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SINGLE BUNCH INSTABILITY SIMULATIONS IN THE STORAGE RING OF THE ALS-U PROJECT*

D. Wang†, K. L. F. Bane, S. Santis, M. P. Ehrlichman, D. Li, T. Luo, S. Omolayo, G. Penn, C. Steier, M. Venturini
Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Abstract

As the broad-band impedance modeling and vacuum-chamber design of the new Advanced Light Source storage ring (ALS-U) are reaching maturity, we report on progress in our single-bunch collective effects studies. A pseudo-Green function wake representing the entire ring was earlier obtained by numerical and analytical methods. Macroparticle simulations using the code *elegant* based on the pseudo-Green function are used to determine the instability thresholds for longitudinal and transverse beam motion. We consider various operating conditions, such as without/with higher-harmonic RF cavities and zero/finite linear chromaticity. Results show enough margin for the broadband impedance budget when the single-bunch instability thresholds are compared with the design bunch charge.

STORAGE RING PARAMETERS

The upgrade of the Advanced Light Source (ALS-U) to a diffraction-limited soft x-rays radiation source with brightness about two orders of magnitude higher than in the existing ALS is currently underway at the Lawrence Berkeley National Laboratory (LBNL). The storage-ring parameters are listed in Table 1 [1]. The parameters are for lattice version *v20r*. The 500 mA average current is distributed evenly among the 284 bunches of the beam, consisting of eleven 25- or 26-bunch trains. The harmonic number is $h = 328$. The design bunch charge, which is more relevant for single-bunch broadband-impedance driven instabilities, is 1.15 nC. Without high-order harmonic cavity (HHC) the natural rms bunch length is 4.5 mm. With HHC the FWHM bunch length is 34 mm. In these simulations the HHC is tuned to induce a flat-top bunch profile. The simulations without HHC are relevant for the commissioning and early-operation phase when the beam current is too low to drive the passive HHC.

PSEUDO-GREEN FUNCTIONS

The *elegant* [2] simulations make use of the total pseudo-Green functions shown in Fig. 1. These were obtained with a 1 mm rms length drive beam using the code CST [3] in both the longitudinal and transverse plane. This corresponds to an impedance frequency spectrum cut-off of about 100 GHz, which we believe is adequate to include the spectral range of interest.

Table 1: ALS-U Storage Ring Parameters

Parameters	
Beam energy, E	2.0 GeV
Tune, ν_x/ν_y	41.357/20.354
Natural chromaticities, $\xi x/\xi_y$	−65.2 /−64.84
Emittance, ϵ_{x0}	116 pm
Energy spread, σ_δ	11.4×10^{-4}
Revolution time,	0.67 μs
Energy loss/turn, U_0	217 keV
FWHM bunch length (with HHC),	34 mm
Natural rms bunch length (no HHC),	4.5 mm
Single bunch charge,	1.15 nC

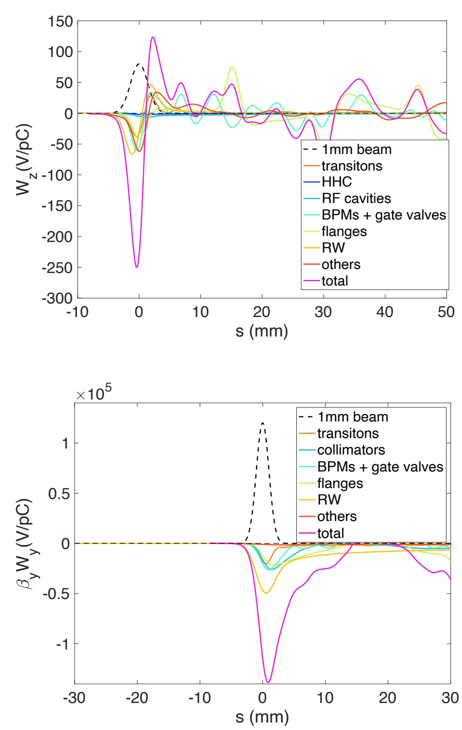

Figure 1: Longitudinal (top) and vertical (bottom) pseudo-wake functions for the various sources, as indicated in the in-set, and their total (1 mm long rigid drive bunch).

