Simulations on multi bunch dynamics at FLASH with different damping of the HOM at 3,9GHz cavities (With RF Focussing!)

Evgenij Kot

XFEL beam dynamics meeting, 24.09.07

Problem description

- The 3rd harm cavity is planned to be installed in order to provide better bunch qualities.
- HOM could affect the transverse MB dynamics of the bunches thus causing an additional MB emittance.
- HOM are planned to be suppressed by the HOM couplers with an average damping factor of 10^{-5}
- The question in this context: how strong should be the damping of the HOM of the 3,9GHz cavities to provide the suitable multi bunch dynamics (i.e $\varepsilon_{MB} << \varepsilon_{SB}$) and to verify if it is a possible option to use the 3,9GHz cavities without HOM couplers.
- *New:* investigate the problem with RF focussing.
- *New:* investigate the dependence of the mb instabilities on the cavity offset rms.

Background

- HOM of the 3,9GHz cavities: described in

  „*A Design of a 3rd Harmonic Cavity for the TTF 2 Photoinjector*“ J. Sekutowicz, R. Wanzenberg

  „*Higher Order Modes of a 3rd Harmonic Cavity with an Increased End-cup Iris*“ T. Khabibouline, N. Solyak, R. Wanzenberg
- HOM of the 1,3GHz cavities:

  „*Monopole, Dipole and Quadrupole Passbands of the TESLA 9-cell Cavity*“ R. Wanzenberg
- Passage between cavities:

  „Matlab Functions for Calculations of the Linear Beam Optics of FLASH Linac“ V. Balandin, N. Golubeva.

Main Formulas of the Model

Wake fields:

$$W_{\parallel}^{(m)}(s) = -\sum_n \omega_n \left(\frac{R^{(m)}}{Q}\right)_n \cos\left(\omega_n \cdot s/c\right) \exp\left(-1/\tau_n \cdot s/c\right)$$

$$W_{\perp}^{(m)}(s) = c\sum_n \left(\frac{R^{(m)}}{Q}\right)_n \sin\left(\omega_n \cdot s/c\right) \exp\left(-1/\tau_n \cdot s/c\right)$$

Energy deviation due to wake fields:

$$\Delta E\left(s_j\right) = -eq\sum_{i<j} W_{\parallel}^{(0)}\left(s_j - s_i\right) - eq\sum_{i<j}\left(x_j x_i + y_j y_i\right) W_{\parallel}^{(1)} + \ldots$$

Transverse kick due to wake fields:

$$\vec{\theta}_j = \frac{eq}{E_j}\sum_{i<j}\left(x_i \vec{e}_x + y_i \vec{e}_y\right) W_{\perp}^{(1)}\left(s_j - s_i\right)$$

