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ALTERNATIVE RF TUNING METHODS PERFORMED ON SPOKE CAVITIES FOR ESS AND MYRRHA PROJECTS

P. Duchesne, S. Blivet, G. Olivier, G. Olry, T. Pépin-Donat
Université Paris-Saclay, CNRS/IN2P3, IJCLab, Orsay, France

Abstract

In order to obtain the target frequency in operation, the resonant frequency of superconducting radiofrequency cavities is controlled and adjusted from the manufacturing to the end of preparation phase. Reaching this right frequency can be challenging due to the narrow frequency range defined by the tuning sensitivity of the cavity and the capability of the tuner. Mechanical deformation until plasticity is attained is of great interest to tune SRF cavities when large frequency shift is needed. But once a cavity is dressed with its helium tank, the only accessible part is its beam pipe, reducing the mechanical action to a push/pull action. This limited possibility has hence to be skilfully associated with chemical etching. An original mechanical tuning of Spoke dressed cavities consists in increasing the pressure inside the helium tank to induce a permanent deformation of the cavity walls. The frequency shift induced by nonlinear deformation is numerically evaluated in order to determine the pressure increments. Both methods were successfully performed on the cavities of the ESS accelerator and of the Myrrha project.

INTRODUCTION

The frequency adjustment of a SRF cavity is performed from the manufacturing to the end of the processing phase in order to hit the nominal frequency in operating configuration. A target frequency that will be measured at room temperature and in air at the end of the processing phase is then determined by taking into account the frequency shift due to the changes of the cavity shape and of the dielectric medium induced by the modification of the working conditions (vacuum and low temperature mainly).

From the manufacturing to the processing phase, a part of the operations generates some frequency shifts that can serve the purpose of frequency adjustment; while others have to be compensated. For the ESS double Spoke resonators and the MYRRHA single Spoke resonators, operating at 352.21 MHz, the RF tuning process was developed on the basis of several prototypes.

Today, 29 ESS cavities were built and more than half of them were already prepared and tested at IJCLab. Two MYRRHA cavity prototypes were built and tested. While the cavity frequency was monitored and adjusted until the end of the processing phase, several cavities met some unexpected frequency shifts and their frequency was finally outside the target range. Two different tuning methods were hence used to reach the frequency requirements before the test at cold temperature in a vertical cryostat.

FREQUENCY SHIFTS DURING THE CAVITY LIFECYCLE

Figure 1 gives the evolution of the resonant frequency of a number of built ESS cavities during their lifecycle. Table 1 summarises the measured frequency shifts.

The RF tuning process starts from the manufacturing phase. The frequency shifts produced by the electron beam welding (EBW) of the cavity end dished walls onto the cavity shell (cylinder), the helium tank integration and the leak checks are compensated in advance by trimming operation of the shell. Before welding, the cavity cylinder is indeed provided with an overlength corresponding to a frequency range of 1 MHz. For all the ESS cavities, a tolerance of ± 150 kHz around the target frequency was thus achieved at the end of manufacturing.

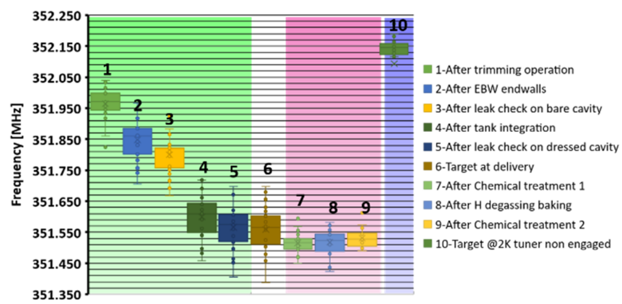

Figure 1: Evolution of the RF frequency during the ESS cavities lifecycle.

During the processing phase, the frequency variation due to the first leak checks, the chemical treatments and the baking at 650 °C for hydrogen degassing, is of the order of several tens of kHz. It is to be compared with the quite narrow target frequency range of the ESS resonators, defined by the tuner capability and the cavity sensitivity: ±40 kHz.

The strategy chosen to adjust the frequency during this phase focuses on chemical treatments. The buffered chemical polishing (BCP) can be performed in vertical and horizontal positions for the ESS cavities due to the presence of the high pressure rinsing ports (only in the horizontal direction for the MYRRHA ones). These two BCP treatments do not etch the cavity walls in a same way and finally cause frequency changes which are different in magnitude and sign. Consequently, for each cavity, a judicious combination of some BCP operations is predefined to get the target frequency.

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Table 1: Frequency Shifts (kHz) Measured on the Built ESS Cavities

	Operation [number of cavities]	Ave-rage	Standard deviation	Min	Max
Manufacturing	EBW endwalls [29]	-115	48	-250	-53
	Leak check [29]	-50	4.5	-79	-30
	Tank integration [29]	-200	64	-325	-80
	Leak check [29]	-38	22	-91	31
Preparation	BCP1 (bulk) [23]	-44	70	-164	120
	H degassing [22]	4	30	-51	65
	BCP2 (light) [12]	-0.7	32	-59	63
Test	@2K no tuner [19]	622	21	606	703

While the impact of the chemical treatments on the frequency is thus well controlled, the high temperature baking performed in our laboratory on the dressed cavities, can vary the frequency from -51 to 65 kHz; a range measured on more than twenty cavities. Up to now, there is no clear explanation of the differences found between the cavities. As a result, at this lifecycle step, some cavities presented a frequency which was too low by several tens of kilohertz and that any chemical treatment could not compensate. An alternative tuning process based on the plastic deformation of the cavity walls was then applied.

