Numerical calculations of the microwave threshold in the MAX IV 3 GeV ring

Galina Skripka

September 30, 2015

MAX-lab Internal Note 20150930

1 Motivation

Simulations of collective effects in the MAX IV 3 GeV ring were done with the tracking code *mbtrack* [1]. The code is a 6D macroparticle tracking code performing transformations under the influence of various wakefields. Each bunch is presented by a number of macroparticles which are sorted into bins according to their longitudinal position. The discrepancy in the results for the microwave instability was noticed depending on binning and number of particles. This report summarizes the studies of the microwave instability threshold dependence on binning and number of particles, and converged 'true' threshold value is obtained.

2 Bunch profile depending on the effect of geometric impedance and harmonic cavity (HC)

Depending on number of bins and different effects included in the tracking the bunch shape evolves differently from turn to turn.

Tracking was performed with and without the geometric impedance as well as with and without the HC. Fig. 1 shows the evolution of bunch profile under the effect of HC simulated as providing optimal bunch lengthening, i.e. flat potential condition [2], for the corresponding currents. The expected effect is obtained: we can see the optimal 'flat top' bunch at 2.84 mA current. The tracking was done for 50000 turns with no geometric impedance included.

The following tracking was performed with geometric impedance included without the HC. In Fig. 2 we can see bunch evolution affected by the geometric impedance Z_{geom}: the bunch is lengthened due to the reactive part of impedance (potential well distortion takes place) and leans to the front due to resistive part of the impedance.

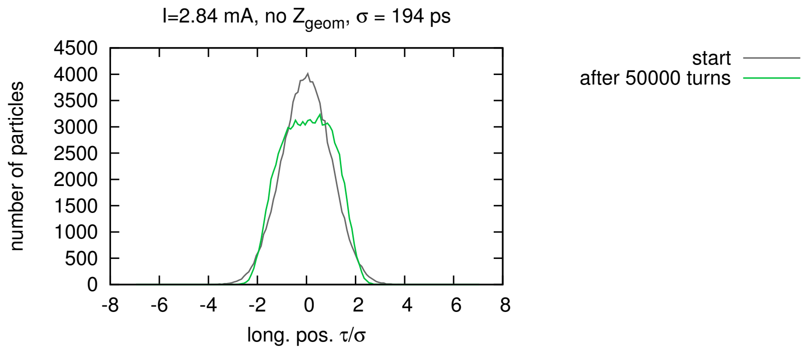

Figure 1: Bunch evolution with HC providing ideal potential.

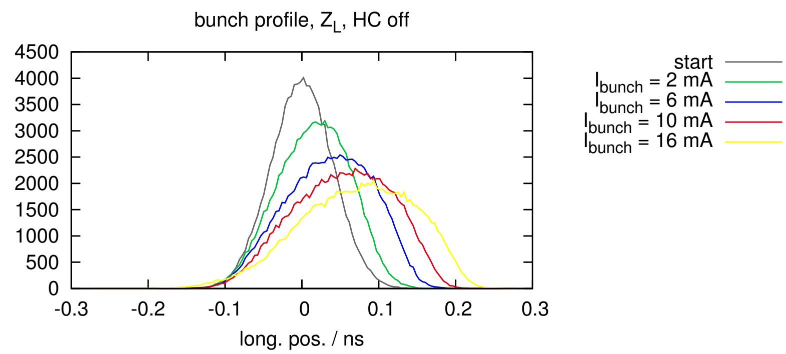

Figure 2: Bunch evolution with Z_{geom}.

Combining the two effects (ideal HC and Z_{geom}) we see the bunch leaning front and lengthened, but not a 'flat top' as in presence of HC only. It is presented in the Fig. 3 below.

With less number of bins the bunch is more lengthened and asymmetric. The bunch profile with 687 bins is the correct one and it will be shown in the next section.

3 Convergence of the results depending on the binning and number of macroparticles

If the number of particles used in the tracking is not enough to 'fill up' the bins the numerical modulation is induced on the bunch. This leads to the onset of instability appearing at smaller current than the real physical threshold. Thereby,

