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New Filling Pattern for SLS-FEMTO

Natalia Prado de Abreu, Paul Beaud, Gerhard Ingold
and Andreas Streun

Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

A new filling pattern was developed envisioning the upgrade of the FEMTO laser. The new filling pattern was tested and optimized and could be used as a normal user operation mode with a few more modifications. We show, in this report, the results of the test of 2 different filling patterns.

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Introduction

The working principle of the FEMTO beamline uses a laser beam interaction in the modulator wiggler to introduce an energy modulation in a thin slice of the bunch. The dispersion of the magnetic chicane transfers the energy modulation to a horizontal amplitude in order to separate the short satellite bunches laterally from the core beam. The radiation from one of the satellites is then extracted by a system of apertures (slits) whereas the radiation from the core beam and from the chicane magnets and ring dipoles is blocked.

Since the laser repetition time is shorter than the horizontal radiation damping time, the satellite does not merge back into the core beam before the next laser beam interaction. But due to the dependency of the betatron tune on energy and amplitude it filaments and forms a beam halo. Some amount of the halo radiation will be transmitted by the apertures of the beamline and provide an unwanted background signal. Depending on the laser repetition time, the halo is composed from the relics from a number of previous laser beam interactions. The total halo radiation accepted by the beamline determines the noise-to-signal (N/S) ratio of the experiment [1].

An upgrade of the laser repetition rate from the present 2 kHz to 10 kHz is under consideration to increase the flux for FEMTO. Before purchasing a new laser however a new filling pattern has to be tested. This new filling patten 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.

We were able to define a new filling in which the camshaft bunch would not suffer so much from transient effects from the third harmonic system [1] providing FEMTO with the necessary phase stability and peak current. In this report we describe the main characteristics of the hybrid-5 mode and compare the results with some previous tests of the same mode with a slightly different filling pattern.

Main Goals

The main concern when developing a new filling pattern for the SLS ring is to keep the reliability of the machine such that users not sensitive to the special mode will not notice any difference. In the case of the Hybrid-5 mode the idea is to have 5 camshaft bunches to be used in the FEMTO beamline that, together with the laser upgrade, will provide 5 times more flux.

The main goals in setting up the Hybrid-5 mode were:

- HOM free mode during store and injection;

[1] Comparison of the simulations of beam-cavity interactions and the effect of transient effects in the 3HC in SLS will we be further discussed in the separate note, yet to come.

- 400 mA of total current;
- 5 camshafts with 4 mA each and with a bunch length of 30 ps;
- gaussian or nearly gaussian stable camshafts (no double peak distributions);
- stable beam phase;
- at least 4 hours of beam lifetime and
- make sure that all other ring systems and parameters are working properly and/or with acceptable values (orbit correction, RF, etc...).

New Filling setup and Optimization

The first test of a Hybrid -5 mode was carried out in December 2008 where a train of 60 bunches were followed by 11 empty buckets, a camshaft and an additional 24 empty buckets, repeating five times around the ring (see Figure 1). This amounts to an average current in the filled buckets of 1.3 mA. The main problem in this setup was that the camshaft suffered from transient effects due to the third harmonic cavity which happen to have a relative phase with the accelerating system just right to define a longitudinal potential with two very close stable fixed points. This leads to a split in the bunch, which in the streak camera image had 2 peaks, as shown in Figure 2 (B), and a heavy reduction on the THz radiation measured at the FEMTO beamline.

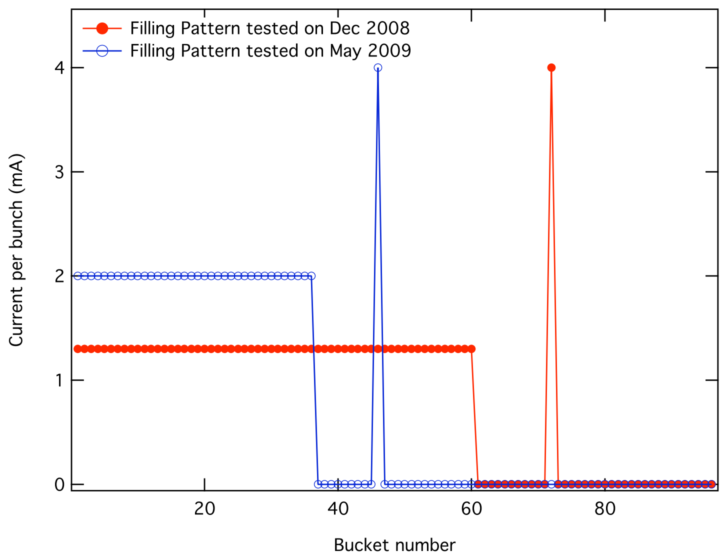

Figure 1: The two tested filling patterns for the Hybrid-5 mode.

