SIMULATIONS OF MECHANICAL RESONANCES IN SRF CAVITIES IN LOW BEAM CURRENT CW OPERATION

N. Solyak*, M. Awida, I. Gonin, T. Khabiboulline, Y. Pischalnikov, W. Schappert, V. Yakovlev
FNAL, Batavia, IL 60510, USA

Abstract

The low beam current for CW operation of the planned accelerator facilities requires cavities to be mechanically optimized to operate at a high loaded Q and thus, low bandwidth with higher sensitivity to microphonics. The essential source of microphonics detuning is fluctuations in the helium pressure df/dp. Last year's several methods for reducing df/dp has been proposed. One of the other possible sources of RF frequency instability is mechanical resonances. The cavity could be driven out of operating frequency by the mechanical deformations due to vibrations caused by external factors. In this paper we present the COMSOL multiphysics algorithm developed for evaluation of operating frequency shift due to mechanical resonances in SC cavities. We discuss the results of simulations for 9-cell elliptical 1.3 GHz cavities. The comparison of COMSOL simulations and measurements of ILC type cavities at KEK as part S1 global program and in Horizontal Test Stand at Fermilab is presented. All high gradient cavities in cryostat #2 will be measured to get more statistics.

COMSOL SIMULATIONS

COMSOL multiphysics software has been used to develop the algorithm of calculations of mechanical resonances in the complete cavity assembly, including the Helium tank and the blade tuner, CAD model of cavity assembly is shown in Figure 1.

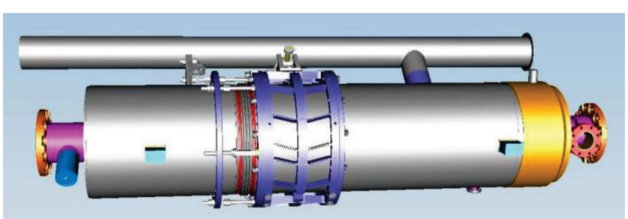

Figure 1: CAD model of an ILC cavity.

NX software was used to create the full coupled model consisting of the RF domain and helium vessel assembly. Figure 2 shows detailed cross-section of the mechanical assembly including the niobium cavity shell and helium vessel. Material properties for 2 K operating temperature used in the simulations are listed in Table 1. Boundary conditions used in calculations are the following:

- fixed displacement of the Vessel supports
- tuner stiffness is simulated by applying the spring constant as shown in the Figure 2.

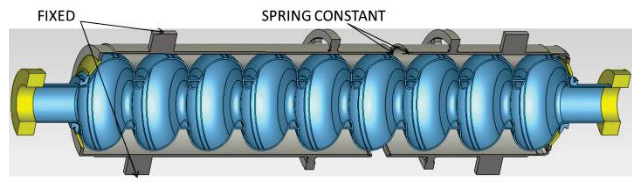

Figure 2: Solid model used in COMSOL. Materials: Niobium, Titanium, Niobium-Titanium

Table 1: Mechanical Properties of Materials at 2K

	Yuong's modulus,GPa	Poisson's ratio	Density kg/m^3
Niobium	118	0.38	8700
Titanium	117	0.37	4540
Niobium-Titanium	68	0.33	5700

Figure 3 shows the COMSOL plots of displacement of 8 lowest mechanical modes, 5 of them are transverse (blue background) and 3 are longitudinal (yellow background). Longitudinal modes typically have higher contribution to the RF frequency shift, than transverse one for the same excited amplitude. In simulations we not include tuner itself (weight and location asymmetry) and liquid helium inside the vessel.

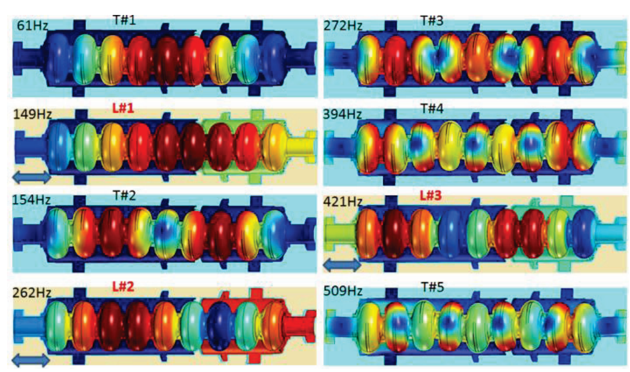

Figure 3: Plot of displacements of 8 lowest mechanical modes in ILC dressed cavity. Tuner stiffness =20 kN/mm.

