ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-TUP080

TUNER DESIGN AND TEST FOR 166.6 MHZ SRF CAVITY OF HEPS*

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Abstract

The 166.6 MHz superconducting RF cavities have been proposed for the High Energy Photon Source (HEPS), a 6 GeV kilometre scale light source. The cavity is of quarter-wave type made of bulk niobium with β=1. Each cavity will be operated at 4.2 K providing 1.2 MV accelerating. To compensate the frequency change due to manufacturing uncertainty, Lorentz force, beam loading, He pressure and microphonics the plunger tuner and gap tuner are chosen as options. Now the plunger tuner and low temperature gap tuner have been tested with cavity, while the warm gap tuner is being designed. Details of the design and summary of the test results of the two type tuners with cavity are presented in this paper.

INTRODUCTION

The baseline and main parameters for Storage Ring SRF system of HEPS have been public [1, 2]. IHEP is developing 166.6 MHz superconducting RF cavities for HEPS, the structure is shown in Fig. 1. In order to realize the proposed on-axis injection scheme, five 166.6 MHz cavities have been chosen as the main acceleration cavity, while two 500 MHz single cell cavities as third harmonic cavity. Adjusting the cavity resonance frequency to the accelerator frequency during operation is essential to the RF system stable and have a perfect transmission of the radiofrequency power to the beam. To meet the requirements of 166.6 MHz SRF cavity, the tuner system needs newly designed. Two type tuners have been designed and test for the performance verification. The structure of plunger tuner is compact, but to the SRF cavity install and cleaning is difficult. So only warm test has been done for the plunger tuner. The gap tuner is widely used for SRF cavity to tuning frequency for its install and maintains easily. A type gap tuner has been designed and completed the low temperature test.

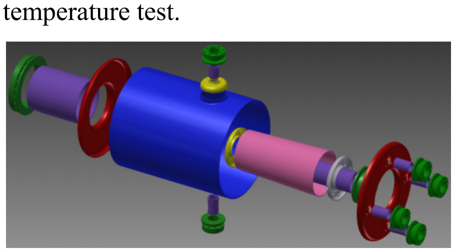

Figure 1: 166.6MHz cavity components.

PLUNGER TUNER

Table 1 is the main tuning parameters of plunger tuner for 166.6 MHz cavity according the tuning requirements.

Table 1: Main Parameters of Plunger Tuner

Parameters	Value	Units
Tuning range	±66.8	kHz
Motor stroke	±20	mm
Tuning resolution	<20	Hz
Tuning sensitivity	3.34	Hz/um
Operating temperature	4.2	K

Structure

The new type 166.6 MHz cavity has for ports at the end of large beam pipe for HPR (High Pressure Rinsing). We chose one HPR port to install the plunger tuner. As Fig. 2 shown is the tuner install and working principle. The plunger tuner designed with low temperature motor, during working the motor drive the plunger output or input the cavity along the linear bearings.

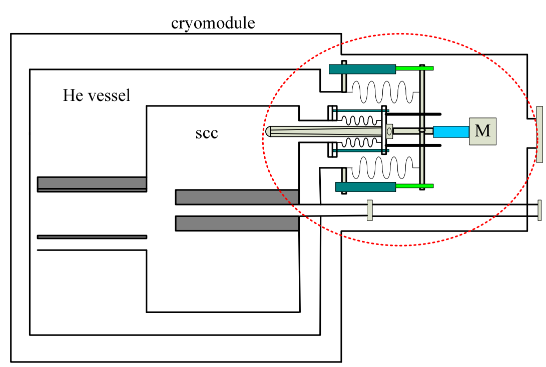

Figure 2: Overview of the plunger tuner with cavity.

Due to the 166.6 MHz working at 4.2K temperature, prevent bubbles holding in the plunger pipe during cooling is difficult than 2K working. A Special cooling structure is designed as Fig. 3 shown.

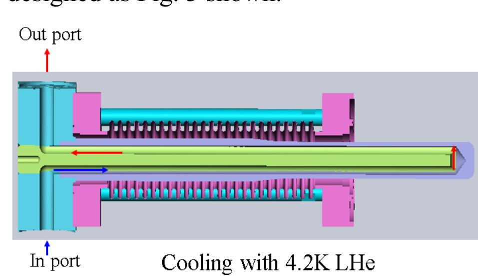

Figure 3: The cooling structure of plunger tuner.

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Inside the plunger pipe is a partition board with oval groove. Liquid helium from the down port into the plunger pipe and the up port outside. The bubbles produced due to the RF heat can't be trapped in the plunger pipe.

RF Simulation

Figure 4 shows the frequency deviation versus plunger length for six different plunger radii. Considering the radius cavity HPR Port for the tuner install is 17.5 mm, so the radius of plunger we chose is 13 mm with frequency sensitivity is 3.34 kHz/mm simulated with CST MICROWAVE STUDIO software.

