THE TRASCO-SPES RFQ

A. Pisent, M.Comunian, A. Palmieri INFN/LNL, Legnaro, Padova, Italy
E. Fagotti, Università degli Studi di Milano, Milano, Italy - INFN/LNL, Legnaro, Padova, Italy
G.V. Lamanna, CINEL Strumenti Scientifici, Vigonza (PD), Italy
S. Mathot, CERN, Geneva Switzerland

Abstract

A high intensity RFQ is under construction at LNL. Developed within TRASCO research program, the Italian feasibility study an ADS (Accelerator Driven System), it will be employed as the first accelerating element of SPES facility, the ISOL project of LNL. The RFQ operates at the frequency of 352 MHz in CW mode. It delivers a proton current up to 30 mA and consists of six brazed segments whose length is 1.2 m. In this article the results obtained from the construction of a 20 cm "technological model", aimed at testing the construction procedure of the final structure, will be discussed. Finally we will report about the machining and the outcomes obtained after RF testing of the first two segments built up to now.

INTRODUCTION

The high intensity RFQ under construction at LNL, developed within TRASCO project [1] for ADS application, will be used as the front-end of a new generation ISOL facility for the production of exotic beams (SPES project [2]). The 5 MeV beam of the RFQ will also be used for the production of the neutrons necessary for the BNCT (Boron Neutron Capture Therapy); the first studies will be devoted to the application of this therapy for the treatment of skin melanoma. The construction of both this facility and a 20MeV, 10 mA superconducting proton linac (SPES-1) has been funded and is starting. In Table 1 the main RFQ parameters are listed.

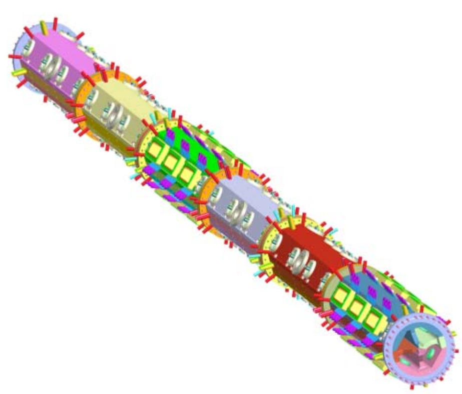

Figure 1: Layout of the TRASCO-SPES RFQ

CONSTRUCTION PROCEDURE

The RFQ consists of three modules 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 segments, which are the basic construction units (Figure 1). Each segment, built in OFE copper, is made of four main parts (A, B, C, and D in Figure 2). The head flanges between segments 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 segment (opposite to the coupling or end cells). Moreover, the vacuum grids with their cooling channels are directly machined on the copper bulk.

Table 1: Main RFQ parameters

Energy Range	0.08-5	MeV
Frequency	352.2	MHz
Proton current	30	mA
Duty cycle	100	%
Emittance T RMS in/out	0.20/0.21	mm mrad norm.
Emittance L RMS	0.19	MeV deg
RFQ length	7.13	m (8.4 λ)
Intervane voltage	68	kV (1.8 Kilp.)
Transmission	95	%
Q (80% of Superfish result)	8000	
Beam Loading	0.148	MW
RF Power	0.726	MW

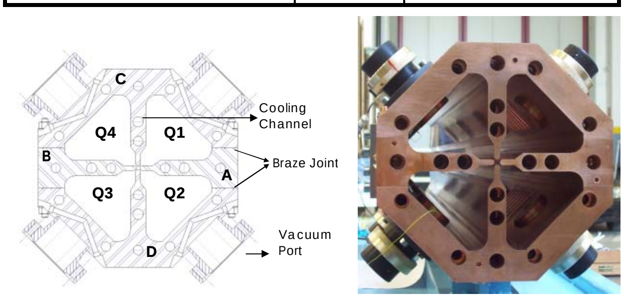

Figure 2: Transverse section of the RFQ with the indication of quadrants and pieces to be brazed.

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 B-Ag68CuPd-807/810 (according to ISO 3677) and the brazing temperature is 820^{O}C. After first brazing, the seat 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 and the SS flanges for vacuum ports or couplers are brazed in vertical position in a vertical vacuum furnace. The brazing alloy is B-Ag72Cu-780 (according to ISO 3677) and the brazing temperature is 790^{O}C.

RF and mechanical measurements allow to check the correctness of each step. The whole machining of the cavity is made by CINEL Strumenti Scientifici at Vigonza (PD), Italy, and the vacuum brazing as well as the copper heat treatment are made at CERN.

THE 20 CM TECHNOLOGICAL MODEL

The construction procedure above explained in its essentials has been checked with the construction of the so-called "20 cm technological model" (Figure 3). It is a 22 cm long RFQ, without modulation, onto which a vacuum, a tuner and a power coupler port and one cooling channel of each kind have been built. The RFQ copper test structure is coupled to an end plug (FMEC in the following) in order to get the proper boundary conditions for the quadrupole mode at the nominal frequency. The design of the whole structure has been accomplished by means of MAFIA and HFSS codes.