Blade-tuner stiffness is varying from cavity to cavity. Figure 4 shows the dependence of frequencies vs. tuner stiffness for three lowest longitudinal modes. Lines in this plot corresponds the first three frequencies measured for cavity equipped with blade-tuner in S1 global studies. Stiffness of the blade tuner was approximately 20-30 kN/mm.

solyak@fnal.gov

ISBN 978-3-95450-143-4

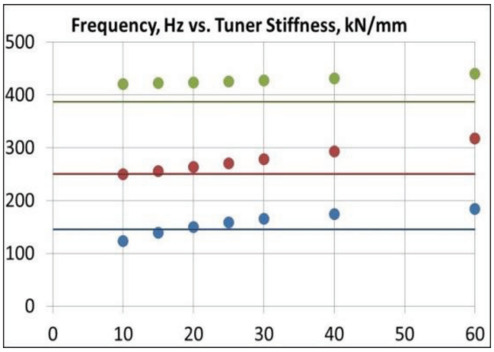

Figure 4: Frequencies of the first 3 longitudinal modes vs. tuner stiffness. Three lines represent the measured mechanical frequencies of the blade-tuner equipped cavity at S1G experiment.

EXPERIMENTAL MEASUREMENTS OF CAVITY MECHANICAL RESONANCE FREQUENCIES

Two ILC type cavities (C1-AES004 and C2-ACC011) equipped with blade tuner were carefully studied in frame of S1 global program at KEK [1]. Cavity was measured in cryostat after cool-down. Another two cavities with same design were studied in Horizontal Test Stand (HTS) at Fermilab. All cavities have been measured with two different methods: CW and pulse mode. In first method the cavity was powered by low signal (~1 W) in CW mode. Phase difference between Pi & Pt signals when cavity mechanically excited by short piezo pulses has been recorded and analyzed (Figure 5). Cavity worked at pulse RF power mode (~1 ms) for alternative, second method of measuring cavity's mechanical resonances. Cavity has been mechanically excited by short piezo pulses some ms prior to the arrival of the RF pulse. The cavity response to the piezo excitation can be measured in time window defined by RF pulse. The response can be characterized by a 2-dimensional array relating the amplitude of the piezo impulse at any time relative the arrival of the RF pulse to the detuning of the cavity at any point in time during the RF pulse. This array can be used to obtained piezo-detuning impulse response.

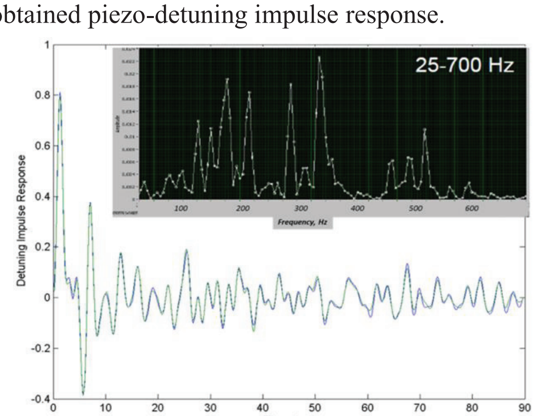

Figure 5: The Piezo-Detuning Impulse response of blade equipped cavity C1 in CW mode of operation. Cavity installed into S1G module. Insert: FFT of the response.

Next Figure 6 shows the comparison of both methods for a blade tuner equipped cavity C1 at S1G studies. Figure 7 shows difference in response between C1 and C2 in CW mode.

