MICROPHONICS ANALYSIS AND COMPENSATION WITH A FEEDBACK LOOP AT LOW CAVITY GRADIENT

by

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ABSTRACT

For FEL projects based on a superconducting linac operating in CW mode, the RF power optimization finally comes up against the microphonics disturbances, which result in an unpredictable detuning of the cavities. A new piezoelectric tuner was developed and mounted on a TTF 9-cells cavity with an appropriate instrumentation. This system enables a full characterization of the disturbances and the tuner behavior. Modeling, simulations and experimental validations were carried out to demonstrate the feasibility of a feedback compensation for a multi-cell cavity. The results also bring to some recommendations that may overcome the limitations pointed out in the present experimentation.

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LIST OF ILLUSTRATIONS

INTRODUCTION

In linacs with low beam loading as FEL drivers, a high external quality factor (Q_e) is preferred in order to reduce the nominal radiofrequency (RF) power required since RF power sources still represent the most costly RF component for an accelerator module. However, the cavity bandwidth decreases with increasing Q_e. Any disturbance resulting in a cavity detuning leads to strong accelerating gradient errors in amplitude and phase and a high extra-power requirement due to the action of the low level RF system; the extra power scales proportional to the square of cavity detuning. Since FEL drivers would operate in a continuous wave (CW) or nearly-CW mode, the main disturbance is produced by the microphonics, related to the environment acoustic or mechanical vibrations and the excitation of the cavity system mechanical eigenmodes (MEM). However, the disturbance can be cancelled using either a feedback or a feedforward technique with a fast piezoelectric tuner (FPT). Two recent experiments have demonstrated their application to a single cell 80 MHz QWR [1] and a 6-cell 805 MHz elliptical cavity [2].

The EuroFEL study has dedicated a work package to the analysis and compensation of microphonics in different environments and conditions as representative as possible of a nominal FEL driver operation, with different FPT's and compensation algorithms. The reference cavity considered in EuroFEL is a 9-cell 1300 MHz cavity already used in an existent VUV-FEL (FLASH) in Hamburg [3]. It is equipped with a new large dynamic FPT designed for Lorentz forces compensation. This report only deals with the feedback approach for the microphonics compensation while the feedforward approach has been investigated elsewhere [4]. The first part of the program was carried out in CryHoLab, a horizontal cryostat dedicated to research and development on superconducting cavities and their associated components at CEA Saclay, before its relocation and the second part in HoBiCaT a similar cryostat at BESSY. Two cavities and two FPT's were used to provide a comparison regarding the piezo-actuator to the cavity detuning transfer function. The transfer function measurement technique has to be chosen according to the cavity bandwidth. Two different Q_e's, respectively $1.3\ 10^6$ and $3.8\ 10^7$ have been considered.

1. EXPERIMENTAL ENVIRONMENTS

By definition, 'microphonics' refers to mechanical vibrations generated by human activities and machines transmitted to a cavity by its physical links to the ground. They may be enhanced by the surrounding infrastructure, housing, etc. Their amplitude and spectrum are therefore in some extend site dependent. The present study was carried out on two different sites: CryHoLab and HoBiCaT, both are horizontal cryostats dedicated to the test of superconducting cavities, power couplers, or tuners. They attempt to reproduce as representative as possible the operation conditions of a cryomodule used in a linear accelerator. General features of these two sites are presented below.

1.1. CryHoLab

This horizontal cryostat is located at CEA Saclay. It provides a cylindrical experimental space at liquid helium temperature (4.2 K down to 1.8 K) of 0.7 meter of diameter by 1.5 meters long (Figure 1). RF sources are available for 704 MHz as well as for 1300 MHz components tests. For the lower frequency, a solid-state amplifier delivers power up to 700 W in a CW mode. An induction-output-tube (IOT) of can supply for power to a maximum of 80 kW, also in CW mode. For the higher frequency, a klystron can deliver up to 1.8 MW for 1 ms pulse at a maximum repetition frequency of 6.25 Hz. However, only low power is required for the microphonics study and a few tens watts solid-state amplifier is sufficient. The cryogenic system is composed of a pumping unit coupled to a Helial 4012 refrigerator with an 80 W cooling capability at 1.8 K and 13 mbar. At the time of the tests, a proportional control for the cryogenic was not implemented, but only an on/off control using binary-state valves.

1.2. HoBiCaT

Located at BESSY, the HoBiCaT cryostat (Figure 2) is very similar to CryHoLab with the main difference that it can house two 9-cell cavities instead of one. Useful space is 1.1 meters of diameter by 3.5 meters long. Furthermore, A VKL 7811ST klystron supplies the coupler with up to 10 kW of CW RF-power. A three-stub tuner allows a variation of the coupling by a factor of 10. The facility is equipped with multiple thermocouples, thermo-resistors, pressure sensors, etc. Thanks to a modern cryogenic control, He-pressure stability has been measured and determined to be better than 0.03 mbar rms. This residual pressure variation only detunes a 9-cell cavity by about 1 Hz. More details are found in [5].

Figure 1: CryHoLab, a horizontal cryostat located at CEA Saclay

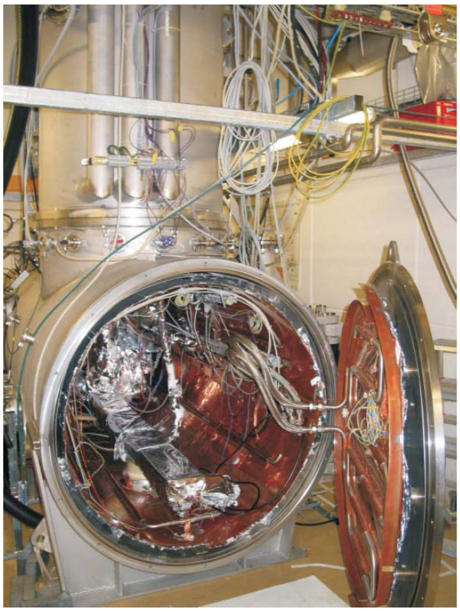


Figure 2: HoBiCaT, a horizontal cryostat for 2 cavities testing at BESSY

2. FAST PIEZO TUNER OF SACLAY-II TYPE

The new Fast Piezo Tuning system (FPT) is based on the lever arm design already used for the current Saclay tuner, which is operating at TTF since 10 years (Figure 3). The static tuning is obtained with the combination of the lever arm and a screw, which is driven by a stepper motor and a gearbox. Like the SOLEIL/Super 3HC tuning system [6], the new FPT uses a symmetric lever arm action. One of the links to the He tank is equipped with two piezoelectric elements (PZTs) which provide for the fast tuning. The whole system operates in vacuum at liquid He temperature. The tuner is designed to lengthen the cavity only. The cavity is acting as a spring on the FPT in order to generate a compression force on the piezo elements, which is mandatory to maintain their mechanical integrity during operation. In addition, the neutral point of the tuner is outside its operating range to suppress backlash. During cool down, the preload force on the piezo is expected to decrease due to the difference between the multiple materials thermal contraction. Therefore, an initial setup at room temperature is necessary, where the cavity is elastically lengthened by 0.75 mm using the zero adjusting screws.