The results of the RF measurements are reported in Table 2

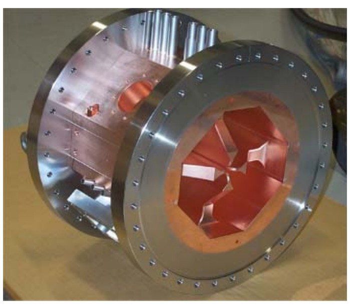

Figure 3: The 20 cm technological model after brazing

Table 2: Results of measurements of the copper test model ("H" is for HFSS, "M" is for MAFIA)

	Before 1^{st} brazing	After 1^{st} brazing	After 2^{nd} brazing	Simulations
Q_0	5504	6590	5936	7044 (M) 7742 (H)
f_q (MHz)	349.312	349.328	349.602	348.63 (M) 350.70 (H)
f_{d1}(MHz)	366.66	367.056	367.441	368.07 (M) 371.11 (H)
f_{d2}(MHz)	369.31	369.141	369.002	368.20 (M) 371.35 (H)

The leak test was successful (leak rate=$5\cdot10^{-10}$ torr·liter/sec). The cooling channels, after being leak tested are being tested in a closed water circuit to check the corrosion due to water cavitation. One of the slug tuners has been built and tested. In particular the vacuum seal (Viton® O-ring) and the RF seal between tuner and RFQ surface have been successfully tested on the 20 cm RFQ. The calibration of the pick-up (V_{pu} vs. $V_{intravane}$) was tested by feeding the cavity with a known power through a loop in critical coupling conditions; the measured V_{pu}/ $V_{intravane}$ agrees with calculation within 20%.

THE FIRST RFQ SEGMENT

After machining, the first segment of the RFQ was assembled in CINEL for preliminary RF measurements. In addition to the usual RF measurements it was decided to perform a "pre-tuning" of the structure, whose goal is to have an overall field variation $\left|\Delta u_q(z)\right|+\left|u_{d1}(z)\right|+\left|u_{d2}(z)\right|<0.05$, "q" being the quadrupole component and "d1" and "d2" being the dipoles Q1-Q3 and Q2-Q4 (See Figure 2) components respectively, aimed at checking the effectiveness of the tuning algorithm [3]. The components, extracted from bead-pull measurements in the four RFQ quadrants, are normalized in such a way that:

$$\frac{1}{L}\int_0^L \left(u_q(z)^2+u_{d1}(z)^2+u_{d2}(z)^2\right)dz=1$$

This procedure has been repeated before and after 1^{st} brazing and after 2^{nd} brazing. For such purpose a set of temporary brass "dummy tuners" has been employed. The tuners are in number of 4 per each quadrant and are initially set to 4.62 mm penetration. One tuner per quadrant is equipped with a loop for proper excitation of quadrupole and dipole modes. The RFQ segment has been equipped with the FMEC at the high-energy end. All measurements have been done with an Agilent 8753 ES Vector Network Analyzer.

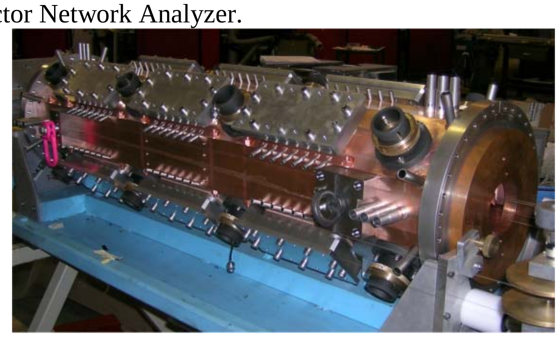

Figure 4: The first RFQ segment after 2^{nd} brazing

After electrodes mechanical alignment with initial tuner settings, a quadrupole frequency f_q=350.698 MHz, dipole frequencies f_{d1}=346.493 MHz, f_{d2}=346.093 MHz and an unloaded Q=4500 have been measured. After moving the pieces A and B towards the external of 30 µm and 50 µm respectively the values of f_q=351.416 MHz, dipole frequencies f_{d1}=347.324 MHz, f_{d2}=346.666 MHz and an unloaded Q=4800 have been measured. Then the pre-braze measurements have been done at CERN. The frequency variation due to the 1^{st} brazing is Δf_q^{0-1} =74 kHz, and the frequency variation between 1^{st} and 2^{nd} brazing is Δf_q^{1-2}=360 kHz. The Q_0 has increased to 5600 after 1^{st} brazing and to 5700 after 2^{nd} brazing. Such values, about 30% lower than the specifications, are supposed to be due to the presence of brass tuners and to the end plugs. As for the field measurement results, in Figure 5 the behaviour of the quadrupole and dipole components is reported before and after 1st brazing.