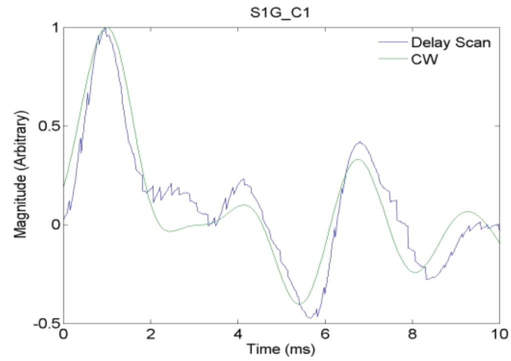

Figure 6: A comparison of the Piezo-Detuning Impulse response measure during CW and Pulse operation for cavity C1 equipped with blade tuner and installed into S1 Global cryomodule.

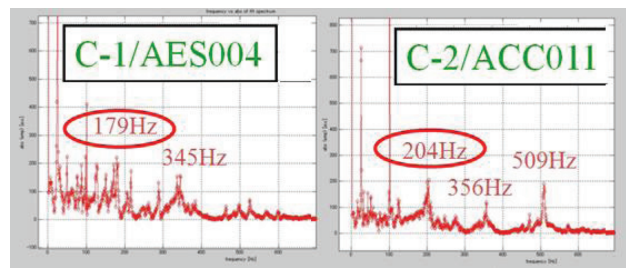

Figure 7: FFT of piezo impulse response for two cavities tested in CW mode in S1G experiment.

S1-Global experiment provided unique opportunity to measure with the same technique cavities equipped with 3 different tuners. In addition to the cavities with blade tuner two more tuners (Sclay/DESY scissor style side tuner and KEK- slide jack tuner) measured at CW and RF pulse mode. Results are presented in Figure 8. One can see that in cavity with Saclay tuner one frequency is dominates, while other tuners have several mechanical modes with comparable contribution to the cavity detuning.

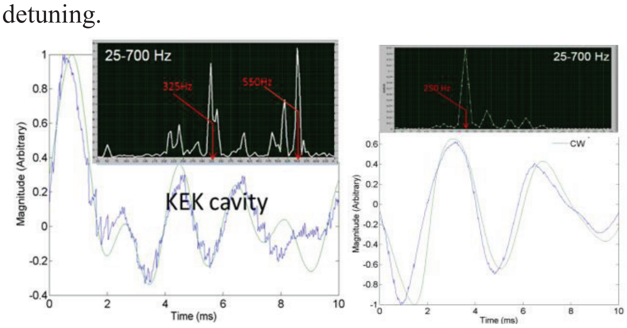

Figure 8: A comparison of the Piezo-Detuning impulse response measure during CW (green) and Pulse operation (blue) for cavity equipped with DESY/Saclay tuner (left) and KEK tuner (right) installed into S1-Global cryomodule.

ISBN 978-3-95450-143-4

Another cavity equipped with blade-tuner (TB9AES009) was measured in RF pulse and CW modes at HTS/ Fermilab. Figure 9 shows the cavity detuning impulse response of the cavity in 1 ms RF pulse mode operation. Three strongest mechanical resonance frequencies of cavity are presented in the Table 2 for RF pulse and CW mode of operation. Modes in table are listed according to their strength. One can see that third mode in pulse and CW regime has different frequency. It possible that mode 3 and 4 (not shown in table) has comparable contribution, and was counted in different order for pulse and CW regime of testing.

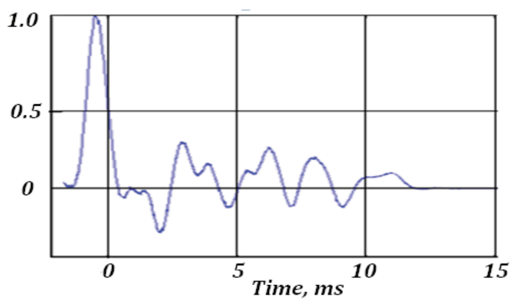

Figure 9: The Piezo-Detuning Impulse response of blade equipped cavity in RF pulse mode of operation. Cavity TB9AES009 installed into HTS.

Table 2: Cavity (TB9AES009) mechanical resonance frequencies measured in RF pulse and CW mode operation. Strength is shown in arbitrary units.

