HOM CHARACTERIZATION FOR BEAM DIAGNOSTICS AT THE E-XFEL INJECTOR.

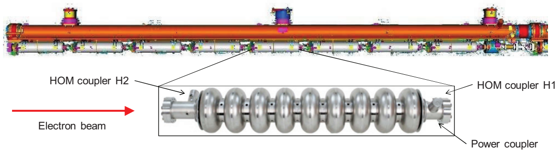
N. Baboi#1, T. Hellert[1,2], R.M. Jones[3,4], N. Joshi[3,4], L. Shi[1,3] and T. Wamsat[1]
[1]DESY, Hamburg, Germany; [2]The University of Hamburg, Germany;
[3]The University of Manchester, U.K.; [4]Cockcroft Institute, Daresbury, UK

Abstract

Higher Order Modes (HOM) excited by bunched electron beams in accelerating cavities carry information about the beam position and phase. This principle is used at the FLASH facility, at DESY, for beam position monitoring in 1.3 and 3.9 GHz cavities. Dipole modes, which depend on the beam offset, are used. Similar monitors are now under design for the European XFEL. In addition to beam position, the beam phase with respect to the accelerating RF will be monitored using monopole modes from the first higher order monopole band. The HOM signals are available from two couplers installed on each cavity. Their monitoring will allow the on-line tracking of the phase stability over time, and we anticipate that it will improve the stability of the facility. As part of the monitor designing, the HOM spectra in the cavities of the 1.3 and 3.9 GHz cryo-modules installed in the European XFEL injector have been measured. This paper will present their dependence on the beam position. The variation in the modal distribution from cavity to cavity will be discussed. Based on the results, initial phase measurements based on a fast oscilloscope have been made.

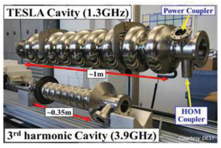
Superconducting cryo-modules

8 cavities are built into one cryo-module



SC Cavities in the European XFEL

Two types of cavities:
- TESLA cavity: 1.3 GHz
- 3rd harmonic cavity: 3.9 GHz



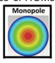
Each cavity has 9 cells. RF power is input through the power coupler, while the HOM power generated by the beam is extracted through 2 special couplers mounted in the beam pipes at either end.
8 cavities are mounted in one cryo-module

Higher Order Modes (HOM)

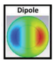
HOMs are electromagnetic resonant fields excited by electron bunches when passing accelerating structures. They depend on the beam properties, therefore they can be used for beam diagnostics.

There are various types of HOMs:

> Monopole modes: azimuthal Symmetry



> Dipole modes: two azimuthal nodes



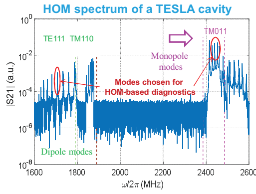
Dipole Modes

Their amplitude varies linearly with the transverse beam position and charge:

$$\sim q \cdot r \cdot (R/Q)$$

where q = bunch charge, r = bunch offset and R/Q indicates the interaction strength between the bunch and the mode.
Therefore dipole modes can be used for beam position monitoring.
For each dipole mode there are 2 polarizations, i.e. two modes orthogonal to each other. One of them responds e.g. to horizontal beam movement, the other to vertical.

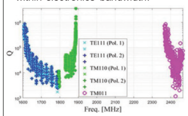
HOM spectrum of a TESLA cavity

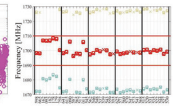


HOM spectra

First 5 TESLA (1.3 GHz) modules

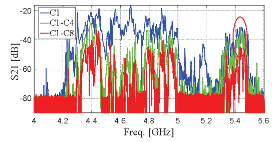
Transmission spectra (S21) were measured for each 1.3 GHz cavity during RF tests. (data taken from cavity database)
Modes with high R/Q have Q below 10^5, as required by beam dynamics.
Several cavities have modes shifted to higher frequency, but still within electronics bandwidth.





