STUDIES ON A PLUNGER TUNER SYSTEM FOR A DOUBLE SPOKE CAVITY MODEL

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Abstract

ESS-Bilbao proton linac warm section will end at 50 MeV. A cryomodule with two double spoke cavities, currently in R&D stage, will be tested at that energy. The two spoke cavity prototypes to be built will be fully compatible with the ESS project spoke cavities (β 0.57). Different tuning systems will be studied for ESS spoke resonators, and one alternative is the use of plunger tuners. In this paper, a study of this kind of tuners on DSR cavities is presented, including electromagnetic and thermal simulations. These results will be tested experimentally on the β 0.39 DSR aluminium model built at ESS-Bilbao within this year.

INTRODUCTION

ESS-Bilbao light ion linear accelerator [1,2] 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.

In the present ESS-Bilbao linac design the normal conducting section ends at an energy of 50 MeV. A superconducting section will follow, and the first step is to build two prototypes of SC double spoke resonator cavities (DSR) and a cryomodule to test them with beam at 50 MeV.

The DSR cavity prototypes will be equivalent to the ESS project ones and will have the same RF design, increasing in this way the cavities statistics for this European project [3]. Apart from the RF design, other aspects of the cavity will be different in order to test diverse approaches to, for example, mechanical stiffening or tuner system.

During the last years spoke cavities have received an increasing interest for their application in high power proton linacs ([4,5]). About the frequency tuning system for these cavities, the usual approach has been to use cavity deformation. In addition to this conventional method, a niobium plunger tuning system will be considered for ESS and ESS-Bilbao prototypes. This method has been successfully designed and tested for Spiral-2 QWR cavities [6]. The plunger tuners must be built in niobium and kept at 4.2 K during operation.

In this report electromagnetic and thermal simulations results for a plunger tuning system in a DSR cavity are presented.

SIMULATION DETAILS

The electromagnetic design and simulations of the tuner have been done using the β=0.39 DSR cavity model made in aluminium in ESS-Bilbao [7]. The plunger tuning system will be tested at room temperature also in this cavity model.

Codes Accuracy

Numerical simulations have been done using COMSOL Multiphysics software [8]. As the accurate calculation of surface fields and frequencies is critical for the design process of the Nb plunger tuner, a benchmark of the simulation code has been performed, using the same procedure than K. Tian in [9], where simulation results obtained using different codes are compared with models with known analytical solution (a sphere of radius 10 cm). Our results are shown in Fig. 1. The obtained accuracy for frequency and for surface magnetic field is of the same order of the best results shown in [9].

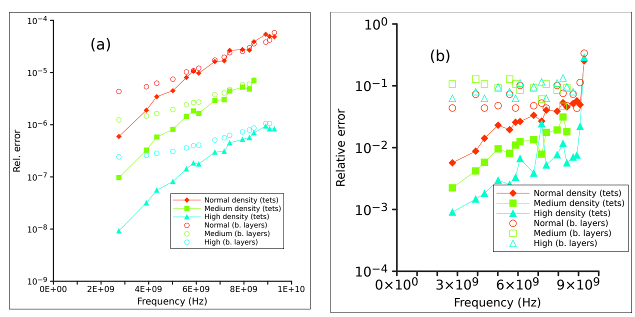

Figure 1: Accuracy of the numerical values of resonant frequencies and magnetic surface fields for a 10 cm radius sphere compared to analytical values. Accuracies are of the same order than the best reported in reference [10].

Simulations of Cavity with Tuners

General details on the model cavity modes and field profiles (numerical and measurements) have been described elsewhere [7]. All simulations have been done using COMSOL and MATLAB as scripting language. Plunger tuners are simulated as cylindrical volumes subtracted from the main vacuum of the cavity. The location of the plunger in the cavity is described for each of the cases studied.

Cavity Field Distribution

The change on resonant frequency introduced by the plunger tuner can be described, for small changes, using Slater theorem:

$$\Delta\omega = \frac{\omega_0}{4U}\iiint_{removed}\left(\frac{B^2}{\mu_0} - \epsilon_0 E^2\right)dV$$

so if tuner is introduced in region of predominance of magnetic field energy frequency will rise, and vice versa. The distribution of electric and magnetic fields is shown in Fig. 2.