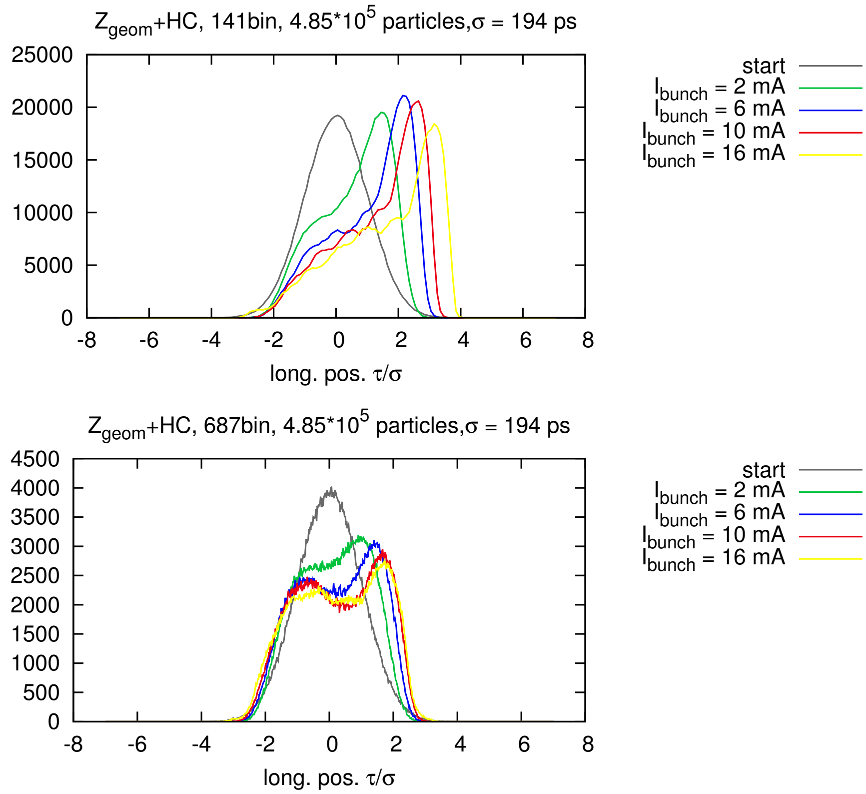

Figure 3: Bunch evolution with Z_{geom} and HC and different binning: 141 bins (top), 687 bins (bottom).

the previously obtained results [3] were found to show not the physically but numerically triggered instability, which led to the search of binning and number of particles sufficient to provide the real microwave threshold.

3.1 Binning

The binning was studied for both 40 ps short bunches and 194 ps bunches lengthened by the HC with ideal potential.

The short bunch lengthening and energy spread was studied with 100, 141, 241 and 341 bins over $\pm 7\sigma$ and results are shown in Fig. 4.

At low currents the discrepancy is negligible but at higher currents the energy spread behavior obtained with 100 bins is significantly different. We can conclude that 141 bin over $\pm 7\sigma$ is enough to exclude the numerically induced error.

Next, the sufficient binning for the bunches with HC lengthening was inves-

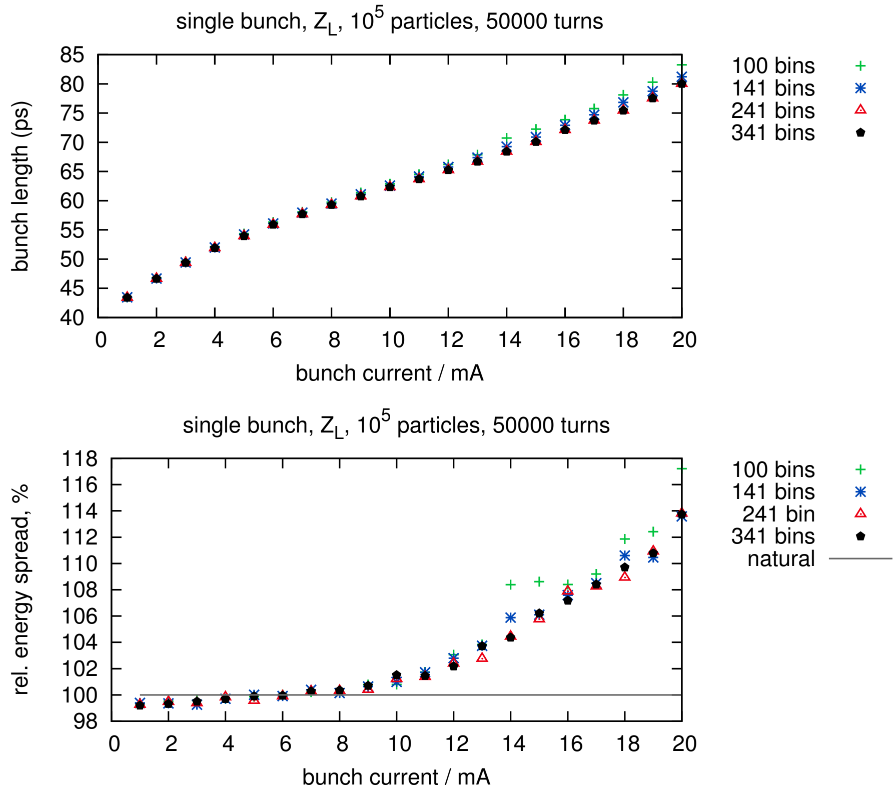

Figure 4: Bunch lengthening(top) and energy spread (bottom) for short bunch with different binning.

tigated. The bunch with HC is 4.85 times longer (40 ps $\rightarrow$ 194 ps), thus, to preserve the same width of the bin as for the short bunch the number of bins was multiplied by the factor 4.85 resulting in 687 bins filled by 100000 particles. The tracking was also done with less and more bins: 141,287,387,487,587,687 and 787 bins. The results are presented in the Fig. 5 below.

Similar to the situation with short bunches the discrepancy between simulations is more clear at higher currents. The conclusion is that 487 bins is already sufficient binning to exclude the numerical error.

