TESTS OF A NEW BUNCH CLEANING TECHNIQUE FOR THE ADVANCED LIGHT SOURCE*

W. C. Barry, M. J. Chin, F. Sannibale, LBNL, Berkeley, CA 94720, U.S.A.

Abstract

A new bunch cleaning technique is being tested at the Advanced Light Source (ALS) of the Lawrence Berkeley National Laboratory. The new procedure allows for high purity, arbitrary filling patterns and is potentially compatible with standard user operation and with the incoming top-off injection mode. The description of the new system and the results of the first tests at the ALS are presented.

INTRODUCTION

The Advanced Light Source at the Lawrence Berkeley National Laboratory is a third generation synchrotron light source operating at 1.9 GeV and optimized for the generation of soft x-rays. The storage ring usually operates with 400 mA of stored electrons equally distributed among 276 contiguous buckets out of a total of 328 available. The main reason for having a gap of empty buckets of this size is to allow some users to perform experiments with a long relaxation time. For such users, a higher current "camshaft" bunch (~10 mA) is placed at the beginning of the ~ 100 ns gap. The light from the camshaft excites the samples and the empty gap of ~ 100 ns permits data taking during the sample relaxation period without the contaminating radiation of the other bunches.

In a real machine, because of imperfect injection, some of the "empty" buckets are usually populated with undesired electrons. At the ALS, the current of the parasitic bunches is typically of the order of 0.1% with respect to the camshaft. This is a severe limitation for a number of users that require bunch “purity” of 10^{-4} or better. For a total period of about 4 weeks per year, a special mode of operation with only two high current bunches (~ 30 mA/bunch spaced 328 ns from each other) is run, with a procedure for cleaning the undesired bunches added to satisfy these special purity requirements.

Unfortunately, the present ALS bunch cleaning technique is not compatible with standard camshaft user operation, nor with the incoming top-off injection operation. In order to overcome these limitations, a new bunch cleaning technique is being tested and in this paper we report on the results obtained so far.

CLEANING TECHNIQUE DESCRIPTION

At the present time, during the special two bunch mode of operation, bunch cleaning is performed in the ALS storage ring every ~ 2 hours, right after injection and energy ramping to 1.9 GeV. The beam impedance of the ALS vacuum chamber induces a shift in the betatron frequency that depends on the single bunch current. Because of this, the small current parasitic bunches have a tune that is significantly different from that of the two high current main bunches. By stimulating the beam at the betatron frequency of the parasitic bunches, one can generate large transverse oscillations of the undesired bunches with minor excitation of the main bunches. A scraper can then be inserted to clean these unwanted particles without disturbing the “good” bunches.

The described procedure achieves the required level of purity but requires several minutes for the complete cleaning cycle and significantly perturbs the main bunches, making it incompatible with top-off operation where the beam will be injected every ~ 30 s and with normal user operations with the camshaft.

A promising new technique has been proposed [1] that has the potential to overcome these limitations.

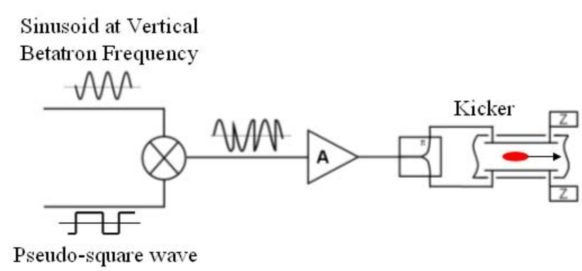

Figure 1: Basic scheme for the new cleaning technique.

With reference to Fig.1, two signals, a sinusoidal wave at the frequency of one of the betatron sidebands and a pseudo-square wave that switches polarity synchronously with the transit of the bunches to be saved (see Fig. 2), are mixed together. The resulting signal is still an excitation at the beam betatron tune, but has zero amplitude at the passage of the good bunches.

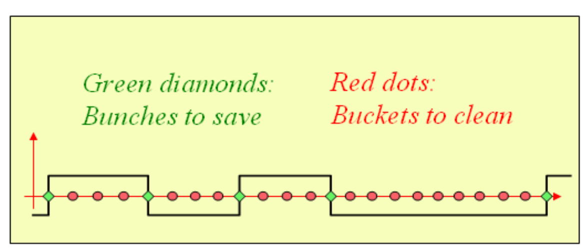

Figure 2: Example of the pseudo-square wave signal.

The signal is then amplified and sent to a transverse kicker for beam excitation. If the amplitude of the excited oscillations is large enough, the parasitic bunches will be

* Work supported by the Director, Office of Science, of the U.S. Department of Energy under Contract DE-AC02-05CH11231.

lost in the smallest aperture part of the vacuum chamber while the main bunches will be unaffected.