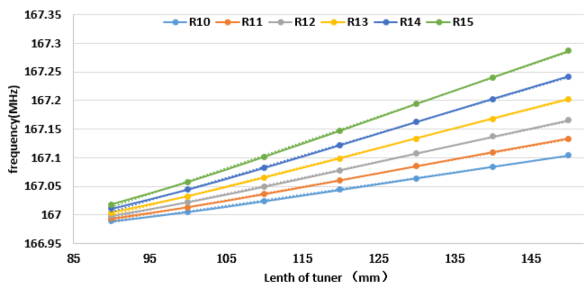


Figure 4: Frequency shift versus plunger length for six plunger radii.

Because of the plunger is made of bulk Niobium the same as the cavity, so as not to limit the cavity performances, the surface magnetic field on the plunger surface has to be equal or lower than the maximum surface magnetic field in the cavity when no plunger is installed.

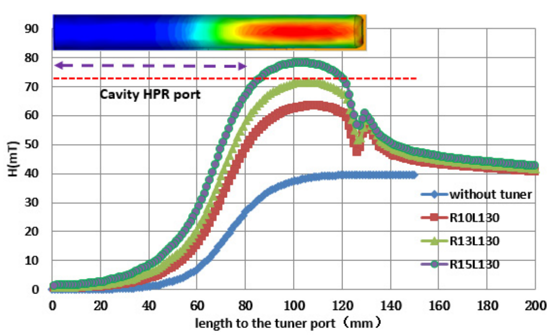


Figure 5: Magnetic field along the plunger for three plunger radii.

Figure 5 shows the surface magnetic field on the plunger versus the position. The curves plotted are the values of the surface field along a line. The surface field along the plunger is maximal on the plunger side facing the interior conductor of the cavity. The surface field on the plunger is equal 75 mT in the case R= 13 mm, confirming the maximal radius of the plunger allowable to meet the tuning requirements.[3]

As the operating temperature is 4.2 K for the 166.6 MHz cavities, power dissipations have to be kept as low as possible to limit the ruing cost of the cryogenic plant. As Fig. 6 show is the simulation model of plunger tuner with cavity and Table 2 is the simulation results for the components of plunger tuner. The material for the bellow and flange is stainless steel. For the plunger of tuner 270 mm and 26 mm of diameter, the adds power dissipation is about 5%, below 2 W considering the maximal cavity dissipation of 33 W.

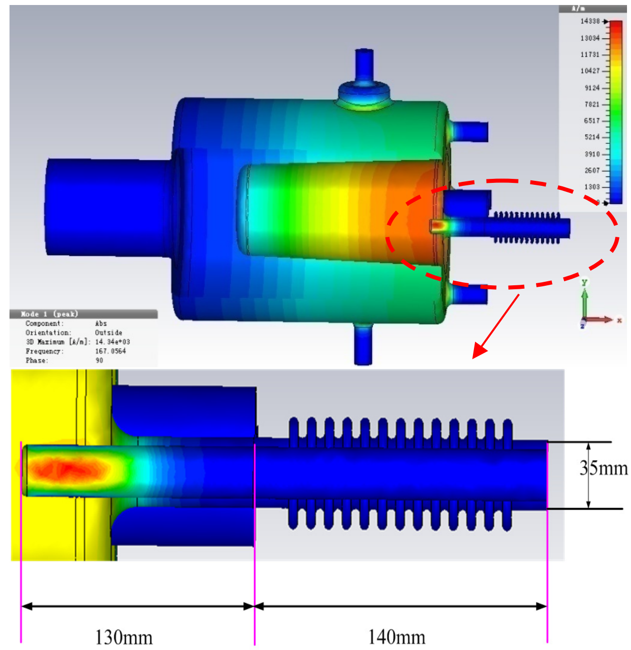


Figure 6: The simulation mode of plunger tuner with cavity.

Table 2: Main Parameters of Plunger Tuner

Radius (mm)	Plunger loss (%)	Bellow loss (W)	Flange loss (W)
No tuner	0	0	0.0021
10	0.59	0.572	——
13	0.79	1.186	0.0175
15	0.95	2.822	0.0200

Warm Tests

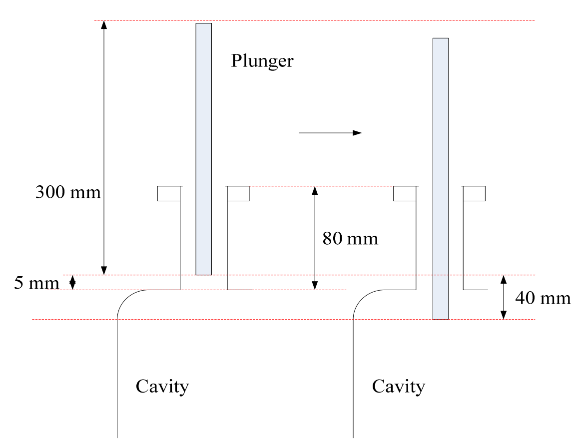


Figure 7: Plunger tuner tuning stroke.