3.2 Number of particles

The results obtained above were checked for cases with larger amount of macroparticles:

For the short bunch with:

- 10000 particles

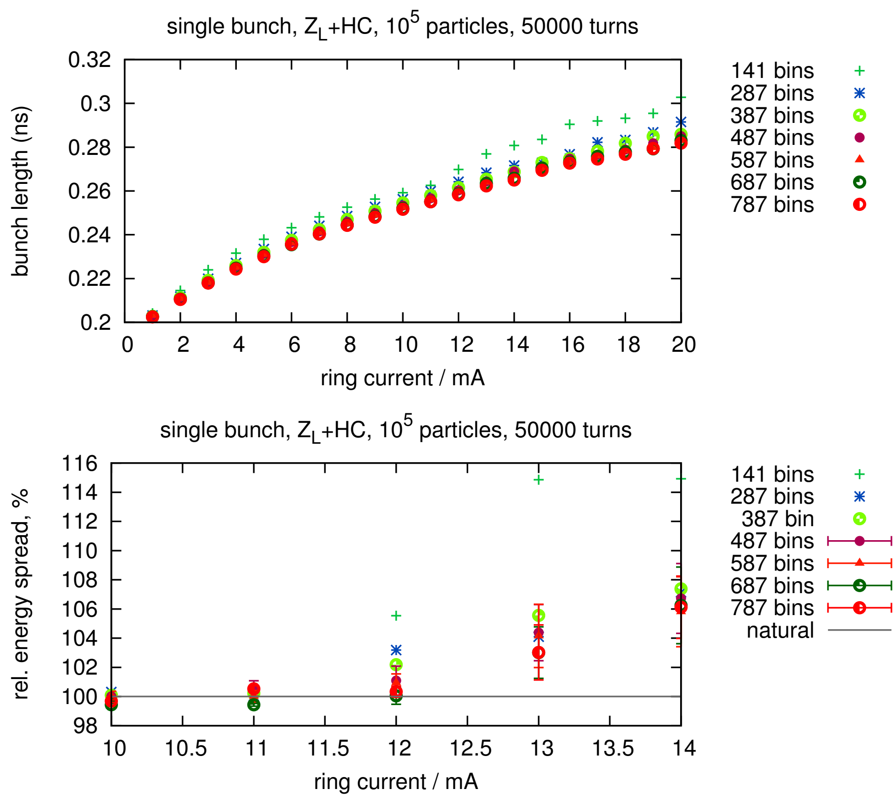

Figure 5: Bunch lengthening(top) and energy spread (bottom) for lengthened bunch with different binning.

- 100000 particles
- 1000000 particles

10 000 particle was shown to be not enough, but 100000 and 1000 000 particles converge to the same result for the energy spread.

For the lengthened bunch 10000 particles case was excluded from the beginning as it was not enough to "fill up" even the bins of short bunch. Thus, the tracking was performed with:

- 100000 particles
- 485000 particles
- 1000000 particles

100000 particles proved to be enough to fill up the long bunch.

4 Microwave instability threshold

The threshold of microwave instability was obtained, considering all of the above. The tracking was complete with:

- bare lattice geometric longitudinal impedance
- short range resistive wall
- HC off/ ideal potential
- 100 000 particles
- 141 bin over $\pm 7\sigma$ for short bunch
- 687 bin over $\pm 7\sigma$ for lengthened bunch
- current ramp 1 mA every 50000 turns

The results are presented in Fig. 6.

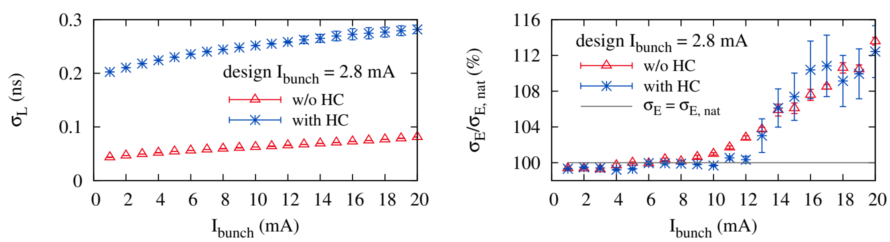

Figure 6: Bunch lengthening(left) and energy spread (right)with and without the effect of HC.

The microwave threshold is at 8 mA w/o HC and at 12 mA with HC providing ideal potential, both thresholds are well above the nominal 2.84 mA per bunch current (500 mA total). At the 20 mA current per bunch the energy spread is 15% above the nominal.

References

[1] R. Nagaoka and R. Bartolini, "Study of Collective Effects in SOLEIL and DIAMOND Using the Multiparticle Tracking Codes SBTRACK and MBTRACK", Proceedings of PAC'09, Vancouver, Canada, 2009, p. 4637

[2] A. Hofmann and S. Myers, "Beam Dynamics in a Double RF System", CERN-ISR-TH-RF-80-26, C80-07-07-30, 1980, p. 610

[3] Klein, M. and Nagaoka, R. and Skripka, G. and Tavares, P. F. and Wallén, E. J., "Study of Collective Beam Instabilities for the MAX IV 3 GeV Ring", Proceedings of IPAC2013, Shanghai, China, 2013, p.1730