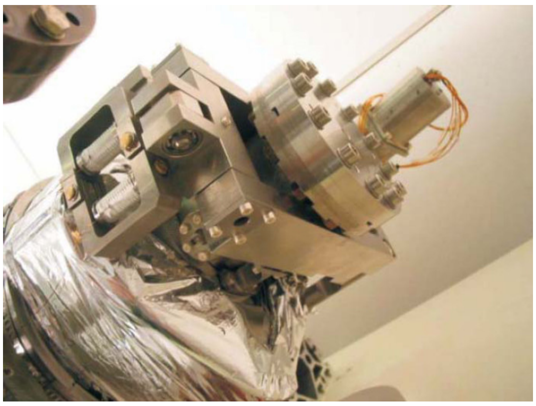
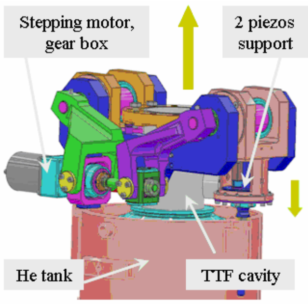


Figure 3: Saclay-I tuner in operation on FLASH, with a piezo stack

Figure 4 shows the FPT and its mounting position on the He tank. The piezo support is designed in order to minimize the shear stress in both PZTs regardless of the static tuning setup. The computed cavity elongation over piezo stroke ratio is 0.22. The balance between the two piezos requires tight machining tolerances of the support. In the right side of Figure 4, the piezo support loaded with NOLIAC 30 mm stack actuators is shown. The stiffness of the tuner was measured using a pneumatic jack. The experimental value is 70 kN/mm.



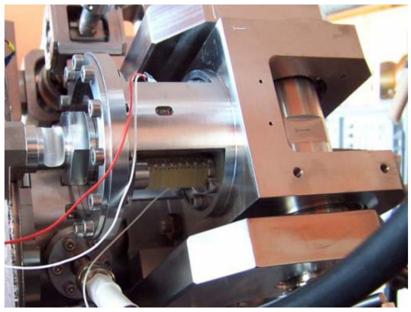


Figure 4: New Saclay-II fast piezo-tuner

3. DETUNING MEASUREMENT–MICROPHONICS ANALYSIS

3.1. Detuning measurement techniques

A microphonics analysis consists in recording the cavity instantaneous detuning and then processing the data off-line using the Fourier transform. A 2D or 3D spectrogram is the most effective method to perform a microphonics analysis since it provides the most relevant properties of a perturbation, i.e. amplitude, frequency, onset and decay times. Furthermore, the amplitude change of a disturbance may be tracked within a specific frequency channel. For a cavity with a bandwidth wider than the microphonics spectrum, which is typically a few hundreds of Hertz, a phase demodulation of the transmitted signal of the cavity driven at a fixed nominal frequency would provide a measurement of the cavity detuning. The phase demodulation signal corresponds to the low pass filtered signal at the output of a mixer receiving at its inputs the fixed frequency reference signal and the transmitted cavity signal. The whole system should be complemented with a phase constant limiting amplifier and a phase shifter, respectively to de-correlate the amplitude modulation and to zero the dc contribution. To calibrate the measurement, one has to detune the cavity with the stepping motor and measure simultaneously the new resonant frequency by transmission and the demodulator readout voltage. Of course, this technique is only effective when the microphonics induced detuning can be minimized during the calibration step. One achieves these conditions by switching off the cryogenic regulation and all the pumping systems for a short time. For a very low bandwidth cavity, a phase-locked loop (PLL) is necessary (Figure 5). Moreover, the PLL gain defined as $K_{PLL} = K_d K_0$, where K_d is the phase detector sensitivity given in V/rad and K_0 is the voltage controlled oscillator sensitivity given in rad/s/V, should be high enough. As an example, if the loop filter cutoff frequency is set to 500 Hz, then K_{PLL} should be as high as 10^5, otherwise a detuning measurement error in amplitude and phase would appear (Figure 6, bottom). A simulation with a cavity model defines the minimum gain required. For low amplitude microphonics, the choice of a low K_0 would provide a much better accuracy in the detuning measurement thanks to a higher signal to noise ratio.

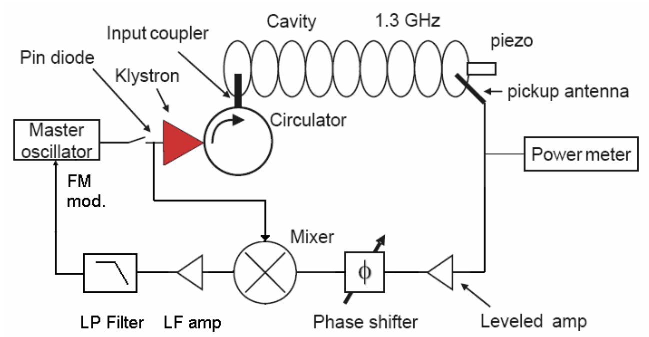


Figure 5: Phase-Locked Loop used at BESSY for microphonics analysis

3.2. Microphonics analysis in CryHoLab

For the tests in CryHoLab, the cavity was equipped with a power coupler because the same cavity served also for Lorentz force compensation at high gradient in pulse mode. A waveguide to coaxial N-type connector transition was mounted on the coupler for the low gradient experimentations. The external quality factor was measured to be 1.3 10^6, which corresponded to a cavity bandwidth of 1 kHz. Therefore, the open-loop configuration was chosen for the microphonics analysis. To ensure a better helium-bath pressure stability, the helium cycling through the refrigerator was disconnected and the helium gas was sent to buffer tanks.

The detuning signal was digitized with a sampling rate of 10 kS/s, covering a frequency analysis up to 5 kHz, and a resolution of 16 bits. A Matlab code was elaborated for the time and spectral domain analysis: 2D, 3D spectrograms, local spectrum at a given time, or amplitude change in time domain of a given frequency channel could be displayed. Figure 7 shows a record of cavity detuning over 15 minutes with running turbomolecular pumps. It represents about 9 millions of data points. Three different regimes of disturbances were identified due to different causes: binary-state helium control valve, vacuum pumps motors harmonics exciting the neighboring MEMs, or excitation of MEMs by other environmental noises. The total detuning rms value was 8.5 Hz. The first regime corresponds to a low frequency oscillation, typically lower than 5 Hz, with variable peak detuning up to 100 Hz and decaying within five seconds. A zoom on such an oscillation is displayed in Figure 8, while Figure 9 shows the corresponding spectrogram. Looking in a channel centered at 1.4 Hz, the decay time of the disturbance can be evaluated (Figure 10). This kind of disturbance is specific to CryHoLab. It should not exist in a cryogenic plant operating at 1.8 K.

