PROGRESS ON THE FABRICATION OF A CW RADIO-FREQUENCY QUADRUPOLE (RFQ) FOR THE PROJECT X INJECTOR EXPERIMENT (PXIE)*

M. D. Hoff, A. J. DeMello, A. R. Lambert, D. Li, J. W. Staples, and S. P. Virostek
Lawrence Berkeley National Laboratory, Berkeley CA 94720, USA

Abstract

The Project X Injector Experiment (PXIE), a prototype front end of the Project X accelerator [1] proposed by Fermilab, is currently under construction. The complete PXIE beamline [2] is made up of an H^- ion source, a low-energy beam transport (LEBT), a 2.1 MeV, 162.5 MHz radio-frequency quadrupole (RFQ) accelerator, a medium-energy beam transport (MEBT) and a 30 MeV section of superconducting cryomodules. The 4.45 m long CW RFQ consists of four separate modules that are joined by means of specially designed bolted joints. Each module consists of four solid copper vanes that are brazed together to form a 4-quadrant accelerating cavity. The ~100 kW of total wall power heat is removed by means of gun drilled water cooling passages. Mode stabilization is provided by a series of brazed, water cooled pi-mode rods. Tuning is achieved using a total of 80 fixed slug tuners. Fabrication of the PXIE RFQ is now under way at LBNL. Details of the RFQ mechanical design and an update of the fabrication progress are presented in this paper.

MODULES

The 4.45 m long RFQ is assembled from four approximately equal length modules. The modules are sized based on the available copper C101 billet size, available milling machine capacity, general handling considerations and the desire to minimize joints. Each module is fabricated from four tee shaped pieces of copper that weigh approximately 940 kg each before machining (see Fig. 1).

MACHINING

The outer wall features are machined first. The outer wall is machined flat, followed by the pi-mode rod holes, slug tuner ports, sensing loop ports and the vacuum pump port are cut. Then the vane is flipped over and mounted to a 3 inch stainless steel plate for cavity machining. The stainless plate allows easy handling and mounting of the part in the milling machines. The precise cavity contours, pi-mode rod clearance holes and then the four mating braze surfaces are cut with a standard shaped end mill (see Fig. 2 and Fig. 3). The last step is the machining of the vane tip modulations, as described later in this paper.

Figure 1: Raw tee shaped copper for vane fabrication.

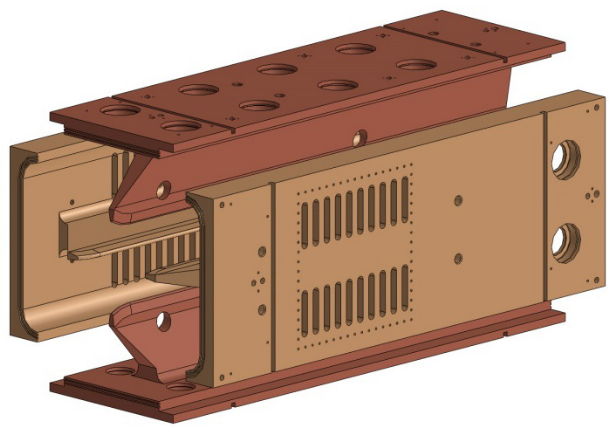

Figure 2: Exploded CAD model of four machined vane.

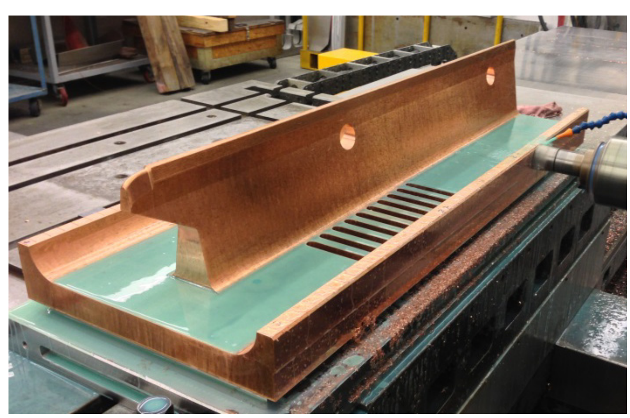

Figure 3: Module 1, horizontal vane being machined.

* This work is supported by the Office of Science, United States Department of Energy under DOE contract DE-AC02-05CH11231.

