MECHANICAL DESIGN OF THE IFMIF-EVEDA RFQ

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Abstract

The IFMIF-EVEDA RFQ is L=9.8 m long cavity, whose working frequency is equal to 175 MHz. In the base line design the accelerator tank is composed of 9 modules flanged together and a pattern of lateral CF100 flanges allows to host the dummy tuners and the couplers, and a pattern of CF 150 flanges the apertures for vacuum pumping manifolds as well. The construction procedure of each module foresees the horizontal brazing of four half–module length electrodes and then the vertical brazing of two brazed assembly. The progresses in the design and engineering phase, as well the description of all the fabrication phases are reported.

THE IFMIF-EVEDA RFQ GEOMETRY

The design specifications and geometrical definitions of the RFQ cavity were reported in the IFMIF-EVEDA RFQ DESIGN [1] and are confirmed (Figure 1).

We decided to produce a prototype module with slightly different length of the sub-modules (due to the limited capability of the raw material production) forcing to have a different positioning of the vacuum and coupler ports.

We have already started the production phase of the prototype components (via a rough cut of the profile using an EDM, followed by the pre-milling of a 2 mm stock on the components) and in the last months the copper supplying firm arrived to produce a full length copper block fulfilling all specs in terms of grain size and homogeneity. The main changes in the mechanical design of the cavity concern the cooling ducts lay out, the vacuum port geometry and the design of the vacuum and mechanical coupling of the modules.

The Cooling Lines

We developed a technique to thread the channel (M14) of the external cavity body where the power dissipation is higher, increasing the heat exchanging surface while providing a well developed turbulent flow of the fluid. The number of ducts is consistently reduced even though we had to renounce to collect the connections far from the bolted flanges. The vane ducts maintain a smooth surface due to a limited power dissipated (Figure 2).

We performed several flu-dynamic simulations for the threaded and smooth channels to characterize properly the fluid flow and the global fluid exchanging coefficient. We compared the FEM analysis of different packages as STAR CCM+ (in collaboration with the CERN ST CV Group), COMSOL Multi-physics and ANSYS. We also tuned the FEM analysis results with the test results performed in a similar configuration by the IPHI CEA Group for their cooling system, due to the uncertainties related to this kind of simulations.

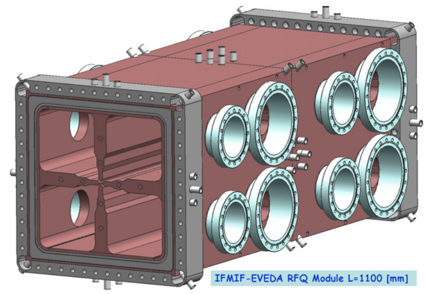

Figure 1: The IFMIF-EVEDA RFQ module.

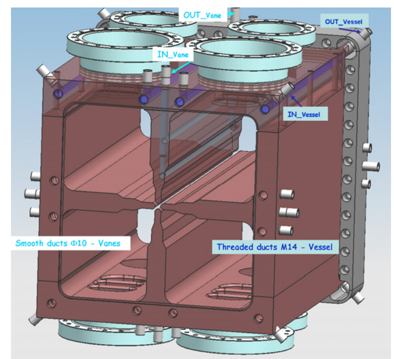

Figure 2: The cooling ducts lay out for an Half Module. There are independent threaded ducts (M14) for the vessel and smooth ducts in parallel (D10) for the vanes.

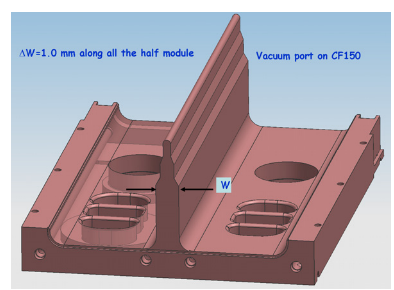

Figure 3: The vacuum port.

The Vacuum Port

The vacuum port is made directly on the copper bulk of the RFQ, and the grids' structure, width and transparency results from the optimization between pumping, RF detuning and heat removal efficiency. The grid structure will not protrude as assumed in the preliminary design proposed and the volume compensation is provided via the thickening of the vane base "w", thus avoiding the components stock increasing during the pre-machining phases (Figure 3). The aim is to minimize the machining energy needed for the finishing of the surface and the induced machining stresses that represent a critical issue during the brazing phases. The geometry of the cavity and the cooling channels dimensioning are tuned to avoid a specific cooling for the vacuum port.

The Vacuum Tightness and the Mechanical Coupling of the Modules

We decided to de-couple the vacuum tightness flange and the mechanical coupling flange due to the relevant transversal dimensions of the cavity resulting on a very large diameter for a unique stainless steel bolted flange.

