3D ASPECTS OF THE IFMIF-EVEDA RFQ: DESIGN AND OPTIMIZATION OF THE VACUUM GRIDS, OF THE SLUG TUNERS AND OF THE END CELL

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Abstract

In order to attain the stringent goals that assure the required performances of the IFMIF-EVEDA RFQ in terms of field uniformity, Q-value and RF-induced heat removal capability, the study of the 3D details of the cavity is particularly important. In this paper the main issues regarding the design of the slug tuners, cavity ends and vacuum grids are addressed, as well as the related optimization procedure.

RFQ PARAMETERS AND CAVITY DESIGN

The main RFQ parameters are listed in Table 1, and the 3D layout in Figure 1.

Table 1: IFMIF RFQ input design parameters

Particles	D+	
Frequency	175	MHz
Input Current	130	mA
Energy (in-out)	0.1-5	MeV
Max Surface Field	25.2	MV/m (1.8 Kp)
Length L	9.78	m
Voltage min/max	79/132	kV
Mean aperture R_0	4.1 / 7.1	mm
Pole tip radius ρ	3.08/5.33	mm
Q_0 (SF) (z=0-z=L)	15100-16700	
Max. Power Density (z=0-z=L)	1.6-3.1	W/cm^2
Total power P_d (no beam)	0.708	MW

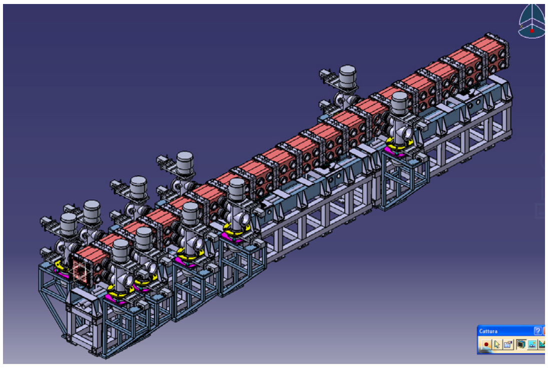

Figure 1: IFMIF RFQ layout.

The P_d is related to the 2D power calculated by SUPERFISH, P_{SF}, by means of the relationship

$$P_d = P_{SF}\alpha_{3D}\alpha_v$$

where α_{3D}=1.3 (for 3D losses) and α_v = 1.21 (= 1.1^2) for voltage enhancement. These margin will be used throughout the analyses shown in the next paragraphs.

DESIGN OF THE SLUG TUNERS

The IFMIF-EVEDA RFQ is equipped with 88 slug tuners (22 tuners/quadrant) in order to correct the voltage ripples within the limits set by beam dynamics (2% max dipole and upper quadrupole components allowed). Such tuners have a diameter of 89 mm and have to be inserted into the 90 mm holes in the RFQ vessel, whose depth is 45 mm. The main tuner insertion depth in the RFQ volume is equal to 15 mm.

The design of the tuner is shown in Figure 2.

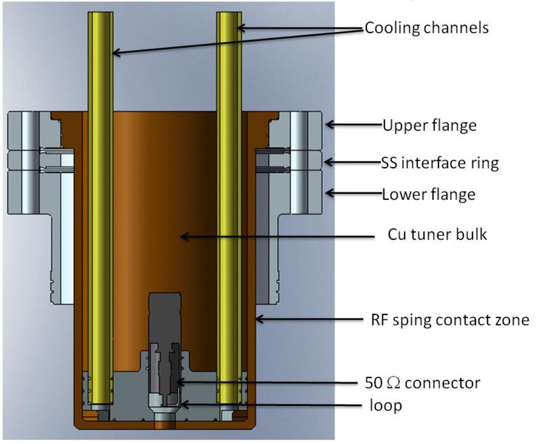

Figure 2: The tuner layout.

