

## SPOTLIGHT ON

# Storage ring filling patterns

## for time-resolved based experiments: measuring the purity of electron bunches

When the storage ring operates in top-up injection mode, electrons can accumulate in parasitic bunches, deteriorating the purity of the electron beam filling patterns and hence the quality of time structure of the photon beams provided to the beamlines. But did you know that it is possible to clean out a bunch of electrons?

### Different ways of filling up the storage ring

In a storage ring, the accelerating voltage of the radiofrequency (RF) cavities compensates for the energy loss of electrons due to synchrotron radiation and allows them to be regrouped into bunches. In the SOLEIL storage ring (354-meter circumference), the electrons revolve with a 1.18  $\mu$ s revolution period or a revolution frequency of 846 kHz. As the RF frequency in the accelerating cavities is 352 MHz, the electrons can regroup into 416 separate bunches evenly spaced by 2.84 ns intervals. Each bunch is spread out longitudinally with an approximately Gaussian distribution with a standard deviation (sig-

ma) typically of the order of 12 ps RMS (i.e. 28 ps Full Width Half Maximum) under normal operating conditions (nominal alpha, RF voltage of 3 MV and about 1 mA per bunch).

The photons emitted by these electron bunches are also produced in form of bunches.

If the aim is to have the flux (or brightness) as high as possible, regardless of its temporal distribution, the preferred filling pattern would be 416 bunches as uniform as possible. In the case of SOLEIL, the production of electrons by the linear accelerator (Linac) is then done in the so-called long pulse mode (LPM), which produces 295 ns macropulses, corresponding to a quarter of the storage ring circumference. This injection mode is called "4 quarter injection mode" which is close to uniform filling pattern and achieves a maximum stored beam intensity of 500 mA.

On the other hand, some users of synchrotron radiation take advantage of the time structure of radiation, in particular to study the dynamic properties of materials by means of time-resolved pump-

probe experiments. At SOLEIL, this is particularly the case of the TEM-PO and CRISTAL beamlines.

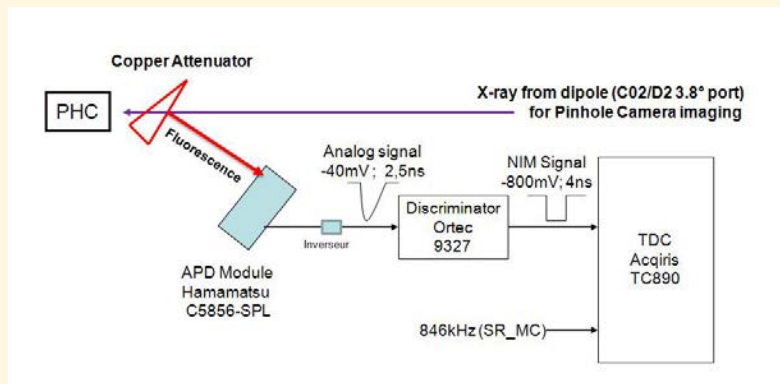
However, the time scales of observed phenomena (and detector response) are rarely of the order of magnitude of the 2.84 ns separating two subsequent bunches, but rather in the order of magnitude of a few tens of nanoseconds: the 8 bunch (8 bunches evenly spaced by 148 ns) and 1 bunch (1.18  $\mu$ s between two bunches) filling patterns answer this strong need.

