# COLLECTIVE EFFECTS SIMULATIONS FOR THE TPS STORAGE RING

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*Abstract*

Taiwan Photon Source (TPS) is a new third generation synchrotron storage ring which will be built at the present site of the NSRRC. Single bunch effects in the TPS storage ring have been simulated with tracking code ELEGANT. Geometrical, resistive-wall and CSR wakes have been taken into account in the simulations. Thresholds of the longitudinal microwave instability and of the CSR induced instability have been obtained.

## INTRODUCTION

When traversed by charged particles, cross section variations of the vacuum chamber wall generate wake fields. These wake fields can influence the motion of trailing particles. This may lead to energy loss, to beam instabilities, or produce undesirable secondary effects such as excessive heating. For a realistic simulation of collective effects in the storage ring, the wake field produced by a point charge (i.e. wake function) need to be known. Unfortunately, there is no method at present to compute this field numerically. The approximate wake function can be obtained from the wake field of a very short bunch [1]. To make the wake field of a finite-length bunch casual, the part in front of bunch center should be reflected and added to the back [2].

## APPROXIMATE WAKE FUNCTION

Natural bunch length of the TPS storage ring is 2.86 mm. In order to obtain approximate wake function, wake fields produced by the 0.5 mm Gaussian bunch have been simulated with GdfidL [3]. Beam position monitors, bellows, bending chambers, flanges, gate valves, photon absorbers, pumping slots chambers, SRF cavity, SRF cavity tapers, injection section taper, straight section tapers, and insertion device tapers have been simulated. In order to reduce memory consumption, nonuniform mesh have sometimes been used as well as moving window technique, when fields are only calculated within a rather short window along the bunch path. Longitudinal resistive-wall (RW) wake potentials for a Gaussian bunch have been calculated using Piwinski's formula [4] assuming circular Aluminum beam pipe. The RW model of the TPS storage ring consists of: 48 m of Al beam pipe with $r = 5$ mm, 60 m with $r = 10$ mm, and 410.4 m with $r = 15$ mm. Figure 1 shows comparison of wake potentials from a 0.5 mm bunch for all the components as well as total wake potential. The most significant wake fields are due to the bellows, tapers, and resistive walls.

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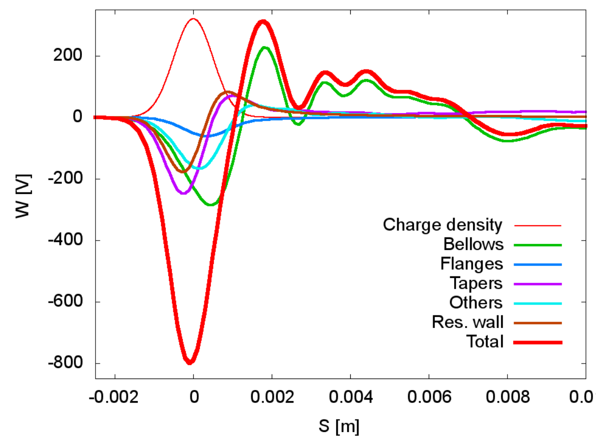


Figure 1: Longitudinal wake potentials as function of distance from 0.5 mm bunch for various groups of elements.

Convolution of the approximate wake function with 3 mm Gaussian function shows good agreement with the wake potential directly calculated by GdfidL for the 3 mm bunch [5].

## CSR INDUCED INSTABILITY

The CSR induced instability has been studied with account for a shielded CSR wake. $2 \times 10^5$ macroparticles have been tracked for $2 \times 10^4$ turns in parallel tracking code Pelegant [8]. Figure 2 shows the current dependence of the average energy spread and bunch length. The bars indicate standard deviation from the average value. It is seen that both bunch length and energy spread begin to grow if the bunch current exceeds the value of 3 mA. At the same time, micro structures develop in the longitudinal phase space (Fig. 3). These micro structures are especially pronounced at even higher bunch currents.

## LONGITUDINAL MICROWAVE INSTABILITY

To study longitudinal microwave instability, both the approximate wake function and shielded CSR wake have been used as input for Pelegant. $2 \times 10^5$ macroparticles have been tracked for $2 \times 10^4$ turns. The wake field have been ramped up during first thousand turns. Figure 4 shows the dependence of the energy spread on the number of revolutions around the ring. The dependence of the bunch length on the number of revolutions is similar to that of Fig. 4. If the bunch current is below 2 mA, the en-

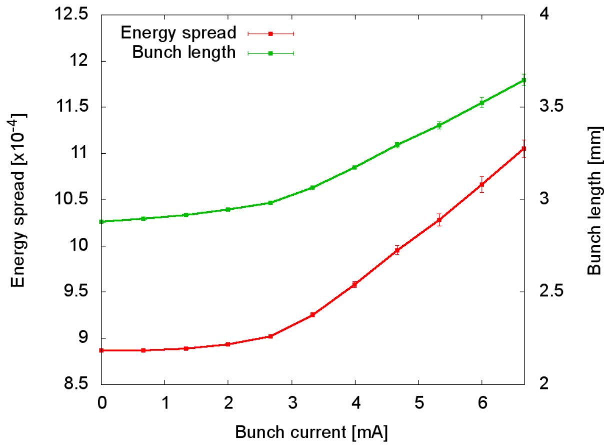


Figure 2: CSR induced instability. Current dependence of the average energy spread and bunch length.

