MEASUREMENT AND COMPENSATION OF MICROPHONICS IN CW-OPERATED TESLA-TYPE CAVITIES*

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Abstract

When operating TESLA type cavities in cw-mode, microphonic detuning becomes the most prominent source for fluctuations in their resonant frequency. Such fluctuations increase the required RF power-reserve and the amplitude and phase-jitter of the accelerated electron beam. It is therefore highly desirable to be able to compensate microphonics. For the purpose of frequency adjustment various tuning systems have been developed (DESY, Saclay, KEK, INFN) which all change the cavity dimensions by applying an external force on the cavity-liquid He tank system, doing so either rapidly with a piezo-actuator or slowly but at a larger overall range with a stepper motor. Two tuners were tested: the Saclay I tuner and the Saclay II tuner. They were compared with respect to their usability for microphonics compensation. Microphonics were characterized and furthermore compensated using a feedback algorithm for slow frequency drifts caused by the cryogenics system up to 1Hz and a feed-forward algorithm for the de-excitation of mechanical resonances of the cavity-tank-tuner system above 1Hz.

INTRODUCTION

Energy recovery LINACS are operated with small beam loadings, which implies high loaded Q values, or small bandwidths for the accelerator-cavities. Thus, any small deviation in the cavity resonance frequency enforces a significant increase in the power reserve that is required for maintaining a constant field gradient. A too high level of phase error thwarts the whole point of the ERL which is to save energy. It is therefore highly desirable to understand what amplitude level of microphonics should be expected. Also, when aiming at a compensation of microphonics, the mechanical properties of the cavity-tank-tuner system must be investigated, which implies a thorough characterisation of the tuner.

EXPERIMENTAL

Experiments have been performed at the HoBiCaT [1] (Horizontal Bi-Cavity Test) facility, see Figure 1, located at BESSY. HoBiCaT mainly serves the purpose of adapting TESLA technology to CW-operation, as required for the planned BESSY-FEL [2].

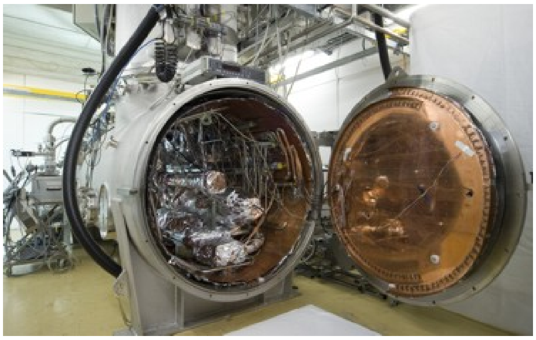

Figure 1: The cryostat of the HoBiCaT facility.

The HoBiCaT cryostat is cooled with liquid Helium delivered by a Linde TCF-50 and suitable for operating two cavities at 1.8 K with 80 W of heat load simultaneously. The Helium pressure is recorded with a Rosemount 3051s sensor located at the top of the expansion chamber at the end of the Helium supply line. CW RF-power can be generated with a 400 W solid state amplifier, a 10 kW Klystron or a 30 kW IOT transmitter. Cavities are equipped with a TTF-III coupler and a three-stub-tuner, which allows for the variation of their loaded Q between $3 \cdot 10^7$ and $3 \cdot 10^9$ or in terms of the bandwidth from 0.2 Hz to 22 Hz. All presented experiments were done at 1.8 K. RF operation is performed with a phase-lock-loop circuit which consists of a master oscillator (Rohde & Schwarz SML02), a mixer (Mini Circuits ZEM-4300), a levelled amplifier (HP 8347A), an instrument amplifier with integrated low-pass filter (Signal Recovery Model 5113), a phase shifter (Herley 7820), a variable pin-diode attenuator (Herley 3461C) and a pin-diode switch (Mini Circuits ZMSW-1111). With sufficiently high bandwidth, the circuit can be operated open-loop. As an alternative to closed loop operation, the phase error signal can also be fed into a piezo-amplifier, which operates a piezo-actuator that is integrated into the tuner layout and hence attached to the cavity.

TUNERS

Tuners are used to maintain a constant resonant frequency in each cavity, that is 1.3 GHz for the TESLA type. They are active mechanical devices, here manipulating the cavity length, driven by a stepper motor for coarse changes and piezo actuators for fine adjustments. They have to meet several - sometimes contradictory - requirements: the tuning range is desired to be as large as possible; tuners should exhibit little to no hysteresis; a large mechanical stiffness

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* Work partially supported by the EU Commission in the sixth framework programme, contract no 011935 EURO-FEL-DS5, BMBF and Land Berlin.

