IMPACT OF FILLING PATTERNS ON BUNCH LENGTH AND LIFETIME AT THE SLS

N. Milas[*] and L. Stingelin, Paul Scherrer Institute, CH-5232 Villigen, Switzerland

Abstract

The filling pattern can impact in the effective bunch lengthening of a passive 3rd harmonic system and, as a consequence, the Touschek component of the beam lifetime. Using a longitudinal dynamics tracking code, in which the effects of the accelerating system and the 3rd harmonic system are taken into account, we can calculate the synchronous phase drift caused by the transient beam-loading and thus the effective bunch increase for several different filling patterns. In this note we present a comparison between simulation and measurements for the SLS.

INTRODUCTION

The SLS is a 3rd generation light source that delivers to its users high quality and high brightness synchrotron radiation. The stored electron energy is 2.4 GeV and the stored total current 400 mA. In the machine 4 bell-shaped copper cavities [1] ensure that the beam recover the energy lost on each turn and a passive super-conducting 3rd harmonic cavity (3HC) stretches the bunches to provide longer lifetime and stability [2]. The SLS works in top-up mode together with a filling pattern feedback system which makes it possible to have tailored current profiles around the ring. In normal operation mode, in order to have the slicing beamline (FEMTO) [3] working together with the others, a filling pattern in which a bunch train of 390 filled buckets (with ≈ 1 mA) plus 1 camshaft (i.e., a single bunch with 4 mA) in the gap is used.

As observed in other laboratories [4] running with a gap in the current distribution causes transient effects in the cavities, and particularly in the 3HC those transient effects make the effective bunch lengthening smaller. Also, in order to allow for the FEMTO beamline to have high peak currents the camshaft has to be in a position in the train where the effect of the 3HC is minimum. With this constraints in mind we studied and measured three different possible filling patterns and compared the results with the ones obtained from simulation. The three filling patterns have different purposes: the first aims at improving the effective bunch stretch and also Touschek lifetime and beam stability; and the second and third comes from the possible upgrade of the FEMTO LASER to a higher repetition rate [5].

SIMULATION PROGRAM

The model used in the simulation considers that, given the desired filling pattern, every possible bucket is filled with electrons and each one of those bunches is represented by a single macroparticle. The bunches pass periodically through the accelerating cavities and contribute to the cumulative build-up of the induced fields. This program is based on a similar tracking code described in more details in [4]. The parameters used in the simulation code are listed on Table 1 and some fine tuning of the 3HC is done matching the measured excited voltage in the cavity with the one calculated in the program by changing the detune.

Table 1: Nominal SLS parameters

Parameter	Description	
E	Beam Energy	2.4 GeV
σ_ϵ	rms $\delta E/E$	9×10^{-4}
C	Circumference	288 m
f_{rf}	RF frequency	499.632 MHz
h	Harmonic number	480
α	Momentum compaction	6×10^{-4}
U_0	Radiation loss/turn	530 MeV
V_{rf}	Main RF voltage	2.1 MV
Q	3HC quality factor	2×10^8
R/Q	3HC geometric factor	88.4 Ω

FILLING PATTERNS SETUP

Special Mode

In this first test mode, instead of 390 equally filled buckets, the current density in the first and last 60 bunches in the train is higher than the current in the 270 central bunches, as show in Fig. 1. We tested 3 different cases, also show in Fig. 1:

- Special Mode 1 (SM1): case in which the current per bunch in the central 270 bunches is either 50% or 70% of the current per bunch in the 60 bunches on each side on the train. Both situations give approximately the same average bunch stretching and thus lifetime increase and will be treated as one case only.
- Special Mode 2 (SM2): optimized situation in which the average stretch is maximum. In this case the current per bunch in the central 270 is 60% of the current in the remaining 120.
- Special Mode (with noise - SM noise): case in which on top of the optimized current pattern (Special Mode 2) we added a random noise with 0.2 mA rms.

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[*] natalia.abreu@psi.ch

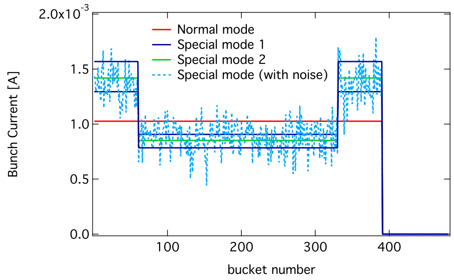

Figure 1: Current profile of the tested modes.

