

ASSEMBLY AND RF TUNING OF THE LINAC4 RFQ AT CERN

C. Rossi, A. Dallochio, J. Hansen, J.B. Lallement, A.M. Lombardi, S. Mathot, D. Pugnati, M. Timmins, G. Vandoni, M. Vretenar, CERN, Geneva, Switzerland
M. Desmons, A. France, Y. Le Noa, J. Novo, O. Piquet, CEA, Gif-sur-Yvette, France

Abstract

The fabrication of Linac4 is progressing at CERN with the goal of making a 160 MeV H⁻ beam available to the LHC injection chain as from 2015. In the Linac4 the first stage of beam acceleration, after its extraction from the ion source, is provided by a Radiofrequency Quadrupole accelerator (RFQ), operating at the RF frequency of 352.2 MHz and which accelerates the ion beam to the energy of 3 MeV. The RFQ, made of three modules, one meter each, is of the four-vane kind, has been designed in the frame of a collaboration between CERN and CEA and has been completely machined and assembled at CERN. The paper describes the assembly of the RFQ structure and reports the results of RF low power measurements, in order to achieve the required accelerating field flatness within 1% of the nominal field profile.

INTRODUCTION

The initial conceptual design of a compact 3 MeV RFQ, published at CERN in 2007 [1], was soon after followed by the detailed study of beam dynamics, performed at CERN, and RF design, jointly done by CERN and CEA, [2]. After the mechanical design, the fabrication of the Linac4 RFQ started in 2009 at CERN and was recently completed with the assembly of the three modules that form the accelerating structure. Aiming for maximum reliability, the design choice was for a traditional four-vane structure with a constant section profile; particular attention was given in the design to avoiding the use of dipole mode suppressors by limiting the RFQ length to 3m (3.5 wavelengths) and by carefully compensating local perturbations. In particular, an original solution was to adopt brazed vacuum ports that could precisely compensate for the local field perturbation introduced by the cavity openings. Remaining errors are compensated by slug tuners.

The very tight tolerances imposed by the compact design, in the absence of resonant coupling cells, have put great pressure on the machining and assembly teams and required intense work at the metrology workshop.

The three 1-m long RFQ modules have been assembled at the end of July at the CERN metrology workshop, then the RFQ has been moved and installed at the 3 MeV Test Stand where the last tuning of the accelerating field is presently being performed, with the finalization of the piston tuners and of the RF power coupler, before the start of the RF commissioning foreseen in November.

Figure 1 shows the RFQ cavity installed at the Test Stand and connected to its cooling system.

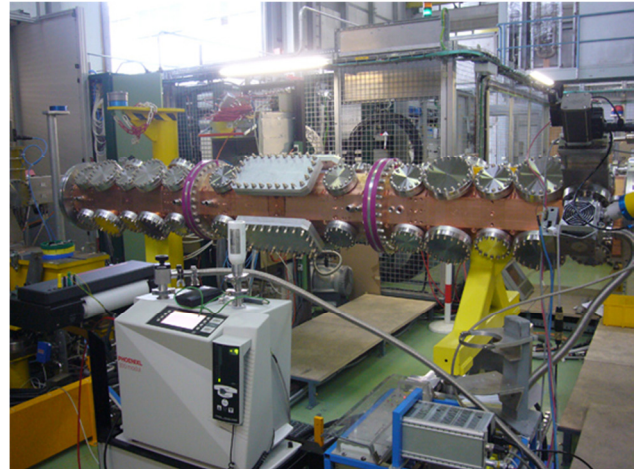


Figure 1: The Linac4 RFQ on its support, installed at the 3 MeV Test Stand.

RFQ MODULE FABRICATION

The fabrication of the RFQ is done through two brazing steps: with the first brazing the four RFQ vanes are assembled to form the RFQ cavity, while the second brazing, at lower temperature, is used to assemble the stainless steel flanges of the piston and vacuum ports and the two end flanges [3]. In the following we report the most relevant aspects of the construction of the three modules that form the RFQ. By convention we have called T1 the first module in the beam direction, followed by T2 and T3; in the fabrication process T1 and T3 were fabricated first, being very similar to each other from the mechanical point of view, while T2 was the last module to be built, due to the additional difficulty presented by the large waveguide openings for the RF power coupler.

T1

The fabrication of T1 started in 2009; it has been in fact the prototype on which all procedures have been tested and the fabrication strategy has been tuned. For that reason a considerable amount of metrology checks has been performed during its fabrication in order to assess that the fabrication was progressing well. For the same reason particular attention has been put into the RF bead-pull measurements, which were performed at each step of the assembly phase: mechanical assembly, first brazing and second brazing.

In table 1 the key dates for the construction of the module T1 are presented.

