FABRICATION AND TESTING OF TRASCO RFQ

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Abstract

The Legnaro National Laboratory (LNL) is building the 30 mA, 5 MeV front end injector for the production of intense neutron fluxes for interdisciplinary application. This injector comprises a proton source, a low energy beam transport line (LEBT), a radio frequency quadrupole (RFQ) and a beam transport line designed to provide a 150 kW beam to the beryllium target used as neutron converter. The RFQ, developed within TRASCO project for ADS application, is designed to operate cw at 352.2 MHz. The structure is made of OFE copper and is fully brazed. The RFQ is built in 6 modules, each approximately 1.2 meter long. This paper covers the mechanical fabrication, the brazing results and acceptance tests for the various modules.

INTRODUCTION

The high intensity RFQ under construction at LNL, developed within TRASCO project[1] for ADS study, will be devoted to the application of Boron Neutron Capture Therapy (BNCT) for the treatment of skin melanoma[2]. The main RFQ nominal parameters are listed in Table 1.

Table 1: Main RFQ parameters

Parameter	Value	Unit
Energy In/Out	0.08/5	MeV
Frequency	352.2	MHz
Proton Current (CW)	30	mA
Emit. t. rms.n. in/out	0.20/0.21	mm-mrad
Emit. l. rms.	0.19	MeV-deg
RFQ length	7.13	m (8.4 λ)
Intervane Voltage	68	KV (1.8 Kilp.)
Transmission (Waterbag)	98.5	%
Q (70% of SF result)	7000	
Beam Loading	0.148	MW
RF Power dissipation	0.847	MW

The RFQ consists of three electromagnetic segments 2.4 meters long resonantly coupled via two coupling cells in order to reduce sensitivity to machining errors. Each module consists of two 1.2 meters long modules, which are the basic construction units.

In order to accelerate the 30 mA CW proton beam up to 5 MeV, the maximum amount of power expected to be delivered to the RFQ is about 995 kW (148 kW beam power + 847 kW dissipated power). The possibility of a ten percent voltage increase respect to the nominal is considered in the dissipated power value. The power is generated by one klystron and supplied to the RFQ by a WR2300 waveguide system. Due to the fact that each RF coupler is rated for a maximum of 140 kW[3], the RF power is split in eight ways via magic-Tee dividers. An artistic view of the integration of the RF distribution, vacuum system and support is presented in Fig.1.

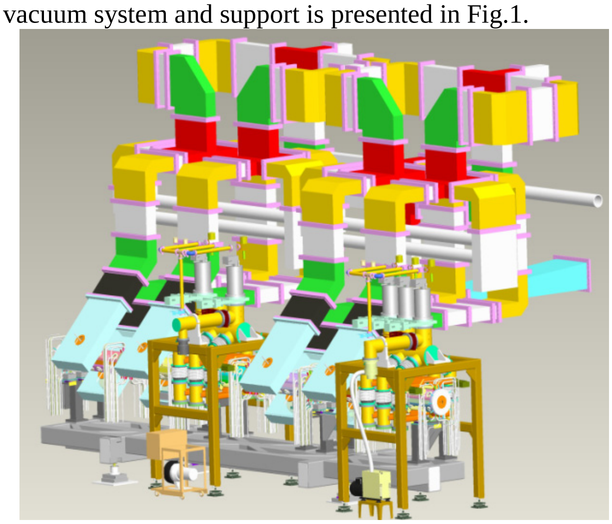

Figure 1: Integration of RFQ with ancillaries.

MECHANICAL FABRICATION AND BRAZING

Each module, built in OFE copper, is made of four main parts. The head flanges between modules and the rectangular vacuum flanges are made of SS (LN316). To reduce the number of brazing joints, the longitudinal cooling passages are deep-hole drilled from one side and closed with brazed plugs on the flat surfaces of the RFQ module (opposite to the coupling or end cells). Moreover, the vacuum grids with their cooling channels are directly machined on the copper bulk.

Two brazing steps occur. In the first the four main parts are brazed in horizontal position in a horizontal vacuum furnace, as well as the OFE plugs for the cooling channels. The brazing alloy is Ag68CuPd-807/810 (57.3% at., 38,4% at., 4.3% at.) and the brazing temperature is 815°C. After first brazing, housings for the head flanges and the flat end surfaces (where the cooling channel plugs are located) are machined. In the second brazing cycle the head SS flanges, the inlet and outlet cooling water SS tubes, the SS supports for vacuum ports flanges and the SS flanges for couplers are brazed in vertical position in a vertical vacuum furnace. The brazing alloy is Ag72Cu-779 (40% at.) and the brazing temperature is 785ºC.

Maximum temperature of the OFE copper stabilization cycle before finishing turned out to be extremely important to avoid deformation after brazing. For the first two modules this temperature was 250ºC. After brazing both the modules showed a two hundreds microns longitudinal bending (banana shape). Moreover the module 2 presented an important displacement in one transversal direction that entailed the opening of eight more tuner holes for frequency recovery. Relaxation of stress induced during machining was identified as the main effect in comparison with the deformations due to the brazing heat treatment.

