BUNCH DIFFUSION MEASUREMENTS AT THE ADVANCED LIGHT SOURCE*

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Abstract

In storage ring based synchrotron light sources, a long beam lifetime is usually a fundamental requirement for a high integrated brightness. The dynamic aperture and the momentum acceptance of lattices are carefully studied and maximized as much as possible for a long lifetime performance. On the other hand, large momentum acceptance and dynamic aperture increase the probability that a particle diffuses from one bunch to another. Diffusion can represent a severe limitation for those experiments where the samples have long relaxation times requiring empty buckets between bunches. At the Advanced Light Source (ALS) of the Lawrence Berkeley National Laboratory we have characterized the particle diffusion for the present lattice in order to evaluate its impact on a special user operation dedicated to these long relaxation time experiments and on the incoming top-off injection mode for the ALS.

INTRODUCTION

The Advanced Light Source (ALS) at the Lawrence Berkeley National Laboratory is a third generation synchrotron light source operating at 1.9 GeV and optimized for the generation of high brightness soft x-rays. Twice per year a special user operation shift of two weeks is dedicated to experiments where a long relaxation time for the samples is required. During such a period, only two opposite bunches are stored in the ring with about 30 mA of current each. Experiments require that all the other 326 remaining buckets must be free from particles at a “purity” level of ~ 0.001% of the total stored current. Such a requirement can only be fulfilled by using special procedures that clean the "empty" buckets of undesired particles, which can be due to non-perfect injection, for example. Even after a succesful cleaning, particle diffusion from one bunch to another can progressively repopulate empty buckets, necessitating a new cleaning procedure after some period of time. Because of this, characterization of the diffusion rate is important so the proper bunch cleaning strategy can be adopted.

The diffusion rate depends on the ring lattice and in particular on its dynamic aperture and momentum acceptance. In modern storage rings, these two parameters are usually carefully maximized for a long beam lifetime. In this situation, longitudinal phase space trajectories outside the RF bucket can exist and can bring a beam particle scattered by synchrotron radiation emission, Coulomb scattering, residual gas scattering, etc., from the parent bunch to the proximity of a following bucket. At this point, a new photon emission or a scattering phenomenon can result in the “capture” of the particle by the bucket, generating diffusion.

In this paper the diffusion measurements performed with the present ALS lattice are presented.

BUNCH POPULATION MONITOR DESCRIPTION

The bunch population at the ALS was measured with a photon counting detector at beamline BL 7.0.1, in the branch dedicated to x-ray inelastic scattering experiments. Figure 1 shows a schematic diagram of the beamline. Samples of different materials can be illuminated by a pulsed monochromatic x-ray beam. The timing and duration of each photon bunch is determined by the position and length of electron bunches in the storage ring and the brightness of the photon bunch is proportional to the number of electrons in the electron bunch.

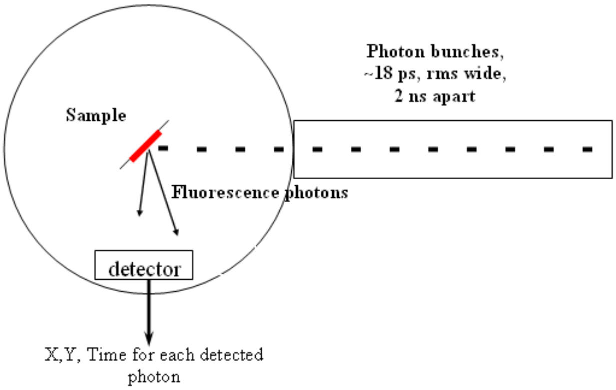

Fig. 1. Schematic diagram of the experimental set-up on BL 7.0.1. The X-ray photons from the pulsed source excite the sample, which fluoresces under X-ray irradiation. A position sensitive photon counting detector records individual fluorescence photons. The time of each photon is measured relative to the orbit clock signal. Different materials have been investigated, some of which do not result in any delay in the emitted fluorescence photon.

The ability of BL 7.0.1 to accurately measure the timing of each recorded photon allowed us to investigate the brightness and timing of the photon bunches which are, in turn, directly related to the longitudinal distribution and number of electrons in the storage ring bunches. The intensity of the scattered photon beam is tuned in order to

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have a single photon at the time impinging on the detector. The time of arrival of each photon at the detector is then measured relatively to the storage ring orbit clock. A total acquisition time on the order of one minute is generally sufficient to acquire enough statistics to construct a low noise time histogram of the detected events, which represent the bunch population in the ring. The detector has a variable width timing window that allows for accurate study of a small portion of the storage ring, e.g. a particular electron bunch and its vicinity. For the diffusion measurements presented here, we chose a Highly Ordered Pyrolytic Graphite (HOPG) sample material which does not exhibit any fluorescence delay, thus directly projecting the timing properties of the photon beam onto the detector input surface.