3.9 GHz cavities

Most modes propagate in the whole 8-cavity module.
- Band around 5.46 GHz chosen for module related beam monitoring
- Band around 9.06 GHz chosen for localized monitoring



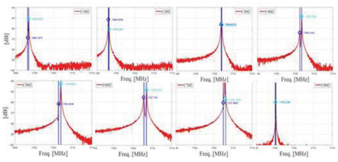
Beam spectra for 1.3 GHz cavities in E-XFEL injector

Spectra were measured with Tektronix RSA6114A for each cavity around the frequencies of interest for HOM-based diagnostics

Dipole mode at ca. 1.7 GHz

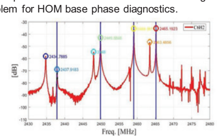
- Two polarizations of the mode can often be identified
- Very narrow split for some cavities.

(vertical line are mode frequencies from transmission measurements)



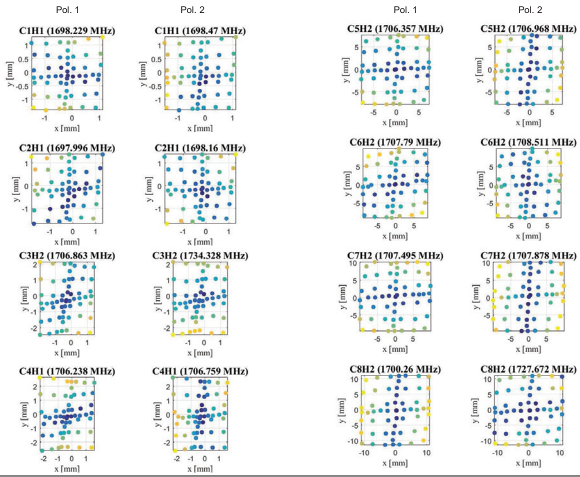
Monopole modes around 2.4 GHz

To be used for beam phase measurement.
Vertical lines: expected modes from transmission measurements
Additional peaks were found to be modes from neighboring cavities.
No problem for HOM base phase diagnostics.



HOM spectra vs. beam offset

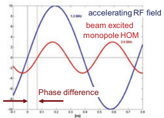
Mode polarization varies from cavity to cavity.
Complex data analysis for beam position monitoring



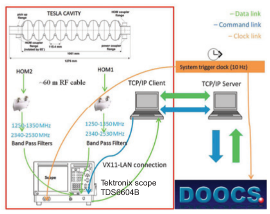
HOM-based beam phase monitoring

Principle

Measure RF signal and beam excited signal

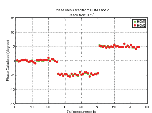


Experimental setup



Can trace RF phase change of -5deg and +5deg

Resolution obtained with this experimental setup: **0.12deg** (obtained by comparing results from both couplers)



The European XFEL

Max. energy [GeV]	17.5
Bunch charge [nC]	0.02 - 1
Max. bunch frequency [MHz]	4.5
Max. bunch number / pulse	2700
Pulse repetition frequency [Hz]	10
Max. pulse length [mm]	600

Summary

In preparation for the HOM-based diagnostics now under design for the E-XFEL, we analysed the HOM spectra in the first five 1.3 GHz modules and the 3.9 GHz module. The selected modes are within the bandwidth of the electronics. For the monopole modes one could also observe peaks from the neighbouring cavities, which do not constitute a problem for the phase monitoring.
The dependence of the dipole spectra on the beam position was analysed. There is a variation from cavity to cavity in the polarization rotation, which makes a complex signal processing necessary.
Further measurements are planned after the start of beam operation of the entire E-XFEL linac, and when the prototype electronics is available for beam tests.

Acknowledgments

We thank the E-XFEL shift crew for the help during the beam measurements. Special thanks are addressed to Alexey Sulimov for the fruitful discussions.

The work is part of EuCARD-2, partly funded by the European Commission, GA 312453

WEPG03, IBIC2016, Barcelona

European XFEL
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG
The Cockcroft Institute of Accelerator Science and Technology
MANCHESTER 1824 The University of Manchester
EuCARD²