A NOVEL FREQUENCY TUNING SYSTEM BASED ON MOVABLE PLUNGER FOR SPIRAL2 HIGH-BETA SUPERCONDUCTING QUARTER-WAVE RESONATOR

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Abstract

SPIRAL2 aims at building a multi-purpose facility dedicated to nuclear physics studies, including the production of rich-neutrons isotopes. The multi-beam linear accelerator is composed of superconducting accelerating modules and warm focusing magnets. IPN Orsay is in charge of the high energy accelerating modules, each hosting two superconducting 88 MHz quarter-wave resonators operating at an accelerating field of 6.5 MV/m (β = 0.12). The static and dynamic frequency tuning is achieved by the insertion and displacement of a niobium plunger into the magnetic field area. The efficiency of the tuning (1 kHz/mm) has been validated during the tests of the cryomodule. In this paper we discuss the impact of such a tuning system, based on experimental results on SPIRAL2 cavities, on the different aspects: maximum accelerating field, Qo slopes, quench, multipacting and microphonics.

INTRODUCTION

The multi-purpose linear accelerator for SPIRAL2 has entered the construction phase since April 2006 [1]. Niobium quarter-wave resonators, composing the high energy part of the linac, have already been prototyped and qualified thanks to the construction of 2 cavities. These high-beta (β = 0.12) cavities resonating at 88 MHz, contrary to the low-beta ones (β = 0.07), are not tuned with a classical wall-deformation system due to the too low frequency shift versus the force applied [2]. The solution retained is the frequency tuning with a niobium movable plunger inserted into the magnetic field part of the cavity. This paper will present the full mechanism in the first part and then discuss the different results obtained with electromagnetic simulations and tests.

DESCRIPTION

The Plunger

The plunger, consists in a tube made of niobium (RRR = 250) with a length of 250 mm, a diameter between 30 and 20 mm (not yet defined) and a wall-thickness of 3 mm (see Fig. 1). It is totally filled with liquid helium when the cavity is operating. The plunger is maintained on the top cavity port through a stainless steel bellow stiffened by 3 guiding rods. A stainless steel bell, linking the rod coming from the motor and the plunger, closes the liquid helium circuit (See left Fig. 2). The bellows permit a total translation of about 5 mm. This kind of plunger achieves the static tuning as the plunger penetrates into the cavity of about 50 mm and the dynamic tuning thanks to its motion on a total range of about 4 mm.

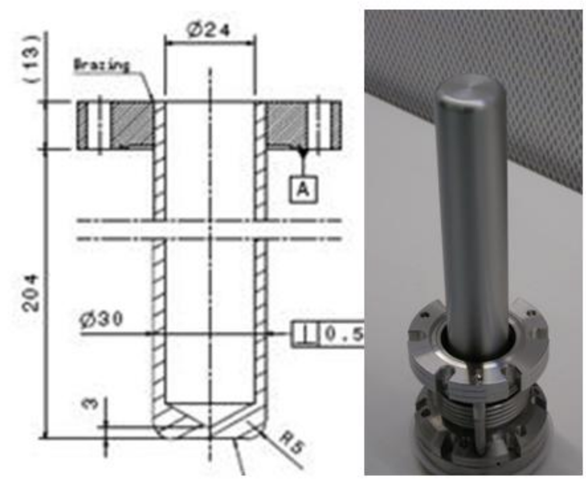

Figure 1: Picture and sketch of the plunger.

The Motion Controller

The plunger is controlled by a stepping motor, installed on the top of the cryomodule. The stepping motor controller and the gear box provide a total reduction of about 0.125 μm/step. The motion is transmitted to the plunger through a rod fixed on the closing bell (See right Fig. 2).

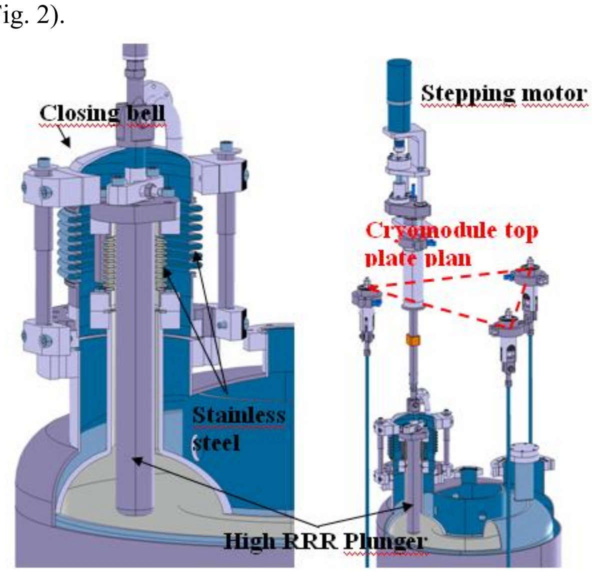

Figure 2: The system in its entirety.