Damping of the HOM: $\tau_n \rightarrow dampingfactor \cdot \tau_{n0}$

Assumptions

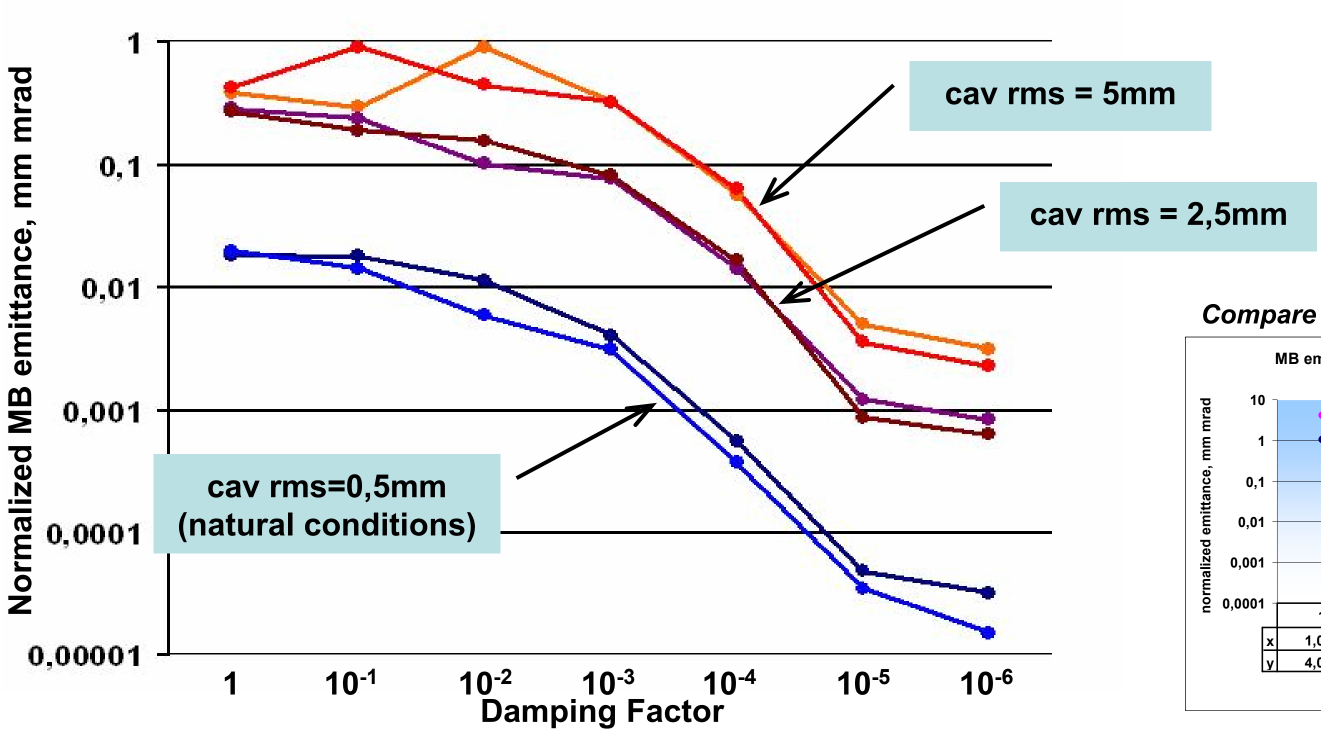
- Simulation region: from the quadrupole Q9ACC1 at 13,5827m (right after the ACC1) to the entrance into the Undulator 1 at 203,3288m (Q22SEED)
- Supposed place for the 3,9GHz cavities: between V10ACC1 at 14,0177m and 1UBC2 at 19,235m.
- Amount of 3,9GHz cavities: 4 cavities with 9 cells each.
- HOM of the 1,3GHz cavities are damped by the order of 10^{-5}
- Decouple single bunch effects from MB effects
- All monopole and dipole modes from the first four passbands for both cavities (1,3GHz and 3,9GHz) have been taken into account.
- Inject bunches on crest ideally i.e. without slope divergence and without transverse offsets.

Parameters for Simulations

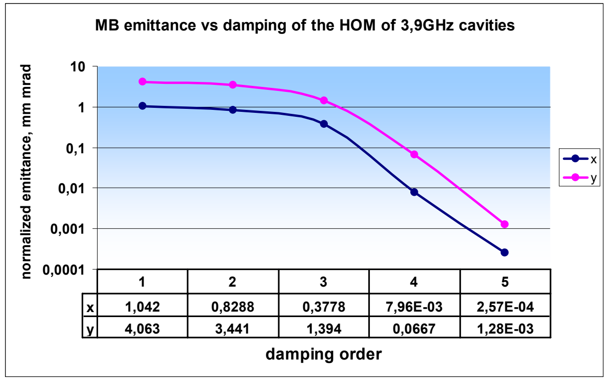
bunch charge	**1nC**
pulse length	**120μm**
bunch spacing	**200ns**
number of bunches per train	**600**
cavity misalignment	**0,5-5,0 mm rms**
cavity detuning	**0,1% rms**
normalized SB emittance	**1,4mm mrad**

- 50 linacs have been simulated and averaged for each measurement.

