SELF-CONSISTENT SIMULATIONS OF PASSIVE LANDAU CAVITY EFFECTS*

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Abstract

We discuss passive Landau cavity effects for arbitrary fill patterns. We present a new algorithm for the self-consistent calculation of the long-range multibunch interaction and implement it in the parallel OASIS code. As an application, we show numerical simulations with parameters of the passive Landau cavity system of the MAX-IV storage ring, which consists of normal conducting cavities. Together with with the uniform filling case, which is planned for nominal operations of the MAX-IV storage ring, we discuss the case with a gap in the fillings.

EQUATIONS OF MOTION

We assume M bunches, each with N electrons, circulating in a ring with circumference C and revolution period T_0. According to the steady state beam loading compensation scheme shown in Fig.1, for self-consistent simulations of passive Landau cavity effects, the dynamics of the particles in bunch m ($m = 0, .., M-1$), under the one-turn map approximation, is governed by (without radiation damping and quantum fluctuations)

$$\begin{aligned}
\delta_{n+1} &= \delta_n \\
&+ \frac{e}{E_0}\Big[V_{gr}\cos\Psi\sin(\phi_s+\theta_L+\Psi-\omega_{rf}\tau_n) \\
&- V_m(\tau_n) - V_{rf}\sin\phi_{s0}\Big], \\
\tau_{n+1} &= \tau_n - \eta T_0 \delta_{n+1}, \qquad (1)
\end{aligned}$$

where n is turn number, e the electron charge, δ is the relative energy deviation with respect to the nominal energy E_0, τ is arrival time and η the momentum compaction. Here V_{gr} (generator voltage) V_{rf} (rf voltage), ϕ_s (synchrotron phase), Ψ (detuning angle) and θ_L (load angle) are the parameters of the main cavity and $\sin\phi_{s0} = U_s/(eV_{rf})$, where U_s is the energy loss per turn. $V_m(\tau_n)$ is the collective voltage induced by the passages of the M bunches through the main and Landau cavities.

The self-consistent calculation of $V_m(\tau_n)$ for a narrow-band resonator wake can be done efficiently by computing averages, via a MonteCarlo integration, of trigonometric functions with respect to the "history" of the bunch densities [3]. For the case of an arbitrary long-range wakefield interaction, see [2], where the collective voltage is calculated via a Taylor series expansion. The algorithm is implemented in OASIS, a self-consistent parallel code for efficient simulations of instabilities driven by short and long-range wakefields [3], and allows the study of passive Landau cavity effects for normal conducting cavities. The case with superconducting cavities is at the moment computationally too expensive. However, we are planning to extend the capability of the algorithm to cover the superconducting case, since our ultimate goal is the study of the passive Landau cavity system of the NSLS-II storage ring, which is planned to operate with superconducting cavities. Notice that Eq.(1) provides Robinson damping of the 0 mode by properly detuning the main cavity. This is crucial vhenever the longitudinal radiation damping is not strong enough to suppress the Robinson instability induced by detuning the Landau cavity for bunch lengthening.

UNIFORM FILLINGS

As an application of our current algorithm, we study passive Landau cavity effects with parameters of the MAX-IV storage ring [1] (see Table 1), which will be operated with normal conducting cavities (see Table 2). In our simulations we include only the fundamental mode of the main and Landau cavity. The optimal bunch lengthening can be estimated by calculating the collective voltage induced by equally spaced stationary bunches [4]. According to the parameters of MAX-IV the optimal bunch lenghtening for uniform fillings is ≈ 200ps.

