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DEVELOPMENT AND PERFORMANCES OF SPOKE CAVITY TUNER FOR MYRRHA LINAC PROJECT

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Abstract

In the framework of the Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA) 100 MeV linac construction, a fully equipped prototype cryomodule is being developed. In order to control the resonance frequency of the cavities during operation, a tuner has been studied with the specific requirements: high degree of reliability and high tuning speed. This paper reports the design consideration and the first performances measurement in vertical cryostat test at an early stage of the prototyping phase.

INTRODUCTION

Main purpose of the tuner is to bring the cavity at the nominal resonant frequency of 352.2 MHz, and to maintain it during beam operation. As a project requirement, an additional purpose is to be able to detune the cavity of 100 times bandwidth quickly [1,2] (within a second), but also to retune it quickly. Finally, another challenge is to enhance the reliability of the tuner. In order to meet this point, the selected tuner design is essentially coming from the ESS double spoke tuner design which is shown in Fig.1 and has already been extensively tested [3-5] and improved during the ESS prototype phase.

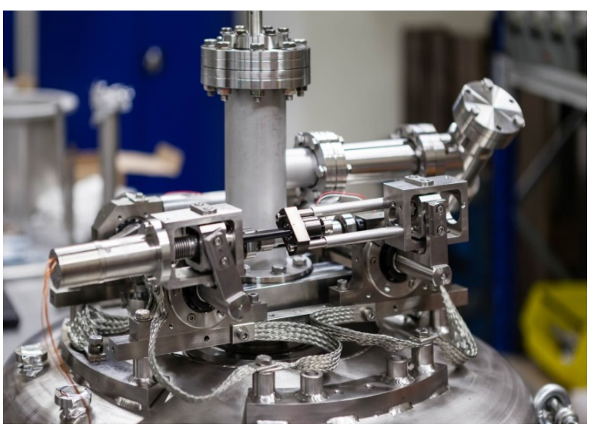

Figure 1: ESS Prototype tuner.

As shown in Fig. 2, an ESS prototype tuner has been adapted in order to fit on a MYRRHA single spoke prototype cavity for a vertical cryostat test to get preliminary results on the motor and piezo actuators performances during a cold test (cavity at 2K). During this test, cavity mechanical resonant modes were observed by both piezo and will be used to build a numerical model for control system loop simulation [6].

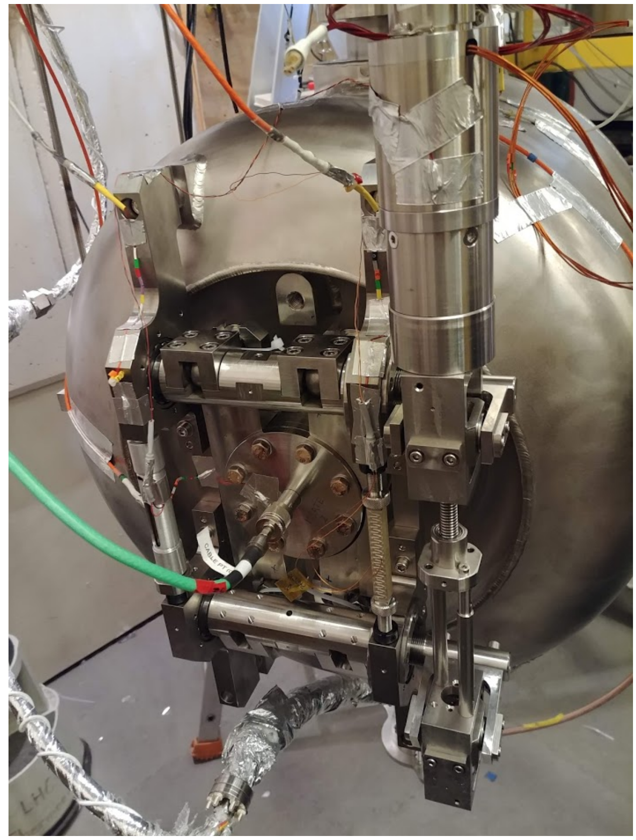

Figure 2: Adapted prototype tuner for MYRRHA single spoke cavity.