Consequently machining procedure changed. For the remaining modules a full annealing at 600 °C preceded finishing. In addition finishing was as soft as possible in order to minimize induced stress. The success of the new procedure was evident after the brazing of the third module (Fig.2). Banana shape and transversal movements generated by brazing heat treatment turned out to maintain nominal tolerances (±20 μm). Almost the same results were obtained after brazing of RFQ4 and RFQ5.

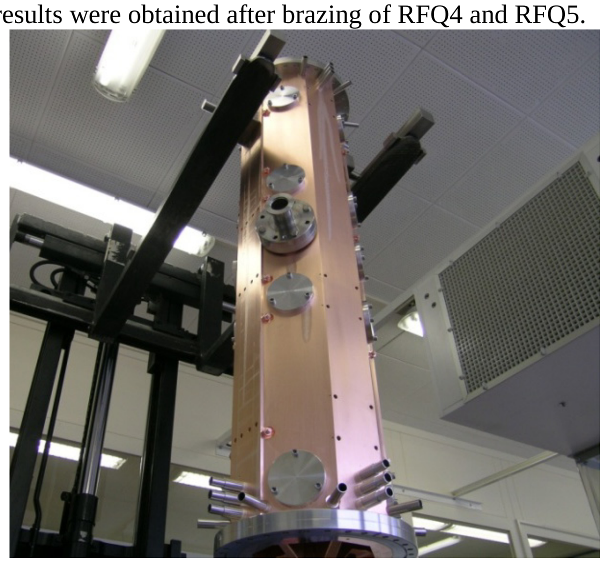

Figure 2: Module 3 after vertical brazing.

Some minor problems characterized the brazing of module 3 and 4. Module 3 experienced a vacuum leak after vertical brazing. Leak was caused by a bad nickelization process of the head SS flanges. A repairing brazing was attempted before summer without success. This will force to remove the head flanges and to repeat the vertical brazing with new nickelized flanges. Regarding RFQ4, the water channel plugs experienced some problem of brazing alloy flow. Plugs with not visible brazing alloy were removed and re-brazed in the vertical brazing last week. RFQ6 is currently under first brazing.

The plan for the next future foresees the brazing completion before the end of the year.

ACCEPTANCE TESTS

RF and mechanical measurements allow checking the correctness of each fabrication step.

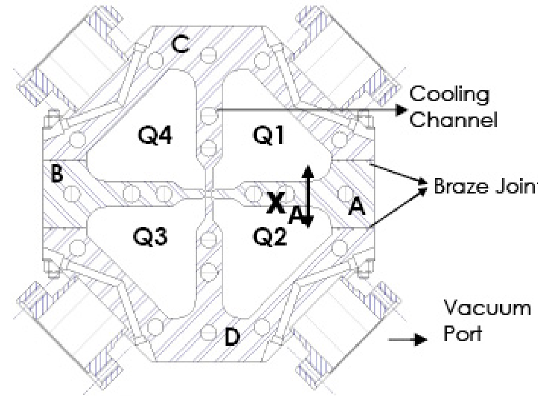

Figure 3: Nomenclature for electrodes and quadrants.

With reference to Fig.3, let Δx be the extra thicknesses of the electrodes A and B, with respect to their nominal values Δy the amount of extraction of the electrodes A and B with respect to their nominal position. The initial values of such parameters are Δx=50μm and Δy=0μm. The first measurement step foresees the determination of the quadrupole and dipole frequency {fQ, fD1, fD2} in such configuration and with tuners set at the nominal penetration. Then Δy is varied by means of the application of calibrated spacers and a new set of {fQ, fD1, fD2} is found. The knowledge of these two sets permits us to determine the values of Δx^* and Δy^* that fulfil the conditions fQ= 352.2 MHz and fD1=fD2 within the precision limits of the spacers and of the milling machine (±10μm). Then the thickness Δx^* is removed from the electrodes A and B and the definitive spacers are applied. With this configuration the tuning operations (based on bead-pulling measurements) are performed up to the achievement of an overall ±5% longitudinal uniformity of the electric fields in all quadrants.

The modules RFQ2 to RFQ6 successfully underwent such characterization before 1st brazing step with the values for Δx^* and Δy^* presented in Table.2. Concerning RFQ1 the Δy tuning was not yet introduced; as a result the quadrupole mode was tuned, but the two dipoles were splitted by about 2 MHz.

For RFQ1 and RFQ2 the entire set of RF measurements (including bead pulling) was repeated at CERN immediately before brazing. The reproducibility found allowed to skip this step for the following modules.

After brazing, a set of mechanical measurements is foreseen in order to check the effect of brazing upon some important parameters, namely the reference plane distance (directly related to R_0) and the width of the coupling gap. Then the tuning procedure is repeated up to the achievement of the above-mentioned specifications.

Table 2: Pre-braze setting for the RFQ modules.

