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.

As a preliminary configuration two undulators were installed and commissioned separately: a 5.5 mm gap Nd$_2$Fe$_{14}$B U20 undulator [3] at the downstream position and a 5.5 mm Pr$_2$Fe$_{14}$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-

Table 1: SOLEIL SR Main Parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
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<tbody>
<tr>
<td>Energy [GeV]</td>
<td>2.75</td>
</tr>
<tr>
<td>Circumference [m]</td>
<td>354.097</td>
</tr>
<tr>
<td>Natural Emittance [nm.rad]</td>
<td>3.9</td>
</tr>
<tr>
<td>Current uniform/hybrid/8 bunch [mA]</td>
<td>500/450/110</td>
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02 Photon Sources and Electron Accelerators
A24 Accelerators and Storage Rings, Other
netic blocks of the undulator itself were slightly demag-
netized. Retracing back the cause of this major damage mak-
ing 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 dep-
osition investigations showed that, at full current of
500 mA and with a gap closed down to 5.5 mm, the pow-
er 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 lev-
eels of power densities, the temperature rises are still lim-
ited 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 tem-
perature is then raised to 450 K together with large ther-
al gradients leading to high risk of mechanical deforma-
tion 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 demagnetiza-
tion.

TECHNICAL SOLUTION

It became clear that the unique characteristics of SO-
LEIL (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 low-
ered 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 deci-
sion was instead taken to design a new type of interlock
based on the angle inside the first undulator. The thresh-
old value of ± 25 µrad does not lead to any higher rate of
beam trips during normal operation. The condition to
toggle 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 specifi-
cations [7].

This solution led to a temporary solution in June 2015
to allow the two long beam lines to operate simultaneous-
ly by restricting the lower gap value of the upstream un-
dulator to 8 mm instead of 5.5 mm). A temporary
Sm2Co17 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 undula-
tor.

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.
REFERENCES


[4] A. Ghaith et al., “Progress of PrFeB Based Hybrid Cryogenic Undulators at SOLEIL”, TUOAA3, these Proceedings.