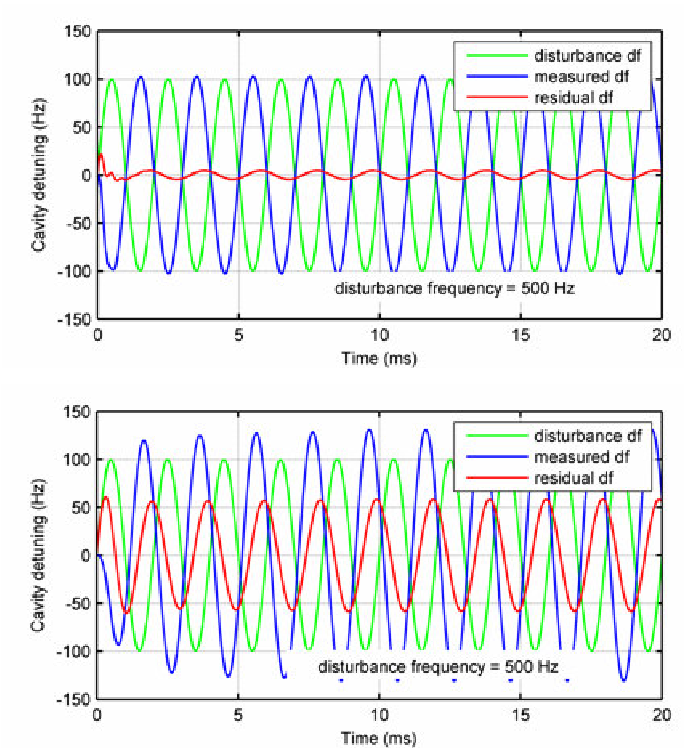


Figure 6: Impact of K_{PLL} on detuning measurement (top 10^5, bottom 10^4)

The spectrogram in Figure 11 illustrates a case of the second regime dominated by the 50 and 100 Hz harmonics. The variation of the amplitude in the time domain must relate to some vacuum pumps internal regulation processes (Figure 12). When the pumps were switched off, disturbances around 50 Hz and 100 Hz were strongly reduced, leaving only a few resonances below 300 Hz (Figure 13).

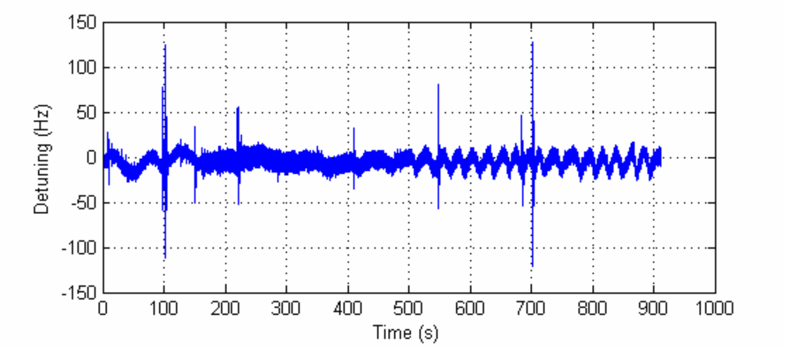


Figure 7: Record of a 9-cell cavity detuning

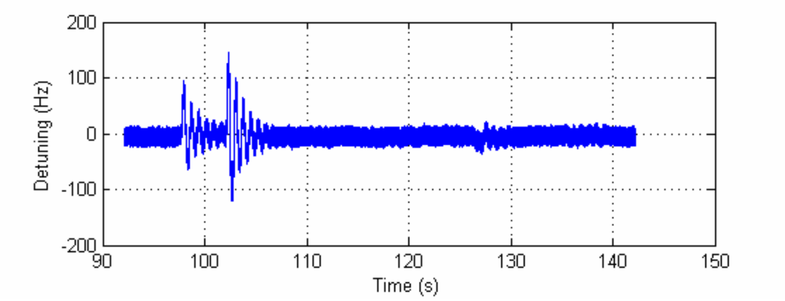


Figure 8: Zoom on a very low frequency oscillation

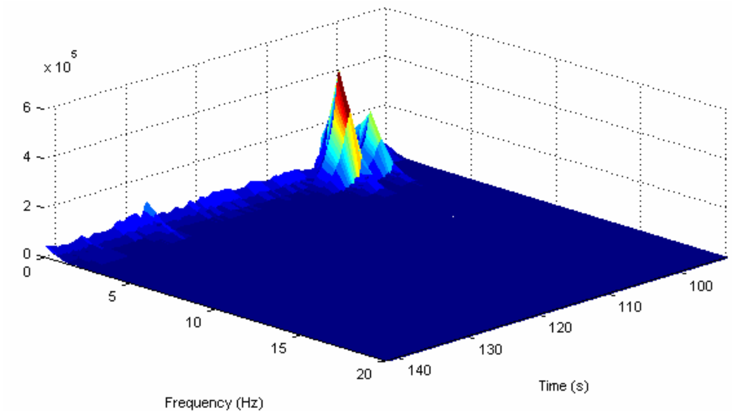


Figure 9: Spectrogram of a low very low frequency oscillation

The major disturbance at 115 Hz may correspond to the first longitudinal MEM, which is known from the mechanical and RF simulations to provide a strong detuning to the cavity. The absence of detuning contributions above 300 Hz indicates that the environmental noises are rather bandwidth limited or the detuning effect of the MEMs at higher frequency is very low; surely both. This third regime presents typically an rms detuning of 1.5 Hz with peak-to-peak amplitude of 7 Hz.

