INVESTIGATION OF PASSIVE STABILIZATION- AND DIFFERENT TUNING SYSTEMS FOR TESLA CAVITIES WITH RESPECT TO CW OPERATION*

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Abstract

BESSY has planned a free-electron-laser that will be operated with TESLA type cavities at high Q-values in CW mode. These operating parameters imply a low cavity bandwidth and thus a high sensitivity towards ponderomotive oscillations, in particular microphonics. In the HoBiCaT facility, located at BESSY, we have tested various tuning systems (Saclay I, Saclay II) and compared their usability for CW operation. Furthermore, the impact of ”Rossendorf”-type stabilization fixtures on the mechanical properties was investigated.

INTRODUCTION

Tuners are used to achieve and maintain a constant resonant frequency in each cavity, that is 1.3 GHz for the TESLA type. The tuners investigated here are active mechanical devices, manipulating the cavity length via levers that are attached to cavity and tank. Coarse frequency changes are realized by a stepper motor driving a spindle interconnecting the levers. For fine adjustments, piezo-elements are included in one of the levers acting upon the cavity by changing the lever-length. Tuners 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 is needed in order to achieve a short response time, which determines the maximum modulation frequencies the tuner can compensate. In CW mode of operation no dynamic Lorentz force detuning due to pulsing occurs. Thus, the main contribution to frequency deviations arises from microphonics. As CW machines are operated at a low cavity bandwidth (i.e. 20 Hz in STARS as opposed to 300 Hz at FLASH) microphonics have a direct impact on the necessary RF-power reserve and the operation cost of the facility. Thus, the tuners become a fairly crucial part of the accelerator. At HoBiCaT [1], see Figure 1, we have tested several aspects arising for tuners from CW operation.

DUAL CAVITY OPERATION

Single RF operation is performed with a PLL, as described in [2]. For parallel operation of a second cavity, another low-level RF control system has been built[1],

Figure 1: The cryostat of the HoBiCaT facility.

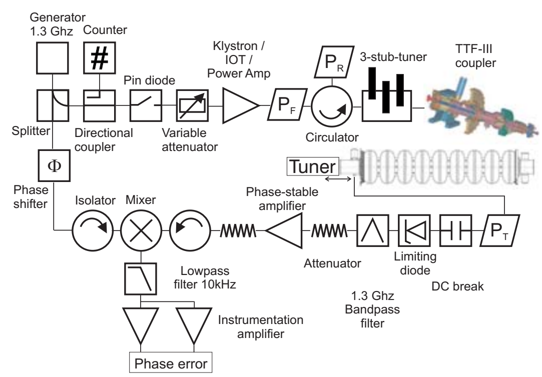

Figure 2: Phase-lock-loop for RF operation.

optimized for higher precision measurements, see Figure 2. The 1.3 GHz master signal from the generator (Rohde & Schwarz SML02) is split in two (splitter Mini-Circuits ZAPD-2). One part is passed through a phase shifter (Herley 7820) and an isolator (Valvo VFO 1139) to the LO input of a mixer (Mini Circuits M2AC); the second part is passed through a directional coupler, a pin diode switch (Mini Circuits ZMSW-1111), a variable attenuator (AMC 473) to the RF amplifiers, alternatively a 400 W amp (PA23-420B), a 10kW klystron (CPI VKL-7811ST), or an 18 kW IOT (CHK5-1320W). The amplified RF is passed through a waveguide, a circulator, a three-stub-tuner and a TTF-III coupler into the cavity. The returning signal, measured with a pickup antenna at the far end of the cavity, is passed through a DC-break, a limiting diode (OMNIYIG SL2D1), a 1.3 GHz bandpass filter (LORCH 8BC 1300/55 S), another 3dB attenuator and isolator, finally connecting to the RF input of the mixer. The resulting phase error signal of the cavity is passed through a 10 kHz low-pass filter (custom made) to several parallel instrumentation amplifiers

