COMPLETION OF THE FABRICATION OF TRASCO RFQ

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Abstract

The TRASCO RFQ will accelerate the 40 mA cw proton beam from the ion source to the energy of 5 MeV, for the production of intense neutron fluxes for interdisciplinary applications. The RFQ is composed of six modules of 1.2 m each, assembled by means of ultra high vacuum flanges. The structure is made of OFE copper and is fully brazed. RFQ modules were manufactured in CINEL Scientific Instruments S.r.l. while chemical treatments and brazing were done at CERN. This paper covers the brazing results of the last four modules and low power tests performed for preparation to the high power test of the first electromagnetic segment.

INTRODUCTION

Legnaro National Laboratory has started the final tests of the TRASCO RFQ. Manufacturing and brazing of the first segment have been already described [1]. In the previous paper we have presented results of the first brazing process for the last four modules. Module 3 experienced a vacuum leak after the vertical brazing while some of the water channels plugs of the Module 4 had problem with brazing alloy flow and were removed. Regarding Module 4, plugs were successfully brazed during the vertical brazing. Vacuum leak in the third module allowed identification of a weak point in the brazing of the diametric joint of the stainless steel head flanges. Recovery of the problems took some months. The entire RFQ structure was complete and installed at LNL in November 2009 (Fig. 1).

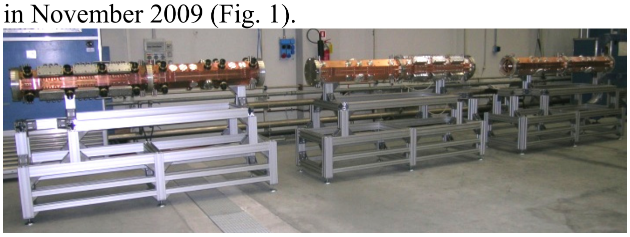

Figure 1: The complete TRASCO RFQ structure assembled at LNL.

Subsequently, ancillaries necessary for the high power RF tests of the First Electromagnetic Segment (FES) were developed (Fig. 2): Copper End-Plates (CEPs), Bridge Cavity for high power couplers test, Vacuum Skid for the first segment, Cooling Skid for frequency tuning of the cavity.

Considering that the FES was exposed to the air for a long time, surface treatment was necessary. We disassembled the structure and pumped into the RFQ, through a re-circulating system, a solution of citric acid and detergent at 60°C. After chemical polishing we re-assembled the structure and started the final RF measurements.

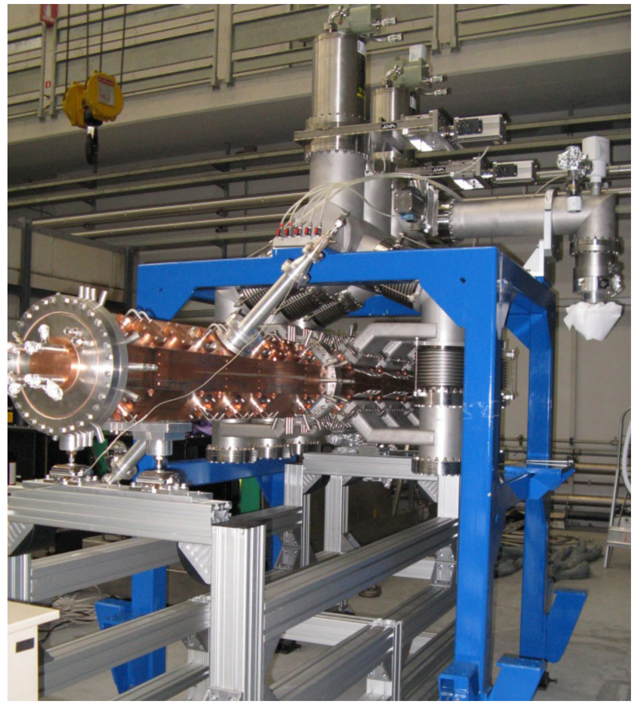

Figure 2: Final assembly of the first electromagnetic segment with vacuum system, aluminum couplers and copper end-plates.

