Instrumentation upgrade for Top-Up operations at the Australian Synchrotron

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Abstract. The Australian Synchrotron introduced Top-Up operations in May 2012. Upgrading the machine for Top-Up has required major developments in many of the accelerator systems. Investigations prior to the start of Top-Up operations demonstrated that the Infrared Microspectroscopy beamline was particularly sensitive to injection noise. A gating event has been implemented as part of our timing system upgrade to pause the data collection during injection. In Top-Up mode injections can happen when the gaps of insertion devices are closed. A variable vertical aperture has been installed in the BTS to scape potentially damaging electrons and protect the equipment.

1. Introduction
The Australian Synchrotron (AS) is a third generation light source that opened for users in 2007. It was running in decay-mode with two daily injections to 202 mA until May 2012, when Top-Up was implemented for common operations. The Top-Up mode keeps the storage ring (SR) current steady, which maintains a constant heat-load on the equipment and improves the stability of the beam in the SR and on the beamlines. In this mode the beam is stored in the SR at 202 mA and is then topped up as soon as the current is predicted to decay to 200 mA. This is a so-called current based mode, where the gun is triggered only once per injection.

To achieve this milestone the instrumentation of the machine and the beamlines has been upgraded. As top-up related disturbances were observed on some sensitive beamlines, a way to pause data acquisition during injection has been implemented for routine operations.

A vertical aperture has been placed in the Booster-to-Storage Ring transfer line (BTS) to remove electrons that could be harmful to the three in-vacuum undulators (IVUs). This is necessary because Top-Up injections can happen with the IVU gaps closed. Electrons with a non-suitable position or angle could hit the IVUs and need to be scrapped upstream.

2. Top-Up warning event
Data acquisition on the Infrared Microspectroscopy (IRM) beamline at the AS is performed using a Fourier transform infrared (FTIR) spectrometer. This comprises a Bruker V80v FTIR spectrometer coupled to a Hyperion IR microscope. The V80v spectrometer measures the spectral intensity of the mid-infrared beam by means of a Michelson interferometer, with raw data consisting of interferogram traces acquired at an acquisition rate of 40 kHz during the movement of the interferometer mirror. Such instrumentation is highly sensitive to source beam...
noise at frequencies ranging from sub-Hz to several kHz, and the IRM beamline was therefore expected to be highly sensitive to beam disturbances associated with Top-Up injections. This beam noise was predicted to render data collection problematic for users, as the disturbance in the interferogram trace would result in poor signal-to-noise in the calculated absorbance spectra. Evidence from other synchrotron IR beamlines such as at ALS [1] and Diamond had shown that it was necessary to “gate out” the injection period for this reason, and this has been achieved by pausing data collection, for the period of disturbance, in response to a trigger signal provided by the storage ring control system. Prior to the start of Top-Up operations, several periods of test beam were used to study the effect of injection on the resulting data at the IRM beamline.

Infrared spectra were collected in a manner similar to typical user configurations. The IR beam was focused on a sample of formalin-fixed MCF-7 cells attached to an infrared transparent substrate (CaF$_2$). Sample and reference interferograms were collected at 40 kHz acquisition rate using a narrow-band mercury cadmium telluride detector, co-added for 16 consecutive interferometer scans, and converted to absorbance data at a spectral resolution of 4 cm$^{-1}$.

Figure 1 shows three interferogram traces, off-set vertically for clarity. The large “bursts” at around 1800 data points and 5300 data points are the two points of zero path difference in the travel of the interferometer moving mirror, with data collected in both the forward and backward direction of mirror travel. The lower trace shows the effect of a single injection shot at around 6400 data points, which occurred during one of the 16 co-added interferogram traces. All three interferogram traces show smaller disturbances resulting from the 1 Hz operation of the septum magnet, which was in continual operation during early Top-Up tests.

![Figure 1. Three interferograms (16 co-additions each) showing the effect of the septum magnet (a, b and c) and of a single injection shot (c).](image1)

![Figure 2. IR absorbance spectra from same interferograms shown in Figure 1, with noise effect from injection shot in one spectrum (c).](image2)

Figure 2 shows infrared absorbance spectra calculated from the same interferograms. Spectrum c, which included the injection shot disturbance in the interferogram, shows noise across the whole spectrum that is not present in spectra a and b. The inset in Figure 2 is an enlargement of the area indicated by the dashed box and the noise level present in spectrum c in this biologically important spectral region renders such data unusable. Furthermore, analysis of a number of such spectra showed that the smaller but more frequent disturbances caused by the 1 Hz operation of the septum magnet led to a 160% increase in spectral noise in the region around 1350 cm$^{-1}$, and a 60% increase in the region around 1800 cm$^{-1}$.
To enable operation of the IRM beamline to continue unaffected by the operation of Top-Up injection, a gating system has been implemented that pauses data collection for a defined period during the injection cycle. It is based on the event timing system in place at AS [2]. An event receiver (EVR) has been installed at the beamline, the settings of which can be applied through EPICS process variables (PVs) via a graphical user interface. Like other EVRs in the facility it is located to the accelerator network. However the beamline PVs can be accessed and managed at the beamline itself through a gateway.

