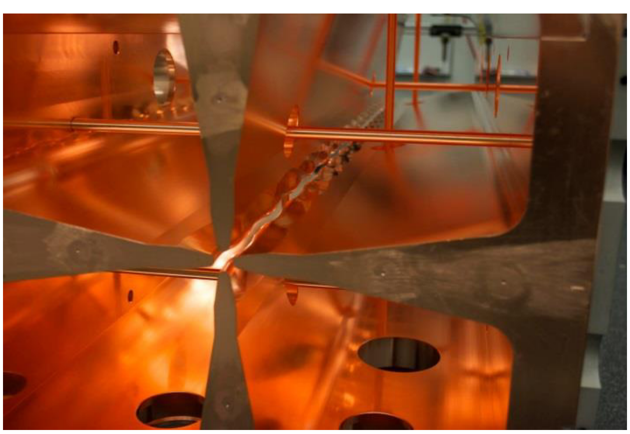

Figure 7: Brazed RFQ inner cavity

All RFQ modules have been brazed, as well as confirmed vacuum tight. The modules now move to their final machining step.

MODULE END MACHINING

The final step of the RFQ fabrication process is end machining of the module, in which they are trimmed to their final length. In addition, RF spring and O-ring grooves are added, as well as dowel holes for module alignment. The primary RF seal between modules is created at this point via a 250 micron raised lip that borders the inner cavity. When modules are bolted together, this raised lip is crushed, creating excellent RF contact between modules. After end machining in complete, the RFQ modules are ready for installation on the support stand and subsequent beamline assembly.

SUPPORT STAND

The support stand for the PXIE RFQ is nearing completion. Temporary six-strut supports are used for supporting each module during the initial assembly, as well as for module-to-module adjustment and alignment. After all modules are assembled, the temporary supports are removed and the entire RFQ beamline is supported and aligned with a single six-strut system.

CONCLUSION

The PXIE RFQ is in its final fabrication stages. All vane fabrication was successfully completed, and all modules are brazed and verified as vacuum tight. The support stand is near completion and module end machining has commenced. The fully assembled RFQ beamline is scheduled for delivery in June of 2015.

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[2] M. Hoff, et al, "Progress on the Fabrication of a CW Radio-Frequency Quadrupole (RFQ) for the Project X Injector Experiment (PXIE).

[3] CuSil is a brand name of Morgan Technical Ceramics-WESGO Metals, Hayward, California.

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