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PROTOTYPE SSR2 TUNER PROCUREMENT AND TESTING AT IJCLab FOR PIP-II PROJECT

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Abstract

IJCLab is involved in the PIP-II project on the design and development of accelerator components for the SSR2 (Single Spoke Resonator type 2) section of the superconducting linac. Five prototype tuners have been built and are being tested at IJCLab. After a short description of the tuner, this paper reports on the procurement strategy and the performance observed at both room and low temperatures in vertical cryostat test with SSR2 prototype cavities. This paper will also share results on accelerated lifetime tests performed in a dedicated nitrogen-cooled cryostat.

INTRODUCTION

The SSR2 tuner (see Fig. 1) for the PIP-II project is based on a mechanical deformation system using a lever arm coupled to an actuator system consisting of a stepper motor and two piezoelectric actuators. It is an adapted version of the SSR1 cavity tuning systems from the same project [1]. The entire system shares all the constraints experienced by the cavity, such as vacuum, low temperatures and radiation. An important feature of this tuner is that every active components are assembled on a plate called "motor cartridge" which is located on the side of the cavity and accessible for replacement in case of maintenance through a service port of the cryomodule.

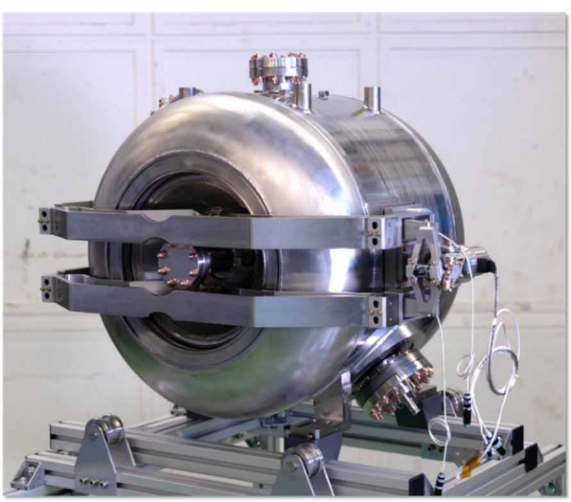

Figure 1: Prototype SSR2 cavity equipped with its tuner.

PROCUREMENT

Tuners are made up of three types of components: mechanical parts, motor actuators and piezoelectric actuators. They are ordered separately and assembled in laboratory environment.

Mechanical Parts

Due to the risk of magnetic trapping of the cavity during superconducting transition, particular attention is paid to magnetic permeability, so as not to magnetize certain elements of the tuning system. Most mechanical parts (notably the arms) are made from stainless steel AISI 316L (see Fig. 2) to limit magnetization. However, an upgrade to AISI 316LN is planned to further reduce the risk of magnetization. Also, most of the screws are made of silicon bronze C65100.

Figure 2: Every parts of the tuner before first assembling.

Piezoelectric Actuators

The piezoelectric actuators manufactured by PI are low-voltage, multi-layer encapsulated models giving high resistance against risk of mechanical shocks during handling and also against moisture over the storage and installation phases. Individual acceptance tests are carried out for the piezoelectric actuators, with capacitance and stroke measurement. Two piezoelectric actuators are installed for each tuner, sharing force and giving the capability to be used alone or in parallel.

Motor Actuators

Phytron delivered the entire motor actuator which consist of a stepper motor attached to a planetary gearbox and coupled to a screw-nut system as illustrated in Fig. 3. All of these components are dry-lubricated for low-temperature operation under vacuum. Motors are tested immediately after installation.

Figure 3: Motor actuator.

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TUNER TESTING

Tuner Assembling

At the start of an installation on a SSR2 cavity, the tuning system is arranged in three parts: two arms, and a motor cartridge. Assembly is carried out by first hooking the two arms onto the cavity, then placing the motor cartridge on its side. The system then needs to be carefully adjusted, and a mechanical clearance placed between the tuning system and the cavity to ensure that the cavity can deform freely due to the effects of vacuum pressure and thermal shrinkage.

Room Temperature Testing

A verification test was carried out at room temperature. The motor is first assembled with a clearance, resulting in a non-linear region at the start of the action. At the beginning of the test, the motor moves to make contact with the cavity and gradually pushes it. After travelling on a reasonable linear region, the motor moves backward while releasing the mechanical stress on the cavity resulting in an increase of its resonant frequency.

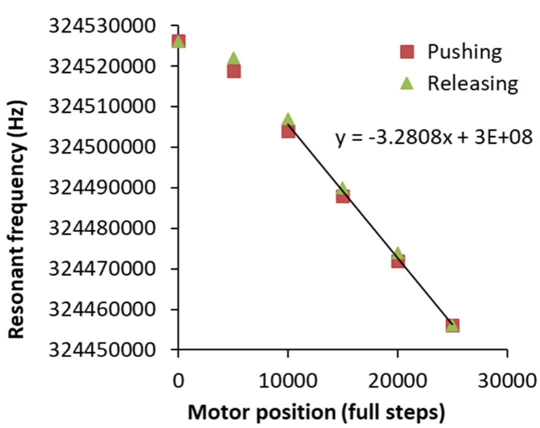

Figure 4: Tuning sensitivity test at room temperature.

