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

M. Ge†, F. Furuta, T. Gruber, D. Hall, S. Hartman, C. Henderson, M. Liepe, S. Lok, T. O'Connell, P. Pamel, P. Quigley, J. Sears, V. Veshcherevich, Cornell University, Ithaca, New York, USA
B.H. Choi, J. Joo, J.W. Kim, W.K. Kim, J. Lee, I. Shin, Institute for Basic Science, Daejeon, Korea

Abstract

The half-wave-resonators (HWR) for the RAON project require a slow frequency tuner that can provide at least 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 tuner design, prototype fabrication, and first test results.

INTRODUCTION

A HWR cryomodule [1] for the RAON project [2, 3] comprises two HWR cavities, each of which requires an individual slow frequency tuner. The development of the HWR tuner at Cornell University 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 moving smoothly at low temperatures (4.2K-2K). In this paper, we prove the scissor-section scenario can work for the HWR tuner.

TUNER 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. In this design, we aim for a tuning amount of up to 200 kHz, which will give an adequate margin for the HWR frequency control.

Mechanical Design

The equivalent circuit model of a cavity shows that the cavity resonant frequency (f_0) is inverse proportion to the square root of capacitance (C), as is described in Eq. (1):

$$f_0 \propto \frac{1}{\sqrt{LC}}, \qquad (1)$$

For the HWR cavity, reducing the gap (shown in Fig. 1 insert plot) will increase the capacitance of the cavity and decrease its frequency. We used CST Microwave Studio [5] to simulate the frequency shifts versus the distance change per gap, as is shown in Fig. 1. For decreasing 80 kHz tuning amounts, the cavity is needed to be squeezed 0.44 mm from the beam-pipe direction (0.22 mm for each gap). While for the -200 kHz tuning, the two gaps has to be reduced by 1.06 mm in total (0.53 mm for each gap).

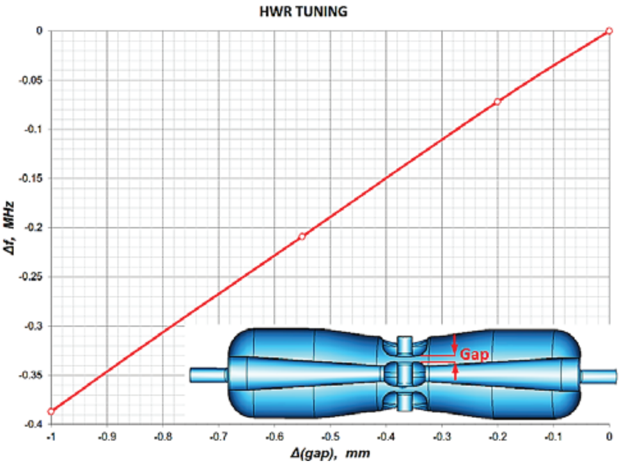

Figure 1: Curve of the frequency shifts versus gap change; the insert plot shows the gap in the cavity.

The 3D model, shown in Fig. 2, 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.

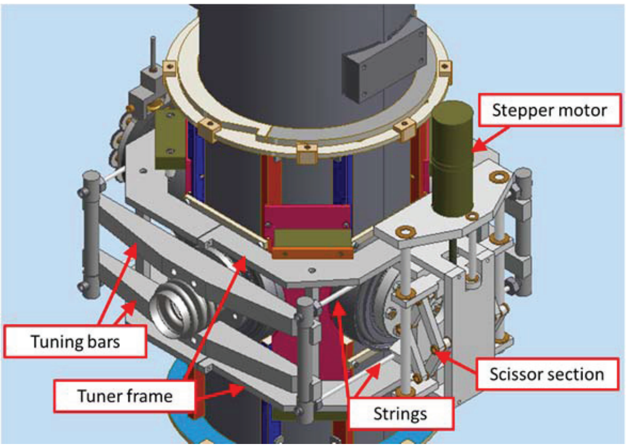

Figure 2: 3D model of the tuner installed on a HWR.