The described technique is already in routine operation at Spring 8 [2] in Japan and is being tested at the ESRF [3] in France. In both of these cases, the cleaning is performed in the injector booster ring during energy ramping. At the ALS, we are trying to clean in the storage ring for several reasons: i) in our present lattice we measured electron diffusion from one bunch to the other [4] and being able to clean in the storage ring when the contamination level becomes unacceptable will solve this problem; ii) cleaning in the storage ring can be simpler than in the booster because of the generally more stable and reproducible beam characteristics; iii) the requirements for a clean injection become much more relaxed; iv) the relatively low energy of the ALS allows for a reasonably low level of power in the cleaning amplifiers; v) most of the expensive hardware needed for the cleaning (kickers and amplifiers) already exists in the storage ring as a part of the transverse feedback system (TFB) and can immediately be used for the cleaning.

The drawback of cleaning in the storage ring is that it must be transparent to the users. This requires accurate and stable timing for the cleaning system along with a bandwidth in the power amplifiers large enough to switch from zero to full excitation in less than a RF period.

If the cleaning time is short compared with the interval between two injection cycles (~ 30 s for the future ALS top-off operation), then a “veto” signal can be sent during the cleaning to the more sensitive users allowing them to disregard or inhibit data taking during that period.

THE ALS IMPLEMENTATION

Table 1 shows the relevant ALS parameters and the cleaning system settings used during the test. We excited the beam at the vertical betatron sideband with the lowest frequency. The vertical plane was selected because of the smaller aperture that the vacuum chamber presents in this plane. The excitation was distributed over a band of a few kHz, in order to account for tune variation with energy due to the non-zero chromaticity, for tune shift with amplitude due to lattice non-linearities and for tune spread due to the jitter in our quadrupole power supplies.

As already mentioned, we mainly used hardware from the existing ALS TFB: the 10 KHz – 250 MHz 300 W class A solid state amplifier and the transverse kicker, a simple 30 cm stripline. Both the TFB and the cleaning systems could operate simultaneously without any noticeable interference.

The only new part in the system was the pseudo-square wave generator. A low cost Xilinx demonstration board, the ML403 (HW-V4-ML403-USA), was used to build a variable delay/variable width pulse generator clocked at the ALS 500MHz RF frequency. The ML403 is a general prototyping platform for the 4VFX12 Virtex-4 FPGA. The ML403 differential SMA inputs were connected directly to the outputs of a Mini-Circuits ADT1-1WT RF transformer fed by the single-ended ALS RF.

Inside the 4VFX12, the 500MHz was divided by 4, and then fed into a Digital Clock Manager (DCM) module configured for +/-256 steps of phase control. This clock reduction was done to make routing of the FPGA logic easy. Although 125MHz clocking to the pulse generator meant that clock edges would step by 4 with respect to the bunches, the phase control of +/- 256 steps over 8ns provided by the DCM allowed for a minimum timing step of ~ 16 ps and was sufficient to align a zero-crossing of the pulse to any bucket.

Setting of the delay and width of the pulse was provided by a Control Room PC LabVIEW application running a simple sockets communication protocol that was received via Ethernet and interpreted by software running on the 4VFX12’s Power-PC core processor. This allowed the ML403 to be installed inside the ring at the TFB rack.

Both the FPGA firmware and the Power-PC software were stored in the ML403’s on-board FLASH memory, allowing the system to self-configure on power-up.

Table 1: ALS Cleaning system relevant parameters

Beam energy	1.9 GeV
RF frequency	499.65 MHz
Revolution period	656.5 ns
Relative energy spread (rms)	0.1 %
Vertical Tune	8.20
Vertical chromaticity	1.4
Vertical excitation frequency	304.6 kHz
Excitation bandwidth	4 kHz
Kicker type	stripline
Kicker transverse shunt impedance	~ 9000 Ω
Amplifier operation power	~ 150 W
Amplifier bandwidth	~ 250 MHz

EXPERIMENTAL RESULTS

Figure 3 shows scope tracks of some of the cleaning system signals. In the left panel the time scale is 4 ns per division and the scope is in a long persistence mode.

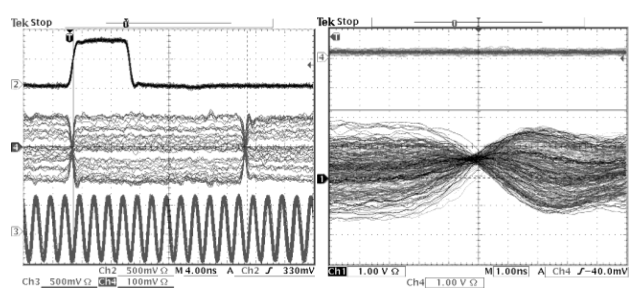

Figure 3: ALS cleaning system characteristic signals. See text for the description.