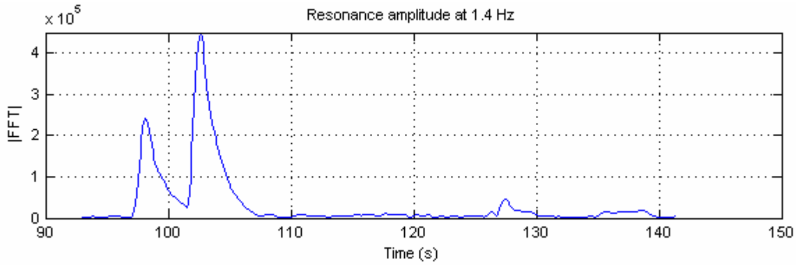


Figure 10: Very low oscillation onset and decay

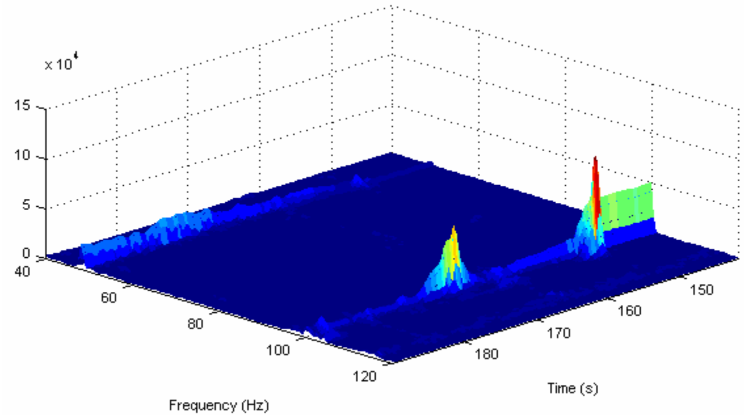


Figure 11: Vacuum pumps harmonics driven cavity detuning

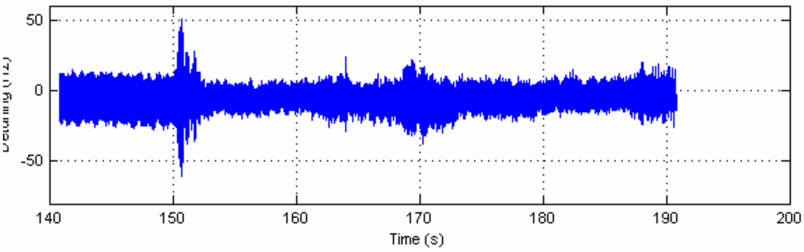


Figure 12: Vacuum pumps disturbance in time domain

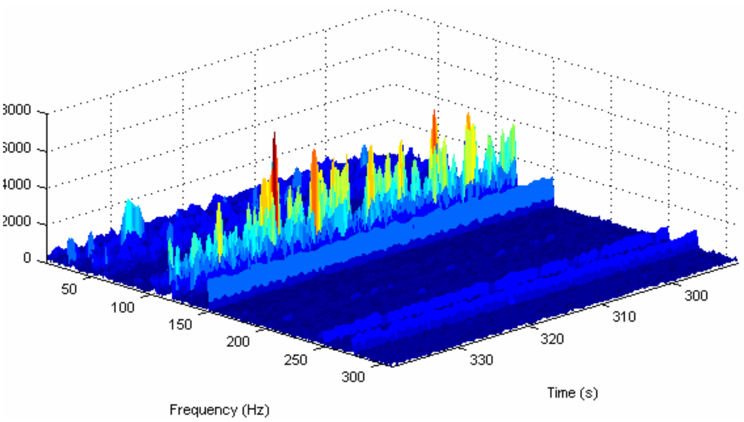


Figure 13: Low amplitude detuning with pumps switched off

4. TRANSFER FUNCTION–MECHANICAL EIGENMODE

4.1. *Transfer function measurement*

The identification of transfer functions (TF), FPT to FPT or FPT to cavity detuning is obtained as a Bode diagram from the harmonic response in a discrete frequency sweep using a lock-in amplifier which provides an excellent noise rejection. Since the quality factor of each mechanical mode (Q_m) is unknown a priori, each frequency step should last long enough, typically 5 seconds, in order to reach a steady state before the measurements of amplitude and phase are taken. A diagram block is given in Figure 14 and Figure 15 shows a picture of the system integrated in a bench.

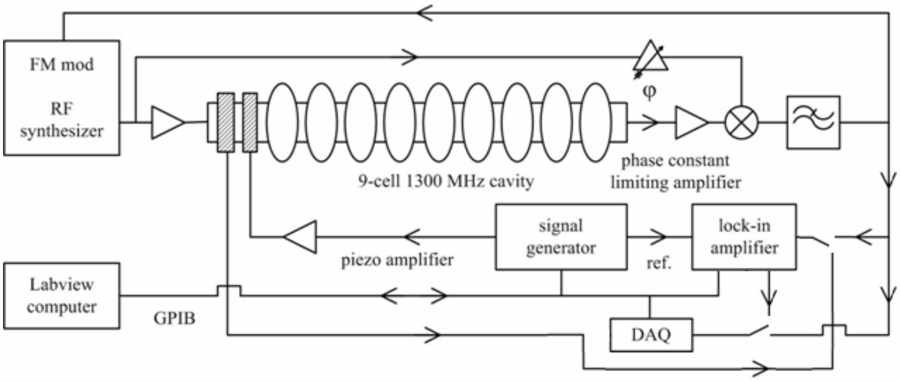


Figure 14: Block diagram for the transfer functions measurement

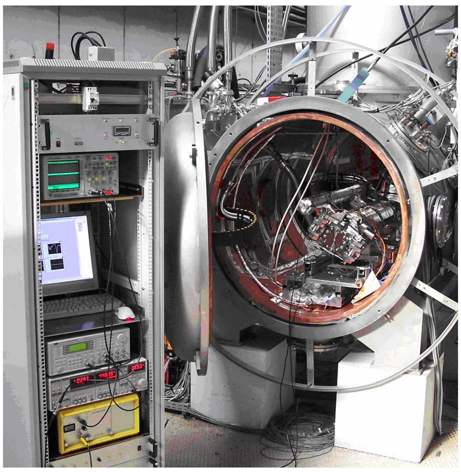


Figure 15: Integrated instrumentation for transfer function measurement

4.2. Room temperature measurement

The transfer function measurement provides a direct measurement of the MEMs properties. As the latter may change, according the temperature variation that impacts on the mechanical boundary conditions, transfer functions were measured at different temperatures. Measurements were first performed at 300 K in CryHoLab. A comparison of FPT to FPT and FPT to detuning transfer functions is shown in Figure 16.

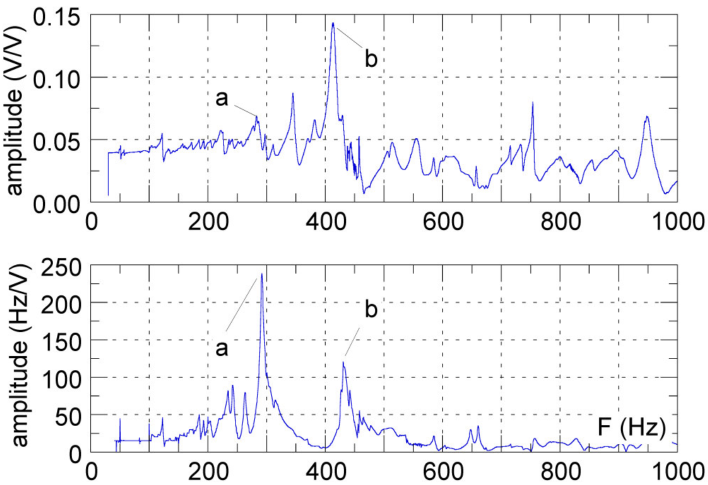


Figure 16: TF at 300 K, FPT to FPT (top), FPT to cavity detuning (bottom)

The relative amplitude between the two dominant modes labeled as ‘a’ and ‘b’ appears different in the two TFs, which indicates that the detuning of the cavity does not depend only on the longitudinal length variation. It rather depends on a complex mechanical coupling between the FPT and the MEMs on the one hand and between the MEMs and the cavity detuning on the other hand. Another way to assess the higher frequency modes and their associated Qm’s consists in exciting periodically one FPT with pulses and reading the signal of the second FPT on a real-time spectrum analyzer (RTSA). Strong MEMs with high Q are displayed as long hot trails on the RTSA (Figure 17a), which shows such resonant modes around 2.5 kHz. Nevertheless, their detuning contribution is expected to be weak from a theoretical analysis: mechanical and RF simulations. Microphonics have also been analyzed with the RTSA on one FPT signal; the resonance ‘b’ appeared as a continuous hot line (Figure 17b). The excitation of lower MEMs was also visible.

