

DESIGN OF THE RADIO-FREQUENCY QUADRUPOLE COLD MODEL FOR THE ESS-BILBAO LINEAR ACCELERATOR

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Abstract

This work presents the design of the ESS-Bilbao LINAC RFQ cold model. The process goes through the electromagnetic design of the cavity by properly setting the resonant quadrupole and dipole modes to the required resonance frequency. The prototype includes the vane modulation designed to accelerate a 75 mA proton beam from 75 keV to 3 MeV, with an operating frequency of 352.2 MHz. To this end, electromagnetic and electrostatic simulations have been performed by means of the commercial software COMSOL.

INTRODUCTION

As a part on the ongoing development of a proton accelerator for the ESS-Bilbao project [1], a radio frequency quadrupole (RFQ) [2] has been designed in order to be manufactured 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 modelling. 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 total length of the RFQ Cold Model has been set to 1m. Since the operating frequency of the quadrupole mode is set to 352.2 MHz, the cavity has been properly designed to fulfill this specification. Nevertheless, it is crucial to ensure also that other modes such as the dipole modes (usually in close vicinity to quadrupole mode in these structures) [2] do not affect the response. To this end, a complete parametric study of the frequency variation of the modes with the RFQ dimensions has been done. Figure 1 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].

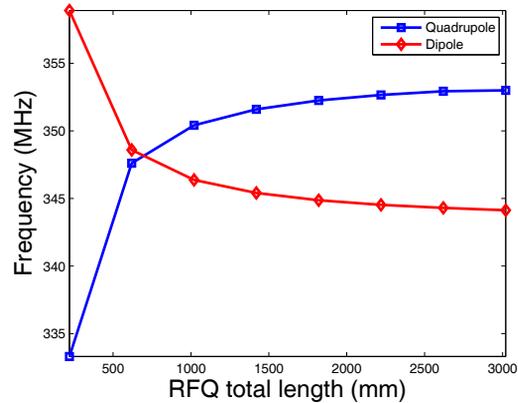


Figure 1: Variation of the RFQ resonant modes with total length

Another important constraint is the quality of the accelerating field generated by the quadrupole mode along the whole RFQ. Thus, it is very important to ensure field flatness [6]. Since the field distribution along the RFQ is seriously influenced by the shape of the RFQ endings (radial matchers) and the curvature radius of these elements is imposed by specifications a complete study of the radial matchers shape including the upper part of the resonant lobes has been done in order to ensure field flatness along the RFQ as it is depicted in Figures 2, 3 and 4.

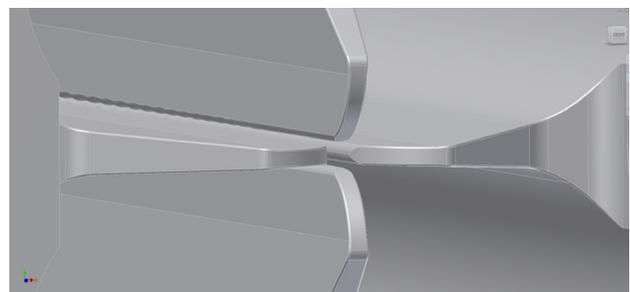


Figure 2: Detail of the radial matchers

Particles in the RFQ are accelerated by a generated alternating longitudinal field. This field is achieved by means of the vane modulation [2]. 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 4.5×10^{-3} mm (shaper) to 1.6 mm (accelerator). As it can be seen, the presence

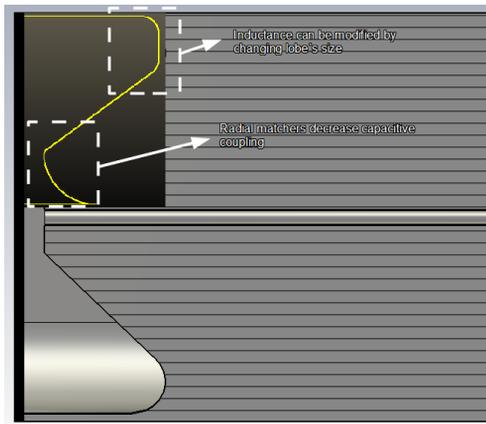


Figure 3: Radial matcher fine design

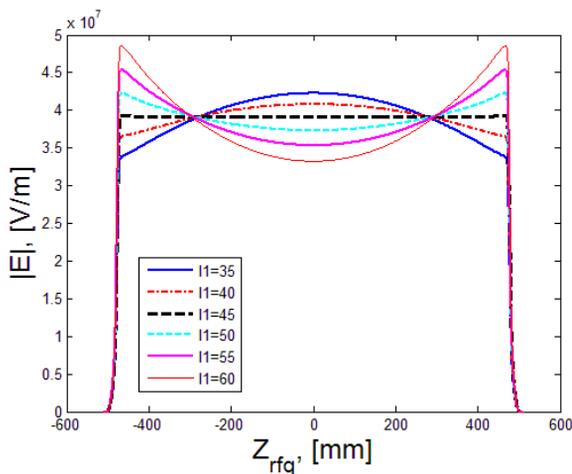


Figure 4: Variation in field flatness along a non modulated 1m RFQ regarding the penetration of the lobe inside the cavity (l)

of the modulations requires from a very accurate simulation procedure in order to obtain realistic results from electromagnetic simulations. Fine adaptative meshing strategies have been used with a high number of total meshing tetrahedros (4×10^7), which makes simulation procedure heavy and very time consuming. In addition, 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 [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 $\phi_{rod}=35\text{mm}$. Finally, electromagnetic simulations have been performed in order to evaluate the effect of the slug tuning rods in the quadrupole mode. Figure 5 shows the tuning range obtained when simultaneous actuation is provided to all the rods.

