SPOTLIGHT ON

Stability of the electron beam

Feedback systems

Stability of the electron beam is one of the quality criteria in synchrotrons. It requires means of controlling, on the one hand, the disturbances that can modify the beam's position, and on the other, the instabilities intrinsic to the electron bunches that could affect its dimensions. The SOLEIL Sources and Accelerators Division has set up several systems that control and improve this stability on a permanent basis. This effort is paying off.

Installation of the vertical transverse feedback system, in March 2008. From left to right: Manh Huy N'Guyn (Vacuum Group), Daniel Lefèbvre and Carlos de Oliveira (Design-Engineering Group).

Orbit feedback systems

The stability of the electron beam position is one of the fundamental performances of a synchrotron radiation facility. In order not to disturb the scientists' work on the beamlines, fluctuations in position and angle of the electron beam must remain well below 10% of its size and divergence. At SOLEIL, as the beam size can be very small, in the order of 8 µm in the vertical (for 1% coupling), the beam must not move more than 0.8 µm!

When the machine was designed, all precautions were taken to ensure the best possible stability: foundations of the ring and experimental slabs isolated from the synchrotron building and resting on nearly 600 piles (15 m deep); design of the girders supporting the magnets of the ring, with vibration eigen modes pushed to high values to minimize amplification of ground vibrations; resurfacing of the neighboring road; tunnel temperature regulation within +/- 0.1° C; injection in top-up mode, etc. The orbit feedback systems, the last link in this chain, correct any drifting of the electron beam position by keeping it as near as possible to the reference orbit.

Available since the machine started in January 2007, the slow orbit feedback uses the 56 main correctors of the machine located inside the sextupoles. Every 10 seconds, the horizontal and vertical orbits are read via the 120 beam position monitors (BPM) of the ring and the system calculates the currents to be sent to the correctors to bring the orbits as close as possible to the reference orbits. This is effective in the frequency range from 0 to 0.05 Hz, and corrects the slow deviations in the beam position, due, for example, to temperature variations or deformations of the machine.

Since September 2008, the fast feedback has also been put in operation. It works with another group of 48 "air" correctors (a set of coils placed around the belows without magnetic yoke) situated at each extremity of the straight sections. In this case, the orbits are read and corrected 10,000 times per second. This feedback is effective in the 0 to 200 Hz frequency band. This allows perturbing phenomena at higher frequencies to be corrected: ground vibrations, deformation of the machine when using overhead cranes, 50 Hz from the mains, perturbations during transiant changes in the magnetic fields of undulators and even earthquakes! As the time available for calculation is very small in this system, a dedicated communication network linking the 120 BPM electronic modules had to be developed and the calculation algorithm had to be distributed within these same units. Thus, in less than 100 µs, data from the 120 BPMs are distributed around the ring, and the new set points calculated and sent to the 96 corrector power supplies.

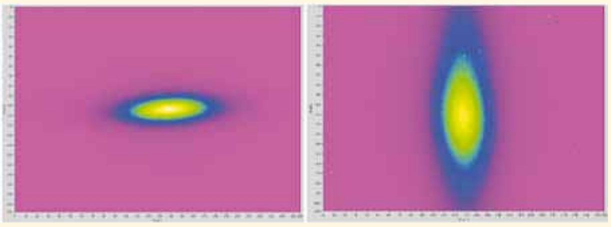
These slow and fast orbit feedback systems involve more than 300 different actors (BPMs, corrector power supplies, synchronization cards, current monitors). Permanent supervision is therefore necessary to guarantee the reliability of the system.

Usually, the simultaneous use of two orbit feedback systems implies a so-called frequency "dead" band around 0.1 Hz, in which none of the corrections are effective. Notably, it would not have been possible to correct perturbations due to changes in the configuration of the undulators. At SOLEIL, a specific interaction software was developed and installed between the two systems, allowing them to act in a complementary fashion and thus making them compatible and therefore effective over the whole frequency range from 0 to 200 Hz. This is the first interacting system of this kind.