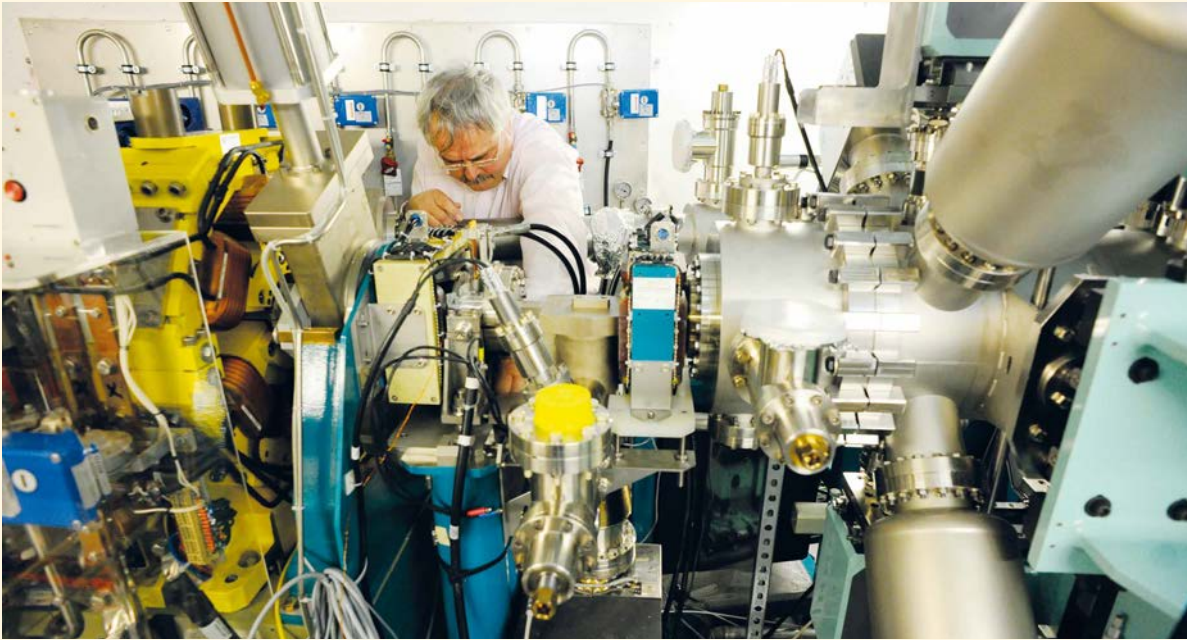
Although intensities per bunch are higher than in the uniform filling mode, the total intensity that can be stored in these modes is limited: 120 mA (8 x 15 mA) in 8 bunches and 20 mA in 1 bunch. These values originate partly from the collective effects exacerbated by the high density of electrons per bunch and partly from the interactions with the vacuum chamber pipe of the storage ring.

In order to simultaneously meet the needs of high-flux high brilliance experiments and temporal structures, the most commonly used filling pattern in radiation centers are the so-called hybrid modes, where most of the intensity is given by a large number of small contiguous bunches, followed by a window in the middle of which a single (usually higher intensity) bunch is located.

At SOLEIL for the production of these isolated bunches, the Linac works in short pulse mode (SPM): electrons from the cathode are extracted by high-voltage pulses of about 2 ns long RMS in such a way as to minimize the acceleration of electrons out of the targeted bunch; however despite various measures implemented to prevent this phenomenon, some electrons are ex-

figure 1 : Purity measurement: acquisition scheme.





Lodovico Cassinari, in charge of the Diagnostics Group, working in the tunnel of the storage ring.

tracted from the cathode outside of this time period and accelerated by the Linac.

### The purity of stored bunches

Purity is defined as the ratio between the number of photons emitted by undesirable electrons in a supposedly empty bunch and the number of photons emitted by the electrons of the desired bunch (assumed to be isolated), which comes down to be the ratio between the numbers of electrons in the respective bunches.

The injection is done in quarters (corresponding to 295 ns macro-pulses); the pulsed kicker magnets that allow the incident beam to be injected into the ring are sized accordingly: they are active for time spans slightly longer than these 295 ns. During injection of the isolated bunch, these very pulsed magnets can unfortunately allow the injection of undesirable electrons collected at different stages of the acceleration process (“dark” current emitted by the LINAC gun, for example).

Parasitic bunches thus created with very low intensity: an electron circulating in the ring corresponds to a 13.5 pA current, compared to the current stored in the desired bunches (of the order of a few milliamperes).

However, in the top-up injection mode, as the lifetime of these parasitic bunches is significantly larger than that of the main bunch, the reinjection process may lead to an accumulation of electrons in the parasitic bunches while keeping the intensity of the main bunch constant.

This could result in a deterioration of the purity, lead to a degradation of the time resolution, and worsen the signal to noise ratio of the beam-line time-resolved experiments.