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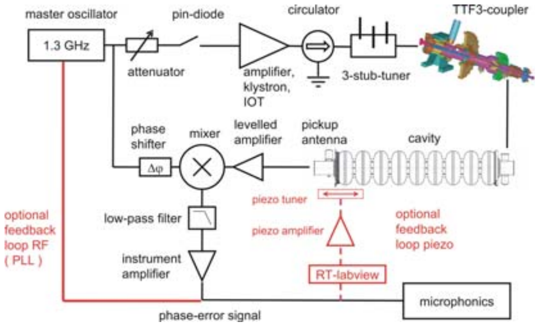

Figure 2: Schematic of the low power RF control.

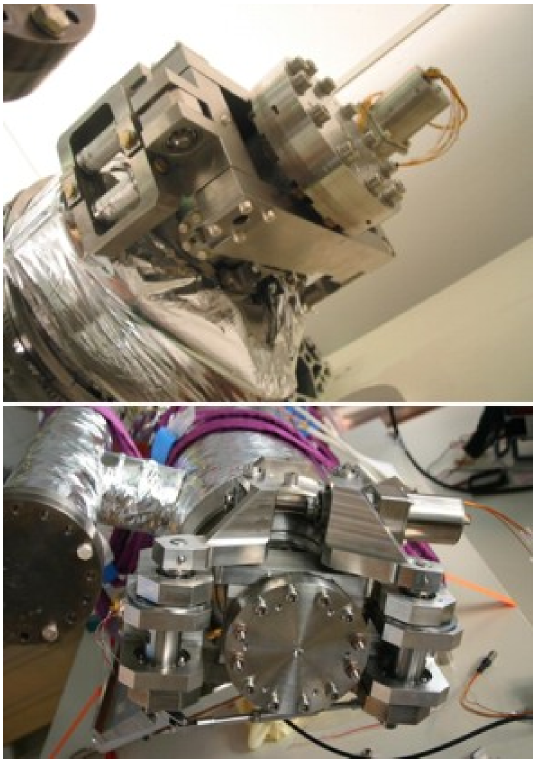

Figure 3: Saclay I tuner (upper picture) and Saclay II tuner (lower picture)

is needed in order to achieve a short response time, which determines the maximum modulation frequencies the tuner can compensate. In this work, two different tuning systems have been compared. The Saclay I tuner which is being used in the first versions of the DESY modules, and the Saclay II tuner [4] which was constructed to cope with several drawbacks of its predecessor. In particular, our version of the Saclay I tuner had a stiffer piezo holding frame as compared to the DESY version and was equipped with two high voltage piezos (Piezomechanik PSt 1000/16/40). The Saclay II tuner was equipped with two low voltage piezos (from Noliac SCM series).

The improvement in the design of the Saclay II tuner over the Saclay I version is that the piezos are now attached to the cavity such that the pre-stress applied on the cavity is not released upon motor-pretuning anymore. This improvement requires a 1 MHz lower pre-tuning upon cavity assembly as compared to the Saclay I version, meaning that present cavities working with the Saclay I tuner cannot be upgraded. In Table 1 comparative measurements of different relevant parameters are listed. The main improvement of the newer version is the significantly increased stiffness, which leads to a drop in the piezo response time (group delay) from 290 μs to 150 μs. Also the piezo tuning range was increased from 870 Hz to 1420 Hz. Regarding the motor tuning characteristics, the new principle was accompanied by several drawbacks: the mechanical play (remanence) when changing direction of motor-turns, was significantly increased—from 30 Hz to 55 Hz in terms of cavity detuning. Also the Saclay II tuner exhibited a mechanical backlash leading to an 8-shaped hystersis curve at the destination pre-tuning. Despite these drawbacks, the Saclay II version is the favored one.

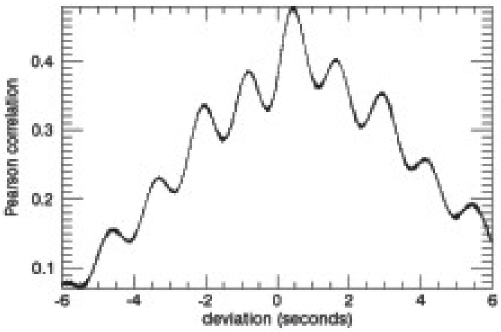

Figure 4: Correlation function between liquid Helium pressure and phase error signal.