When the motor is turning, the scissor-section will move the frames ① and ② in the reverse directions, as is shown in Fig. 3 (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. 3 (b).

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

---

* Work supported by the Ministry of Science, ICT, MSIP and NRF. Contract number: 2013M7A1A1075764.

† mg574@cornell.edu

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 whole weight of the tuner. Table 1 summarizes the thermal expansion rate of Ti, Nb, and SS.

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

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

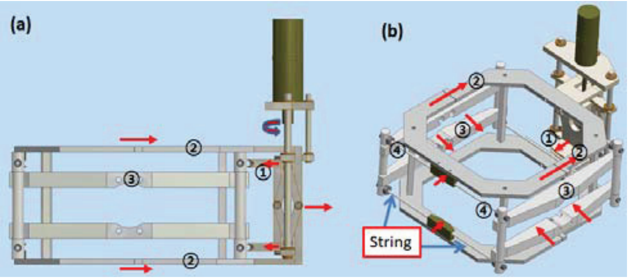

Figure 3: Illustration of the moving mechanism of the tuner.

Stress Analysis

We performed a finite element analysis (FEA) which predicts that 5000N applied on each beam-pipe flanges will squeeze the cavity about 1.06 mm, therefore decrease the frequency about 200 kHz. The stress analysis on the tuning bars is carried out based on the 5000N loads; the results (see Fig. 4) shows that maximum stress is 91MPa, which is below the yield strength of stainless steel (250 MPa).

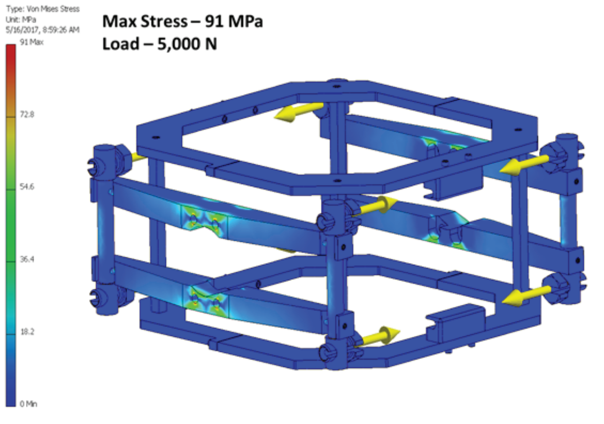

Figure 4: Stress distribution on the tuning bars based on the 5000N load at maximum detuning.

The load on the scissor section is much less than 5000N, because the string deflects with a small angle α shown in Fig. 5 (a). As the force on the flange is 5000N, each string will have 1250N, i.e. $F_2 = F_3 = 1250\,N$. $F_1 = 2F_2\tan(\alpha)$, here $0° < \alpha < 6.5°$ computed by the FEA simulation; thus it can obtain $F_{1\,max} = 284\,N \approx 300\,N.$ The force analysis on the scissor-section is shown in Fig. 5 (b); As the scissor is attached on the string, the horizontal force is equal to the force pull on the string in the middle, i.e. $F_6 = F_7 = F_{1\,max} \approx 300\,N.$ The vertical force $F_4 = F_5 = \frac{F_6}{\tan(\beta)}$, here $31.2° < \beta < 55°$. Thus $F_{4\,max}$ =495N. We use 600N in the simulation to give adequate margin. The simulation results are shown in Fig. 6 (a)-(c), which turns out the max stress is far below the yield strength of titanium (276 MPa).

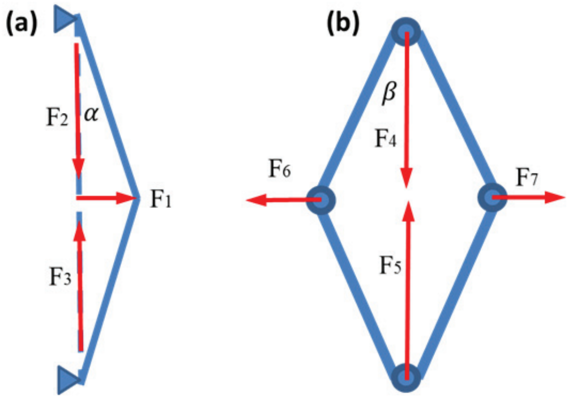

Figure 5: Force analysis (a) on the string; (b) on the scissor section.

