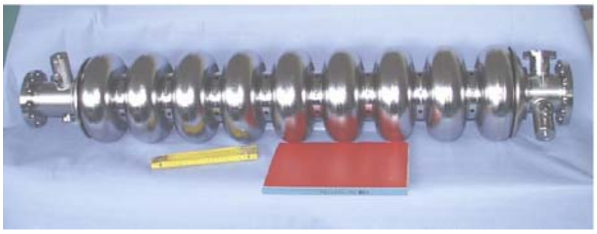
EU contract number RII3-CT-2003-506395 CARE Conf-04-027-SRF

SRF



Dynamic Lorentz Force Detuning Studies in TESLA Cavities

Valeri Ayvazyan, Stefan N. Simrock, *DESY*

Abstract

Dynamic detuning of the superconducting rf cavities due to Lorentz force induced mechanical excitation is a critical concern since the magnitude can approach the cavity bandwidth and require significant additional rf power for field control. In this paper, the influence of high accelerating fields on the resonance frequency in superconducting TESLA cavities is discussed. Cavities at the TESLA Test Facility have been operated at the design operating gradient close to 25 MV/m. It is shown that Lorentz force detuning constant factors are different for different cavities, significant spread have been observed.

Contribution to the conference EPAC 04, Lucerne, Switzerland

Work supported by the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395).

DYNAMIC LORENTZ FORCE DETUNING STUDIES IN TESLA CAVITIES

Valeri Ayvazyan, Stefan N. Simrock, DESY

Abstract

Dynamic detuning of the superconducting rf cavities due to Lorentz force induced mechanical excitation is a critical concern since the magnitude can approach the cavity bandwidth and require significant additional rf power for field control. In this paper, the influence of high accelerating fields on the resonance frequency in superconducting TESLA cavities is discussed. Cavities at the TESLA Test Facility [1] have been operated at the design operating gradient close to 25 MV/m. It is shown that Lorentz force detuning constant factors are different for different cavities, significant spread have been observed.

INTRODUCTION

The Lorentz force detuning in the pulsed superconducting cavities at the TESLA Test Facility (TTF) is of the order of the cavity bandwidth if operated at 25 MV/m. The additional rf power required to control the cavity fields is 25% and is proportional to the square of the detuning i.e. to the 4th power of the accelerating field.

$$\frac{P}{P_0} = 1 + 0.25 \cdot \left(\frac{\Delta f}{f_{12}}\right)^2 \text{ and } \Delta f = -K \cdot E_{acc}^2 \text{ i.e.}$$

$$\frac{\Delta P}{P} \approx K^2 E_{acc}^4$$

where P_0 is the power required for beam acceleration for matched conditions with design beam loading on resonance, f_{12} the cavity bandwidth, Δf the cavity detuning, K the Lorentz force detuning constant, and E_{acc} the field gradient. One should note that the Lorentz force detuning constant is usually defined for static detuning (steady state) while the dynamic detuning can be smaller (single pulse) or larger (resonant excitation). In the dynamic case an effective detuning for the whole pulse duration or only flattop portion (for single pulse or a given repetition rate) can be defined.

The additional power needed for control strongly depends on the Lorentz force detuning constant K. It is therefore important to measure the effective K factors during the flat-top and their spread for the cavities installed in the TTF linac. During cavity filling the rf control system can follow the cavity detuning (at least on average) so that only the flat-top portion of the cavity detuning is relevant for the additional control power needed. A typical illustration of gradient phase and cavity detuning as observed during closed loop operation is shown in Figure 1.

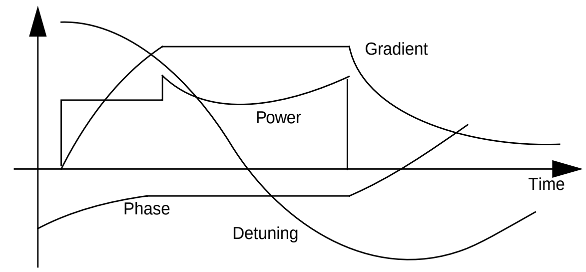


Figure 1: Time varying cavity parameters during rf pulse. The increased power during the flat top is due to the dynamic Lorentz force detuning.