BRAZING RESULTS

Vertical brazing of Module 3 showed a vacuum leak through the main SS head flange. In a first moment the problem was identified in a bad nickelization process of the flanges. After machining of both the head flanges (Fig. 3), new flanges nickelization and new vertical brazing, the same problem was found. In the mean time we discovered similar problem on one of the head flanges of module 5.

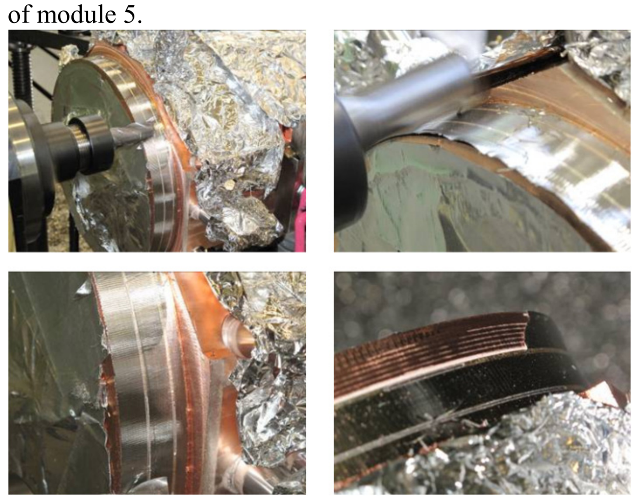

Figure 3: Stainless steel head flange machining after bad brazing cycle.

After deep analysis, the problem was found both on the support structure inside the brazing furnace and on a bad engineering of the diametric joint between SS head flange and copper support. Leakage risk after brazing was reduced by machining a third brazing groove into the joint. With this improvement, the remaining brazing cycles on the last four modules were successful.

RF MEASUREMENT FOR CAVITY CHARACTERIZATION

After surface treatment, FES was assembled for low power RF measurements. In addition to the Aluminum tunable End Plates (AEPs) for bead-pulling measurements [1], the equipment included two aluminum couplers (Fig. 2) with adjustable loop height (h_{loop}).

For high power test preparation of RFQ cavity we proceeded step by step.

Effects on Frequency

Vacuum-induced frequency detuning was theoretically estimated to be 86 kHz. This value well fits with the measured 92 kHz. Dielectric wires used for bead-pulling caused a measured detuning of 26 kHz. Temperature frequency detuning was confirmed to be $\Delta f/\Delta T$ = -5 kHz/°C, as simulations foresee. As a consequence, the frequency goal was found to be f = 352.2 - (0.092+0.026) - $\Delta f(\Delta T)$ = 352.082 MHz - Δf (ΔT), where ΔT is the difference between the temperature during measurements and the temperature fixed for operation (23°C).

Copper End-Plates

RF joints of the CEPs consist of a thin copper slice, brazed on the octagonal plate perimeter (Fig. 4). This slice is pressed against the cavity plane by a nickel-chromium C-tube [3]. Because of the delicacy of this contact we decided to install them just once, at the end of the assembly procedure. In particular this means that the RF contact effect on the Q value was known only after the cavity tuning.

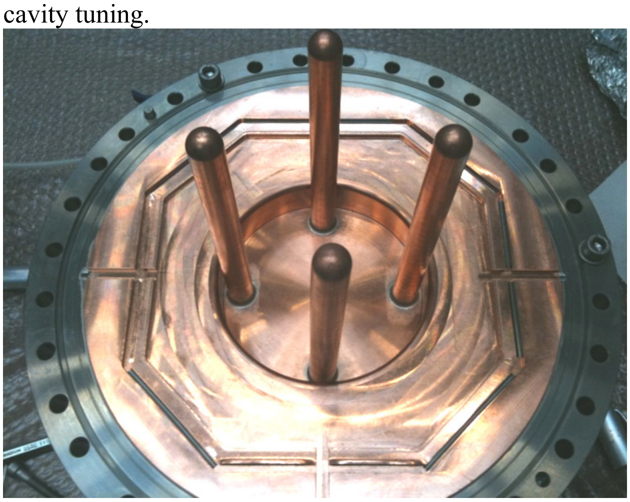

Figure 4: Copper End-Plate (high energy side). Dipole stabilization rods and RF contact are visible.