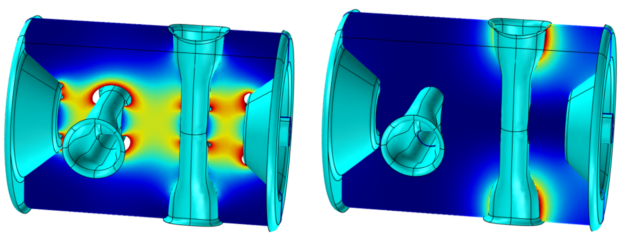

Figure 2. Distribution of electric field energy density (left) and magnetic field energy density (right), with the same colour scale, for the π mode (352.2 MHz) of the cavity.

According to Fig. 2, two approaches can be taken. One is to introduce the tuner perpendicular to a spoke bar, decreasing frequency, and the other is to introduce them from the cover side, raising the frequency. Both approaches will be described.

RESULTS

Plunger Tuner Through the Cavity Side Wall

The first point to study is the longitudinal position of the tuner. Three positions have been studied (Fig. 3a). Plunger diameter is 35 mm. The strongest effect on cavity frequency is obtained for the tuner directly perpendicular to a spoke bar. In this position the effect on the frequency is negative, as the volume removed corresponds to mainly electric field energy. For the plunger in the centre, the effect changes from positive to negative due to the complex fields distribution inside the cavity volume. Similar results are obtained inserting the plunger at different azimuthal positions, for each of the longitudinal positions considered (Figs. 3b,c,d). According to the change of frequency, the most interesting situation corresponds to the one perpendicular to the spoke bar, although other issues must also be taken into account, like for example the perturbation effect on the accelerating electric field symmetry. This should be studied in future activities.

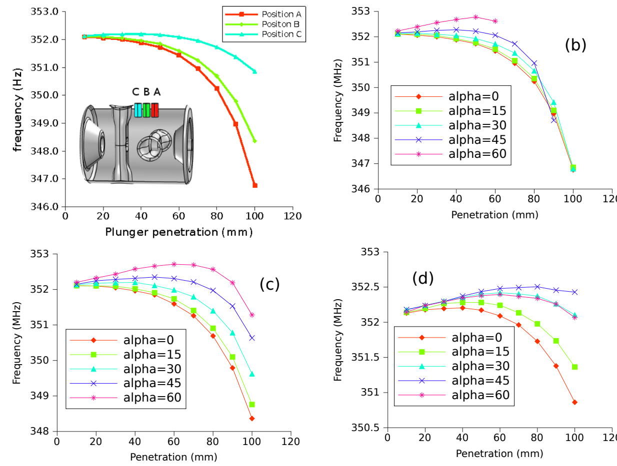

Figure 3: Resonant frequency variation of the cavity (a) when a plunger tuner of 35 mm diameter is inserted in different positions. Frequency change for different azimuthal angles and the longitudinal positions described in (a).

Plunger Diameter and Number of Plungers

The effect on the frequency will of course be dependent on the plunger tuner diameter, as according to Slater theorem the change in frequency depends on the volume removed. As is shown in Fig. 4, the bigger the plunger the higher the effect. The best strategy in choosing the right diameter should be to choose the smaller one able to provide the desired frequency range. With the use of more than one plunger the same change in cavity volume can be obtained with plungers of less diameter. This effect is shown in Fig. 5. The use of more than one plunger can, however, be limited by the increased difficulty for cooling and positioning inside the cryomodule and stepping motor operation.

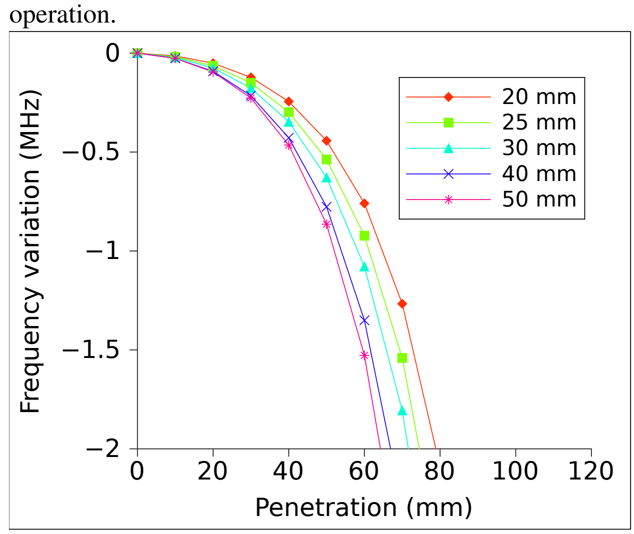

Figure 4. Change of frequency introducing one plunger of perpendicular to a spoke bar, for different plunger radii.