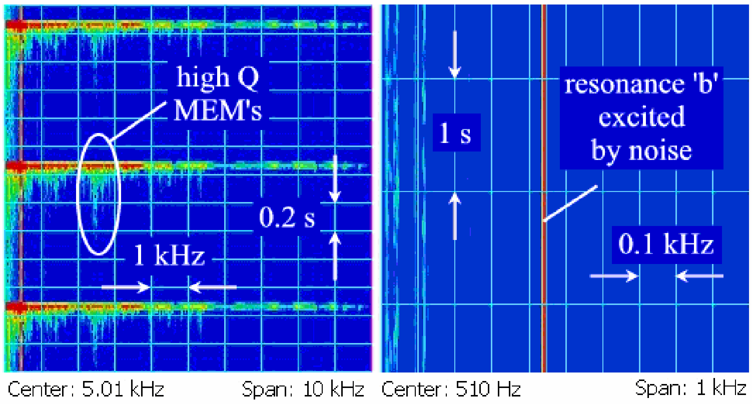


Figure 17: High frequency modes (a: left), microphonics (b: right) at 300 K

4.3. Measurement at 4.2K

Figure 18 shows a FPT to cavity detuning TF measured with 1 Hz of resolution. It is quite similar to that obtained at room temperature (Figure 16). However, a more detailed examination would point out frequency and amplitude shifts as well as Q variations, all attributable to the change of mechanical boundary conditions and a different nominal setting of the tuner.

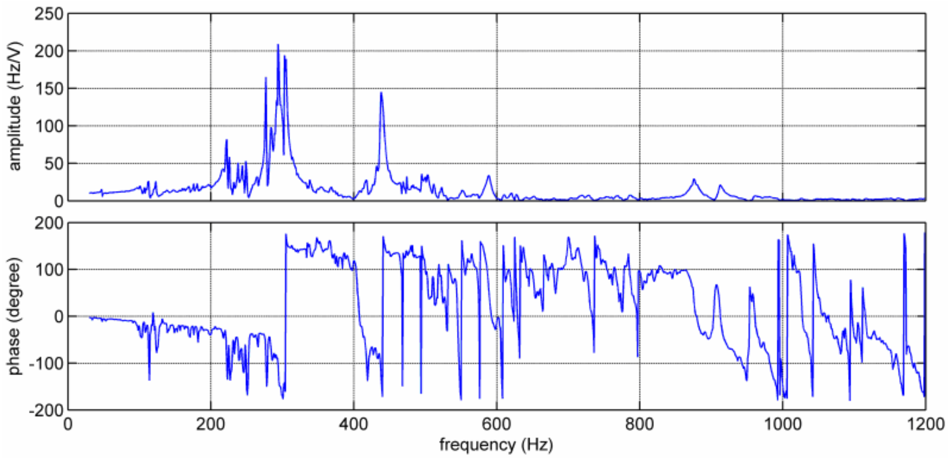


Figure 18: FPT to cavity detuning transfer function at 4.2 K

4.4. Measurement at 1.8K

Because of the relocation of CryHoLab, the cavity test at 1.8 K was carried out at BESSY in HoBiCaT. Another fast piezo tuner exactly the same model as the one used at 4.2 K at Saclay was mounted on another standard 9-cell cavity. The external quality factor for the power coupling was set to 3.8 10^7. Thus, a closed-loop configuration with a PLL can be tested for the transfer function measurement. A loop filter cutoff-frequency of 30 kHz and a gain higher than 10^5 ensured an error free detuning measurement as pointed out in section 3.2. Figure 19 shows one of the results obtained in HoBiCaT at 1.8 K. Comparing this result to the one obtained at 4.2 K (Figure 18), one can notice that the general aspect is similar; groups of mechanical modes are observed at about the same frequencies and relative amplitude are preserved. However, a more careful examination will show some difference. The most remarkable is the amplitude of the highest resonance, which reached only 150 Hz/V instead of 200 Hz/V. Not all the noticeable small differences may be put down to the cryogenic temperature difference, since material mechanical properties variation between 4.2 K and 1.8 K is expected to be negligible. Actually, the piezo actuator preload may affect more significantly the transfer function. In order to assess the stability of the transfer function, measurements were taken in several sequences with increasing frequency sweep as well as decreasing frequency sweep. No significant change was observed. Long-term variation over six months has also been checked without noticeable drifts in amplitude or phase.

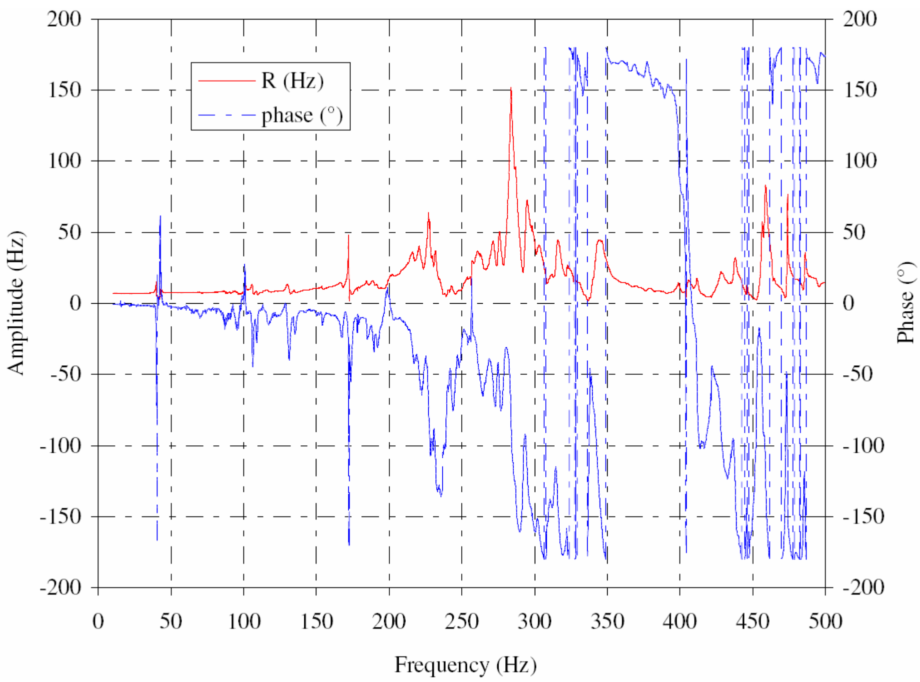


Figure 19: FPT to cavity detuning TF measured in HoBiCaT at 1.8 K

4.5. Transfer function modeling

Because of the complexity of the TF evidenced by Figure 18 and Figure 19, any feedback compensation efficiency prediction is bound to fail without an accurate model of the system composed by the tuner, cavity and cryomodule (TCCS). Meanwhile, this TF involves more than 30 resonances in a frequency span even limited to 1.2 kHz, ruling out any attempt to derive a canonical form: H = N/D, where N and D would be very high order polynomials. Indeed, the stability analysis of such a system is extremely sensitive to the numerical precision of the calculation.