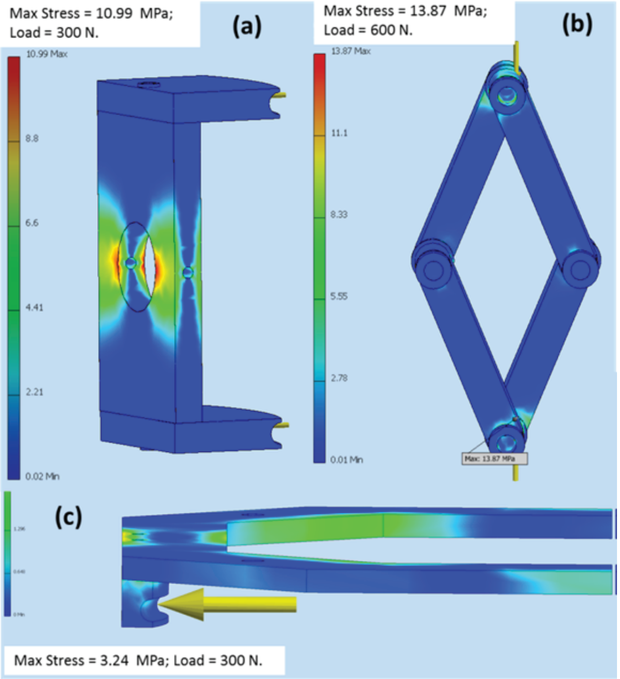

Figure 6: Stress distribution on the scissor-sections (a) the part connect the scissor and the string; (b) the scissor part; (c) the frame connects the string by its hook.

PROTOTYPE TUNER AND TESTS

A prototype tuner was fabricated for the cold tests to confirm the scissor-section movements at low temperature as well as for the long-term tests to check the threads can support >20 years of operation.

We adopt a Phytron cryogenic stepper-motor (VSS UHVC-X0) [8] with a 1:100 harmonic drive gearbox; its photograph is shown in Fig. 7. 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 about 200 kHz, i.e. 2.5 Hz/step. The motor driver we adopted is from GalilTools [9] 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 7: Photograph of the Phytron cryogenic stepper-motor with 1:100 harmonic drive gearbox.

Cold Tests

We use a spring load to simulate the cavity in the cold tests depicted in Fig. 8 (a). In the tests, the tuner frame was kept in a liquid nitrogen bath (77K), as is shown in Fig. 8 (b). To avoid binding on the thread, we used graphite-loaded bronze bushings, displayed in Fig. 8 (c). The cold tests suggest that the tuner can be smoothly turned up to 6 revolutions.

After the cold test, we inspected the threads and the bushing using the Cornell Optical Inspection System [10]. Wear on the threads was observed as is shown in Fig. 9. To solve the wear problem, we plan to use a TECASIN insert which has been used in the LCLS-II tuner [11, 12].

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 [13]. Long-term tests have started, and we will report results in a future paper.

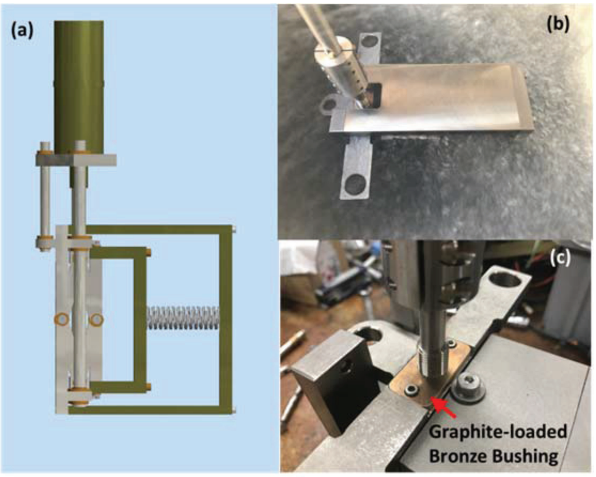

Figure. 8: Prototype tuner for the cold tests (a) Schematic of the prototype tuner with a spring load; (b) the tuner in liquid nitrogen bath; (c) photograph of the graphite-loaded bronze bushing.

