ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF052

HIGH QL AND HIGH GRADIENT CW OPERATION OF TESLA SCRF 9-CELL CAVITY

K. Przygoda*, R. Rybaniec[1], V. Ayvazyan,
L. Butkowski, M. Hierholzer, H. Schlarb, C. Schmidt, J. Sekutowicz, DESY, Hamburg, Germany
[1]also with ISE WUT, Warsaw, Poland

Abstract

In the paper we would like to present the performance of superconducting radio frequency (RF) TESLA 9-cell 1.3 GHz cavity operated at continuous wave (CW). The cavity has been setup for extremely high loaded quality factor (Q_L of order of $3 \cdot 10^7$) and gradients up to 23 MV/m. The design hardware and firmware components as well as developed high level software procedures allows automatic procedure of cavity ramping up from low to high gradient operation. The microphonics as well as a pendoromotive effects are sensed, identified and applied for cavity detuning correction. The RF and piezo feedbacks are demonstrated and preliminary results are briefly discussed.

INTRODUCTION

The 1.3 GHz SCRF cavities in linear accelerators (linacs) such as Free Electron Laser in Hamburg (FLASH) and European X-Ray Free Electron Laser (E-XFEL) are typically driven by 10 MW klystrons and operated in a short pulse (SP) mode. In SP mode a duration of the single RF-pulse is about 1300 μs and a repetition rate is up to ten Hz. Due to the fact the full width at half maximum (FWHM) bandwidth of a cavity resonator in such mode (at nominal gradient of 23.6 MV/m) is 433 Hz for the FLASH and 283 Hz for the E-XFEL ($Q_L \sim 4.6 \cdot 10^6$), the leading source of the RF field disturbance is a Lorentz force detuning (LFD). The required cavity detuning for the E-XFEL is to be less than 10 Hz, and for this purpose cavities are equipped with the piezo tuners. A microphonics noise, which is unpredictable phenomena, becoming a dominating source of the RF field errors in the CW mode. The CW cavities are usually driven by the inductive output tubes (IOTs), and operated with a quality factors of order of $1.5 \cdot 10^7$ and above. In order to achieve a stable acceleration of 10^5 bunches per second, with a nominal operating gradient of 15 MV/m (future possible upgrade scenario for the E-XFEL machine), the accelerating RF field stability should be better than 0.01% in amplitude and 0.01 degrees in phase. Within the paper we would like to demonstrate performance of the MTCA.4 based LLRF control system applied for the RF field stabilization of CW cavities operated at high Q_L (from $1.6 \cdot 10^7$ up to $2.8 \cdot 10^7$) and relatively high gradients (20 MV/m and above) [1]. The cavity has been installed at Cryomodule Test Bench (CMTB) facility in DESY. The high level software procedures have been implemented to allow fast system setup, calibration and adjustment to the demanding operating conditions. The system performance has been measured for a single cavity setup and next adopted to support 8 cavities operation packed into a single accelerating module.

* konrad.przygoda@desy.de

CAVITY CHARACTERIZATION IN CW MODE

The cavity parameters have been measured using forward power, reflected power as well as transmitted. The cavity has been operated in long pulse mode (500 ms of the RF pulse duration), open loop and low gradient of order of 6 MV/m. The cavity voltage decay part of the RF pulse has been taken into consideration for the Q_L parameter calculation as shown in Fig. 1. In order to obtain cavity detuning information

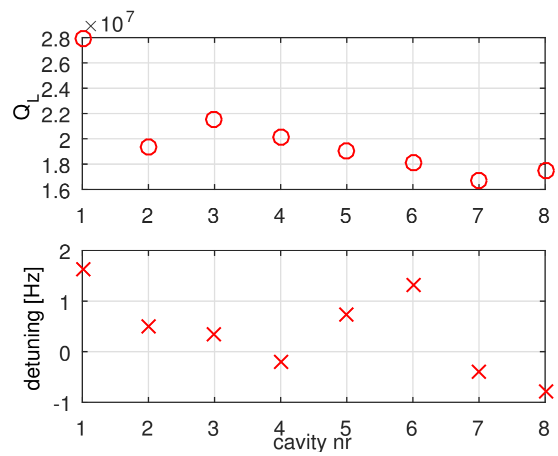

Figure 1: Loaded quality factor Q_L and detuning calculation for accelerating module operated in LP mode.