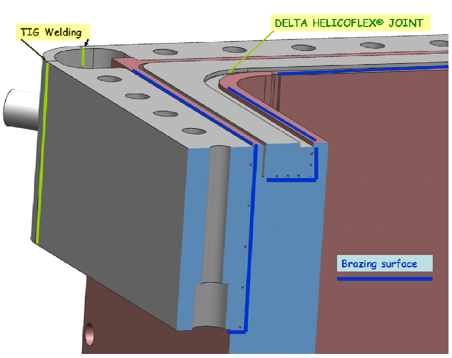

Figure 4: Details of the coupling flange.

The Vacuum Flange

The vacuum tightness is obtained by squeezing a bimetallic DELTA Helicoflex® joint on two symmetrical stainless steel flanges brazed on a groove of the cavity module ends (Figure 4). The SS flange is brazed both on the bottom and on the inner surface (not on the flange corners), leaving a gap of about 2 mm on the outer surface, allowing for a differential thermal expansion of the SS flange and the copper cavity during the brazing cycle. The SS sealing surface will be provided by a copper deposition to reduce the current resistance between modules.

The Modules Mechanical Coupling

We introduced some independent stainless steel plates brazed onto the cavity external skin (Figure 4), housing the bolt seats and providing an effective stiffening of the weak coupling transversal section under the vacuum condition.

We leave the reinforcement independent during the brazing phase thus avoiding any induced stress. Nevertheless some connecting stiffeners will be TIG welded to couple the reinforcement providing a closed stiff flange under the service condition. The bolted surface is designed to provide a very uniform pressure onto the sealing joint and allowing an independent brazing of the SS plates and the passing through cooling lines (Figure 4).

THERMO-STRUCTURAL CALCULATIONS: MAIN OUTCOMES

In order to characterize and predict the structure behaviour under operating conditions (namely RF heat load and vacuum) a thorough campaign of thermo-structural simulations has been carried on. In particular the 2D simulations have been directed to determine, for a given channels' layout and inlet water temperatures, the frequency shift induced by thermal deformations and the 3D simulations have been aimed at determining the cooling mechanism of vacuum ports and/or studying the effects of vacuum shrinkage.

2D Simulations

The input data for 2D thermo-structural simulations is the profile of the power density in W/cm^2 $p_d= ½R_s|\boldsymbol{H}|^2$ ($Rs[\Omega]=2.609\cdot10^{-4}(f[MHz])^{½}$ surface resistance for copper and **H** magnetic field) on the section contour, given by SUPERFISH simulations and corrected with a margin of 1.573 [1]. In Fig. 5 the temperature map in a 2D section (1/8) of the RFQ is shown. In the same table the radius of the cooling channel, the input temperature (T_{in}), the input velocity (v), the output temperature after 55 cm of structure and the heat exchange coefficient H_c are reported, as well as the power adsorbed (P_c) in each cooling channel. It is worth noticing that a safe value of 10000 for the flat tubes and 20000 for tapered tubes was used.

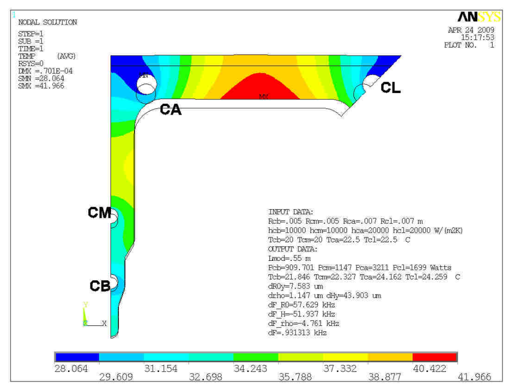

Figure 5: Temperature map in the 2D section in the highest power zone.

Table 1: Cooling channel Specifications

	R	T_{in}	v	T_{out}	H_c	P_c
	mm	^{o}C	m/s	^{o}C	W/m^{2}K	W
CB	5	20.0	3	21.8	10000	909.7
CM	5	20.0	3	22.3	10000	1147
CA	7	22.5	3	24.2	20000	3211
CL	7	22.5	3	24.3	20000	1699

The amount of deformation directly influences the local cut-off frequency of the RFQ, therefore it is necessary to set the water inlet temperatures in such a way to minimize such detuning. Although the amount of such detuning Δf depends on the overall deformation profile [2], a simplified expression accurate within some percent), involving only the mean aperture R_0, pole tip radius ρ end electrode height H can be drawn:

$$\frac{\Delta f}{f} \cong \left(\alpha_{R_0} \frac{\Delta R_0}{R_0} + \alpha_\rho \frac{\Delta \rho}{\rho} + \alpha_H \frac{\Delta H}{H} \right),$$

where the coefficients α_{R0}, α_ρ and α_H can be analytically determined [2]. In particular, the above-presented solution is such that the frequency shift is reduced to ~1 kHz.