To measure the bunch length along the bunch trains we used a streak camera and the mode setup for the bunch length measurement was Special Mode 1 and also the Normal mode of operation, as show in Fig. 2. There is a very good agreement between the simulation and bunch length measurement, and all results are summarized in Table 2.

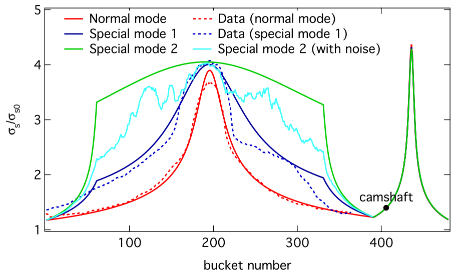

Figure 2: Comparison of simulated and measured bunch length ratios.

From the bunch length results we can estimate the increase in the Touschek component of lifetime. In order to have a good estimate of the total lifetime we used the values for Bremsstrahlung, Elastic Scattering and Touscheck components from a previous measurement, and considered that: $\tau_{tous} \propto \frac{1}{I_b[mA]}\frac{\sigma_s}{\sigma_{s0}}$ [7]. We found that the total lifetime for the normal mode should be around 6.6 hours, the lifetime for the Special Mode 1 around 6.8 hours, an increase of 3%, and for Special Mode 2 around 7.4 hours, a 12% increase. For the lifetime measurement we set up Special Mode 1 (the one with the biggest difference in currents) and then we allow it to reach a steady state condition (~1 hour) then turned on the filling pattern feedback system, which slowly fill up the bunches in the center until the normal mode filling was established. The maximum observed change in lifetime was around 5%, from 8.6 hours to 8.3 hours, when the filling pattern described as Special Mode 2 was reached (see Table 2).

In this case, however, it is more realistic to compare the measurement with the values obtained in simulations for the case in which we included noise in the current distribution, and the effect of the noise in the current filling pattern is to make the bunch lengthening less effective. The calculated average bunch length ratio on the bunch train for this case is then 2.7 and thus the lifetime will increase by 9% instead of 12%, which is closer to the measured 5% increase. Other effects that could account for the smaller lifetime difference measured are: differences on the parameters of the 3HC between simulation and experiment (specially variations in the detune) and outdated the values for the lifetime components (Bremsstrahlung, Elastic Scattering and Touschek).

Table 2: Comparison of the effective bunch lengthening and lifetime increase between experiment and simulation.

Mode	$\langle\sigma/\sigma_0\rangle$		$\langle\tau\rangle$ [hours]	
	data	simulation	data	simulation
NM	1.9±0.1	1.82	8.3±0.1	6.6
SM 1	2.2±0.1	2.35	8.5±0.1	6.8
SM 2	-	3.11	8.6±0.1	7.4
SM noise	-	2.7	8.6±0.1	7.2

Hybrid-5 Mode

An upgrade of the LASER repetition rate from the present 2 kHz to 10 kHz is under consideration to increase the flux for FEMTO. The new filling patten, to accommodate this LASER upgrade, has 5 camshafts bunches instead of only one, as in the current operation mode. This is necessary in order to reduce the repetition rate per bucket and keep the halo at the same level as with the lower LASER repetition rate [8]. In 2008 a Hybrid-5 mode was tested in which we repeated 5 times along the ring the following current distribution: 60 bunches with ≈ 1.3 mA a gap of 11 empty buckets, a camshaft (4 mA) and another gap of 24 empty buckets. This test was without much success since the camshaft bunch length was almost 4 times longer than the one in normal operation. A new Hybrid-5 mode (36×2.1 mA-11×0-1×4 mA- 48×0, repeated 5 times) was again tested in 2009 which achieved the desired goal of keeping the all 5 camshaft bunches short.

