A COLD TUNER SYSTEM WITH MOBILE PLUNGER

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Abstract

Tuner systems for accelerating cavities are required to compensate static and dynamic frequency perturbations during beam operation. In the case of superconducting cavities, these are commonly tuned by deforming the cavity wall in specific places of the geometry. Nevertheless, considering the mechanical properties and frequency versus displacement sensitivity of some structures, tuning by deformation doesn't allow meeting the requirements.

In these specific cases, inspired from the "room temperature technology", an alternative tuning technique by insertion of a helium-cooled superconducting plunger can be considered and has been studied for several projects (IFMIF, ESS-BILBAO). Advantages and drawbacks of such solution will be discussed and the successful results on SPIRAL2 cryomodule developed at IPNO will be presented.

INTRODUCTION

Adjusting the cavity resonance frequency to the accelerator frequency during beam operation is primordial. This point is even critical in the particular case of superconducting structures where the bandwidth of the loaded cavity can be as low as few Hertz. The Frequency Tuning System (FTS) has to compensate firstly static detuning coming from fabrication and surface conditioning uncertainties (frequency swing after an etching is difficult to predict exactly). Secondly, dynamic detuning, caused by cavity environment (microphonics, pressure fluctuations of helium bath, Lorentz forces, etc...) has to be overcome. Depending on their amplitude relatively to cavity loaded bandwidth and the frequency of these perturbations, a fast tuning system can be required. This one is usually coupled to the slow tuner (motor) and consists of a piezoelectric or magneto restrictive actuator.

We can classify FTS in 2 families whether the frequency shift is obtained by deformation or insertion (See figure 1). VCX (Variable reactance) and ferrite tuners won't be discussed here but additional details can be found in [1]. The most common solution adopted is by deformation. A massive mechanical system deforms the cavity volume within the elastic limit of the material to achieve the desired frequency shift. This system has shown by experience a very good reliability. A review talk describes the different type of tuner systems in operation [1].

The other tuning solution, by insertion, is very less envisaged as the system interacts directly in cavity volume adding some additional complexities. A non exhaustive pros and cons of both solutions are inventoried in Table1.

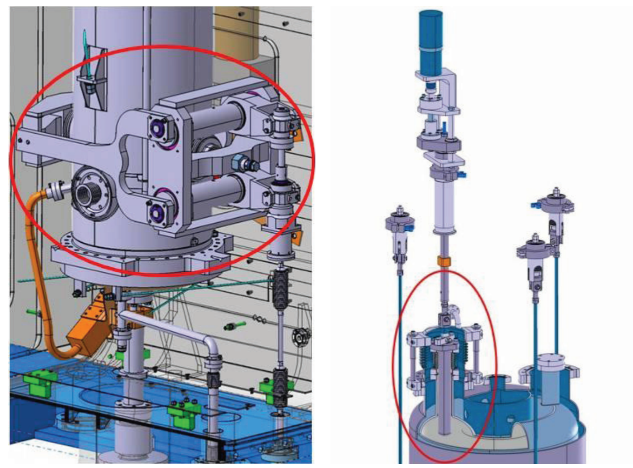

Figure 1: (left) Example of an FTS by deformation used on low-beta Spiral2 Quarter-Wave Resonator (QWR) and developed at CEA Saclay (right) FTS by insertion used on high-beta Spiral2 QWR and developed at IPN Orsay.

Table 1: Pros and Cons of Tuning Solutions

	By deformation	By insertion
Pros	- Reliable - A lot of experience - No direct interactions in cavity RF space - Easy maintenance	- Low force needed - No risks of plastic deformation - Tuning range not limited by Niobium elastic limit - Several tuners in parallel. - More compact
Cons	- Possible irreversible damages (plastic deformation) - Massive (difficult to cool down) - High forces involved - Tuning range limited by limit of elasticity of Niobium - Only one tuner per cavity	- Lack of experience - Inserted in cavity volume (problems of cleanliness, possible RF limitations) - Has to be integrated in LHe loop - Complexity of cleaning procedure and maintenance - Quench problems

The requirements and specificities of some projects, like Spiral2, have forced people to consider seriously this solution as the stiffness and frequency sensitivity of the cavity wouldn't allow reaching easily an acceptable tuning range. Other projects accepted the challenge to study this solution despite the lack of experience of this system. This paper will give an update of 3 different tuner systems using a moving plunger namely ESS-Bilbao, IFMIF and SPIRAL2.

