CAVITY TILT MEASUREMENT IN A 1.3 GHz SUPERCONDUCTING CRYO-MODULE AT FLASH

J. H. Wei[1,2], N. Baboi[2], T. Hellert[3]
[1] University of Science and Technology of China, Hefei, P. R. China
[2] Deutsches Elektronen-Synchrotron, Hamburg, Germany
[3] Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Abstract

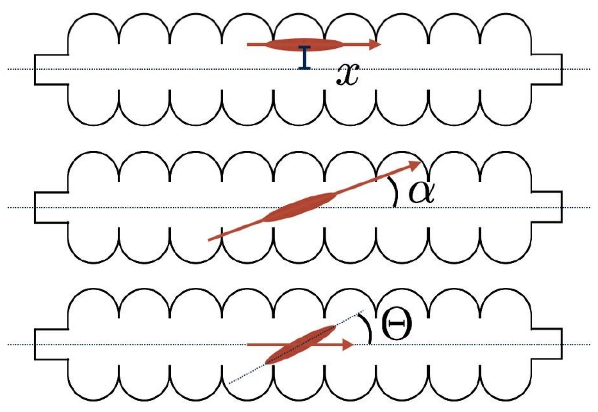
TESLA superconducting (SC) cavities are used for the acceleration of electron bunches at FLASH. The Higher Order Modes (HOMs) excited by the beam in these cavities may cause emittance growth. The misalignment of the cavities in a cryo-module is one of the essential factors which enhance the coupling of the HOMs to the beam. The cavity offset and tilt are the two most relevant misalignments. These can be measured by help of dipole modes, based on their linear dependence on the beam offset. The cavity offset has been measured before in several modules at FLASH. However, the cavity tilt has so far proved to be difficult to be measured, because the angular dependence of the dipole mode is much weaker. By carefully targeting the beam through the middle of a cavity, the strong offset contribution to the dipole fields could be reduced. Careful data analysis based on a fitting method enabled us then to extract the information on the cavity tilt. This measurement has been implemented in the cavities in one cryo-module at FLASH. First results of the ongoing measurements from several are presented in this paper. It is for the first time that the cavity tilt in several cavities has been measured.

Measurement Principle

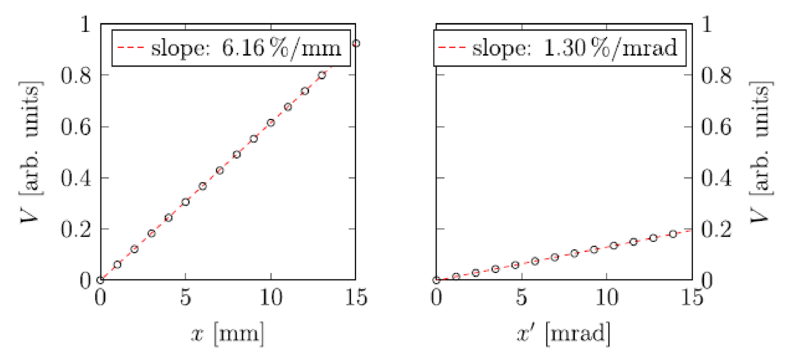
— Dipole Mode Excitation

- There are three scenarios of a bunch traveling through a cavity:
  - (a) $V_x(t) \propto x \cdot e^{-(t/2\tau)} \sin(\omega t)$,
  - (b) $V_\alpha(t) \propto \alpha \cdot e^{-(t/2\tau)} \cos(\omega t)$,
  - (c) $V_\Theta(t) \propto -\Theta \cdot e^{-(t/2\tau)} \cos(\omega t)$,
- For short bunches, as is the case at FLASH, signals from bunch tilt are vanishingly small.
- A sum of contributions from the beam offset and trajectory tilt

$$V_{\text{dipole}} = \sqrt{V_x^2 + V_\alpha^2} = \sqrt{(a(x - x_0))^2 + (b(x' - x_0'))^2}.$$