Fortunately, a basic consideration of the physical process behind the TF provides a simple and practical model. It states that the harmonic response at a given frequency appears as a linear combination of the contributions of an infinite number of MEMs. Practically, only a finite can be considered. Consequently, the system model writes simply:

$$H(s) = H^1(s) + \sum_{i=1}^{N} H_i^2(s),\ \ H^1(s) = \frac{K_0}{\tau s + 1},$$
$$H_i^2(s) = \frac{\omega_i^2 K_i}{s^2 + 2\xi_i \omega_i s + \omega_i^2},\ \ \xi_i = \frac{\delta\omega_i}{\omega_i},\ \ K_i = \pm 2\xi_i \Delta f_i,$$

where the first order TF modeled the contribution of high frequency MEMs with eigenfrequencies higher than ω_N and is used to adjust the static response, ξ_i relates to Q_{mi} the mechanical resonance quality factor: $Q_{mi} = 0.5/\xi_i$. For the TCCS in this study, K_0 is a negative small value about 1 Hz/V. The time constant τ corresponds typically to a cut-off frequency of 1 kHz. The other parameters: $\delta\omega_i$, the half bandwidth, ω_i, the eigenfrequency, Δf_i, the detuning amplitude, are intermediate parameters. For well-isolated resonances, they can be directly derived from the measured TF. More generally, their identification proceeds in two steps: a local fitting followed by a global optimization over the whole frequency span of interest. Actually, the sign of K_i is an additional, very important free parameter for the fitting procedure. A negative sign means that the transient of the associated MEM excited by a sudden shortening of the cavity length would produced a negative detuning, and vice-versa. Only a combination of positive and negative K_i's can reproduce the measured TF with a minimum deviation. A constant delay should also be added to *H* in order to take into account the propagation of the acoustic wave from the tuner to the cavity. Its value is estimated at 400 µs, from the phase slope at low frequency (Figure 18). The fitting result over a short span is presented for illustration in Figure 20.

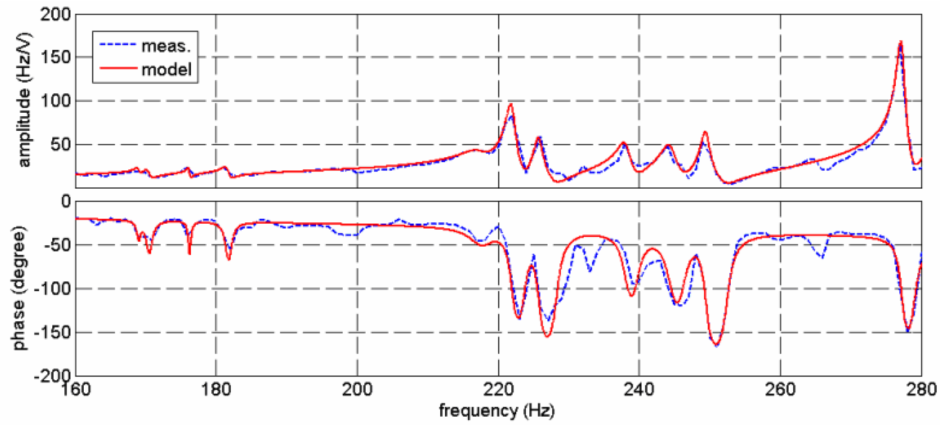


Figure 20: FPT to detuning TF analytical model validation

5. MICROPHONICS COMPENSATION

5.1. Simulation

From section 3.2, the disturbance regime of major concern involves mainly two frequencies corresponding to the pump motors harmonics around 50 and 100 Hz. A classical idea for complex system feedback would consist in providing gains only at the frequencies where disturbances are observed. The Figure 21 shows the TF of the corrector alone, made by a cascade of low pass, band pass type II Chebyshev filters, chosen for their zero phase shifts far from the pass-band, and phase lead network, as well as the open loop TF including in the cascade a model of TCCS.

To assess the effect of microphonics on the accelerating voltage and RF power requirements, the operation of a cavity including the LLRF control system is simulated with a set of parameters taken in [7]: V_{cav} = 27 MV, q_b = 1 nC, $Q_L = 4.6\ 10^7$, T_{bunch} = 2.42 µs. An operation without disturbances needs 11.4 kW of RF power. The simulation used the detuning disturbances measured in CryHoLab as an input. The RF feedback gains are set to 100. The cavity phase errors with and without the compensation are compared in

Figure 22. In the first case, the extra power is limited to about 0.5 kW while it has exceeded 2 kW in the second case.

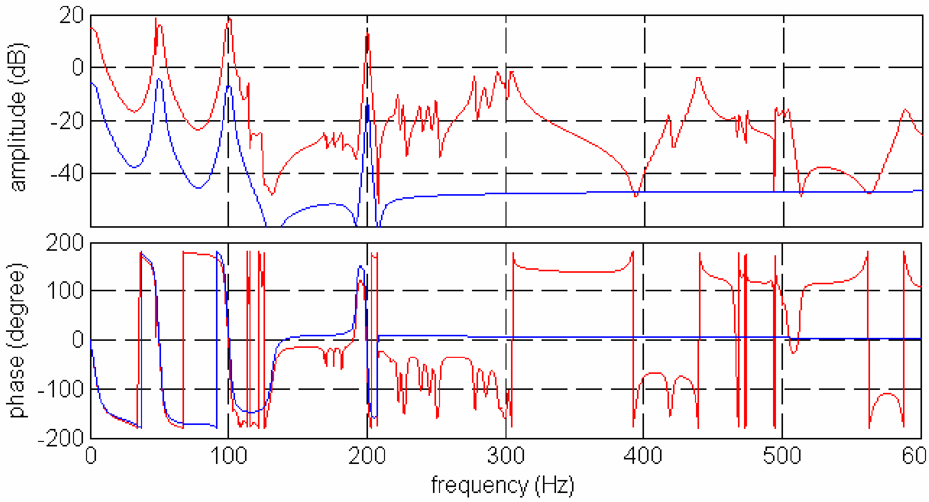


Figure 21: Corrector TF (blue) and open loop TF (red)

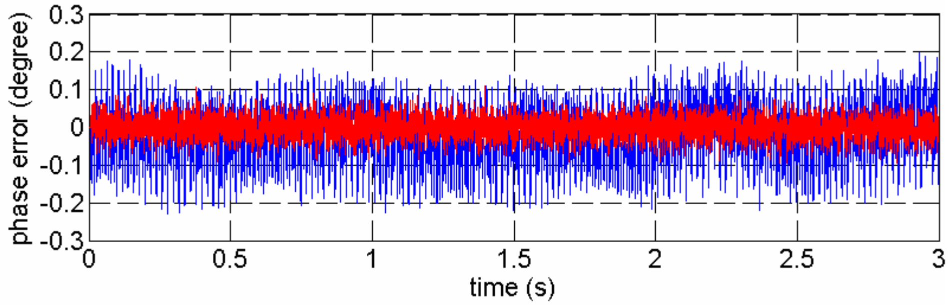


Figure 22: Cavity phase error, with (red) and without (blue) compensation

5.2. Experimental results

The feasibility demonstration for the feedback compensation of microphonics disturbances was made in HoBiCaT at 1.8 K. Firstly, an examination of the recorded microphonics spectrum [8] showed that predominant disturbances were located at low frequencies, especially around 50 and 100 Hz (Figure 23). Therefore, the compensation controller was designed to include an integral, a low pass and two band pass filters (Figure 24). The open-loop gain for each channel was set to the maximum value compatible with the loop stability, based on the measured FPT to detuning TF (Figure 25). Finally, only low gains from 2 to 3.5 were allowed because of numerous transverse mechanical modes (Figure 26).