The test result presented in Fig. 4 shows a motor resolution of 3.3 Hz/step with a native motor resolution of 200 steps per revolution. This result fulfill the project requirement of 9.5 Hz/step and is close to the 3.7 Hz/step estimated value by design.

Vertical Cryostat Testing

In order to qualify the tuners at low temperature, several tests were carried out with three tuners assembled on three SSR2 prototype cavities during their vertical cryostat test (see Fig. 5).

Figure 5: Cavity and its tuner equipped on the cold mass before insertion in the vertical cryostat.

Sensitivity test is carried out in the same way than at room temperature, except that the motor is ran over a larger range and expected to make the cavity reach the exact accelerator frequency of 325 MHz (see Fig. 6).

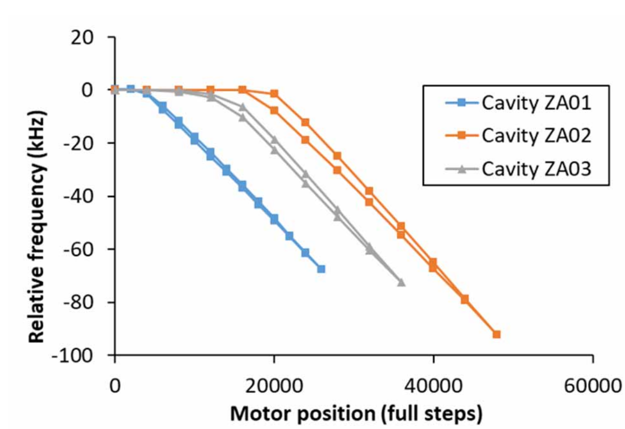

Figure 6: Tuning sensitivity test at low temperature.

Tuning resolutions obtained are respectively 3.1 Hz/step, 3.2 Hz/step and 3.2 Hz/step for ZA01, ZA02 and ZA03 which conform well to the project requirement. For those

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tests, tuning range was not intended to be explore as it comes with some risk for the cavities. Maximum tuning range achieved was 92 kHz for ZA02 cavity while the requirement value is 130 kHz minimum, and design estimated value is 157 kHz.

Hysteresis measurements have been carried out by successively pushing and releasing the cavity then measuring the residual difference as a non-return to initial value. Around 70 Hz of hysteresis is record for motion that shift the cavity frequency of 330 Hz. It corresponds to 1/10 turn of motor backlash for a half-turn movement, which is within the specification range for this type of motor, showing that the contribution of the tuner's mechanical backlash is rather small (see Fig. 7).

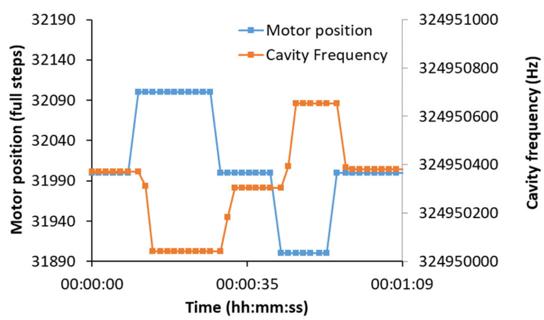

Figure 7: Hysteresis test of the motor.

Piezo measurement are made as following, first P1 is actuated (located on the bottom), and then P2 (located on the top) and finally both piezo are driven in parallel. An automated sequence is run per step of 20 V from 0 to 100 V, with waiting interval of 5 seconds in order to let de frequency measurement stabilizing. The results are shown in Fig. 8.

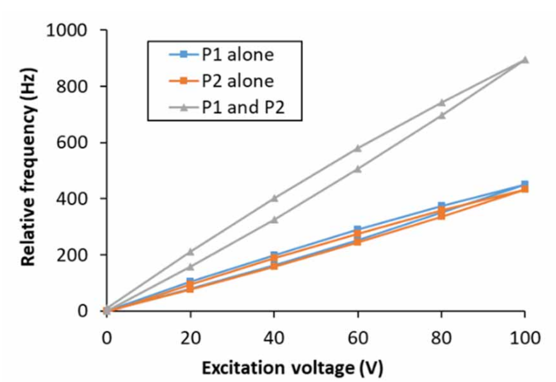

Figure 8: Piezoelectric actuator stroke measurement.

Project requirement is to reach 700 Hz using both piezo. It is fulfilled using both piezo at nominal voltage range +100 V with a corresponding detuning of 896 Hz. Estimated value was 1136 Hz at 120 V range which is specified as the maximum voltage range assuming piezo actuators were cooled down to 20 K. Equivalent value for 100 V excitation range is 957 V.

