RF MEASUREMENTS AND NUMERICAL SIMULATIONS FOR THE MODEL OF THE BILBAO LINAC DOUBLE SPOKE CAVITY

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Abstract

A model of a double spoke resonant cavity (operating frequency 352.2 MHz, β_g=0.39) has been designed and fabricated in aluminium. The RF characteristics of the cavity have been measured in our laboratory. Experimental measurements have involved the determination of the main cavity parameters, and the characterization of the accelerating electric field profile along the cavity axis by means of a fully automated bead-pull method. Additionally, numerical simulations using COMSOL code have been used to fully characterize the cavity. Electromagnetic numerical simulations of the cavity have been also performed to determine its main figures of merit and to identify the most suitable position for opening a port to install a power coupler. In this paper we report the cavity cold model description, the experimental setup and corresponding techniques, together with the numerical methods. The obtained results are described and discussed in detail.

INTRODUCTION

ESS-Bilbao light ion linear accelerator [1] is conceived as a multipurpose machine that will be the core of a standalone accelerator facility in southern Europe and that fulfils the specifications for a driven injector for ESS. The accelerator is designed to be modular and should serve as a benchmark for components and subsystems relevant to the ESS project. The present ESS-Bilbao linac design includes two ion sources (for H- and H+/D+ ions), a normal conducting section including a LEBT, a RFQ (up to 3 MeV) and a three-tanks DTL (up to 50 MeV), followed by a superconducting section composed on a first stage of double (DSR) and triple spoke cavities [1, 2]. DSR cavities will be equivalent to the ESS project ones. As a first step, a model of a DSR $\beta_g = 0.39$ cavity has been designed and built in aluminium by Elytt Energy. This cavity model will be used for testing numerical tools and experimental measurements techniques like the bead-pull method test stand setup. In this report electromagnetic simulations results as well as experimental test stand and some obtained results are described in detail.

ELECTROMAGNETIC SIMULATIONS

The cavity geometry CAD model is shown in Fig. 1. Cavity has a total length of 534 mm ($3/2\beta\lambda = 498mm$) and an internal diameter of 408 mm and includes an aperture of 60 mm in diameter.
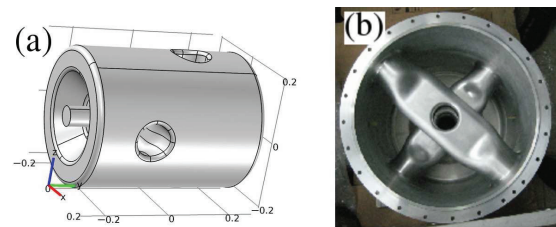

Figure 1: Schematics of CAD model (a) and photograph of its interior showing the two spoke bars (b).

The model has been simulated using COMSOL Multiphysics [3] electromagnetic solver. The computed frequency of the first mode is 352.11 MHz (a comparison of computed and measured magnitudes is given in Table 1). Arrow maps of electric field vector for the three first modes are provided in Fig. 2, together with longitudinal electric field component along the axis.
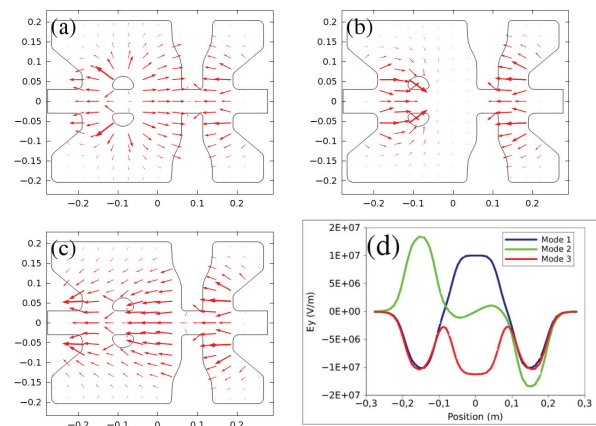

Figure 2: Arrow maps of the three first resonant modes of the cavity: (a) π mode 352.11 MHz, (b) $\pi/2$ mode 394.58 MHz and (c) 0 mode 469.30 MHz. (d) Longitudinal electric field profiles of the three modes.