As Fig. 7 shows is the designed tuning stroke of plunger tuner, for the test plunger we choose the length 300 mm. The tuner stroke is 40 mm, to the frequency shift is about 128 kHz, and the tuning sensitivity of test is about

19th Int. Conf. on RF Superconductivity SRF2019, Dresden, Germany JACoW Publishing
ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-TUP080

3.2 kHz/ mm. Figure 8 is the test site. Installed the plunger tuner with a 166.6 MHz model cavity made of aluminium. Vector network analyser is used to monitor the frequency change of superconducting cavity.

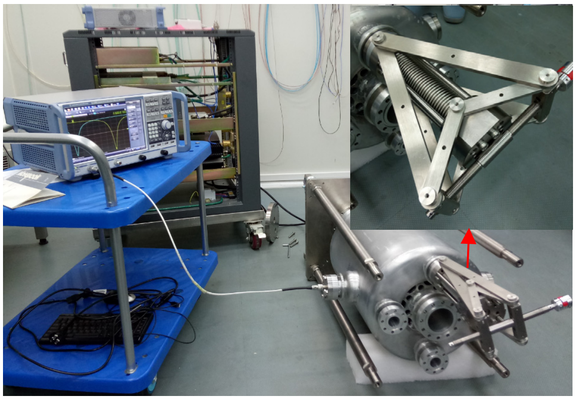


Figure 8: Plunger tuner tuning stroke.

GAP TUNER

A gap tuner has been designed for the 166.6 MHz horizontal test without beam. As table 3 is the main design parameters of gap tuner.

Table 3: Main Parameters of Gap Tuner

Parameters	Value	Units
Motor tuning range	> 90	kHz
Piezo tuning range	> 2	kHz
Harmonic reduction ratio	1:200	--
Arm Mechanical advantage	43:1	--
Motor tuner resolution	1	Hz
Piezo tuner resolution	1	Hz

Tuner Design

With the gap tuner to tuning the cavity frequency after cooling down, and the Piezo to compensate the frequency change due to the He pressure, microphonincs and Lorentz force. Figure 9 is the working principle of gap tuner for the 166.6 MHz cavity. One low temperature motor with four Piezo working together. The Piezo are installed at the two-beam pipe side of cavity. The tuner squeezes the cavity during working.

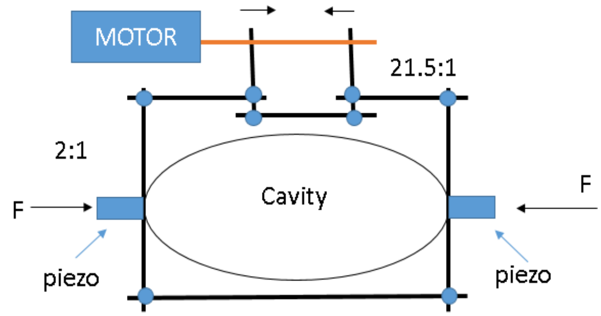


Figure 9: Woking principle of gap tuner

Figure 10 shows the 3D models of cavity, coupler, tuner and test cryostat. The several parts are assembled together to test performance of 166.6 MHz SRF cavity system.[4]

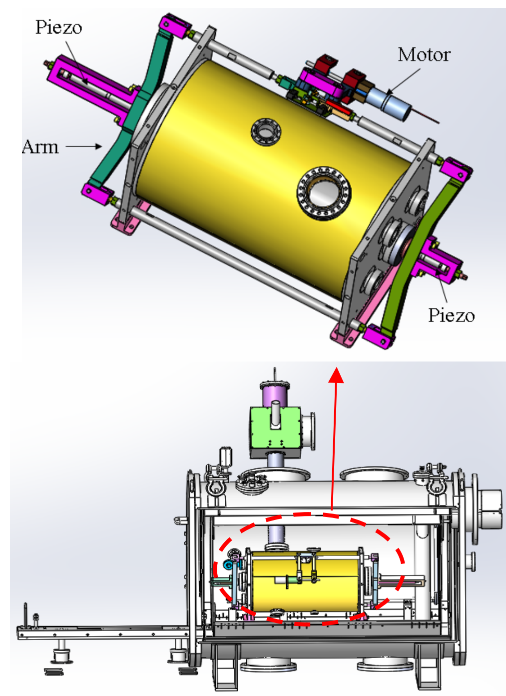
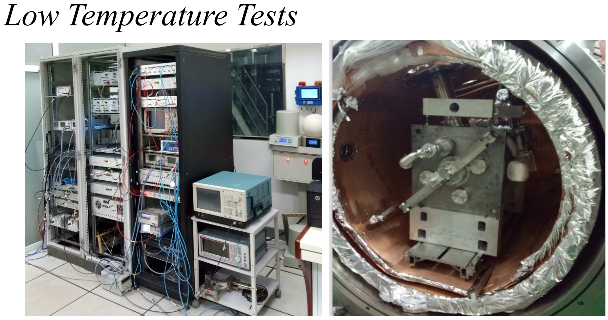


Figure 10: Gap tuner + cavity + cryostat + coupler.