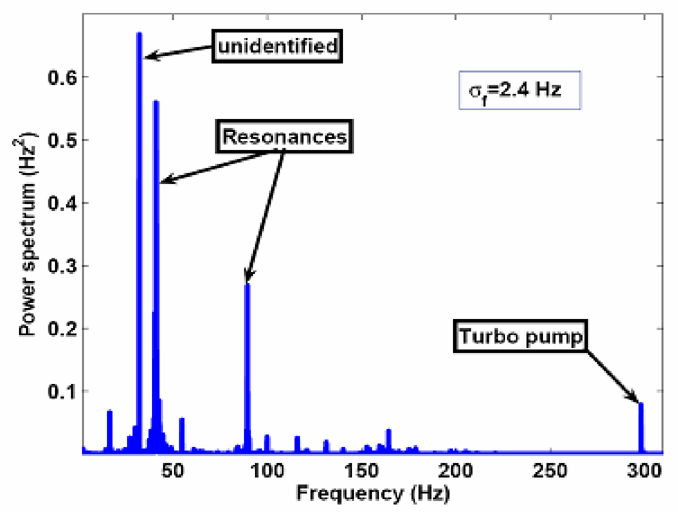


Figure 23: Microphonics spectrum in HoBiCaT at 1.8 K [8]

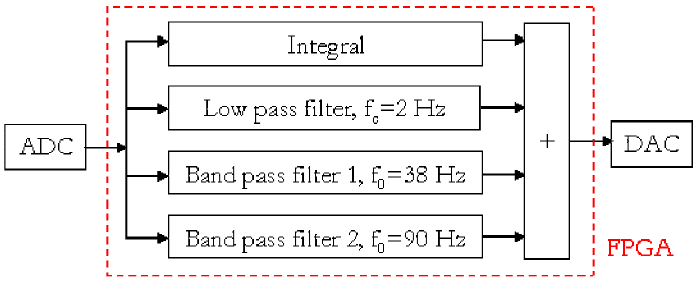


Figure 24: Digital feedback controller block diagram

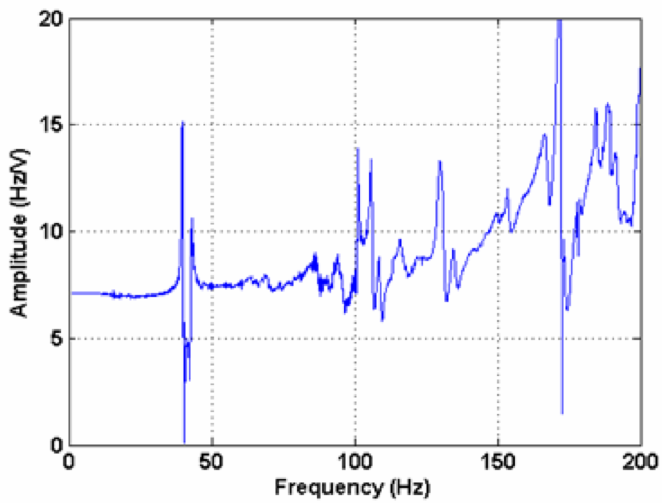


Figure 25: Measured FPT to detuning TF used for feedback controller design

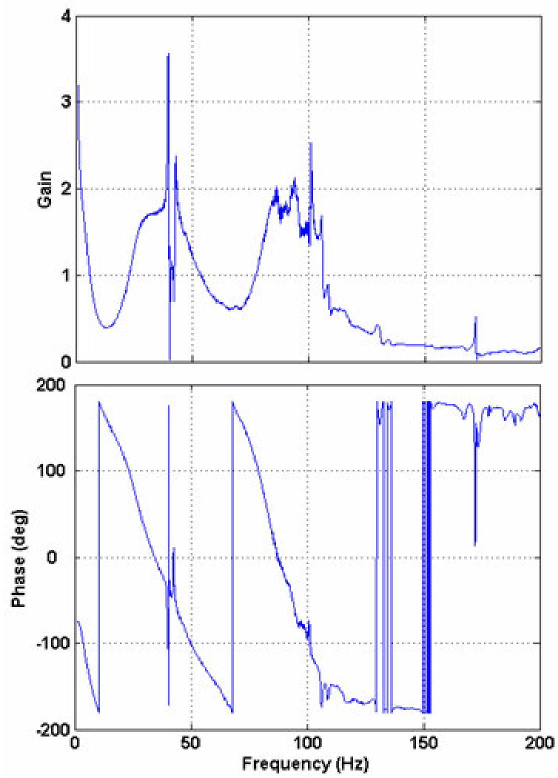


Figure 26: Feedback compensation open-loop transfer function

The implementation of the digital controller was realized with National Instruments CompactRio platform (Figure 27) including a 16 bits ADC and DAC. Chebyshev type II filters need to be synthesized as infinite impulse response digital filters, but only integer operations are allowed with the standard Labview real-time programming tool. Therefore, a second-order sections topology was chosen to synthesize the second order band pass filters. The filters coefficients were re-scaled to integer with 16 bits length. This provided an acceptable input and output dynamic of about 20 dB. Furthermore, because of very low cutoff frequency of the low pass filter, two different sampling rates were necessary for the implementation. The low pass filter used a 200 Samples/s rate while the band pass filters used 5 kS/s. A Labview program rear panel view is presented in Figure 28 as an example.

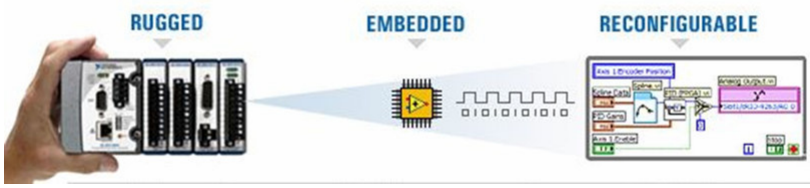


Figure 27: CompactRio platform for digital controller implementation

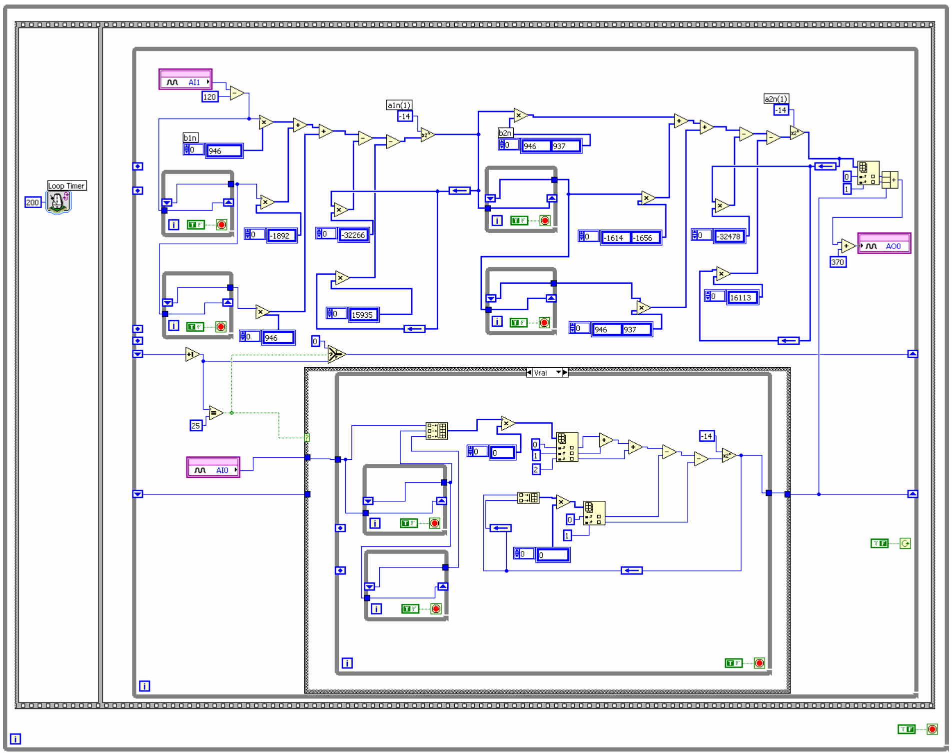


Figure 28: Digital controller rear panel view (Labview RT)