Cavity quality factor Q_0 is computed from the solved fields as $Q_0 = \omega W/P$, where W is the total stored electromagnetic energy and P is the power loss computed as

$$P = \frac{1}{2}R_s \int_S H_{\parallel} dS \qquad (1)$$

integrating over all the boundary surfaces. The value of R_s (aluminium, 300K) is 0.062 Ω and the corresponding quality factor is then $Q_0 = 14074$ (see table 1). Taking

Accelerator Technology
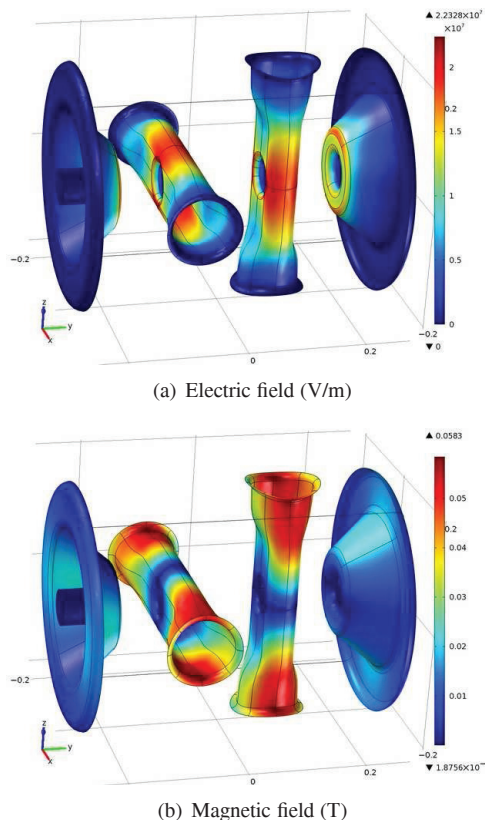
Tech 07: Superconducting RF
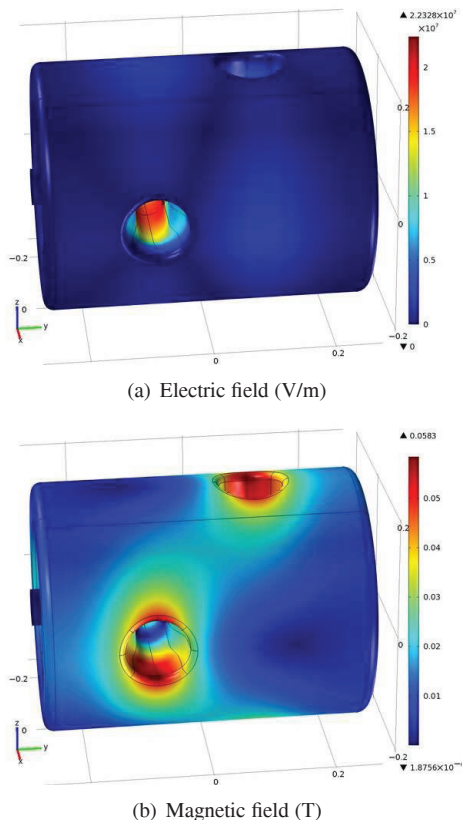
(a) Electric field (V/m)

(b) Magnetic field (T)

Figure 3: Surface **E** (a) and **B** (b) fields in the fundamental mode of the cavity. Magnitudes are scaled to an equivalent energy gain of 2.4 MeV in the cavity.

(a) Electric field (V/m)

(b) Magnetic field (T)

Figure 4: Surface **E** (a) and **B** (b) fields in the fundamental mode of the cavity for the internal surfaces of the model. Magnitudes are scaled to an equivalent energy gain of 2.4 MeV in the cavity.

the R_s obtained for Nb (using BCS derived formula) at 4.2 K instead, the Q_0 of a geometrically equivalent Nb cavity would increase up to $Q_0 = 1.5 \cdot 10^9$.

In order to gain knowledge for the design of real Nb spoke cavities it is also interesting to study the distribution of surface fields. The maximum performance of the cavity in terms of accelerating gradient is limited by the maximum field values on the Nb surface. A common choice for these limits is $E_{s,max}$=25 MV/m and $B_{s,max}$=66 mT. The surface electric and magnetic fields are shown for the outer surface of the cavity in Fig 3. Fields have been scaled to yield an energy gain of 2.4 MeV (for β_0=0.39 and ϕ=0 and a conservative accelerating field of 4.8 MV/m). The value of electric field in the external surface is not very high, as is expected because the electric field should be maximum in the beam axis region for accelerating purposes. Magnetic field appears to concentrate around the contact area between the spokes and the external surface.