The transverse wake is beta-weighted based on the local betatron-function value at the impedance source. In this paper we only report results for the vertical plane since the weighted transverse impedance in the horizontal plane is somewhat weaker [4].

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† dwang2@lbl.gov

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We have carried out a consistency check by convolving the longitudinal pseudo-Green function with a 14 mm Gaussian drive beam to determine the wake potential. The result (magenta dashed curve in Fig. 2) agrees well with the calculation carried out directly in CST when using a 14 mm Gaussian drive beam (blue solid curve).

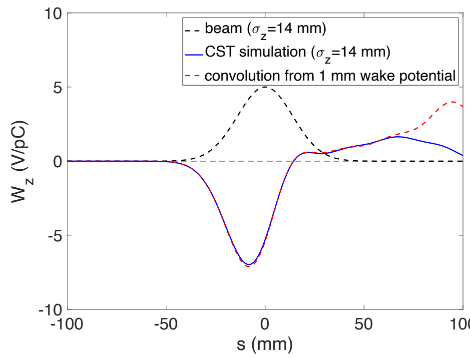

Figure 2: Consistency check of the calculation for the wake potential of a 14 mm bunch based on the longitudinal pseudo-Green function *vs.* a direct calculation in CST.

SINGLE-BUNCH INSTABILITIES

Longitudinal

Short-range longitudinal wake fields can induce bunch lengthening through potential-well distortion and, above a typically well-defined current threshold, instabilities.

We applied the macroparticle simulation code *elegant* [2] to study the longitudinal and transverse single-bunch instabilities. Tracking was done with the 1 mm drive-beam wake potential calculated with CST and analytical formulas (RW) to represent the wake function with the appropriate flag in the *elegant* "WAKE" command set to accept violation of causality. We used 0.4 million particles, and tracked 3 dumping time to get the equilibrium beams while scanning the charge per bunch.

Figure 3 shows the evolution of the rms bunch length and energy spread for varying bunch charge up to 10 nC, corresponding to seven times the design bunch charge. The HHCs are tuned to ideal setting, yielding about a factor four bunch lengthening. Beam dynamics simulations indicate ~4 nC/bunch threshold for the onset of a saw-tooth instability (slow oscillation with millisecond period).

Figure 4 shows the evolution of the rms bunch length and energy spread for varying bunch charge up to 4 nC. The HHCs are tuned off, which is the initial operating stage of the ALS-U as we increase the beam charge. The natural bunch length is about 4.5 mm and the maximum operation charge is 1.15 nC. Beam dynamics simulations indicate ~2 nC/bunch threshold for the onset of a microwave instability (fast oscillations compared to Fig. 3) .

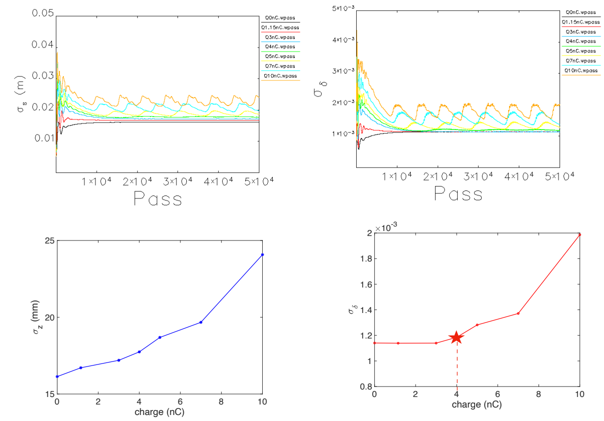

Figure 3: Single-bunch longitudinal dynamics simulations with HHC indicate ~4 nC/bunch threshold for the onset of a saw-teeth instability. The four figures show the rms bunch length revolution at different charge (top left), rms bunch energy spread revolution at different charge (top right), rms bunch length (bottom left) and rms energy spread (bottom right) vs. bunch charge after about 2.5 damping times.

