

# DESIGN AND IMPLEMENTATION OF AUTOMATIC CAVITY RESONANCE FREQUENCY MEASUREMENT AND TUNING PROCEDURE FOR FLASH AND EUROPEAN XFEL CRYOGENIC MODULES

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## Abstract

The superconducting cavities in FLASH and European XFEL [1], [2] should be tuned to the operating frequency after cool down and reversed to initial frequency before warm up by stepper motor tuners. The initial frequency deviates by 300 kHz from the operating frequency of 1.3 GHz to remove mechanical hysteresis of the tuner. The cavities should be relaxed to the initial frequency to avoid the plastic deformation. In framework of digital low level RF (LLRF) and DOOCS control systems [3], [4] we have developed a simple automatic procedure for the remote resonant frequency measurement and simultaneous remote tuning for all cavities which are driven from the single klystron. The basic idea is based on frequency sweeping, both for driving klystron and for generation of local oscillator frequency with constant RF frequency from master oscillator. The developed system has been used during FLASH commissioning in spring 2010, is in use for cryogenic module test stand CMTB at DESY [5] and is planned for XFEL module test stand AMTF.

## INTRODUCTION

In the past finding the resonant frequency of the cavity at FLASH was done in the accelerator tunnel with a network analyzer. Repeated for each cavity individually this method is inconvenient and time consuming. A remote and parallel cavity resonant frequency determination method was needed. This paper describes a simple cavity resonant frequency measurement procedure using the standard infrastructure such as RF power distribution, klystrons, LLRF system and master oscillator. It is implemented in SIMCON-DSP board [3], the same which is used for LLRF control during regular operation. The idea is based on frequency sweeping, both for driving klystron and for generation of local oscillator frequency with constant RF frequency from master oscillator. The frequency sweeping was achieved by implementation of cordic algorithms in firmware on the SIMCON-DSP board. The realized solution allows frequency sweeping in range from  $-20$  MHz to  $+20$  MHz with step of  $\sim 100$  Hz. The cavity field can be detected at low klystron RF power level which makes the procedure safe for the test of warm cavities. In order to automate sweep procedure for a group of cavities driven by a single klystron DOOCS middle layer server has been developed.

The realized solution was tested at horizontal cryostat CHECHIA with a warm cavity, has been used during FLASH commissioning and is in use in cryogenic module test bench (CMTB) at DESY.

## MEASUREMENTS PROCEDURE

Cavity resonant frequency measurement conditions are shown in Table 1. Hardware and software set-up for measurement is presented in Fig.1.

Table 1: Measurement conditions

	Warm	Cold
Loaded quality factor	$10^4$	$3 \times 10^6$
Frequency range [MHz]	$1298.0 \pm 0.4$	$1300.0 \pm 0.4$
Frequency deviation from pulse to pulse [kHz]	10	0.5
Measurement points (pulses)	80	1600
Frequency sensitivity [kHz]	25	1

Frequency measurement is being done for:

- Cavity tuner test (cabling and software).
- Cavity operating mode spectrum measurements.
- Cavity tuning after the cool down.
- Setting the cavities initial frequencies before the warm up.

The LLRF control system is generally used with cold cavities at resonant frequency of 1.3 GHz. Advantages of the low level control with DOOCS system are parallel measurement with data store and remote control.

Warm cavities' resonant frequencies are about 2 MHz lower than 1.3 GHz ( $1298.0 \pm 0.4$  MHz). Cold cavities have the resonant frequency in the range of  $1300.0 \pm 0.4$  MHz.

A cavity has its maximum field on the resonant frequency. The control system measures the frequency for maximal response for each cavity and stores it after one frequency sweep.

The cavities' loaded quality factor  $Q_{load}$  changes from  $10^4$  (warm) to  $3 \times 10^6$  (cold). This implies the differences for cold and warm measurements.