ALTERNATIVE RF TUNING METHODS

The mechanical design of the ESS and MYRRHA resonators was developed by taking into account several criteria: mechanical strength during their lifecycle, suitable RF sensitivities, manufacturing constraints and good accessibility for the processing [1] and [2]. No RF tuning operation based on the plastic deformation of the cavity was initially planned. Two methods were finally selected by considering the possibilities offered by the cavity design. One the one hand, a push/pull movement of the beam pipe on the tuner side could produce a permanent positive or negative frequency shift at room temperature [3]. On the other hand, we proposed another tuning method consisting in the mechanical deformation of the overall cavity by applying an external pressure on its walls. To this purpose, the helium vessel was filled with nitrogen gas. One can note that the high stiffness of the cavity gives an excellent mechanical strength to the application of an external pressure. The theoretical critical pressure of linear buckling of the ESS resonator is estimated to be 29 bars. The strength of the bellows indeed limits the maximum allowable pressure to 7 bars.

Numerical Simulation

In order to locate and estimate the permanent deformation induced by one of the two RF tuning methods, the mechanical behaviour of the cavity was simulated by an elastoplastic analysis performed with ANSYS. The effect of the push/pull operation of the beam pipe can be evaluated knowing the tuning sensitivity of the cavity, which is determined numerically during the design of the cavity by use of a coupled mechanical-electromagnetic analysis. With this method, we noticed that a permanent frequency shift of several hundreds of kHz could be easily achieved as presented for the MYRRHA cavity (Fig. 2). Nevertheless, applying a displacement on the beam pipe generates a local deformation and some highly localized plastic strains (Fig. 3). When a frequency increase less than one hundred kHz is needed, the pressure RF tuning method can be preferred and is finally more used for ESS production cavities.

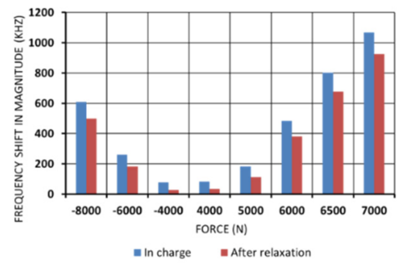

Figure 2: Frequency shifts obtained by the simulation of the push/pull action on the MYRRHA cavity.

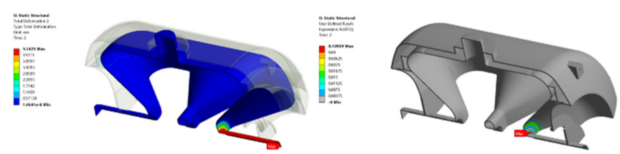

Figure 3: Deformation and plastic strains after applying a tensile force of 7000N on the MYRRHA cavity.

The analysis of the ESS cavity deformation under external pressure shows a nonlinear behaviour beyond a differential pressure of 2.5 bars. The resulting permanent deformation is mainly located on the cylinder walls between the Spoke bars (Fig. 4). The induced plastic strains spread on several areas especially at the top of the Spoke bars and the cylinder (Fig. 4). Compared to a push/pull action, this RF tuning method affects a significant part of the cavity surface preventing the emergence of some high stress concentration areas, which ensure the integrity of the cavity.

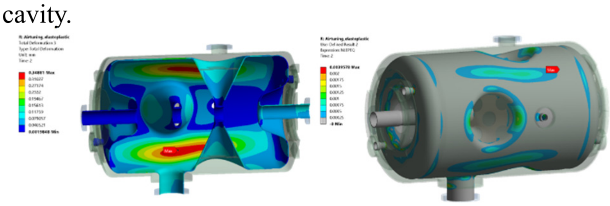

Figure 4: Deformation and plastic strains after applying a differential pressure of 5bars on the ESS cavity.

For the pressure RF tuning method, the estimation of the frequency shift due to the pressure loading and unloading is made with a coupled mechanical-electromagnetic analysis performed with Ansys APDL. The frequency shift in charge and after relaxation was calculated for a differential pressure ranging from 1 to 5 bars (Fig. 5). A permanent frequency shift of a few kHz appears from 3.5 bars. It's estimated to be of 30 kHz after applying a differential pressure of 5 bars, corresponding to the order

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of magnitude intended for the RF tuning of the few ESS resonators whose frequency could not be adjusted by BCP treatment.