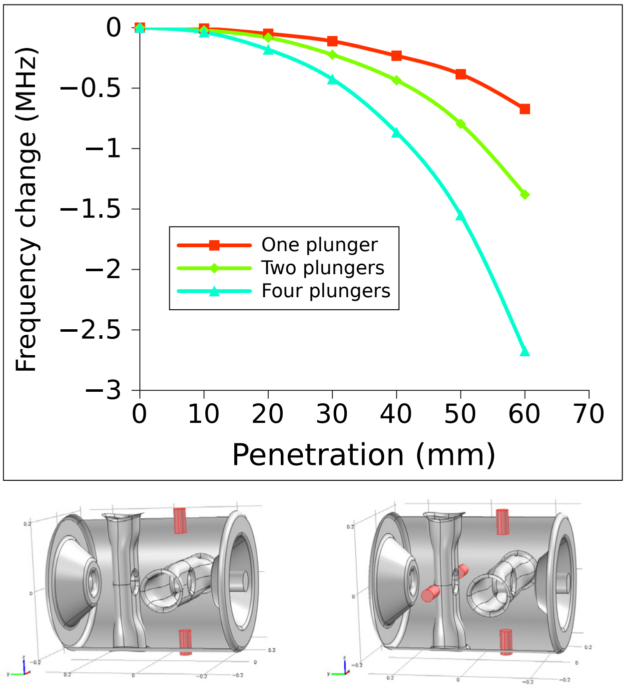

Figure 5. Effect of the number of tuners (of 35 mm diameter) in the cavity frequency. Tuner positions are depicted in the drawings shown.

Plunger Tuners Inserted Through the End Covers

As mentioned above, the effect of the plunger tuners insertion perpendicular to the bars will be of decreasing the resonant frequency. If a frequency rise is preferred, the tuners could be inserted perpendicular to the cavity end covers, removing volume of high magnetic energy and increasing frequency. This is shown in Fig. 6.

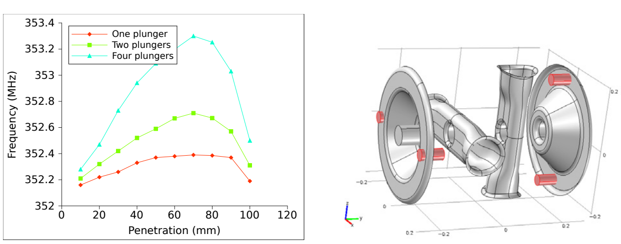

Figure 6: Effect on frequency of introducing plungers through the end covers of the cavity, as depicted in the drawing.

Power losses

The insertion of the plungers modifies the field profiles and increases the cavity effective surface, so power losses generated in the plunger surface must also be calculated. With the plungers entering the cavity through the lateral walls perpendicular to the spoke bar, the vacuum volume removed has not a predominance of magnetic field, and the effect on losses will not be very high. For four plungers (35 mm diameter) penetrating 40 mm in the cavity, power losses are increased by approx. 1 W. For two plungers, a penetration of 50 mm, corresponding to a frequency range of 1MHz, increases cavity losses about 0.5 W. This power losses vales are similar to the obtained for the plunger operation in the SPIRAL2 cavities [6], so the cooling conditions should also be similar.

CONCLUSIONS AND FUTURE WORK

Preliminary studies for a plunger tuner system to be used in a double spoke cavity have been done. This technology has been used in other projects, like SPIRAL2. Electromagnetic simulations show that no an adequate frequency range can be achieved with the use of plungers of 35 mm in diameter placed perpendicularly to the spoke bar. Plungers entering through the end covers can also be used to rise frequency instead of lowering it.

Further studies are of course needed:

- Simulations will be carried out considering all the range in plunger movement in and out of the cavity
- The effect of the perturbed electric field on beam dynamics will also be analysed.
- Mechanical and cooling concepts for the plunger must be done
- Experimental tests using the aluminium cold model and ESS-Bilbao LLRF system will be performed during next weeks.

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