ESS-BILBAO

ESS-Bilbao will be a light ion linear accelerator composed of two ion sources, a normal conducting section with an RFQ and DTL followed by several superconducting cryomodules hosting double and triple Spoke resonators [2]. The RF design of cavities will be equivalent to ESS-Lund but alternative approaches for frequency tuning and mechanical stiffening are under study. An aluminium β=0.39 double Spoke prototype has been fabricated for training and RF simulation checking [3].

Many different scenarios have been simulated. The most favourable option [4] is to install the plunger perpendicular and aligned to a spoke bar (See figure 2, position A).

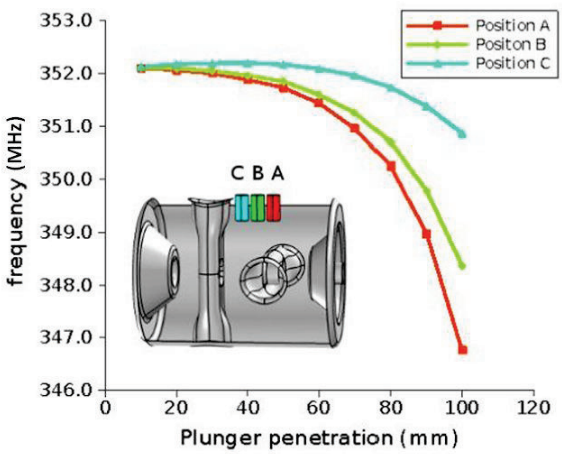

Figure 2: Frequency variation versus plunger penetration at different positions. Plunger diameter is 35 mm [4].

Some measurements on the aluminium prototype have been done to confirm RF simulations. Figure 3 depicts the results showing a very good agreement in frequency shift.

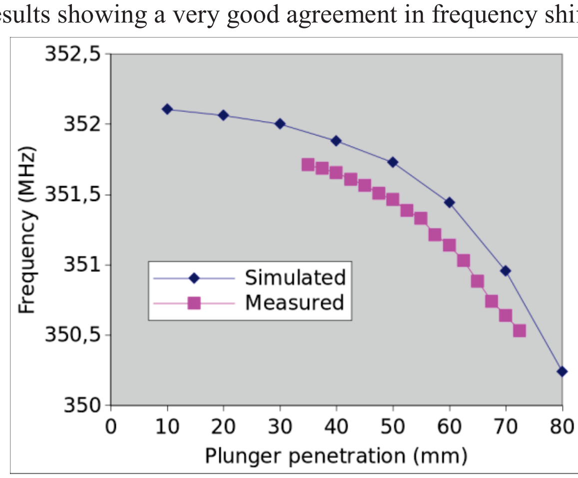

Figure 3: Simulated and measured frequency shift versus plunger penetration. Plunger diameter is 35 mm [4].

Another interesting option studied, offering this time a positive frequency shift, is to insert the plunger through the end cover of the Spoke cavity (See Figure 4).

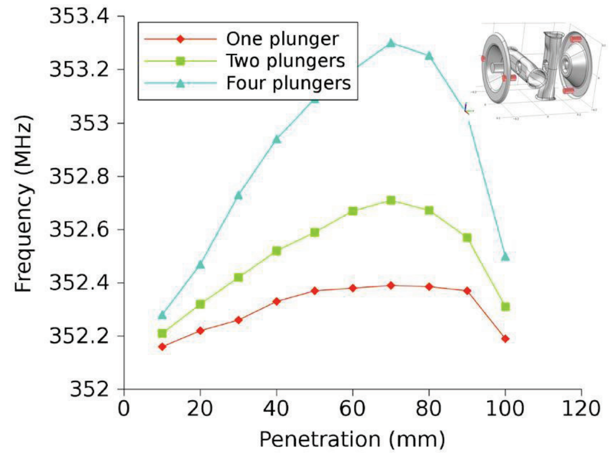

Figure 4: Frequency variation versus plunger penetration at one, two and four plungers [4].

Further studies are carried out to characterize whether any perturbation of the electric field on beam axis is induced by the presence of the tuner. Mechanical and cooling concepts are also being studied.

IFMIF

IFMIF (International Fusion Materials Irradiation Facility) will consist of two high power superconducting linacs delivering CW 125 mA deuteron beam at an energy of 40 MeV [5]. The superconducting Half-Wave Resonators (HWR) will be operated at 175 MHz at an accelerating gradient of 4.5 MV/m. These were originally supposed to be tuned by a moving plunger installed perpendicular to the beam tube in the high electric field area (See figure 5).

