ENGINEERING DESIGN AND FIRST PROTOTYPE TESTS OF THE IFMIF-EVEDA RFQ

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Abstract

In the framework of the IFMIF/EVEDA project, the RFQ is a 9.8 m long cavity, with very challenging mechanicals specifications. In the base line design, the accelerator tank is composed of 18 modules that are flanged together. The assembly construction procedure of each module foresees two brazing steps. In the first step we braze the four copper electrodes and all the copper plugs while in the second step we braze all the stainless steel components as vacuum flanges, vacuum tightness and mechanical flanges and all the cooling lines connectors. An RFQ prototype, composed of 2 modules with a reduced length, aimed at testing all the mechanical construction procedure is under construction. In this article, the progress of the prototype construction and the progresses in the design and engineering phase, as well the description of all the fabrication phases is reported.

THE IFMIF-EVEDA RFQ DESIGN

Within IFMIF EVEDA project the INFN has in charge the construction of the prototype RFQ, operating at 175 MHz in cw and able to accelerate 130 mA deuteron beam up to 5 MeV The detailed design of the accelerator, recently reviewed (DDR), has evolved respect to ref [1] as follows:

The 9.8 m structure is now composed by 18 flanged modules instead of 9 modules each composed by two brazed sub-modules. The new configuration allows to decrease the vane gap between adjacent modules (80 µm instead of 200 µm), so to guarantee negligible accelerating field perturbation and surface field enhancement, as well as a better alignment of the modules. Moreover the stiffness against transverse deformation is increased and the brazing procedure is simplified.

In fig. 1 the general lay- out of the cavity is shown.

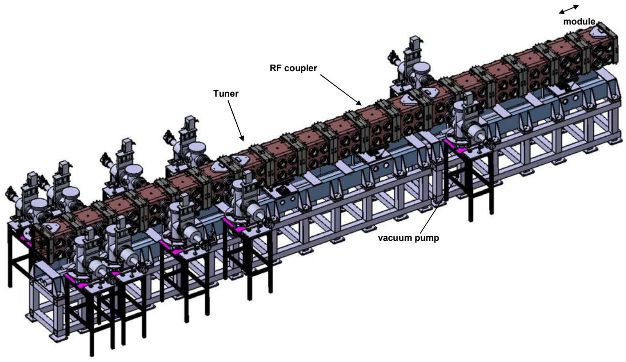

Fig.1: General lay-out of the RFQ cavity.

-Overall transversal dimensions: 430x430 mm.
-Wall thickness=45 mm
-Overall longitudinal length: 543.35 mm
-Vane thickness: $T_{V,max}$=80mm $T_{V,min}$=30 mm.

In the design of the connection flange the mechanical connection was de-coupled towards the leakage tightness.

The cooling duct lay-out has been simplified and updated maintaining two different temperatures for the vane cooling and for the vessel cooling. We decided to renounce to the threaded ducts solution for the channels of the vessel body (due to the non uniform behaviour of the thermal exchange), adopting the simple and blind holes configuration, with identical feeding connections. Due to a refined channel positioning we'll not need to provide dedicated cooling to the grid ports.

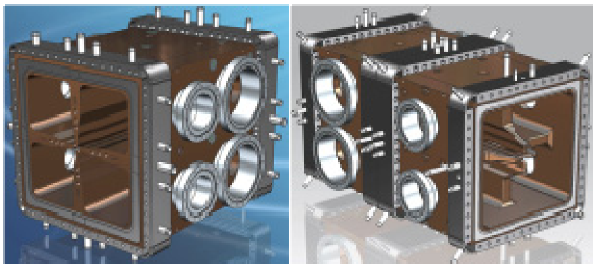

Fig.2: The RFQ final module and the technological prototype.

A RFQ technological prototype has been built consisting of two independent modules 400 mm long with the geometry of the last part of the line. The aim of the prototype is to verify all the design assumption and the production schedule in terms of mechanical coupling and tightness efficiency with the assembly and alignment performances.

THE CONSTRUCTION PROCEDURE

For the construction of the two modules of the RFQ prototype we adopted a conservative construction procedure with a very detailed quality control for all the steps. Essentially we started with three main working steps with two associated annealing processes and we verified that due to our peculiar machining procedure we can reduce at only two steps with a single annealing process performed at 800 C, as reported on follow.