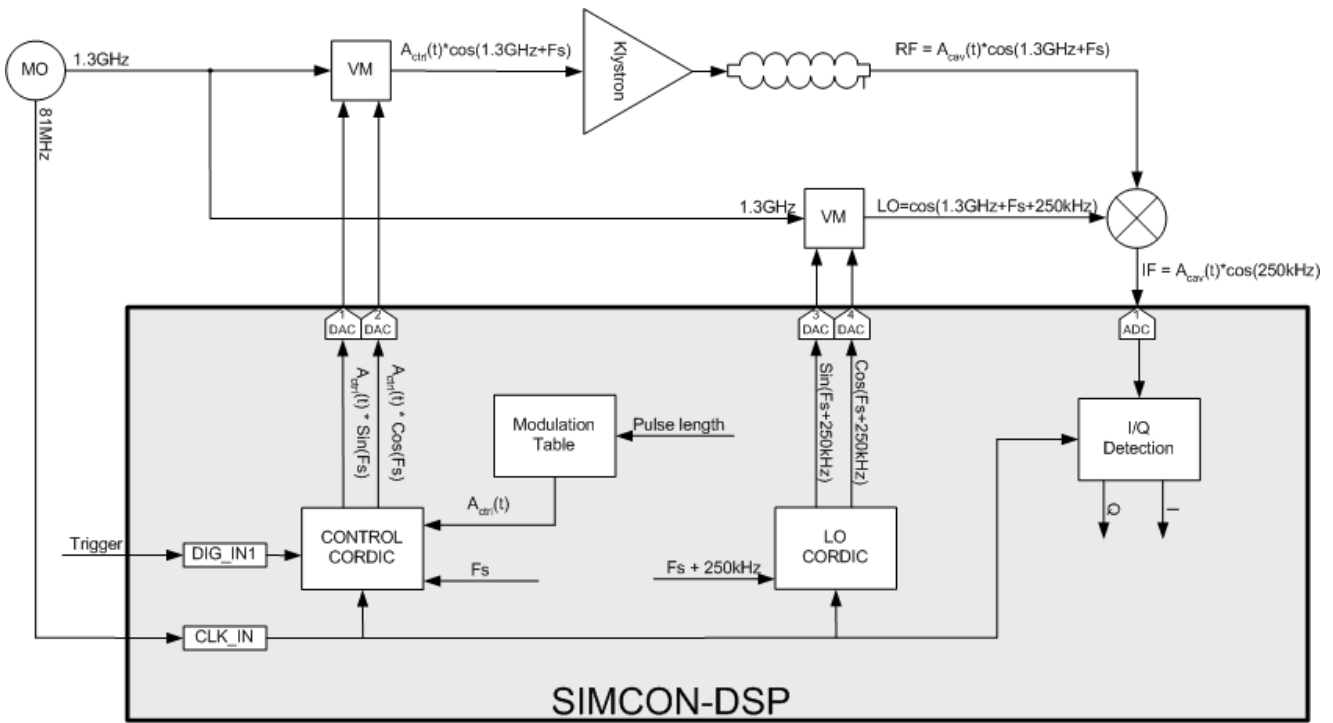


Figure 1: Measurement setup diagram.

To avoid the plastic deformation warm cavity frequency change should be less than 100 kHz. Therefore frequency sensitivity of 25 kHz is needed.

Sensitivity of the control system (noise level) is equivalent to the 0.05 MV/m cavity gradient. Warm cavities have  $10^6$  higher resistive losses compared to cold cavities and even a small field can warm the cavity inside the warm-isolated module.

Warm cavity losses  $P_{loss}$  are defined as:

$$P_{loss} = (E_{acc} \times L)^2 / Q / (R_{sh} / Q) = 250 \text{ W} \quad (1)$$

where  $L = 1.038\text{m}$  – length,  $E_{acc} = 0.05 \text{ MV/m}$  cavity gradient sensitivity,  $R_{sh} / Q = 1030 \text{ Ohm}$ ;  $Q = 10^4$ .

For a pulse duty factor  $T/t = 100$  average power is 2.5 W only for the cavity on the resonance. One sweep in range of 0.8 MHz is necessary for the frequency measurement of all cavities. Each cavity resonance crossing time is less than 1 s making the cavity warming insignificant.

6 kW of incident RF power is needed for the 0.05 MV/m cavity gradient:

$$P_{for} = P_{loss} \times (1 + \beta)^2 / 4 / \beta = 6 \text{ kW} \quad (2)$$

where:  $P_{loss} = 250 \text{ W}$  calculated using equation (1) and coupling coefficient  $\beta = Q_0 / Q_{ext} = 0.01$ .

## MEASUREMENT RESULTS

### Frequency sweeps at cavity test stand

The first test was done with a warm cavity in horizontal cryostat CHECHIA. Cavity frequency has been changed from pulse to pulse and the amplitude from the cavity probe was measured. The cavity probe had  $Q_{ext} = 2 \times 10^{11}$  and incident RF power level was 1 kW. Cavity was tuned

by  $-50 \text{ kHz}$  and  $-25 \text{ kHz}$  by the step motor tuner. The frequency measurement data was stored. The cavity response during frequency sweeps is shown in Fig.2.

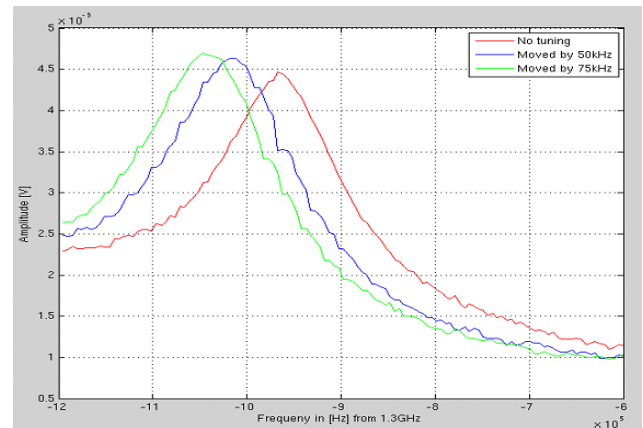


Figure 2: Resonant frequency measurement in the horizontal cryostat CHECHIA .

