DESIGN AND TEST OF THE PROTOTYPE TUNER FOR 3.9 GHz SRF CAVITY FOR LCLS II PROJECT

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Abstract

Fermilab is responsible for the design of the 3.9 GHz cryomodule for the LCLS-II that will operate in continuous wave (CW) mode [1]. The bandwidth of the SRF cavities will be in the range of 180 Hz. In the tuner design, the slow tuner-mechanism slim blade tuner was adopted, which was originated by INFN for the European XFEL 3.9 GHz [2]. The bandwidth of the SRF cavities for LCLS II will be in the range of 180 Hz and fine/fast tuning of the cavity frequency required. A fast/fine tuner made with 2 encapsulated piezos was also added to the design. The first prototype tuner has been built and went through testing at warm conditions. Details of the design and summary of the tests are presented in this paper.

REQUIREMENT FOR THE TUNER

3.9 GHz Cryomodules (and cavities) designs for the LCLS II Project accumulated its best features from the previous 3.9 GHz cryomodule designed and built by FNAL (for DESY/FLASH) [3] and by INFN for EuXFEL [2]. Parameters of the 3.9 GHz cavity for LCLS II project are presented in the Table 1. The significant difference is in the bandwidth of the cavity. For the LCLS II project half bandwidth must be 90 Hz and peak detuning (with active resonance control) must be less than 30 Hz.

TUNER DESIGN

Schematics of the tuner design are shown in Figure 1. The coarse tuner is a slim blade tuner (with a 1:20 ratio) with a design that is very close to the design of the tuner developed by the INFN for EuXFEL 3rd harmonics cryomodules [2].

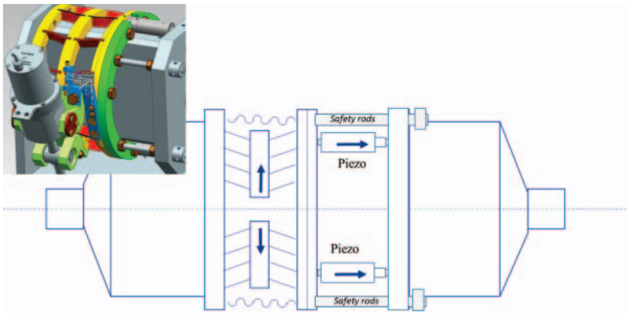

Figure 1: Schematic of the 3.9GHz SRF cavity tuner.

Table 1. 3.9 GHz SRF Cavity and Tuner Parameters

RF frequency	3900	MHz
Operating temperature	2	K
Total voltage available (16 cavities)	80	MV
Average operating gradient	14.5	MV/m
Average Q_0	2.0×10^9	-
Cavity length (L)	0.346	M
R/Q (r/Q)	750 (2168)	Ω (Ω/m)
Geometry constant (G)	275	Ω
Longitudinal Cavity Stiffness	**5.4**	kN/mm
Cavity Tuning Sensitivity	**2.3MHz**	mm
Coarse (slow) tuner range	**750**	kHz
Fine (fast) tuner range	**~1**	kHz
HOM damped Q value (monopole and dipole)	$\leq10^6$	-
Lorentz detuning	≤0.6	Hz/(MV/m)^2
Number of cryomodules	2	-
Number of cavities per CM	8	-
Cavity alignment requirements (RMS)	0.5	mm
Peak detune (with piezo tuner control)	**30**	Hz
Required cavity field amplitude stability†	0.01	% (rms)
Required cavity field phase stability†	0.01	deg (rms)
Q_{ext}	2.2×10^7	-
Half bandwidth of the cavity	**90**	Hz
Active length of 9 cells	345.96	mm
RF beam power per cavity (@300 μ load)	1.5	kW
RF power needed per cavity	1	kW
Cavity dynamic load	17	W

The major modification of this tuner design introduced by FNAL is adding a fast/fine tuner. Two piezo-stacks have been installed between the slow/blade tuner and the ring welded to the He-vessel. Safety rods have been designed between the cavity end flange and main lever of the tuner. These safety rods protect the cavity during transportation and from non-elastic deformation during cavity/helium vessel system pressure tests.