Low Temperature Tests



(a) (b)

Figure 11: (a) LLRF system for horizontal test, (b) The cryomodule during assembly.

Figure 11 is the physical picture of LLRF system for 166.6 MHz SRF system tests and the cryomodule during assembly at the cryogenic testing hall.

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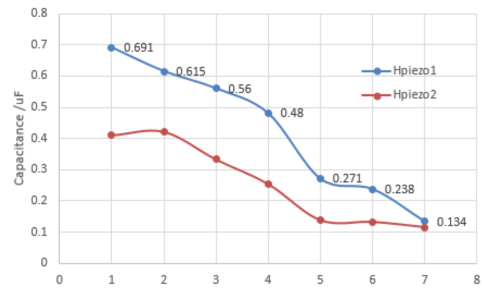
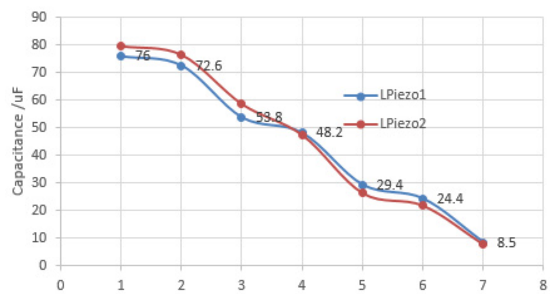
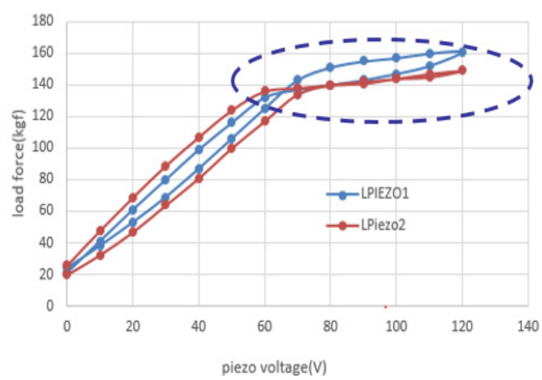


(a) Capacitance varies during cooling down of high voltage Piezo.



(b) Capacitance varies during cooling down of low voltage Piezo.



(c) Tuning performance of low voltage Piezo.

Figure 12: Piezo tuner performance tests.

Two type of Piezo low voltage and high voltage have been tested. As the Fig. 12 (a) and (b) shown the relative change of capacitance of low voltage Piezo after cooling down is less than the high voltage. It can be indirectly reflected that the dynamic range of low voltage Piezo at low temperature is larger than that of high voltage Piezo. The tuning force change is small when the voltage large than 70V of low voltage Piezo as Fig. 12 (c), due to the install of Piezo with load sensor is improper.

The motor tuner working is well during the test, which successfully locked the cavity at 166.6 MHz, as shown in Fig. 13.

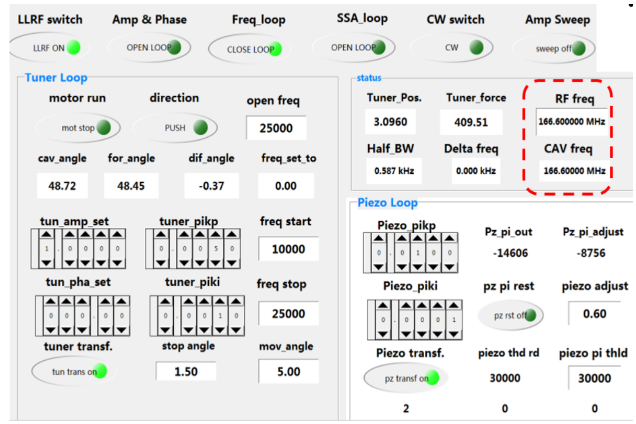


Figure 13: Interface of LLRF and tuning system control software.

CONCLUSION

Two type of tuner have been designed for the HEPS 166.6 MHz QWR cavity. The warm temperature performance of plunger tuner is validated, next the low temperature performance will be evaluated. The performance of gap tuner can meet the 166.6 MHz horizontal requirements.

ACKNOWLEDGEMENT

Thanks for the colleagues of IHEP!

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