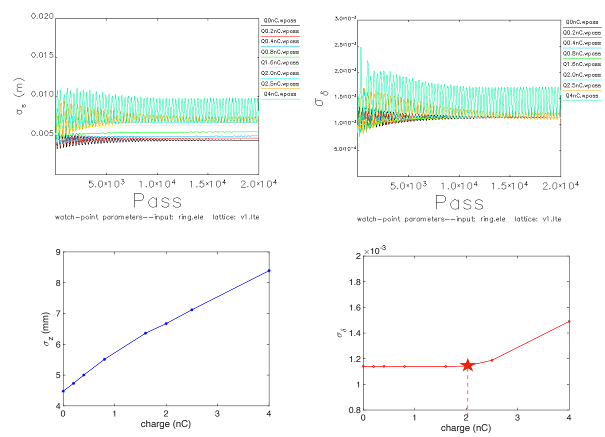

Figure 4: Single-bunch longitudinal dynamics simulations without HHC indicate ~2 nC/bunch threshold for the onset of a micro-wave instability. The four figures show the rms bunch length revolution (top left), energy spread revolution (top right), rms bunch length (bottom left) and rms. energy spread (bottom right) vs. bunch charge.

Transverse

Figures 5 and 6 summarize our study. The data sets shown in the figures correspond to three distinct impedance models including: the resistive wall impedance only, geometry impedance only, and total impedance. We studied the instability threshold in the presence and absence of harmonic cavities.

Elegant simulations at vanishing chromaticity indicate an instability threshold (TMCI) below the design bunch charge. Somewhat surprisingly, the presence of harmonic cavities is seen to aggravate the instability [5]. Positive chromaticities have the expected stabilizing effect, particularly when the

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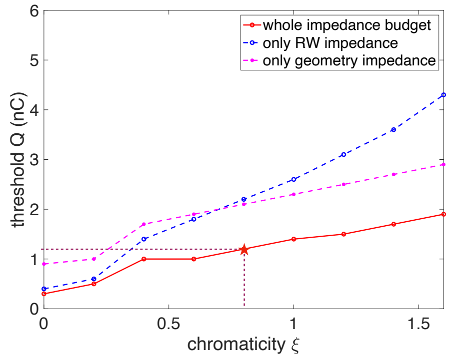

Figure 5: Single-bunch vertical instability threshold (with HHC) as a function of the vertical chromaticity including resistive-wall impedance only (blue line), geometry impedance only (mageta curve) and total impedance budget (red curve).

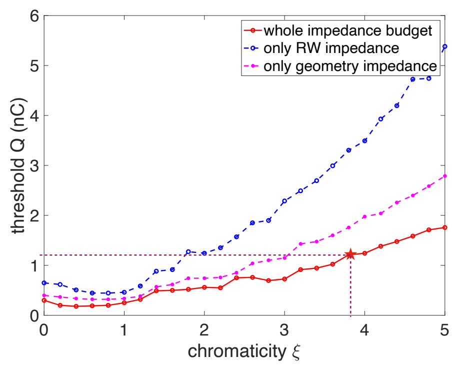

Figure 6: Single-bunch vertical instability threshold (without HHC) as a function of the vertical chromaticity including resistive-wall impedance only (blue line), geometry impedance only (mageta curve) and total impedance budget (red curve).

bunch is lengthened by the harmonic cavities. With the harmonic cavities off, the result of the simulation shows discontinuities in the dependence of the critical charge on chromaticity as different head-tail modes come in and out of play in driving the instability.

The instability threshold improves quickly with finite chromaticity. The design bunch charge for 500 mA operation is $Q = 1.15$ nC. The requirement for the chromaticity is to set chromaticity over 0.8 with HHC, and over 3.8 without HHC, in order to operate at 1.15 nC

The simulation does not include a model of transverse feedback system, which in ALS is found to be quite effective at raising the instability threshold.

CONCLUSION

We have presented simulation studies of single-bunch instability in the ALS-U storage ring. The results suggest sufficient margin for both longitudinal and transverse single-bunch instability thresholds.

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