DESIGN AND FABRICATION OF ESS-BILBAO RFQ LINAC

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Abstract

The RFQ accelerator for ESS-Bilbao is presented. This device will complete ESS-Bilbao injection chain after the ion source and the LEBT. The design was finished in 2015. Machining of the accelerator cavity was started in 2016. The RFQ is a 4-vane structure, aimed to accelerate protons from 45 keV to 3.0 MeV and operating at 352.2 MHz. Total length is about 3.1 meters, divided in 4 segments, which components are assembled by using polymeric vacuum gaskets. The design is presented, including snapshots of beam dynamics, RF cavity design, field flatness and frequency tuning. Cooling and thermo-mechanical design is also described.

INTRODUCTION

ESS-Bilbao is the institution designated to supply Spanish in-kind contribution to European Spallation Source ERIC (ESS). Contributions involve the accelerator (MEBT), the target and instruments. In addition to the in-kind contributions, local projects are also under development, with the main goal of testing components to ESS project and become the first stages of a future accelerator.

Local activities are related to the setting-up of a proton injector, consisting on an ECR ion source and a LEBT [1] already in operation, followed by a RFQ linac, presented in this communication.

The ESS-Bilbao RFQ design was carried out by a local team taking the designs for ISIS-FETS and Linac4 RFQs as references. After a review by a panel of experts in 2013, the RFQ underwent a major revision in design that resulted in the present design. A Technical Design Report with all the design process and modifications can be found in [2].

The RFQ is a 4-vane structure. It has a total length of about 3.1 meters, divided in 4 segments, that are themselves formed by 2 major and 2 minor vanes, assembled together by using polymeric vacuum gaskets instead of brazing or other welding system. The RFQ is currently under fabrication, and first tests are expected to start during 2017.

RFQ CHARACTERISTICS

ESS-Bilbao RFQ is designed to accelerate protons from 45 keV to 3.0 MeV. It is a pulsed machine, operating at 352.2 MHz, with an expected duty cycle in operation of 4% (designed up to 10%). Its main characteristics can be found in Table 1.

The RFQ is split in four segments of around 800 mm length each for easier machining. Each segment is itself an assembly of four components, two major vanes and two minor vanes (Fig. 1), assembled by means of polymeric vacuum gaskets with no brazing or welding. This is the same strategy as ISIS-FETS RFQ [3].

Table 1: ESS-Bilbao RFQ Main Characteristics

	ESS-Bilbao 2015 design
Type	4 vane
Particle	Protons
RF frequency	352.2 MHz
Intervane Voltage	85 kV (uniform)
Energy	45 keV → 3.0 MeV
Design current	60 mA
Input emittance	0.25 π mm mrad
Duty cycle	Up to 10%
Kilpatrick factor	1.85
Number of cells	273
R0	3.44 mm
ρ/R0	0.85
Input/Output matcher	16.674 mm / 14 mm
Total length	3.12 m (3.66 λ)
Number of segments	4 (about 800 mm each)
Method of assembly	Polymeric vacuum gaskets
Plunger tuner ports	16 / segmen

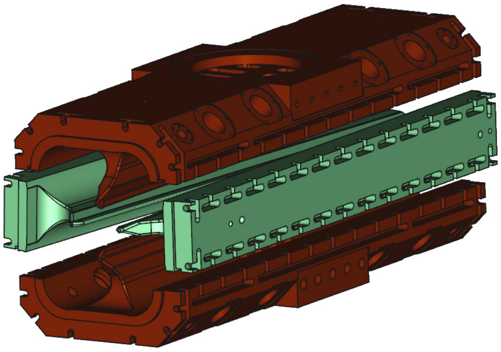

Figure 1: Exploded view of first segment vane.

In each segment there are 16 tuner ports (Ø37 mm) that can be used for static plunger tuners. The power coupler flange also fits in these ports, so that they can be inserted in any position. Additionally, 8 Ø16 mm ports are built in order to be used for pick-ups or other sensors needed at

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any moment. Vacuum grid ports are for standard Ø21 mm flanges. All ports are machined in the so-called "major vanes".

Additional details on fabrication can be found in [2,7] and references therein.

MODULATION

The ESS-Bilbao RFQ modulation is the result of an optimization process. The modulation is designed for an intervane voltage of 85 kV, uniform throughout the entire length. Vane radius (ρ) is also constant, so to obtain a uniform local frequency and field flatness the mean aperture R_0 should also be constant. Modulation shape is based on a 2-term expansion and has been designed using a modified version of RFQSIM code [4].