The lower track shows the 500 MHz RF frequency of the ALS, used as the master clock for the system. The top track is an “orbit clock” synchronous with one of the good bunches and used for triggering the scope. The central track shows a portion of the excitation signal applied to the beam as measured at the transverse kicker output at the very end of the whole chain. The amplitude of the signal changes according to the sinusoidal excitation at the betatron sideband frequency but it is always zero in two points ~ 24 ns apart (in this particular example the pseudo-square wave was set in order to "save" one bunch out of every twelve. On the right panel the same signal is shown on a time scale of 1 ns per division. The expanded scale illustrates that the actual excitation, measured at the good bunch position, is not zero but it is ~ 1/9 of the signal applied to the other bunches. The actual situation may be better, since in the measurement the jitter of the orbit clock used for triggering the scope could have led to some overestimation of the residual excitation. The track also shows that at plus and minus 2 ns from the good bunch the next adjacent bunches receives a kick at ~ 100 % of the maximum available, indicating that the bandwidth of the whole system and in particular of the power amplifiers is large enough.

The proper timing between the cleaning signal and the beam is achieved by first adjusting the delay in the FPGA board in order to overlap the "zero" excitation notch of Fig. 3 with the signal induced in the same track by the beam. The timing is then fine tuned by further adjusting the FPGA delay to minimize the vertical beam spot size at one of the ALS synchrotron light monitors. During the tests with beam, the variation induced on the vertical beam size by the residual excitation was typically less than 10% of the beam size, with the lower values ranging in the few percent level.

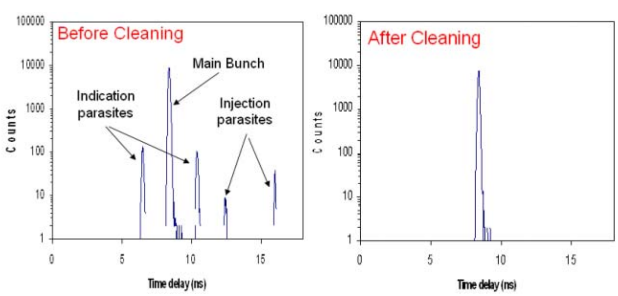

Figure 4: Bunch population at the ALS before and after bunch cleaning

In March 2006, the cleaning technique was extensively tested during the two weeks of two-bunch user operations with successful results. Figure 4 shows two high resolution measurements of the bunch population in the neighbour of one of the main bunches performed at the ALS BL 7.0.1 beamline. The left panel shows the situation right after injection. One of the main bunches is clearly visible along with two "indication" parasites injected on purpose and used for controlling the cleaning process in another purity monitor, faster but with a lower resolution (the population of the main bunch and of the 2 indication parasites is measured in a scope by using the signal from a BPM electrode). Some additional parasites arising from imperfect injection are also visible. The right panel shows the population right after the cleaning procedure. All the parasites are completely wiped out, while the main bunch population is roughly the same, giving a measured purity level smaller than ~ 10^{-5}.

Overall the new procedure was much easier to use than the old one, and allowed for very fast cleaning of the bunches with no need to insert a scraper. The cleaning time was of the order of one second, but during this period of operation we conservatively kept the cleaning signal on for ~ 1 minute. As mentioned before, the actual cleaning time is an important quantity for understanding the compatibility of this system with top-off operation. Fast measurements with high resolution are extremely difficult to do and we are planning to evaluate this quantity mainly by simulations. Nevertheless, these preliminary results seem promising.

During this test period, the beamline shutters were conservatively kept closed when the exciting signal was on, and only after the completion of the cleaning were the shutters opened and light given to users.

In order to verify the possibility of cleaning during experiment data taking, a test in collaboration with some of the two-bunch users was performed. We switched the excitation signal on and they characterized the perturbation induced in their measurements. The results were good: none of them was able to measure any significant contamination of their data. More systematic cleaning tests with a larger number of users are required in order to fully understand the compatibility, especially during normal multibunch camshaft operations, when a large number of stability-sensitive experiments run.

CONCLUSIONS

A new bunch cleaning technique has been successfully tested at the Advanced Light Source storage ring. The results showed a cleaning capability with purity better than 10^{-5}, simplicity of use, reliability and potential compatibility with normal multibunch user operation and with top-off injection mode.

ACKOWLEDGEMENTS

The authors want to express their thankfulness to A. Tremsin, J. Guo and C.-W. Chiu for the bunch population measurements at BL 7.0.1, and to E. Plouviez and P. Ellaume for sharing their operational experience with the ESRF cleaning system.

REFERENCES

[1] H. Suzuki, *et al.*, Nuclear Instruments and Methods in Physiscs Research A 444 (2000) 515-533.
[2] T. Aoki, *et al.*, Proceedings of the 2003 Particle Acc. Conference, Portland, US, May 2003, p. 2551.
[3] E. Plouviez, ESRF Machine Technical Note 01-04/MDT.
[4] W. Byrne, *et al.*, "Bunch diffusion measurements at the Advanced Light Source", this conference.