SIMULATIONS RESULTS

Frequency Sensitivity

We performed all the simulations with CST Microwave Studio [4]. The aim is to evaluate frequency shift and dissipations versus penetration depth and plunger diameter. We calculate a constant frequency shift versus penetration depth of the plunger (See Fig. 3). For a diameter of 30mm, 25mm and 20 mm, the frequency shift is respectively around 1100 Hz/mm, 760 Hz/mm and 480 Hz/mm.

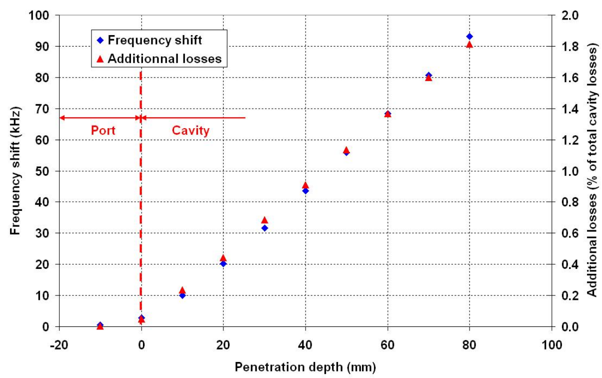

Figure 3: Frequency shift and additional losses versus penetration depth.

Dissipations

As the total losses of the cavity have to be lower than 10W at 6.5 MV/m, dissipations added by the insertion of the plunger have to be evaluated.

The power dissipated on the whole surface of the plunger grows linearly with the penetration depth (See Fig 3). The Φ=30mm plunger increases the power dissipation of about 1% for a penetration depth of 50mm.

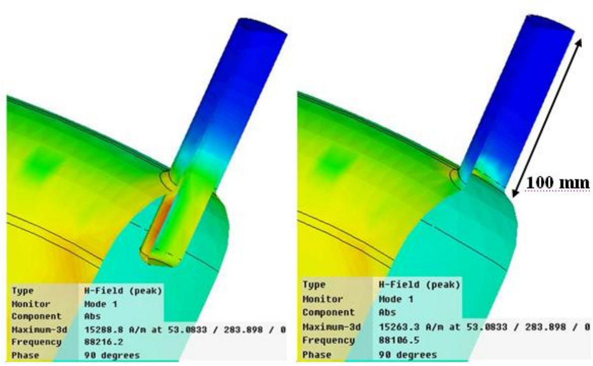

Figure 4: H-field distribution with and without the plunger.

Table 1 shows the additional losses for several plunger diameters and a penetration depth of 50mm.

We also have to take into account the power dissipated onto the stainless steel flange and bellow. In order to limit RF losses onto the flange, the port has been defined long enough.

Thus, with a 100mm long port, the magnetic field at the level of the flange is below 0.01% of the peak field in the cavity when no plunger is installed. The far-field onto the port seems greater when a plunger is installed (See Fig. 5). The magnetic field is multiplied by 100 at maximum!

Nevertheless, the power dissipation onto the flange and bellow is acceptable even for a Φ=30 mm plunger, leading to a increase of 11% of the total losses (See Table 1).

Table 1: Additional losses at 6.5 MV/m

Diameter	Losses on plunger	Losses into the flange*
No plunger	0	~ 0 W
20 mm	0.56 %	0.2 W
25 mm	0.65 %	0.4 W
30 mm	1 %	1 W

* Considering a decreasing field into a stainless steel tube

Moreover, the peak magnetic field of the plunger increases with plunger diameter (See Fig. 5).

Simulations show that the peak magnetic field on the plunger isn't higher than the peak field on the cavity (See Fig. 4). Thus the plunger shouldn't reduce the quench threshold of the cavity.

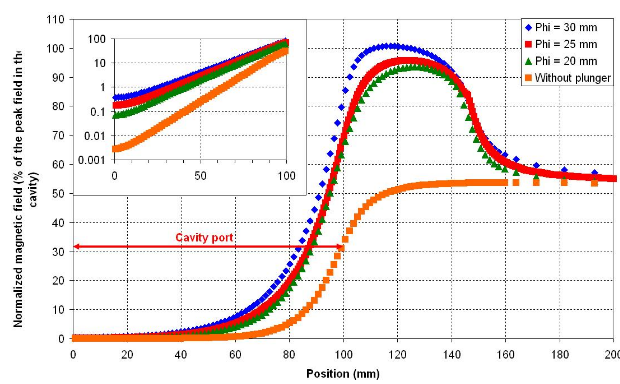

Figure 5: Magnetic field distribution along the plunger for different diameters.

EXPERIMENTAL RESULTS

Mechanical Aspects

The motion controller is clamp on the external vessel of the cryomodule, and the plunger fixed on the cavity. During cool down, a displacement of about 0.64 mm has been recorded due to thermal contractions. The plunger is, at rest, pushed up on the upper mechanical stop due to pressure difference between liquid helium bath and the vessel vacuum. The force is about 1000 N. This induces a mechanical hysteresis of about 20 µm when the plunger is moved up or down (See Fig. 6).

