# A NEW BEAM ANGLE INTERLOCK AT SOLEIL

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*Abstract*

Anatomix and Nanoscopium beamlines are collecting photons generated by two 5.5 mm gap in-vacuum insertion devices installed in a canted straight section. Simultaneous operation of those two beamlines requires particular precautions in terms of alignment of the electron (and photon) beam in the undulators. With the high stored beam current (500 mA), any mis-steering in the upstream undulator could quickly damage the downstream one. Using the classical beam position interlock to guarantee the undulators protection would have constrained too much the operation due to very restrictive position thresholds. Then the machine protection system has been modified to incorporate a new interlock based on the electron beam angle combining two adjacent BPM readings. A description of the system and its performances will be presented.

## INTRODUCTION

SOLEIL [1] is the French third generation synchrotron light source located south of Paris. It delivers photon beams to the users since 2008 is shown in Table 1. Today the 2.75 GeV facility has received more than 20,000 users. A total of 27 beamlines (BLs) take beam on a daily basis.

Table 1: Main SOLEIL Storage Ring Parameters

| Parameters | Values |
|---|---|
| Circumference | 354 m |
| Energy | 2.75 GeV |
| Maximum current | 500 mA |
| Revolution period | 1.18 µs |

Among them two recently constructed long (160 m) beamlines Anatomix and Nanoscopium bring challenges in term of operations. Both BLs use in-vacuum undulators (IVU) as radiation sources that are installed in the same canted straight section. The configuration at SOLEIL is specific since a 12 m long straight section has been transformed and equipped with a strong horizontal chicane for beam separation and a quadrupole triplet for optics adaptation to allow the host of two 5.5 mm minimum gap insertion devices [2]. Their point sources are 6.75 m away (Fig. 1) and make the first undulator a potential hazard for the downstream IVU in term of power deposition. Therefore the radiation angle issued from the upstream insertion has to be precisely and continuously watched for in order to prevent any radiation hitting the NiCu liner sheet of the downstream IVU.

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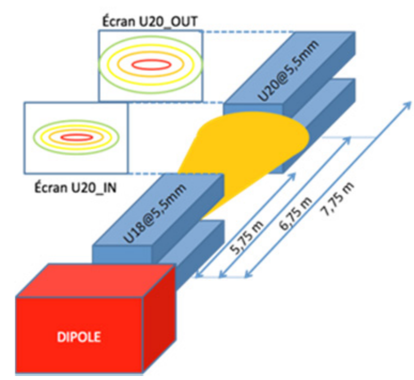


Figure 1: Schematics of the two insertion devices for Anatomix and Nanoscopium beamlines on the same (canted) straight section. In case of mis-steering of the beam in the upstream undulator, radiations may damage the downstream one.

Unfortunately SOLEIL experienced once this issue in 2011: the downstream undulator lower liner sheet was strongly damaged during the first simultaneous gap closing with a 500 mA stored beam leading to the removal of this insertion. Inadvertent mis-steering of the electron beam was aggravated by a wrong vertical offset of the undulator jaws with respect to the beam trajectory. This undulator has then been replaced, and thorough studies were carried out to prevent any such situation to occur again. One of the findings was that the electron beam trajectory in the upstream undulator has to be very carefully aligned and maintained within limits below what was earlier expected so that produced photons pass right into the centre of the downstream one. One of the mandatory steps before allowing again the simultaneous use of the two insertion devices at their minimum gap was an upgrade of the machine protection system (MPS) to protect the device from any accidental beam mis-steering during operation. This will permit simultaneous operation of insertions during the fall of 2015 for an intermediate configuration of the gaps (with gap values respectively 8 and 5.5 mm of the first and second IVUs).

The fastest and easiest way to do that would have been to reduce the vertical position thresholds (currently +/- 300 µm) of the already existing beam position interlock [3] for the two BPMs on each side of the upstream undulator. This would have led to +/-50 µm new threshold values too much constraining for the day-to-day operation (high probability of fake interlocks and strong impact on the beam availability). As a consequence, it has



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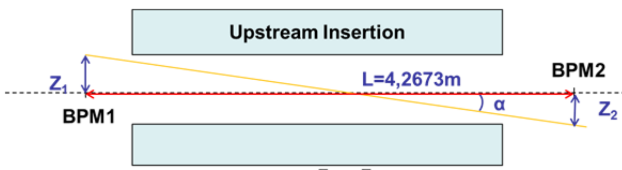
been decided to develop an additional and new type of fast interlock based on the beam angle detection.