— Simulation

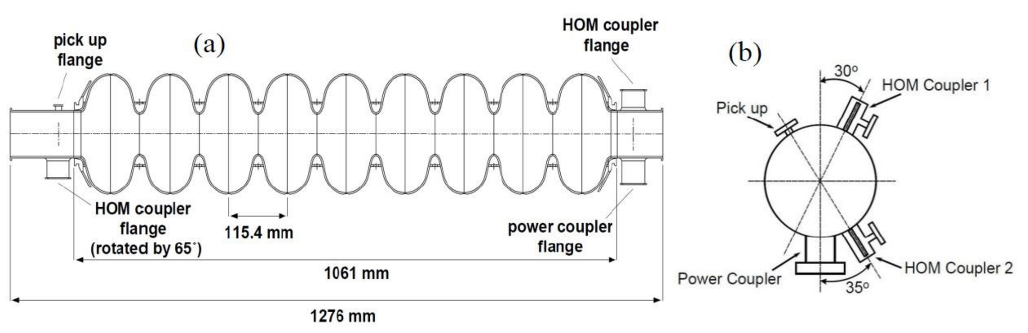


- An amplitude excited by a tilt angle of $x'_0 = 1$ mrad corresponds to an amplitude excited by a trajectory offset of x_0 =214 μm.

Thorsten Hellert, *et al.*, **Phys.Rev.Accel.Beams 20 (2017), 123501.**

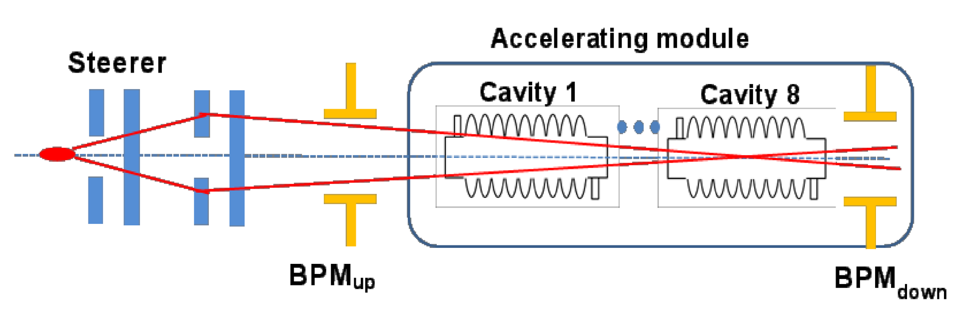
Measurement Setup

— TESLA Cavity



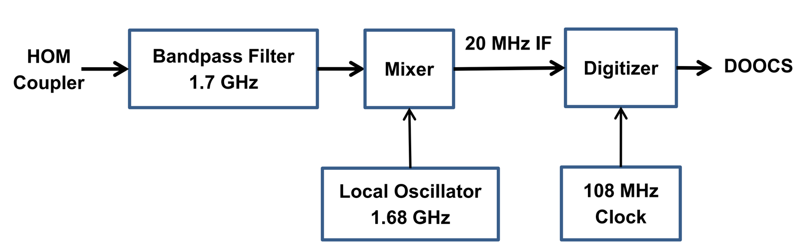
- 9-cell TESLA cavity
- One input power coupler
- One field probe
- Two HOM couplers

— Experiment Setup



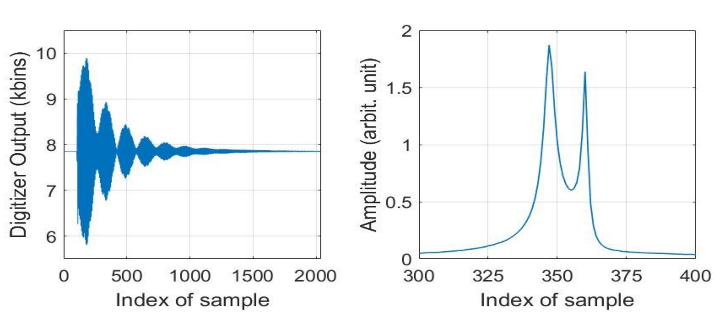
- Two pairs of steerers
- Two BPMs
- Eight cavities in a cryo-module
- Drift space

— Electronics



- The data acquisition system filters the HOM signal at 1.7 GHz with a 20 MHz narrow bandpass and down-mixes to 20 MHz intermediate frequency, which is then sampled at about 108 MHz by the ADC.