### Measuring the purity

The system setup at SOLEIL (figure 1) is based on one of the ESRF facility (Ref. 1), using a well-known method (Ref. 2) called time-correlated single photon counting (TC-SPC).

Advantage is taken of the X-ray radiation used for measuring the transverse dimensions of the beam: a thin (1 mm thick) aluminum window allows the highest energy photons produced by a dipole magnet to come out to be imaged by

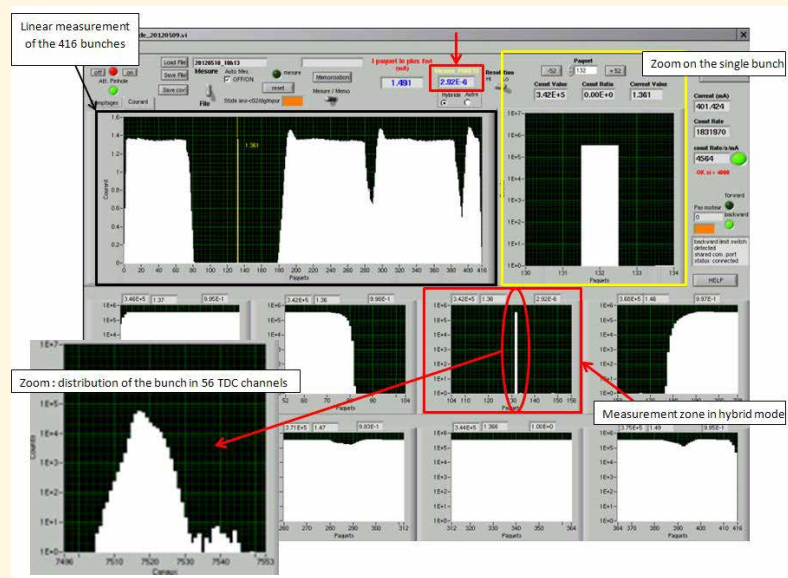
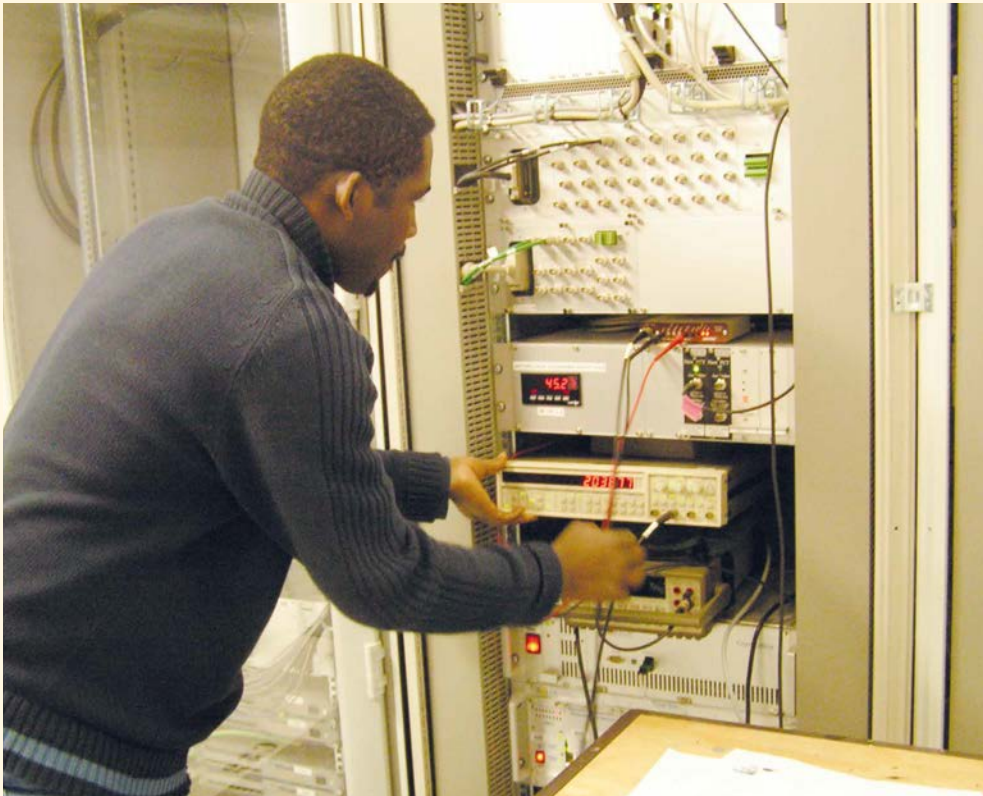


figure 2 : Purity measurement application in the control room.