From the 2-term interpolation of the modulation points, full-vane 3D geometry is built in COMSOL Multiphysics software. FEM electrostatics models are then built cell by cell to compute surface electric field (Kilpatrick value) and local frequency. Full-length electrostatic simulations were done to export electric field for particle tracking analysis using GPT [5].

After several optimization steps, final modulation is obtained. Results are then cross-checked using different codes (Toutatis, PARMTEQ / RFQGen). Some characteristics of the modulation can also be found in Table 1. The dependence of some of them with cell number is shown in Fig. 2.

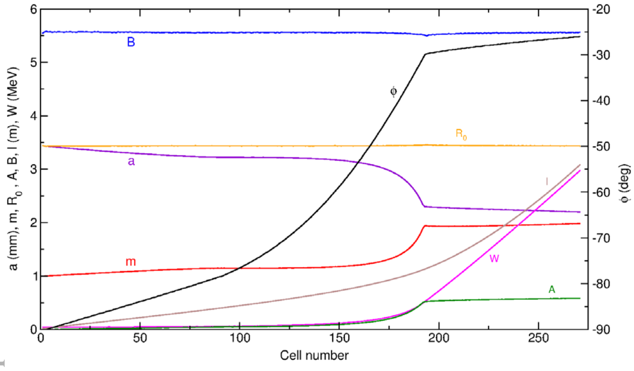

Figure 2: Evolution of modulation parameters vs cell number.

The value of surface electric field was kept by design below, but close to, 34 MV/m (about 1.85 Kilpatrick) to shorten RFQ length. The local (cell-by-cell) resonant frequency was targeted to be as constant as possible. These figures of merit, computed using 3D vane geometries created by scripting and COMSOL simulations [6] can be seen in Fig. 3.

See full description in [2].

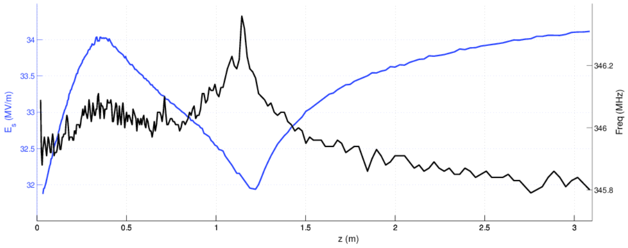

Figure 3: Dependence of surface electric field (left) and cell resonant frequency (right) as a function of z.

CAVITY DESIGN

Cavity Cross-Section Design

The cross section of the cavity is based on the circular lobe approach used by ISIS-FETS [2], but with modified straight vane tips. Mechanical constraints like the width of copper blocks, cooling channels diameter and corresponding wall thickness restricted the parametric optimization. The design frequency for the 2D models was chosen to be 348.6 MHz (several MHz below operating frequency) to avoid problems due to machining.

Final dimensions were selected by a parametric optimization where one parameter was let free to match the frequency. Optimization process aimed at cavity maximizing quality factor. A sketch of the cross section with selected dimensions is shown in Fig. 4.

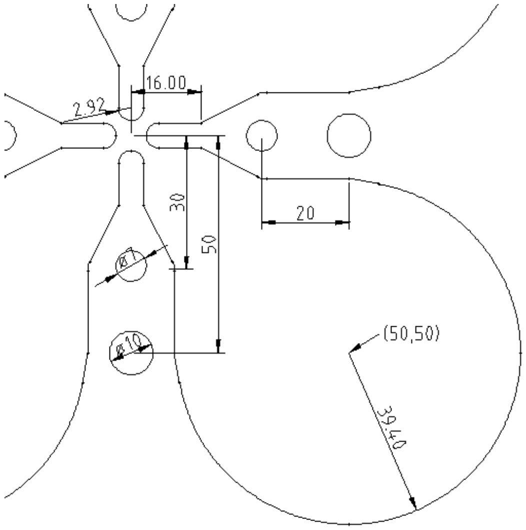

Figure 4: Sketch of a portion of the RFQ cross section, showing some dimensions.

3D Cavity Design

The 3D body of the cavity is constructed by extruding the cross-section, adding the vane modulation solids, the input and output regions and other details like tuner and vacuum ports. Again, the shape has been optimized by finite element simulations aiming at reducing power deposition. Full details can be found in [2].