A special “Top-Up warning” event is created by the event generator and distributed to the beamline EVR through an optical fibre. This event happens 10 s before the stored beam current is expected to drop below 200.0 mA. The expected stored beam current is calculated by a linear least squares fit of the beam current values monitored during the last 60 s. A single injection happens exactly 10 s after the Top-Up warning event. The beamline can therefore use the signal from the EVR to stop data acquisition for the duration of the injection. If the beam current is so low that a second injection is needed shortly after, this will happen not earlier than 16 s after the first one, which allows for a new Top-Up warning event to be created.

The firmware of the Bruker V80v was upgraded to include a dedicated “Synchrotron Correlation Mode” which relies on a positive TTL voltage being detected by a specified signal input channel for data acquisition to be enabled. On detecting a drop of this signal to below the TTL “zero” threshold, data from the current and all subsequent interferometer scans are rejected until the voltage returns again above the TTL threshold. The automatic pause in data collection has been programmed for 1.5 seconds. It requires no intervention by the beamline users, and results in less than a 1% loss of collection time, while the constant current of 200 mA allows the beamline users to collect less frequent reference spectra, leading to an overall gain in sample throughput. As an example of the use of the Top-Up gating Figure 3 shows absorbance maps of a single sample obtained with or without the acquisition during injection.

**Figure 3.** IR absorbance maps of integrated νCH absorbance of lithographically produced polymer test pattern on zinc selenide substrate. Top left IR map recorded with top-up gating in operation, top right IR map recorded without top-up gating. Arrow indicates pixel row in which an injection shot occurred during collection of the preceding reference spectrum, resulting in noise in all spectra within that row of pixels. IR spectra from locations a (noise affected) and b (noise absent) in the map are shown in the bottom left panel. The bottom right panel shows a visible light image of the polymer test pattern. Scale bar = 20 μm.

3. In-Vacuum Undulator protection

In decay mode the IVU gaps are fully open during injection. In Top-Up mode, however, the IVUs can be closed. The injected beam could therefore damage them. To prevent electrons from hitting IVUs with closed gaps, restriction has been made on the phase-space of the electrons that can be injected into the SR.

Tracking studies [3] have been performed to determined the characteristics of the electrons
whose vertical positions and angles are safe. To free the injected beam from electrons that do not meet the requirements a vertical aperture has been placed in the middle of the BTS.

Figure 4 presents the phase-space distribution of the electrons entering the SR and differentiates between the electrons that can circulate multi-turns in the SR (green) and those which are lost within the first turn (blue and red). The area marked in black shows the electrons that a ±4 mm gap aperture lets through. All the selected electrons can circulate multi-turns in the SR. The aperture can therefore protect the IVUs.

Figure 5 shows the experimental effect of the aperture blade opening on the injection efficiency and a beam loss monitor located after the first IVU of the SR. Both the efficiency and the losses decrease with the blade gap. To maximise the capture while minimising the losses, the gap is set to ±3.5 mm during user operations. This setting is consistent with the predictions.

Figure 4. Phase-space distribution of the electrons entering the SR. Green: electrons that do multi-turns in the SR. Blue: electrons that can only complete one turn. Red: electrons that are lost before the first turn. The area selected in black shows the electrons that go through the aperture, when the aperture is set to ±4 mm [3].

Figure 5. Influence of the BTS aperture gap on the beam loss monitor (BLM) counts and the injection efficiency.

4. Conclusion
Top-Up has been implemented with success and has become the usual operation mode at AS since May 2012. This required many instrumentation upgrades to keep beam noise low and guarantee equipment safety on the accelerator and the beamlines.

To avoid injection related disturbances on the IRM beamline a gating event has been implemented to pause the acquisition during injection. This reduces the acquisition time by less than 1% but increases the quality of the data collection. This event is expected to be deployed on other noise sensitive beamlines like the Imaging and Medical Beamline.

An aperture has been installed in the BTS to scrape the electrons whose phase-space properties could damage the IVUs. It is successfully used during user operations.

References
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