

TUNER PERFORMANCE IN THE S1-GLOBAL CRYOMODULE

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Abstract

S1-Global is a collaborative effort of INFN, DESY, FNAL, SLAC and KEK, in the framework of the ILC global collaboration. For this project two cryomodules, 6 meter long and hosting four SC cavities each, were realized and successfully cold tested at KEK-STF. Three different cavity tuning systems, provided with fast tuning capability through piezoelectric actuators (piezo), were installed, and fully characterized in static and dynamic operation: Blade Tuner from INFN/FNAL, Saclay Tuner from DESY, Slide Jack Tuner from KEK. Finally, Lorenz Force Detuning (LFD) active compensation has been successfully achieved during high power cavity tests in pulsed RF regime, where active control of the LFD disturbance up to Hz-level residual detuning has been achieved with each type of tuning system up to the maximum gradient of each cavity. The installation procedures, together with the relevant results and their analyses are summarized in the paper.

TUNING SYSTEMS INSTALLED AT S1-G

Cryomodule-C hosted four TESLA-type cavities [1]. The first two units in the string, C1 and C2, have been procured by FNAL and equipped with INFN coaxial Blade Tuner; the subsequent cavities, C3 and C4, are DESY units equipped with the latest Saclay/DESY lateral tuner.

Cryomodule-A hosted four TESLA-like cavity units from KEK equipped with the coaxial Slide Jack tuner, also developed in KEK [2]. For the first two cavities in the string, A1 and A2, Slide Jack tuner have been installed between the tank pads while for cavities A3 and A4 the same tuner mechanics has been installed outside the pads at the couplers side, thus acting as a lateral tuner.

Blade Tuner

- Light design, tuning action is generated by a cold stepper motor unit through deformation of thin Ti blades to minimize free play and backlash in the mechanics.
- Two low-voltage, multiple thin-layer (0.1 mm) piezo actuators installed at each side of the helium tank.
- Cavity units design developed jointly from FNAL and INFN for CM2 at Fermilab ILC-TA.

Saclay/DESY Tuner

- Well-known mechanics, successfully in use since TTF with minor updates. The units installed at S1-Global are two of the latest FLASH units developed at DESY from the original Saclay design.

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- Installed laterally, the tuning action of a cold stepper motor unit is transferred to the cavity through a compact double leverage.
- Two low-voltage, multiple thin-layer (0.1 mm) piezo actuators installed on one tuner side in a preloading frame, coupled through the leverage mechanics.

Slide Jack Tuner

- Special stiff design specifically developed for KEK TESLA-like cavities. The tuning strain is generated through rolling elements sliding on a sloping surface.
- The tuning driving action is generated outside the vessel and transferred to a feed-trough shaft: no motor units are installed inside the module.
- A single high voltage, multiple thick-layer (2 mm) piezo is installed at the coupler side of the tank.

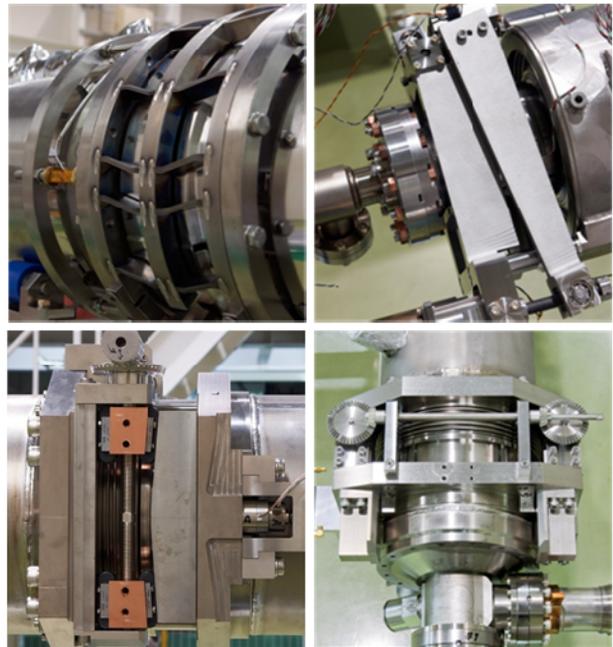


Figure 1: Pictures of S1-G tuners: left-up is Blade, right-up is Saclay/DESY, left-down is Slide Jack central and right-down is Slide Jack lateral.

A selection of few key design parameters of each tuning system is presented in the following Table 1, these expected values have been confirmed experimentally during cold tests.

Immediately after cool-down, failures in two of the eight units installed emerged [3]. Blade Tuner in cavity C2, after completing a first tuning range cycle, became not responsive to driving signal, while Slide Jack in cavity A4 showed stacking of the main driving shaft joint.