To understand the differences in those two modes we simulated each given filling pattern and calculated the amount of stretching on the camshaft bunches for each case. Fig. 3 shows the results for the simulation of the bunch stretching ratio for the normal mode of operation (A) and the two Hybrid-5 modes (B). From this result we noticed that the mode tested in 2008 resulted in a camshaft bunch at least 2 times larger than the mode tested in 2009. This was confirmed by a measurement of the profile of the camshaft for each mode and summarized in Table 3. This difference comes from the fact that the total phase transient excited in the 3HC depends on the current density in the bunch train, and since the bunch train from the 2009 filling pattern is shorter but contains the same amount of current as the one of 2008, it will create a stronger transient in the cavity so that when the camshaft passes the 3HC phase is off by a substantial amount and the effective stretch is reduced. It is also worth to mention that in

2008 the 3HC cavity was running slightly over the optimum condition causing the bunches be the overstretched and unstable, then that's why simulation predicts a smaller bunch length.

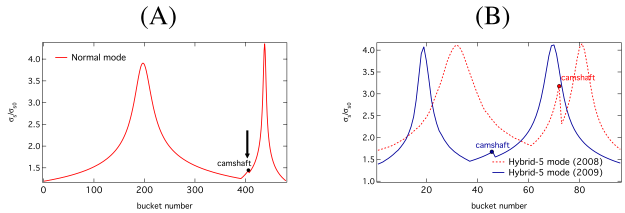

Figure 3: Current Profile of the tested possible operational mode.

Table 3: Comparison of the bunch length of the camshaft bunch between experiment and simulation.

Mode	$\langle\sigma\rangle$ [ps]	
	data	simulation
Normal Mode	35±1	37
Hybrid-5 (2008)	110±2	80
Hybrid-5 (2009)	33±1	42

Comb Mode

In face of new developments of a 100 kHz LASER in DESY, we decided to start the testing of a new "Hybrid" mode. In this case all bunches in the machine would be camshafts. In our first try, we filled 60 bunches spaced by 8 empty buckets each up to 240 mA, this is also called the Comb-mode. We could not fill beyond 240 mA since at this current a fast instability (HOM) kicked in and we lost the beam due to a vacuum interlock. The first results for this mode are show in Fig. 4 together with the simulation results. Notice that, as in the other cases, the agreement between data and simulation is quite good.

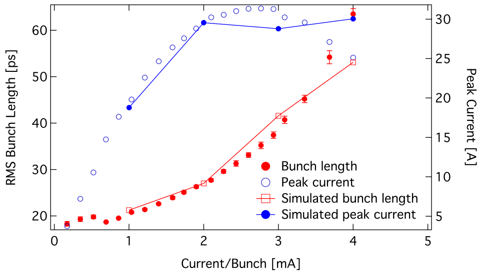

Figure 4: Measured and calculated bunch length for different current in the Comb mode.

For the 240 mA it is possible to see that the calculated bunch length is quite different from the measured one and this is due to the appearance of a longitudinal instability which elongate the bunches. The maximum peak current we achieved in the Comb mode was 35 A, 36% less than in the normal and hybrid-5 modes showed in the sections before, for a total stored current of approximately 180 mA. Although the peak current is smaller, the repetition rate of the camshafts is a factor 60 and 12 higher than, which means that the average intensity on the samples should be 38 and 8 times higher than the normal and hybrid-5 mode respectively, making the Comb-Mode an interesting candidate for the FEMTO beam line.

CONCLUSION

We set up and characterized three different modes for SLS. For the first mode (Special Mode), on the one hand, there is a good agreement between the effective bunch lengthening obtained experimentally and with simulation; the values calculated for the relative increase of total beam lifetime, on the other hand, point in the same direction but the observed lifetime increase with the new filling pattern is almost a factor 2 smaller than the predicted one. This effect on lifetime could be due to differences in the settings of the 3HC or because the parameters used for calculating the total lifetime have changed since the last systematic measurement was performed (2001). For the Hybrid-5 mode the program was able to point out which current distribution was more suitable for the FEMTO operation giving bunch length values comparable with the camshaft measured profiles. For the Comb mode we were able to reproduce the measured bunch length and for a total current of 180 mA we see that in this mode the intensity available to the beam line would be between 38 to 8 times higher than in other modes. We benchmarked a code that calculates the bunch lengthening of the 3 HC cavity for a given filling pattern. The code was tested against 3 different fillings and results from simulation are in very good agreement with the data.

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