TEST OPERATION OF BALL-SCREW-TYPE TUNER FOR LOW-LOSS HIGH-GRADIENT SUPERCONDUCTING CAVITY AT 77 K

T. Higo[1], Y. Higashi, O. Araoka, F. Furuta, Y. Morozumi, T. Saeki, K. Saito, K. Ueno, M. Wake, H. Yamaoka, KEK, Tsukuba, Ibaraki, 305-0801, Japan

Abstract

Super-conducting Radio Frequency (SRF) 9-cell cavities have been developed in Low-Loss (LL) ICHIRO shape at KEK aiming at high-gradient operation for the International Linear Collider (ILC). One of the most important issues to realize high-gradient linac with SRF cavities in pulsed-mode operation is the compensation of the Lorentz detuning of cavities which amounts to 3 kHz at our goal of 45 MV/m acceleration field. None of tuners to date have achieved this specification. A coaxial ball-screw tuner was designed, fabricated and proven to reach this specification in room temperature. The performance was studied also at liquid-nitrogen temperature and the needed dynamic-range for 45MV/m operation was proven at this temperature. The microphonic vibration was measured to be 100Hz order in a test setup. In this paper, we describe these studies and evaluate the feasibility of ball-screw tuner operation at 2 K.

INTRODUCTION

In the Base Configuration Document (BCD) of ILC [1], it is written that a fast tuning of cavity by more than 2 kHz is necessary at the nominal operation field of 31.5MV/m. However, none of tuners in the world to date established this large dynamic range. Recently a compensation of Lorentz detuning up to 20 MV/m in TESLA cavity was proved using mechanical resonance of the cavity[2]. Another tuner with direct pulse operation was proven to compensate the Lorentz detuning of a TESLA cavity at 25MV/m, limited by cavity high field performance[3]. Further study for larger dynamic range with the blade tuner is planned[4]. On the other hand, we have been aiming at the operation of linac even at higher field, 45MV/m. Through the R&D toward this goal, we designed, fabricated and studied a ball-screw tuner[5,6]. Various tests of this tuner were performed by mounting the tuner on a LL ICHIRO cavity whose design field is 45MV/m. The feasibility of compensation of more than 3 kHz was proven in these tests at room temperature and at the liquid-nitrogen temperature. The results of these tests are presented in this paper.

LORENTZ DETUNING

The Maxwell's stress in the ICHIRO cavity was previously estimated to be 2.4kHz[6]. This value is for the case that both ends of the cavity are fixed. In practice, both ends are connected by helium vessel with the tuner system which has a finite stiffness. Therefore, the length between two ends becomes small due to the Maxwell's stress, resulting in a larger Lorentz detuning amount than that of the previous estimation. Now the value at the beam-on period was estimated to be 2.7 kHz[8] as shown in Fig. 1. From this estimation, we design the tuner with its dynamic range of 3 kHz. It is to be noted that in this estimation, we decomposed the total detuning amount into 1 kHz from shrinkage of the cavity and 1.6 kHz from the single cell detuning. These two components add up to become the total detuning amount.

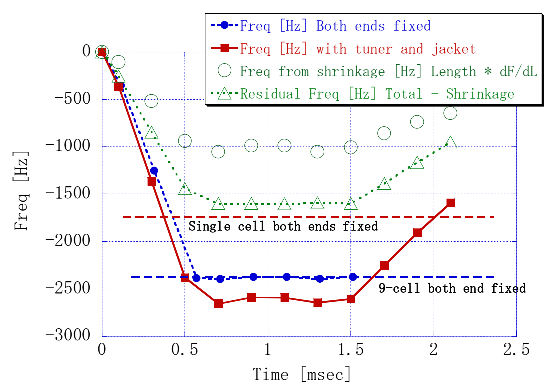


Fig. 1 Estimation of dynamic Lorentz detuning. Blue solid circles show those with both ends of the cavity fixed, while red squares show that in an actual configuration with a tuner mounted on a helium vessel which connects both end plates of the 9-cell cavity.