The second attempt of a Hybrid-5 filling pattern was performed on May 26th and at this time the bunch train was filled with 36 filled bunches, 9 empty ones, the camshaft and more 50 empty buckets, repeated 5 times to cover all 480 buckets (see Figure 1). In this case the phase transient created in the 3HC is much higher than in the previous tested mode because the current is concentrated in less bunches, the average bunch current now is around 2 mA. In this case, when the camshaft reaches the cavity, the harmonic phase has a big offset with respect to the optimum phase and the effect of the 3HC, in this bunch, is almost transparent. The measurement of the THz in FEMTO, as well as streak camera pictures, shows that the bunch is not gaussian (see Figure 2 (A)) and has some asymmetry (the profiles look like a skew normal distribution), but apart from that it is stable and has only one peak, as shown in Figure 2 (C).

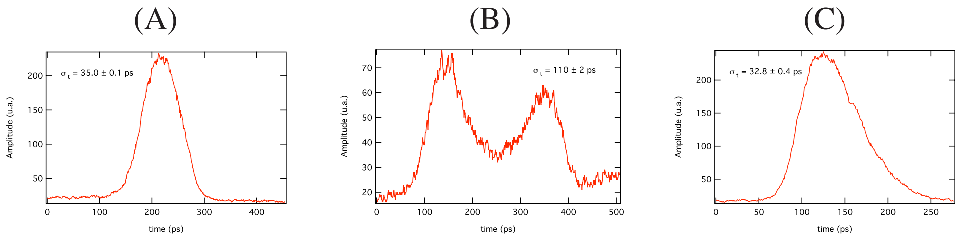

Figure 2: Beam profile measured with a streak camera. (A) Camshaft for the normal mode of operation; (B) Camshaft profile for the measurements of 2008 and (C) Camshaft profile for the measurements of 2009. In each picture is displayed the variance of the profile distribution.

Using the second type of Hybrid-5 filling pattern and using the skew quadrupoles and auxiliary sextupoles it was possible to achieve a beam lifetime of almost 5 hours at 400 mA with an average beam size of $\sigma_x = 67\ \mu m$ and $\sigma_y = 9.6\ \mu m$. The optimization of lifetime and beam size was done with the FEMTO wiggler closed (gap = 12.7 mm). However, probably due to the high charge in the bunches, the BPMs around the insertion device in sector X04 triggered an Orbit Interlock which prevented us from closing its gap.

First test with FEMTO beamline

On May 26^{th} we tested the Hybrid -5 mode also observing the beam from the FEMTO beamline. We stored 400 mA in this mode and monitored the appearance of HOMs, the temperatures in the tapers of sector X04 (X04SA-ID-TAPU/D:TC1/2), the bunch length using the streak camera and also made 2 scans of each bunch observing the THz radiation in the FEMTO beamline.

Figure 3 (A) show the THZ signal measured for each bunch, which is proportional to the square of the bunch charge. In Figure 3 (B) is also shown (dashed line) the scan made with the normal mode of operation where only one camshaft is used. We find that the phase shifts are smaller than the accuracy of the measurement (c.a., 1 ps) and that the bunch is stable and has a single peak. These results are very promising, given that the THz peak intensity measured in the Hybrid-5 mode is slightly lower than the one measure of in the mode with only 1 camshaft. Therefore we can expect to achieve similar photon counts with the new mode.