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[1] according to plans from Michel Luong

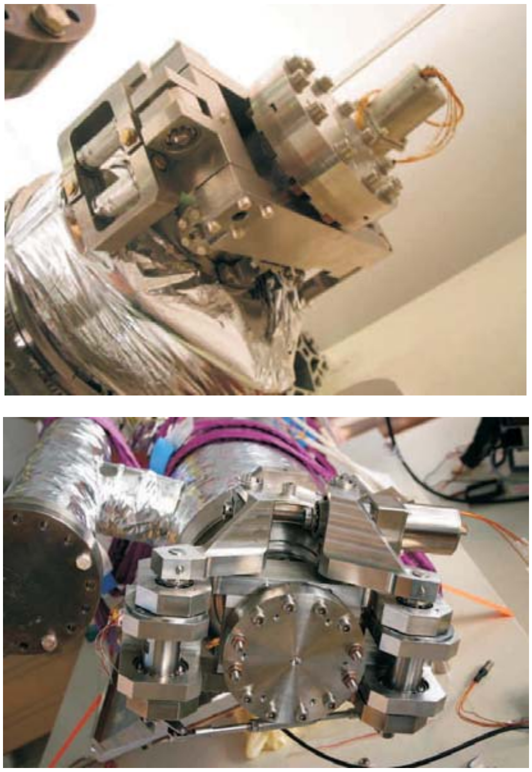

Figure 3: Saclay I tuner (upper picture) and Saclay II tuner (lower picture)

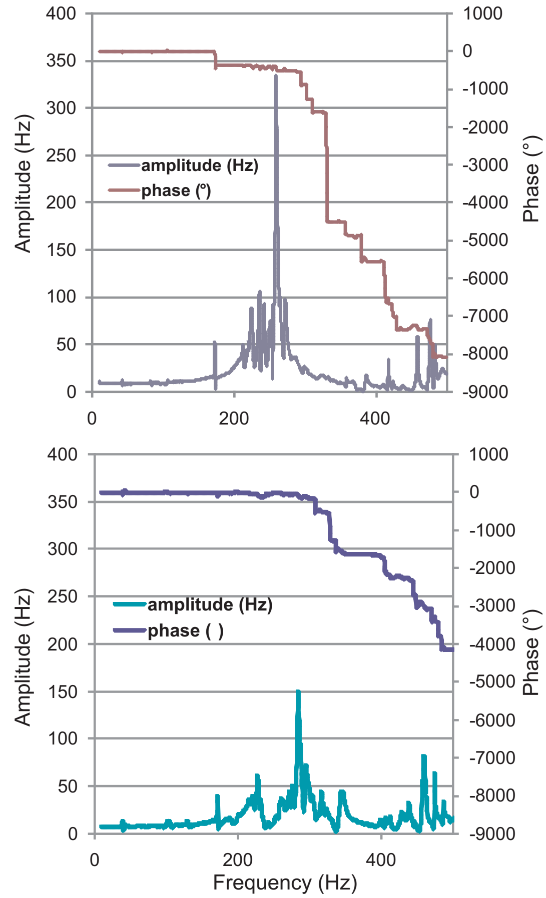

Figure 4: Transfer function of the Saclay I and Saclay II tuner attached to cavity and tank at 1.8 K

(AD8221), and recorded on a scope or a LabView DAQ system. With sufficiently high bandwidths, both PLLs can be operated open-loop with one generator. As an alternative to PLL operation, the phase error signal can also be transferred to the cavity mechanically, by manipulating its dimensions with the piezo-tuner.

TUNERS

Two different tuners have been tested: the Saclay I [3] and Saclay II [4] version, see Figure 3, both developed at Saclay within the framework of the CARE program. Saclay I is presently used in the TESLA modules.