Reference: J. Frisch, et al., "Electronics and Algorithms for HOM Based Beam Diagnostics", 2006



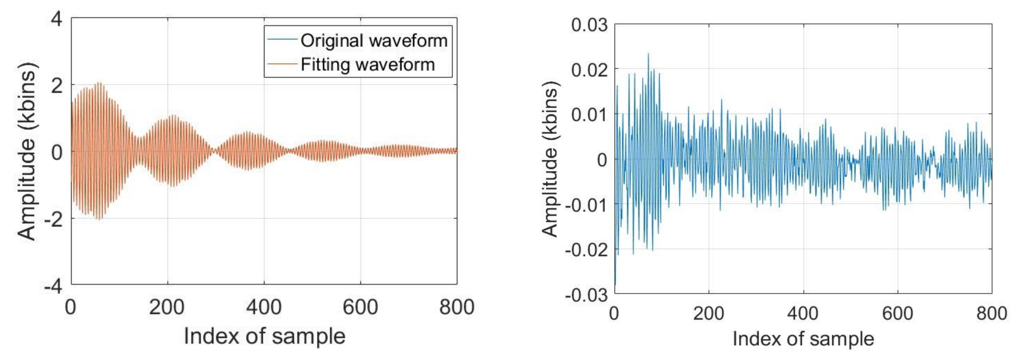
- The two peaks in the spectrum correspond to the two polarizations of the dipole mode.

Signal Fitting

— Function

$$A = a_0 + a_1 \sin(\omega_1 t + \varphi_1) e^{-\frac{t}{\tau_1}} + a_2 \sin(\omega_2 t + \varphi_2) e^{-\frac{t}{\tau_2}}$$