To clarify this point in Fig. 4 the surface fields for the spoke bars are shown. Electric field is concentrated on the lateral side of the spoke bars, while high magnetic field surfaces appear in the extremal parts of the the spokes. According to these pictures, the critical design aspects concerning maximum fields are focused on the spoke bars. Important information concerning how to proceed to improve

the cavity in future designs can be extracted from these field maps and profiles.

LOW POWER RF MEASUREMENTS

The cavity model has been experimentally characterized using the perturbation method by means of the system set-up shown in Fig. 5 and 6. This test bench consist of a cradle to support the cavity under test and to align the kevlar wire with two handles, a DC motor to control the position of the bead, a computer connected to a CompactRIO to automatize the movement of the motor and a network analyzer to measure frequencies and S parameters. In order to synchronize accurately the bead position via the motor and data acquisition by the network analyser, a control program has been implemented using LabVIEW.

RF measurements have been performed with a rotary loop antenna coupled to the magnetic field of the mode and tuned in a critical coupling condition. Table 1 shows the simulated and measured results of the cavity frequencies and the unloaded Q_0 for the fundamental mode. The differences found can be a consequence of the cavity mechanical structure design, since the cavity is composed of four aluminium pieces joint by screws.

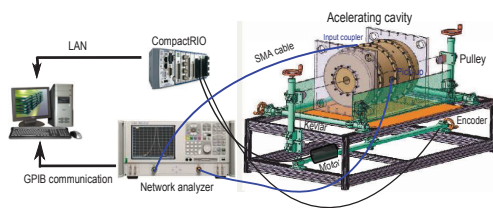Figure 5: Cavity bead-pull test bench implementation.

Figure 6: Cavity bead-pull test bench schematics.

The electric field profile along the beam-axis is obtained by applying the Slater's perturbation theorem based on the indirect frequency shift measurement, with a longitudinal displacement step of 2.5 mm. The simplified formula for the case of a dielectric perturbation bead has been used [4, 5]. The measured **E** distribution along the axis for the fundamental mode is shown in Fig. 7. Higher order modes (HOM), $\pi/2$ @394 MHz and 0 mode @469 MHz are compared with the fundamental mode in Fig 8. The comparison shows very good agreement between simulated and measured outcomes. The HOMs play an important rule in terms of cryogenic losses and beam stabilities. We can verify that the HOM frequencies are very far from the fundamental one, which is one of the advantages of the spokes compared to elliptical cavities.

Table 1: Comparison of Numerical and Measured Results for the Frequency of the Modes and Cavity Q_0 for the Fundamental Mode

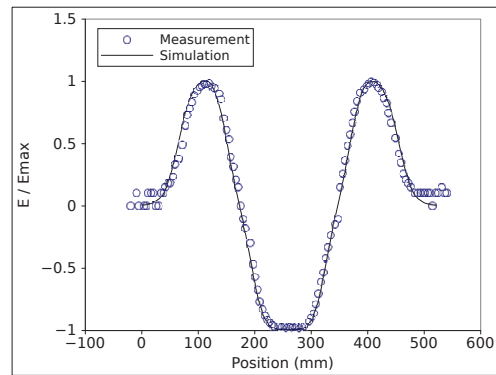| Magnitude	Simulation	Measured
frequency π mode (MHz)	352.11	351.74
frequency $\pi/2$ mode (MHz)	394.58	394
frequency $zero$ mode (MHz)	469.30	469
Q_0	14074	10975

Figure 7: Comparison of normalized electric field values along the cavity axis obtained by numerical simulations and bead-pull technique measurements.
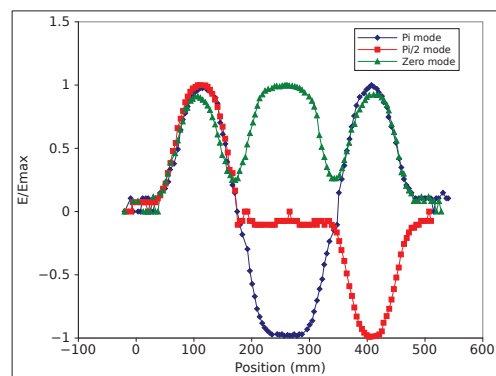

Figure 8: Measured electric field profiles for the first three resonant modes of the cavity.

CONCLUSIONS

A model of a double spoke cavity has been designed and built in aluminium. 3D electromagnetic simulations and RF measurements have been performed showing good agreement between them. This activities helped to develop the bead-pull method test bench and to gain experience in RF measurements of cavities. The simulation results points out the way of improving the design of future spoke cavities to be used by ESS-Bilbao.

REFERENCES

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