Set-screws and special washers were included to prevent loosening of the assembly screws during warmup and cool-down cycles [4].

The 3.9 GHz SRF cavity tuner will include the same active components (electromechanical actuators and piezo-stacks) as used on the 1.3 GHz cavity tuner. [4,5].

The electromechanical actuator LVA 52-LCLS II-UHVC-X1 built by Phytron per FNAL specification was found to

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be reliable and the rad-hard unit satisfied the requirements of the 3.9 GHz cryomodule for the LCLS II Project [5,6]. The stepper motor will be operated at "full-step" mode and can provide frequency setting resolution at 10-15 Hz/step.

The encapsulated piezo P-844K075 will be used for 3.9 GHz fine tuner. It ismade from two 10*10*18mm PICMA butted piezo-stacks built by Physik Instrumente (PI) per FNAL specs for the 1.3 GHz cavity fast tuner. Design details, comprehensive accelerated lifetime tests and radiation hardness tests are described in other papers [5]. Capsulation (and internal preload) of the piezo-stack inside the capsule and the ceramic balls installed between the capsule and tuner frame will minimize shearing forces on the piezo-ceramics and will significantly diminish the problems experienced in the previous version of the slim blade tuner [7]. Two adjustment screws (one for each capsule mounted on the flange welded to He vessel) help to uniformly preload piezo-stacks during assembly.

Maximum required slow tuner frequency is 750 kHz (Table 1). The cavity needs to be stretched to ~ 0.3mm. The forces generated by cavity and applied to each piezo-stack will in this case be less than 1kN. With internal preload on the piezo at ~800N, maximum forces on the piezo will not exceed 50% of blocking forces (4kN). Expected stroke from the P-844K075 piezo-capsule at cryogenic temperature is 5-10um. This stroke will provide fine/fast tuning range on the cavity of ~ 12-24 kHz at nominal piezo voltage V=100V. To control the cavity frequency within 30 Hz, detuning voltage applied to the piezo needs to be in the range of 100's of mV.

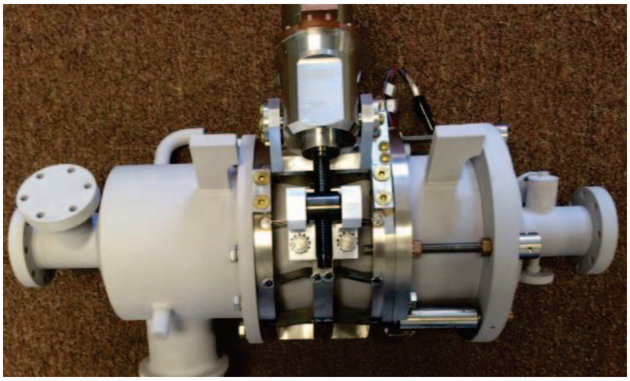

Figure 2: Prototype Tuner, assembled on the "plastic" model of 3.9 GHz dressed cavity/helium vessel system.

For integration purposes the first prototype tuner has been installed on the 3.9 GHz dressed cavity plastic model. (Figure 2). There were no interferences with other components of the cavity.

TUNER "WARM" TEST RESULTS

To conduct prototype tuner "warm" tests a simple setup "cavity-He vessel mock-up" was built. (Figure 3). On the "mock-up" stand stiffness of the cavity /He-Vessel bellow the system is imitated by a combination of spring washers. Tests were conducted when tuner acted against spring with different stiffness.

Figure 3: Prototype Tuner, assembled on the "cavity/He vessel mock-up" stand.

Results of the test of the slow/blade tuner are presented in Figure 5. A stepper motor was run in full step mode with 10,000 steps for one spindle rotation (1 mm thread). The slow tuner pushed against a 5.4 kN spring through two piezo-capsules. The displacement of the plate installed between the tuner and the spring replicating cavity were measured by a dial indicator and laser displacement system. (Figure 3).

