OPERATING SIMULTANEOUSLY TWO IN-VACUUM CANTED UNDULATORS IN SYNCHROTRON SOLEIL

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Abstract

Each long SOLEIL beamline, ANATOMIX and Nanoscopium, takes a photon beam from an in-vacuum undulator with a minimum gap of 5.5 mm. The canted radiation sources are installed in a long straight section of the storage ring. The first closure of both undulators led to the severe damage of the downstream undulator in 2011. The reason for this incident has been investigated and clearly identified. A long-term project has enabled us to find a technical solution for a simultaneous operation of both undulators. A special angle fast interlock was designed and a dedicated photon absorber has been introduced at the entrance of the second undulator while keeping the impact on the beam performance as low as possible. The main technical steps will be reported with an interim solution put in place in spring 2015 and a final solution deployed and validated in May 2016.

INTRODUCTION

SOLEIL [1] is the French third generation synchrotron light source located south of Paris (see Table 1). It delivers photon beams to the users since 2007. Today the 2.75 GeV facility has received more than 20,000 users. A total of 27 (29) beam lines (BLs) take beam on a daily basis.

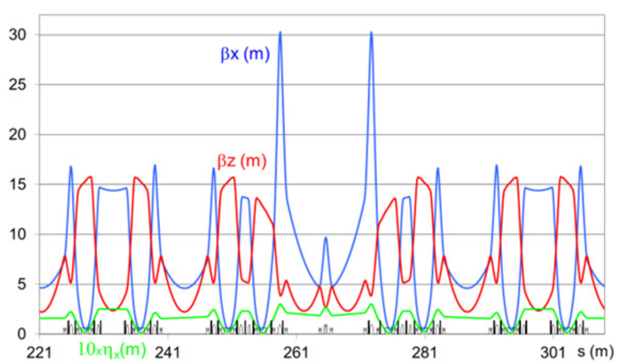

Figure 1: Local optics (beta and dispersion functions): Double vertical waist in a 12 m long straight section to host two 5.5 mm gap in-vacuum undulators.

Each long SOLEIL beamline, ANATOMIX and Nanoscopium, takes its photon beam from an in-(SR) vacuum undulator with a minimum gap of 5.5 mm, installed in a 12 m long canted straight section of the storage ring. The linear optics of the machine has been specially tuned to ensure a minimum vertical size at the center of each undulator; this has been made possible by the introduction of a focusing quadrupole triplet at the center of the section in addition to a 4-magnet magnetic chicane (0.5, 5.38, -11.88, and 6 mrad) (Figure1, [2]).

Table 1: SOLEIL SR Main Parameters.

Parameters	Values
Energy [GeV]	2.75
Circumference [m]	354.097
Natural Emittance [nm.rad]	3.9
Current uniform/hybrid/8 bunch [mA]	500/450/110

As a preliminary configuration two undulators were installed and commissioned separately: a 5.5 mm gap $Nd_2Fe_{14}B$ U20 undulator [3] at the downstream position and a 5.5 mm $Pr_2Fe_{14}B$ cryogenic U18 undulator [3-4] at the upstream position (Figure 2).

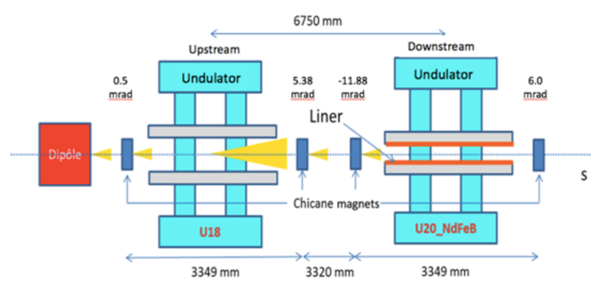

Figure 2: Scheme of the two undulators located in the same straight section for the two canted beam lines. The yellow triangles schematize the radiation produced by the magnetic equipment of the straight section.

UNDULATOR DAMAGE AND ANALYSIS

By November 2011, the first beam tests had been carried out with a 500 mA stored beam, while simultaneously closing both undulators at their minimal gaps. Unfortunately, vertical instabilities and strong out-gazing were quickly observed just in front of the downstream undulator. After removing the downstream undulator during the technical shutdown in January 2012, the reason for this instability was understood: the photon beam from the upstream undulator had overheated the copper and nickel (Cu/Ni) protective sheet (liner) covering the downstream undulator magnets, deforming it and partially piercing it at numerous locations (Figure 3). Moreover a few mag-

ISBN 978-3-95450-182-3

netic blocks of the undulator itself were slightly demagnetized.