Piezo-RF transfer functions

For characterization and comparison purposes, the transfer functions of each tuner were recorded. This was done by applying a sinusoidal voltage signal to one of the piezos. The resulting phase-error signal of the closed PLL was recorded with a lock-in amplifier. The corresponding detuning in terms of the frequency can be easily calculated by taking into account the chosen PLL frequency modulation, which was 2000 in our case. Figure 4 shows the transfer functions of both tuners, taken over an excitation frequency range from 5 to 550 Hz. The lowest resonance occurs at approximately 40 Hz and is displayed in more detail in Figure 5. It is duly noted that this feature can occur at different frequencies for other cavities, depending on the assembly process. We have observed values between 30 Hz and 42 Hz. For the Saclay II tuner a splitting of the spectral line was observed which may be due to a coupling of the resonance with an antisymmetric oscillation of the two levers. It is also noted that in typical microphonics spectra at HoBiCaT, the higher resonances are almost never excited, because they are filtered by the rigid entrenchment and the solid mass of HoBiCaT. Therefore the seemingly small lowest resonance is actually of the highest importance for the whole system.

Piezo-piezo transfer functions

For both systems, also the transfer functions between the two piezos in the holder frame have been recorded. Here, one piezo acts as the actuator, the other one as sensor supplying a pressure induced voltage. In order to account for the different piezo types, in both experiments the excitation voltage of the actuator piezo has been set such, that the low-frequency limit of the detuning amplitude was identical at 14 Hz. The curves in the plot, see Figure 6, have been normalized with respect to their low frequency value in order to account for the different piezo types. As a general trend, the resonances of the piezo frame are shifted towards higher frequencies in the Saclay II tuner, meaning

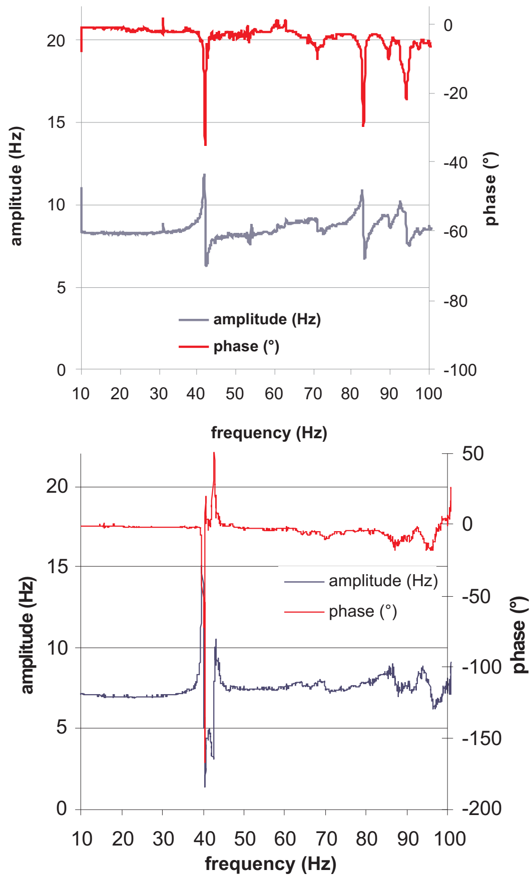

Figure 5: First resonance at 40 Hertz

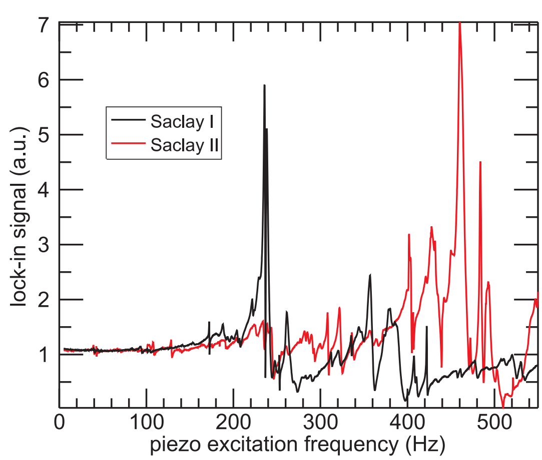

Figure 6: Piezo to piezo transfer function measurement of both tuners

that the latter is stiffer. In contrast to the piezo-RF transfer function, the piezo-piezo transfer function delivers information about the piezo holder-frame rather than the entire cavity-tank-tuner system.