Figure 2 shows the schematics of the photon counting detector and of its associated electronics.

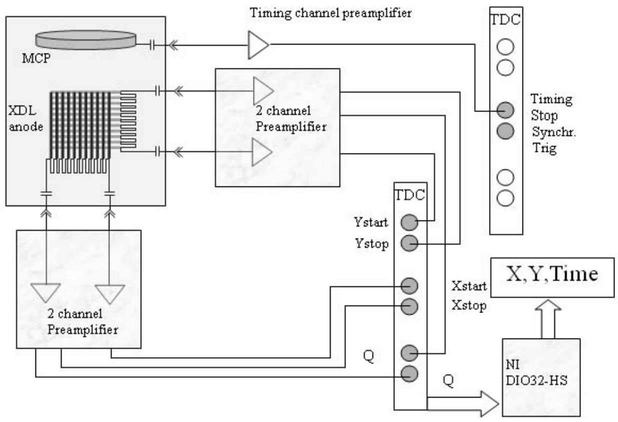

Figure 2. Schematic of the photon counting detector and associated electronics. MCP: micro-channel plate; TDC: time to digital converter electronics; NI DIO32-HS: digital I/O board.

A x-ray photon scattered by the sample produces a photoelectron at the detector input. The photoelectron is amplified by a factor of 10^6-10^7 by micro-channel plates (Photonis) and the resulting charge cloud is collected by a multi-anode readout electrode. The spatial resolution for each detected event, though not used in these measurements, is <50 μm for a 33 mm active area detector. The arrival time of the electrons with respect to the orbit clock is measured and digitised by time to digital converter boards (UCB-SSL) and finally acquired by a computer through a digital PCI I/O board (National Instruments). The overall time resolution of the photon system is ~ 130 ps FWHM, much smaller than the 2 ns time distance between contiguous ALS buckets. Example of bunch population measurements at the ALS are shown in Fig. 3 where a HOPG thin film sample was irradiated for about ~ 60 s by monochromatic 400 eV photons.

MEASUREMENTS

Figure 3 shows two of the bunch population measurements performed at the ALS beamline BL 7.0.1 during our characterization of particle diffusion. About nine out of the possible 328 storage ring buckets were monitored. The distance between contiguous ALS buckets is 2 ns and the peaks associated with the different bunches are clearly visible. The top panel of the figure shows the bunch population right after injecting 24.5 mA of electrons into a single bunch, which is identifiable as the highest peak in the plot. Several other peaks with relative amplitude of ~ 0.1% with respect to the main one are also visible in the panel. This is the typical situation for the ALS and such “parasite” bunches are due to the imperfect operation of the injector.

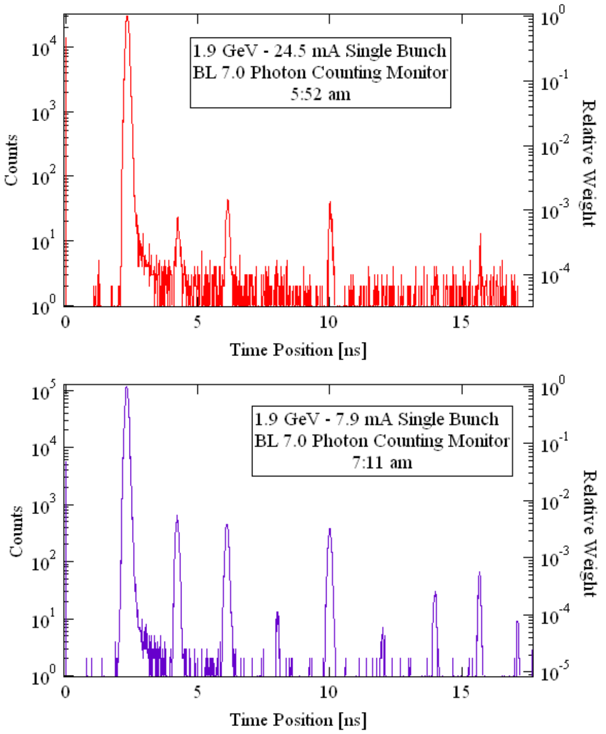

Figure 3. Bunch population measurements of a portion of the RF buckets of the ALS. Top panel: situation right after injection; bottom panel: situation after ~ 76 min.