Module	Δx^*[μm]	Δy^*[μm]
RFQ2	70	20
RFQ3	50	50
RFQ4	70	50
RFQ5	65	40
RFQ6	60	15

To date modules up to RFQ3 underwent such characterization, with somewhat different outcomes. As for RFQ2 a quadrupole frequency increase of 700 kHz and a ± 20% dipole content on the operational mode were observed after brazing. Such a unexpected voltage variation, related to the abnormal bending discussed in the previous paragraph, could not be completely recovered with standard tuners. Therefore eight additional holes for tuners (four in Quadrant 1 and four in Quadrant 4) were machined and the required voltage flatness was recovered. As for the other modules, the RF measurement and tuning procedure was carried out without any particular problem.

RF MEASUREMENTS ON THE 1ST RFQ SEGMENT (RFQ1+RFQ2)

The first RFQ segment was mounted at LNL for low power RF and vacuum tests (Fig.4). Prior to the vertical assembling of the two modules, the beam axis of each RFQ was characterized, and the necessary reference planes and pins were machined.

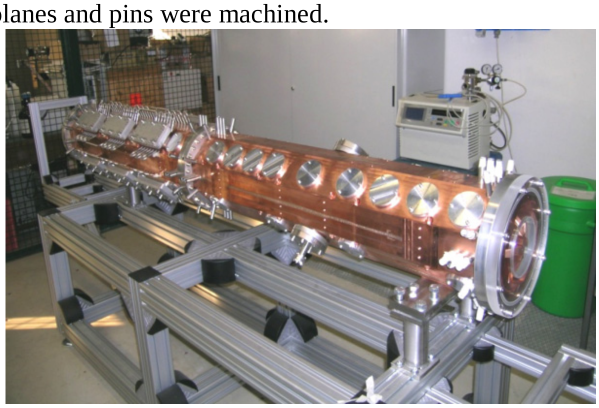

Figure 4: The 1st RFQ segment mounted at LNL.

In order to allow a complete RF characterization, the segment was equipped on low and high energy sides with two aluminum Tunable End Cells (Fig.5) equipped with variable dipole stabilizing rods (DSR). The RF measurements were performed in steps: first the optimum length and transverse position of DSRs that guaranteed the maximum dipole-free region (about ±7 MHz) around the operating mode were determined: the optimum DSR length are equal to Then, the boundary conditions for the TE_{210} mode were tuned by inserting the octagon in the RFQ volume.

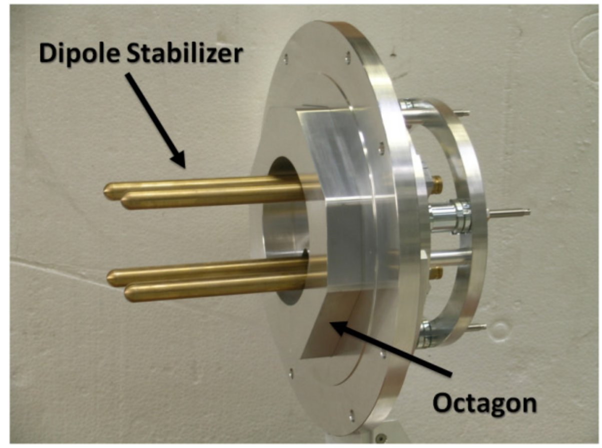

Figure 5: The Tunable End Cell.

Finally the bead pull measurements and the tuning operations (based on an on-purpose developed algorithms making use on the RFQ modal expansion) were performed. The effectiveness of the tuning algorithms is shown in the following two figures, where the voltage perturbations due to upper quadrupole modes and the two kinds of dipole modes $U(z)/U_0$ and $U_{qd1,qd2}(z)/U_0$ are shown before and after tuning (Fig. 6 and 7).

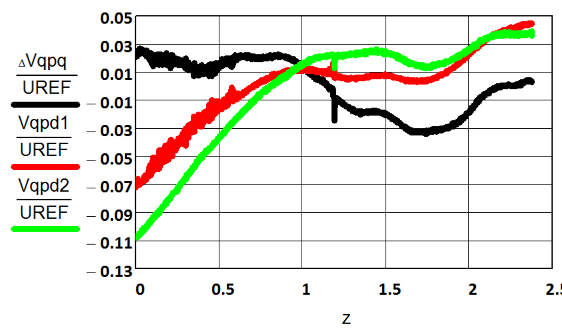

Figure 6: Perturbative quadrupole (black) and dipole (red and green) components before tuning.

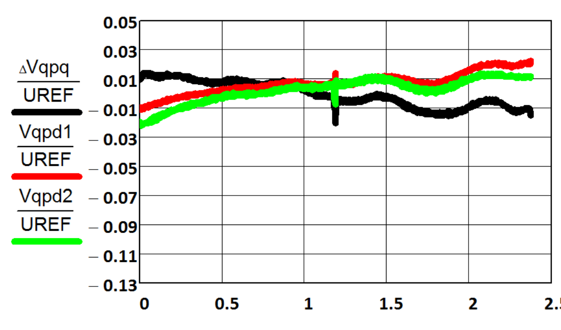

Figure 7: Perturbative quadrupole (black) and dipole (red and green) components after tuning.

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[2] A.Pisent, et al LINAC04, Lübeck, Germany. p. 69
[3] A.Palmieri, et al., Proc. of the XXI Linac Conference, Gyeonju (Rep. of Korea), 18-22 August 2002.