3D Simulations

The vacuum port is made directly on the copper bulk of the RFQ, and the grids' structure, width and transparency results from the optimization between pumping, RF detuning and heat removal efficiency. Also in this case the input data are the power density on the RFQ skin, and the calculations were aimed at determined whether it was possible to exploit the conduction effect of the main channels to have a somehow "indirect" cooling of the grid. The results are encouraging, in the sense that, with this cooling scheme, the maximum temperature in the vacuum port is 66 °C (Figure 6).

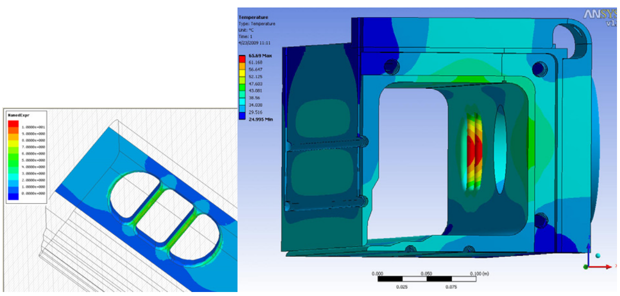

Figure 6: Power density normalized to the 2D max value p_0=5.5 W/cm^2 (LEFT). Temperature map in the vacuum port (RIGHT).

VACUUM SYSTEM DESIGN

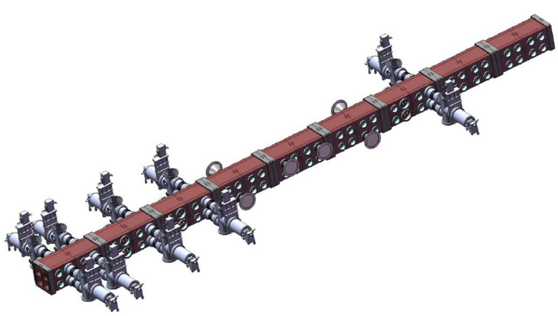

Figure 7: Schematic layout of the vacuum system for the RFQ. The beam comes from the left to the right. Section at beam entrance has 8 pumps, Middle section has 8 couplers, the end section has 2 pumps.

The solution proposed for a maximum design pressure of 5×10^{-7} mbar is a system composed of 10 cryogenic pumps with a DN 200 CF flange and a pumping speed of 2500 lt/s for H_2.

The gas load is mainly deuteron since this is the type of particles accelerated and partially lost in the cavity. Another significant contribution comes from the gas in the LEBT line (Kr + De_2) which passes through the 12 mm dia. hole at the entrance flange of the RFQ, due to the differential pressure. Other gases (CO, CO_2, H_2) are from the out-gassing of copper's surface.

Table 2: Gas Load Estimation (Air)

Losses	**Gas Load** (mbar Lt/s)
LEBT	8.26×10^{-4}
Beam	1.34×10^{-3}
OutGassing	2.90×10^{-4}
Couplers	2.09×10^{-4}
Desp. Yield	1.33×10^{-4}

Although the out-gassing of the surface can be assumed equally distributed along the cavity, this cannot be done for the other sources. In facts, the beam losses occur mainly in the first sections of the RFQ.

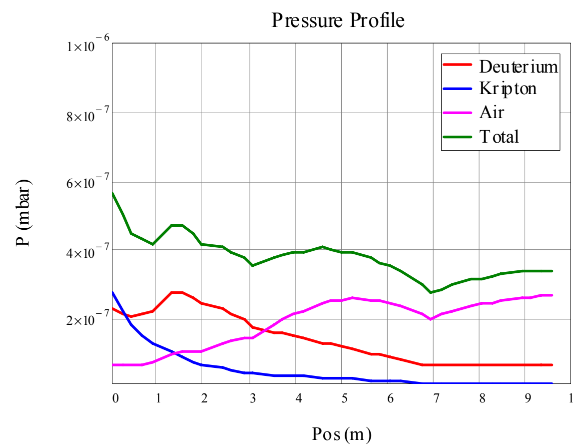

Figure 8: Pressure profile along the RFQ.

For the calculation of the conductance of the whole piping system, the approach followed is to describe the system as made of several elements. For instance the conductance along the RFQ vane is given by the conductance of the free cross section, and the intra-vane conductance is essentially from the small aperture between the poles. The pumping ports and the manifold were instead simulated with Montecarlo methods assuming a diffusive reflection at the wall to obtain the value of the conductance between the center of the RFQ and the pumps. Under the assumption that the system is symmetric in the four vanes the solution of the problem gives the pressure profiles (Fig. 8) along the tank.

AKNOWLEDGMENTS

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REFERENCES

[1] A. Pisent, et. al. "IFMIF-EVEDA RFQ DESIGN", EPAC 2008, Genoa (Italy).
[2] A. Palmieri, LNL annual Report 2008.