CEPs were found differently machined respect to AEPs in some details. The installation of CEPs, without RF joints, detuned the cavity of +100 kHz. Since CEPs cannot be re-machined, this difference was reduced to +20 KHz with a minor reparation of AEPs. Nevertheless we expected an effect on the field flatness after the end-plate replacement. We also verified a shift of the dipole free region towards high frequency (Fig. 5).

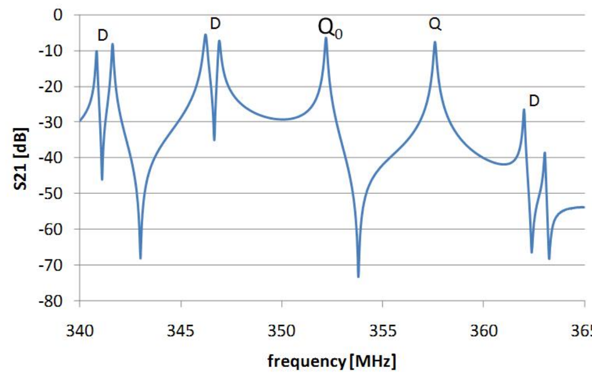

Figure 5: Dipole-free region shift towards high frequency. New center point is at 354.5 MHz.

Tuning

Table 1 shows cavity starting conditions before tuning (Fig. 6). Because of considerations about frequency detuning, RFQ cavity should be tuned at frequency f [MHz] = 352.2 - 0.092 (vacuum contribution) – 0.026 (bead-pulling wires contribution) – 0.016 (temperature contribution) - 0.02 (CEPs contribution) = 352.046. Since the RF signal frequency can follow the cavity resonance frequency in the high power test, we preferred to tune the field flatness within specification with a more relaxed constraint on the cavity frequency.

Table 1: Cavity Initial Parameters

h_{loop}	17	mm
$f_{meas.}$	352.489	MHz
Q unloaded	3500	
temperature	26.2	°C
tuners (nom. penet.)	4.62	mm

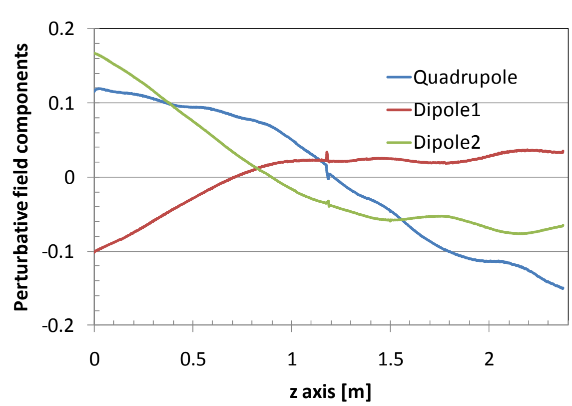

Figure 6: Perturbative quadrupole and dipoles components before tuning.

After tuning (Fig. 7) the resonance frequency was f=352.142 MHz at 27°C. Then in operation we expect to have f=352.3 MHz.

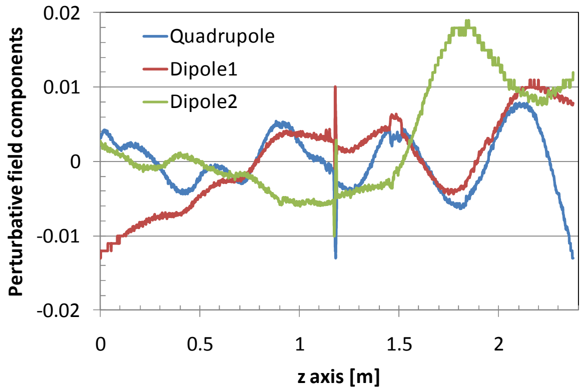

Figure 7: Perturbative quadrupole and dipoles components after tuning.

Aluminum Couplers

With field flatness within specifications (quadrupole = ±1%, dipoles = ±1%), we studied coupler effects on frequency, field flatness and coupling coefficient β (Fig. 8).

Measurements of β at different value of h_{loop} were performed separately for two couplers, for a precise VNA calibration. As one can expect, resonance frequency f_0 increases with h_{loop}.

The field was tuned with h_{loop} = 17 mm. With larger coupler penetration the field error exceeded the design requirements, while for minor penetrations field design requirements specifications were kept. Coupler rotation was verified not affecting the field flatness.

