COMPLETE ELECTROMAGNETIC DESIGN OF THE ESS-BILBAO RFQ COLD MODEL

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Abstract

In this paper, the electromagnetic design process followed in the ESS-Bilbao Radio Frequency Quadrupole (RFQ) Cold-Model project is presented. Since the fabrication of an RFQ is a complicated and expensive task involving many technological and mechanical aspects, the fabrication of a Cold-Model represents a great opportunity to adjust the design and fabrication procedure. Electromagnetic simulations are needed to determine the correct machine geometry able to give the design specifications, such as the resonant frequency for the resonant modes (quadrupole and dipole modes) and the field characteristics along the RFQ length (field flatness). To this end, the finite elements based COMSOL software has been used. As a result, a 1m RFQ model built in Aluminum is presented. The prototype includes a test vane modulation, input and output radial matchers as well as a complete study of the effect induced by the radial matcher lobes in the field and resonant frequency.

INTRODUCTION

The radio frequency quadrupole (RFQ) Cold-Model [1] has been designed as a part on the ongoing development of a proton accelerator for the ESS-Bilbao project [2]. The goal of this element is to be used as Test-Stand for the future driver implemented in the ESS-Bilbao Linac. The final design is intended to produce a 75 mA proton beam able to rise up to 3 MeV from an initial energy of 75 KeV [3]. The Cold-Model will be manufactured in Aluminum. This model represents a great tool in order to test the low level RF electronic systems and the power injection driven by the designed power couplers as well as the accuracy of the manufacturing procedures in comparison to the results obtained from computer modeling. This should be done by performing future in-house measurements of the Cold Model such as resonance frequency, quality factor and the bead-pull perturbation method (measurements of the electric field profile).

COLD MODEL DESIGN

The main objective of the RFQ Cold-Model project is to test the fabrication processes and maximum possible mechanical accuracy. Nevertheless, it also represents a great opportunity to compare the results obtained from electromagnetic simulation software with the measured results previous to the fabrication of the final machine. From an electromagnetic point of view, the most important design parameter is the resonant frequency for the quadrupole mode (figure 1) and its separation with respect to the dipole and high order modes (figure 2).

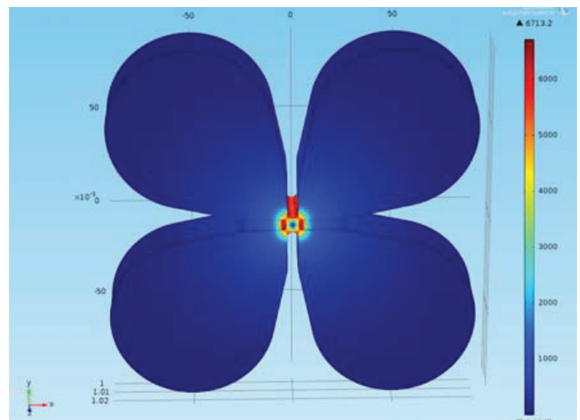

Figure 1: Abs. E field (V/m) for a Quadrupole mode representation in a 20mm (Z axis) Cold-Model section. Frequency = 352.2 MHz.

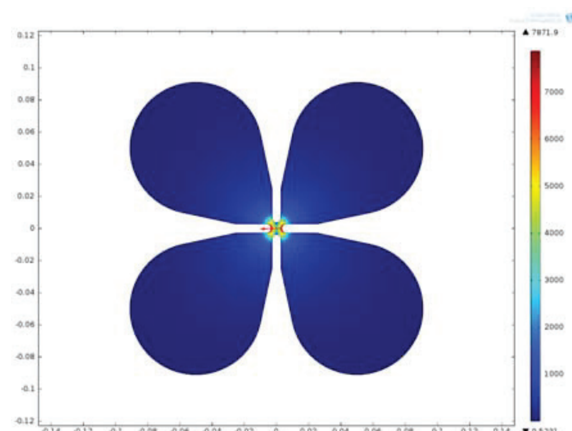

Figure 2: Abs. E field (V/m) for a 2D Dipole mode representation (XY plane at Z=0.5m). Frequency = 346 MHz.