MECHANICAL DESIGN

The tuner applies a pulling action on the cavity beam flange in order to control the resonant frequency. This action results in a concentration of the stress around the iris side of the cavity end cup as shown in Fig. 3.

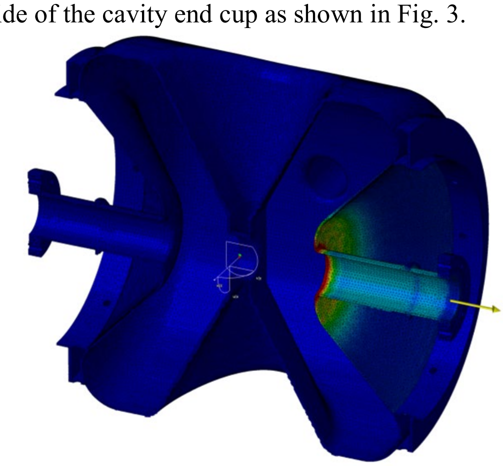

Figure 3: Mechanical stress analysis.

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Simulations on the 3D model of the cavity were made and the data obtained are summarized in Table 1. The maximum allowable stress is defined to a conservative value of 320 MPa. It is reached when applying a displacement of 0.872 mm on the cavity beam flange and corresponds to an ultimate frequency range of 158 kHz. In order to achieve this, the tuner must generate and handle a force of 13.1 kN.

Table 1: Cavity Parameters for Tuning

Parameter	Unit	Value
Frequency sensitivity	kHz/mm	180
Max stress sensitivity	MPa/mm	367
Stiffness	kN/mm	15

Slow Tuner Design

The Fig. 4 describes the kinematic model of the slow part of the tuner. A double lever mechanism acted by a linear actuator gives significant motion reduction to move precisely. The linear motor itself is made from a stepper motor, a planetary gearhead and a MoS_2 coated roller screw.

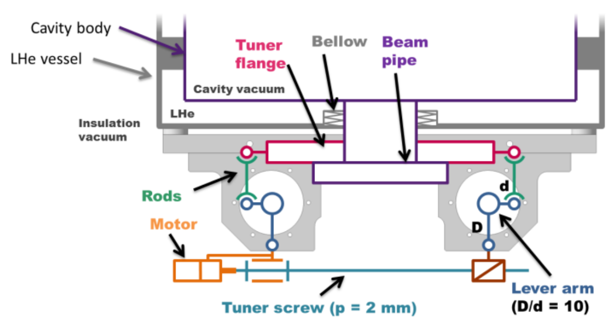

Figure 4: Slow tuner part kinematic diagram.

The kinematic parameters have been optimized in order to satisfy the fast detuning requirement and are resumed in Table 2. The cavity bandwidth of 160 Hz requires controlling the stepper motor with micro stepping method in order to improve the resolution of the system.

Table 2: Tuner Kinematic Parameters

Parameter	Unit	Value
Motor resolution	Step/rev	200
Gearhead ratio		6.25:1
Roller screw pitch	mm	2
Lever arm ratio		20
Motion resolution	µm/step	0.08
Frequency resolution	Hz/step	<14.5

Fast Tuner Design

Piezo actuators have been kept in the design in order to compensate microphonics and also to provide assistance to the slow tuner for the fast detuning and retuning scenario (described in the introduction). They can act independently so it improves the reliability of the system by redundancy. The Fig. 5 shows a displacement field simulation result obtained for a given piezo motion (typically few µm). The cavity motion obtained is then around 48% from the piezos displacement (when both piezo are used).

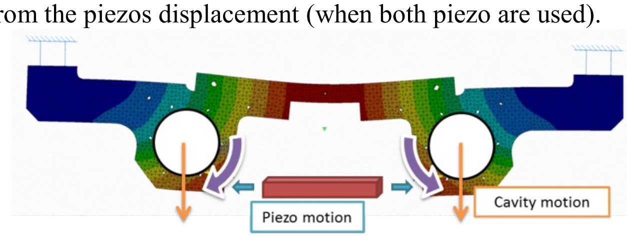

Figure 5: Displacement field simulation result.

