ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-MOPTEV015

SPOKE TUNER FOR THE MINERVA PROJECT

N. Gandolfo, S. Blivet, P. Duchesne, D. Le Dréan, IJCLab, Orsay, France

Abstract

In the framework of the MINERVA construction (MYRRHA Isotopes productioN coupling the linEar acceleRator to the Versatile proton target fAcility), a fully equipped prototype cryomodule is being developed. In order to control the resonance frequency of the cavities during operation, a deformation tuner has been studied. The kinematic model is based on a double lever system coupled with a screw nut linear actuator. The motion is generated by a stepper motor and two piezoelectric actuators working at low temperatures within the thermal insulation vacuum of the cryomodule. Key parameter of this work is the high tuning speed which is required to fulfil the fault tolerance strategy. This paper reports the design study and first tests of the built tuners at room temperature and in vertical cryostat configuration.

INTRODUCTION

The tuner experimentations described in this paper were made using one prototype tuner designed for the MYRRHA project with one prototype cavity, in the continuity of the work done on pre-prototype tuners [1, 2]. The main goals of this experimentation were to qualify the tuner performances, the compatibility with cavity, and verify the capability for fault tolerance feature of the linac [3, 4] which represent a key challenge of this tuner.

TUNER DESCRIPTION

The tuner is based on a double lever deformation system, which induce resonant cavity shift by mechanical deformation of one cavity end cup. This deformation can be obtained by pulling the cavity beam pipe flange while the tuner structure is fixed on the cavity helium vessel. Different types of actuators are used to adjust de cavity resonant frequency: one stepper motor and two piezo actuators. The stepper motor represent the slow tuner. It can be used to adjust the frequency over a wide range in order to compensate uncertainties on the cavity resonant frequency shift occurring during the preparation of the cavity itself and the cool down. The piezo actuators represent the fast tuner. They are useful for fine and fast tuning, when the stepper motor find its limit.

ROOM TEMPERATURE TEST

Cavity was installed in horizontal position and connected to a VNA to track its resonant frequency by looking at S21 parameter. A laser sensor was used to observe micro displacement of the beam pipe (see Fig. 1). The motor position is controlled by steps, which is converted into linear displacement by using an equation that is coming from the tuner kinematic model. This value is equivalent to the linear displacement of the beam flange, in the case that the tuner is infinitely stiff, relatively to the cavity stiffness.

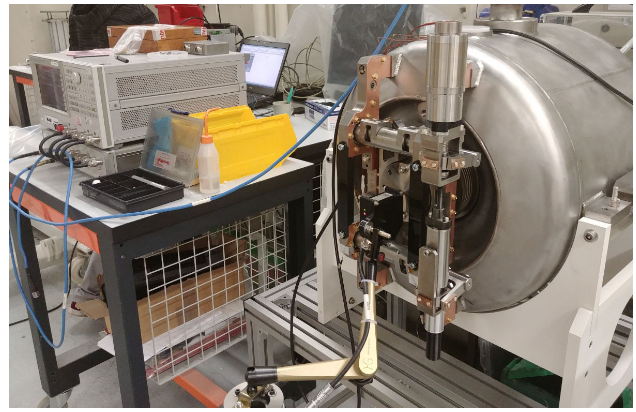

Figure 1: Room temperature setup.

Motor Test

The test routine is a simple back and forth, starting at a point where the cavity is nearly no stressed, and with limited forward displacement in order to not exceed the elasticity limit of the niobium.

Results show a linear action of the tuner on the cavity above 0.12 mm motor position, where the tuner get strongly connected to the cavity. Tuning sensitivity resulting on this region is 112 kHz/mm (see Fig. 2).