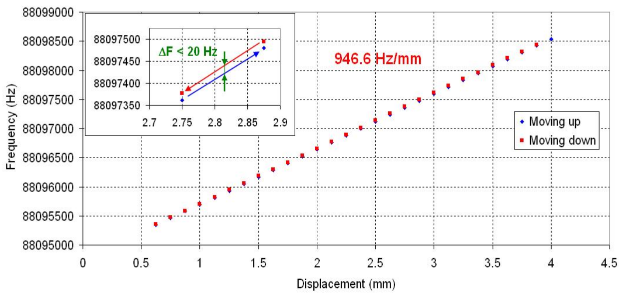

Figure 6: Frequency shift versus plunger. In the upper left corner, mechanical hysteresis when moving up and down.

This hysteresis can be a problem in the case of fast tuning. For the moment, no tests have been done to characterise the regulation efficiency. Only slow regulation (1.3 Hz/s ramp) have been tested, giving a frequency stability better than 4 Hz (See Fig. 7).

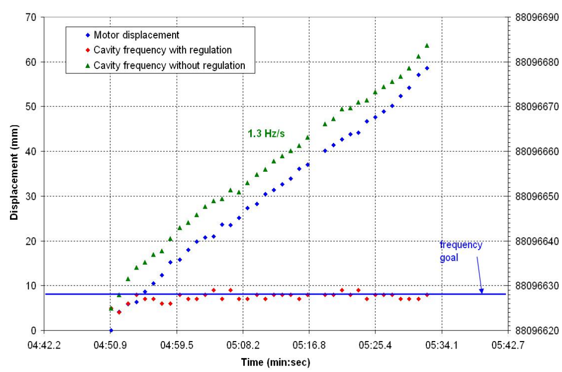

Figure 7: Slow frequency regulation test.

Preliminary tests have been performed to verify if the plunger causes microphonics perturbations. Results obtained [3] show no additional perturbations.

Nevertheless, slow frequency shift due to atmospheric pressure variations and temperature (day and night cycles) have been recorded and can be easily corrected.

Electromagnetic Aspects

The frequency shift measured during the test is constant on the whole range (~ 4mm) and is about 950 Hz/mm (See Fig. 6). This result matches quite well with calculations. Qo versus accelerating field measurements have been plotted to verify whether or not the plunger is acceptable as a frequency tuner for the SPIRAL2 project.

Results obtained for the different tests are good (See Fig. 8). There is no effect visible on Qo value when a plunger is installed whatever its diameter. This was confirmed for two diameters 30 and 20 mm. The Qo drop due to the power dissipated on the plunger is within the measurement errors, estimated at 10%.

Furthermore, the Q-slope and quench limit are unchanged with or without plunger. The plunger doesn't induce more field emission. The same observation is made with multipacting barriers.

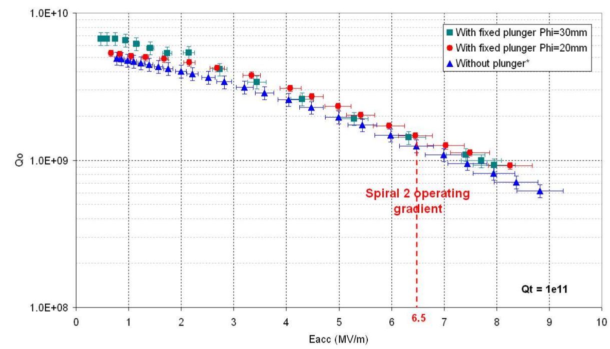

Figure 8: Qo versus accelerating field with Φ = 30mm and 20mm plungers and without plunger.

CONCLUSIONS AND FUTURE WORKS

Preliminary results presented previously show that the movable plunger as the cold tuning system for the SPIRAL2 project is well suited. The frequency sensitivity and the range meet the requirements. The Qo and the accelerating field seem not affected. Neither multipacting barriers, nor field emission are observed with a plunger.

However, several tests have to be done to qualify other aspects:

- Reliability and long term effects of such a tuning system (dust released by the bellows during motion).
- The system must be tested in a frequency regulation loop to quantify how fast can regulate the system and if the mechanical hysteresis is changing during operations.

REFERENCES

[1] T. Junquera et al., "Status of the Construction of the SPIRAL2 Accelerator at GANIL", this conference.

[2] G. Olry and al., Development of a beta 0.12, 88 Mhz, quarter wave resonator and its cryomodule for the SPIRAL2 project", SRF 2005, Ithaca, USA, July 2005.

[3] H. Saugnac and al., "RF Cryogenic Tests on the "Qualifying" beta = 0.12 SPIRAL2 Cryomodule", this conference.

[4] http://www.cst.com.