HOM-based Cavity Alignment Measurement at FLASH

Thorsten Hellert, FEL-Seminar, 30.08.2016
motivation

dipole mode characteristics

experimental setup

data evaluation

outlook
motivation

multi bunch orbit spread

- orbit for 400 bunches
- average over 92 pulses

data: user run with 400 bunches @ 28.01.15
motivation

multi bunch orbit spread

> orbit variations > 1kHz
  - no iron magnets
  - no vibrations
  - GUN
  - RF modules
  - non closed dispersion
  - wakefields, resonances ...

> difficulties
  - unknown sources
  - small number of BPMs
  - insufficient model

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motivation

multi bunch orbit spread

- orbit variations > 1kHz
  - no iron magnets
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  ...(?)

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  - unknown sources
  - small number of BPMs
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> data: user run with 400 bunches @ 28.01.15
motivation

multi bunch orbit spread

data: user run with 400 bunches @ 28.01.15
gradient in MeV/m

time in µs

- vector sum

- Q₁ ≠ Q₂
- beam loading effects
- detuning of cavities
- ...

motivation

RF dynamics
- Vector sum

- \( Q_1 \neq Q_2 \)
- Beam loading effects
- Detuning of cavities
- ...
- Cavity misalignment
- Vector sum

- Gradient in MeV/m

- Time in µs

- Q_1 \neq Q_2
- Beam loading effects
- Detuning of cavities
- ...
- Cavity misalignment

> k_i \neq k_j
- 8 cavities within one module
- cryogenic string
- thermal contraction
- no direct measurement

> beam based diagnostics
  > multi-bunch
- 8 cavities within one module
- cryogenic string
- thermal contraction
- no direct measurement

> beam based diagnostics
  > multi-bunch
  > HOM
Magnetic Field

Electric Field

Beam

basics
dipole modes

\[ V_x(t) \propto x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) \]

\[ V_\alpha(t) \propto \alpha \cdot e^{-\frac{t}{2\tau}} \cos(\omega t) \]

\[ V_\Theta(t) \propto \Theta \cdot e^{-\frac{t}{2\tau}} \cos(\omega t) \]

\[ V_x(t) \propto x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) \]
\[ V_\alpha(t) \propto \alpha \cdot e^{-\frac{t}{2\tau}} \cos(\omega t) \]
\[ V_\Theta(t) \approx 0 \]

> ultra short pulses

Basics

Experimental setup: FLASH

BPM3GUN

BPM9ACC1

1.3

1.3

z in m

cavity n

upstream

downstream
experimental setup: FLASH

BPM3GUN

upstream

cavity n

downstream

BPM9ACC1

1.3

13.4

z in m

amplitude in AU

ω/2π in MHz

TE111
TM110
TM011

basics

measured by L. Shi
BPM3GUN \rightarrow \text{cavity n} \rightarrow \text{BPM9ACC1}

1.3 \quad 13.4 \quad z \text{ in m}

Bandpass Filter 1.7GHz \rightarrow \text{Mixer} \rightarrow \text{Digitizer} \rightarrow \text{amplitude vs time}

local oscillator 1.68GHz \rightarrow 108MHz clock

experimental setup: FLASH
BPM3GUN upstream cavity n downstream BPM9ACC1

1.3 z in m 13.4

Bandpass Filter 1.7GHz
Mixer
Digitizer

local oscillator 1.68GHz
108MHz clock

experimental setup: FLASH

amplitude

basics
experimental setup: FLASH

BPM3GUN

BPM9ACC1

cavity n

BPM3GUN

BPM9ACC1

cavity n

Bandpass Filter 1.7GHz

Mixer

Digitizer

108MHz clock

local oscillator 1.68GHz

amplitude

time

z in m

1.3

13.4
- charge threshold
- electronic artifact
- transient signal
- signal saturation

The diagram shows a raw signal with a digitizer output in 10^3 bits as a function of the index of the sample.
signal processing basics

- charge threshold
- electronic artifact
- transient signal
- signal saturation

Ɣ final signal
data evaluation
data evaluation

- interpolate beam trajectory

- vary beam trajectory
- read BPM values
- drift space

beam position at cavity
data evaluation

- interpolate beam trajectory
  - vary beam trajectory
  - read BPM values
  - drift space

