NOVEL SCHEMES FOR SIMULTANEOUSLY SATISFYING HIGH FLUX AND DYNAMICS EXPERIMENTS IN A SYNCHROTRON LIGHT SOURCE*

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Abstract

Typically storage ring light sources operate with the maximum number of bunches as possible with a small gap for ion clearing. However this mode is not desirable for users doing dynamics or time of flight experiments. These users would like to see only one or two bunches in the ring. The standard approach to satisfying these users is to have separate running times with only a few bunches in the ring – which is not a desirable mode for high flux users. The inability to satisfy both high flux applications and time of flight applications simultaneously is one of the main limitations of synchrotron light sources as they are now operated. In principle it is possible to tailor the properties of individual bunches in such a way as to simultaneously satisfy both classes of uses simultaneously. This paper will discuss several novel schemes that may be able to accomplish this.

INTRODUCTION

Storage ring synchrotron light sources have proven to be one of the most successful tools for probing matter. These light sources can provide light with a variety of properties – high photon flux and brightness, large range of wavelengths (IR to hard x-rays), semi-coherent, short pulses (~10 ps), and variable polarization (linear, circular, elliptical). One of the most attractive features of synchrotron light sources is the ability to simultaneously serve multiple users with a diverse set of requirements. These light sources are very popular as evidenced by the large number of users. In the USA alone, there are more than 10,000 users of the Department of Energy's four synchrotron light sources. And this is a small fraction of the total number of worldwide users.

Even with their success there are still limitations of these light sources. One such limitation is in the ability to serve two classes of experiments simultaneously – namely high flux/brightness experiments together with dynamics/time-of-flight experiments. For high flux and brightness users the storage ring is typically operated with the maximum number of bunches as possible with a small gap for ion clearing. This is in contrast with the dynamics/time-of-flight users that wish so have a large spacing between pulses – microseconds and longer. For rings of large circumference this is somewhat accomplished by having a hybrid filling pattern where part of the ring is filled with consecutive bunches while simultaneously having large gaps in other sections of the ring. In this manner it is possible to have ~ 1 microsecond between pulses while still providing high average current. For smaller rings this is not possible.

So the ALS as well as other light sources, dedicates several weeks per year to a mode of operation where two high current bunches are stored into diametrically opposed buckets. This special mode allows users to perform experiments requiring a long relaxation time. The photons from the main bunches excite their samples and the gap between the two bunches (~ 330 ns) permits data taking during the sample relaxation without the contaminating radiation from other bunches. During standard multi-bunch operation at the ALS 276 contiguous buckets of the 328 available are filled with electrons. A single high current bunch (the "camshaft") is then injected in the remaining ~100 ns gap of empty buckets. Unfortunately, for many dynamics/time-of-flight experiments, the empty bucket gap is too small for them to take data.

Are there other ways to simultaneously satisfy these two classes of users? Below we present a number of schemes that might be possible. The basic theme for these schemes is that one "tailors" the characteristics of individual bunches. For example by changing the orbit or energy of one bunch with respect to the remaining bunches, it is possible to separate the light from that bunch either geometrically or chromatically.

In addition it may be possible to do more. For instance it may be possible to generate a shorter pulse length in individual bunches from those in the long bunch train. The ability to generate short pulses is of great interest to many dynamics users. There already exist a few schemes for generating short pulses in storage rings. One of the well known examples of achieving this is through femto-slicing [1]. In this paper we extend also discuss some other schemes generating "short" pulses for some users while generating high current for other users. This versatility would greatly extend the utility and capabilities of usefulness and capabilities of storage ring light sources.

SIMULTANEOUS SCHEMES

In a multi-bunch fill pattern, the properties of a single bunch can be tailored to have different characteristics then the other bunches. For instance if one changes the orbit and/or the energy of one bunch (or even part of one bunch) with respect to the remaining bunches then the radiation can be separated either spatially or chromatically. The next two sections present two other schemes that have experimentally demonstrated tailoring of a single bunch within a multibunch beam – Pseudo-single bunch kicking and Simultaneous Alpha Buckets.

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Pseudo-single bunch.

To overcome the small gap problem and to allow data taking for these experiments during standard multibunch operation, a new scheme of operation has been developed and is presently being tested at the ALS [2].