In Fig.2 we show self-consistent simulations of Eq.(1) with the OASIS code. OASIS is based on a Vlasov approach and implements a particle tracking method to solve the Vlasov equation, therefore uses $\mathcal{N}$ simulation or representive particles to sample the underlying phase space density, and its number is not necessarily related to the actual number of particles in the bunch N. The simulations of M bunches, each with $\mathcal{N}$ simulation particles, are done in parallel using M processors, by assigning $\mathcal{N}$ of each bunch to a single processor. Eq.(1) is integrated up to 300K turns. The parameters (per cavity) used to solve Eq.(1) are $V_{gr} = 0.495$MV, $\phi_s = 2.728$rad, $\Psi = -1.137$rad and $\theta_L = 0$. The detuning frequency of the Landau cavity is 47.53kHz and the number of simulation particles used is $\mathcal{N} = 100$K. In Fig.2 (left) we plot the bunch length of the bunch train after 300K turns. The red curve represents the numerical result with Landau cavities. The bunch length is roughly constant across the bunch train and approximately equal to 210ps. The curve in blue shows the nominal bunch length of 40ps without Landau cavities. In Fig.3 (top left) we plot the longitudinal density of the bunch train. We clearly see that for uniform fillings the Landau cavities induce roughly the same bunch lenghtening across the train without displacing the bunch centroid.

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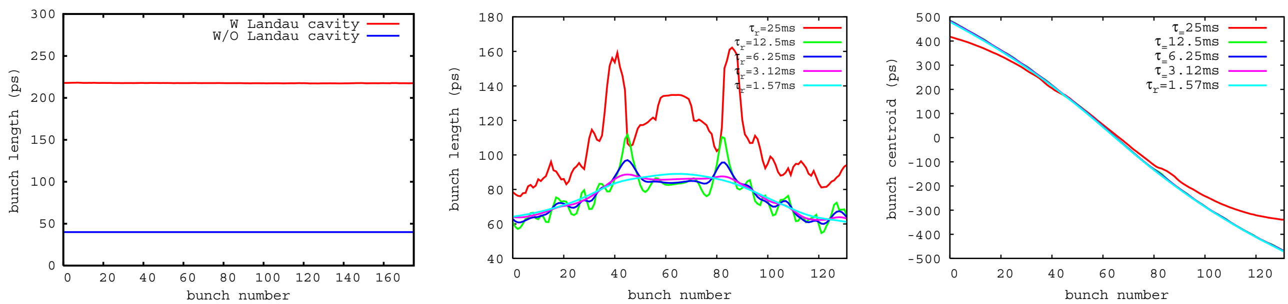

Figure 2: Numerical simulations with OASIS. The number of simulation particles used is $\mathcal{N} = 100$K. Bunch length vs bunch number after 300K turns for uniform fillings and maximum bunch length equal to 210ps (left) and for a gap of 44 bunches in the fillings and several values of the radiation damping time (center). Right: same as center for the bunch centroid.

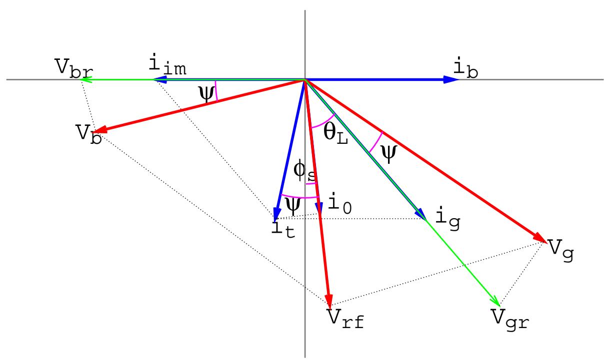

Figure 1: Phasor plot for steady state beam loading compensation according to Eq.(1). Per cavity (main) parameters: V_{gr} is the generator voltage, V_{rf} the rf voltage, ϕ_s the synchrotron phase, Ψ the detuning angle and θ_L the load angle.