PONDEROMOTIVE EFFECTS

In CW-operation two effects contribute to unwanted shifts in the cavity resonance frequency: pressure fluctuations in the liquid Helium bath and microphonics. In Figure 4 the correlation between phase error signal and the pressure in the liquid Helium bath is plotted. The maximum correlation occurs at 400 ms, which is the intrinsic measurement time of the pressure sensor. The side maxima correspond to thermo-acoustic vibrations caused by isolated enclosed volumes within the cryostat. We have optimized the HoBiCaT cryostat and meanwhile achieved pressure stabilities better than 30 μbar, which is close to the resolution limit of the pressure sensor. Pressure fluctuations are easily compensated with the piezo actuator, as discussed later in Figure 7. Microphonics, the second effect, is considered to occur from 1 Hz upwards into the acoustic range. In Figure 5 an integrated Fourier transform of a microphonics spectrum is shown. In particular at 41 Hz a resonance of the cavity (being elastically attached to the Helium tank) leads to a significant increase in microphonics and thus cavity deformation. Other such resonances occur around 170 Hz and higher frequencies.

Table 1: Comparison of Saclay I and II tuner under identical conditions. Favorable values are colored green.

	Saclay I tuner	**Saclay II tuner**
Resolution	0.176 Hz / step	0.09 Hz / step
Tuning range	750 kHz	500 kHz
Spindle movement	40 mm	40 mm
Maximum remanence	30 Hz	55 Hz
Mechanical Backlash	No	Yes
Coercitive Steps	180	350 ... 500
Used Piezo Type	High voltage (0 ... 1000 V)	Low voltage (0 ... +150 V)
Tuning Range	750 Hz (870 Hz at operating cond.)	1420 Hz
Tuning Coefficient	0.75 Hz / V * (0.87 Hz / V)	9.44 Hz / V
Maximum Remanent Frequency	100 Hz	200 Hz
Maximum Coercitive Piezo Voltage	120 V	20 V
Excitation Amplitude	22.5 Hz	19 Hz
Maximum Cavity Response	340 Hz	150 Hz
Group Delay at low Frequencies	361 μs (290 μs @ zero position)	150 μs
Lowest Resonance at 40 Hz	single	double structure

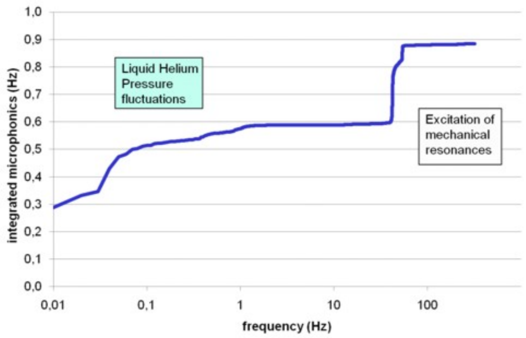

Figure 5: Integrated frequency spectrum from FFT of microphonics measurement as obtained from the phase-error signal.

In Figure 6 the transfer functions of both cavity-tank-tuner systems are shown. Such transfer functions are generated by scanning the actuator piezo frequency at low excitation voltages (avoiding nonlinear excitations) over an arbitrary range (here 10 Hz to 500 Hz) and measuring the cavity response via the phase error signal using a lock-in amplifier. At low excitation frequencies, the derivative of the phase curve over frequency gives the group delay, which is a measure for the response time of the system. The transfer functions are required for the feedforward-compensation algorithm, the result of which is presented below. The rms microphonics value can be immediately read from the integrated microphonics spectra. At HoBiCaT we have obtained rms microphonics values of 1 to 3 Hz and peak-to-peak values of 10 to 15 Hz.

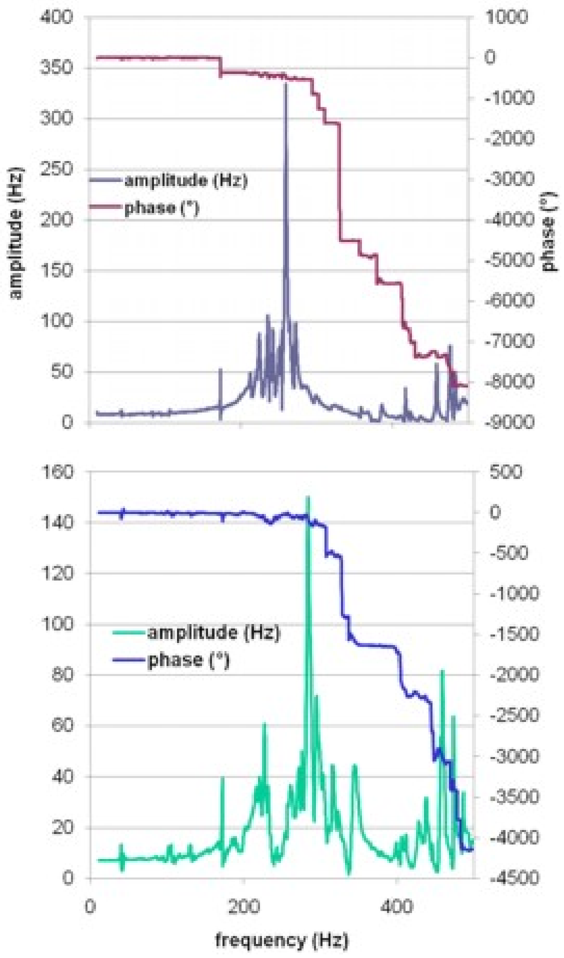

Figure 6: Transfer function of Saclay I tuner (upper panel) and Saclay II tuner (lower panel) taken from 10 Hz to 500 Hz.