Comparison of Saclay I and Saclay II

In table 1 the results from the comparisons are shown. They include measurements not discussed in detail here, like hysteresis and range determination. The main improvement of the Saclay II tuner is the significantly increased stiffness, which lead 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 upgrade to the Saclay II design 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 hysteresis curve at the destination pre-tuning. Despite these drawbacks, the Saclay II version is the favored one.

PASSIVE STABILIZATION

Titanium fixtures, that can be attached between cavity and tank have been developed at Rossendorf, see Figures 7 and 8. While originally intended for earthquake protection, we have investigated, to what extent a passive frequency stabilization can be achieved with those fixtures.

Figure 7: Rossendorf type tank with flanges for 4 fixtures.

Figure 8: Rossendorf fixture connecting ring at cavity neck to helium tank.

For this purpose, we have measured the transfer function of the system in two different cold runs of HoBiCaT. In the first measurement the fixtures were attached, and in the second one they were taken off. Great care was taken, to have otherwise identical operating conditions, i.e. an identical temperature of 1.8 K, the same piezo excitation voltage, same power levels ($P_{forward}$ = 45 W, $P_{transmitted}$ = 2 mW), same cavity bandwidth (Q_L = 7e-7), same PLL parameters (2000 Hz frequency modulation, 10 kHz low-pass filter, gain 25), same tuner: Saclay I, etc. The result of the measurements can be seen in Figure 9, where the difference of the transfer functions, i.e. the difference in

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
Coercive 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 Coercive 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

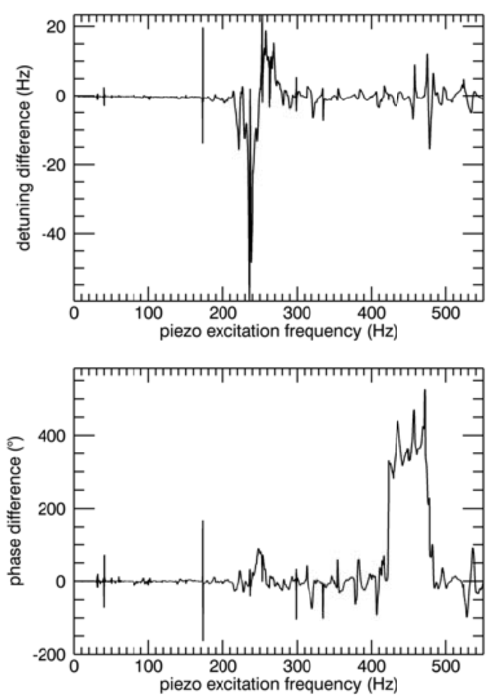

Figure 9: Upper picture: Detuning difference from transfer function measurement of cavities WITH and WITHOUT Rossendorf fingers attached; lower picture: phase difference

detunings resulting from the very same frequency-scanned piezo excitation is plotted. It is almost zero for frequencies up to 200 Hz which means that the fingers have no significant influence here. This is also supported by the plot of the phase differences in the lower curve which remains close to zero most of the time. This implies that both systems have a very similar group delay and thus stiffness. The main resonances of the cavity tank tuner system at 40 and 170 Hz are shifted to slightly (0.5 Hz) higher frequencies when attaching the fixtures. A larger effect can be seen happening to the broader feature above 200 Hz. Its center is shifted by 20 Hz towards higher frequencies, which implies an increase in the whole system's stiffness. The bottomline of these measurements is that the gain in stiffness is very small and from the point of view of microphonics it is probably not worth the effort to install the fixtures into the tank.

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