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EXPERIMENTAL TESTS WITH THE FIRST SEGMENT OF ESS-BILBAO RFQ LINAC*

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Abstract

The ESS-Bilbao RFQ is an assembly of four segments, each one about 800 mm in length. The first segment has been manufactured before the others, so it could be thoroughly tested in order to validate the chosen technological approach for the RFQ, as it uses polymeric vacuum gaskets and bolts instead of brazing. In this paper we report on the tests run with the segment and their results. Vacuum tests, metrology measurements, low power RF tests as well as extensive tuning tests measuring the cavity resonant quadrupolar frequency as a function of cooling water temperature have been done. Experimental results are compared to the expected values obtained from numerical simulations. We describe the experimental set-ups for the measurements and the simulations. Results are analyzed with the aim of validating the design, and to provide predictions for tuning and operation of the whole RFQ. Because of the positive results of the tests reported here, the manufacturing of the remaining segments has already started.

INTRODUCTION

In addition to the in-kind contributions to the European Spallation Source ERIC, ESS-Bilbao develops local projects. The ESS-Bilbao injector is a proton injector that consist of an ECR (Electron Cyclotron Resonance) ion source and a LEBT (Low Energy Beam Transport) system, already in operation [1]. This injector will be completed with an RFQ linac [2], that will accelerate the beam up to 3 MeV.

The RFQ operates at 352.2 MHz with a duty factor up to 10%. It has a total length of about 3.1 m, and it is separated in 4 segments, each one about 800 mm in length. Each segment is itself an assembly of four components: two major vanes (where all ports are machined) and two minor vanes. These vanes are assembled using polymeric vacuum gaskets, without using brazing. The first of the segments was fabricated in advance to study it in detail before the remaining three segments were machined. This paper reports the results of these tests (vacuum, RF measurements, including tests with cooling water in steady and transient regimes) and the analysis using simulation codes.

VACUUM TESTS

Vacuum tests were run with the assembly of RFQ-S1. The aim of these tests was to verify that the correct vacuum levels can be achieved using the O-ring system, with gaskets used on all contact faces (vane-vane and vane-end covers). The results obtained have been positive, reaching a good leakage rate, <2e-10 mbar l/s. The test was performed without connecting the turbo-molecular vacuum pump, but simply using a primary pump connected in parallel with the leak detector (see Fig. 1). The final tests, that will confirm which leak tightness level can be achieved in the RFQ under operating conditions, must be done when all the vacuum grooves are machined. For this, the correct alignment of the four vanes in the assembly must be previously carried out.

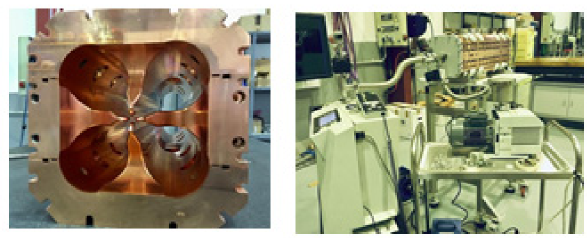

Figure 1: Left: A picture of the assembly of segment 1 of the RFQ. The channels for the O-rings and for the RF contacts can be seen. Right: Vacuum leak tests of segment 1.

FREQUENCY MEASUREMENTS

The aim of the low power RF measurements is to determine the resonant frequencies of the main modes of the segment. As the first segment alone does not constitute a properly tuned resonant cavity by itself (it does not have the resonator's undercut that ends segment 4), an attachment is adapted in the rear end of the segment in order to simulate an adequate ending of the cavity.

The attachment consists of a movable plunger that creates a capacitive coupling with the vanes. The frequency of the section can be controlled modifying the distance between the vanes end and the plunger, so the segment 1 cavity field flatness can be properly tuned this way. The experimental device was fabricated in aluminum. An exploded view of the system can be seen in Fig. 2.

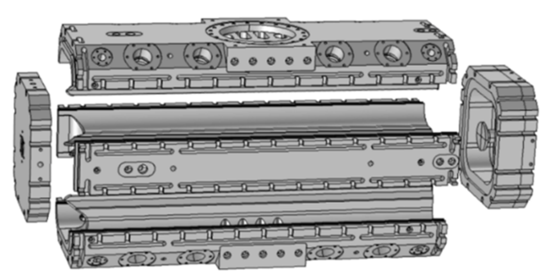

Figure 2: Exploded view of segment 1 with the plunger cover used for RF tests.