### Frequency sweeps at FLASH cryo-modules

The developed procedure has been used for FLASH accelerating modules commissioning in spring 2010. In only a few shifts seven cryo-modules were commissioned. Several hardware errors like wrong cable connections, mirrored frequencies (i.e. wrong sign) with respect to 1.3GHz, motor sensitivity issues, etc were found and fixed. As an example, the results of cavity resonant frequency measurement in the accelerating module 6 (ACC6 at FLASH) before and after cavity tuning are presented in Fig.3.

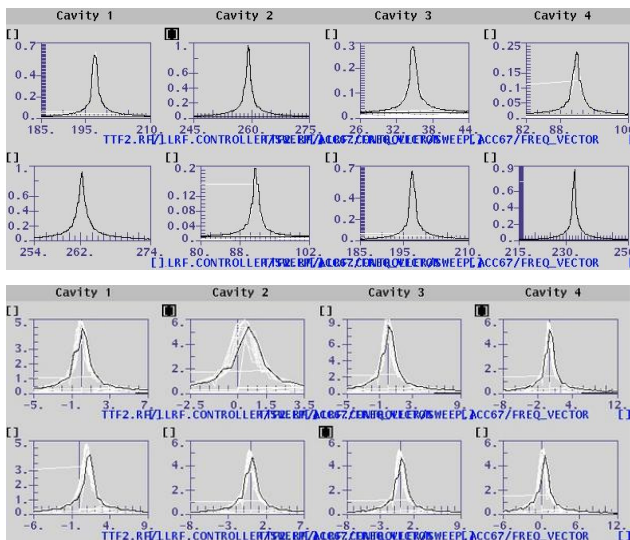


Figure 3: Resonant frequency measurement before and after cavity tuning in accelerating module 6 in FLASH. Frequency  $f = 1300\text{MHz} + \Delta f$ ,  $\Delta f[\text{kHz}]$ .

*Frequency sweeps at CMTB*

The cavities’ resonant frequencies on-line measurements were done with XFEL prototype module PXFEL3 on CMTB [5], see Fig.4. Warm cavity spectra data was being used for cavity operating mode electrical field distribution change detection with cavity mechanical deformation. The data was successfully taken with warm and cold module. Cavity resonant frequency change during the module cool down was measured and documented, see Fig.5. Cavities’ initial tuning to 1.3 GHz was done using the frequency scan data of the cold module. This fully remote controlled measurement eliminated the need of local cavity connections for the network analyzer. Furthermore, all 8 cavities were measured and tuned in parallel. In order to prove the procedure local frequency measurement was done yielding the same data.

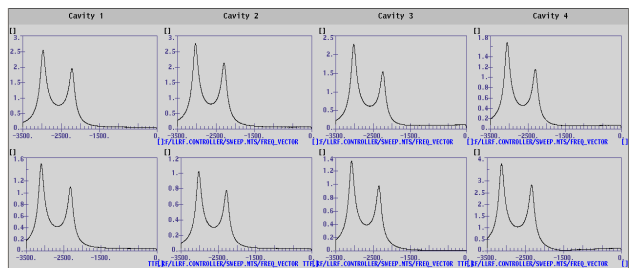


Figure 4: Frequency sweep at CMTB:  $8/9\pi$  and  $\pi$  modes. Frequency  $f = 1300\text{MHz} + \Delta f$ ,  $\Delta f [\text{kHz}]$ .

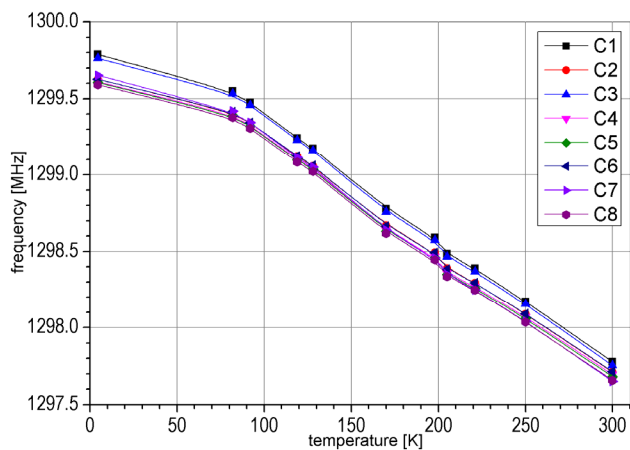


Figure 5: CMTB superconducting RF accelerating module cavities’  $\pi$ -mode frequency vs. temperature.

**SUMMARY**

The automated procedure for cavity resonant frequency measurement and tuning for large scale machines like European XFEL and ILC was developed. Automated and parallel frequency scan of many cavities has speed up the FLASH commissioning. This procedure provides a safe solution for frequency measurement in warm cavities: measurements with a low gradient are possible (below 10 kW of incident RF power). No need for standard hardware and software modifications for the sweeping procedure.

**REFERENCES**

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