Two different piezo have been installed on the tuner. One is manufactured by Noliac [7] while the other one from Physik Instrument (PI) [8]. Specifications are summarized in Table 3. Due to asymmetric design of the tuner, the piezo mounted on P1 position (closest to the motor) is more efficient by around 20%.

Table 3: Piezoelectric Actuators Specifications

Specification	Unit	P1	P2
Manufacturer		Noliac	PI
Reference		NAC5022	PICMA
Dimensions	mm^3	72x10x10	90x10x10
RT Stroke	µm	115.5	94
RT Blocking force	N	4200	3800
RT Capacitance	µF	13.9	32
Max voltage	V	200	120

VERTICAL COLD TEST

Motor Displacement

From the initial position where the tuner is still not connected the cavity, successive 0.1 mm steps, equivalent to 1250 motor steps, are achieved until 1.5 mm. At each step, while the cavity is in self-excited loop, its resonant frequency is read using a frequency meter. As presented on Fig. 6, the measured tuning sensitivity is 101.5 kHz/mm and is closed to the half of the cavity sensitivity. While it is assumed that deformations are almost equally shared between the cavity and the tuner, it was known that the cavity suffers from fabrication issue. Because of some weld joints are missing, it was not possible to precisely correlate the measurements and the simulations.

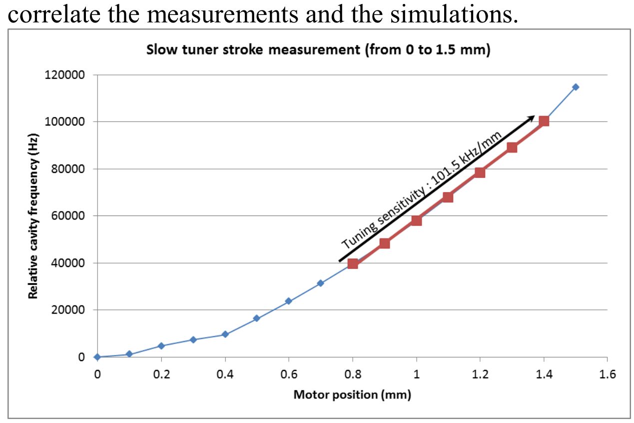

Figure 6: Slow tuner sensitivity measurement.

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In order to satisfy the fast detuning scenario (14 kHz in 1 second), the tuner must reach a speed of 9.375 turn/s. Several tests have been done to verify this by releasing the cavity at this speed. As shown in Fig. 7, some tests were successful but not all of them. Some explanations commensurate with this result like the fact that the tuner screw used for the cold test was a ball screw coming from a previous ESS tuner prototype which was already showing large friction torque at low temperature. However, during previous test at 300K and 77K of the tuner, this test was succeed while respectively lowering the current down to 0.36 A and 0.6 A. There are some rooms to optimize the mechanical design and also the motor control parameters like rising current up to 1.2 A (nominal), modify acceleration profile and micro stepping resolution). More tests will have to be performed then.

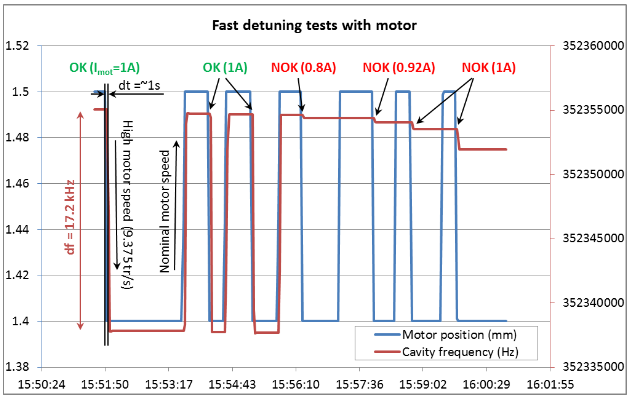

Figure 7: Slow tuner fast detuning tests.

