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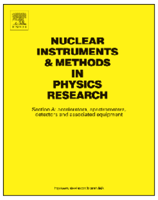

An innovative tuning system for superconducting accelerating cavities

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ABSTRACT

Frequency tuning 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 deformation of the cavity wall in specific places of the geometry. Nevertheless, considering the mechanical properties and the frequency versus displacement sensitivity of some accelerating structures, tuning by deformation does not allow meeting the requirements.

Inspired from the “room temperature technology”, an alternative tuning technique by insertion of a helium-cooled superconducting plunger has been studied and validated for the superconducting Spiral2 accelerator.

1. Introduction

Adjusting the cavity resonance frequency to the accelerator frequency during beam operation is essential to have a perfect transmission of the radiofrequency power to the beam.

As an example in the specific case of Spiral2 [1], the accelerating cavities will be fed by RF amplifiers at a fixed frequency, the accelerator frequency. To maintain a constant accelerating field in a cavity in the case of a shift of the resonance frequency ΔF, the RF power required P_{RF} is given by the following:

$$P_{RF} = P_{RF0}\left[1+\left(2Q_L\frac{\Delta F}{F_0}\right)^2\right] \quad (1)$$

where P_{RF0} is the RF power required of a perfectly tuned cavity, F_0 its resonance frequency and Q_L the loaded quality factor of the cavity.

In the case of a frequency shift of half a pass-band (typically 44 Hz for Spiral2 $\beta=0.12$ Quarter-Wave Resonators), the required RF power is doubled.

As an example, the forward RF power required to accelerate the 5 mA deuteron beam in the Spiral2 $\beta=0.12$ cavities is 13 kW [2]. The maximal frequency detuning acceptable is about 32 Hz as the RF amplifier has a maximum output power of 20 kW.

We can appreciate here the necessity of a frequency tuning system during operation so as to keep the resonance frequency within the regulation capabilities of the RF system.

The Frequency Tuning System (FTS) has to compensate:

- static detuning coming from cavity fabrication errors and surface conditioning uncertainties; and
- dynamic detuning, caused by cavity environment instabilities like pressure fluctuations of helium bath, Lorentz forces (radiation pressure of the RF wave on the cavity walls) and microphonics (mechanical modes excitation by environment).

Table 1 summarizes different sources of frequency perturbation measured during Spiral2 cavity preparation and test.

We can classify FTS in 2 families whether the frequency shift is obtained by deformation or insertion (see Fig. 1). Non exhaustive pros and cons of both solutions are inventoried in Table 2. VCX (Variable reactance) and ferrite tuners would not be discussed here but additional details can be found in [3].

Firstly, the most common solution adopted to tune superconducting cavities 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 types of tuner systems in operation [3].

The requirements and specificities of some cavities, like Spiral2 $\beta=0.12$ cavities, have forced people to rule out the use of a FTS by deformation as the Niobium yield strength, stiffness and frequency sensitivity of some cavities would not allow reaching the required tuning range.

Secondly, the other tuning solution, by insertion, was very less studied as the system interacts directly with the cavity volume adding some additional complexities.

A tuning system by insertion, depending on accessibility, mechanical and RF constraints can be installed either in a high electric field zone (capacitive tuning) as for example on New Delhi booster linac [4] and ISAC2 superconducting linac [5] or in a high magnetic field zone (inductive tuning) like Spiral2. Indeed,

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Table 1
Static and dynamic frequency perturbations.

Type	Description	Typical amplitude
Static	Fabrication tolerance	± 20 kHz
	Chemical etching	$+55$ (± 5) kHz
	Mechanical deformation due to pressure force when cavity is pumped down	-6.5 (± 1) kHz
	Permittivity change (air to vacuum)	$+25$ (± 1) kHz
	Mechanical deformation due to cooling down (thermal contraction)	$+141.5$ (± 3) kHz
	Power coupler insertion	-1.5 kHz
Dynamic	Lorentz forces (-1.8 Hz/(MV/m)^2)	-76 ± 10 Hz
	Microphonics	$< \pm 10$ Hz
	Pressure fluctuations of helium bath (± 10 mbar)	± 50 Hz