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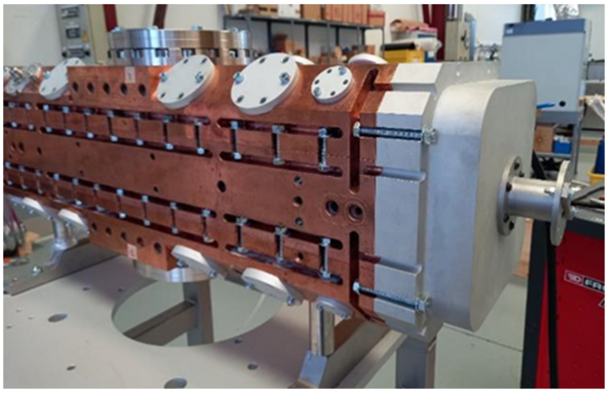

Figure 3: Segment 1 with the plunger cover in position, ready por RF tests.

A picture of the segment during tests can be seen in Fig. 3. The frequencies measured (the quadrupolar fundamental mode frequency and the first two dipolar frequencies) are collected in the experiment. Their values will depend on the plunger position (see Fig. 4), as the distance between the vane ends and the plunger changes the capacitance and the local frequency. The optimum position will be the one that results in a frequency that matches the segment design frequency without tuners and a flat field profile. This is determined with the help of numerical simulations of the system.

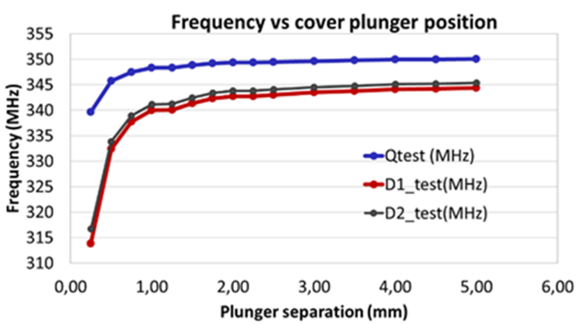

Figure 4: Quadrupolar and dipolar modes frequencies as a function of back plunger distance to the vane ends.

Frequency values are also dependent on the assembly of the vanes. If there are asymmetries or mechanical deformations, the values of the dipolar modes will reflect this. Measurements for different assemblies (Fig. 5) reflect consistently a difference of about 1 MHz between the two dipolar modes. These frequencies should ideally be the same for an RFQ with no asymmetries, and the difference is expected to be around 0.1 MHz for the actual segment 1, due to the vacuum ports, modulation and other issues, as will be discussed later this paper.

METROLOGY ANALYSIS

In order to understand the results, a measurement of the geometry of the assembly was done. The profile of the vane tips at the front and rear ends of the segment were measured and analyzed. The diameters of the vane tips were obtained by fitting 3D geometric data to the semicircular cross section of the vane tips. The distances (horizontal or vertical) between the vanes were also obtained this way. The assembly description obtained this way was combined with the geometry of the individual vanes (done by the manufacturer).

The deviations were incorporated in a numerical FEM model of the segment and plunger system. Deviations were applied as a deformation of the computational mesh. The results (see Table 1) reproduce quite well the measured frequency values. This allowed us to estimate which deformations come from mechanical errors in the machining of the vanes and which could be attributed to the assembly of them to conform the segment. The assembly procedure was complicated by geometric deformations in the external flat surfaces of the vanes, that are used as reference and fixed planes to assist in the assembly.

A comparison of the frequencies obtained in the measurements and the simulations with deformed meshes can be seen in Table 1. Frequency values are slightly different because not all the details are included in the simulation models, but the relative difference between the two dipolar modes can be explained considering the vane tips deformations and the vanes displacements. The analysis also suggested the assembly operations needed to achieve an optimum assembly.

Finally, numerical models of the whole length of the RFQ were produced this way, to anticipate the required tuning operations to be done when segments 2-4 are machined.

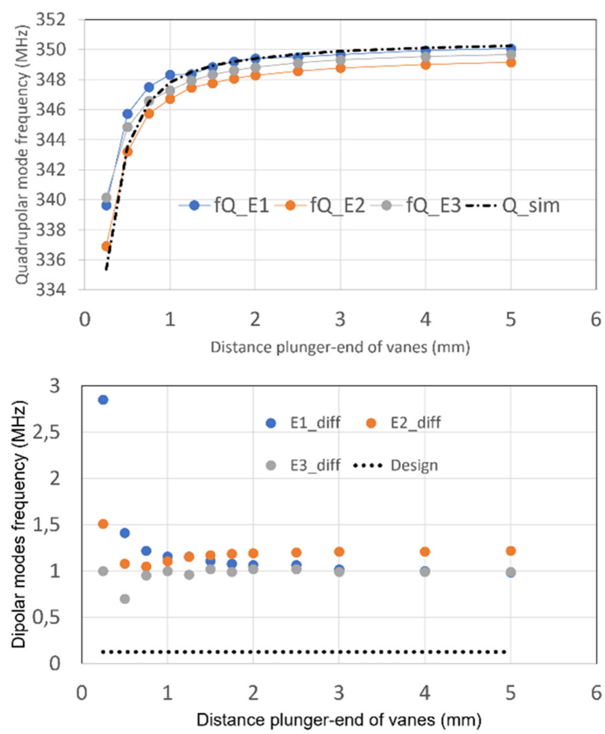

Figure 5: Measured quadrupolar frequencies (up) and dipolar frequencies difference (down) as a function of plunger position, for different assemblies. The values expected from simulation are plotted as a dashed line.