Table 1: Tuners Main Design Parameters

Parameter	Unit	Blade	Saclay	S. Jack
Range	kHz	600	500	900
Sensitivity @ 1.3 GHz	kHz / turn	25	20	15
	Hz / step	1.5	1	3

Recent investigation, following the dismantling of Cryomodule-A, revealed that A4 tuner mechanics suffered a deformation due to excessive tightening of main bolts thus leading to an enhancement of friction in the bearing-shaft joint. Failure in the C2 tuning system will be explained as soon as the cryomodule-C is dismantled, later this year.

TUNERS CHARACTERIZATION

Continuous wave low power has been initially set for a test session specifically devoted to tuner characterization in July 2010, from October then high power pulsed tests have been conducted achieving the study and active compensation of LFD.

Firstly, measurements confirmed for each tuner mechanics the expected static tuning performances, reported in Table 1. Then, piezo (PZT) tuning capabilities have been investigated: cavity instant detuning have been acquired in response to both a static and dynamic piezo input, while the resonator was locked within a PLL loop.

Analyses of detuning responses allowed determining the peak fast tuning performances for each system independently from the maximum gradient achievable by the cavity. As reported in Table 2, the maximum frequency shift in 1 ms time window has been extracted from data (“dynamic shift”) for a given SIN pulse amplitude and compared to static piezo tuning range for each tuner. The equivalent ratio (linear fit) of the two values is computed and it is shown in the last column.

Results also show a loose coupling between and discharging of actuators in C2 thus confirming the issue already observed. FFT of acquired data (Figure 2) allowed for further evaluation of tuning system bandwidth and results correctly confirmed expectations:

- “soft” Blade and Saclay units act as lower bandwidth systems, with dominant poles at lower frequencies and longer rise time. Tuner external stiffness is lower, thus requiring lighter cavity constraints and higher LFD compensation capabilities.
- “stiff” Slide Jack unit acts as an higher bandwidth system with dominant poles at higher frequencies and shorter rise time. The LFD to be compensated is minimized but strong cavity constraints are required.
- The larger static stroke in C1 does not lead to equivalently higher dynamic stroke. In turn the same harmonic behaviour with very small overshooting induces lower sensitivity to LFD.

LFD Measurements

Lorentz Force Detuning (LFD) has been accurately measured for each tuning system during high power pulsed test within the limit gradient of each cavity. A collection and a comparison of resulting values is presented in [3] and [4].

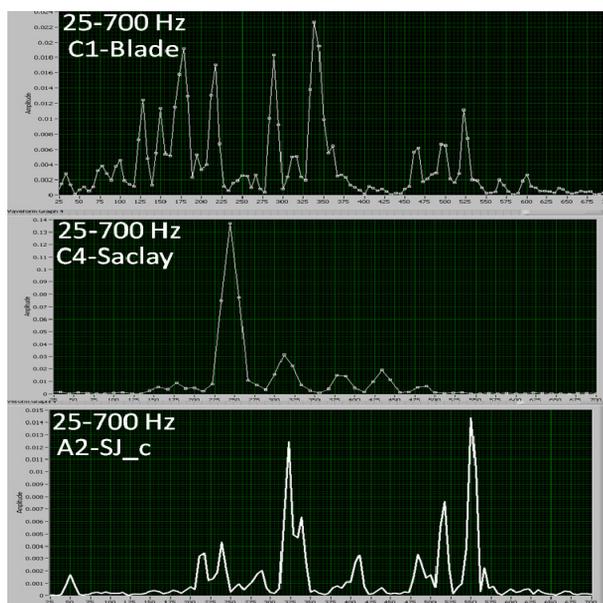


Figure 2: Spectral analyses (25 to 700 Hz, amplitude in V) of the detuning response of three different tuners.

Table 2: Tuner Tests Results and Analyses of Acquired Data. C2 Range Limited by Piezo Discharge at Higher Voltage.

Cavity/Tuner	PZT Max Voltage, Capacitance	Max Static shift	Max dynamic shift	Normalized Ratio
C1-Blade	200 V, 4.1 μ F (total pzt 1+2)	2650 Hz @ 200 V	1040 Hz @ 135 V	0.6
C2-Blade	200 V, 3.9 μ F (total pzt 1+2)	560 Hz @ 100 V	590 Hz @ 100 V	1.1
C3-DESY	200 V, 2.0 μ F (only pzt 2)	1010 Hz @ 200 V	1100 Hz @ 180 V	1.2
C4-DESY	200 V, 1.9 μ F (only pzt 1)	1060 Hz @ 200 V	1170 Hz @ 170 V	1.3
A1-S.J cent.	1000 V, 0.19 μ F	190 Hz @ 500 V	270 Hz @ 470 V	1.5
A2-S.J cent.	1000 V, 0.21 μ F	350 Hz @ 500 V	450 Hz @ 470 V	1.4
A3-S.J lat.	1000 V, 0.20 μ F	210 Hz @ 500 V	270 Hz @ 470 V	1.3
A4-S.J lat.	1000 V, 0.21 μ F	450 Hz @ 500 V	450 Hz @ 470 V	1.1

These analyses confirmed expectations for three tuning systems after CW tests:

- The highest LFD sensitivity is shown by the Saclay/DESY tuner that has the sharpest harmonic response and thus the highest overshooting.
- The higher stiffness of KEK package is confirmed by the lowest flat-top LFD sensitivity among the tuners.
- The LFD sensitivity during the pulse rise-time is remarkably similar among the different devices.