TUNER DESIGN

Tuner Design

In order to obtain a large dynamic range with keeping a large stiffness of the tuner system in a longitudinal direction, a coaxial ball-screw type tuner was designed. The pitch of ball-screw is 40 mm with the diameter about 300mm. The longitudinal movement of the cavity is realized by circumferential movement on a large worm wheel attached on a male screw. The slow tuning is performed by a worm gear driven by a pulse motor. This slow tuning part is mounted on a ring loosely coupled to helium vessel via twelve thin blades so that the slow tuner as a whole can be pushed fast by PIEZO actuator mounted on a helium vessel. The schematic view of the tuner is shown in Fig. 2 and a picture of ball-screw tuner is shown in Fig. 3.

toshiyasu.higo@kek.jp

1-4244-0917-9/07/$25.00

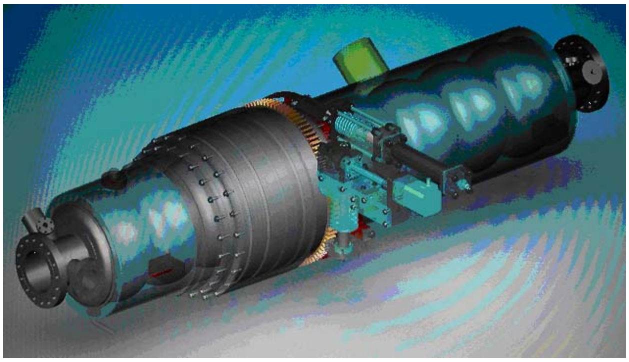


Fig. 2 3D-CAD of dressed LL type cavity

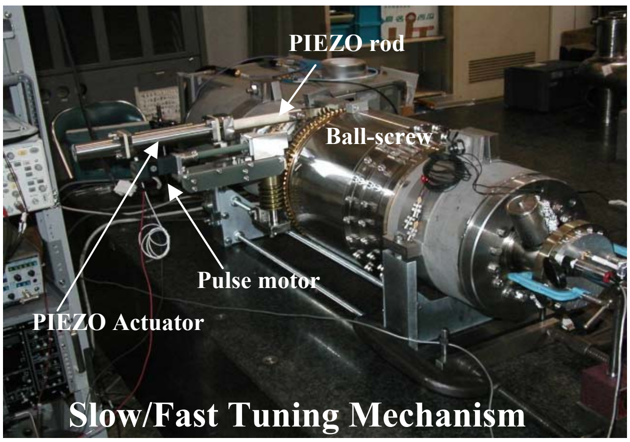


Fig. 3 A picture of ball-screw tuner during experimental evaluation of the tuner.

MECHANICAL CHARACTERISTICS

Mechanical Resonance At 77 K

The characteristics of tuner system at cold temperature was performed at 77 K. The cavity RF frequency response was measured at liquid nitrogen temperature. The result was shown in Fig. 4. The resonance at 247 Hz is the main component of the oscillation. The difference from the spectrum taken before[5] is speculated to be the improvement of its mechanical coupling at various places of the tuner driving mechanism.

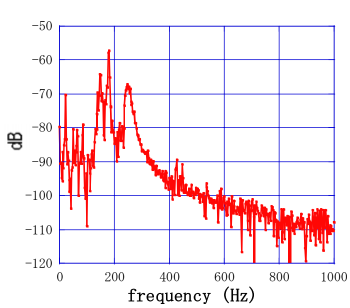


Fig. 4 Frequency response of cavity at 77 K.

Mechanical resonance Excitation At 77 K

The RF resonant frequency of the cavity change was measured with the tuner being driven at its mechanical resonant frequency of 247Hz. The result is shown in Fig. 6. A full range of 2.7 kHz was established after applying 25 shots of Piezo drive voltage at 247 Hz with 315 V. Since the maximum allowed voltage of the Piezo is 1 kV, we speculate that 3 kHz is easily obtaiend with a little more voltage. It is also found that the amplitude of tuner compensation is linearly increasing in this time range so that 30 oscillation is enough even at the present voltage level to reach 3 kHz.

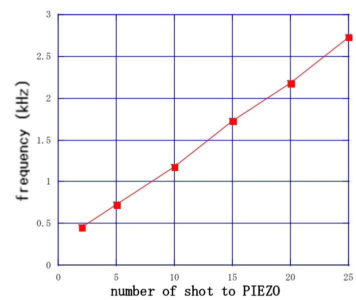


Fig. 5 Tuning range vs. applied number of shot to the Piezo. Applied voltage is 315 V.

Demonstration Of 3 kHz Tuning At 5Hz Operation at 77 K

The mechanical Q in the resonant mode of 247Hz was measured to be 212 at 77 K. Then the Piezo was continuously driven at 247 Hz with the applied voltage of 315 V. The frequency shift of 3.3 kHz was observed as shown in Fig. 6, where the control signal and frequency shift are shown as blue and red lines, respectively.