Table 1: Fast kicker system characteristics

Parameter	Value
Kicker type	Stripline
Electrode length	0.6 m
Characteristic impedance	50 Ohm
Deflection angle at 1.9 GeV	73 µrad/kV
Pulse amplitude	1 kV
Repetition rate	~ 3 MHz (max)
Kicker Pulse width	~ 60 ns FWHM
Shot to shot stability	< 2.5 x 10^{-3}

A fast kicker system capable of selectively kicking turn by turn the camshaft without perturbing the other bunches in the ring was constructed and installed in the ALS ring. Table 1 shows the main parameters of the system. By using such a kicker to synchronously kick the camshaft, one can force it on a stable vertically displaced orbit. The beamline users located where the displacement is large can collimate out the photons from the other bunches and only use the radiation from the displaced camshaft bunch. By operating in this way a pseudo-single bunch mode can parasitically be achieved during standard multibunch operation.

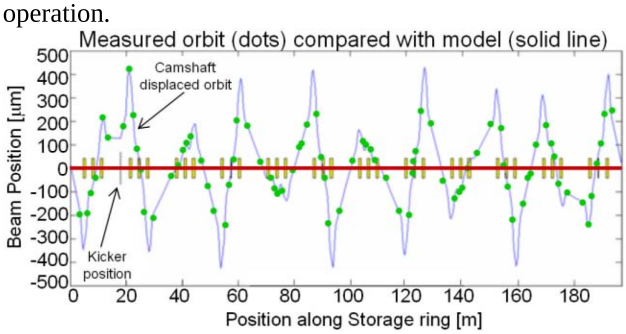

Fig. 1. Theoretical and measured displaced orbit of the camshaft bunch.

Fig. 1 shows the remarkable agreement between the theoretical displaced camshaft orbit (solid line) and the actual orbit (dots) measured when the kicker was operated at 1.522 MHz (ALS revolution frequency) with a ~750 V excitation (~ 55 µrad kick). The figure also shows how in some of the beamlines (position along the ring) the displacement is large enough to allow them to operate in the pseudo-single bunch mode.

Also by kicking the bunch every nth-turn, the orbit does not close for n-turns and potentially interesting orbits can be generated. One can control the "repetition rate" of the pseudo-single bunch to a certain extent because each kick frequency creates a different displacement at the beamline. This makes reaching each beamline with one kicker attainable. When triggering the kicker every other turn, the effect at the synchrotron light monitor is quite obvious (Fig. 2).

Furthermore, the displacement amplitude can be controlled by exploiting the fact that the orbit is proportional to $1/\sin(\pi\nu)$. Since the vertical fractional tune in the ALS is .2, kicking the bunch every fifth rotation will in resonance with the beam. If the tune was exactly .2, the bunch would be kicked out of the accelerator. However, if the tune is changed a small amount off .2, the kick will be just off resonance and a potential large amplification of the bump can be achieved. Fig. 3 shows the result for a vertical tune of 9.188. Local single bunch-closed bumps can be also obtained if more than one kicker is used.

Fig. 2. Synchrotron light image kicking every other turn.

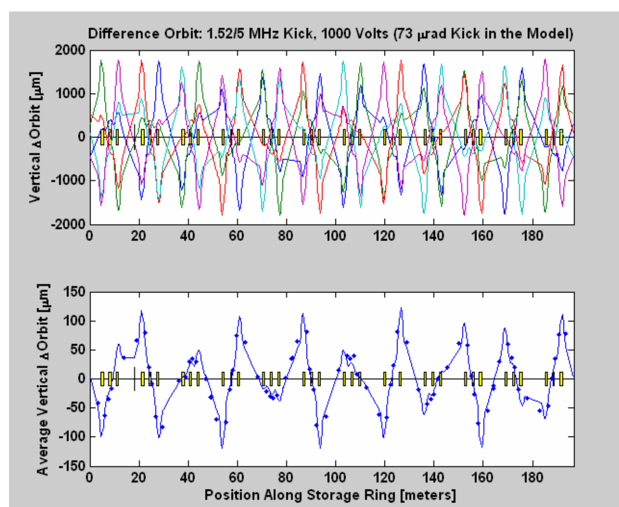

Fig. 3. Top: 5 model orbits when kicking every fifth turn. Bottom: average of the 5 model orbit as well as the actual difference orbits (dots).

