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FREQUENCY TUNER DEVELOPMENT AND TESTING AT CORNELL FOR THE RAON HALF-WAVE-RESONATOR*

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Abstract

The half-wave-resonators (HWRs) for the RAON project require a slow frequency tuner that can provide >80 kHz tuning range. Cornell University is currently in the process of designing, prototyping, and testing this HWR tuner. In this paper, we present the optimized tuner design, prototype fabrication, test insert preparation, and cryogenic test results. The performance of the tuner is analysed in detail.

INTRODUCTION

A RAON HWR cryomodule [1-3] houses two HWR cavities, each of which requires an individual slow frequency tuner. Cornell University is developing the prototype HWR tuner, which is based on the pneumatic tuner developed by Argonne National Laboratory (ANL) [4]. The pneumatic tuner requires a pressure regulation system to control tuning amounts; as an alternative way, we adopted a scissor section mounted with a cryogenic step-motor to replace the bellow section of the pneumatic tuner. In this way, the HWR tuner will be merely driven by electrical signals. The main concern of this design is that the scissor section could bind or not move smoothly at low temperatures (2K – 4.2 K). In this paper, we prove the scissor-section scenario can work for the HWR tuner.

TUNER DESIGN AND FABRICATION

The preliminary design of the HWR tuner has been reported in Ref. [5]. In this section, we briefly review the design. The target frequency of the HWR (geometrical $\beta = 0.12$) is 162.5MHz at 2K. The slow frequency tuner ought to provide at least 80 kHz tuning range. We designed the maximum tuning amount up to 200 kHz, which will give an adequate margin for the HWR frequency control.

Mechanical Design

The 3D model, shown in Fig. 1, illustrates the HWR tuner structure: two tuning bars are mounted on each beam-pipe flange; four strings link the two pairs of tuning bars. The scissor-section driven by the cryogenic stepper-motor is attached on the strings by its frames.

When the motor is turning, the scissor-section will move the frames ① and ② in the reverse directions, as is shown in Fig. 2 (a). The frames ① and ② are attached on the strings via their hooks by which the frames can push the strings ④ in the middle and squeeze the cavity beam-pipe flanges by the tuning bars ③, depicted in Fig. 2 (b).

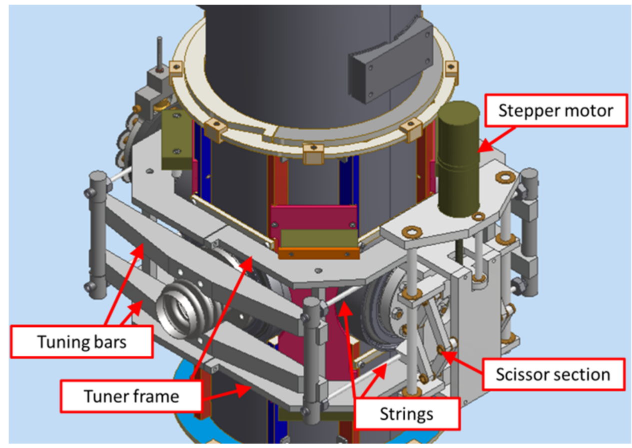

Figure 1: 3D model of the tuner installed on a HWR.

The material for the tuning bars is 316 stainless steel (SS) to avoid thermal stress between the tuning bar and beam-pipe flange which is made of SS as well. The ideal material for the strings is titanium (Ti) which has similar thermal expansion coefficient to niobium (Nb); thus a Ti string gives very small thermal stress cross the tuner and does not change the cavity frequency much during cooldown. Since a Ti string is not easy to obtain, we explore SS strings and control the thermal stress by adjusting the tension of the string. The scissor-section is made of Ti for reducing the total weight of the tuner. Table 1 summarizes the thermal expansion rate of Ti, Nb, and SS.

Table 1: Material Shrinkage Rate from 300K to 2K [6, 7]

Material	$\frac{\Delta L}{L}$ (%)
Ti (grade-2)	0.172
Nb	0.146
SS (316L)	0.319

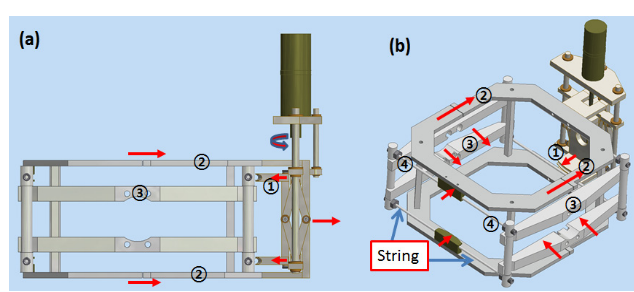

Figure 2: Illustration of the moving mechanism of the tuner.