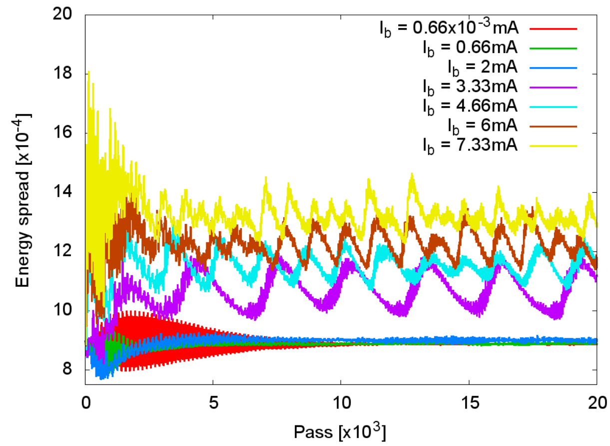


Figure 4: Longitudinal microwave instability. Dependence of the bunch length on the number of revolutions.

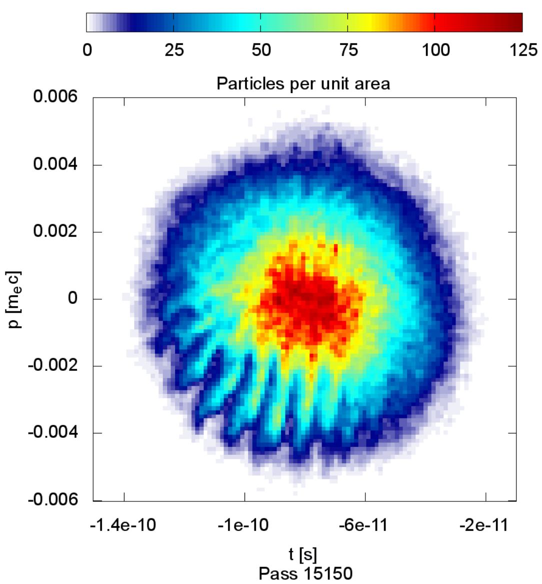


Figure 3: CSR induced instability. Distribution of particles in the longitudinal phase space.

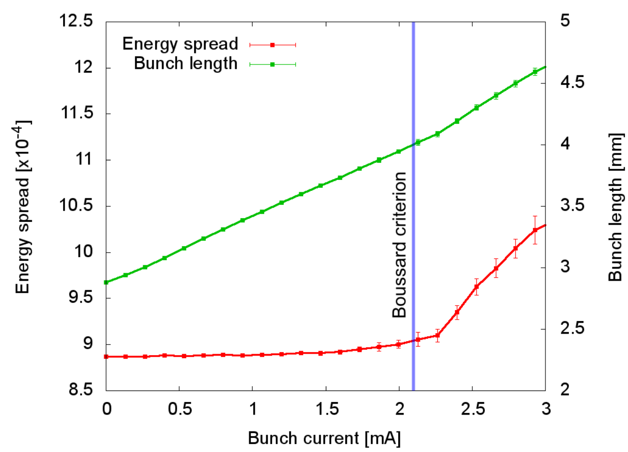


Figure 5: Longitudinal microwave instability. Current dependence of the average energy spread and bunch length. Tracking results vs. Boussard criterion.

ergy spread and bunch length approach equilibrium values. Above this current value there is more complicated time-dependent behavior, including sawtooth type oscillations.

Figure 5 shows the current dependence of the average energy spread and bunch length. The bars indicate standard deviation from the average value. It is seen that although the bunch length increases steadily, the energy spread shows the threshold behavior characteristic to the microwave instability. The blue line indicates the threshold current which is given by Boussard criterion [6] (the SPEAR scaling has been applied to the value of the broad-band impedance obtained in [5]). It is seen that there is good agreement between threshold current values obtained numerically and analytically. This threshold current of the longitudinal microwave instability is at least 3 times higher than the nominal bunch current.

Bunch density distribution have been studied at different values of the bunch current. Results obtained from tracking code have been compared to the solution of the Haissinski's equation [7]. Figure 6 shows how the bunch shape evolves with the increase of the bunch current. Up to 2 mA the bunch shape is still close to Gaussian. Above this current value the bunch shape became significantly distorted. It should be noted here that the bunch current 3.33 mA is 5 times higher than the nominal current. This current value is well above the threshold of the longitudinal microwave instability. Besides the time dependent sawtooth oscillations of the bunch length are already present at this current value.