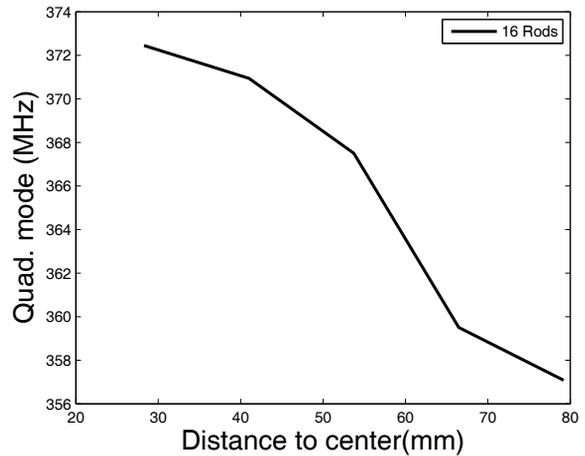


Figure 5: Variation of the quadrupole resonance frequency for different slug tuner positions

It can be seen that a significant tuning range is obtained (up to 20 MHz for a 50 mm penetration). Nevertheless, this values will not be obtained in real operation since the effect of the rods over the accelerating field has to be carefully considered. Figure 6 shows how the accelerating field provided by the resonant quadrupole mode changes when the rods approach the vane region. Thus, rod penetration in real operation will consists on a few millimetres and therefore obtaining a smaller tuning range (2-3 MHz).

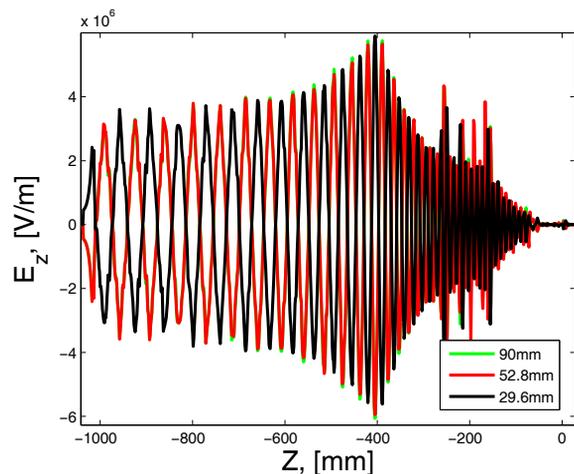


Figure 6: Representation of the accelerating field for the quadrupole mode along for different tuning levels (distance to center)

FINAL PROTOTYPE

On the basis of the simulation results presented, a final Cold Model for the ESS-Bilbao Linac is presented. The complete layout for the RFQ is depicted in Fig. 7. As it can be seen, the final positions for the slug tuning rods are

showed in the picture. The final dimensions of the RFQ are: $L=1067.4$ mm (RFQ Cold Model total length), $h=w=260$ mm (height and width).

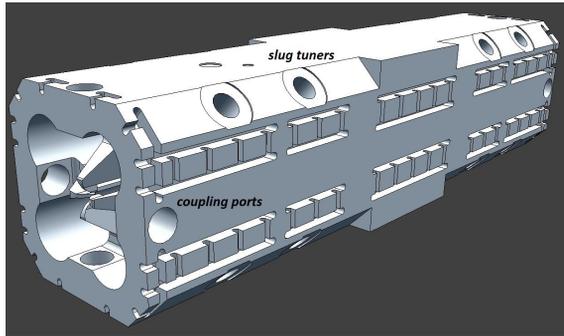


Figure 7: Layout of the ESS-Bilbao RFQ Col Model. Where $L=1067.4$ mm is the total length, $h=w=260$ mm are height and width, $\phi_{tuner}=35$ mm is the tuner diameter and $\phi_{coupler}=21.27$ mm is the diameter of the input power ports

Since the Cold Model must be driven by RF power in order to perform lab experiments, input power ports have been added in the radial matchers vicinity regions as it is also depicted in Fig 7. In this area, the magnetic field turns from one lobe to the adjacent one and the RF power can be easily coupled by a coupling ring. To this end, coaxial RF couplers have been designed and will be manufactured (Fig. 8). The diameter of the external conductor for the power coupler is $\phi_{coupler}=21.27$ mm. As it can be seen from picture Fig. 8 8 coupling ports have been placed in the structure (4 at each side). Due to this fact, different types of RF injection will be tested by changing the number of RF couplers as well as its placement.

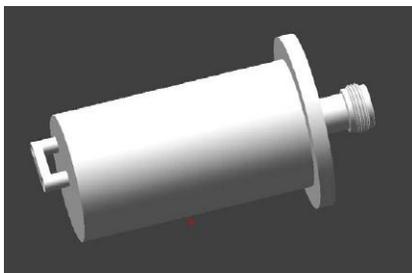


Figure 8: Layout of the designed RF power coupler

CONCLUSIONS

A final prototype for the ESS-BILBAO RFQ Cold Model has been successfully designed and is currently under development to be manufactured. Many specifications have been imposed in the Cold Model design: the first one is the quadrupole resonance frequency, which is set to 352.2 MHz. Also, field flatness case and its relations with the radial matchers design has been properly studied. In addition, a very challenging element such as the vane modulations has been successfully included fulfilling the operation frequency requirements. Finally, slug tuning rods have been implemented in order to compensate a possible frequency deviation. All these important elements taken into consideration will be able to be evaluated once measurements could be performed.

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