Simulation Results: Normalized Emittance



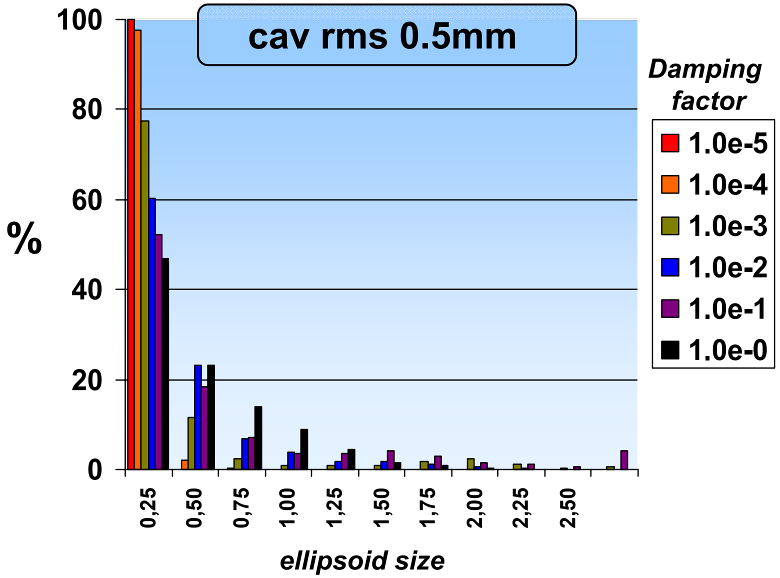
Compare with results without rf focussing:



hor. plane	cavity offset rms		
damping	0.5	2.5	5.0
1.0	1.8353e-2	0.1360	0.9586
10^{-1}	1.7976e-2	0,2386	0,9268
10^{-2}	1.1371e-2	0,2322	0,9008
10^{-3}	4.1112e-3	7.6286e-2	0.3215
10^{-4}	5.6219e-4	1.444e-2	5.6808e-2
10^{-5}	4.915e-5	1.2288e-3	4.915e-3
10^{-6}	3.2715e-5	8,3355e-4	3.1724e-3

vert. plane	cavity offset rms		
damping	0.5	2.5	5.0
1.0	1.9673e-2	0.2696	0.6570
10^{-1}	1.4251e-2	0,1911	0.8951
10^{-2}	5.9802e-3	0.1550	0,4513
10^{-3}	3.1020e-3	8.189e-2	0.3256
10^{-4}	3.7526e-4	1.6491e-2	6.3105e-2
10^{-5}	3.554e-5	8.885e-4	3.501e-3
10^{-6}	1.5427e-5	6,2714e-4	2.2523e-3

Bunch Distributions for Different Scenarios - I



	<0.25σ	0.25-1.00σ	>1.00σ
10^{-5}	100	0	0
10^{-4}	97.6	2.4	0
10^{-3}	77.4	14.7	7.9
10^{-2}	60.2	33.7	6.1
10^{-1}	52.3	29.3	18.4
1.0	46.9	46.0	7.1

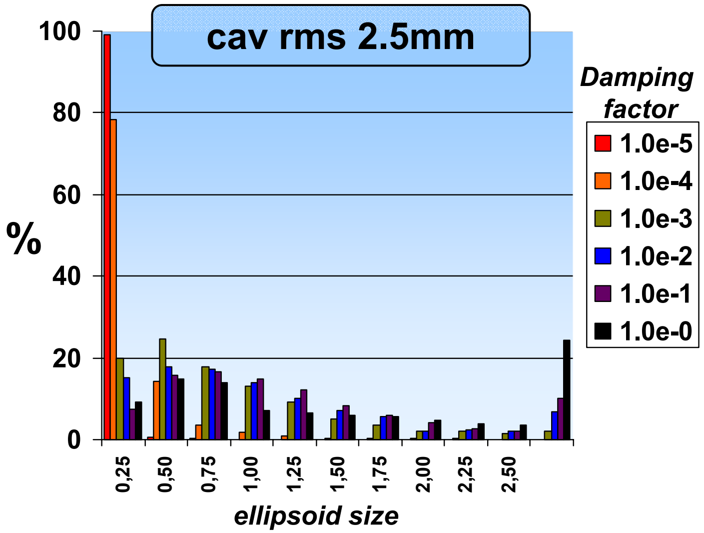
Single bunch normalized emittance of 1.4mm mrad assumed.