With a Q_0=5500, a loop penetration h_{loop} = 17 mm was sufficient to get critical coupling condition (beam power included). However we expected a Q value around 7000 (70% design value) with proper RF contacts.

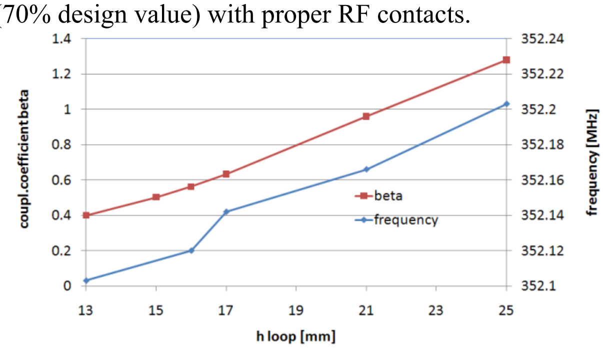

Figure 8: Effect of coupler penetration on cavity frequency and coupling coefficient β.

Copper Tuners and CEPs Assembly

When this tuning was completed the thirty-two movable tuners were replaced with water-cooled copper ones machined to the final penetration of the movable tuners in three stages: eight tuners plus eight tuners and finally the last sixteen. After each stage the RFQ tuning was checked, but no tuner adjustments were necessary.

Tuners provided with RF pick-up loop were alternated with tuners without loop. Since bead-pulling measurements cannot be done with CEPs, a measurement of the field by tuner pick-ups with AEPs was done as a reference (Fig. 9). The comparison with pick-up measurements with CEPs (Fig. 10) showed an important change of boundary conditions. In particular dipole components exceeded 2% limit required by beam dynamic study. This field condition was considered acceptable for the high power test.

Finally the High Power Coupler design was defined with 3D HFSS simulations, based on the measurement of Q_0=8100 obtained with RF contact installation.

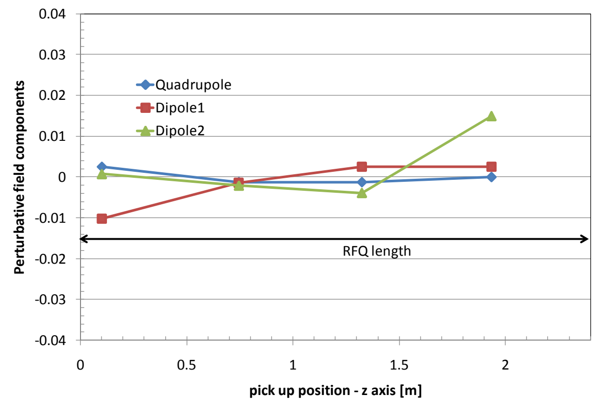

Figure 9: Perturbative quadrupole and dipoles components measured with RF pick-up loops with AEPs on.

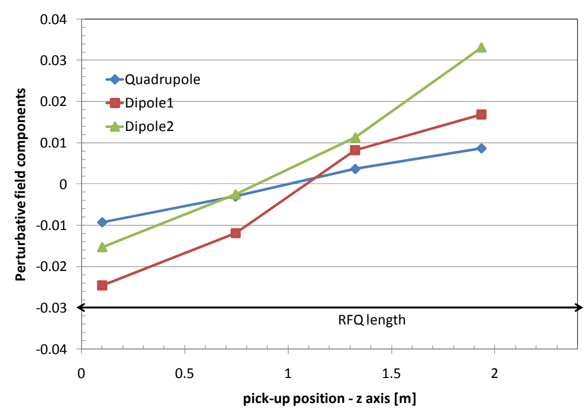

Figure 10: Perturbative quadrupole and dipoles components measured with RF pick-up loops with CEPs on.

ACKNOWLEDGEMENTS

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REFERENCES

[1] E. Fagotti, M. Comunian, A. Palmieri, A. Pisent, C. Roncolato, F. Grespan, S. J. Mathot, “Fabrication and Testing of TRASCO RFQ”, LINAC’08, Victoria, September 2008, MOP038, 2C-RFQs, p.151.
[2] A. Palmieri, “Internal Note”.
[3] J. Stovall, private communication.