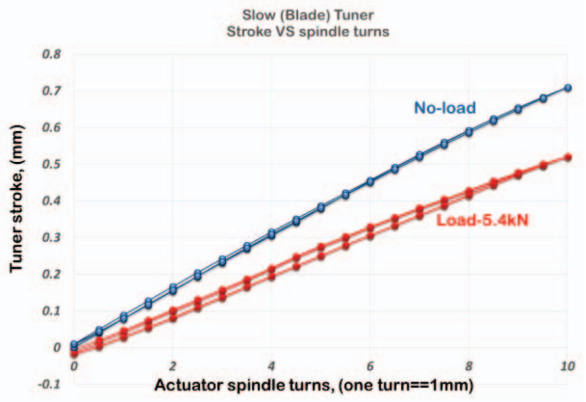

Figure 4: Slow Tuner stroke vs actuator spindle turns. Red – slow/blade tuner operated against spring with k~5.4 kN (expected stiffness of the cavity/He-vessel system). Blue- tuner operated against "zero" load.

From the two curves presented on the Figure 4 (red- with load (5.4kN spring) and blue - with no-load) the stiffness of the blade tuner can be estimated at k_{tuner}~ 27 kN/mm. The coarse (blade) tuner ration changed from ~1:20 (when operated against 5.4 kN load) to ~1:14 when the tuner operated against zero load. From the "5.4 kN load" curve, the slow tuner resolution is estimated to be ~5nm/step or 10-12Hz/step.

The results of the piezo tuner test are presented in Figure 5. The piezo test was performed when the tuner was stretched on~150um (three turns on the spindle). At this point the tuner was loaded at ~ 1kN. During the piezo test the voltage on the piezo did not exceed 60V. The maximum stroke (red curve) from the piezo tuner was 12um. Figure 5 also presents the hysteresis curve (blue) of the "free-standing" piezo-capsule. These are measurements of the maximum stroke of the piezo (~18um at V=60V) when stiffness of the blade tuner and "mock-up" setup are taken out of consideration. The results of the tuner piezo test presented in Figure 6 allowed estimating efficiency of the tuner system. The piezo efficiency (portion of the piezo stroke that will compress cavity) is near 67%. One of the methods of increasing efficiency is to change the amount of the blades in the region where the piezo is attached to the blade tuner. At the same time the expected piezo-tuner range at cryogenic temperature (even with 67% efficiency) will be near 5um or 10-12 kHz. This is ten times large than the technical requirements of the piezo-tuner (Table 1).

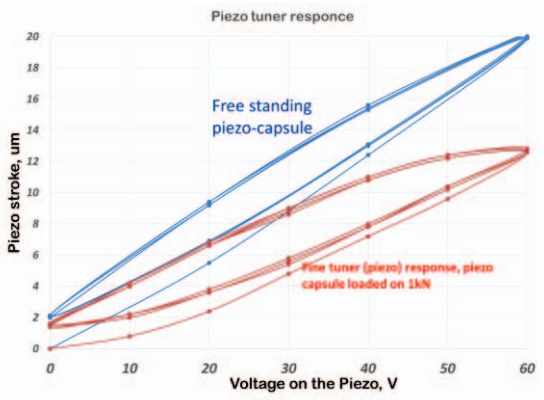

Figure 5. Fast (piezo) tuner stroke vs voltage applied to piezo (red). Blue –stroke of "free standing piezo-capsule" vs voltage applied to piezo-stack.

CONCLUSION

A prototype compact tuner for a LCLS II project 3.9 GHz SRF cavity was designed, built, installed into a "cavity/He vessel mock-up" stand and then tested. The tuner exhibited the expected stiffness, range and resolution for both slow and fast tuning mechanisms. Tuner parameters (as measured warm) met or exceeded technical requirement specifications. The next step is to install the prototype tuner on the dressed cavity for cold tests as a part of an extended dressed cavity design verification program.

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