Retracing back the cause of this major damage making the undulator not usable anymore for the beam line, it was concluded that mis-steering of the electron beam led to a large heat deposition. The vertical angular aperture of radiation cone produced by the upstream undulator was under-evaluated during the project design. In particular, the real longitudinal profile of the liner (coming from vertical position of magnets and poles) was not taken into account in the evaluation of the power deposition on the liner.

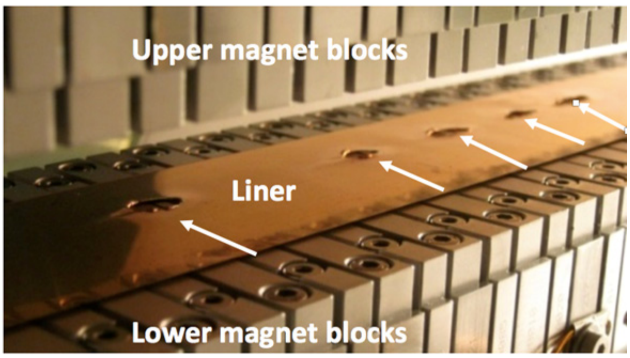

Figure 3: Close view of the upper and lower jaws of the downstream in-vacuum U20 undulator. The damaged liner exhibits a series of holes (white arrows) along the first third of its length (2 m).

Thorough thermo-mechanical and radiation power deposition investigations showed that, at full current of 500 mA and with a gap closed down to 5.5 mm, the power deposition along each liner is about 60 W (and 144 W at the entrance taper). In an ideal case (electron beam well centered in the axis of the undulator and perfect planar liners or profile altimetry), the linear power ranges from 20 to 40 W/m along the 2-meter-long liner. At these levels of power densities, the temperature rises are still limited to 200 to 300 K and their gradients are low enough to prevent any mechanical deformations.

However, taking into account that the real liner profile altimetry exhibiting peaks up to 100 µm and alignment errors of 140 µm, the linear power density may be much strongly increased locally by a factor of 40 (light and shadow effect) reaching about 1500 W/m. The local temperature is then raised to 450 K together with large thermal gradients leading to high risk of mechanical deformation or blistering. This effect of blistering alters even, furthermore, the liner altimetry and so the local power deposition. An unstable process is set in motion and very large temperatures up to the liner melting point may then be reached including realistic alignment errors.

Two improvements were first identified: to cope with this blistering risk issue a better altimetry can be achieved by swapping the undulator magnets (instead of shimming their vertical position); a triple layer liner to avoid bi-lam effect has been also considered but not kept.

However, simulations have shown that the operational risk was still too high in the case of an accidental electron beam vertical offset occurrence: the power deposition of 60 W per liner shall heat the undulator magnets inducing an additional risk of partial magnet block demagnetization.

TECHNICAL SOLUTION

It became clear that the unique characteristics of SOLEIL (lever arm linked at a great distance between the two undulators, magnetic gaps of 5.5 mm) significantly increases the risk of damaging the undulator for any large enough accidental vertical displacement of the incident electron beam. First, the machine protection system was upgraded in order to add a much tighter tolerance for the beam motion inside the upstream undulator. Secondly, a dedicated absorber was designed to block the radiation of the upstream undulator in case of an incident.

Beam Angle Interlock

The machine interlock system [5-6] includes angle and position interlock taking into account only the horizontal and vertical positions of the electron beam at each of the 122 BPMs of the ring. Studies revealed that the threshold of the existing position interlock should have to be lowered from 800 µm down to 50 µm in order to prevent the photon beam to reach the downstream undulator. This low value is not compatible with the operation. The decision was instead taken to design a new type of interlock based on the angle inside the first undulator. The threshold value of ± 25 µrad does not lead to any higher rate of beam trips during normal operation. The condition to trigger the interlock also depends on the undulator gaps and the stored beam current (lower threshold set to 20 mA). The interlock was developed in house. It is based on the 10 kHz data flow of the BPM Libera electronics that are processed on a dedicated FPGA board. The maximum delay to trigger the machine interlock was measured to be circa 1.9 ms which is well below the 100 ms specifications [7].

This solution led to a temporary solution in June 2015 to allow the two long beam lines to operate simultaneously by restricting the lower gap value of the upstream undulator to 8 mm instead of 5.5 mm). A temporary Sm_2Co_{17} U20 was installed as an upstream undulator while manufacturing in house a second U18 cryogenic undulator. The first U18 was installed for Nanoscopium, being the first of the two beam lines to get into operation.

Dedicated Movable Photon Absorber

The only solution in order to operate both undulators at 5.5 mm full gap was to design a dedicated absorber to be inserted right at the entrance of the downstream undulator.

