DEVELOPMENT OF A SLOW TUNER FOR THE 162.5 MHz SUPERCONDUCTING HALF-WAVE RESONATOR IN IMP *

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Abstract
Within the framework of the C-ADS project, Institute of Modern Physics(IMP) has proposed a 162.5MHz HWR Superconducting cavity for low energy section (β=0.09) of high power proton linear accelerators [1, 2]. A compact slow tuner has been developed for final tuning of the resonance frequency of the cavity after cooling down to operating temperature and to compensate microphonics and Lorentz force detuning. The slow tuner is driven by an external stepper motor and gear box for coarse cavity adjustment. To reduce the force requirements of the actuator, a lever arm and scissor jack mechanism have been applied. The tuner design and recent results of warm tests as the first prototype are presented.

BASIC CONSIDERATIONS

Frequency tuner is an essential and critical component of acceleration systems based on superconducting cavities. The rf tuning during operation bases on the principle of a slight elastic deformation at both ends of the tank. A slow tuner must cover a wide tuning range (several hundred kHz), while providing a resolution of the order of 1 Hz. Furthermore the frequency tuners should be free of hysteresis, and guarantee a long lifetime of more than 10 years [3]. Basically, there are two methods for mechanical tuner. The first one is to mechanically deform the cavity. The other technique is to insert a probe into the magnetic or electric field of SC cavity. The tuning method adopted by IMP is to change the length of the cells by mechanical adjustment of the overall length of the cavity, which introduces no new HOMs [4]. Figure 1 shows the structure of the mechanical tuner for HWR.

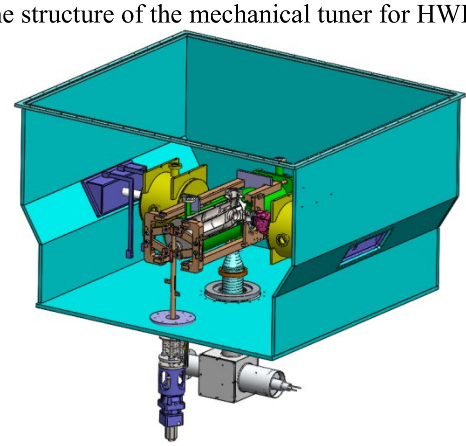

Figure 1: view of β =0.09 HWR with helium tank, mechanical tuner, main coupler to be mounted in test CM.

The SC HWR cavity was constructed from pure niobium with a specified pre-processed cell wall thickness of 2.8 mm. The flange which connect the cavity to the helium shell are constructed from 45 % Niobium and 55 % Titanium. A 3 mm thick helium shell with attached 0.2 mm thick bellows which exists between the helium shell and NiTi flange allows axial movement to tune the HWR cavity. Both the helium and bellows are constructed from Grade 2 Titanium.

TUNER DRIVE ASSEMBLY

As displayed in Figure 2, the tuner mechanism is consisting of a scissor-jack like assembly coupled to two dual-member lever arms. One dual-member lever arm is connected to each beam port flange. As shown, each lever arm member is pivoted at one end, connected to the beam port flange between its ends, and connected to the scissor-jack assembly at its other end. Anti-backlash flex pivots are used at the connection of the lever arm members to the beam port flange.

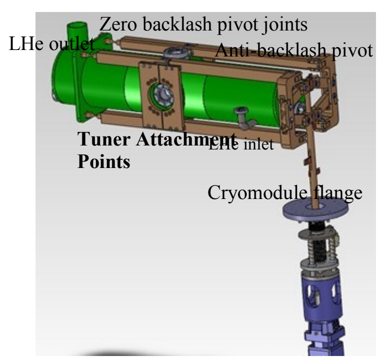

Figure 2: Tuner Installed on Cavity with helium tank.

The scissor linkage is actuated by the opposing motions of the two concentric tubes. When the inner tube is pushed upward and the outer one pulled downward, the scissor linkage pulls inward on the ends of the lever arms, thus applying a compressive force to each beam port flange. Anti-backlash flex pivots are used to connect the scissor-jack assembly's links. These allow the connected links to transmit both the input motion and the input force to the lever arm members. Due to their position control characteristics, it is desired to use a stepper motor to provide the input power required to accomplish slow and coarse tuning of the cavity. A lead screw coupled to the output shaft of the stepper motor can be used to convert the motor's rotary motion into the required linear motion.