an electromechanical model of the RF resonator has been introduced [2]. The cavity tuning range has been confirmed using DC bias voltage scan applied to the cavity piezo tuner (see Fig. 2). During the DC bias voltage scan procedure the pendoromotive effects have been indicated and included as a correction coefficient for the cavity tuning algorithm (see Fig. 3). The microphonics noise has been recorded using piezo element configured as a mechanical vibration sensor. The spectrum analyses of the obtained data allowed assessment of dominant frequencies and as a result correct adjustment of the piezo feedback controller (see Fig. 4).

CAVITY RAMPING UP PROCEDURE

The cavity ramping up procedure has been implemented in order to allow LLRF system setup, calibration and adjustment to any conditions defined by the user. The procedure

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF052

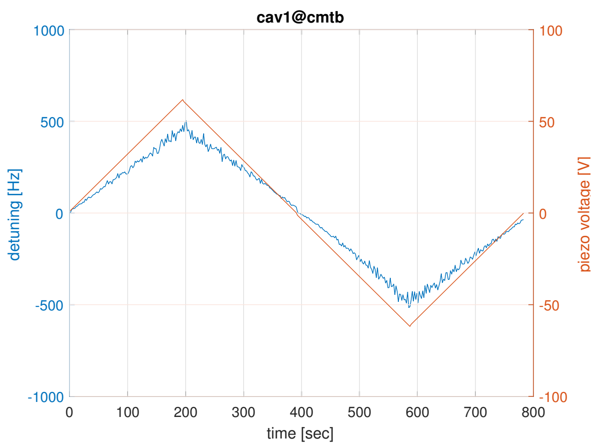

Figure 2: The DC bias voltage scan applied to the piezo tuner versus cavity detuning parameter. The piezo voltage range has been setup to ± 62V with a single step of 0.625 V.

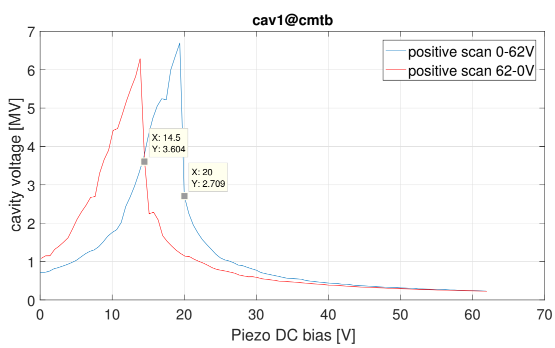

Figure 3: The cavity pendoromotive effects measurement for CW cavity operated at low gradient. The cavity voltage has been measured versus applied piezo DC bias voltage.

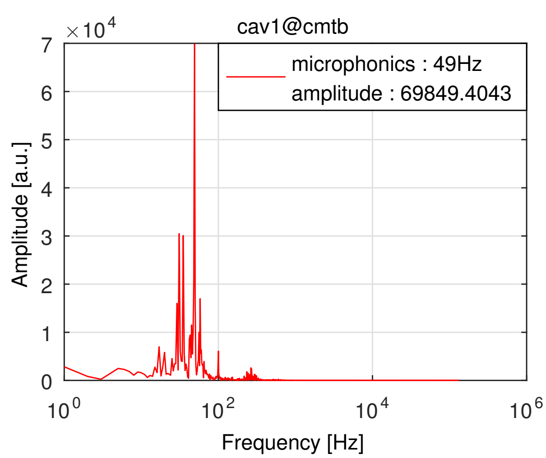

Figure 4: The microphonics noise spectrum analyses using piezo sensor data. The dominant 49 Hz frequency is a dominant disturbance identified by the measurement system.

assumes the RF cavity is pre-tuned below 1 kHz using slow frequency tuners based on stepper motors. The input parameters are the initial and target RF setpoints. Before starting a new ramping up procedure the feedback and feedforward controllers are deactivated. The following subsections are describing in details an each stage of the cavity trip approach.