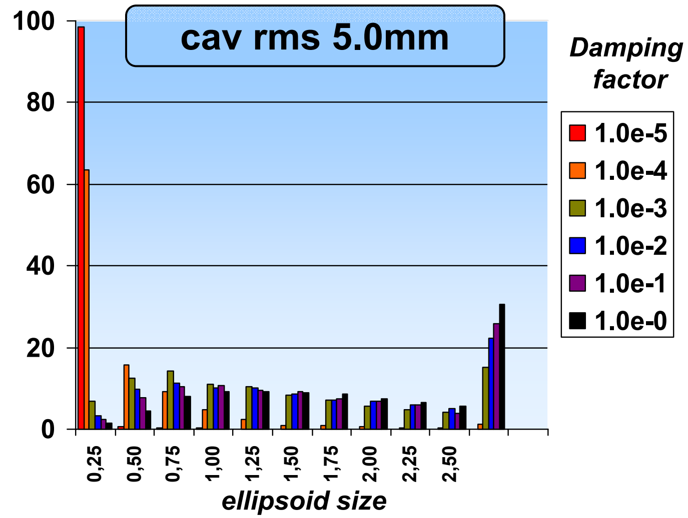
According to

$$d_i = \frac{x_i - \langle x \rangle}{\sqrt{\varepsilon_x^{SB} \cdot \beta_x}} + \frac{x_i' - \langle x' \rangle}{\sqrt{\varepsilon_x^{SB} \cdot \gamma_x}} + \frac{y_i - \langle y \rangle}{\sqrt{\varepsilon_y^{SB} \cdot \beta_y}} + \frac{y_i' - \langle y' \rangle}{\sqrt{\varepsilon_y^{SB} \cdot \gamma_y}}$$

the percentage of bunches has been calculated, which are confined in the ellipsoids of different sizes around the average point $(\langle x \rangle, \langle x' \rangle, \langle y \rangle, \langle y' \rangle)$

Bunch Distributions for Different Scenarios - II





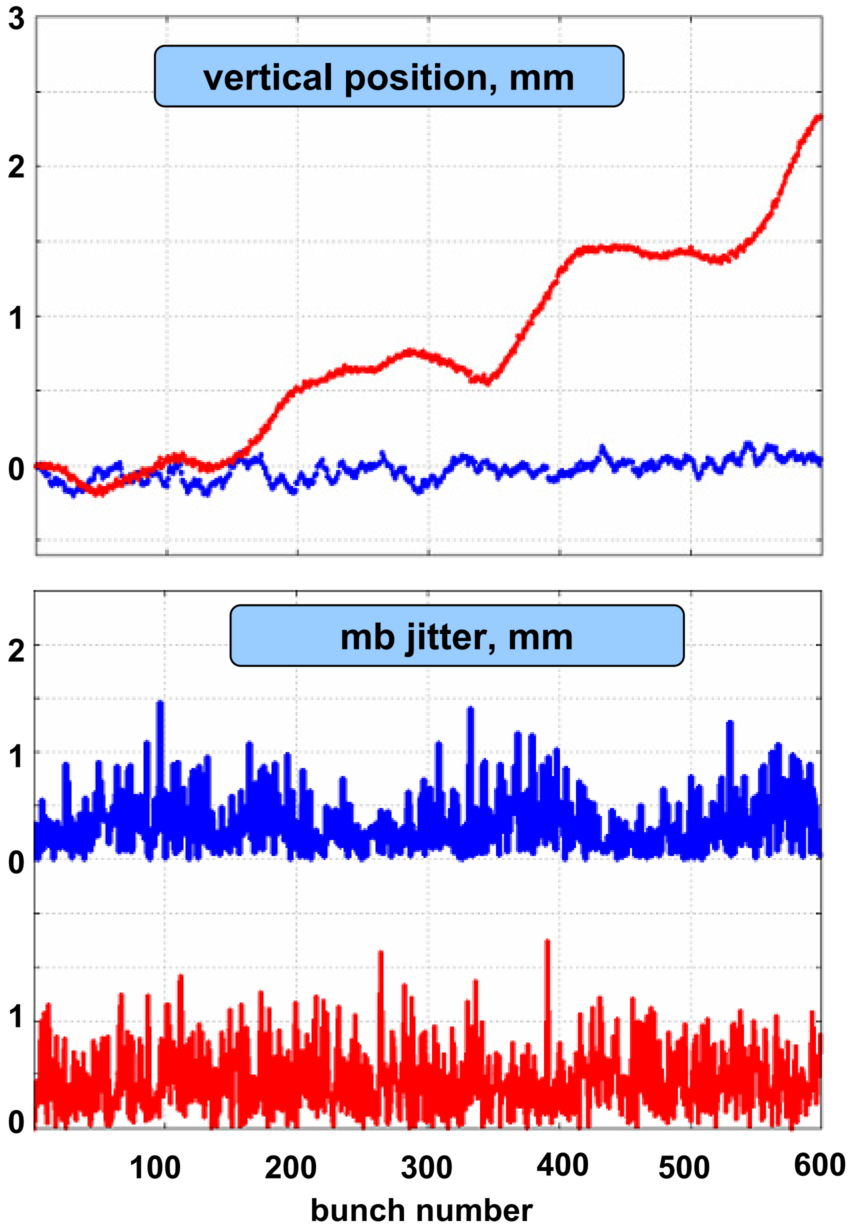
	<0.25σ	0.25-1.00σ	>1.00σ
10^{-5}	99.1	0.9	0
10^{-4}	78.4	19.5	2.1
10^{-3}	19.9	55.3	24.8
10^{-2}	15.2	48.8	36.0
10^{-1}	7.4	47.3	45.3
1.0	9.1	36.1	54.8