Such design is aimed at minimizing the number of machining steps to be performed just after the final tuning on the assembled RFQ. The tuner insertion depth is determined by adjusting the thickness of the SS interface ring sandwiched between the CF 100 flanges brazed on the RFQ and tuner bulks respectively. The cooling channels of 12 mm diameter are brazed on the internal Stainless Steel bulk. Half of the tuners are also equipped with a 50 Ω connector, in order to sample the longitudinal profile of the voltage also under full power operation.

An important issue associated with the design of such tuners is the minimization of the RF losses due to the currents flowing on the surface in the space between the tuner and the 90 mm hole. In fact the resulting geometry gives way to a coaxial waveguide, whose mode TE_{11} mode has a cut-off frequency of about 1 GHz and couples with the RFQ magnetic field. HFSS simulations were performed in order to study the behaviour of the surface currents in this zone The profile of the H field along this coaxial waveguide space is shown in Figure 3, and it can be seen that a significant amount of surface current (up to the 50% of the value on the RFQ wall) is still present even at about 50 mm from the RFQ wall.

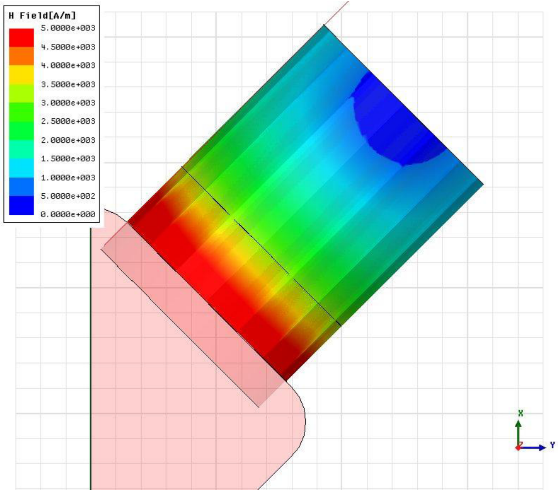

Figure 3: the H field magnitude on the tuner surface inserted in the 90 mm hole in the RFQ vessel.

The effect of that is a drop of the Q value up to the 20% of the theoretical value. This inconvenient can be overcome by inserting a RF spring contact at about 40 mm from the RFQ wall. In this way the Q drop turns to be below 10%.

DESIGN OF THE VACUUM GRIDS

The vacuum grids introduce a discontinuity in the upper wall of the RFQ, which creates a frequency shift and an enhancement in current density. HFSS simulations (obtained by importing the detailed grid solid model) allowed to determine the power density map. In the power density map calculated with HFSS (normalized to the 2D value) on the grid is shown, with the power margin included, as well as the associated temperature distribution, calculated with ANSYS.

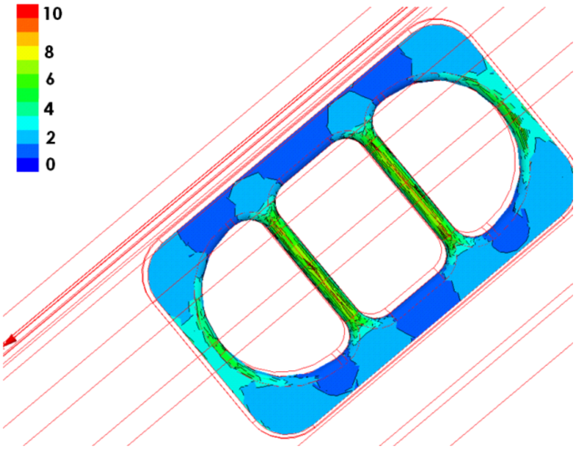

Figure 4: Power density map on the vacuum grid, normalized to the 2D value.