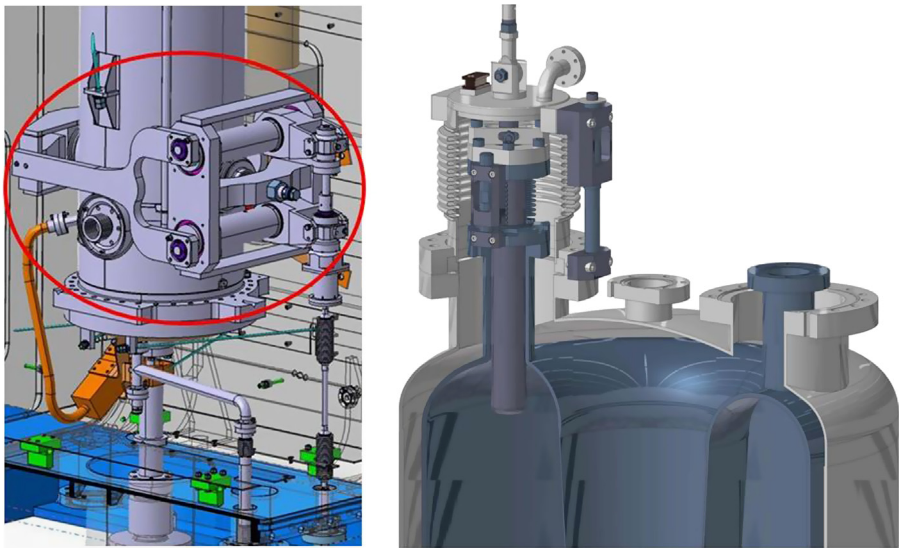

Fig. 1. (left) Example of a FTS by deformation used on Spiral2 $\beta=0.07$ Quarter-Wave Resonator (QWR) and developed at CEA Saclay. (right) FTS by insertion used on Spiral2 $\beta=0.12$ QWR and developed at IPN Orsay.

depending on the cavity type and the RF power coupler configuration, the tuning solution is imposed so as not to interfere with it.

As an example, the choice of an inductive tuning on the top part of the $\beta=0.12$ Spiral2 cavity was imposed for two reasons:

- The frequency sensitivity of a capacitive tuner of the same dimensions compared to an inductive tuner is about 20 times less. In that sense, a capacitive tuner would need to extend all over the cavity bottom (tuning plate) to achieve the tuning range. Since the RF power coupler specifications imposed the use of a capacitive coupling on the bottom part of the cavity, the tuning system would be difficult to implement in the same area.
- At the sight of the large cavity diameter, it was technically too risky at the time of cavity construction to braze a flange on the bottom of the cavity to install a deformable tuning plate.

Moreover, one has to keep in mind that for these two solutions problematics are not the same beside cleanliness. For a capacitive tuner, great care has to be taken to limit the multipacting problems. As an example, simulations done on a superconducting CH-cavity [6] showed very strong multipacting barriers in between the multiple bellow corrugations. On the other side, an inductive tuner, because of strong power dissipations occurring on its surface, has to be cooled very efficiently and RF contacts should be kept far enough to limit RF currents on non-superconducting parts.

Remark: problems of RF losses can also happen with the capacitive tuner even though RF currents are supposed to be low, as experienced on the IFMIF cavity prototype [7].

Spiral2 project accepted the challenge to study this solution despite the lack of experience in inductive tuner; first of its kind to be installed on a superconducting accelerator. This paper will give an overview of all calculations and qualification tests performed for the SPIRAL2 FTS. This paper is an improved and more complete version of [8], including the very last experimental results of series cryomodules.

2. Spiral2 FTS presentation

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 [1], is composed of two sections, a low beta ($\beta=0.07$) and a high beta ($\beta=0.12$) section respectively in charge of CEA Saclay and IPN Orsay. Among the different specificities of this linac, the QWR from the high beta section [9] is tuned by a moving plunger made of bulk Niobium with a diameter of 30 mm inserted in a high magnetic field zone. To ensure a good stability of the plunger temperature during operation, the hollow plunger is filled with liquid helium. A stainless steel bellow with Conflat flange closes the cavity volume. The helium tank is extended up to the top of the plunger and defined in between the two stainless steel bellows