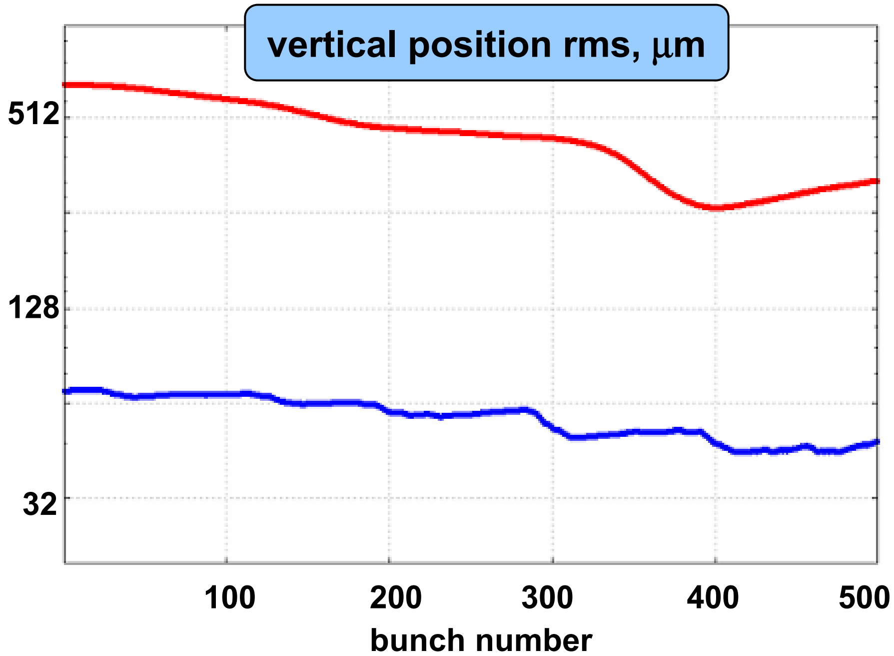
	<0.25σ	0.25-1.00σ	>1.00σ
10^{-5}	98.5	1.2	0.3
10^{-4}	63.4	29.6	7.0
10^{-3}	6.8	37.7	55.5
10^{-2}	3.1	31.1	65.8
10^{-1}	2.5	28.9	68.6
1.0	1.5	21.8	76.7

Two Kinds of Linacs

- Cavity offset rms = 2.5mm
- Cavity detuning rms = 0.1%rms
- Cavity damping factor = 10^{-2}

- Most Linacs show the normal behaviour (blue).
- In cases of damping factor 1.0-10^{-3} sometimes an instability occurs.
- Affects the statistics a lot!
- No instable Linacs have been observed for damping factor 10^{-4} – 10^{-5}





Conclusions

- MB emittance blow up of up to 200% is possible if the 3rd harmonic cavities are operated without HOM couplers.
- Damping of the HOM by 10^{-4}-10^{-5} required for the stable operating conditions with negligible mb effects. Since HOM couplers provide the damping of 10^{-5} no problems about mb dynamics are expected in this case.