Phase I

1 -Qualification of CuC2 raw blocks.
2 -Deep drilling of the cooling ducts (only blind holes).
3 -Pre-cut of the raw profiles with a limited stock.
4 -Dimensional check.
5-Pre-finishing of the back-side openings.
6 –Dimensional check.

7 -Annealing process under vacuum (800°C).
8 -Dimensional shape check and validation.
Phase II.
1 –Finishing on all surfaces.
2 –Dimensional shape check and validation.

The very limited stress induced by the EDM pre-finishing seems to give distortion within 20 µm after the process annealing. The very limited distortions surveyed after a smooth milling machining and a consequent annealing process allow for a more condensed schedule.

The RFQ components are then individually geometrically qualified and assembled to compose the module geometry. A geometrical and RF test of the module is then performed. We therefore re-machine the common surfaces to allow for a extremely precise positioning of the brazing tooling.

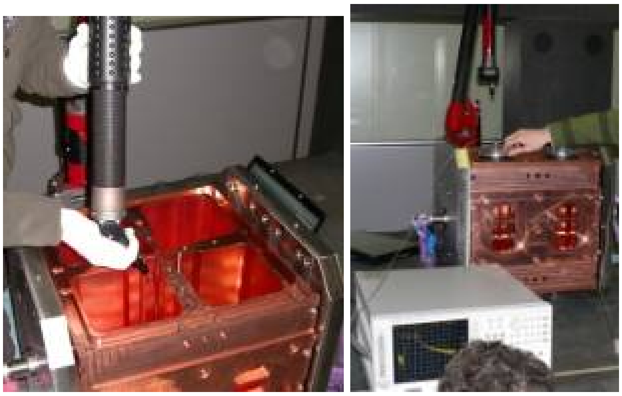

Fig.3: RFQ components alignment with RF validation.

The first module of the RFQ prototype has been brazed at CERN following a procedure that takes the maximum advantage of the experience of 352 MHz RFQ's already brazed at CERN [3]. The larger transverse dimensions induced several design changes both in the machining and the brazing tooling.

Two different brazing steps are foreseen:

1st brazing (Ag-Cu-Pd), horizontal RFQ position, performed @815°C for the coupling of all copper components;

2nd brazing (Ag-Cu), vertical RFQ position, performed @ 785°C for the coupling of all the Stainless Steel components.

The process is very critical and we studied the tooling with extreme care to embed or limit the distortion induced by the thermal cycle. In the brazing assembly configuration tooling, the aim is to embed any relative displacement between adjacent components while assuring stress free constraints on the elements that could result on unpredictable permanent deformations. The mechanical quality of the cavity is mainly related to the successful brazing process.

We performed some FEM analysis of the thermal cycle in the oven to optimize the orientation of the components towards the radiating screens and to verify the stress-strain behaviour of the assembly during the cycle:

The first brazing in Winter 2010 with a very high dimensional quality of the assembled module (Fig. 4). The overall maximum mis-alignment of the vane tips being less than ten microns (Fig. 5).

Fig.4: The RFQ prototype module after the first brazing step.

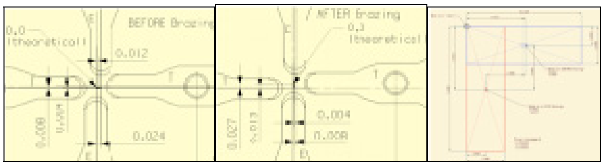

Fig.5: Displacements summary.

After the first brazing the beam axes displacement, being less than 10 micron, along the two transversal axes, is well below the required beam axis position tolerances.

The definition of the machining tolerances is essentially driven by the requests of planarity and surface finishing imposed by the brazing process.

We tested two different kind of milling machining center: ultra-precise (YASDA) and some high level standard MMC as Deckel-Maho and Ferrari D10 in-house).

The dimensional check and validation is a basic guideline for the acceptance of the geometry of the components (copper and stainless steel). We made the prototype measurements by means of point to point CMM and PMMs, but we'll extensively use a continuous scanning measurement to increase the efficiency and the speed of the components survey. The special probes available with this kind of CMM will allow for scanning survey inside the module giving the opportunity to reconstruct the real geometry shape until the module completion and after the module assembly (up to two modules).

RFQ COOLING DESIGN

About 600 kW RF power are removed by means of 28 channels longitudinally drilled along the RFQ modules (fig..6); the water velocity is approximately 3 m/s, the temperature of the channels on the vane and on the cavity wall can be separately tuned so to achieve a tuning range of ±100kHz. The maximum temperature on the vacuum grids is approximately 60 deg C (Fig. 7).

