CHARACTERIZATION OF A PIEZO-BASED MICROPHONICS COMPENSATION SYSTEM AT HoBiCaT*

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Abstract

In the superconducting driver linac for the BESSY FEL, piezo actuators will be utilized to rapidly counteract the detuning of the cavity resonance caused by nm mechanical oscillations (microphonics). This is of importance to guarantee field stability and lower the power consumption of the RF system for the superconducting cavities. To design a suitable compensator, mechanical and electro-mechanical transfer functions, as well as the tuning range of the system under operating conditions have been measured.

INTRODUCTION

Noise produced or transferred by the cavity's ancillary equipment shifts the RF resonance frequency with time and may excite mechanical eigenmodes of the cavity body leading to stronger total detuning. As the superconducting cavities for the BESSY FEL linac will be driven in continuous wave mode at a very high quality factor [1] the RF's field amplitude and phase are very susceptible to any kind of detuning. Tight RF control is required to ensure, that the bunch timing requirements for lasing in the undulator sections of the FEL are fulfilled [2]. In principle this will be compensated for by the low level RF control system, but the amount of RF power needed rises quadratically with the cavity detuning. For a TESLA cavity operating at 16.0 MV/m and a quality factor of $3{\cdot}10^7$:

$$P_\mathrm{f} = 2.1\ \mathrm{kW} \cdot \left(1 + \left(\frac{\Delta f}{f_{1/2}}\right)^2\right) \qquad (1)$$

where $f_{1/2}$ is the cavity bandwdith. Peak detuning of the order of one ore more cavity bandwidths may lead to a loss of the electro-magnetic field because of limited available RF power. Thus it is important to measure the amount of microphonics noise to be expected in a cryomodule of the TESLA type cavities and to find a way to counteract and minimize this effect.
At BESSY we therefore built a piezo tuner system in a sensor actuator configuration following the design given by [3] to fit into the Saclay tuner type. We will show the analysis of the microphonics, also reported in an extra paper [4], the characterization of the tuner system and finally first results of an approach to control microphonics detuning.

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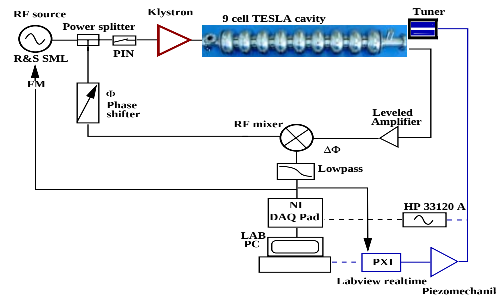

Figure 1: Measurement scheme for tuner characterization and piezo based microphonics control

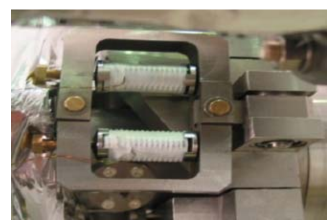

Figure 2: This picture shows the piezo tuner frame included into the Saclay tuner of the Tesla cavity.

MEASUREMENT SETUP

The measurement setup is shown in figure 1. The cavity can be driven open loop by a low noise RF signal generator or in closed loop mode following the shifting resonant frequency of the cavity by a phase locked loop. The nine cell TESLA cavity has been driven in continous wave mode at a field of about 1.0 MV/m and loaded quality factors between $3{\cdot}10^7$ and $4{\cdot}10^8$. The cavity detuning is measured by down converting the RF signal from the pick up antenna at an RF mixer to the frequency range of interest. A leveled amplifier and a 10 kHz lowpass filter ensure, that only frequency deviations invoked by cavity detuning are measured. The error signal is measured and analyzed by a National Instruments data acquisition system. The different controller algorithms have been implemented on a PXI realtime machine.

