VALIDATION OF THE MICROWAVE INSTABILITY IN THE DAMPING RING OF SUPERKEKB USING VFP SOLVER

L. Wang#, SLAC, Menlo Park, CA, USA
H. Ikeda, K. Oide K. Ohmi and D. Zhou, KEK, Japan

Abstract

Microwave instability driven by coherent synchrotron radiation (CSR) impedance in the Damping Ring of Super-KEKB is a concern due to its high bunch current and strong CSR. To confirm the threshold of the instability, we simulate the microwave instability using Vlasov-Fokker-Planck (VFP) solver to provide a benchmark with Particle-In-Cell (PIC) code. The longitudinal wake potential is calculated as a sum of the contributions from the vacuum chamber components distributed around the ring, including geometric and CSR wake fields. The CSR wake is dominant. Our study shows that the threshold is just above the design current and saw-tooth type of instability can be clearly seen above the threshold.

INTRODUCTION

SuperKEKB is a next generation B-factory [1]. A small Damping Ring (DR) is added to reduce the emittance of the positron beam. This paper briefly summarizes the numerical study of the microwave instability in SuperKEKB Damping Ring using Vlasov-Fokker-Planck (VFP) code [2, 3]. VFP approach has an advantage in reducing the numerical noise comparing with PIC code where the number of particles used in the calculation is typically much smaller than the real number. Table 1 lists the main parameters of the Damping Ring.

Table 1: Main Parameters SuperKEKB Damping Ring

Physics	***Unit***	
Beam Energy	GeV	1.1
Maximum bunch charge	nC	8 (5e10 e-)
Circumference	m	135.5
Maximum stored current	mA	70.8
Energy loss per turn	MV	0.091
Horizontal damping time	ms	10.9
Injected-beam emittance	nm	1700
Equilibrium emittance (h/v)	nm	41.4/2.07
Coupling	%	5
Emittance at extraction(h/v)	nm	42.5/3.15
Energy spread	%	0.055
Bunch length	mm	6.53
Synchrotron tune		0.02569
Momentum compaction factor		0.0141
Number of normal cells		32
Cavity voltage for 1.5 % bucket-height	MV	1.4
RF frequency	MHz	509
No. of bunch trains/ bunches per train		2/2

CSR IMPEDANCE

Table 2 shows the parameters of the bending magnets along the SuperKEKB Damping Ring. The CSR impedance is calculated for a rectangular shape of vacuum chamber with width of 34.0 *mm* and height of 24.0 *mm* using finite difference code [3]. A finite element solver has been developed to compute the CSR impedance with arbitrary cross-section of beam pipe. There is an excellent agreement with the finite difference code [3].

The CSR impedance is calculated by tracking the radiation field through half of the DR. Figure 1 shows the CSR impedance. A beam spectrum with *rms* bunch length of 0.05mm is also shown for comparison. To improve the accuracy of the instability simulation, the CSR impedance is calculated up to a few Terahertz to better model the interaction with micro-bunch. There are many spikes in the impedance spectrum due to the interference of the radiation fields along the long beam line. These narrow spikes induce long range wake field as shown later.

Table 2: Parameters of Bend Magnets in SuperKEKB DR

Bend	Length[m]	Bending angle	# of elements
B1	0.74248	0.27679	32
B2	0.28654	0.09687	38
B3	0.39208	0.12460	6
B4	0.47935	0.15218	2

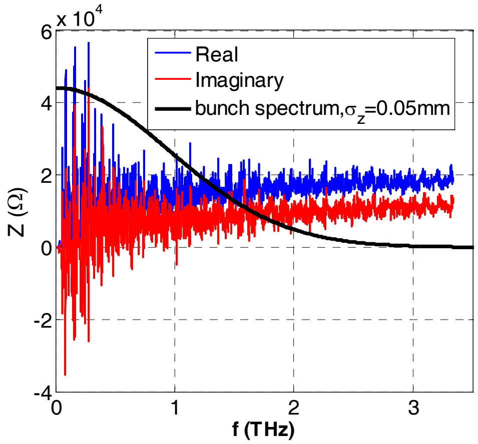

Figure 1: Calculated CSR impedance in the Damping Ring.

STUDY OF THE DEPENDENCE ON NUMERICAL PARAMETERS

A Vlasov-Fokker-Planck code [2, 3] is used to simulate the microwave instability. Besides the CSR wake, geometric wake is also included. Figure 2 shows the wakes. The CSR wake in the plot is convoluted with a 0.5

Email address: wanglf@slac.stanford.edu

mm long Gaussian bunch. It clearly shows that the CSR wake is dominant and it has much longer range. The long range wake may cause multiple bunch effect if the bunch space is short [5]. It shouldn't be an issue for SuperKEKB Damping Ring due to its long bunch spacing. It is worth pointing out that the geometric wake in our case is resistive type while the CSR wake is inductive.