beam position at cavity

steerer limits

lost charge

phase-jump of Cav. BPM

cavity 2

cavity n

x in mm

y in mm

z in mm

z0
zn
zf
\[ P_{out,x} = \frac{\omega^2}{4Q_{ext}} \left[ \frac{R}{Q} \right] \frac{x^2}{x_0^2} q^2 \exp \left( -\frac{\omega^2 \sigma_z^2}{c^2} \right) \]
\[ P_{out,x} = \frac{\omega^2}{4Q_{ext}} \left[ \frac{R}{Q} \right] \frac{x^2}{x_0^2} q^2 \exp \left( -\frac{\omega^2 \sigma_z^2}{c^2} \right) \]
\[ \tilde{x} = x \cos \phi + y \sin \phi \]
\[ \tilde{y} = y \cos \phi - x \sin \phi \]

\[ f (\tilde{x}, \tilde{y}) = A_x (\tilde{x} - \tilde{x}_0)^2 + A_y (\tilde{y} - \tilde{y}_0)^2 + c \]

\[
\arg \min_{\tilde{x}_0, \tilde{y}_0, \phi} \left( \sum_i f (\tilde{x}_i, \tilde{y}_i) - P_i \right)
\]
\[ P_{\text{out},x} = \frac{\omega^2}{4Q_{\text{ext}}} \left[ \frac{R}{Q} \right]_0 \frac{x^2}{x_0^2} q^2 \exp \left( -\frac{\omega^2 \sigma_z^2}{c^2} \right) \]

- assume \( \langle P(x',y') \rangle = \text{const.} \)
- sort \( P \) by \((x,y)\)
- fit 2D parabola

> cavity x-y-center
data evaluation

\[ P_{out,x'} = \frac{\omega^2}{4Q_{ext}} \left[ \frac{R}{Q} \right]_0 \frac{x'^2}{x_0^2} q^2 \exp \left( -\frac{\omega^2 \sigma_z^2}{c^2} \right) \]

- assume \( <P(x,y)> = \text{const.} \)
- sort \( P \) by \( (x',y') \)
- fit 2D parabola

> cavity \( x'-y'-\text{center} \)
\[ V_x(t) \propto x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) \]

\[ V_\alpha(t) \propto \alpha \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) \]
data evaluation

aligned

expected results
Data evaluation and expected results:

**Aligned**

- Diagram with a straight line indicating alignment.
- Graphs showing a consistent pattern at the origin (x=0) and a shifted pattern (x'=0) along the axis.

**Offset + Angle**

- Diagram with a line tilted at an angle, indicating a shifted and rotated pattern.
- Graphs showing a consistent pattern at the origin (x=0) and a shifted pattern (x'=0) along the axis, but tilted.

This visualization helps in understanding the impact of alignment versus offset and angle on data patterns.
data evaluation

aligned

offset + angle

offset

expected results
data evaluation

aligned

offset + angle

offset

offset + angle

expected results

offset

offset + angle

offset + angle
data evaluation

measurement results

horizontal offset

horizontal rotation

residual

residual

x in mm

x' in μrad

x in μm

x' in μrad

index of cavity

index of cavity
data evaluation

measurement results

vertical offset

vertical rotation

residual

residual
Data evaluation

Stretched wire system

- measurement till 2004
- results within TDR limits

> not reproducible!
data evaluation

stretched wire system

HOM (peak):
cavities x: +/- 0.25 mm
y: +/- < 0.6 mm

overall module tilt ≈ 0.1 mrad

measurement till 2004
results within TDR limits

not reproducible!

https://labcit.ligo.caltech.edu/~BCBAct/PDF%20files/ITRP_Weise_TTF.pdf
HOM (peak):
cavities  x: +/-  0.25 mm
y: +/-  < 0.6  mm
overall module tilt ≈ 0.1 mrad

wire (peak):
cavities  x: +/-  0.35 mm
y: +/-  0.25 mm
overall module tilt ≈ 0.1 mrad
• assume $\langle P(x',y') \rangle = \text{const.}$
• sort $P$ by $(x,y)$
• fit 2D parabola

> cavity x-y-center

\[
V_x(t) = A_x \Delta x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) + A_{x'} \Delta x' \cdot e^{-\frac{t}{2\tau}} \cos(\omega t) + c
\]
\[
V_y(t) = A_y \Delta y \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) + A_{y'} \Delta y' \cdot e^{-\frac{t}{2\tau}} \cos(\omega t) + c
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- measurement & data evaluation scripts developed
- experimental experience gained

> data unreliable(?)
conclusion

- measurement & data evaluation scripts developed
- experimental experience gained

> data unreliable(?)

next steps:
- HOM shifts in octobre 2016
- focus on uncorrelated beam trajectories
- get reliable data

> realign GUN section(?)
conclusion

- measurement & data evaluation scripts developed
- experimental experience gained

> data unreliable(?)

> thanks for your attention!

next steps:
- HOM shift at octobre, 17th
- focus on uncorrelated beam trajectories
- get reliable data

> move GUN section