RFQ TUNING

Static Tuning

Static tuning of the RFQ is to be provided by a set of plunger tuners. For each segment of 800 mm there are 4 sets of 4 tuner ports, so a maximum of 64 tuners could be installed in the whole length (two ports will be used by the power couplers). The static tuners will rise cavity frequency to the operative value keeping the voltage profile as flat as possible (field flatness).

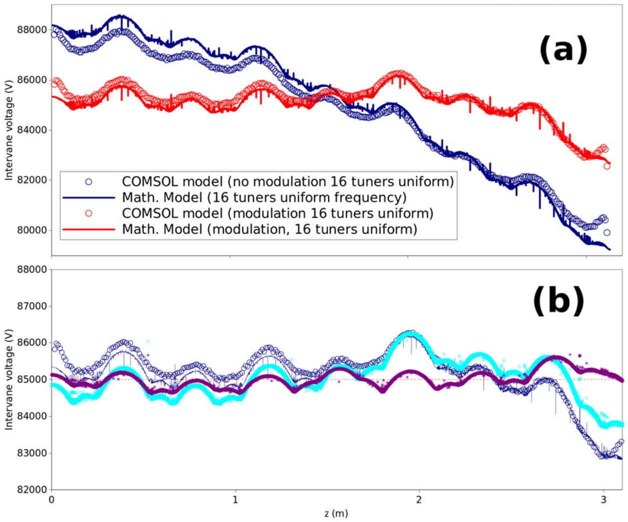

Figure 5: Mathematical model compared to FEM simulations. See text for details.

A transmission line model, calibrated by comparison to FEM simulations of the whole length of the RFQ, has been developed. This model allows to quickly compute the optimum penetration of tuners to compensate any field profile deviation. The model takes as input the modulation, cut-offs and any other local frequency perturbation. Examples of the comparison of voltage profiles obtained with the model and with whole length FEM models are shown in Fig. 5a. This tool has also been used to optimize output cut-off geometry (Fig. 5b).

Dynamic Tuning and Cooling Design

The RFQ is water cooled. The cooling removes the excess heat and also is used to fine tune the RFQ cavity during operation by controlling the thermal expansion driven frequency changes.

Cooling channels and temperature distribution for a duty cycle of 5% are shown in Fig. 6. At this duty, power deposited is 937 W in the simulated quarter, 3.75 kW in one segment and 15 kW in the whole RFQ wall (no considering tuners). Cooling circuit include longitudinal channels along vanes and dedicated circuits for the vacuum grid. Plunger tuners are also water cooled.

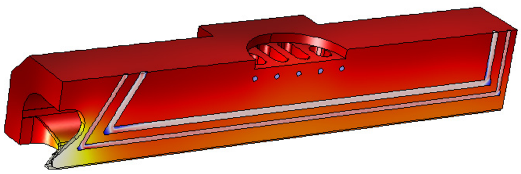

Figure 6: A quarter of first segment showing temperature map in the copper and water velocity in channels.

Dynamic control will operate varying the input temperature of cooling water. By coupled multi-physics simulations including RF, heat transfer, CFD, thermo-mechanical deformation and mesh updates, the thermal detuning can be computed. Control algorithms have been designed to operate on a closed loop. An example of a power on-power off transitory is shown in Fig. 7.

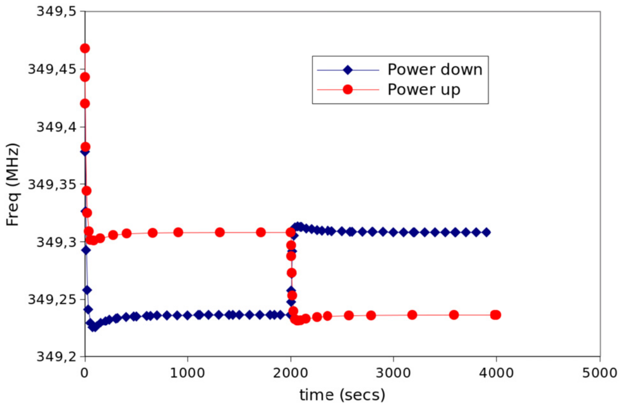

Figure 7: Cavity change in frequency due to a power up or power down. Frequency value does not consider plunger tuners.

CONCLUSIONS

ESS-Bilbao RFQ design has been summarized. Fabrication was started in 2016 and initial tests are planned for 2017.

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