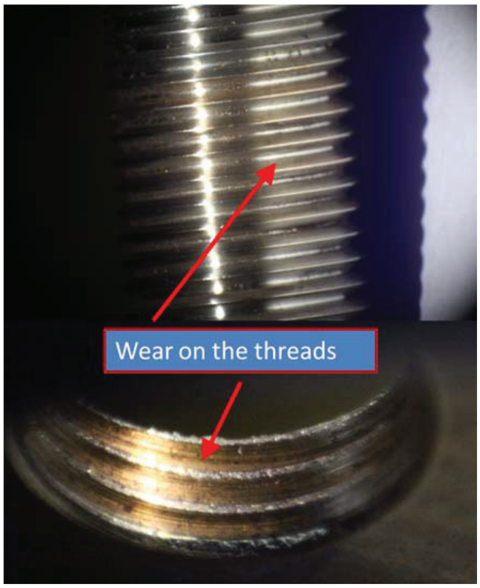

Figure 9: Optical inspection images of the threads of the tuner after the cold test.

CONCLUSION

The HWR tuner has been successfully designed and prototyped. The tuner can provide up to 200 kHz tuning range, which gives sufficient margin for cavity frequency control. We performed stress analysis and thermal analysis. The results show that stresses are well below the yield strength. Cold testing and the long-term testing of the tuner have started.

ACKNOWLEDGMENT

We are grateful to Dr. Zachary Conway and Dr. Mike Kelly from ANL for very helpful advice on the HWR tuner design.

REFERENCES

[1] W.K. Kim, *et al.*, “Design and assembly of the QWR and the HWR cryomodules”, *Journal of the Korean Physical Society* (2015) 67: 1287, doi:10.3938/jkps.67.1287.

[2] S.K. Kim, “Rare Isotope Science Project: Baseline Design Summary”, 2012, `http://risp.ibs.re.kr/orginfo/info_blds.do`

[3] H.J. Kim, *et al.*, “Progress on superconducting Linac for the RAON heavy ion accelerator”, in *Proc. IPAC’16*, Busan, Korea, May 2016, paper MOPOY039, pp. 935-937.

[4] M.P. Kelly et al., “Microphonics in the ATLAS upgrade cryomodule,” in Proc. 14th Workshop of RF Superconductivity (SRF’05), Berlin, Germany, September 2005, pp. 269.

[5] `https://www.cst.com/products/cstmws`

[6] Y. He, “Mechanical design of the ERL Main Linac Cryomodule prototype”, August 2014, unpublished.

[7] `http://cryogenics.nist.gov`

[8] `http://www.phytron-elektronik.de/antrieb/index.php?Set_ID=160&PID=3`

[9] `http://www.galilmc.com/motion-controllers`

[10] M. Ge, *et al.,* “Surface Topography Techniques at Cornell University: Optical Inspection and Surface Replica”, in *Proc. IPAC’16*, Busan, Korea, May 2016, paper WEPMR015, pp. 2292-2294.

[11] N. Huque, *et al*., “Accelerated life testing of LCLS-II cavity tuner motor”, in *Proc. SRF2015*, Whistler, BC, Canada, September 2015, paper THPB062, pp. 1257-1261.

[12] Y. Pischalnikov, *et al*., “Reliability of the LCLS II SRF cavity tuner”, in *Proc. SRF2015*, Whistler, BC, Canada, September 2015, paper THPB065, pp. 1267-1271.

[13] S. Lee, *et al*., “Design of RF power coupler for RISP half wave resonator”, in *Proc. IPAC’16*, Busan, Korea, May 2016, paper WEPMB041, pp. 2208-2210.