Dipole modes typically appear at frequencies close to the quadrupole mode [1], therefore it is crucial to ensure that no degeneracy between the operating quadrupole mode and the dipole modes occurs. Since the design frequency of the quadrupole mode is set to 352.2 MHz, the cavity has been properly designed to fulfill this specification. To this end, a complete parametric study of the frequency variation of

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the modes with the RFQ dimensions has been done. Figure 3 shows the variation in the Quad/Dip modes with the total length of the RFQ. As it can be seen, a minimum frequency distance between modes (5MHz) has been achieved to the desired RFQ length and therefore no extra mode suppression elements are required [4] [5]. As it can be seen, the distance between modes strongly depends on the total length of the machine. In this case, convergence is observed for lengths higher than 1m. Thus, it can be expected not to find any interference between modes if the design is extended to 4m (final RFQ cavity)

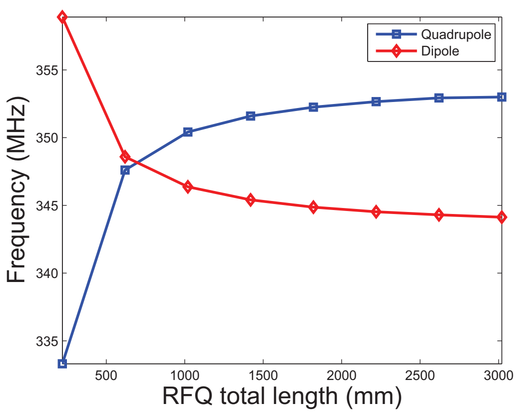

Figure 3: Variation of the RFQ resonant modes with total length.

RFQ endings represent another important part when designing and RFQ. Endings are composed of two elements: radial matchers and radial matcher lobes. Input and output matchers are needed to accomodate the input beam and to deliver a proper beam to the RFQ output respectively. The geometry of these elements is imposed by beam dynamics specifications and it can not be modified at the EM design state. In our case, one test input matcher and one test output matcher have been included in the Cold-Model design. Both geometries are set identical in order to simplify the design. Radial matcher lobes are used to let the magnetic field turn from lobe to lobe (figures 4 and 5). On the contrary to radial matchers, radial matcher lobes can be tuned and have been object of study in order to determine their effect on the electromagnetic field.

As it is depicted in figure 6 the geometry of this ends drastically affects the field quality along the RFQ.

Another important element added to the RFQ Cold-Model is vane modulation. Protons in the RFQ are accelerated by a generated alternating longitudinal field. This field is achieved by means of the vane modulation [1]. Therefore, a sample vane modulation representative of the four RFQ sections (radial matcher, shaper, gentle buncher and accelerator) has been implemented in the Cold-Model. That is, a variation in the modulation amplitude range from $4.5\text{x}10^{-3}$ mm (shaper) to 1.6 mm (accelerator). As it can be seen, the presence fine details in the structure requires from a very accurate simulation procedure in order

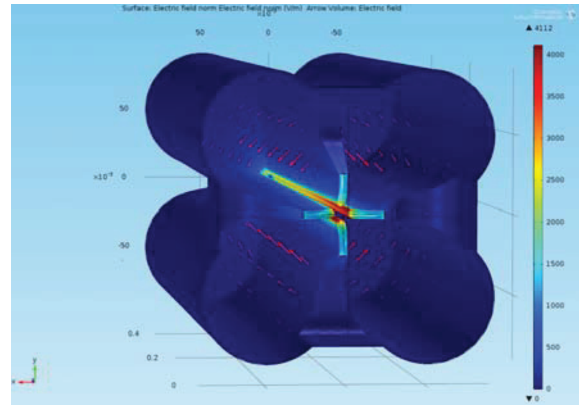

Figure 4: Abs. Electric field (V/m) on the RFQ ends for the quadrupole mode.

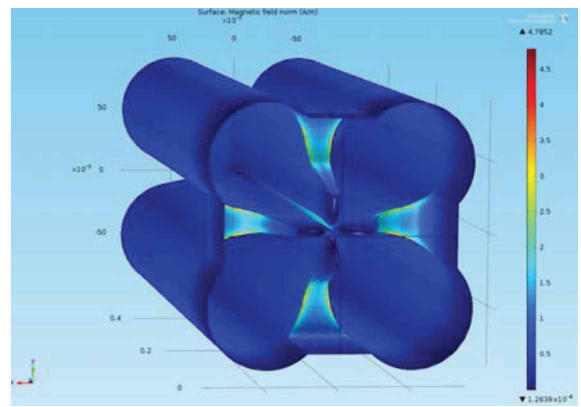

Figure 5: Abs. Magnetic field (A/m) on the RFQ ends for the quadrupole mode.