Figure 3 shows the growth of bunch length and energy spread with bunch population. The effects of different wake are compared. The CSR wake causes negligible growth in bunch length and energy spread at low bunch current. However, the geometric wake induces linear growth in bunch length due to potential well distortion when the bunch charge is below the critical value. The distortion of the bunch profile is clear seen in the simulation. However, there is no instability below the threshold. Comparing the results of different wake cases, it clearly shows that the bunch lengthening is mainly due to geometric wake when the current is below the critical value, while CSR effect is dominant when bunch current is above that critical current.

It is always good to check the convergence of the simulation. The simulation is done in the normalized phase space, which is rectangular region with maximum domain ***qmax*** (and minimum –***qmax***). The whole domain contains (2****nn***+1)^2 mesh points, and the time step is given by **ndt**, the number of steps per synchrotron period. A large **ndt** of 1024 is used all the time to better represent the effect of the average CSR kickers. A too small **ndt** can cause artificial growth in bunch length and energy spread [6]. Figure 4 shows the convergence test of the numerical parameters: mesh number, the domain used in the simulation and the mesh size. A domain of 16σ, a grid number of 1000×1000 and a time step of 1/1024 synchrotron period is good enough.

Figure 4 clearly shows that the microwave instability starts at about bunch population N_p=5.5×10^{10}, which is slightly above the designed bunch population of 5.0×10^{10}. The simulations have been done for very high current in order to clearly see the instability threshold.

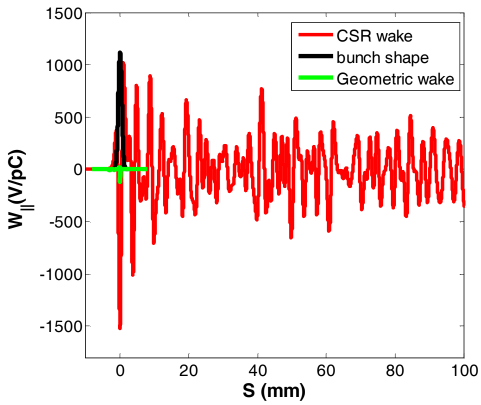

Figure 2: Geometric and CSR wake of the DR.

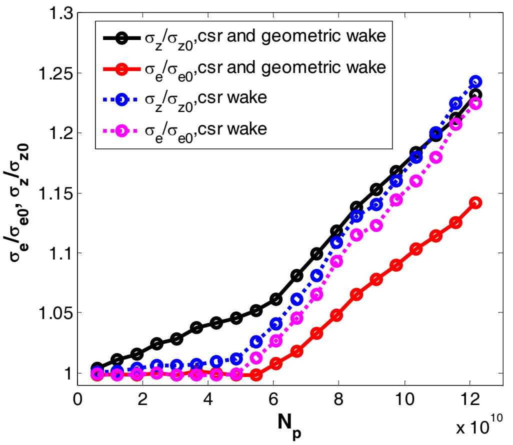

Figure 3: Bunch length and energy spread at different bunch intensity with various types of wake, The numerical parameters used are: **qmax**=8, **nn**=300, **ndt**=1024.

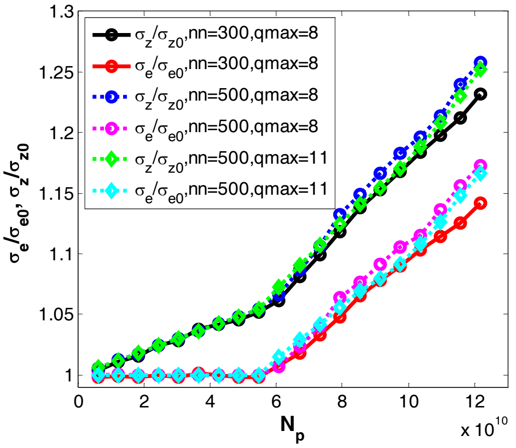

Figure 4: Dependence of bunch the length and energy spread on the mesh size, mesh number (**nn**) and the size of domain used (**qmax**). Both geometric and CSR wakes are included.

HIGH FREQUENCY IMPEDANCE AND SAWTOOTH INSTABILITY

The microwave instability happens in sub-millimeter level and even short. The short range wake field and the impedance at high frequency are important. When a wake field convoluted using a short bunch with higher frequency impedance is used, the instability (near and above the threshold) becomes much strong. The saw-tooth type of instability becomes clearer above the threshold and the threshold is slightly lower. This indicates the importance of the impedance with high frequency. Figure 5 and 6 shows the evolution of bunch length and energy spread with bunch population near (N_p=5.5×10^{10}) and above the threshold (N_p=8.5×10^{10}). It clearly shows the saw-tooth type of instability. The period is about 1.9 *ms*. Figure 7 shows the spectrum of the bunch length and energy spread in Fig. 6. The modes at ν_s, $2\nu_s$, $3\nu_s$, and $4\nu_s$ are clearly seen. Figure 8 shows the example of the phase space near and above the threshold. The micro-structure is clearly visible when the instability happens.