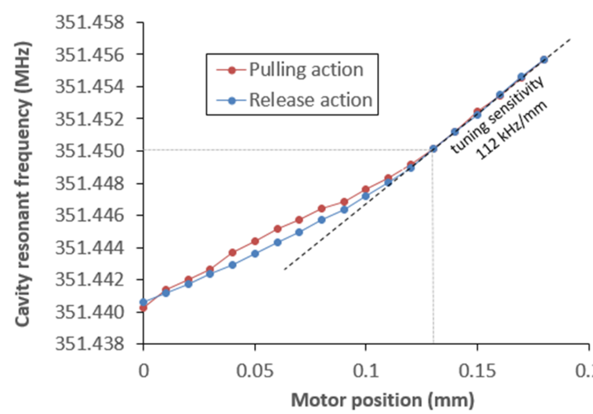

Figure 2: Complete motor run at room temperature.

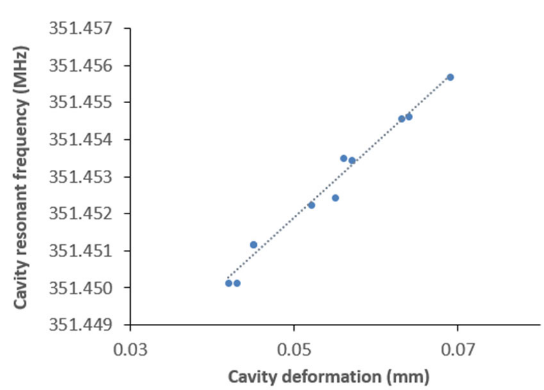

Figure 3: Cavity sensitivity measurement.

ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-MOPTEV015

In the linear region, cavity frequency was compared with the beam flange displacement which reflect the end cup deformation. Cavity sensitivity was then found at 202 kHz/mm, this is just 12% above the value calculated of 181 kHz/mm (see Fig. 3).

Piezo Static Test

A DC scan is made using a voltage amplifier, the piezo actuators are powered gradually from 0 to 200 V, and then from 200 V to 0 (see Fig. 4). Each steps of measurement must be done at similar timing in order to get rid of creep and drift effect.

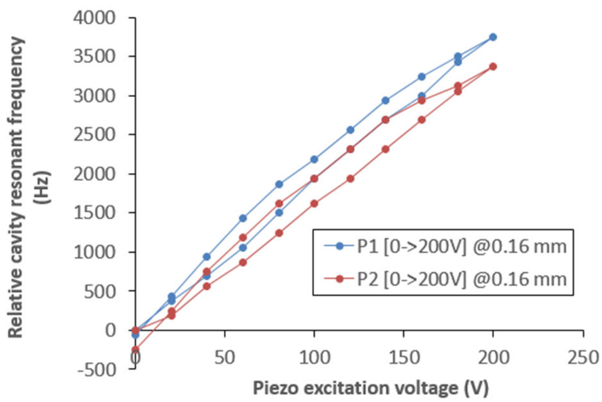

Figure 4: Piezos response to a DC scan.

Piezos are named distinctly as follow: P1 is the one closed to the motor assembly and P2 is at the opposite (see Fig. 5). Maximum tuning range obtained is 3.7 kHz and 3.2 kHz respectively for P1 and P2. The same tuner design always exposed a better response from P1 than on P2 in the range of 20 to 30% but for some reasons, the difference found here is much lower.

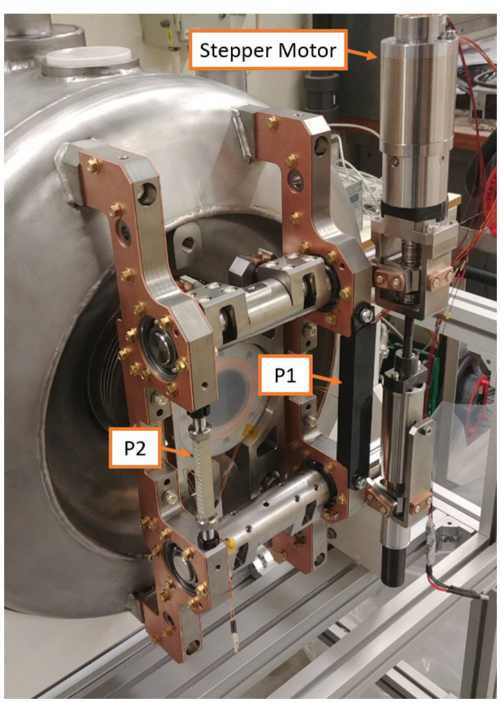

Figure 5: Close view of the tuner.