Cavity Tuning with Piezos

The cavity tuning with piezos is predicted by an activation of the RF open loop controller to the initial setpoint value and long pulse operation (400 ms of the RF field duration). In order to tune the cavity as close as possible to the resonance frequency of order of 1.3 GHz the least mean square optimization (LMS) algorithm is introduced. It assumes epsilon criteria to be less than 0.5. If the criteria is not met the DC bias voltage applied to the piezo tuner is adjusted using Eq. 1:

$$DC_{bias}[n+1] = DC_{bias}[n] + \mu\varepsilon \qquad (1)$$

where μ means optimization speed and ε refers to the cavity detuning parameter. The example cavity tuning process is shown in Fig. 5.

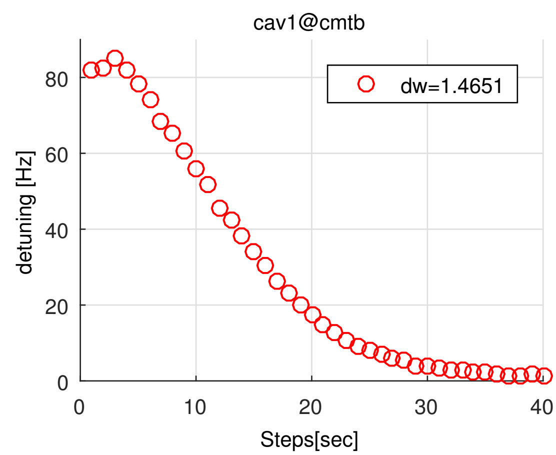

Figure 5: The cavity detuning measurement before and after tuning with piezos using LMS algorithm.

RF Phases Calibration

The forward power and cavity voltage phase rotation algorithm is applied after cavity tuning process in order to setup correctly piezo integration feedback controller. The piezo integration feedback controller assuming the cavity is on resonance when difference between forward and cavity voltage phase measurement is 0 degrees of the mean value. The cavity phase rotation is performed using amplitude and phase components of a complex representation of the RF vector field. The Eq. 2 is applied for the phase correction algorithm:

$$Phase_{corr}[n] = -\frac{1}{n}\sum_{i=1}^{n} Phase_{meas}[n] \qquad (2)$$

Piezo Feedbacks Operation

The piezo integration feedback controller is one of the most important stages of the cavity trip procedure. It tunes

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF052

the cavity to the exact resonance curve peak and try to compensate for any RF field changes. This fact allows increasing the RF setpoint value with relatively small steps and avoiding unexpected transmitted power drops that can be caused by the pendoromotive effects as shown Fig. 6. During the RF setpoint ramping process the standard deviation of the microphonics noise is measured and when reaching the threshold the active noise cancellation algorithm is applied (see Fig. 7) [3] .

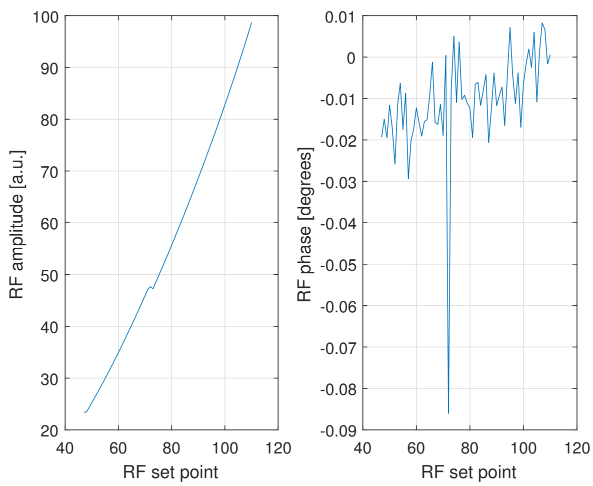

Figure 6: The RF setpoint iteration after piezo integration feedback activation.