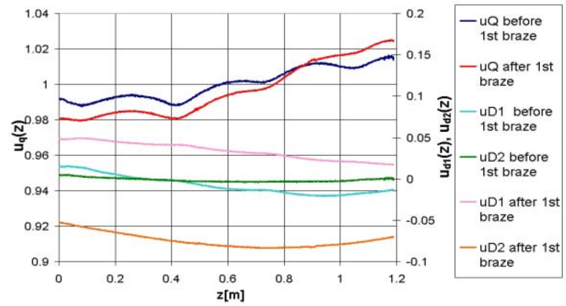

Figure 5: Field variation before and after 1st braze

In Figure 6 the same curve before and after 2nd brazing is shown.

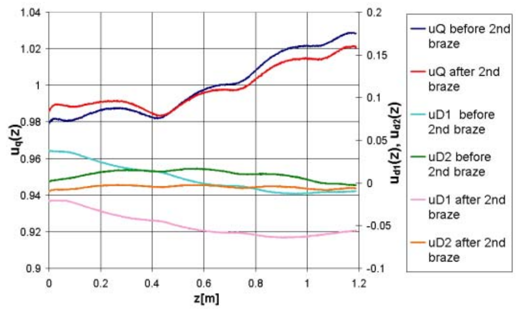

Figure 6: Field variation before and after 2nd braze.

The quadrupole mode keeps almost unchanged after each brazing step, while the dipole modes are a little bit mixed up.

Finally, the effectiveness of the tuning algorithm is shown by comparing the field variation before and after tuning (Figure 7) after the 2nd brazing. The field variation is lower than 1.5 % for any z, well below the “pre-tuning” specifications, and the dipole component content is about 1% of the total.

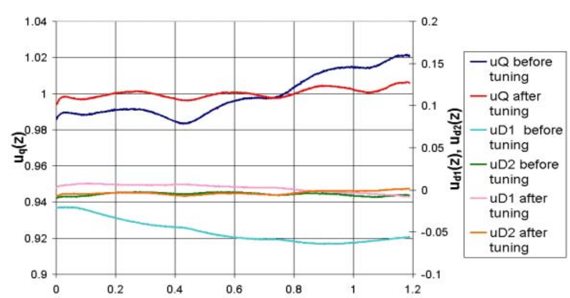

Figure 7: Effect of tuning upon field variation.

These results demonstrate the validity of the construction procedure and the attainment of the mechanical tolerances. It has to be added that a major vacuum leak has been found in the vacuum flange region. This has been the consequence of an unadapted mechanical tolerance of the flange and mounting fixture in the horizontal furnace. Therefore, the retained procedure is to braze the vacuum flanges also in vertical position (as described above) with a more complete fixture non usable in the horizontal furnace. A new flange design has been also adopted.

A repairing brazing cycle for the first segment will be performed soon. The leak tests of the main brazing joints, of the cooling channels and head flanges have been successful.

THE SECOND RFQ SEGMENT

The second RFQ segment has undergone the same alignment and RF measurement procedure as the first. Some extra regulations were made available: the pieces A and B have been constructed 80 µm thicker than nominal dimensions on both sides, to allow adjustment of the quadrupole frequency and dipole frequencies spacing. Flush copper plugs have been applied to the coupler ports. After electrodes mechanical alignment with initial tuner settings a quadrupole frequency f_q=353.200 MHz, dipole frequencies f_{d1}=347.881 MHz, f_{d2}=346.413 MHz and an unloaded Q=4400 have been measured. After removing 70 out of 80 µm thickness and moving A and B pieces towards the external of 20 µm the values of f_q=352.195 MHz, dipole frequencies f_{d1}=346.272 MHz, f_{d2}=346.113 MHz and an unloaded Q=4400 has have been measured.

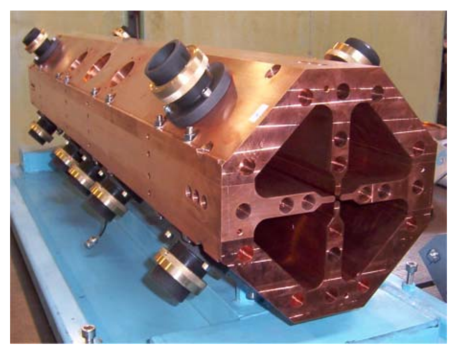

Figure 8: The 2nd RFQ segment.

The second segment has been brazed at CERN and is being delivered to Italy for machining and post 1st braze measurements.

ACKNOWLEDGMENTS

The authors wish to thank Enzo Bissiato (INFN-LNL) and Michele Franco (INFN-Bari) for their help during the operations of assembling RFQ and measurement setup, Fabio Scarpa (INFN-LNL) for his help in setting up the pick-up calibration measurements and Augusto Lombardi (INFN-LNL) for useful comments.

REFERENCES

[1] INFN-TC-00-23 21
[2] LNL-INFN(REP) 181-02.
[3] G.V. Lamanna et al. EPAC 2002, Paris, France page 924.