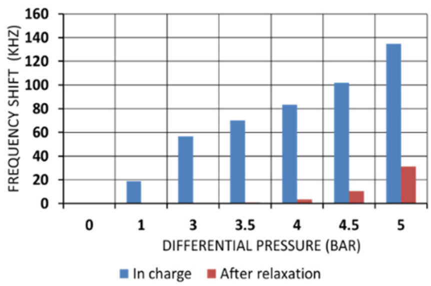

Figure 5: Frequency shifts of a ESS double Spoke cavity computed for the application and removal of differential pressures.

Experimental Measurements

Several RF tuning operations were performed at IJCLab on some ESS and MYRRHA cavities. For the push/pull processing, a specific tooling was built for the MYRRHA prototypes; it is also suitable for the ESS cavity. An overview of the experimental device is shown in Fig. 6. Fasten on the helium vessel to the tuner supports, the tooling changes the cavity frequency by acting on its beam pipe and then deforming its shape. Force is controlled by a load cell and deformation by use of a position sensor. The RF frequency is measured with a network analyser and normalized at 20 °C, knowing the temperature of the cavity during the test. The two MYRRHA cavity prototypes were tuned by use of a push/pull process: one under traction, the other under compression. The measures are presented in Fig. 6 (see the dots) and exhibit a good agreement with the simulation (lines). In addition to this tuning functionality, this device allows to measure the cavity stiffness and the tuning sensitivity. Those two parameters are indicated in Table 2, wether being measured with the tooling or estimated by use of our finite element modeling.

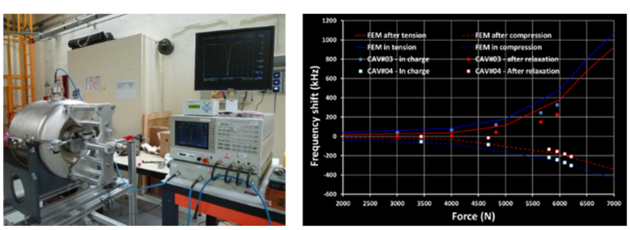

Figure 6: (Left) Experimental setup for the RF tuning by a push/pull action on a MYRRHA Spoke cavity prototype. (Right) Frequency shift measured on the two MYRRHA cavity prototypes with a push/pull action.

Table 2: Some Characterictics of the MYRRHA Cavity

Characteristics	FEM	Measures
Cavity stiffness [kN/mm]	15	[12.8; 14.5]
Tuning sensitivity [kHz/mm]	180	[190; 210]

The experimental device used for the pressure RF tuning method is shown on Fig. 7. The cavity remains at the room pressure. The helium vessel is gradually filled with nitrogen gas up to a step pressure (monitoring the pressure with a sensor) and then emptied. At each filling and emptying step, the RF frequency is measured with a network analyser: i.e. under pressure loading and at rest.

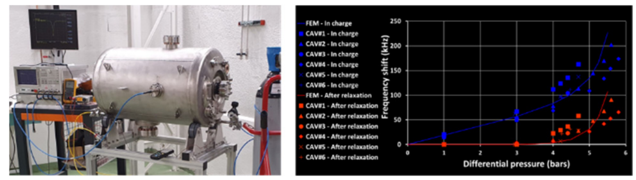

Figure 7: (Left) Experimental setup for the RF tuning of the ESS cavity by pneumatic pressurization. (Right) Frequency shift induced by pneumatic pressurization of the ESS Spoke cavities (Right) Frequency shift induced by pneumatic pressurization of the ESS Spoke cavities.

The RF tuning starts by applying a differential pressure of 1 bar in order to define the pressure sensitivity of the cavity in the linear domain; which is useful to estimate the following pressure steps. This sensitivity to the pressure at room temperature, $K_{P@20°C}$, varies from 15 Hz/mbar to 21 Hz/mbar for the six ESS cavities that were tuned with this method*.

Figure 7 presents the frequency shifts measured (see the dots) under a differential pressure loading (in blue) and after relief of this pressure i.e. after relaxation (in red). The numerical estimations (continuous lines) are consistent with the experience which gives us confidence that the deformation produced with this RF tuning method is well controlled. The numerical simulation also points out that above a differential pressure of 3 bars, the frequency shift can increase rapidly. This is the reason why the frequency target was achieved by implementing several pressure step cycles for all RF tuning of the ESS double Spoke cavities.

CONCLUSION

For the processing phase of the ESS double Spoke cavities, a new RF tuning operation, based on a permanent deformation of the cavity walls by applying a pressure inside the helium tank, is now proposed and used when the other usual operations cannot. During the lifecycle of the cavity, only the effect of the H degassing baking on the frequency is indeed not well evaluated. So, when a cavity features a too low frequency (from a few kilohertz to several tens of kilohertz from the target frequency), the pneumatic RF tuning operation becomes a good alternative. The numerical simulation of this tuning gives a good understanding of the involved mechanical deformation and also an estimation of the frequency shift depending on the pressure loading. This pneumatic RF tuning was successfully performed at IJCLab on six ESS cavities. The push/pull action remains the efficient solution to reduce the frequency or compensate a frequency shift up to some hundreds of kHz.

* It can be noted that this sensitivity range is the same as the one measured in a vertical cryostat at cold temperature on other ESS cavities that were not tuned.

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