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TUNING SPECIFICATION

The tuner is used to make the resonant frequency of the cavity equal to the RF drive frequency of 162.5 MHz. The cavity must be able to operate under different conditions, which sets a lower bound on the necessary tuning range. The dominant driver of mechanical deformations is vibrations due to various external sources. Generally sources of frequency detuning for SC cavity include (i) tolerances in the cavity parts; (ii) variation in weld shrinkage; (iii) variation in the frequency shift due to attachment of the helium vessel; (iv) variation in the frequency shift produced by etching; and (v) variation in the frequency shift during the cooling down; (vi) variation in the frequency shift by beam loading; (vii) variation in the liquid helium bath pressure; (viii) Lorentz force detuning [5]. Based on the above considerations, the frequency offsets that the tuner must accommodate are given in Table 1.

Table 1: Tuning Specifications

Parameters	value
Frequency/MHz	162.5
Tuning sensitivity/(KHz/mm)	180
Tuning force/(KN/mm)	2.2
Tuning range/KHz	360
Tuning resolution/Hz	9
Tuning resolution step/nm	50
Fine Tuning Range/Hz	180
Df/f (Tuning range/Freq.)	2.2
Backlash Tolerance/Hz	<2

Typical frequency variations come from ground motion, vibrations, and bath pressure fluctuations. Bath pressure fluctuations will be regulated by the cryoplant. The rate of change of bath pressure will be slow enough such that the frequency correction could be made via a feedback loop. The corresponding frequency shift is dependent on the cavity's frequency sensitivity to pressure fluctuations (df/dP), which is a design parameter. The predicted |df/dP| for the β = 0.09 162.5 MHz HWR cavity is less than 10Hz/mbar after cavity optimization. A preliminary design goal of 360 kHz full tuning range has been chosen for the tuner. This tuning range provides a comfortable safely margin for the operational offsets given in the table above, with additional margin for the frequency variation. A fine tuning range of 180 Hz is adequate; and this provides a same margin of cavity bandwidth. The tuning range and resolution can accommodate differences between the designed and the operated frequencies.

TUNING TESTS

A reference scheme for the tuner testing device is shown in figure 3. A prototype of this device is currently under realization at IMP laboratory, it will be rack mounted and fully computer controlled via Low Level RF system, which is the only interface to the operators. The operators will be able to start the check routine and display results through the control panel. A linear position stage, driven by a DC motor, moves the mechanical tuner. Two feedback loops are closed around the system: one inner loop around the DC servo system; one outer loop around the cavity itself.

Figure 3：The experimental setup for tuning with Low Level RF system.

According to the test studio, the tuning sensitivity for the SC HWR is obtained, which is presented in the Figure 4. From the fitting curve, the tuning sensitivity is calculated by 170 KHz/mm, which is near the simulation result of 180 KHz/mm.

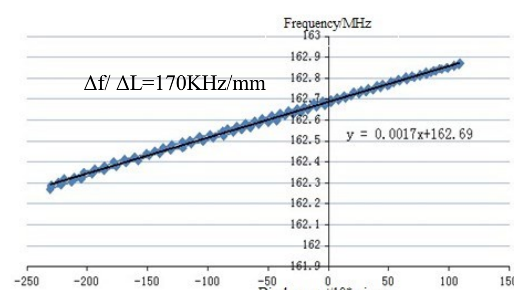

Figure 4： The relationship between frequency and displacement during the tuning test.

This graph actually represents the case of an ideal mechanism. The ideal mechanism does not itself offer any additional resistance to be overcome. As illustrated in Table 2, ideally 2.2 kN input force on the concentric actuating tubes will accomplish the 3.39 mm of beam port flange displacement required for the full range of coarse tuning in the third measurement.

Table 2: Tuning Test Results

	deta f(KHz)		Disp.(mm)		Total.detaf
	pull	push	pull	push	(KHz)
design	252	360	1.4	2	612
Test 1	49.45	70.26	0.456	0.455	120
Test 2	173.73	229.36	0.905	1.415	400
Test 3	253	395	1.09	2.3	630

Before horizontal test, the HWR cavity welding with the helium vessel, mechanical tuner, main coupler and solenoids will be mounted and assembled together for cryomodule installation. Figure 5 represents all the devices, including the beam diagnostic component, have been installed together outside the cryomodule. The tuner test setup consists of the mechanical tuner, low level RF system, network analyzer, power convertor and some Measuring tools.