Detailed studies were carried out to define its geometry in order not to jeopardize the performance of the storage ring in terms of collective effect induced instabilities, beam losses, injection efficiency and beam lifetime.

The absorber is a piece of copper with an asymmetric 90-degree U shape (Figures 4-5). The vertical aperture of 2.8 mm enables to completely shield the liner and the magnet blocks. It enclosed the photon beam produced by the upstream undulator (U18) in a 2 mm x 1.4 mm gap while the electron beam is located at -11 mm from the U-border of the absorber. The upper right part of Figure 5 shows the Cu asymmetrical absorber before installation in its vacuum vessel.

Impedance-wise, the maximum power deposited in structure is 43.4 W for 500 mA in a 3⁄4 filling pattern. The impedance is split between resonances and broadband taper-like behavior.

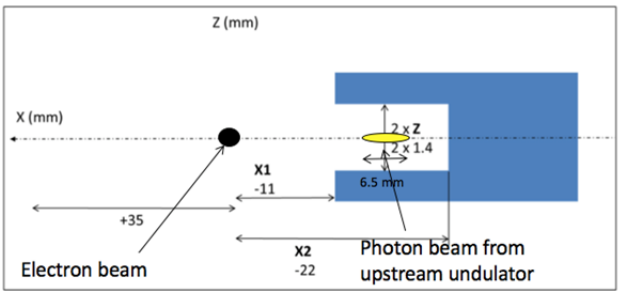

Figure 4: Dedicated U-shape photon absorber installed at 5.4 m from the center of the upstream undulator. The core photon beam is enclosed by the absorber. The (not shown) photon distribution tails are stopped by the piece of Cu.

Experiments have confirmed the TRACY3 and GdFidL simulations showing no impact on the beam-lifetime and injection efficiency and consequently no local losses.

The absorber main purpose is to prevent photons from reaching the upper or lower jaws of the downstream undulator. It is not designed to take the full power of a 500 mA electron beam or a photon beam largely off-center.

The local interlock was upgraded a second time to assure the protection of the local absorber when inserted. The current threshold for activating the interlock was lower down to 5 mA. The interlock also prevents the closure of both insertion devices simultaneously when the absorber is extracted.

All the systems were successfully installed during technical shutdown of January 2016. The setting up of the absorber and machine interlocks as well as the checking the absence of deleterious effects on the beam were followed by a series of radioprotection tests that were completed in late May 2016.

CONCLUSION AND OUTLOOK

The unforeseen impact of the radiation emitted by the upstream undulator on the second one has been understood and solved. The root cause was mainly related to the imperfect planarity of the liner which was heated by an mis-steered beam. A movable asymmetric absorber and a new interlock system have enabled the simultaneous closure of the two in-vacuum canted undulators at their minimal gaps of 5.5 mm. An additional diagnostic (imager) shall be installed in the front end of the beam lines in August 2017 to monitor regularly any variation of the alignment of the equipment in redundancy of the XBPM. The final cryogenic U18 undulator [4] of ANATOMIX shall be installed and fully commissioned during the first semester of 2018.

ACKNOWLEDGEMENT

This multidisciplinary project involved many groups: magnetism and insertion devices, accelerator physics, electronics and data acquisition, control, mechanical engineering, machine operation, diagnostics and synchronization, alignment and metrology, ultra-vacuum, security, building and infrastructure, as well as the team member of the two long beam lines. This complex project took into account the constraints of operating or constructing ANATOMIX and Nanoscopium beam lines, but also the ability to intervene only during sufficiently long shutdown period.

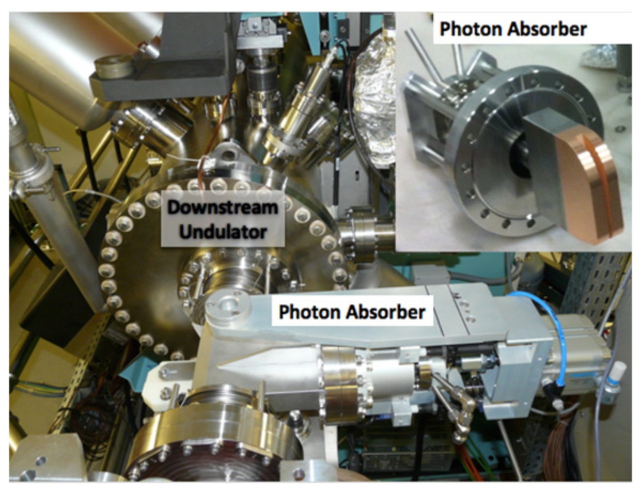

Figure 5: Dedicated absorber installed just before the downstream insertion. The beam direction is marked as a red arrow.

ISBN 978-3-95450-182-3

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