Several tests were performed with different parameters for the corrector: for instance, changing the center frequency of the pass band filters, or their bandwidth. It came out, which could be easily understood that a larger bandwidth increases the compensation efficiency when the gain has not to be reduced to ensure stability. On the whole, one observed that the compensation efficiency is limited to only 50 % for very low 'natural' microphonics lower than 2 Hz-rms, while the compensation is more effective for higher amplitude intentionally generated microphonics. In the last case, the disturbance reduction may reach a factor of three. Theses results are compatibles with the simulations. The major limiting factor turned out to be the low gain permitted by the stability, due to the fact that unluckily, two transverse mechanical resonances are located very close to the 50 and 100 Hz rotating machine harmonics. Figure 29 shows a result where a 40 Hz disturbance was superposed to the 'natural' microphonics with a thumper.

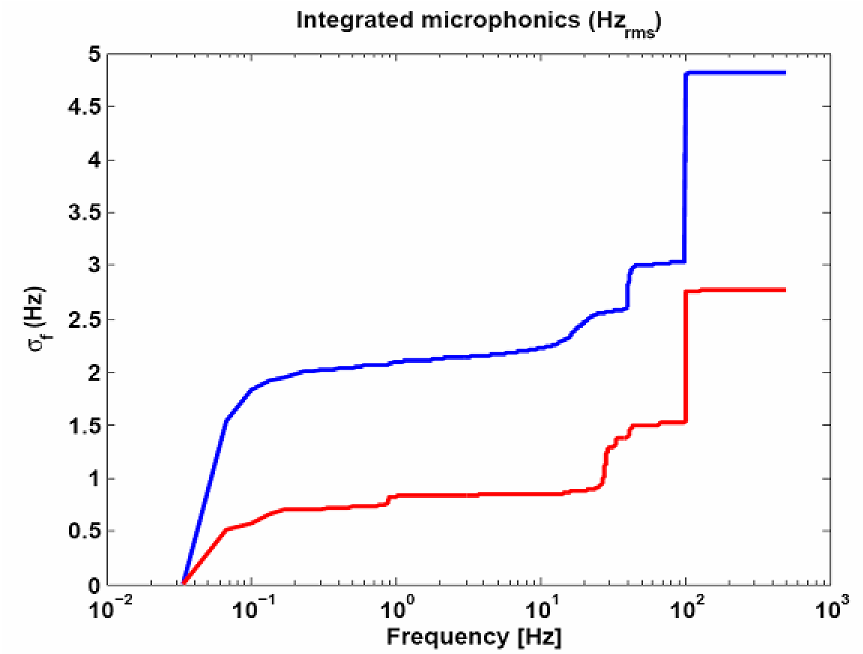


Figure 29: Example of microphonics reduction with a feedback compensation

CONCLUSION

The microphonics disturbances on a cavity operated in CryHoLab has been measured. Fourier spectrograms were used to analyze the evolution of the spectra with time. This analysis pointed out three distinct regimes of perturbation: a strong but quickly damped very low frequency oscillation due to cryogenic control, a quasi-stationary oscillation around 50 and 100 Hz due to the operation of vacuum pumps motors, and some lower amplitude oscillations related to the excitation of the mechanical structure eigenmodes by environmental noise. These results reflect the general trends also observed in HoBiCaT

Two new piezo tuners (Saclay-II) were developed and mounted on two standard Tesla-type 9-cell cavities. The tuner integrates two piezo stacks; both can operate as an actuator or sensor. The instrumentation for measurement of the piezo-tuner to cavity-detuning transfer function has been validated in CryHoLab at room temperature and at 4 K, and at BESSY in HoBiCaT at 1.8 K. Modeling and simulation activity enabled to design a feedback controller for the microphonics disturbance compensation based on the piezo actuators.

After the mounting of the Saclay-II piezo tuner on a 9-cell cavity provided by BESSY, the method of transfer function measurement in closed loop with a phase-locked loop on a narrow bandwidth cavity ($Q_L \geq 3\ 10^7$) was first demonstrated. This measurement is essential for microphonics compensation based on a feedback loop. The latter was implemented on a CompactRIO platform, including a FPGA for the signal processing and a Labview Real-time programming tool. In order to prevent instabilities, feedback gains are only provided through digital IIR filters in frequency ranges where microphonics were observed, namely around 40 and 100 Hz during the test. The 'natural' microphonics detuning in HoBiCaT is rather low, not exceeding 2 Hz-rms. Activating the feedback compensation loop gave only 50 % reduction of the detuning. The limitation was set in this case by the resolution of the piezo tuner, which was originally designed for the Lorentz force compensation with a large dynamic, and the limited feedback loop gains. Resolution is a matter of mechanical design: kinematics and plays. When an artificial detuning was purposely generated, a detuning reduction factor from 2 to 3 was obtained, which may appear poor but still corresponds to an extra RF power reduction of a factor 4 to 9 since this power scales as square of the detuning. This result agrees with the simulation. Indeed, many mechanical transverse resonant modes at low frequencies make the loop unstable as the gain is increased. As a conclusion, piezo tuners resolution should be improved and transverse mechanical modes should be damped or shifted to higher frequencies, far from the rotating machines harmonics excitations, in the perspective of microphonics compensation with a feedback loop.

REFERENCES

[1] S. Simrock et al., "First Demonstration of Microphonic Control of a Superconducting Cavity with a Fast Piezoelectric Tuner", PAC'03, Portland, 2003.

[2] T. Kandil et al., "Adaptive Feedforward Cancellation of Sinusoidal Disturbances in Superconducting RF Cavities", LINAC 2004, Lübeck, 2004.

[3] Information on VUV-FEL at Hambourg: http://vuv-fel.desy.de/.

[4] A. Neumann et al., "Characterization of a piezo-based Microphonics Compensation System at HoBiCaT", Proceedings of EPAC 2006, Edinburgh, Scotland, 2006.

[5] J. Knobloch et al., "Status of the HoBiCaT Superconducting Cavity Test Facility at BESSY", Proceedings of EPAC 2004, Lucerne, Switzerland, 2004.

[6] P. Bosland et al., "Third harmonic superconducting passive cavities in ELETTRA and SLS", Proc. of 11th SRF workshop, Sept 2003, Travemunde, 2003.

[7] J. Sekutowicz, "Parameter set for CW and nearly-CW Operation of a XFEL Driving Superconducting Linac", EuroFEL report 2005-DS5-003.

[8] A. Neumann et al., "Microphonics Measurements in a CW-driven Tesla-type Cavity", Proceedings of EPAC 2006, Edinburgh, Scotland, 2006.

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