Progress in Brazing a Prototype Module for the IFMIF/EVEDA RFQ Accelerator


1INFN, Laboratori Nazionali di Legnaro, Legnaro (Padova), Italy. 2INFN, Sezione di Padova, Padova, Italy.

INTRODUCTION

The construction of the IFMIF/RFQ [1] needs several tests for validating the production steps of the 18 modules that constitute the RFQ. After a first brazing test made at CERN in 2010, a similar module was built to test additional feature.

This prototype module consists of four copper modulated electrodes that assembled altogether form the four vanes of the RFQ cavity. As in the first prototype module horizontally brazed at CERN, the electrodes are shorter than the final module (400 mm instead of 550 mm). However, in this case one extremity of the electrodes is machined to create undercuts for the correct RF matching with the end cell. The geometry of the four lateral ports was also modified according to the new design version of the tuners made in 2011. This modification requires to machine undercuts on the external wall the cavity and the brazing of 4 copper cylinders.

BRAZING SETUP

Due to the good results obtained from the brazing test for a smaller version of this module [2], the assembling is made vertically as shown in figure 1. As in the previous test the copper parts are hold together by means of some molybdenum rods terminated with some stainless steel plates. The compression force is provided by several Nimonic 90 springs acting along the three space directions.

The alignment of the four pieces is achieved with the aim of eight reference plane. A couple of springs creates a force on a calibrated alumina that lines up two adjacent planes.

The lateral copper cylinders are kept in contact with the body of the module using some molybdenum clips. Moreover, the long drilled holes of the electrodes are closed with copper plugs to make the cooling channels.

The former test gives also good result for an heterogeneous brazing thus some stainless steel part was also brazed. However, instead of making the module in one singular step brazing, it was only chosen to anticipate the brazing of two stainless steel frames at the top and at the bottom of the structure. They not only are the base plane for the vacuum sealing in the final installation, but also keep together the four copper parts during the thermal cycle enhancing the stability of the structure. These parts are clamped by triangular stainless plate with rods that are arranged inside the cavity.

The assumptions for the geometry of the brazing joints were the same of the previous test as well as the brazing filler material (i.e. silver copper alloy $T_{\text{sol}} = 824 ^\circ C$ $T_{\text{liq}} = 852 ^\circ C$).

The whole structure is positioned on a stainless steel baseplate with four groups of alumina (97%) tiles inserted between the baseplate and the electrodes in order to isolate the module thermally. Each group of tiles is composed of two alumina plates (one on top of the other) in a such way that they can freely slip laterally, while the planarity is kept constant. This turns out to be a fundamental parameter for this arrangement, because during the thermal cycle the copper parts must be able to freely expand without introducing additional stress. The slip system is also optimized to keep low the friction coefficient between the two alumina plates at high temperature.

![Fig. 1. 3D View of the geometry of the brazing setup. The numbers indicates the positions of the thermocouples (11 in total not all shown in the figure).](image-url)

Nuclear Physics LNL Annual Report
The heating ramp phase from room temperature to the brazing point temperature was kept slow to avoid any induced stress from thermal gradients. The maximum gradient registered on copper respect to the average temperature was below 50 °C. Before brazing, the parts were thermalized around 810 °C and the experimental value of the thermal emissivity coefficient was measured. After this, the thermal history of the system can be reconstructed and also predicted. In fact the working point was regulated accordingly to the numerical simulations carried out during the thermal cycle in order to cross the interval between $T_{\text{ad}}$ e $T_{\text{liq}}$ of the brazing filled metal in 1.5 hr. This phase corresponds to the second step in the thermal chart of figure 2. Afterwards, the cooling phase was controlled to keep the cooling rate below 100 °C/hr.

![Therm. Cycle on 07/02/2012 7.00.00](image)

**Fig. 2.** Chart of the mean temperature of the copper parts and stainless steel parts during the brazing. The parts in stainless steel are warmer/cooler than the copper ones due to their different ratio mass/surface.

**RESULTS**

After the brazing, the tooling was dismounted and the module was visually inspected (figure 3). The joints, especially on the top side, turned out to be perfectly brazed with good integrity between the connections. Also the longitudinal joints between copper parts shown a uniform wetting. The four copper cylinders for the tuner ports presented good adhesion in spite of a small accumulation on the bottom of the ports.

Large defects were found on the bottom side of the module. To begin with unexpected flows occurred at the interface of the stainless steel frame, such that some zones near the base of the electrodes accumulated large quantity of brazing material. Also the joints for the plugs at the electrodes showed an irregular wetting with large voids between parts. The brazing filler metal turned out to be removed by capillarity by the alumina tiles.

All these evidence seems to be compatible with the fact that the lower part of the structure was warmer respect to the rest. Some evidence can be also found from the thermometers, however the signal to noise ratio is too low to confirm a thermal gradient of 2-3 °C.

![Fig. 3. Picture of the prototype module after the brazing. This view corresponds to the bottom side of the vertical brazing setup shown in figure 1.](image)

In spite of these features, the structure has passed the vacuum leak test (figure 4). The module was horizontally positioned to have the four long longitudinal sealing along the side and the lateral ports on the top and the bottom. The apertures of the RFQ were sealed using plastic material. Also the cooling channels were tested without any variation of the helium signal of the leak test.

![Fig. 4. Charts of the measured signals during the leak test. The leak tightness specification is below 10⁻⁶ mbar l/s.](image)

The module was also geometrically checked with the aim of a portable 3D measuring arm at the reference plane. The recorded deviations between two nearby reference planes stay below 56 μm.

This result was also confirmed by the RF test [4] which reported a small shift of the resonant frequency from the nominal value (below 100 kHz) after the brazing phase.