All the tuner parts have been fabricated at Cornell University. Fig. 3 shows the tuning bars, the tuner frame, and the strings.

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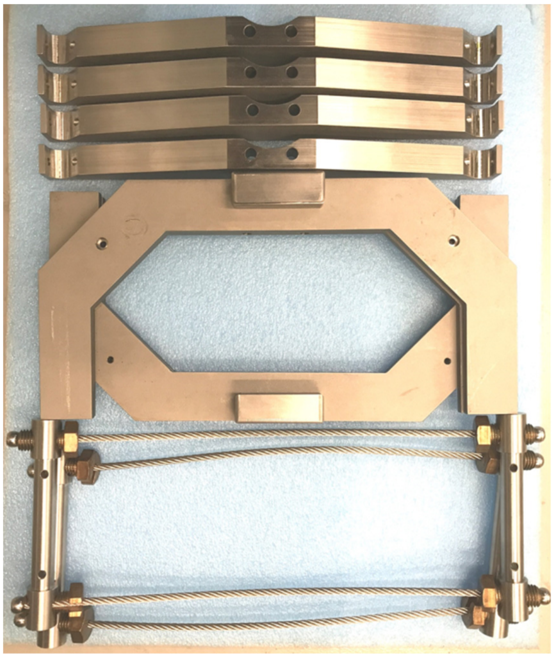

Figure 3: Photograph of the fabricated HWR tuner parts.

DEVELOPMENT OF THE RF INSERT FOR THE TUNER TESTS

Since the cryogenic stepper-motor of the tuner cannot be kept in a liquid helium bath, the liquid helium ought to be filled into the HWR helium tank during the tuner tests. The RF insert, for this reason, has to be modified by adding a reservoir in it, as is shown in Fig 4 (a) and (b). The reservoir has been designed and fabricated (Fig 4 (c)), which has ~240L volume allowing the cavity to be cooled down from 4.2K to 2K. The reservoir will be installed in the RF insert after the HWR tests [8]. Fig 4 (d) shows the tuner mounting location on a HWR dressed cavity.

PROTOTYPE TUNER AND TESTS

We adopt a Phytron cryogenic stepper-motor (VSS UHVC-X0) [9] with a 1:100 harmonic drive gearbox; its photograph is shown in Fig. 5. The motor has 200 steps per revolution; taking account the gear ratio, it will be 20000 steps per revolution. A 3/8th- 24 threads is used in the prototype tuner. In this case, four revolutions from the output of the gearbox can tune the cavity by about 200 kHz, i.e. 2.5 Hz/step. The motor driver we adopted is from GalilTools [10] with a necessary modification to cut off holding currents. The driver can drive the stepper-motor under vacuum without extra heating up the motor when not running.

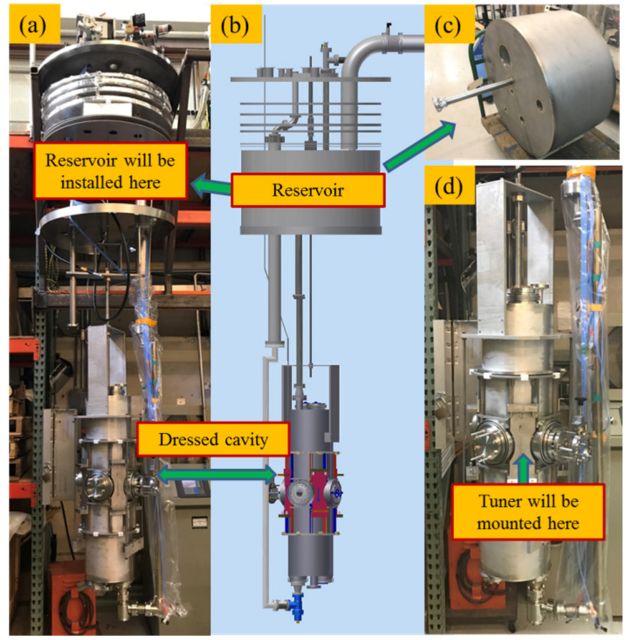

Figure 4: Developments of the RF insert for the tuner tests based on the current HWR insert, (a) The current RF insert for the HWRs tests; (b) 3D model of the modified RF insert for the tuner tests; (c) Fabricated Reservoir; (d) A dressed HWR indicated the tuner mounting location.

