Time-Resolved Experiments at the CLS – Issues for Consideration

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Canadian Light Source Inc.
101 Perimeter Road
University of Saskatchewan
Saskatoon, Saskatchewan Canada

	Signature	Date
	Original on File – Signed by:	
Author	J.M. Vogt	2007-12-06
Reviewer #1	J.C. Bergstrom	
Reviewer #2	L.O. Dallin	
Approver	E. Matias	

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1.0 INTRODUCTION

1.1 PURPOSE

Time-resolved experiments usually require a high-purity single-bunch fill pattern in the Storage Ring. Some time-resolved experiments have already been carried out at the CLS, but these were unusual in the sense that they only required very low bunch purity, which CLS was able to deliver.

The purpose of this document is to discuss requirements and options for upgrading the facility to accommodate those time-resolved experiments that need higher bunch purities than can currently be generated. This revision gives an update on the progress during the last 12 months.

1.2 SCOPE

This document covers the necessary machine development and various options for the user interface, but none of the development that may be needed on the beamlines.

1.3 DEFINITIONS AND ABBREVIATIONS

SLS: Swiss Light Source

TDC: Time-to-digital converter

XSR: X-ray synchrotron radiation diagnostic beamline

2.0 SINGLE-BUNCH INJECTION INTO THE STORAGE RING

In order to fill a single bucket in the Storage Ring, one would ideally inject a single bunch per injection rather than injecting multiple bunches and purifying the beam after injection. This is essential when running in top-up mode, but it is also preferable when not running in top-up mode to keep the radiation levels as low as possible.

The CLS Timing System allows the injection of a single bunch into any bucket in the Storage Ring, or the accumulation of any pattern of multiple isolated bunches. However, neither the LINAC nor the Booster is currently capable of generating a single bunch.

2.1 SINGLE BUNCH IN THE LINAC

The best way to generate a single bunch is to reduce the pulse width of the LINAC gun to about 2 ns or less. However, this is not possible with the existing gun because the switching time of the video deflectors is too long. There are two ways to upgrade the LINAC for single-bunch capability:

- Design and install faster video deflectors,
- Replace the gun with a modern, fast-switching gun (available off the shelf).

The existing system of video deflector plates and cables is neither impedance-matched nor terminated. Nevertheless, the rise and fall times are only about 2 ns. An improvement of a factor of 2 or 3 is needed, which should be feasible with an impedance-matched, terminated system.

In the context of upgrading the LINAC, replacing the gun is a good choice, but it is expensive. There is a common model of a fast-switching gun in use at several facilities, but these guns only work at 90 keV (the old gun of the LINAC has 220 keV), so the whole front end of the LINAC would have to be replaced or modified. That would be significantly more labour-intensive and involve a higher schedule risk than redesigning the video deflector plates.

One disadvantage of these guns is that their beam current varies considerably over the duration of a pulse that would be used for multi-bunch fills. There are different ways to overcome this problem if the Storage Ring is to run in multi-bunch mode. At the SLS for example, the gun is only run in single-bunch mode and multi-bunch fill patterns are generated as a combination of single bunches. Another approach would be to inject multiple bunches into the Storage Ring until the desired maximum bunch current is reached, and then to top up the lower bunches in single-bunch mode.

2.2 BUNCH PURIFICATION IN THE BOOSTER

Bunch purification in the Booster has been attempted at the CLS without much success. While the whole beam can easily be kicked out of the Booster, it proved impossible to extract all bunches but one. As the amplitude of the kick was increased, the satellite bunches were not yet removed completely when the central bunch already lost much of its current, and the current ratio between the central bunch and the satellites was at best 10:1. The likely reason is that the chromaticity of the Booster cannot be controlled (the Booster has a large, negative chromaticity).

A first step toward bunch purification in the Booster would be the installation of sextupoles to adjust the chromaticity. However, since we do not fully understand why we can extract the whole beam but not retain the full current in a single bunch, there is no guarantee that the method will work once the sextupoles are available.

3.0 BUNCH PURIFICATION IN THE STORAGE RING

If single bunches cannot be injected into the Storage Ring, any unwanted bunches have to be kicked out after injection. In this case, the Storage Ring cannot run in top-up mode unless a significant amount of temporary bunch impurity can be tolerated by the experiment.

Since electrons can skip from their original bunch to the trailing bunch, a bunch purifier needs to be implemented in the Storage Ring if high purity is desired. Depending on the bunch purification method chosen, kicking out unwanted bunches after injection may come at no additional expense, other than giving up operation in top-up mode.

3.1 FREQUENCY DOMAIN VS. TIME DOMAIN

There are two fundamentally different approaches to bunch purification in the Storage Ring. The first one is a frequency domain approach, which makes use of the fact that the tune of a bunch changes with the bunch current. If the difference in tune between the desired bunch and the satellite bunches is high enough, it is possible to excite a fatal betatron oscillation in the satellite bunches without harming the desired bunch. This approach requires a high current ratio between bunches though. Therefore it can be used to kick out electrons that skipped into a trailing bunch, but it cannot be used to purify the beam after multi-bunch injection.