Static Piezo Tests

DC Scans are made by smoothly applying successive voltage steps and measuring the cavity frequency at each step. Measurements put on Fig. 8 shows significant less amplitude response on P2 than on P1. After investigations, it appears that P2 was damaged and was already damaged before its installation in the vertical cryostat. The main consequence is a reduction of stroke, 46 µm instead of 106 µm (measured at room temperature). At low temperature, capacitances have been measured respectively at 3.87 µF and 3.80 µF for P1 and P2. The tuning range observed on P1 even with unipolar mode has been measured and is superior to 1.5 kHz and will grant some operation margins if compared to the expected LFD [9]. However, for same reason mentioned about the tuning sensitivity, these tests have to be performed again on a properly manufactured cavity for verification.

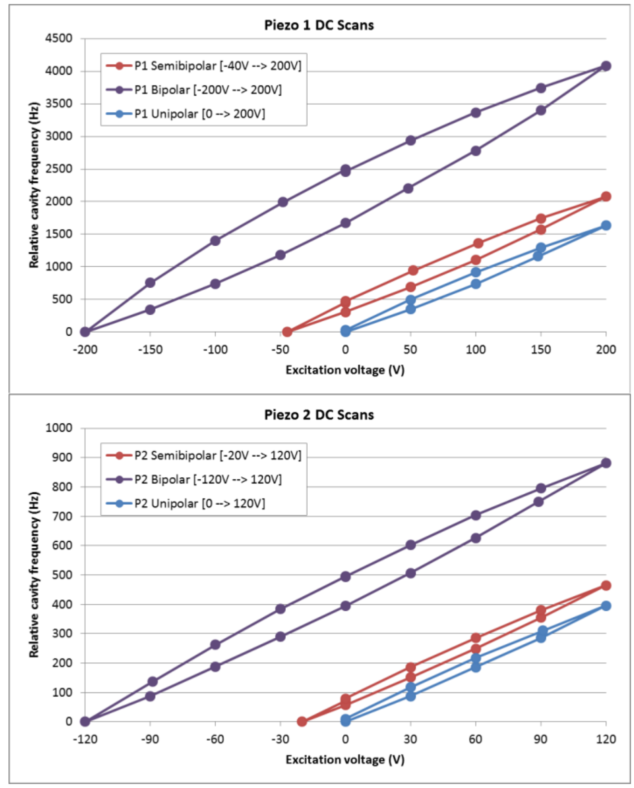

Figure 8: Piezo DC scan test.

Dynamic Piezo Tests

For the dynamic tests, cavity frequency response is measured using a cavity resonance monitor (CRM) system [10].

Transfer function have been measured by sending a blank noise signal on a piezo, acquiring its own signal and the CRM output, and then comparing them by using FFT based signal processing libraries. Results of this measurement are shown on Fig. 9.