## REQUIREMENTS

The beam angle interlock system must be robust and present a high reliability. It must trigger the MPS in less than 100 ms in order to prevent both heating up of the magnets of the IVU (demagnetization hazard) and damage of its liner sheets. The three conditions to be met simultaneously are:

- Machine stored current > 20 mA
- Both undulator gaps < 25 mm
- Beam vertical angle in upstream undulator > 25 µrad




$$\alpha = \frac{Z_2 - Z_1}{L}$$

Figure 2: The new beam angle interlock should detect beam angle default between the two BPMs around the upstream insertion device.

As any interlock system, the beam angle detection should be designed on hardware/firmware based technology. It will be connected to the global machine protection system as a new input [4]. This latter turn off the RF switch of the main storage ring radiofrequency cavities and quadrupoles (redundancy). To ensure one-turn loss of the stored beam in the highly shielded injection section, one of the injection kickers is trigged at the same time since a few years.

## IMPLEMENTATION

The beam angle interlock system must collect information from different subsystems, namely:

- Two BPMs for angle calculation,
- DCCT for current threshold detection,
- Undulator gap motion controllers for gap threshold detection.

Then this information has to be treated in order to generate the logical signal that will trigger the machine protection system (Fig. 3).

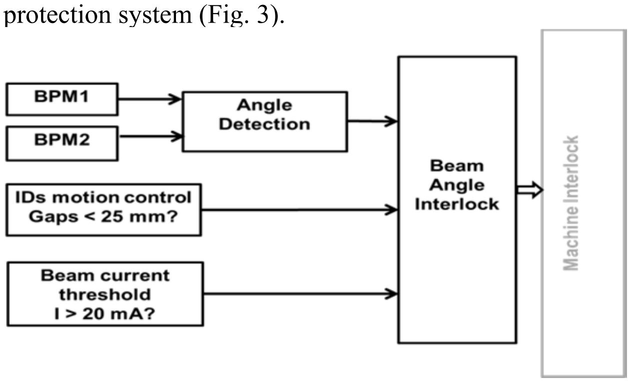



Figure 3: General architecture of the beam angle interlock system.

### *BPM Electronics*

SOLEIL BPM system is based on Libera Electronics [5] that provides, among other data flows, Fast Acquisition (FA) position data sampled at 10 kHz. This data flow is already used for the position interlock system (internally of the Libera) and for the fast orbit feedback correction system.

In order to use the same data flow for the angle interlock, Libera FPGA design has been modified. FA data are distributed in one of the two RS485 frontside ports for serial communication (Fig. 4).


Figure 4: SOLEIL BPM Electronics based on Libera units have been modified to output the 10 kHz sampling position data in one of the RS485 port.

Position data are coded into 16 bits and transported over the RS485 link using an UART protocol adding start/stop and parity bits (Fig. 5). The baud rate on the transmission lane is 1.25 Mbit/s. Data distribution is started automatically as soon as the Libera module is switched ON.

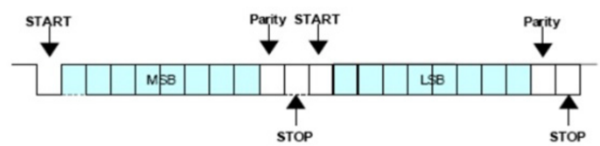



Figure 5: Data protocol over the RS485 transmission line.

### *Angle Detection*

A first electronic board is used to convert the data electrical format from RS485 (differential link) to TTL. Then, the output of this conversion board is connected to a FPGA board (Tews Technologies TCP631) on which the frame decoding is done but also the angle calculation, and the angle fault detection (Fig. 6).