MEASUREMENT OF LORENTZ FORCE DETUNING

The dynamic Lorentz force detuning during the rf pulse is measured at different gradients. The detuning at the end of the rf pulse is obtained from a measurement of the time varying phase $\phi(t)$ during the field decay immediately following the rf pulse. The slope $d\phi/dt = \Delta\omega$ is the instant detuning of the cavity. If the pulse length is shortened in small increments one obtains the time varying detuning which is highly repetitive from pulse to pulse.

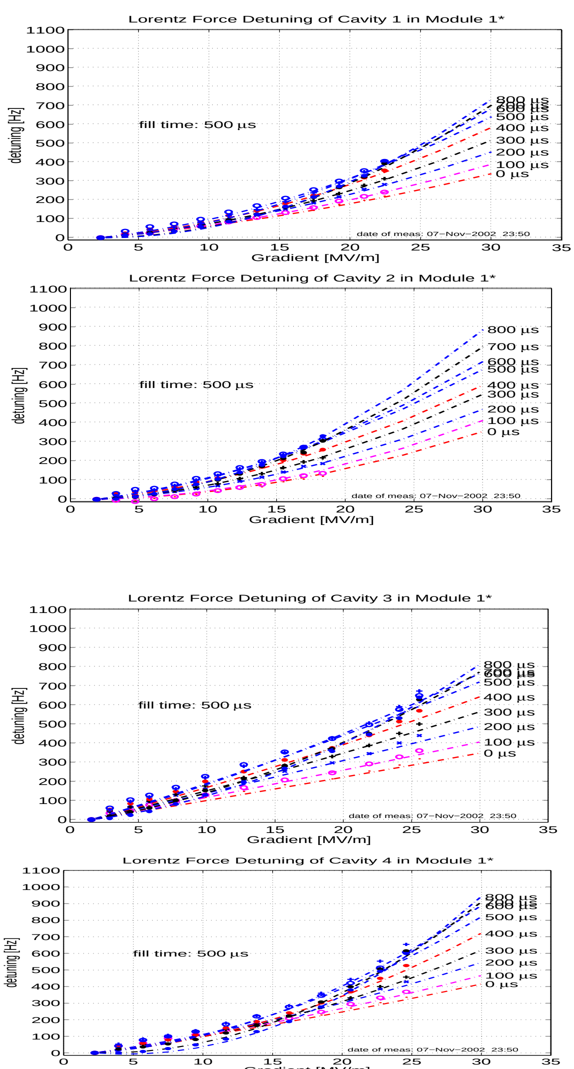
The results from the measurements for the cavities in cryo module 1 installed in location ACC2 (Module 1*) during the high gradient run from June 2002 to November 2002 are shown in Figures 2 a through 2h. The data shows the cavity detuning as a function of gradient for different times during the flat-top while operated at an repetition rate of 5 Hz. While the symbols reflect the actual measurement data, the curves are extrapolated to 30 MV/m using a second order polynomial.