ACCELERATED LIFETIME TEST

Another project requirement is defining the lifetime of the motor actuator to operate at least for 1,250 revolutions. A test campaign has been defined with the motor cartridge alone to be tested in a liquid nitrogen cryostat assuming the environment conditions are close enough to the cryomodule environment.

The motor cartridge is mounted on an aluminum plate (see Fig. 9) which acts as a dummy cavity, representing the same stiffness and carrying a calibrated strain gage sensor to monitor the motor's action throughout the test in term of force transmitted along the actuator screw.


Figure 9: Motor cartridge installed on the cold mass before insertion in the liquid nitrogen cryostat.

The test was planned to be run over a full working week and was scheduled as follow:

- Monday afternoon: characterization test
- Tuesday morning: stress test
- Tuesday afternoon: characterization test
- Wednesday morning: stress test
- Wednesday afternoon: characterization test
- Thursday morning: stress test
- Thursday afternoon: characterization test
- Friday morning: stress test
- Friday afternoon: characterization test

Characterization test means a full round trip with several checkpoints by measuring backlash and piezoelectric actuator responses. Stress test consist of applying 50 cycles on the tuner on the nominal tuning range meaning the actuator

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never loose contact on a cycle, and force ramp up to maximum value at the maximum motor position. The compilation of the stress tests are shown in Fig. 10 and show no significant anomaly on the motor response.

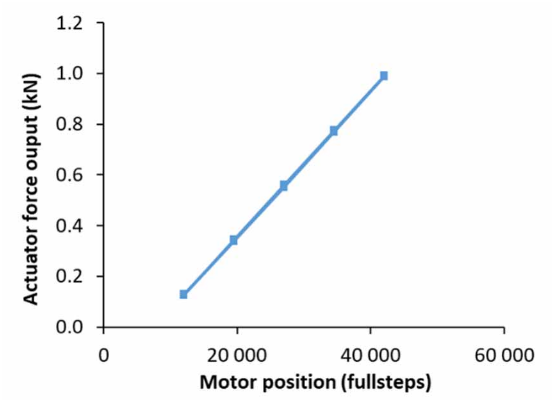

Figure 10: Compilation of every stress tests, 200 cycles are shown equivalent to 1,200 motor revolutions.

Piezoelectric actuators stroke have also been measured and their response are in a range of 7% of stability maximum for a given motor position (see Fig. 11).

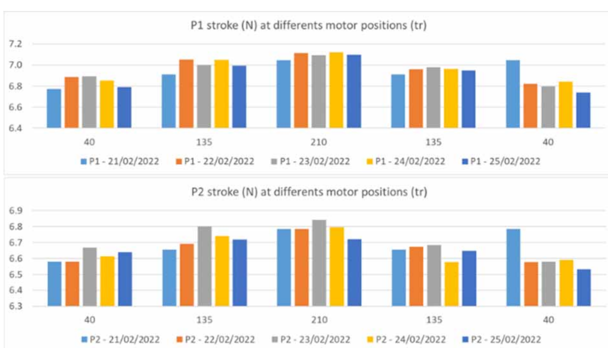

Figure 11: Compilation of every piezo stroke measurements at different motor positions over the lifetime test.

After the lifetime test, a visual inspection has been performed and did not reveal any significant sign of wears, especially on the screw (see Fig. 12).

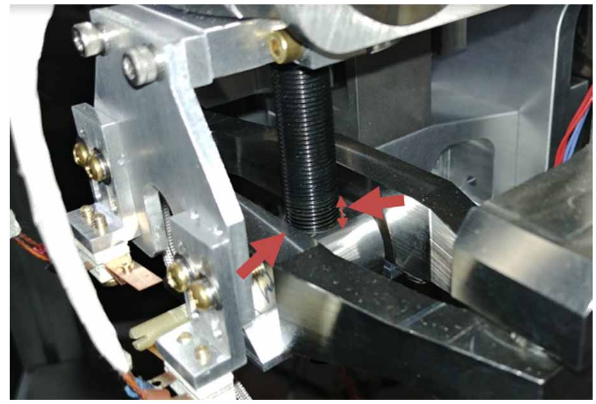
Figure 12: Picture of the main screw showing only slight color modification after the accelerated lifetime test.

CONCLUSION

Five prototype tuner have been built, three of them have been tested. The performances recorded fulfill the project requirement in term of resolution and fast tuning range. Additional tests must be achieved to verify the full tuning range. An accelerated lifetime test have been practiced on one motor cartridge and show no performance degradation after a sequence of more than 1,200 motor revolutions. Additional tests are foreseen to qualify a limit of durability of such actuator which also have been extensively tested successfully on some other projects [2]. Among all of these results the system show no specific weakness.

ACKNOWLEDGEMENTS

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