The bottom panel shows the population for the same buckets after about ~ 79 minutes. The total current dropped from 24.5 mA to 7.9 mA, while the relative population in the parasites is increased and their relative amplitude is now ~ 1% of that of the main bunch.

Figure 4 shows the number of particles measured in the main bunch (red circles) and in the first parasite 2 ns downstream the main bunch (blue crosses) as a function of time. It can be seen that, while the current in the main bunch decreases, the current on the parasite increases due to diffusion of particles from the main bunch.

DATA ANALYSIS

Let us consider two contiguous bunches. The first one, which we will indicate as the main bunch, contains several orders of magnitude more particles than the second one, referred as the parasite bunch. The rate of change in the number of particles in the parasite bunch is given by:

$$\frac{dN_D}{dt} = DN_M(t) - \frac{N_D(t)}{\tau_D} \qquad (1)$$

where N_D and N_M are the number of particles in the parasite and main bunches respectively, τ_D is the parasite bunch lifetime and D is the diffusion coefficient. D is a constant that represents the probability that a particle diffuses from the main bunch to the parasite one in a unit of time.

The population in the main bunch at a given instant is given by:

$$N_M(t) = N_{M0}\exp(-t/\tau_M) \qquad (2)$$

where τ_M is the main bunch lifetime and N_{M0} its population for $t = 0$.

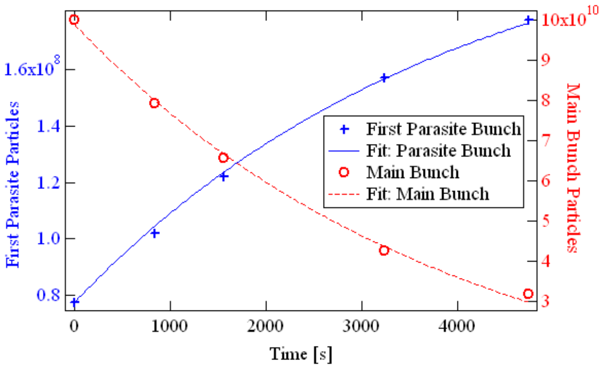

Figure 4. Crosses and circles: measured number of particles in the main and in the parasite bunches as a function of time. Solid and dashed curves: theory fitting functions.

The second term in the right hand side of Eqn. (1) becomes negligible when:

$$D >> \frac{N_D}{N_M}\frac{1}{\tau_D} \qquad (3)$$

In the following derivation, we assume that condition (3) is fulfilled and so we neglect this term. The validity of such an assumption will be verified once the value for D is known. Neglecting the term in Eqn. (1) and using Eqn. (2) we can integrate with respect to time, obtaining the following expression for the population of the parasite bunch:

$$N_D(t) = N_{D0} + \tau_M\, D\, N_{M0}\left[1 - \exp(-t/\tau_M)\right] \qquad (4)$$

The values $N_{D0} \sim 7.7 \times 10^7$ and $N_{M0} \sim 9.9 \times 10^{10}$ were extracted from the data in Fig. 4. Equation (2) was used for fitting the main bunch data (red dashed curve in Fig. 4) obtaining a value for τ_M during the measurement of ~ 3960 s. This lifetime and Eqn. (4) were then used for fitting the parasite bunch data (blue solid line in Fig. 4), obtaining for the diffusion coefficient:

$$D \cong 3.6 \times 10^{-7}\ s^{-1} \qquad (5)$$

Using this value for D and considering that during these measurements τ_D was ~ 40 hours and N_D/N_M was between 10^{-2} and 10^{-3}, one can verify that criterion (3) was actually satisfied.

CONCLUSIONS

The measured diffusion coefficient at the ALS implies that for maintaining the bunch purity of 10^{-5} required by user experiments, a bunch cleaning procedure needs to be performed every ~ 27.5 s. Such a number is compatible with the incoming top-off injection mode of operation where a single shot injection cycle will be performed in the storage ring every ~ 30 s. The new bunch cleaning procedure being used at the ALS [1] generates a small perturbation on the beam that lasts for less than a second. By doing the cleaning right after the injection, the same "veto" signal sent to "sensitive" users to indicate that the beam is being perturbed by the injection transient can also be exploited to alert them of the perturbation from cleaning.

If other modes of operation will require a longer period between two bunch cleaning procedures, then the diffusion coefficient needs to be decreased. This can be achieved, for example, by reducing the dynamic aperture of the lattice and finding the proper compromise between lifetime and a reasonable diffusion rate.

ACKNOWLEDGEMENTS

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REFERENCES

[1] W. C. Barry et al., "Tests of a new bunch cleaning technique for the Advanced Light Source", this conference.