Table 1: MAX-IV Storage Ring Parameters (Bare Lattice)

Parameter	Symbol	Value	Unit
Beam energy	E_0	3	GeV
Average current	I	500	mA
Number of bunches	M	176	
Harmonic number	h	176	
Circumference	C	528	m
Bunch length w/o HC	σ_τ	40	ps
Energy spread	σ_p	7.7×10^{-4}	
Energy loss per turn	U_s	364	keV
Momentum compaction	η	3.07×10^{-4}	
Long. radiation damping	τ_r	25	ms

NON-UNIFORM FILLINGS

We now discuss the case of a gap in the fillings. We assume 44 empty buckets and 132 filled buckets, with the same average current $I = 500$mA. The per cavity parameters used are $V_{gr} = 0.491$MV, $\phi_s = 2.729$rad, $\Psi = -1.139$rad and $\theta_L = 0$. The detuning frequency

Table 2: Main (4 Cavities) and Landau ($m = 3$) Cavity

Per cavity parameter	Symbol	Value	Unit
RF frequence (main)	ω_{rf}	$2\pi\times99.93$	MHz
RF frequency (Landau)	$m\omega_{rf}$	$2\pi\times299.793$	MHz
RF voltage (main)	V_{rf}	0.255	MV
Shunt impedance (main)	R_L	2.6	MΩ
Shunt impedance (Landau)	R_H	2.3644	MΩ
Quality factor (main)	Q_L	21000	
Quality factor (Landau)	Q_H	21000	

of the Landau cavity is 47.53kHz. The bunch centroid and bunch length vary accross the bunch train as shown in Fig.2 and Fig.3. For the nominal radiation damping $\tau_r = 25$ms we observe a dipole instability (as shown in Fig.4, center) as well as an increase of the bunch length vs bunch number, as shown also in Fig.2 (center) by the red curve. This instability is not present for smaller values of the radiation damping. We observe also that the bunch length shows two spikes around bunch number 40 and 85. These spikes weaken when reducing τ_r, disappearing at $\tau_r = 1.57$ms, as shown by the cyan curve in Fig.2 (center) and by the longitudinal density across the bunch train shown in Fig.3 (bottom right). We are investigating the nature of this effect. Notice that the bunch centroids for $\tau_r < 25$ms are roughly the same, as shown in Fig.2 (right). The numerical results discussed in this paper are preliminary and will be subject to further analysis.