Table 1: Key Dates of the Construction of RFQ Module T1

Status	Date
Start T1 vane machining	June 2009
T1 assembly	March 2010
T1 first brazing	May 2010
T1 second brazing	November 2010

The evolution of the fabrication errors can be traced from the RF bead-pull measurements, in particular by looking at the asymmetries between the four quadrants, which can be referred to capacitance errors associated to the main quadrupole (QQ) and dipole modes (SQ and TQ) in the cavity. In Fig. 2 the vertical scale ranges between -2% and +2%, the error that can still be corrected by the available range of the piston tuners which is $\pm 2.3\%$ for the quadrupole mode and $\pm 3.5\%$ for dipole modes.

Figure 2 shows how, in the case of T1, the measurements performed after the second brazing, green trace, show errors quite below the level of 1%, allowing to assess the conformity of module T1 to the specification.

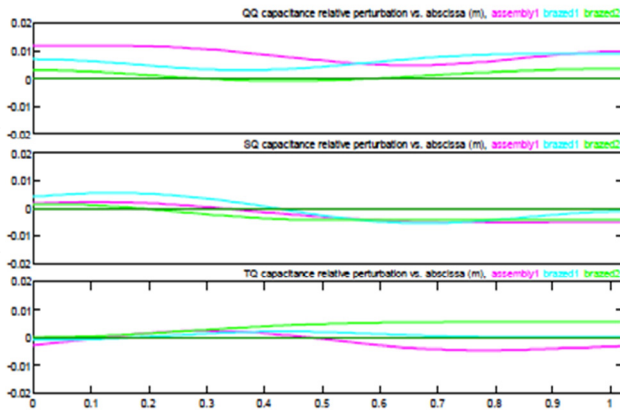


Figure 2: Capacitance errors for quadrupole (QQ) and dipole modes (SQ and TQ) in module T1.

T3

The fabrication of T3 was started at the beginning of 2010, when the construction of T1 was already well advanced. This choice was done in order to profit from the consolidated fabrication procedure coming from the T1 experience. In table 2 the key dates of T3 fabrication are summarized.

Table 2: Key Dates of the Construction of RFQ Module T3

Status	Date
Start T3 vane machining	January 2010
T3 assembly	December 2010
T3 first brazing	February 2011
T3 second brazing	May 2011

After the second brazing, the error associated to the quadrupole mode stays very low and the errors relative to the two polarizations of the dipole mode are lower than 1%, assessing the excellent quality of the fabrication process for this module.

The behavior of the relative error associated respectively to the quadrupole and dipole modes in T3 is represented in figure 3.

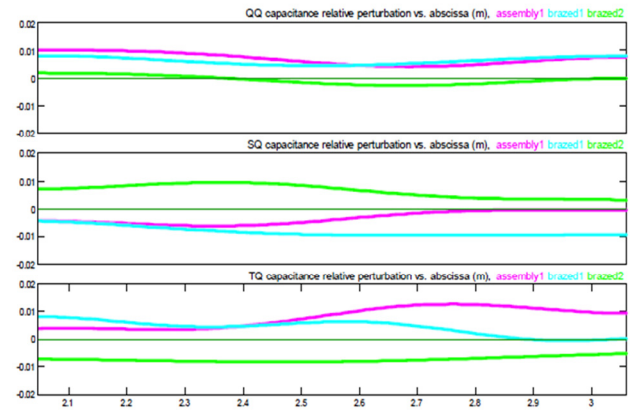


Figure 3: Capacitance errors for quadrupole (QQ) and dipole modes (SQ and TQ) in module T3.

T2

The fabrication procedure of T2 was different because of the presence of the four large stainless steel flanges (one per quadrant) designed to receive the ridged waveguide coupler that feeds the RF power to the RFQ cavity. For symmetry reason, four ports have been machined, but only one is used for the RF power coupler, while rectangular pistons are installed in the remaining three ports in order to make the field locally symmetrical.

The first attempts to braze these flanges were not successful, leading to an important modification to the mechanical design and to the brazing procedure. A traditional brazing of the hippodrome collar was followed by the EBW of the large stainless steel flange, finally permitting the perfect brazing of the ports. A view of the brazed port is presented in Figure 4.

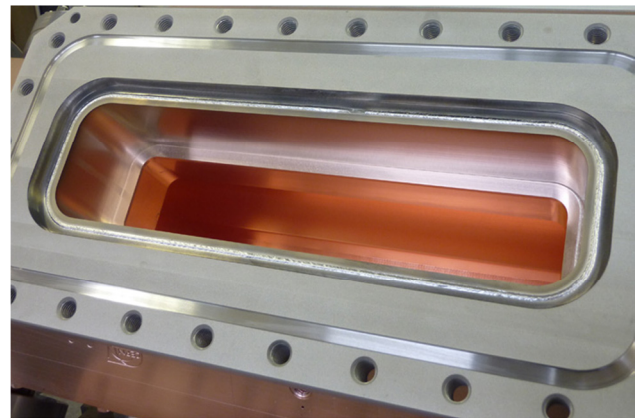


Figure 4: Close view of one of the RF coupler ports.