ISBN 978-3-95450-138-0

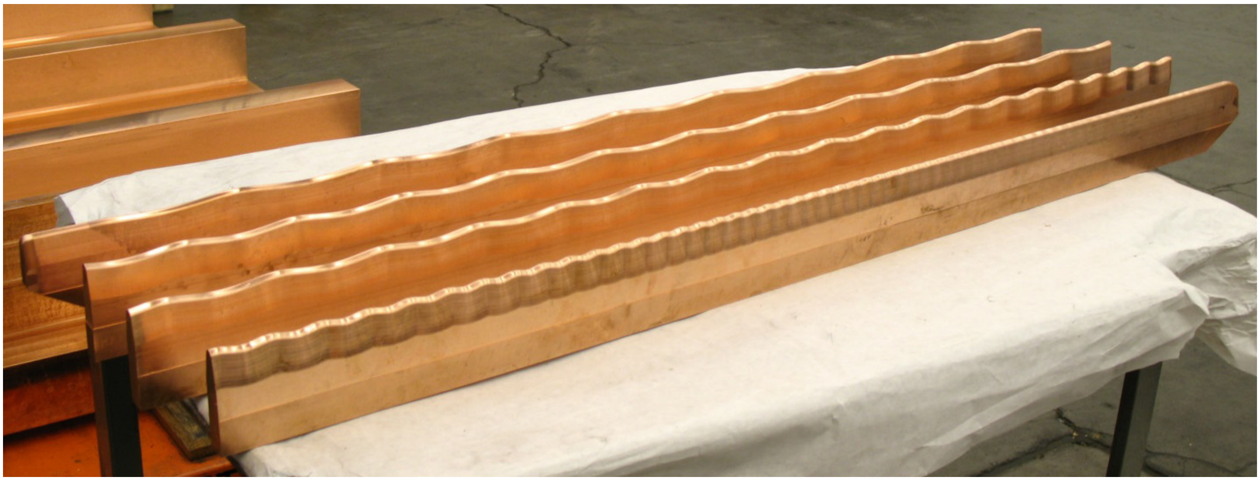

Figure 4: Modulation cut test piece.

PI-MODE RODS

RF mode stabilization between cavity quadrants is accomplished with 8 hollow copper rods per module, 32 total [3]. The rods are approximately 10 mm O.D. by 5 mm I.D. by 425 mm long (see Fig. 5). The rods are hollow to allow coolant to flow inside the rods during operation. The rods are brazed to the cavity walls at the same time the four vanes are brazed together. The rod passes through a clearance hole in the vane that divides the quadrants (see Fig. 6).

Figure 5: Pi-mode rod with two ferrules.

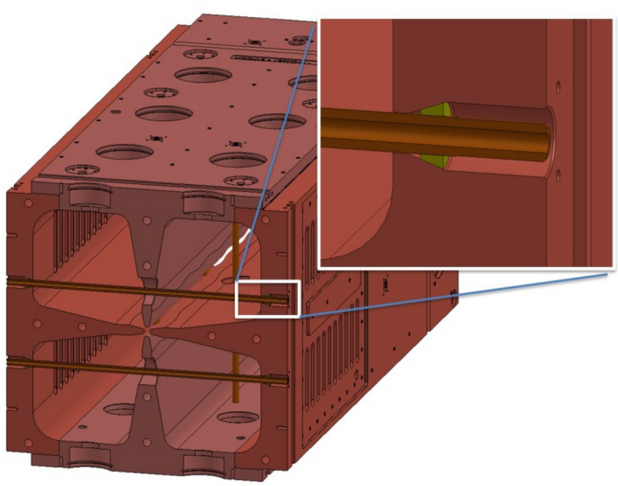

Figure 6: Pi-mode rod with ferrule detail.

VANE TIP MODULATIONS

Vane tip modulations are machined using a specially made carbide cutting tool. Using a profile cutting mill is much faster than a ball end mill (see Fig. 4 and Fig. 7).

Figure 7: Modulation profile cutting tool.

COOLING PASSAGES

Cooling of the RFQ body is accomplished by blind gun drilling ∅12 mm holes most of the long length of the vane. The long gun drilled hole is connected to the outside vane wall by cross-drilled holes at each end. The entry point for the gun drilled hole is then sealed with a tight fitting copper plug that is electron beam welded vacuum tight (see Fig. 8).

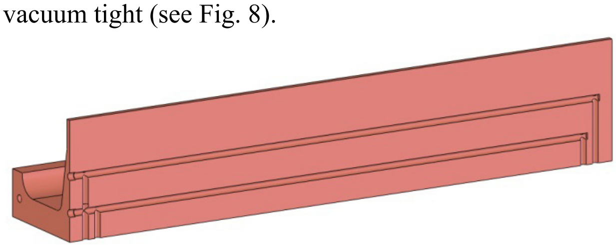

Figure 8: CAD model of gun drilled cooling passages.

BRAZING

When the majority of the machining is complete, the four vanes of a module are gently brought together using a kinematic, 6 strut fixture to check braze surface fits and measure RF cavity resonance. After the test fit, the vanes are separated, cleaned and CuSiL [4] braze alloy in the form of ∅1 mm wire is loaded into pre-machined grooves. The vanes are then brought back together and clamped into position. Pi-mode rods are then installed and clamped into position too. Brazing is done in a hydrogen furnace in the vertical position. The engineered clamps, using Inconel [5] Belleville washers, allow the copper to expand, yet maintain a firm clamping force during the heat up and cool down cycle (see Fig. 9).