VERTICAL CRYOSTAT TEST

Description

A MYRRHA spoke cavity was installed on a cryostat, with its own tuner, in order to make a full characterization of the system. The environment was made as close as possible from what there is in an operation cryomodule, in order to provide the most pertinent data. The cavity is in horizontal position (see Fig. 6) and cooled at 2K using its helium vessel. The jacketed cavity and its tuner are operating into a thermal insulation vacuum in the range of 10^{-6} mbar.

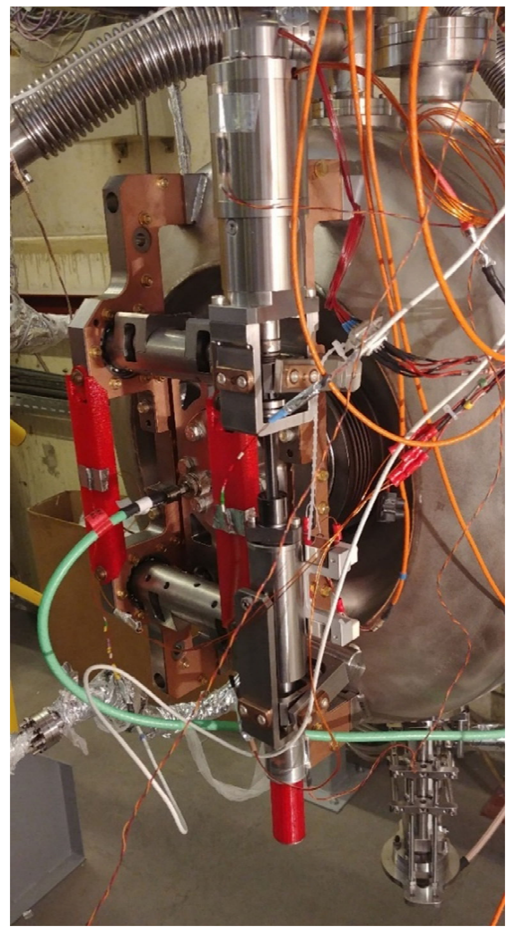

Figure 6: Cavity and tuner mount for cryostat test.

Motor Test

The same test routine was used than for the room temperature test except the possible range of the motor was much higher simply because the elastic limit of the Niobium at 2K is much higher.

Linear region start around the position 0.5 mm (see Fig. 7) which correspond also to the beginning of the effective tuning range. From this point, the tuning sensitivity found is 128 kHz. This value is 15% higher than for the room temperature test. Exact reasons to explain this difference are unclear but it may come from different behaviour of the mechanical joint from room temperature to low temperature. This behaviour have already been see in previous tuner design and experiments.

ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-MOPTEV015

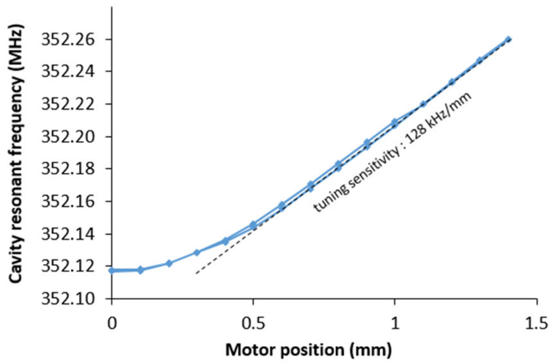

Figure 7: Cavity frequency versus motor position.