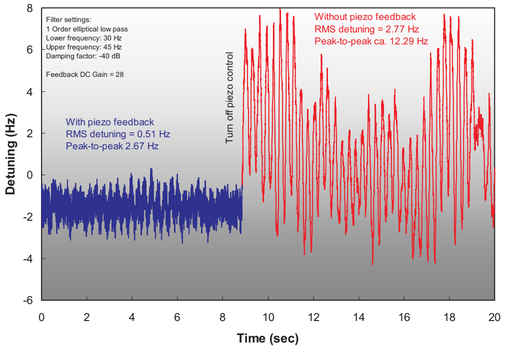

Figure 7: Feedback compensation of fluctuations in the liquid Helium bath. The plot shows the behavior of the phase-error signal upon turning OFF the feedback piezo compensation, which leads to the occurence of phase fluctuations that are correlated to the Helium pressure.

COMPENSATION OF MICROPHONIC DETUNING

In order to compensate the cavity resonance frequency changes induced by residual pressure fluctuations in the liquid Helium bath, a PID type feedback algorithm was implemented on a Realtime LabView system. Figure 7 shows this algorithm in operation: control is active in the left part of the recorded microphonics and then suddenly turned off. As a result, pressure fluctuations are not compensated anymore and lead to an increased phase error signal. In Figure 8 the result of the feed-forward compensation is depicted. The principle of operation is explained in [3]. In brief, it is based on a least mean squares algorithm, which takes into account an analytical fit of the transfer function, continuously estimating which frequency deviation is most likely to be expected next and sending a counter-signal to the piezo. By using a combined feed-forward / feedback compensation algorithm we have managed to reduce microphonics to well below 1 Hz rms and below 3 Hz peak-to-peak.

OUTLOOK

So far measurements have only been performed on one cavity at a time. By equipping HoBiCaT with two cavities, which is planned for the immediate future, it will be possible to measure the correlation of microphonics for two cavities. This is of great importance for the better understanding of microphonics in multi-cavity arrays, like an accelerator module. Here, two scenarios can be expected: a strong correlation of the microphonics in the different cavities would open up the possibility to compensate for it with the above mentioned feed-forward algorithm; a weak or no correlation would imply that the rms microphonics value remains the same as in the case of a single cavity.

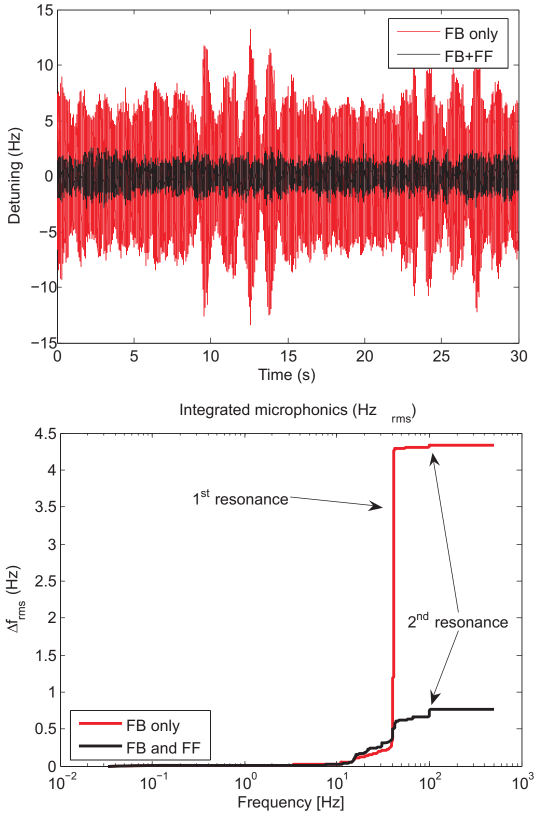

Figure 8: Feed forward compensation of microphonics.

ACKNOWLEDGMENT

Thanks are due to Michael Schuster, Sascha Klauke, Stefan Rotterdam, and Dirk Pflückhahn for the technical operation of HoBiCaT. We would like to acknowledge the significant help from and discussion with Michel Luong, Guillaume Devanz, Eric Jacques, Pierre Bosland from CEA Saclay, and Bernd Petersen, Rolf Lange, Kay Jensch, Clemens Albrecht, Stefan Simrock and Lutz Lilje from DESY.

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