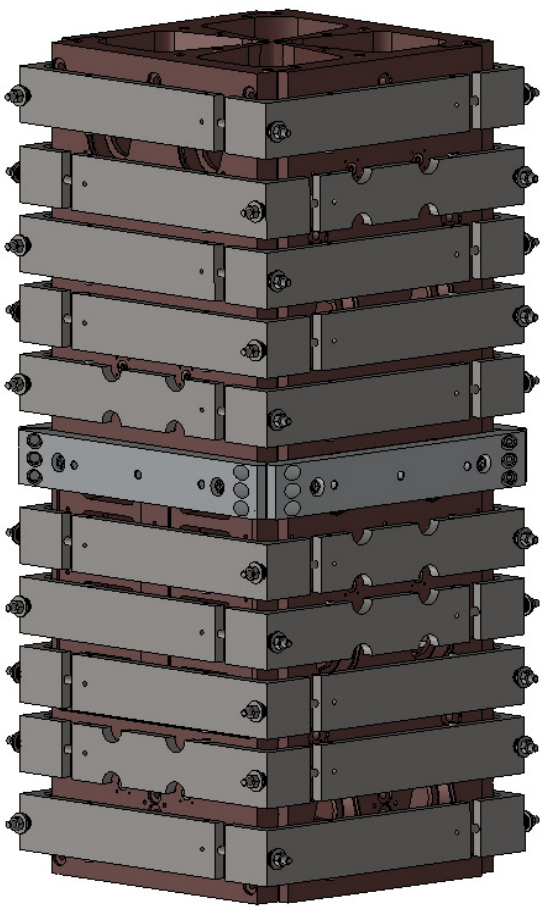

Figure 9: CAD model of vertical module braze with clamps.

POST BRAZE

After brazing the four vanes and 8 pi-mode rods together, the module is machined to its final length with O-ring and RF sealing geometry added to the ends.

Coarse tuning of the RFQ cavity is accomplished with 80 approximately equally spaced slug tuners. First temporary, length adjustable tuners are installed and RF resonance measurement are taken. The temporary tuners are adjusted in length until the desired RF resonance is achieved. The temporary tuners are removed, measured and replaced by non-adjustable, slug tuners. The slug tuners are sealed with an RF joint and O-ring. The slug tuners are held in place with a commercial snap ring.

JOINT PLATES

Modules are joined together using stainless steel plates that form a collar around the soft copper. The collar is tied to the module with a keyed groove and bolts. The collar contains pockets for bolts and nuts to clamp the modules together, squeezing the RF seal and O-rings in place (see Fig. 10).

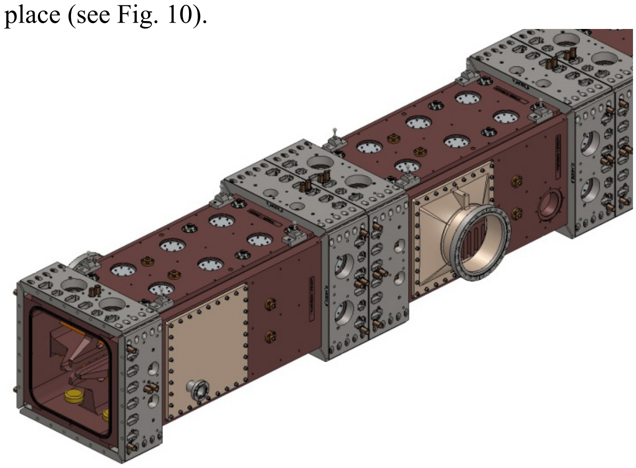

Figure 10: Joint Plates connecting modules.

SUMMARY

LBNL is currently constructing an RFQ for the Project X front end. The RFQ is being fabricated with solid copper vanes that are hydrogen furnace brazed together into four modules 4.45 m long total. Cooling will be accomplished with gun drill passages along the length of individual vanes. 32 Pi-mode rods linking adjacent cavities will provide RF stabilization. Brazed modules are mechanically connected using a special joint plate with bolts. Final tuning is accomplished with 80 static slug tuners. Fabrication is underway at LBNL with expected delivery of the RFQ to FNAL in 2014.

REFERENCES

[1] S. Nagaitsev, et al, “Project X – A New Multimegawatt Proton Source at Fermilab,” PAC’11, New York, NY, USA, pp. 2566-2569.

[2] S. Nagaitsev, et al, “PXIE: Project X Injector Experiment,” IPAC’12, New Orleans, May 2012, THPPP058, p. 3874 (2012).

[3] S. Virostek, et al., “Design and Analysis of the PXIE CW Radio-Frequency Quadrupole (RFQ),” IPAC’12, New Orleans, May 2012, THPPC034, p. 3359 (2012).

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

[5] Inconel is a brand name of Special Metals Corporation, New Hartford, New York.

ISBN 978-3-95450-138-0