(A) (B)

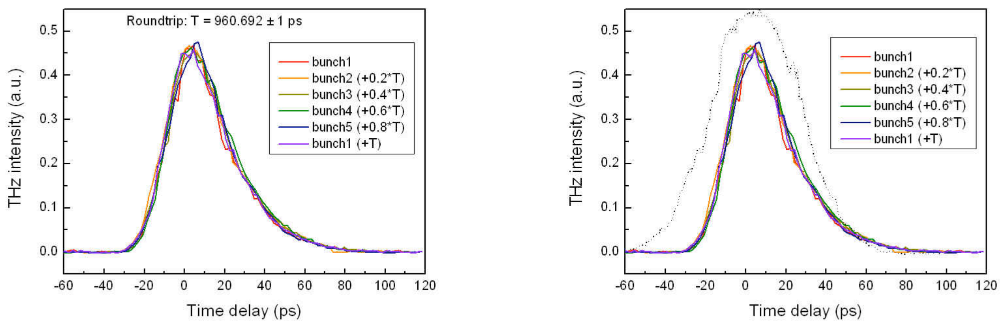

Figure 3: (A) Beam profile measured at the FEMTO beamline for the hybrid 5 mode. (B) Comparison of measured profiles for the hybrid 5 and the normal operation mode (black dashed line in the plot).

Additional to-do list

Although the first tests with the Hybrid-5 mode are promising it is still necessary to check and optimize some of the machine systems and parameters in order to have a fully operational new filling mode. A list of this steps is given below:

- Make a BBA to get the BPMs right calibration constants;
- Check for the new BPM calibration settings;
- Check if there is saturation in the BPMs reading due to the high current per bunch in this mode;
- Define a new operational mode for the BPMs in sector X04SA, just before and after the material science wiggler in order to be able to close the ID gap;
- Further optimization of lifetime and beam size using the skew quadrupoles and auxiliary sextupoles;
- Check with all other users if this new mode of operation is transparent or at least acceptable.

Conclusion

We successfully set up and tested a Hybrid-5 mode in which 5 camshafts are included between small bunch trains. This represents an increase of 5 times in the FEMTO flux and is a possible scenario for the laser upgrade for this beamline. Most of the important parameters, as stability and lifetime, where tested and are in accordance with what is accepted by FEMTO and other beamlines, however some more optimization is necessary in order to make this mode fully operational.

APPENDIX: First test of the Comb-mode - a new ”Hybrid” 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 since the repetition rate for the new laser is 10 times higher than the case of 10 kHz upgrade, what would require 50 single-bunches.

In our first try, on July 9^{th}, 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 in Cavity 04; we also observed a pressure rise in the other cavities of the machine. The first results for this mode are show in Figures 4 (A) and (B).

(A) (B)

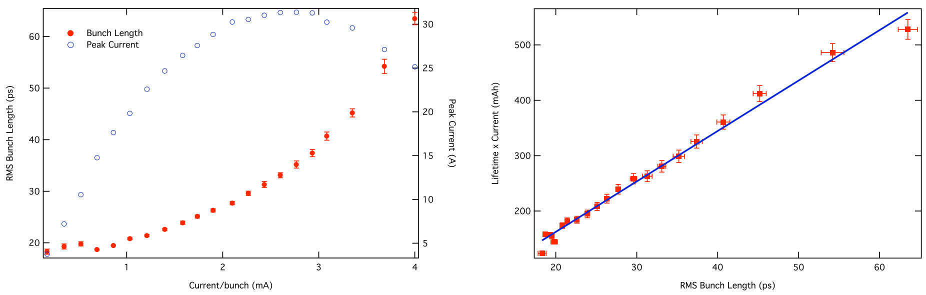

Figure 4: First test of the Comb-Mode. (A) Rms bunch length and peak current as a function of the current per bunch and (B) Linear dependence of the Lifetime*Current versus bunch length indicating the lengthening is not due to instabilities in the beam.

For the mode of operation with only one camshaft or the Hybrid 5 mode the peak current in the single-bunch is around 50-55 A. As can be seen in Figure 4 (A) the maximum peak current achieved was around 33 A in the Comb-mode, which is 40% lower than the usual value for FEMTO. In Figure 4 (B) one can observe that there is a linear dependency of the product of lifetime and current to the bunch length showing the the bunch lengthening observed is not due to instabilities. Up to 240 mA all bunches had a single-peaked gaussian profile.

This is just a first test of this new mode and more studies are to follow. The next step is to detune the 3HC in order to reduce the bunch lengthening at higher currents in an attempt to obtain the necessary peak current of 55 A and than next try to store 400 mA in this mode in order to make it compatible with all other SLS users.

References

[1] A. Streun, “Halo background in SLS-FEMTO”,Internal Report SLS-TME- TA-2008-0311.