The initial configuration of the modules presented 10 mm diameter ducts for vane cooling and M14 (threaded) ducts for vessel cooling [1]. Such a choice was done in order to get an increase in the heat transfer coefficient, as well as the heat transfer area, due to the dissipated power increment with distance from beam axis. The experimental tests showed that this advantage was not so evident for our relatively short channels, and smooth channels were finally adopted.

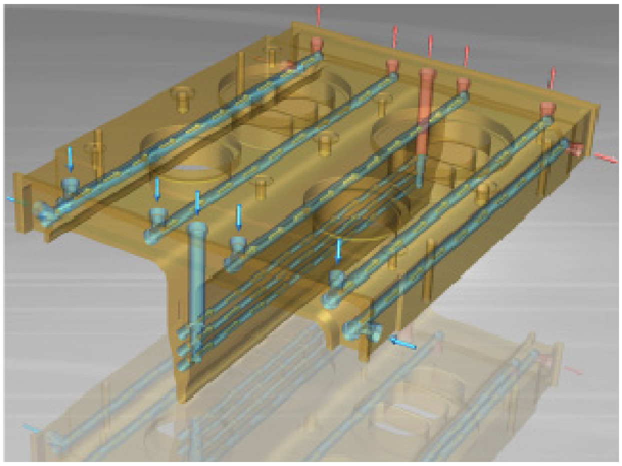

Fig.6: Final cooling channels configuration.

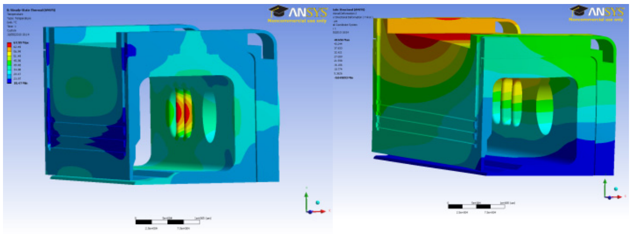

Fig. 7: Module temperature [°C] and deformation (vertical component) [μm]

Table 1 enlists the FEM CFD analysis results: we noticed uncertainties on heat transfer coefficient evaluation, this induced us to perform a full scale cooling test providing by means of surface resistors the nominal power. The temperature map on the component was then captured with an infrared thermal camera.

Table 1: FEM CFD analysis summary

	Smooth	Threaded
Average heat transfer coefficient [W/(m^2*K)]		
Star CCM+	14500	9900
Comsol	5000	12000
Experimental	11500	9500

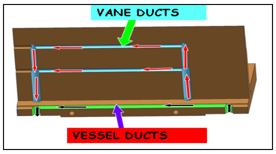

Fig. 8: Cooling layout

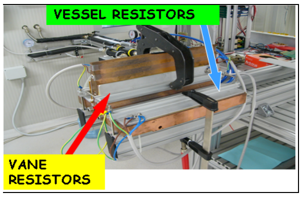

Fig. 9: Power input system

The first case considered the behavior of the smooth ducts for the vane (Fig. 10). The results obtained state that both the FEM and experimental results are similar, as shown in Figure 9.

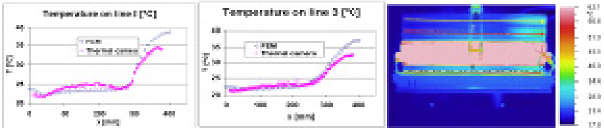

Fig. 10: Vane cooling channel (smooth) results

The second case studied the threaded ducts for the vessel, as reported in fig. 11.

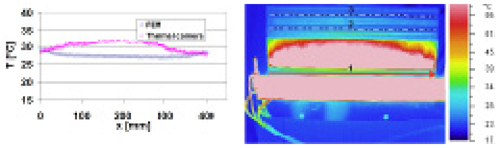

Fig. 11: Vessel channel cooling results (threaded)

The turbulent flow was not uniform along the duct as shown by the FEM analysis. The temperature uniformity being mandatory for the proper cavity operation we decided to adopt smooth duct also on the vessel despite of a minor value of the heat transfer coefficient. Due to this fact the relative position of the cooling channels has been redesigned. Integrated thermal-CFD analysis with Ansys CFX 12 and thermal-structural analysis with Ansys Workbench 12 have been improved in order to take in account temperature rise and convective coefficient variation along the module and to guarantee same mass flow on vane cooling ducts.

AKNOWLEDGMENTS

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