The other approach is a time-domain method that applies a kick to all bunches except at the time when the bunch of interest travels through the kicker. One way to accomplish this is by gating off the signal that excites the kick (before it is amplified). Another way is by forcing a 180° phase shift in the signal that kicks the beam, timed in such a way that the zero-crossing of the signal amplitude occurs when the bunch of interest passes through the kicker. Given enough amplifier power to excite all bunches within the existing tune range, this method works for any bunch impurity and can therefore be used to purify the beam after multi-bunch injection.

3.2 TRANSVERSE FEEDBACK SYSTEM

Bunch purification in time-domain is one of the features of the transverse feedback system that is being implemented in the Storage Ring. The kicker, which has been fabricated, has enough bandwidth and shunt impedance for bunch purification. The kicker is likely to be installed during the April 2008 shutdown. Amplifiers have been purchased and have already been installed. The tender for the transverse feedback electronics has recently been awarded to Instrumentation Technologies. Delivery of the system is expected in spring or summer of 2008. It is expected that the software development and system commissioning will stretch into 2009.

4.0 MONITORING THE FILL PATTERN IN THE STORAGE RING

A fill pattern monitor has been implemented as part of the XSR instrumentation. It consists of an avalanche photo diode used as a single-photon counter, and a multi-hit TDC, which records the time at which an X-ray was detected with a resolution of 25 ps. The time stamps are histogrammed using the Storage Ring orbit trigger as a reference. A peak is accumulated for every bunch in the Storage Ring, with a clear separation between adjacent peaks. The integral of the peak is a measure of the relative current in the bunch.

Bunch current ratios of 1 in 10^7 have been measured. However, the software of the fill pattern monitor is in a rudimentary state. While all necessary features are available, the user interface is not suitable for general use, and the only way to distribute the fill pattern readout to the beamlines is by handing out hardcopies.

One of the future enhancements may include a second fill pattern monitor located in the Storage Ring tunnel. This would separate the measurement of the fill pattern from the operation of the XSR beamline and permit the use of the other XSR beamline instrumentation at the same time as the fill patter monitoring.

5.0 FILL PATTERNS

Various fill patterns can be used for time-resolved experiments. According to the experience of other facilities, the following fill patterns are likely the most useful for the users:

- A single bunch in the Storage Ring,
- 3 equally spaced bunches with 94 empty buckets between any two of them,
- 5 equally spaced bunches with 56 empty buckets between any two of them,
- A bunch train of about 70 bunches and a single bunch in the row of empty buckets.

For the first 3 options the Storage Ring runs in a dedicated time-resolved mode, and the choice of the fill pattern depends on the needs of the experiment, i.e. the time constant of the phenomenon studied and the current required to run the experiment. The last option is a compromise between the regular, high-current operation and time-resolved studies, in order to run both simultaneously.

6.0 USER INTERFACE

For time-resolved studies, the user needs to know the relative bunch population, or bunch purity. Also, a reference signal is needed to synchronize the experiment with the synchrotron light flash produced by the single bunch.

6.1 BUNCH POPULATION MEASUREMENT

In the simplest case, the bunch purity would be measured by the operator and communicated to the user when requested. However, in order to deliver a beam of known average purity for the duration of an experiment, the bunch purity should be monitored continuously. It would then make sense to make this information available to the user at any time.

Depending on the accuracy with which the bunch purity is to be measured, such a measurement may take up to 10s of minutes. It may therefore become necessary to synchronize the bunch purity measurement with the experiment.

6.2 TIMING REFERENCE SIGNAL

In time-resolved experiments, the measurement needs to be synchronized with the instant the synchrotron light is produced. A reference signal which indicates the Storage Ring revolution frequency can easily be distributed to any endstation. The timing of this signal with respect to the arrival of the synchrotron light at the endstation depends on a number of factors:

- The location and the length of the beamline,
- The cable length to the endstation,
- The bucket that is filled (the timing of the reference signal does not change with the bucket number).

The first two contributing factors are constant once the experiment is set up, and can easily be adjusted for in the electronics of the experiment. The bucket number can be controlled by the operator, and it can actually be used to adjust the timing between the reference signal and the synchrotron light.

Depending on the requirements of the time-resolved experiments, several enhancements of the Timing System capabilities should be considered:

- If the fill pattern consists of multiple, equally spaced bunches, multiple reference signals per turn may be needed. Currently only one such signal is generated.
- If the fill pattern consists of multiple, isolated bunches that are not equally spaced, the reference signal may need to indicate their spacing. This would be more difficult to implement than a reference signal marking equally spaced bunches.
- The reference signal may need to indicate the timing of the bunch, i.e. if a different bucket is filled, the timing of the reference signal may need to shift.

6.3 BEAM REFERENCE SIGNAL

Another way of obtaining a timing reference is by combining the 4 signals of a beam position monitor. The advantage is that such a signal it truly beam-based. It is a low-jitter signal that tracks the synchrotron oscillation of the beam. It is harder to use though than the Timing System reference because:

- The signal is distributed electrically, which makes it susceptible to noise pickup.
- It is an analog signal, i.e. the signal amplitude varies with the bunch current.
- The signal is only available when there is beam in the Storage Ring.