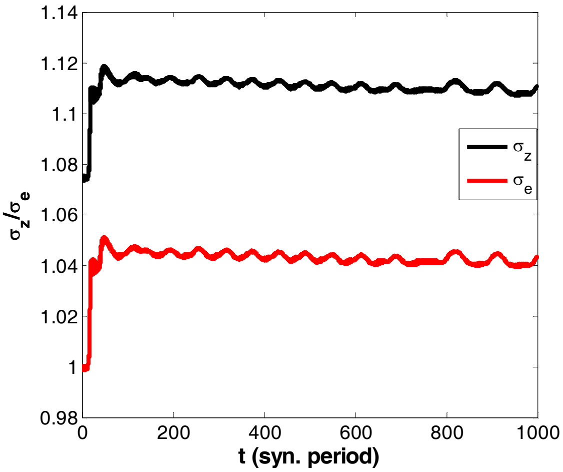

Figure 5: Development of the normalized bunch length and energy spread near threshold (N_p=5.5×10^{10}).

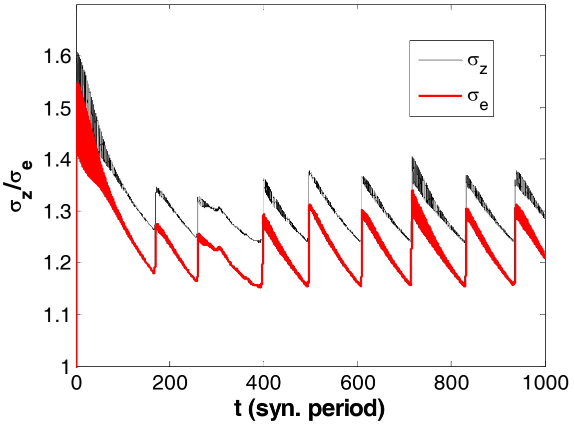

Figure 6: Evolution of the normalized bunch length and energy spread above the threshold (N_p=8.5×10^{10}).

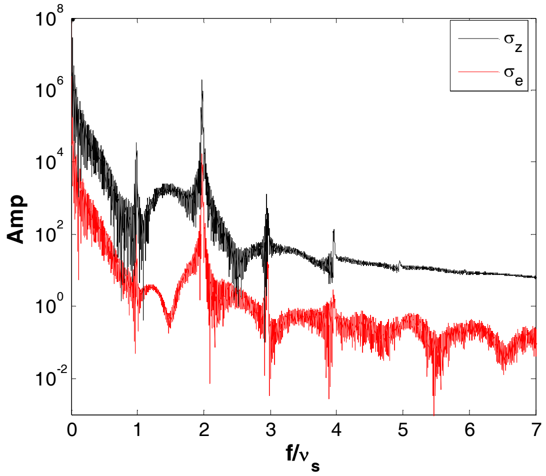

Figure 7: Oscillation spectrum of the bunch length and energy spread with N_p=8.5×10^{10}.

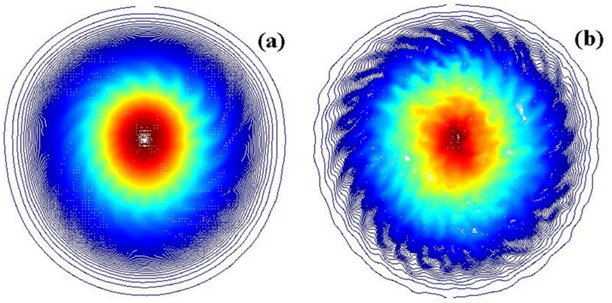

Figure 8: Examples of phase plot with N_p=5.5×10^{10} (a) and N_p=8.5×10^{10} (b).

SUMMARY AND DISCUSSON

Our study of the microwave instability using the Vlasov-Fokker-Planck code first time suggests a higher instability threshold in the DR, which is slightly above the nominal bunch charge. Therefore, the microwave instability in the SuperKEKB Damping Ring shouldn’t be a serious problem based on this study.

However, further studies may be necessary. First, the cross-section of the vacuum chamber in the bending magnet is ante-chamber. Its impacts on the CSR impedance should be investigated. It may further shield the CSR field due its narrower gap. Nevertheless, it is worth of study. Secondly, the simulation of the microwave instability is not trivial. The bunch length is much longer than the wave length of the instability, therefore a large number of grids or macro-particles is required. A good algorithm to suppress the numerical noise and powerful computation resource are essential.

ACKNOWLEDGEMENTS

One of the authors Wang gratefully and sincerely thanks Yunhai Cai, Robert Warnock at SLAC, Hitoshi Fukuma, Kaoru Yokoya and Mitsuo Kikuchi at KEK for their fruitful discussions and great supports. Wang also thanks KEK for the financial support of this work.

REFERENCES

[1] M. Masuzawa, “Next Generation B-factories”, in the Proceedings of IPAC 2010, FRXBMH01, Kyoto, Japan, May 23-28, 2010.
[2] Robert L. Warnock, SLAC-PUB-11955(2006).
[3] K. L. F. Bane, Y. Cai, and G. Stupakov, Phys. Rev. ST Accel. Beams 13, 104402 (2010).
[4] Demin Zhou, Kazuhito Ohmi, Katsunobu Oide, Lei Zang, and Gennady Stupakov, Japanese Journal of Applied Physics 51 (2012) 016401.
[5] Robert L. Warnock, Private communication.
[6] H. Ikeda, et. al., these proceedings.