The transfer function between the piezo's driving signal and the response of the cavity's RF has been measured with an external function generator fed to the modulation input port of the Piezomechanik piezo amplifier. All measurements have been performed under cryogenic conditions operating the SRF structure at 1.8 K. The parameters of the Piezomechanik piezo tuner are given in table 1. The high voltage piezo chosen offers a high stiffness and large dis-

Open loop travel (μm)	20-40
Driving voltage (V)	0 to -1000
Unloaded resonance frequency (kHz)	8.0
Stiffness (N/μm)	290
Preload (Nm)	2.0
Operating temperature measured (K)	60.0
Tuning range measured (Hz)	1000
Group delay (ms)	1.6

Table 1: Piezo stack parameter, the first five parameters given at T=293 K

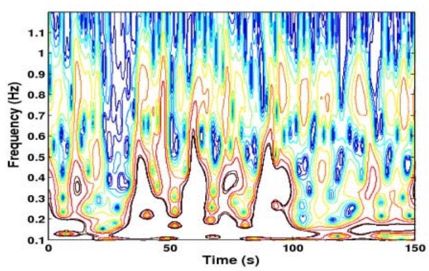

Figure 3: Wavelet analysis of the lower frequency RF spectrum showing the randomness of the spectral components induced by LHe pressure fluctuations.

placement which allows a tuning range of 1000 Hz at the operating temperature of 60 K.

CHARACTERIZING THE PIEZO TUNER

To develop a tuner system one has to analyze the system first thus measuring the microphonics detuning spectrum. A detailed description is given in [4]. Most of the shift in resonance is caused by helium pressure fluctuations below 1 Hz (60%). A time frequency analysis of the lower frequency spectrum with Morlet wavelets show a time varying and stochastic behavior of these pressure fluctuations (fig.3). This randomness inhibits a feedforward control by adapting to the detuning error signal. Above 1 Hz the dominant error sources are excited mechanical resonances as described later and external contributors like the turbo pump [4]. Thus there is need to determine the transfer function which has to be considered for a controller algorithm.

Tuner transfer function

The tuner transfer function has been measured applying a sinusoidal signal to the piezo amplifier sweeping a range from 0-1000 Hz in steps of 0.1 Hz. Between frequency shifts a delay of 3 s has been permit to imply the relaxation time of the mechanical system. The measurements results showed a deviation of less than 10% between different data sets. The result given in Figure 4 shows about eleven resonances in the range of 0-400 Hz of which the first two at 41 and 90 Hz are of most concern. Due to their narrow bandwidth they are easily excited and are always present in the usual microphonics spectrum.

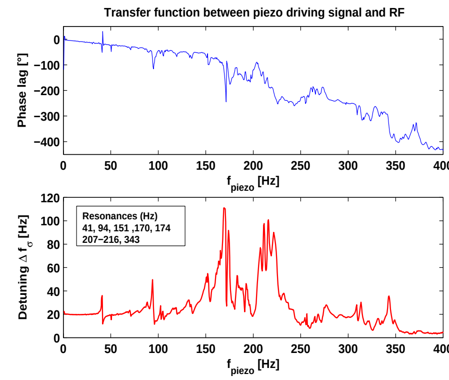

Figure 4: These plots show the phase and amplitude transfer function between the piezo driving signal and the response of the cavity's RF. Several resonances can be identified.

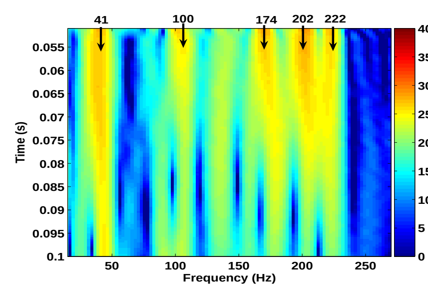

Figure 5: Windowed discrete fourier analysis of the step response of the cavity's RF after applying a step like piezo detuning of 39 Hz.