**Purity measurement:** Francis Dohou, from the Diagnostics Group, is checking the acquisition electronics.

an optical device called a pinhole camera.

A strip of copper serving as an attenuator is inserted between the X-ray beam and the pinhole camera.

Fluorescent radiation from copper is collected by an avalanche photodiode (APD) radiation hardened by a lead shield. This assembly is motorized to allow the block containing the photodiode to move from its measuring position to its rest position (protection against radiation induced damages in the tunnel).

Given the dynamics required by the system (5-6 orders of magnitude between the intensity of the main bunches and the parasitic bunches), the diode is not used in a linear, but rather in a stochastic mode (hence the use of an avalanche photodiode).

Going through the intermediary of the copper fluorescence, the amplitude of the pulses generated by the avalanche diode is no longer a function of the bunch intensity. On the other hand, at any time, the probability of photons emitted by electrons and deflected by the dipole

exciting a copper atom recorded by the photodiode is proportional to the number of these electrons.

Thus, the temporal distribution of the pulses emitted by the diode reflects the temporal distribution of electrons circulating in the ring.

After data processing (discriminator to eliminate diode noise), the pulses are stored in 23624 channels, 50 ps wide, of a TDC (Time-to-Digital Converter), thus covering the 1.18  $\mu$ s storage ring revolution period (figure 2).

The 50 ps resolution of the TDC would not give a good representation of the distribution within a bunch (of the order of 20 ps RMS); however, this resolution is sufficient to distinguish two consecutive bunches (separated by 2.84 ns).

To achieve the resolution required for measuring the purity ( $10^{-6}$ , i.e. a factor of one million between the intensity of the main bunch and the residual bunch), the pulses are accumulated until they reach a million hits in the main bunch. With 4000 counts/mA/s and 5 mA for the main bunch in hybrid mode, the measurement takes 50 seconds. Typically, the purity achieved

during the filling up of the storage ring in hybrid mode (from 0 to 430 mA) is of the order of a few  $10^{-6}$  for supposed empty bunches, except for the bunch that immediately follows the isolated bunch, which is usually of the order of  $10^{-5}$ . However, poor adjustment of the injection parameters (especially in the dephasing of the Linac pulse or of the pulsed magnets) can lead to higher values. Moreover, the situation can only deteriorate progressively over successive injections in top-up mode (see above). It is not uncommon to achieve a purity of  $10^{-4}$  after a few days of uninterrupted beam. This value is within the tolerance of the current demand of the beamlines.

### Cleaning out the bunch

Being not immune from an incident that could lead, for example, to the unexpected injection in the empty quarter, it is therefore useful to be able to clean the stored beam by removing unwanted bunches. This means being able to excite a bunch strongly enough to make it unstable without affecting the other bunches. This is accomplished by using the bunch per bunch transverse feedback (FBT) that suppresses the transverse oscillations of individual bunches, which are induced by the interaction of each bunch with its environment (other bunches, vacuum chamber, and ions, etc.).

The transverse feedback used by SOLEIL has sufficient resolution to be able to reverse the polarity of the deflection applied to a particular bunch (anti-feedback). It is thus possible to resonantly excite the targeted bunch, while keeping the feedback function on other bunches.

Developments are underway to implement this "bunch cleaning" function during the machine operation.

#### → Contact :

**Lodovico.cassinari@synchrotron-soleil.fr**

#### References:

- [1] B. Joly, G.A. Naylor "A High Dynamic Range Bunch Purity Tool", DIPAC 2001 - ESRF, Grenoble, France.
- [2] S. Takano "Beam Diagnostics with Synchrotron Radiation in Light Sources", IPAC, 2010, Kyoto, Japan.