Figure 5: Photograph of the Phytron cryogenic stepper-motor with 1:100 harmonic drive gearbox.

Cold Tests

A cold test has been carried out on the scissor-section of the prototype tuner to confirm the movements at low temperature. We use a spring load to simulate the cavity in the cold tests depicted in Fig. 6 (a). In the tests, the tuner frame was kept in a liquid nitrogen bath (77K), as is shown in Fig. 6 (b). To avoid binding on the thread, we used graphite-loaded bronze bushings, displayed in Fig. 6 (c). The cold tests suggest that the tuner can be smoothly turned up to 6 revolutions.

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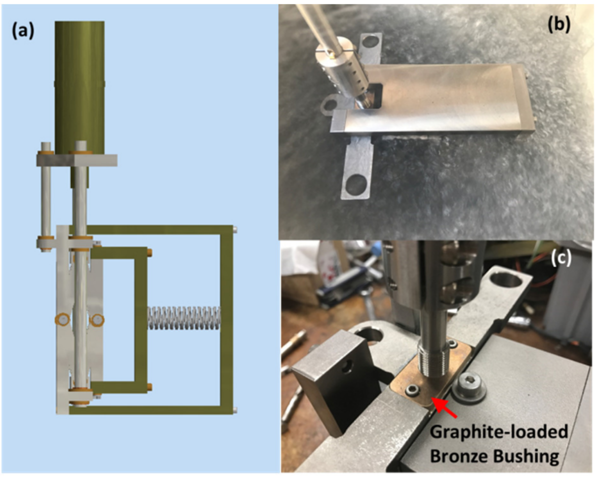

Figure 6: Prototype tuner for the cold tests (a) Schematic of the prototype tuner with a spring load; (b) the tuner in liquid nitrogen bath; (c) photograph of the graphite-loaded bronze bushing.

After the cold test, we inspected the threads and the bushing using the Cornell Optical Inspection System [11]. Wear on the threads was observed as is shown in Fig. 7 (a). We made new inserts using TECASINT 2391 [12], which contain 15% MoS_2 to replace the graphite-loaded bronze bushing. The fabricated TECASINT insert is shown in Fig. 7 (b). TECASIN inserts have been successfully used in the LCLS-II tuner [13, 14].

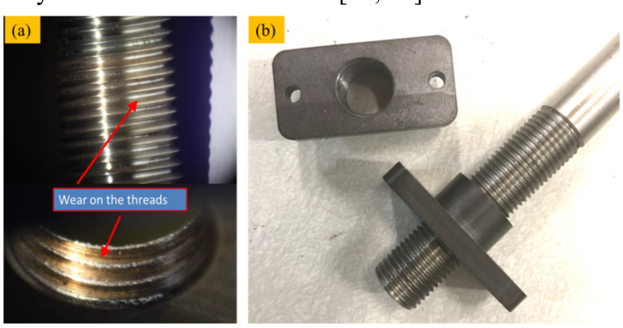

Figure 7: (a) Optical inspection images of the threads of the tuner after the cold test; (b) Photography of the fabricated TECASINT insert.

Long-Term Tests

The tuner ought to be operated for 20 years. We assume the cryomodule will be warmed up twice a year, i.e. 40 thermal cycles in the tuner's lifespan, which requires the tuner to travel the full tuning range (200 kHz). Since the cryomodule will be operated stable at 2K, the tuner is assumed to be operated only twice a day to compensate frequency shifts of the cavity. We estimate there will be ~730 cycles per year, which requires covering 10 bandwidth of the cavity, i.e. ~800Hz [15]. Long-term tests have started, and we will report results in a future paper.

CONCLUSION

A new HWR tuner has been successfully designed and fabricated, based on the ANL HWR tuner. The maximum tuning amount is 200 kHz, which gives an adequate margin for the HWR frequency control. A prototype version of the tuner has been fabricated and has been tested at LN_2 temperature. Wear was observed on the drive screw threads after the cold test. TECASINT inserts have been made to avoid the wear issue. Additional cold tests and a long-term test will be started soon. The RF insert for the full-system cryogenic tuner test is under construction.

ACKNOWLEDGMENT

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