Similar results were achieved by applying a step input voltage to the piezo's driving amplifier which results in the step response of the electro-mechanical system (Figure 5). All results including the mechanical quality factors of the resonances are given in Figure 6. Resonances occurring at such low frequencies as 41 Hz inhibit the control microphonics detuning by classic means. Determining the slope of the phase transfer function one obtains the group delay

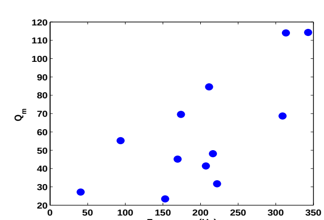

Figure 6: Mechanical quality factor of the cavity's eigenmodes

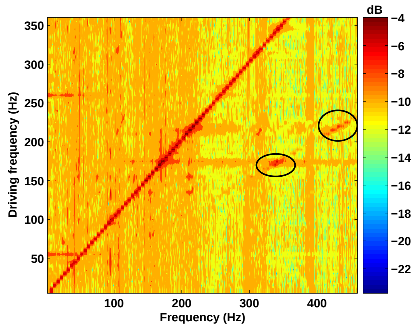

Figure 7: Frequency map of the tuner transfer function given the frequency response of the cavity on the abscissa and the driving frequency on the ordinate. Diagonal lines represent the transfer function and higher harmonics.

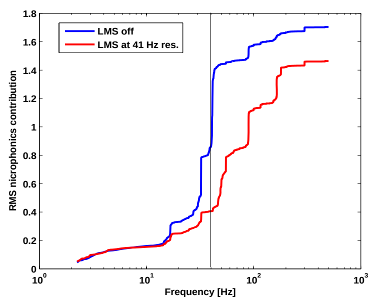

Figure 8: Compared are the integrated microphonics detuning spectra for the case with LMS feedforward control applied at an excited cavity mechanical resonance (red) with the case where the controller had been turned off (blue).

or response time of the tuner $\Delta t = \frac{\Delta\Phi}{\Delta\omega}$ which showed to be independent of the tuning range used in these experiments. A value of 1.6 ms was obtained limiting the range of the controller to $\sim$ 630 Hz.

To implement an adaptive feedforward control algorithm there is a need to check for non-linearities, that means if the piezo tuner may excite higher order modes when working in some lower frequency range.

In Figure 7 shows the whole frequency map of the transfer function measurements. Encircled in black are shown areas where mechanical resonances are excited by higher harmonic content of the piezo tuner. There is also a weak coupling between the 41 and 94Hz resonance.

PIEZO BASED MICROPHONICS CONTROL

Knowledge of the transfer function enables adaptive feedforward control considering the mechanical resonances and changes of amplitudes of microphonics contribution with time. Referring to noise cancelation techniques used in spacecrafts [5] and first results achieved at FermiLab [6] we tried to cancel the main detuning contribution of the 41 Hz resonance using the amplitude and phase information from the transfer function and feeding these results to a least-mean-square filter algorithm (LMS):

$$Y(n) = \vec{W}^{\mathrm{T}}(n-1)\cdot\vec{X}(n)$$
$$\vec{W}(n) = \vec{W}(n-1) + \frac{\mu}{\left|VAR(\vec{X}(n))\right\|}\cdot e(n)\vec{X}(n) \quad (2)$$

with Y being the signal fed to the piezo, $\vec{X}$ a reference signal of the microphonic contribution, $\vec{W}$ the filter coefficient vector, which is updated by the actual detuning e. μ is the factor which defines the rate and range of convergence for the filter parameter.

The result in Figure 8 shows a reduction of the 41 Hz component by a factor of 10^4. Nevertheless some of the oscillation energy seems to be shifted to the 94 Hz resonance thus decreasing the net gain of the controller. For the controller algorithm we used a sampling rate of 2.0 kHz and 400 samples for the LMS calculations.

OUTLOOK

The piezo tuner characterized here is well suited for microphonics control. In future measurements we will test different adaptive algorithms for the controller to achieve a net reduction of the total detuning.

The reason or source for the two first narrow bandwidth mechanical resonances has to be analyzed further to optimize the tuner's design to prevent excitation of these modes.

A stiffer tuner frame has been built and will be tested soon.

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