Transverse feedback system

At SOLEIL there are two main ways of filling the ring: the "multi-bunch" method with the aim of distributing 500 mA in a large number of electron bunches, and the "time structure" method consisting of a small number of bunches (1 or 8). Although the radio frequency (RF) system uses superconducting cavities that have been specially designed to avoid multi-bunch instability on the longitudinal plane, it was necessary to set up a very efficient feedback system in the transverse planes to overcome instabilities which develop differently according to the two modes:

- "Multi-bunch": instabilities result from the interaction between the beam and the vacuum chambers (more precisely with the high frequency electromagnetic fields induced by the beam in the vacuum chambers). There are also extremely violent instabilities due to the interaction between electrons and ions (present in the residual vacuum) through the passage of a single train of electron bunches.
- "Time structure": instabilities arise from coherent oscillation modes within the bunches. Coupling of these different modes can provoke strong beam blow-ups called transverse mode coupling instability.



Images of the beam transverse dimensions (pinhole) with and without (on the right) transverse feedback system.

Considering the ambitious performance of SOLEIL in terms of total current and current per bunch and the small vertical apertures adopted for the vacuum chambers, simulation had predicted instability thresholds at relatively low currents. It was therefore decided to develop a high performance bunch by bunch digital feedback system to damp these instabilities.

The basic system includes very fast beam position monitors (BPM), a RF front-end, a FPGA[1] based digital system, stripline kickers (to act on the beam), and power amplifiers. The chosen digital system was developed at the Japanese synchrotron, SPring-8. Starting with the betatron motion measured for each bunch, it carries out the filtering required so that a stabilizing signal is re-injected onto the said bunch. All of these operations are performed by a FPGA with a latency of less than one revolution time. Three systems are presently available, equipped with stripline-type kickers, of which two were specially designed and developed at SOLEIL to obtain very high efficiency.

In the absence of feedback the threshold of multi-bunch instability at zero chromaticity is very low: of the order of 30 mA on the vertical plane and 40 mA on the horizontal plane. Operation of the feedback allows stabilization, under the same conditions, of the beam up to about 500 mA. Nevertheless, sudden losses do still sometimes occur due to the ions.

To ensure good functioning regardless of the configurations of insertions, the transverse feedback systems are operated in combination with moderate chromaticities. The very powerful structure of the FPGA allows the movements of each bunch to be measured and damped, while a single bunch is excited to measure its betatron tunes, and allows also applying different gain values to each bunch.

The efficiency of the feedback is remarkable in the single bunch mode: more than a factor 3 is gained on the threshold at zero chromaticity and the beam can be kept stable practically up to 20 mA with moderate chromaticity.

As expected from simulations, transverse feedbacks are vital at SOLEIL to maintain a stable high intensity beam, while keeping the transverse sizes very close to the theoretical values. The systems developed at SOLEIL have proved their efficiencies both in multi-bunch and single bunch modes.

Tune feedback system

One of the challenges when operating SOLEIL's storage ring is to keep constant and very small the transverse sizes of the photons beam delivered to each beamline. This action is performed mainly by maintaining constant the very strong focusing of the electron beam in both horizontal (H) and vertical (V) planes via two groups of quadrupoles. This focusing is characterized by two parameters called tunes, the current values of which are 18.2020 and 10.3170. Modifying these tunes can induce a reduction of the lifetime or of the injection efficiency. These values vary essentially as a result of two phenomena. On the one hand, the beam image current that circulates on the walls of the vacuum chambers acts on the electron beam by focusing it and induces tunes changes between 0.011 (H) and -0.008 (V) when ramping the stored current between 20 and 400 mA. On the other hand, each insertion device introduces small tune changes (natural focusing, or due to imperfections) that can for example reach 0.007 for HU640 undulator (in vertical polarization mode).

Since March 2009, a feedback system on the tunes has been successfully set up to compensate for these effects when the beam is delivered to the beamlines. This system functions at 0.1Hz and stabilizes the tunes with an accuracy of 2×10^{-4}. It adjusts the settings of 2 quadrupole families of the ring in the most effective way by using the tune measurement achieved by the transverse feedback system (see above: this measurement is performed by exciting a single electron bunch without disturbing the positional stability of the beam).

Thanks to this system, the performance of the storage ring in terms of lifetime and injection efficiency have been significantly improved and are less sensitive to the undulator configurations which are controlled without restrictions by the Users on the beamlines.

Associated with a constantly increasing level of availability of the beam (above 96 % in 2009 and exceeding 98% from September 2009 to April 2010), these three feedback systems ensure the best possible beam conditions for scientists to carry out their research on the SOLEIL beamlines.

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1. FGPA: "Field Programmable Gate Array", an integrated circuit that is capable of being reprogrammed in the field after manufacture.