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Table 1: Frequency Values at Different Assemblies and by Simulations

	Dipolar 1	Dipolar 2	Quadrupolar
E1	337.72	338.94	347.5
E2	334.978	336.028	345.741
E3	336.484	337.434	346.703
S1	335.241	335.3758	346.556
S2	335.294	335.4745	346.641
S3	334.386	335.364	346.143

RF MEASUREMENTS WITH WATER TEMPERATURE

Cavity frequency (segment 1 with the plunger cover attached) was measured as a function of cooling water temperature. The RFQ has three different types of cooling channels: channels type 1 and 2 run along the vane tip, while channels type 3 cool down the vacuum grid. As there are no channels specifically included to control the temperature of the RFQ body due to the mechanical design, the experimental tests summarized here were carried out in order to validate the control operation. A schematic of the experimental set-up is shown in Fig. 6.

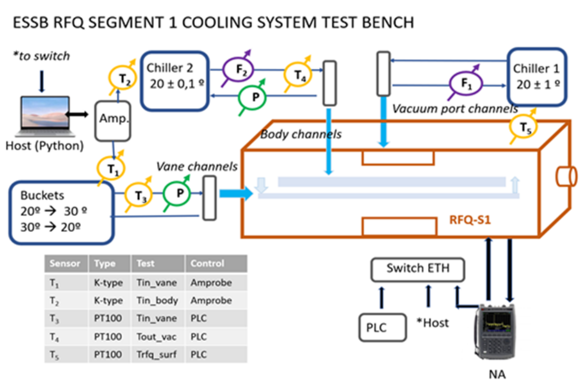

Figure 6: Schematic of the experimental setup for the frequency measurements as a function of cooling water temperature.

For the tests, all channels of the RFQ-S1 were fed with water controlled in flow and temperature. All magnitudes were collected and stored. The most relevant experiment was the transient operation (step response). For this test, all channels were kept at a constant 20 ºC water temperature, while channels type 1 (that run closer to the vane tips along each of the vanes) were kept steady at 30 ºC until water temperature was suddenly changed to 20 ºC (Fig. 7). The analysis of such a unit-step transient allows to determine the transfer function of the frequency vs temperature system, needed to design the dynamic control of the RFQ operation using cooling water.

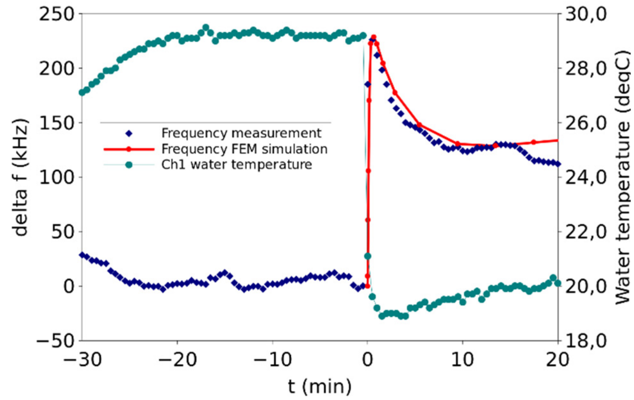

Figure 7: Transient evolution of the quadrupolar frequency change of segment 1 during a unit-step transition from 30 ºC to 20 ºC. Measurements are compared to simulations results.

A simulation model, including the transient operation described above, was calibrated with the measurements. The model validated this way (see Fig. 8) will be used to simulate the dynamic electromagnetic and thermomechanical behavior of the full length of the RFQ.

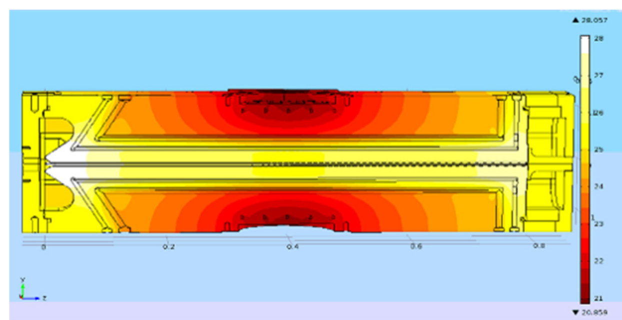

Figure 8: Temperature map of the simulation model calibrated with the measurements.

CONCLUSIONS

A thorough characterization of the first segment of the ESS Bilbao RFQ has been key to validate the technological approach and launch the manufacturing of the remaining segments.

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