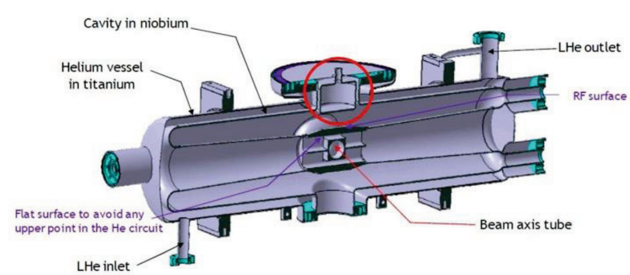

Figure 5: Drawing of the IFMIF HWR. The hollow plunger (circled) is cooled by liquid helium [6].

The plunger, made of bulk Niobium, has a diameter of 100 mm. A 1.5 mm thick NbTi membrane isolates the cavity vacuum allowing a tuning range of ± 1mm. In these conditions, the mechanical stress is kept under 125 MPa [6]. The penetration in the cavity volume is limited to 4 mm to avoid any rise of the peak electric field and multipacting problems. The tuning sensitivity has been simulated and is above 50 kHz/mm as depicted in figure 6.

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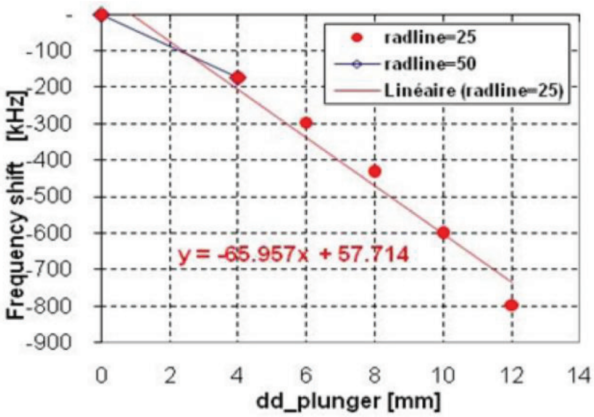

Figure 6: Frequency sensitivity of the plunger [6].

During first prototype tests, the maximum accelerating field achieved was of the order of 1 MV/m with a degraded Qo [7]. The problem was located on the plunger neck and membrane. As visible on Figure 7, a significant residual magnetic field of about 20 mT (at operating gradient) heats up the NbTi membrane due to its limited thermal conductivity. A simplified design replacing the NbTi membrane by a Nb plate confirmed partially this limitation as the field was brought up to 2.5 MV/m but still with a degraded Qo [7]. The residual magnetic field at the level of the RF gasket is still of the order of 2 mT at the operating gradient. Additional tests were performed where the plunger was inverted dividing the residual magnetic field on the RF gasket by 25. Consequently, the accelerating gradient was brought up to 4 MV/m (not limited by the plunger) with an acceptable Qo [7].

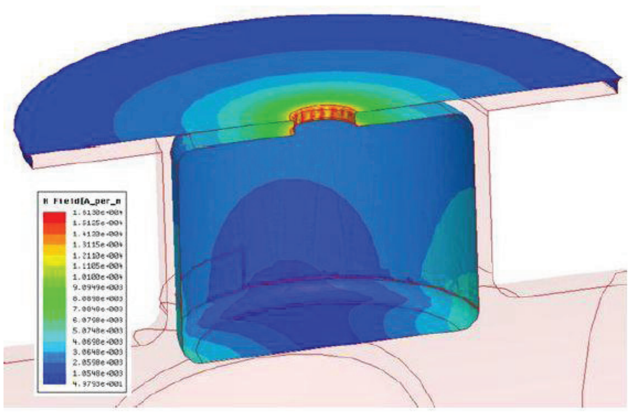

Figure 7: Magnetic field distribution on plunger [7].

Unfortunately, this solution has been abandoned due to technical difficulties and the tight time schedule of the project. A new tuner by deformation has been designed [8].

SPIRAL2

Spiral2 accelerator is a multi-beam CW superconducting linac capable of delivering 5 mA deuteron beam at an energy up to 40 MeV. This driver, under construction at Ganil in Caen in France [9], is composed of two sections, a low beta and a high beta section respectively in charge of CEA Saclay and IPN Orsay. Among the different specificities of this linac, the QWR from the high beta section are tuned by a moving plunger with a diameter of 30 mm, an average penetration of 50 mm and a tuning range of ± 4 mm (See Figure 8).