The time dependent sawtooth oscillations of the bunch length and energy spread have been studied in more detail to understand the physics behind this effect. These oscillations resemble sawtooth instability which has already been

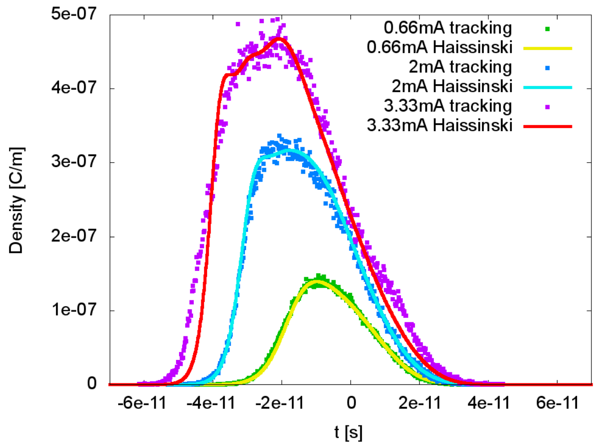


Figure 6: Longitudinal microwave instability. Bunch density distribution. Tracking results (after 14k turns) vs. solution of Haissinski's equation.

studied both analytically and experimentally (see e.g. [9]). Some properties of the sawtooth instability are : occasional bursting behavior, switching between the modes, instability displaces only a few percent of the beam particles, instability saturates.

At bunch current 3.33 mA, a quadrupole mode is excited in the beam phase space as shown in Fig. 7. At bunch current 6 mA, the quadrupole mode switches to sextupole mode with higher frequency (Fig. 8).

Tracking results show that there is occasional bursting behavior of the bunch length and energy spread after some

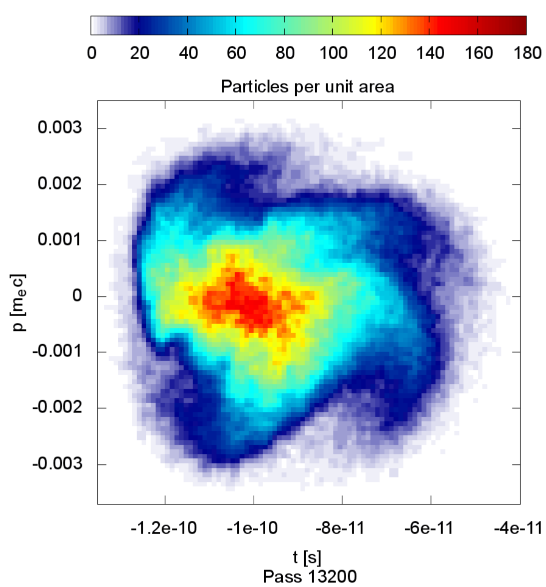


Figure 7: Longitudinal microwave instability. Distribution of the particles in the longitudinal phase-space. Quadrupole mode.

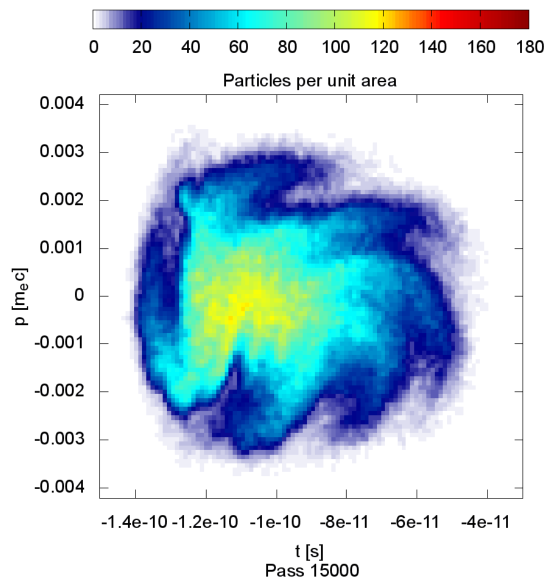


Figure 8: Longitudinal microwave instability. Distribution of the particles in the longitudinal phase-space. Sextupole mode.

threshold current, there is switching from the quadrupole mode to the sextupole mode, the instability displaces only a small number of particles. These are the features of the sawtooth instability and we can cast the oscillations observed in the result of particles tracking as the sawtooth instability.

## CONCLUSION

Approximate wake function for the TPS storage ring has been obtained and used for particles tracking. Threshold currents of the longitudinal microwave instability and the CSR induced instability has been obtained. It is confirmed that nominal single bunch current of the TPS storage ring is below the threshold of these effects. Time dependent oscillations of the bunch length and energy spread can be classified as the sawtooth instability.

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