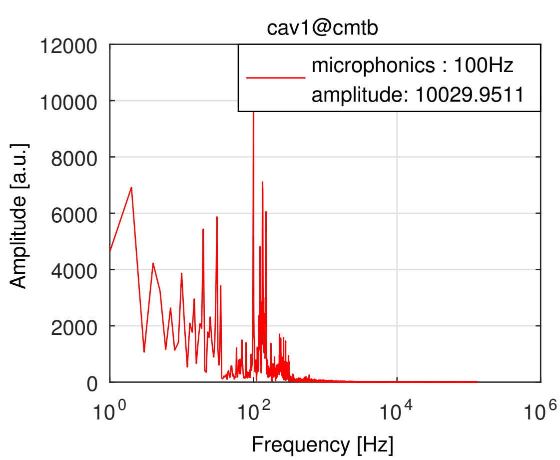

Figure 7: The RF oscillation dumping at frequency of 49 Hz.

RF AND PIEZO FEEDBACKS PERFORMANCE

The RF field stabilization performance has been measured for a single and 8 cavities operation after trip to the high gradient operation. For the single cavity operation the chosen cavity has been tuned to resonance frequency while the others have been detuned by tens of kHz. The single cavity setup performance is demonstrated in Fig. 8. The RF field

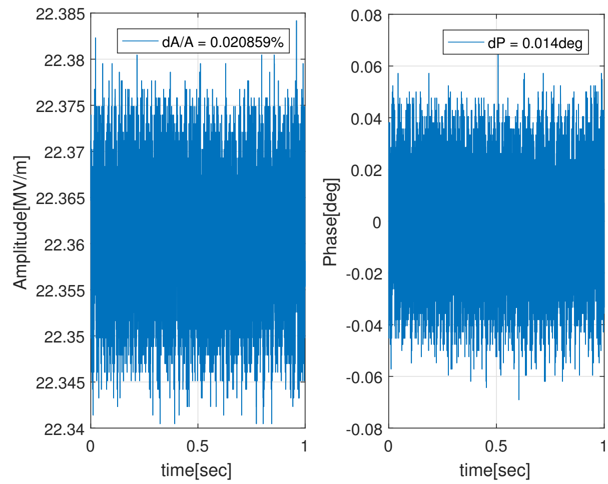

Figure 8: The RF and piezo feedbacks performance for a single cavity setup at CMTB.

stabilization for 8 cavities included in the global vector sum is depicted in Fig. 9.

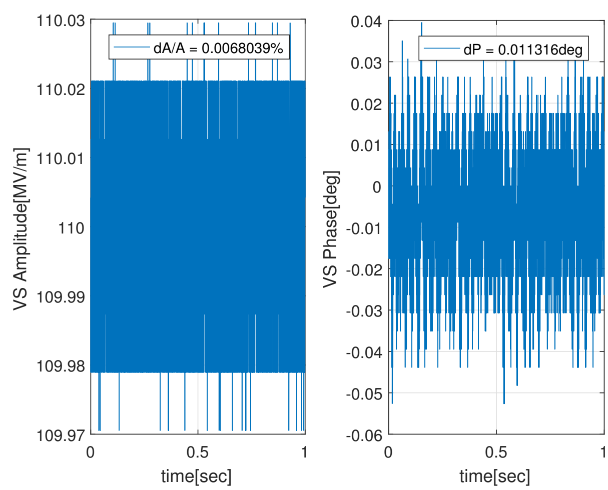

Figure 9: The RF and piezo feedbacks performance for a single accelerating module composed of 8 SC cavities operated in CW.

ACKNOWLEDGEMENT

We would like to express our gratitude to colleagues from the MSK LLRF team and other groups at DESY. Special thanks are also addressed to J. Branlard, A. Belland, W. Cichalewski, T. C. Guemues, D. Kostin, T. Kozak, W. Merz, R. Onken.

REFERENCES

[1] K. Przygoda *et al.*, in *Proc. IPAC'17*, pp. 3966–3968.

[2] R. Rybaniec *et al.*, in *Proc. IPAC'14*, pp. 2456–2458.

[3] R. Rybaniec *et al.*, in *Proc. RT2016*, pp.1382–1388.