



# **SRF HOM Beam Diagnostics**

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# Aim



#### > HOM-based beam diagnostics for the European XFEL

- Beam phase (wrt RF) and position
- In 3.9 GHz and 1.3 GHz cavities



#### > Benefits

- Reduction in emittance dilution from transverse wakefields via centering beam in accelerating cavities
- Direct, on-line measurement of beam phase wrt RF phase

Monitor beam excited monopole HOM and fundamental mode from klystron, leaking through HOM-coupler

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- Signals are available through the same cable
- Signal from klystron and beam are easy to separate



# HOM Beam Position Monitoring (HOMBPM)

- Dipole modes are the main component of potentially damaging wakefields
  - Their amplitude is proportional to the exciting beam offset
- Idea : Monitor dipole modes from existing HOMcouplers in SC cavities
  - Align beam on cavity axis and thus reduce excited wakefields
  - Measure beam position
  - Measure cavity alignment in cryo-module
  - Choose mode(s) with high R/Q
     More representative for wakefields
     Stronger signal, i.e. better resolution



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# Previous Experience with 1.3 GHz Cavities (FLASH)

#### > SLAC, CEA, DESY

- > HOMBPM-electronics installed in 40 cavities in FLASH
  - Use 1 dipole mode at 1.7 GHz
  - Used as operator tool for beam alignment
  - Used for measurement of cavity alignment
  - Demonstrated use as BPM 10 µm rms resolution

#### > Difficulty

 Instability of calibration into BPM-signals (phase or frequency drifts?) → EuCARD<sup>2</sup>





#### EuCARD, Task 10.5: UROS, UMAN, DESY, FNAL

- Considerably more challenging than 1.3 GHz cavities, mostly due to 4-cavity coupling
- ➤ EuCARD → Studies (simulations and measurements) of feasibility of HOMBPMs in 3.9 GHz cavities and defined the specs for the electronics
  - ⇒ Use bands of modes instead of single modes
  - Coupling modes around 5.4 GHz for high resolution (~ 20 μm rms)
  - Trapped modes around 9 GHz for localized measurement
- > HOMBPM-electronics for FLASH now built at FNAL
- > Difficulty
  - Instability of calibration into BPM-signals observed (same problem as for 1.3 GHz cavities?) → EuCARD<sup>2</sup>

# **Candidate HOMs in 3.9 GHz Cavities**



# EUCARD

#### > Significantly more challenging

- 8 coupled cavities cf. 4
- higher bunch frequency (4.5 MHz beam repetition rate cf 1 MHz)
- Different orientation of cavities in module



#### > Demands significant theoretical and experimental studies $\rightarrow$ EuCARD<sup>2</sup>

- Careful experimental characterization of each cavity and full module
- Simulations of full 8-cavity module Cascading methods Full module simulation

Challenging to simulate the entire 3.9GHz chain @ XFEL\* directly

Alternatively, structure can be decomposed in terms of cavities, HOM couplers, bellows etc:



> Based on a model order reduction technique (MOR) compact models of each individual segment reflecting its RF properties are created:

$$\frac{\partial}{\partial t}\mathbf{x}_r(t) = \mathbf{A}_r \,\mathbf{x}_r(t) + \mathbf{B}_r \,\mathbf{i}_r(t) \qquad \mathbf{v}_r(t) = \mathbf{C}_r \,\mathbf{x}_r(t)$$

\*Figure courtesy of E. Vogel

Concatenation of the compact models based on the topology of the module...

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...results in a compact model of the entire chain:

$$\frac{\partial}{\partial t}\mathbf{x}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{i}(t) \quad \mathbf{v}(t) = \mathbf{C}\mathbf{x}(t)$$

Based on this reduced model a variety of multi-cavity properties is conveniently computable, such as eigenmodes, R/Q factors, external Q factors, S-parameters and transient beam excitations.



# **Modes in Presence of Geometrical Errors**

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Perturbed Geometry

- > Application of perturbative methods for eigenmode computations
  - Aim: <u>Efficient</u> eigenmode computation (parameter studies)
  - Common solvers: Full computation necessary for every geometry variation

 $\rightarrow$ Computationally expensive and inefficient

- Solution: Perturbative methods
  - Full eigenmode computation solely for one (unperturbed) geometry necessary
  - Derive eigenmodes of a varied (perturbed) geometry from these unperturbed eigenmodes

#### → Significant reduction of computational effort



Slide Courtesy of Korinna Brackebusch / University of Rostock

## **Participants in Task 12.4**





#### > Deliverable:

M48: Report on characterisation of HOMs in XFEL cryomodules

#### > Milestones

 M24: Completed characterisation of HOMs in the 8-cavity XFEL 3HC module (Activity Report)

- M24: Cold S21 measurements on XFEL modules performed (Activity Report)
- M36: Beam-based measurements on XFEL modules performed (Activity Report)
- M36: Completed coupled cavity simulations of 8-cavity module (Activity Report)
- M45: Design of electronics for XFEL HOM diagnostics (Activity Report)

# Status and Plans for HOM-based Beam Position Monitoring (HOMBPM)



# Status and Plans for HOM-phase Beam Phase Monitoring



	FLASH	European XFEL
1.3 GHz Cavities	<ul> <li>Proof-Of-Principle made (SLAC/CEA/DESY)</li> <li>Electronics under design (same as for XFEL HOMBPM, WUT/DESY)</li> <li>EuCARD<sup>2</sup>: experimental studies</li> </ul>	- Same as for FLASH
3.9 GHz Cavities	<ul> <li>So far no isolated monopole mode identified, which could be used for phase monitoring</li> <li>Theoretical (and experimental) studies (lower priority in EuCARD<sup>2</sup>)</li> </ul>	- Same as for FLASH

# **Summary and Conclusion**



- > Get more from existing accelerator components
  - Aim at improving beam quality and stability with small addition to the XFEL (no new vacuum component)

Based on previous experience (including EuCARD), but new challenges

- Impact on other SC accelerators
  - ASTA facility at FNAL
  - KEK-STF
  - ILC etc.