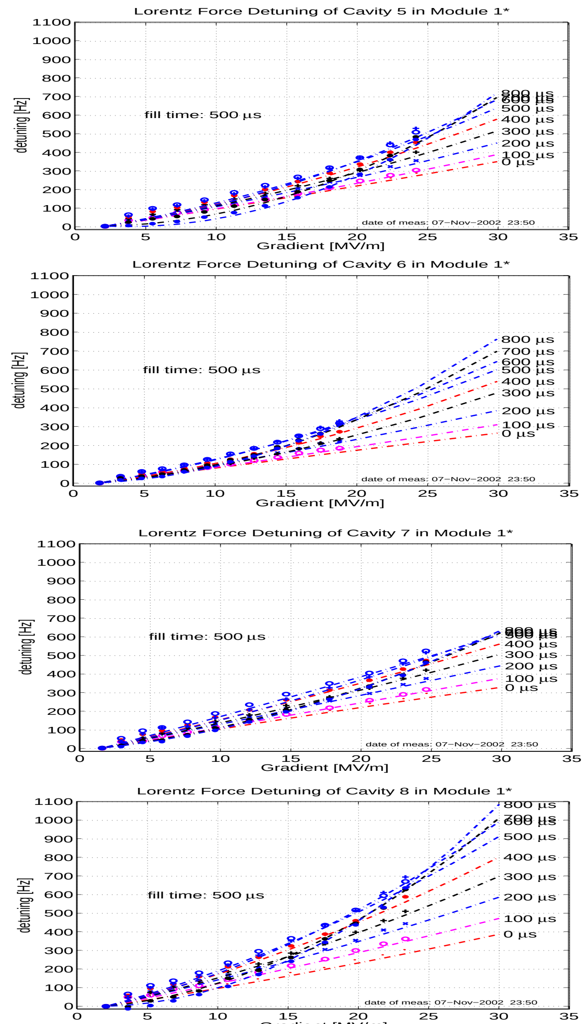
As expected the detuning scales with the square of the gradient. While a significant portion of Lorentz force detuning occurs during the cavity filling, the detuning during the flat-top dominates the rf power requirements. At 20 MV/m (XFEL), 25 MV/m (TESLA 500), and 35 MV/m (TESLA 800), the detuning during the flat-top ranges from +- 100 Hz to +-150 Hz (20 MV/m), +-150 Hz to +-200 Hz (25 MV/m), +-300 Hz to +-500 Hz (35MV/m). During the cavity filling the low level rf system can track the average change in detuning so that only the spread in the detuning results in additional power required for control. The additional power required for control of the cavities at 20, 25 and 35 MV/m ranges from 20% - 150%.

Table 1: Detuning and Power Requirements

	20MV/m	25MV/m	35MV/m
detuning flat-top [+-Hz]	70-130	100-200	300-400
detuning filling [+-Hz]	80-120	100-150	170-250
design detuning filling + flat-top [+-Hz][a]	130	625*2/3/ 2 = 200	400
add. power during flat-top [%]	3-10	5-22	45-83

a. based on K = 1 Hz/(MV/m)^2, 2/3 during 1.3ms rf pulse





Figures 2: Lorentz force detuning of TTF cavities in Module 1* at a gradient close to 25 MV/m.

The observed spread in Lorentz force detuning is about a factor of 2 (Figure 3). No conclusive explanation has yet been found for this spread but it could be a result in differences in mechanical dimensions of cavity and tuning frame, and/or stiffness of the niobium of different cavities.

Recently the Lorentz force detuning has been measured in cavity 5 at ACC1 (Figure 4) which is permanently installed in the VUV-FEL Facility. This cavity has reached 35 MV/m during many hours of operation and shows relatively small Lorentz force detuning of +-220 Hz during the flat-top (800 us) at 35 MV/m during 5 Hz operation. It is planned install a cryo module with 8 cavities operable at 35 MV/m in the VUV-FEL where better statistics on the spread of Lorentz force detuning at high gradients can be obtained.

The dynamic Lorentz force detuning can be compensated with a Piezoelectric tuner [2]. This compensation has been performed at a gradient of 35 MV/m during many hours of stable operation.

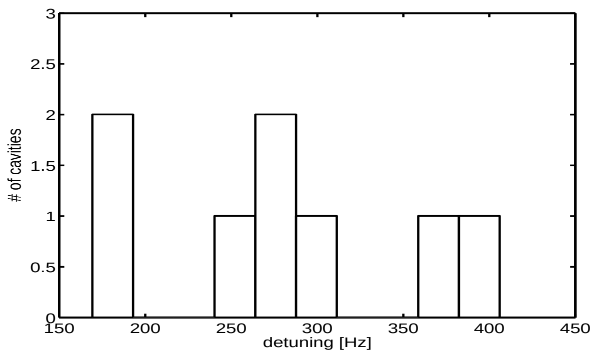


Figure 3: Spread of Lorentz force detuning (flat-top) of cavities in Module 1* at gradient 25 MV/m.