Initial tests of the system at the ALS have been very encouraging. Before the pseudo-single bunch can become an official mode of operation, more extensive testing needs to be done. For example, the transparency of the operation for the all the beamlines not using the pseudo-single bunch must be systematically and carefully investigated. More detailed information on the system can be found elsewhere [3].

Simultaneous Alpha Buckets

Another method for separating the radiation of one bunch from the rest is to change the energy of that bunch. In that way the bunch will both follow a different orbit (dispersion orbit). Also the difference in energy can be utilized to isolate that bunch. For instance if one can obtain a sufficiently large energy shift then the radiation from an insertion device peak will be shifted and can be isolated with a monochrometer.

One way to have one bunch with a different energy than the others is to create other stable energy fixed points. This can be done by controlling the nonlinearities of the longitudinal motion. If we look at the longitudinal equation that relates the relative circulation time of a particle with respect to the nominal particle (ΔT/T) as a function of the relative energy deviation of the particle with the nominal particle (δ) one has

$$\frac{\Delta \mathrm{T}}{\mathrm{T}} = \alpha_1 \delta + \alpha_2 \delta^2 + \alpha_3 \delta^3 + \alpha_4 \delta^4 + \ldots \quad (1)$$

where α_1, α_2, α_3, and α_4, are the first, second, third, and forth order momentum compaction factors [4]. The off energy fixed points are given when ΔT/T = 0. Depending upon the strength of the momentum compaction factors, eq. 1 may have more than one fixed point with different values for δ. If there is a sufficiently large stable region around the fixed points then one can populate them with current thus having some bunches with different energies.

This has in fact been already achieved at several rings – first at BNL's UV ring [5] and more recently at SOLEIL [6]. The Brookhaven group called this mode of operation "simultaneous alpha buckets". At Brookhaven, they were able to store bunches with an energy deviation of ~0.5%. They showed that they had the predicted photon energy shift in the insertion devices (~1.5% on the third harmonic). This peak could be easily selected with a monochrometer.

In the SOLEIL experiment they stably circulated bunches with 3 different energies. The difference between the SOLEIL experiment and the Brookhaven experiment was that in the Brookhaven experiment only α_1 and α_2 were important whereas α_3 was also important (larger) for the SOLEIL experiment.

ADJUSTING THE PULSE LENGTH

There is a qualitatively difference between the two experiments that is very suggestive. One can define the effective momentum compaction, α_{eff}, as the local momentum compaction near a fixed point. In the case of the Brookhaven experiment the magnitude of α_{eff} , was the same for each fixed point. For the SOLEIL experiment, the magnitude of α_{eff} for the two off-energy buckets was nearly twice that as for the on-energy bucket. Since the bunch length is proportional to the squareroot of α_{eff}, the bunch lengths of bunches in the different buckets was different. Now one may not make too much of a squareroot of 2 difference however by just playing with eq. 1 it is possible to make the different α_{eff}s much larger. So one could run some bunches in a normal momentum compaction mode and others in a quasi-isochronous mode. It still remains to see if one can arrive at a lattice where one can practically do this but in principle it is possible (see Fig.4).

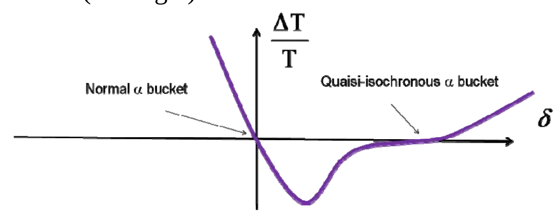

Fig. 4. Momentum compaction factors adjusted to have a large and small momentum compaction bucket.

Finally another way of producing at times a short pulse with a long time between pulses is to combine the pseudo-single-bunch mode of operation by exploiting synchrobetatron coupling. It was demonstrated at the APS [ref] that by transversely kicking the beam it is possible through synchrobetatron coupling to cause a tilt in the beam. This can be combined with pseudo-single-bunch operation by first putting one bunch on a different orbit and then occasionally "not" kicking it. Then the bunch will tend to wobble about the new orbit and at certain turns it will be tilted in the vertical longitudinal plane while being separated from the plane of the main bunch train thus allowing one to take advantage of the tilt without seeing the main bunch train. Being able to tailor the orbit and/or energy and pulse length is more speculative but would be very exciting and challenging.

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