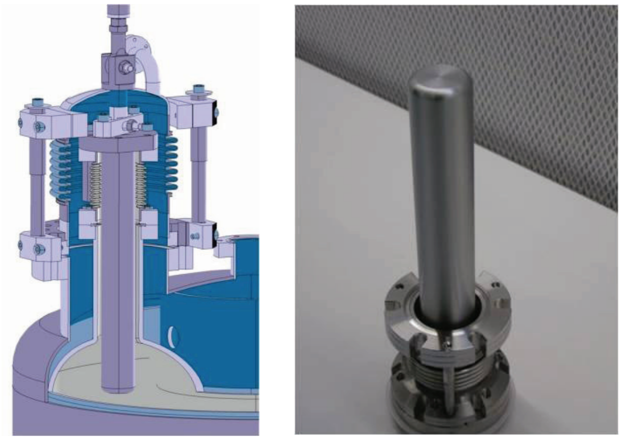

Figure 8: Overview of the Spiral2 tuning system.

RF Simulations and Results

Many RF simulations were done before prototyping to make sure the cavity performances wouldn't be impaired at the operating gradient of 6.5 MV/m. Table 2 summarizes the different results [10, 11].

Table 2: Summary of RF Simulations with a Plunger Diameter of 30mm.

Criteria	Results
Peak magnetic field on the plunger is not greater than the peak field on cavity wall	~ 100%*
Frequency sensitivity is constant on tuning range	~ 950 Hz/mm
Additional dissipations do not exceed 1W	~ 1W @ 6.5 MV/m
Residual magnetic field above the cavity port stays below 1mT	~ 0.25 mT @ 6.5 MV/m

* Percentage of the peak magnetic field on cavity wall without plunger.

Many RF tests have been done up to now confirming the RF simulations. In the case of Spiral2, all cavities have been validated in vertical cryostat with their plunger showing no visible degradations of cavity performances only if the plunger surface is prepared with the same standards as the cavity (See figure 9).

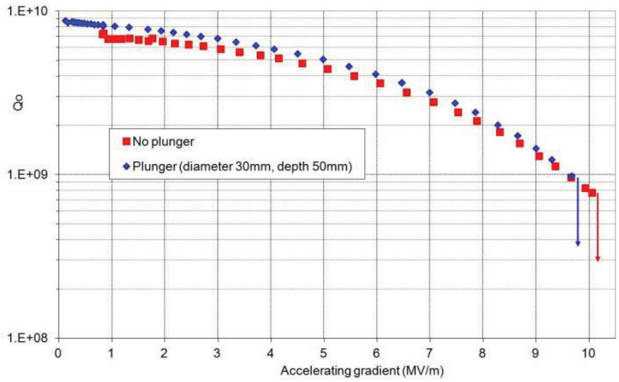

Figure 9: Influence of plunger on a Qo curve. In-between both tests, the cavity has just been warmed up and vented for plunger installation in a clean room. No additional etching or HPR.

Quench Problematic

Nevertheless, an important observation has been done during cryomodule RF tests while cavities were tested up to their quench limit. In the case of strong coupling, when the cavity quenches, the Qo drops very quickly and equalize at one point the external coupling. During a short period of time, the cavity is then very close to the critical coupling and the whole RF power is transmitted to the cavity (meaning about 3 kW when the cavity is operated at 6.5 MV/m without beam loading). The overall energy stays limited if the quench is localized on the cavity. As this one is propagating over all the geometry, the Qo drop is significant enough so the final Qo stays well below the external coupling. But if we now consider that the quench is localized on the plunger, it only propagates over the plunger surface. As this one is isolated from cavity surface with stainless steel below, the Qo drop is limited and the Qo stays relatively close to the external coupling. If the Rf power is maintained, in the case of Spiral2 cryomodules, about 500 W is still transmitted into the cavity after 50 seconds (See figure 10).

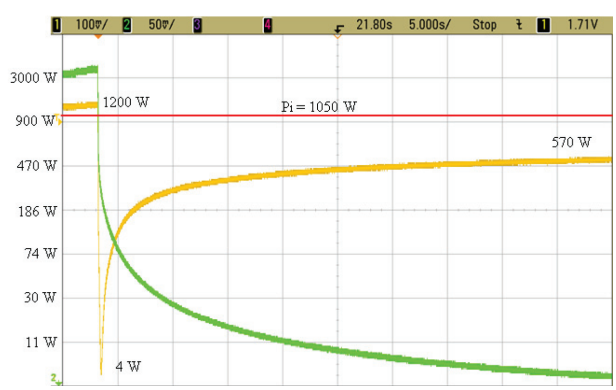

Figure 10: Screenshot of the evolution of the pick-up signal (green) and reflected power (yellow) during a cavity quench when the RF power is maintained at 1050 W. The vertical scale is for reflected power. The horizontal scale is 5 s/div [11].