REFERENCES

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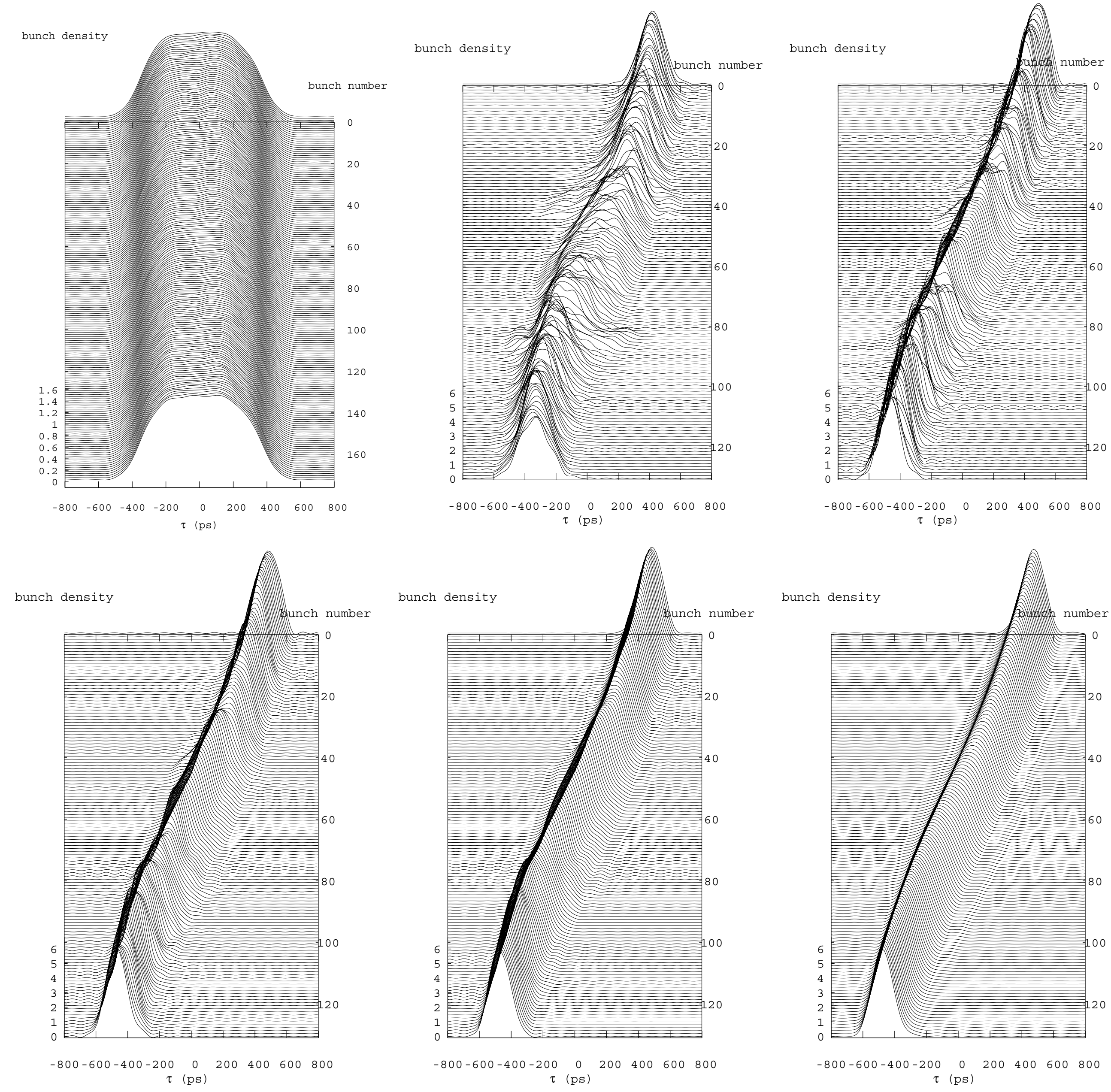

Figure 3: Bunch train after 300K turns for uniform fillings and maximum bunch length equal to 210ps (top left) and for a gap of 44 bunches in the fillings and radiation damping time τ_r=25ms (top center), τ_r=12.5ms (top right), τ_r=6.5ms (bottom left), τ_r=3.12ms (bottom center) and τ_r=1.57ms (bottom right).

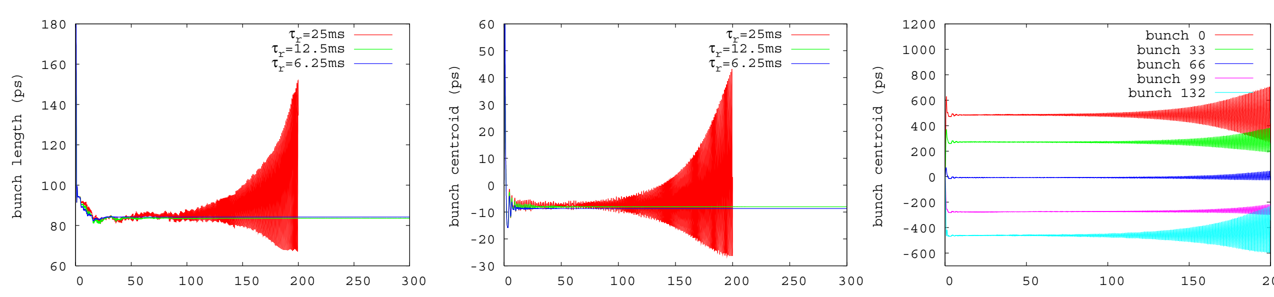

Figure 4: Time evolution of bunch length (left) and bunch centroid (center) for bunch number 66 and several values of τ_r, and time evolution of bunch centroids for τ_r=25ms (right).

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