LFD ACTIVE COMPENSATION

FNAL Piezo Control System

A LFD control system built at FNAL was delivered and commissioned at KEK during the S1-G LFD studies [5]. It features an adaptive feed-forward algorithm based on least-squares to adaptively determine the optimal waveform for each individual cavity. Such signal remarkably exhibits the actual frequency content of the system under control, as shown in Figure 3.

To achieve this result the control systems execute a simple calibration routine that effectively measures the piezo-to-detuning impulse response: a sequence of impulses from 10 ms prior to the arrival of the RF pulse to 10 ms after is generated and the resulting detuning is recorded. Once calibrated, the control system proved to be capable of automatically maintain stable LFD compensation while the cavity gradient is ramped. At S1-G the FNAL setup has been successfully applied to each of the three different tuning systems achieving LFD compensation up to few Hz residual level.

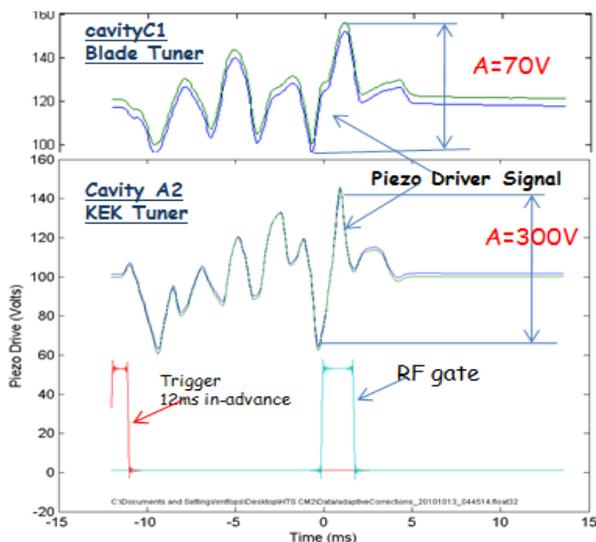


Figure 3: comparison of piezo control signal computed by the LFD system for two cavity units with significantly different frequency content.

KEK Piezo Control System

The LFD control system developed at KEK exploits a single piezo control pulse, an inverse cosine, in

conjunction with a proper static cavity pre-detuning by motor tuner [4]. The set of pulse parameters, depicted in Figure 4 and limited to four elements, allows using a simple control electronics.

A single ad-hoc pulse is generated via a PC-based hardware and fed to piezo actuators prior to the start of RF pulse. The same electronics takes charge of computing cavity detuning.

Although the initial search for the optimum values must

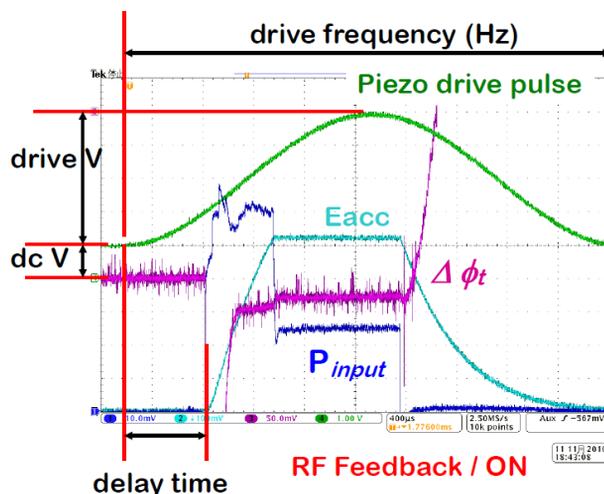


Figure 4: Overview of piezo pulse parameters for the KEK LFD control system.

be done manually for each unit, such control scheme proved to be extremely robust and LFD compensation is easily achieved with different pulse shapes.

Finally, also the KEK control setup has been successfully applied to each of the three different tuning systems achieving LFD compensation up to few Hz residual level.

SUMMARY

The S1-Global project allowed for an extensive experimental characterization of three different cold tuning systems, a comparison of results is here presented.

Although issues emerged on few elements to be further investigated, performances confirmed design values.

Active compensation of the LFD has been successfully achieved with each type of tuner and moreover with the use of two different control systems by FNAL and KEK.

REFERENCES

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