The realization of T2 has delayed the RFQ completion, initially foreseen for the end of 2011. Several test pieces had to be produced and an accurate preparation work on the RFQ cavity was required. Well controlled procedures allowed preserving the excellent quality of the module construction all the way through this process. In table 3 the key dates for the T2 construction are summarized.

Table 3: Key Dates of the Construction of the RFQ Module T2

Status	Date
Start T2 vane machining	June 2010
T2 assembly	June 2011
T2 first brazing	July 2011
T2 second brazing first	September 2011
T2 second brazing last	May 2012

Figure 5 reproduces the behavior of the quadrupole and dipole relative errors after the assembly steps.

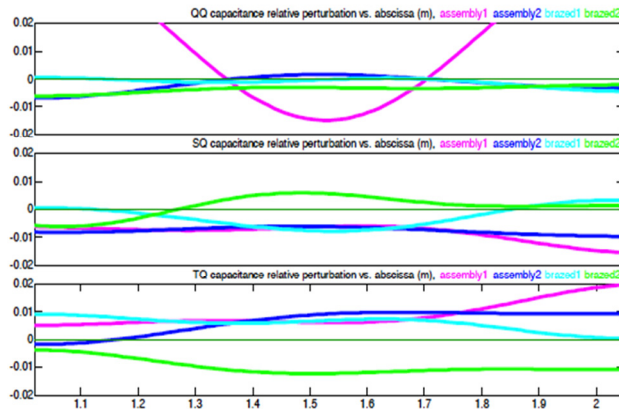


Figure 5: Capacitance errors for quadrupole (QQ) and dipole modes (SQ and TQ) in module T2.

In figure 5 the pink trace (assembly 1) reproduces the effect of a bad compensation of the electromagnetic field penetrating the 1 mm gap between the dummy RF ports and the waveguide openings situated at the middle of this module. The blue trace shows how this effect could be completely compensated by inserting the dummy RF ports by additional 0.7 mm inside the RFQ cavity. The green trace reproducing the error profile after the last brazing step confirms still a good fabrication quality for this module in spite of having passed several times in the brazing furnace.

RFQ MODULE ASSEMBLY

The principle for the final assembly of the three modules was based upon very precise metrology measurements of the reference points located at the entrance and exit of each module. The connection between adjacent modules has been realized by means of centering rings that were machined so to bring the optimized beam axis of the two modules to coincide within $\pm 30 \mu\text{m}$ when bolted together and a key was used to establish the right azimuthal orientation.

RF Bead-Pull Measurements of the Assembled RFQ

After the RFQ assembly a first series of bead-pull measurements is required to tune the two end cells, thus allowing the fabrication of the end flanges equipped with quadrupole rods. Afterwards, further bead-pulls will allow the fine tuning of the accelerating field and to

establish the correct power coupling. Figure 6 documents the result of the first measurements with all pistons in flush position.

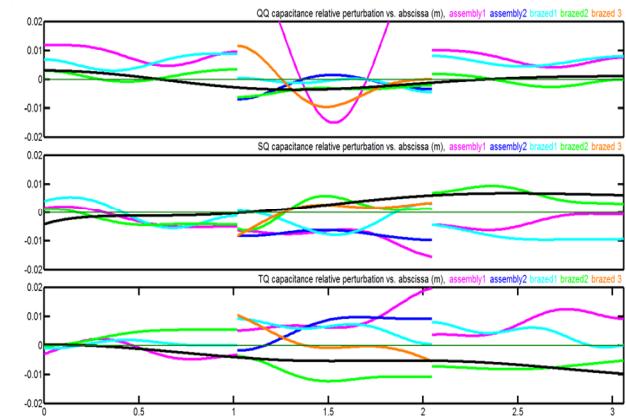


Figure 6: Capacitance errors for quadrupole (QQ) and dipole modes (SQ and TQ) in the assembled RFQ. Lines in colour represent measurements of individual modules, while the black line results from the assembled RFQ measurements, before its final tuning.

The assembled RFQ shows very small errors, within the $\pm 1\%$ range, that confirm the excellent quality of the RFQ machining and assembly.

The RF spectrum shows a separation between the accelerating quadrupole mode and the closer dipole modes of 6 MHz, while the first quadrupole mode is 3 MHz apart.

CONCLUSION

The fabrication of the Linac4 RFQ is approaching its end; within few months we should be able to power the RF cavity and start the commissioning of the accelerator. The first beam tests are foreseen before the end of 2012.

The RF measurements performed until now have confirmed the excellent quality of the mechanical construction, which was able to respect the very tight tolerances imposed by the design.

REFERENCES

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