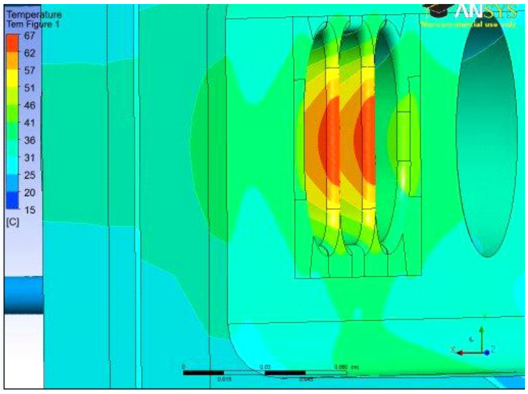

Figure 5: Temperature distribution on the grid (ANSYS). The maximum temperature on the grid is equal to 67°C.

For the calculated values, cooling of the grids is not necessary. However, the vacuum grids need an "a priori" field compensation, since their presence creates a non-periodic inductance perturbation The corresponding frequency perturbation is calculated as the detuning induced by the grids averaged over the vacuum port: in our case the detuning induced by the vacuum port is equal to δf=-546 kHz on a 550 mm RFQ module, for an overall detuning of about -250 kHz. This circumstance provokes a longitudinal variation of the voltage of ± 30%.

The compensation scheme adopted for this case consists of increasing of the electrode width of 1.5 mm in the modules in which vacuum grids are present. Calculations performed with perturbative model show that this solution recovers the frequency detuning and decreases the voltage ripple to the residual value of ±0.5 % (Figure 6).

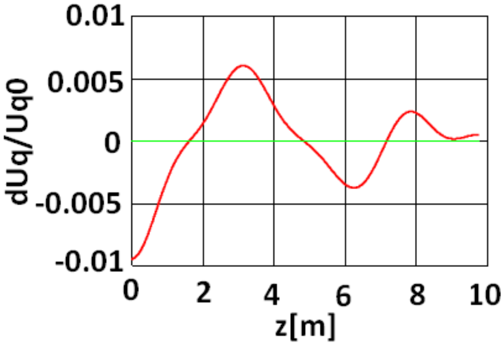

Figure 6: Quadrupole voltage perturbation after compensation.

DESIGN OF THE END CELLS: HIGH ENERGY SIDE

The low and high energy sides of the RFQ require a vane undercut, in order to implement, at least for the operating frequency, the perfect H boundary conditions for a four-vane RFQ. At the same time the design of such undercuts must guarantee a reliable heat removal in the hot spots and a containment of the electrode deformation in such away to avoid spoiling of the voltage longitudinal uniformity. Since the 2D power density on the RFQ wall in the high energy end is about twice the corresponding value on the low energy side, the design of the undercut for the former case appears to be more critical.

The vane undercut for this case is shown in Figure 7, where the cooling channels' position is determined by the 2D optimization studies [1]:

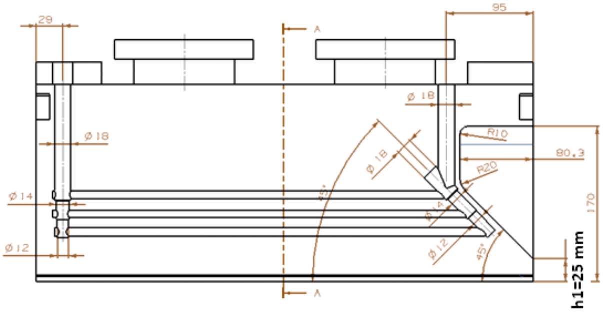

Figure 7: The high energy vane undercut, including the cooling ducts.

The 45° angle of the undercut guarantees the access of the cooling channel as close as possible to the hot spot at the electrode base (~80 W/cm^2), which is the most severe of the entire RFQ. Moreover, the capacitive zone of the cell (height h1), the most difficult to be cooled and at the same time the most sensitive to deformations, is chosen in such a way to have a relatively low amount of power density (about 17 W/cm^2) . The map of power density is shown in Figure 8.