Piezo Static Test

In the same way than for room temperature test, several steps of voltage are applied to the piezo, however, additional ranges of operation were used:

- Unipolar voltage : 0 to 200 V
- Semi bipolar voltage : -45 V to 200 V
- Bipolar voltage : -200 V to 200 V

DC scan were done for each piezo at two different motor positions to check any variation from the preloading condition (see Fig. 8). Every measurements are in the range of 1100 Hz to 1200 Hz for unipolar excitation, there is no significant change between the two motor position tested 0.9 mm and 1.3 mm nor between the two piezos.

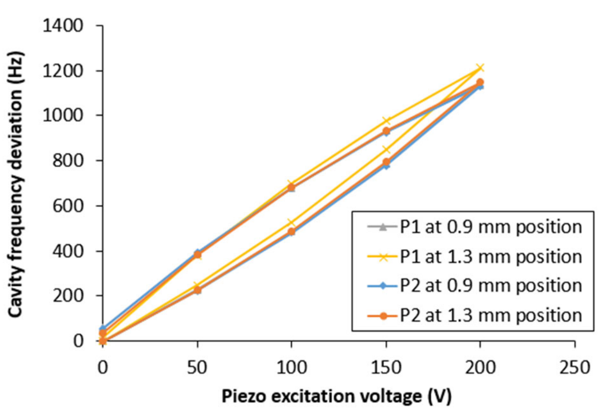

Figure 8: Piezos response at different motor position.

Figure 9 shows how the piezo accommodate from using them in different excitation mode. Total range of detuning for each mode are 1210, 1560 and 3230 Hz for unipolar, semi bipolar and bipolar voltage excitation respectively (see Fig. 9). The range is nearly tripled by using bipolar operation, which should be carefully used by controlling the piezo temperature in order to prevent any degradation.

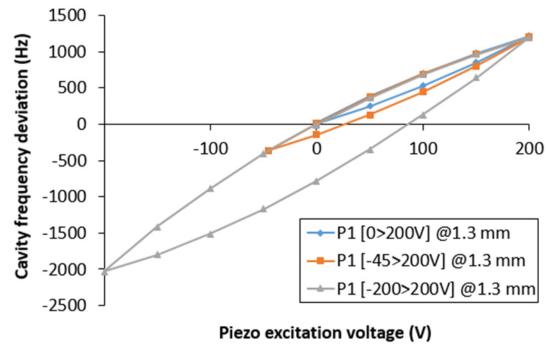

Figure 9: Piezos response with different excitations.

Piezo Dynamic Test

For the dynamic tests, cavity frequency response is measured using a cavity resonance monitor (CRM) system in order to extract the electromechanical transfer function. Results of this measurement are shown on Fig. 10. Remarkable similitude can be made notably about the main resonance peak around 300 Hz for each system.

Motor Fast Detuning Test

In order to satisfy the requirements for fault recovery scenario, the tuner must have the capability to detune the cavity to 14 kHz in 1 second. Multiple cycles have been successfully ran with the parameters found in Table 1.

Table 1: Motor Driver Relevant Parameters

Parameter	Unit	Value
Motor speed	µstep/s	13,000
Motor acceleration	µstep/s²	200,000
Motor current	A	1.0
Microstep size	-	1/8

ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-MOPTEV015

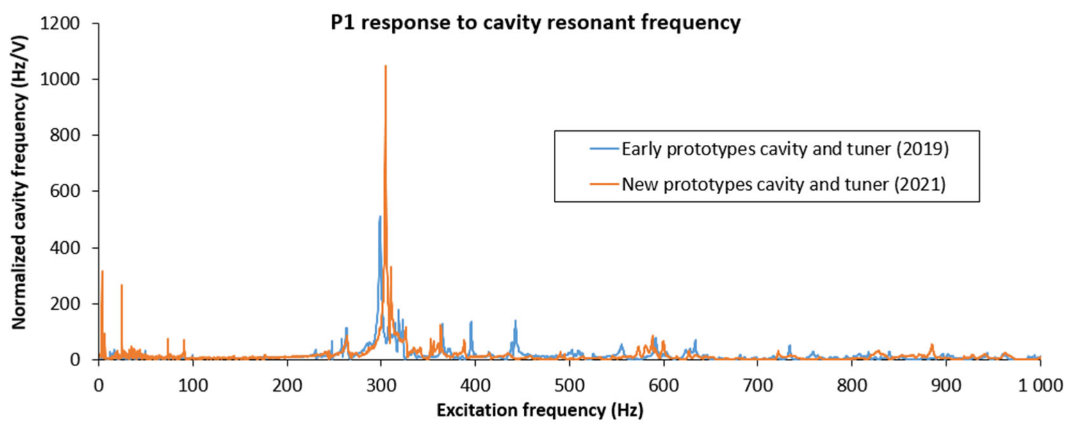

Figure 10: Transfer function of piezo sensitivity measured from early prototypes on 2019 (in blue) and new prototypes on 2021 (in orange).

With 128 kHz/mm tuning sensitivity, the motor speed required to make 14 kHz in 1 second is 11,300 µstep/s. The test showed good reproducibility with several cycles as shown in Fig. 11 and Fig. 12.

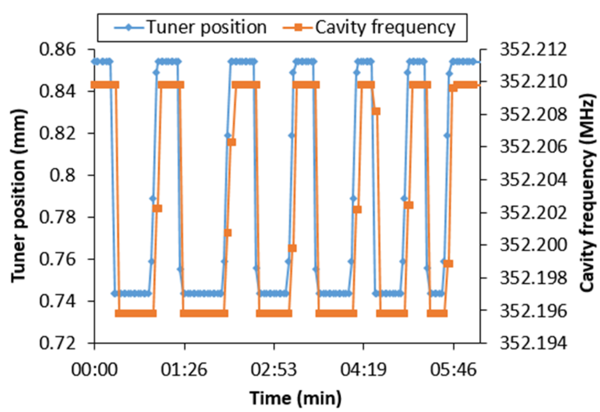

Figure 11: Cavity response to multiple fast motion.

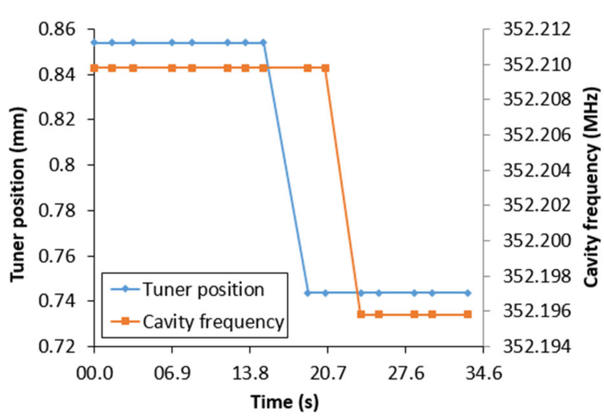

Figure 12: Cavity response to a single fast motion.

CONCLUSION

One prototype tuner with the last design prototype cavity for Minerva project have been successfully tested. The requirement for fast detuning is satisfied. Additional tests are scheduled for the current and next year in order to verify the durability of the tuner. The design will serve as a reference for the construction of the project.

REFERENCES

[1] N. Gandolfo *et al.*, "Fast tuner performance for a double-spoke cavity", in *Proc. LINAC'14*, Geneva, Switzerland, Sep. 2014, paper THPP07.

[2] N. Gandolfo *et al.*, "Fast tuner performance for a double-spoke cavity", in *Proc. SRF'19*, Dresden, Germany, Jul. 2014, paper TUP087.

[3] J.-L. Biarrotte *et al.*, "Beam operation aspects for the MYRRHA linear accelerator", in *Proc. TC-ADS-2*, Nantes, France, May 2013.

[4] F. Bouly *et al.*, "Fault Tolerance and Consequences in the MYRRHA Superconducting Linac", in *Proc. LINAC'14*, Geneva, Switzerland, Sep. 2014, paper MOPP103.