Also the coupling of Lorentz force detuning from a cavity to the adjacent cavities has been measured. While one cavity has been operated at 20 MV/m (around 400 Hz detuning during the pulse) the crosstalk has been determined to be less than 3 Hz.

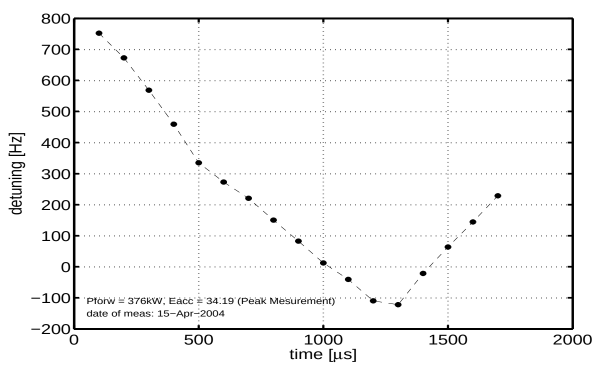


Figure 4: Lorentz force detuning of Cavity 5 (AC72) in VUV-FEL Facility at gradient close to 35 MV/m.

ISSUES FOR RF CONTROL

The design Lorentz force detuning is 1 Hz/(MV/m)^2. Due to the mechanical dynamics of the cavity only 2/3 are active during a single 1.3 ms pulse. Repetitive pulsing can lead to some degree to resonant enhancement mainly due to the excitation of the lowest mechanical mode at around 230 Hz (Q = 100). However when changing the repetition rate from 1 Hz to 5 Hz the change in detuning during the flat-top has been small. Typically the detuning during the flat-top at 25 MV/m is of the order of +-150 Hz resulting in addition power for control of 12%.

An adaptive feedforward scheme can be used to obtain the correction signal. The response of the detuning curve to a small step input which can be shifted in time in discrete steps can be determined and define a response matrix. This matrix can be inverted to determine the appropriate signal to the piezo actuator needed to compensate the Lorentz force detuning. Slow drifts in operating parameters require regular update of the feedforward settings.

If no countermeasures such as the active Lorentz force compensation with the piezo tuner are taken the result of the large spread in Lorentz force detuning could lead to excessive demands on rf power in particular when increasing the gradients to 35 MV/m. An additional effect of the spread in Lorentz force detuning are imbalances in the cavity field resulting in strong slopes of cavities relative to each other while the vector-sum is controlled to the required level of amplitude and phase stability[3].

The results of the operation of a high gradient cavity at 35 MV/m with beam and only +220 Hz of Lorentz force detuning are very promising and if reproducible may not require a piezo tuner.

CONCLUSION

The Lorentz force detuning has been measured for 8 cavities in one cryo module and a high gradient cavity in the first cryo module of the VUV-FEL. While a large spread of Lorentz force detuning has been measured in the cryo module (2 of the cavities showed very strong detuning), the high gradient cavity showed only moderate detuning at 35 MV/m.

No conclusions on the position dependence in the cryo module or the history of the cavity assembly could be drawn.

If the high gradient cryo module with 8 cavities (all above 35 MV/m) under construction show reproducible results, a piezotuner may not be necessary. It is however foreseen to install piezo tuner even for operation at lower gradients of 20.1 MV/m for the European XFEL to simplify operation and to be prepared for operation at higher repetition rates where resonant enhancement may play a role.

We want to express our thanks to Lutz Lilje for providing information about the piezo tuner set-up.

REFERENCES

[1] The Conceptual Design Report for the TESLA Test Facility, Edited by D.A. Edwards, DESY, Hamburg, 1995. http://tesla.desy.de/TTFReport/CDR/TTFcdrTab.html

[2] M. Liepe, W.-D. Moeller, S.N. Simrock, Dynamic Lorentz Force Compensation with a Fast Piezoelectric Tuner, Proc. PAC'01, Chicago, p.1074, 2001

[3] S.N. Simrock, I. Altmann, K. Rehlich, T. Schilcher, Design of the Digital RF Control System for the TESLA Test Facility, Proc. EPAC'96, Barcelona, Spain, p.349, 1996