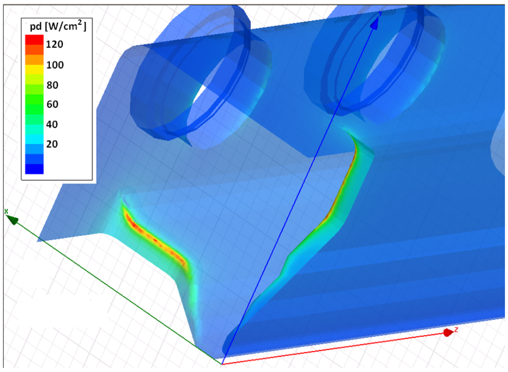

Figure 8: Power density in the vane undercut.

The input data of power density pd [W/m^2] from HFSS simulations were transferred to ANSYS Workbench in order to evaluate temperatures and displacements, through a complete thermo-fluid-dynamics simulation, since the 45° angles of the cooling channels can determine a significant change of the water velocity. For this simulation an inlet temperature of 19°C in the vanes and 22°C in the vessel was assumed, as well as an inlet water velocity of 3m/s.

The water velocity profile is shown in Figure 9, while the temperature distribution is shown in Figure 10 and the deformation profile in Figure 11.

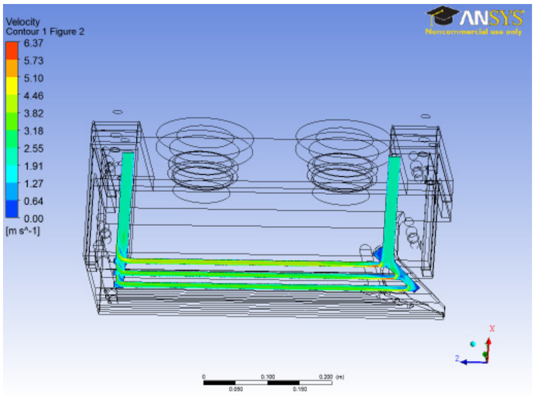

Figure 9: Water velocity distribution in the cooling channels [m/s].

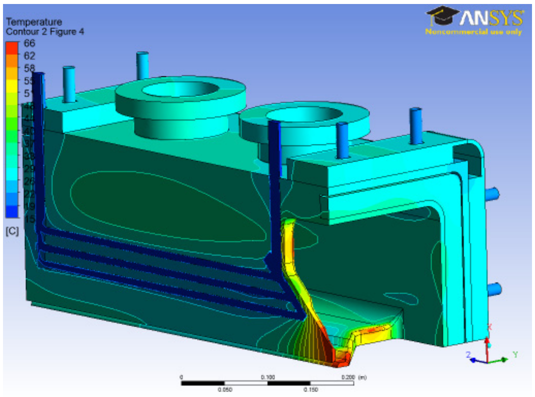

Figure 10: Temperature distribution in the vane undercuts. The maximum value is equal to 66°C.

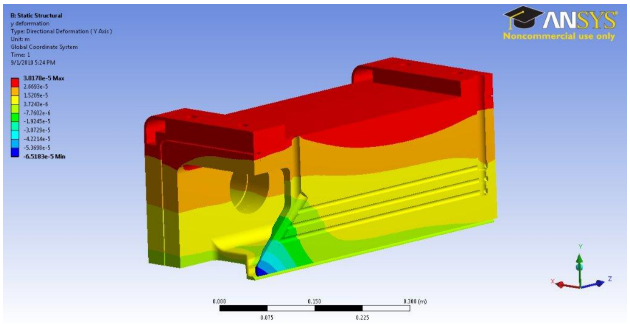

Figure 11: Deformation distribution along the high energy side (y component).

The most dangerous deformation occurs in the pole tip zone and it varies from 70 µm to 0 µm towards the beam axis in the first 20 cm of the structure. This effect was simulated with HFSS on a l=4.896 m (half RFQ length) (in order to see the effect of the perturbation on a longer range), and the results is that the voltage drop is in the order of ±0.8%.

REFERENCES

[1] F. Scantamburlo et al., these proceedings.