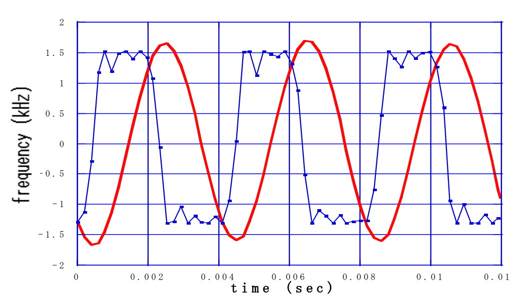
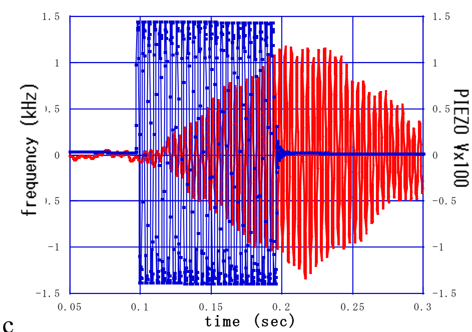


Fig. 6 Demonstration of 3 kHz tuning for Lorenz Force detuning at 45MV/m operation.

Fig. 7 shows the build up of the frequency compensation as the number of cycles of Piezo driver voltage. Frequency change of 2.5 kHz was observed after 122 ms from the first driving cycle of the Piezo. The blue lines and the red lines show control signal of Piezo and resultant frequency change, respectively. The dynamic range of this compensation can be linearly increased by increasing the number of cycles of the driving voltage but the number of cycles is limited to about half of the beam pulse separation of 200ms. Therefore, the driver voltage should be increased to reach the dynamic range of 3kHz. In this example, the frequency change after driving voltage off is determined by the frequency spread of excited spectrum and the damping of the mechanical resonances. The main component is still 247Hz so that if we apply the same drive voltage at the same frequency but with 180 degree shifter in phase, the damping of the oscillation should be fast and the cavity comes back to the original situation by the time the next pulse comes in 200ms later. This method was also confirmed to work.



c

Fig. 7 Frequency change due to 25 shots of Piezo at the cavity mechanical resonance of 247 Hz.

Microphonic Measurement

The cavity is subject to various vibrational environment in the practical situation. Therefore, any high-Q resonance exists, the oscillation becomes large and it can not be compensated because of its randomness. It is called “microphonic.” It was measured with a practical setup with the tuner mounted on a helium jacket connected to end plates. The measurement was done at the mechanical center of KEK where many mechanical machines are operated in a close distance. The result is shown in Fig. 8. The maximum frequency shift amounts more than 100Hz. This value is fairly large consideering the bandwidth of Q value, about 500Hz.

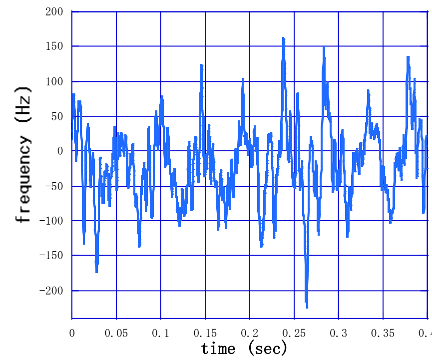


Fig. 8 Frequency shift due to microphonic perturbation.

SUMMARY

A coaxial ball-screw tuner was designed, fabricated and studied at 77 K. The feasibility to reach the high dynamic range of 3 kHz needed for 45MV/m operation was proven by using mechanical resonance at 247 Hz with its Q value of 212. This mode is used with a burst of 25 cycles to resonantly excite the cavity mechanical mode for Lorents detuning compensation. The excited oscillation can be damped before the next pulse coming 200ms later. The microphonic oscillation was also measured to be more than 100Hz, which should be reduced.

REFERENCES

[1] BCD, ILC Web site, http://www.linearcollider.org/cms/.

[2] P. Sekalski et al., EPAC 2006, THPCH175, Edinburgh, UK, 2006.

[3] G. Devanz et al., LINAC06, THP016, Knoxville, USA, 2006.

[4] C. Pagani, private communication.

[4] Y. Higashi, http://lcdev.kek.jp/ILC-AsiaWG/WG5notes/.

[5] T. Higo et al., LINAC06, THP037, Knoxville, USA, 2006.

[6] T. Higo et al., ILS Asia NOTE, 2006-001, http://lcdev.kek.jp.

[7] T. Higo, http://lcdev.kek.jp/ILC-AsiaWG/WG5notes/.