As the consequence, the helium flow at the exhaust stays abnormally high for several minutes and the temperature probe installed in the plunger was totally burnt. A quench detection system has to be set up in order to stop the RF power within one second to ensure a fast recovery of the operating conditions.

Mechanical Hysteresis Problematic

After prototyping period, some mechanical modifications of the tuner mechanism have been performed to increase tuner reliability and decrease the hysteresis. Very first tests after this upgrade showed very bad results. The mechanical hysteresis was not only increased, but a significant overshoot was also visible. As an example, when the plunger is pushed down, the frequency increases. If the plunger is then pulled up, the frequency would first keep on increasing and then eventually start decreasing (see Figure 11).

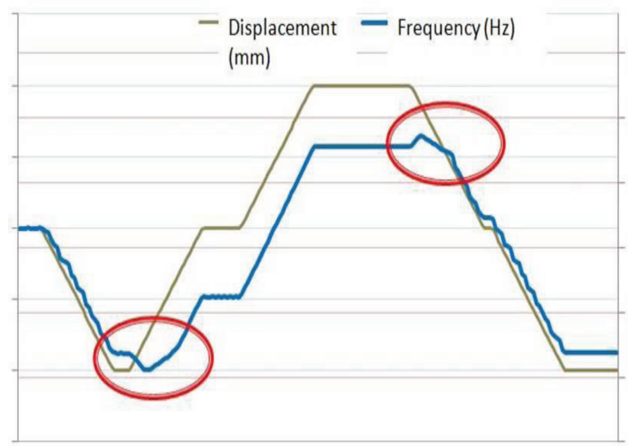

Figure 11: Example of frequency overshoot when direction of motion is inverted. The overshoot is of the order of 100 Hz.

Frequency regulation was first impossible as the overshoot was of the order of the loaded cavity bandwidth. This overshoot was coming from a plunger swing motion as illustrated in Figure 12. Because of mechanical plays, the plunger is slightly tilted one way or the other depending on the direction of the motion.

This problem has been solved firstly by improving the mechanical system (reduction of plays and hyperstatism) and also by forcing this swing motion perpendicular to the magnetic field gradient. As showed on Figure 12 (blue arrows), the swing motion was originally happening in the picture plane, toward strong fields.

Two cryomodules have been tested so far since these improvements, the hysteresis have been reduced to about 20 Hz and the overshoot, rarely visible, is limited to few Hertz. During these validation tests, plungers have also been cycled during several hours to check if any degradation was visible over time. No freezes or increase of hysteresis have been observed.

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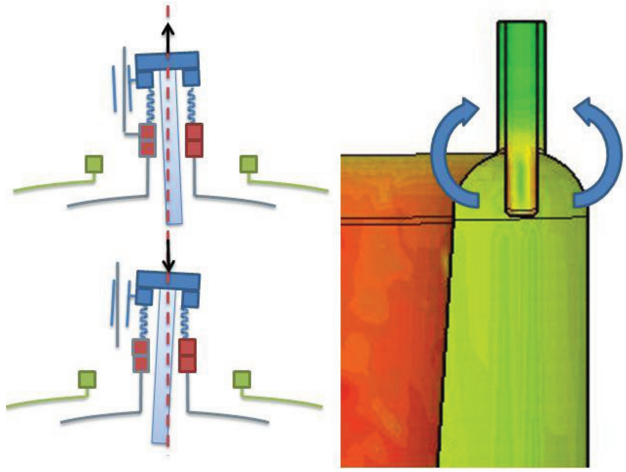

Figure 12: Illustration of the plunger swing motion.

CONCLUSION

Tuning a superconducting cavity by insertion with a moving plunger becomes an alternative solution. As a consequence of new accelerating structures being more and more considered for high power linacs (Spoke cavities, QWR, HWR), tuning by insertion appears to be a complementary solution when the mechanical properties of the cavity are too restrictive.

ESS-BILBAO project are considering this solution. Several tuner positions are studied offering the possibilities to either increase or decrease the frequency of the cavity. RF simulations and direct measurements on an aluminium prototype show that an adequate tuning range can be achieved easily. Additional RF simulations to evaluate surface fields and residual fields on cavity flanges are now required and all the mechanical design has to be done.

IFMIF project have also considered this promising solution but had to be abandoned because of the very tight schedule. With more time, additional studies could have been done to tackle the problem of the high residual magnetic field on the RF joints and NbTi membrane.

SPIRAL2 accelerator will be the very first superconducting linac to operate with such tuners. Even though several difficulties have been encountered as described in this paper, the Spiral2 plunger has been validated on two cryomodules. Nevertheless, the lack of experience of such a tuner makes the evaluation of the long term behaviour difficult.

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