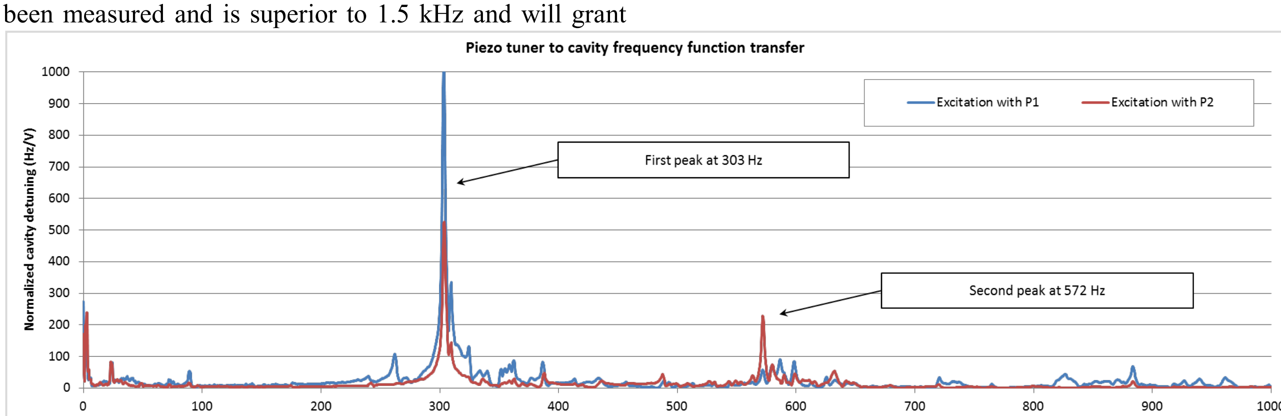

Figure 9: Transfer function from P1 to cavity (in blue) and from P2 to cavity (in red).

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Low frequencies (<100 Hz) peaks are mainly identified as measurement noise. Static gain measurements have been respectively measured to 7 Hz/V and 4 Hz/V for P1 and P2. Two mains modes have been located at 303 Hz and 572 Hz. These measurements will be reconstructed as a numerical model and implanted into the control loop system simulation in order to define the optimal controller parameters for the low level RF (LLRF) strategy.

Pure delay measurement has been made. It is defined as the time between the beginning of a piezo action (voltage step on the piezo amplifier) and the beginning of the cavity frequency rising. It is equivalent as the travel time of the acoustic wave from the piezo actuator to the cavity through the different mechanical parts of the tuner. In order to measure it, a step signal is generated on a piezo, and the CRM output is acquired at the same time. As shown on Fig. 10, the delay value observed is 0.64 ms.

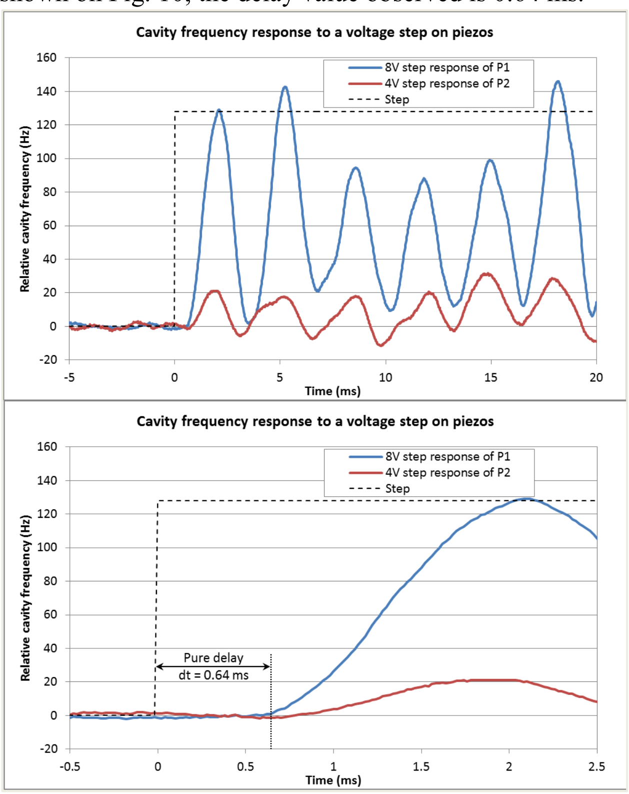

Figure 10: Cavity response to a voltage step on piezos.

CONCLUSION

An upgraded tuner from ESS prototype phase has been tested at low temperature with a MYRRHA spoke cavity. Slow tuner measurements were done and shown that it succeed to tune the cavity but still also needs some optimizations to fulfil the fast detuning requirement all the time. Piezo actuators have been tested and validate the design for the rest of the prototyping phase. Mechanical modes of the cavity have been identified and will be useful to improve the simulation model of the control loop system. Future works are already planned for testing a consolidated tuner prototype with an accelerated lifetime test at 77K temperature.

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