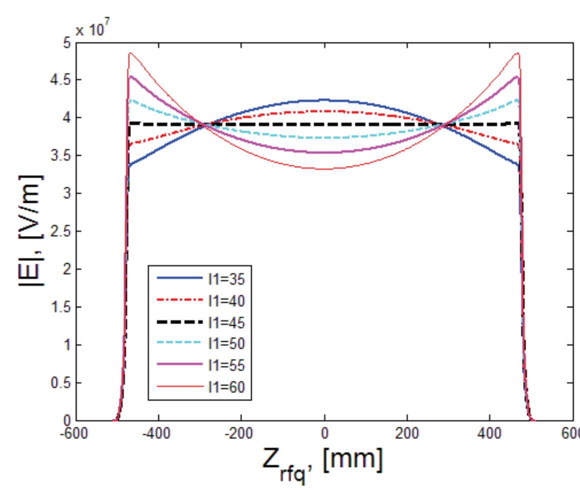

Figure 6: Variation in field flatness along a non modulated 1m RFQ regarding the penetration of the lobe inside the cavity (l_1).

to obtain realistic results from electromagnetic simulations. Fine adaptative meshing strategies have been used with a high number of total tetrahedrons ($4\text{x}10^7$), which makes the simulation procedure heavy and very time consuming.

Finally, electronically controlled slug tuning rods have been implemented in the model in order to compensate for the possible frequency deviance due to the fabrication process or during operation as well as for modifying vane profile along the RFQ [7]. To this end, 16 slug tuning rods consisting on 4 stages of 4 tuners each separated 141mm from each other have been implemented in the 1m RFQ Cold Model. These tuners could be either simultaneously or independently actuated as well as removed if less tuning rods are required to perform the experiment. The diameter of the rods is ϕ_{rod}=35mm. Finally, electromagnetic simulations have been performed in order to evaluate the effect of the slug tuning rods in the quadrupole mode. Figure 7 shows the tuning range obtained when simultaneous actuation is provided to all the rods. A significant tuning range is obtained (up to 20 MHz for a 50 mm penetration)

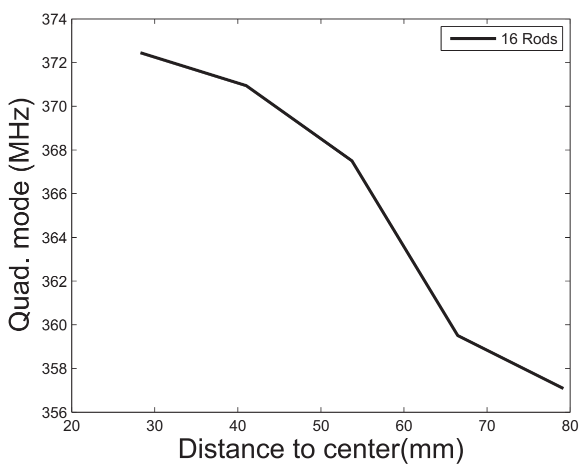

Figure 7: Variation of the quadrupole resonance frequency for different slug tuner penetration.

COLD-MODEL PROTOTYPE

On the basis of the simulation results presented, a final Cold-Model for the ESS-Bilbao Linac is presented and its complete layout for the RFQ is depicted in Fig. 8. The final dimensions of the RFQ are: L=1067.4 mm (RFQ Cold Model total length), h=w=260 mm (height and width). Moreover, the final positions for the slug tuning rods are shown in the picture.

CONCLUSIONS

A final 1 meter aluminum prototype for the ESS-BILBAO RFQ Cold Model has been successfully designed and is currently under development to be manufactured. Quadrupole resonance frequency has been set to 352.2 MHz with a minimum separation respect to the dipole modes of 5 MHz . Also, the effect of the radial matchers and radial matcher lobes on the field distribution (field flatness) has been properly studied. In addition, a very challenging element such as the vane modulation has been successfully included fulfilling the operation frequency requirements. Finally, slug tuning rods have been implemented in order to compensate a possible frequency deviation. The usefulness of all the features included in the Cold-Model will be tested once measurements could be performed.

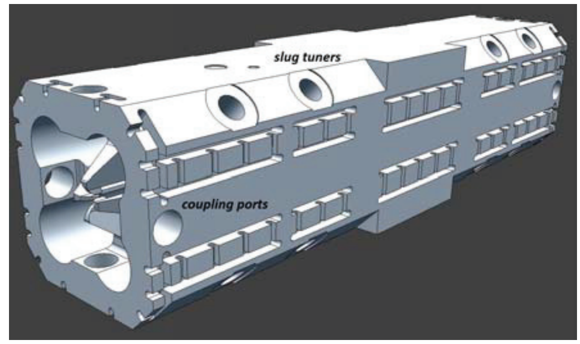

Figure 8: Layout of the ESS-Bilbao RFQ Cold-Model. Where L=1067.4 mm is the total length, h=w=260 mm are height and width, ϕ_{tuner}=35 mm is the tuner diameter and $\phi_{coupler}$=21.27 mm is the diameter of the input power ports.

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