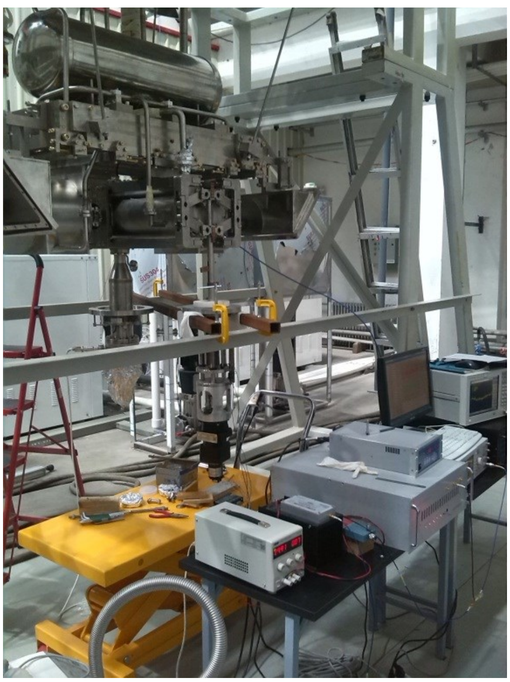

Figure 5: Tuner test area and SC HWR cavity with helium vessel controlled by low level RF system.

A set of hysteresis test was performed: using a 1 MHz range. The test consists of three complete cycles of the tuner position over the applicable range. The results of the 1 MHz test are shown in Figure 6. The deviation of this different value in the same place for the tuning is due to hysteresis. The reason for this hysteresis results from the lead screw. Additionally, to measure the hysteresis and resolution of the mechanical tuner, the test tuning range should be decreased to several KHz level.

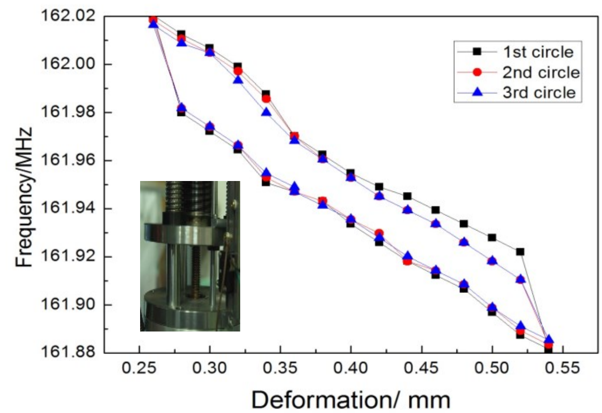

Figure 6: Hysteresis for the slow tuner.

Combined stepper motor and piezo tuning is the method of choice, even though most piezo tuners have been developed for pulsed operation. To improve the mechanical tuner for a CW mode machine, improving the stability of micrphonics compensation algorithms is an effective method directly. In the following development for the tuner in IMP VTA, a piezo tuner will be taken into account to improve the capability for tuning system to compensate the mircrophonics detuning and Lorentz force detuning effect. Now the lab in IMP has introduced two kinds of piezo driven tuner from PI company, one will be designed to operate at room temperature and the other will be operating at low temperature 4.2 K.

CONCLUSION

A preliminary design has been completed for a 162.5 MHz $\beta = 0.09$ HWR tuner in IMP. A prototype of the cavity tuner and drive mechanism will be constructed and evaluated on the one HWR cavity two solenoids in IMP test cryomodule. The fast tuner driven by a piezo actuator will be applied recently in the tuning system.

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REFERENCES

[1] WANG Zhi-Jun, HE Yuan, LIU Yong et al. Chinese Physics C,2012, 36(3): 256-260 (2012).
[2] Weiming Yue, Yuan He, Shenghu Zhang et al. Proc. of the 26th LINAC. Tel-Aviv, Israel, 2012,600.
[3] Oliver Kugeler, "Cavity Tuners" ERL09 workshop at Cornell, June ,2009; http://accelconf.web.cern.ch/AccelConf/ERL2009/talks/wg314_talk.pdf
[4] H. Padamsee et al. RF Superconductivity for Accelerator, John Wiley & Sons, 1998
[5] HE Shou-Bo et al. Study on the frequency tuning of half-wave resonator at IMP. Chinese Physics C, 2013 (publishing)

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