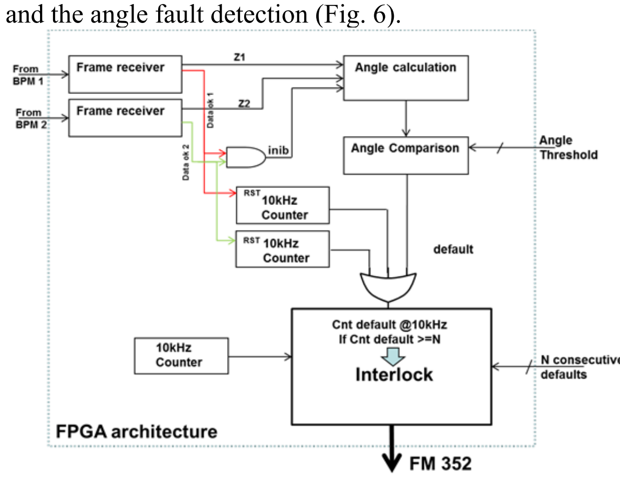



Figure 6: FPGA architecture for the angle detection.



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Calculated angle is compared to user configurable thresholds and the angle interlock signal is emitted if several consecutive angle faults (outside thresholds) are detected. The angle interlock signal is not emitted after a single detected default in order to prevent beam trips due to false errors (BPM spikes for example). This number of consecutive faults needed to emit the interlock is also user configurable.

Moreover, the logic is able to detect a fault in the incoming position data rate (≠10 kHz) or corrupted data. Any communication error is considered as a default.

### *Insertion Device Motion Control*

Information from gap motor encoders is collected by a TLCC that compare the gap position reading value to the gap threshold (25 mm) and generate a fault signal if gaps of the two undulators down crossed threshold.

### *Beam Current Threshold Detection*

Beam current value in the storage ring is measured with a DC current transformer. On top of it, a Programmable Logic Controller (PLC) is already used to generate ON-OFF signal depending on the beam current value to inhibit/uninhibit different systems like top-up injection, beam position interlock, injector...

An additional output of this system has been allocated for the beam angle interlock with a threshold that is presently set to 20 mA (typical maximum low current for commissioning and machine dedicated studies with possible orbit distortion).

### *Beam Angle Interlock*

The logic combining the different faulty signals to generate the interlock signal is implemented in a PLC module (Siemens FM352). Interlock output is trigged when all the three conditions, namely beam angle, gap positions and beam current are met. Any interlock is latched and hold until acknowledgment by the user.

## PERFORMANCE

The beam angle interlock system is configured to trigger the machine protection system after ten consecutive faulty conditions (recorded at 10 kHz). As explained earlier this margin is taken in order to improve the robustness of the system against false detections.

With this configuration, the total time needed to trip the beam after a beam angle fault has been measured equal to 1.9 ms. This delay is the sum of ~1.1 ms for beam angle error detection itself (system wait for 10 consecutive faults) and 0.8 ms for the machine protection system. Dedicated measurement has been performed using a fast air coil corrector to steer the beam outside the limits, and measuring the delay between angle default and beam loss on BPM post-mortem data (Fig.7).

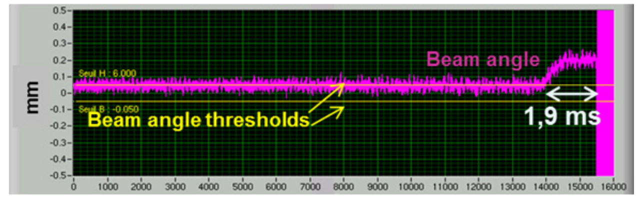


Figure 7: The beam is killed 1.9 ms after the beam angle exceed the threshold.

## OPERATION

The beam angle interlock system has been put in operation since May 2015 in order to allow the simultaneous use of the two undulators installed on the same canted straight section. Since then, the system has been fully operational and did not constrain the day-to-day operation. The system has also shown both high reliability and robustness.

## CONCLUSION

This new vertical beam angle interlock system has been in operation at SOLEIL since May 2015 to allow the simultaneous operation of two in vacuum insertion devices mounted on the same (canted) straight section for an intermediate configuration of their gaps.

Additional diagnostics like a post-mortem buffer of the beam angle measurements just before the beam loss will be implemented soon.

In order to ensure a safe operation of simultaneously both undulators closed to their minimum gap (5.5 mm), the addition of a dedicated photon absorber is mandatory. This latter is under final design and should be installed in front of the downstream absorber beginning of 2016. This will require an extension of the angle interlock system: it will be duplicated in the horizontal plane to protect the absorber.

It will also be possible in the future to integrate as a new input in the system, the photon BPM reading installed in the frontend of the BLs to provide a redundant signal and additional information about the variation of the pointing angle of the photon beam produced by the upstream undulator.

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