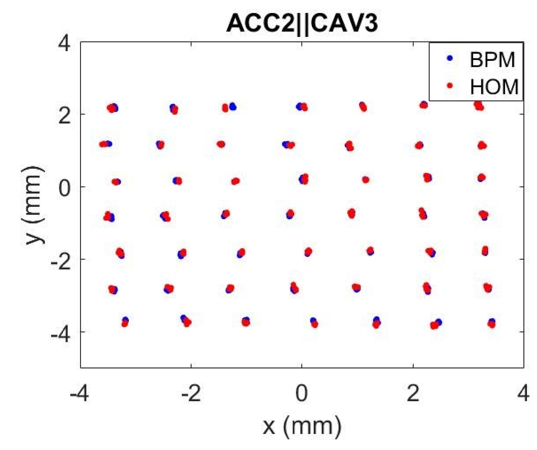
— Fitting Waveform



- R^2 over 0.99
- RMS: 9 bins
- SNR: 80 dB

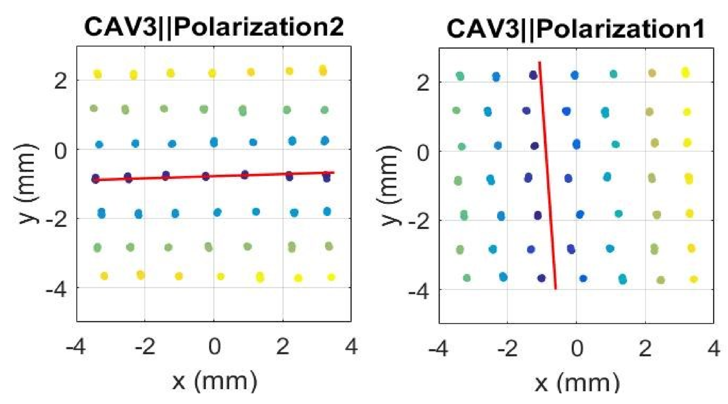
Cavity tilt measurement

— Beam offset calibration



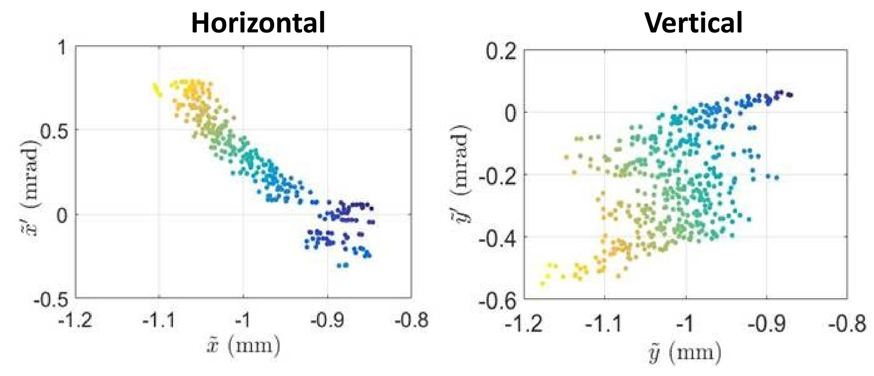
- RMS error: 0.05 mm in *x* and 0.06 mm in *y*.
- Center offset: (0.83,-0.80) mm.
- Scaling factor: 0.65 kbins/mm in *x* and 0.27 kbins/mm in *y*.

— Polarization axes

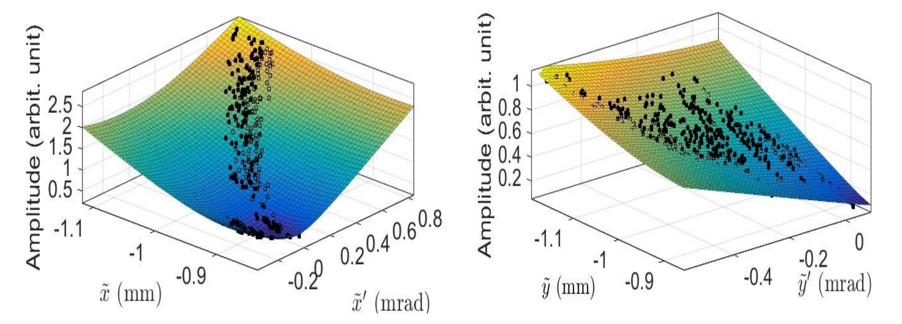


- Skew angle of the polairzation axes: 1.7° for $\tilde{x}$-axis and 94.1° for $\tilde{y}$-axis with respect to the horizontal plane.

— Cavity tilt



- Scaling factor: 0.65 kbins/mm in *x* and 0.27 kbins/mm in *y*
- the ratio between the tilt and offset dependence of the dipole mode is about 1 mrad:0.3 mm.



- Cavity tilt in two polarization axes with respect to the cavity axis

Cavity	Polarization $\tilde{x}$	Polarization $\tilde{y}$
#3	-0.056 mrad	0.190 mrad
#6	0.082 mrad	0.654 mrad
#7	0.118 mrad	0.194 mrad

Summary

- In addition to the beam offset, a tilt of beam trajectory can also excite dipole modes.
- Base on the signal fitting method, the amplitude of the dipole mode can be obtained.
- The cavity tilt measurement has been made in a whole module (ACC2) at FLASH. The cavity tilt in two polarization axes has been measured in several cavities.
- An amplitude excited by a tilt of $\tilde{x}'$= 1 mrad corresponds to a trajectory offset of about $\tilde{x}$ = 0.3 mm.

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