RF pulse mode		CW mode	
Frequency (Hz)	Strength (a.u.)	Frequency (Hz)	Strength (a.u.)
147	1	145	1
387	0.52	350	0.8
470	0.47	160	0.48

Recently we tested one more cavity in CW mode at HTS. This test was performed after tuner lifetime studies. The stiffness of the tuner position was small after failure of the stepper motor at the end of the tuning range. To get a better statistics and understand errors of measurements 100 pulses were recorded and analyzed. Table 3 presented frequencies of the mechanical modes, averaged over 100 seeds.

Table 3: Frequencies of mechanical resonances measured for cavity C4 in CW mode at HTS.

Frequency (Hz)	Strength (a.u)
192.277	0.0970
194.216	0.0799
220.954	0.0708
350.211	0.0680
300.044	0.0610

Measured power spectrum from piezo impulse response and calculated one from resonance modes are shown in Figure 10 for comparison

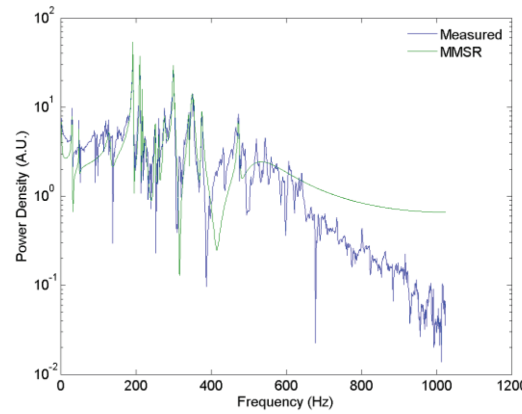

Figure 10: Measured and calculated spectrum of the cavity impulse response.

Results from HTS may not be the same as obtained from cavity installed in cryostat, due to different environment. In HTS cavity is sitting on table (Figure 11), while in cryostat it is connected to return pipe.

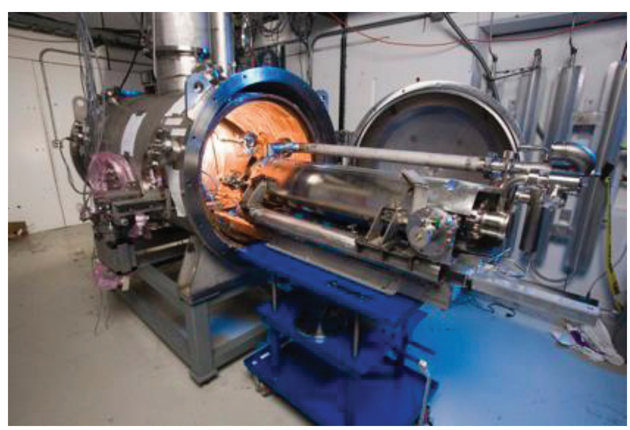

Figure 11: 1.3 GHz cavity loaded to HTS.

SUMMARY AND FUTURE PLANS

Full mechanical model of the ILC type cavity equipped with blade tuner was built and bunch of simulation was done to understand mechanical properties of design and effect of mechanical resonances on cavity detuning. Measurements of the cavity detuning response on piezo pulse in short RF pulses and in CW mode were performed for several cavities, two of them were installed at KEK cryomodule in frame of S1G studies and two other tested in HTS at Fermilab. Results shows that cavity with blade-tuner has several mechanical resonances that contribute to detuning. The frequencies of resonance are scattered from cavity to cavity, depending of stiffness of tuner and probably environment. For better understanding we are planning to measure all eight ILC cavities equipped with blade-tuner installed in CM2 at NML. These cavities were measured in 1 ms pulses in HTS prior installation and comparison these data with those obtained in CM2 will clarify the picture.

REFERENCES

[1] Y.Yamamoto, et al., "Test Results of the International S1-Global Cryomodule," SRF2011, Chicago, (2011).
[2] W. Schappert, et al., "Adaptive Lorentz Force Detuning Compensation in the ILC S1-Global Cryomodule at KEK," SRF2011, Chicago, (2011).

ISBN 978-3-95450-143-4