BPM SYSTEM INTERLOCK FOR MACHINE PROTECTION AT SOLEIL

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Abstract

SOLEIL, a third generation light source, has its Beam Position Monitors (BPM) processed by the LIBERA electronics built by Instrumentation Technologies. This electronics initiated and specified by SOLEIL features a fast hardware interlock output for machine protection. Although interlocks are available in both horizontal and vertical planes, it was initially thought that only the vertical interlocks would be useful. Actually, the high photon beam power densities delivered by the in-vacuum undulators could damage vacuum chamber elements in case of accidental orbit shifts in horizontal or vertical direction. The crotch absorbers, the XBPMs and their upstream absorbers were designed on the basis that they will be protected with interlock thresholds not tighter than ±1mm. This approach was also applied for specifying the apertures of the XBPMs and of their upstream absorbers. More recently SRW simulations showed that the crotch absorber apertures downstream the new canted undulators needed special attention.

INTRODUCTION

The Soleil BPM (Beam Position Monitor) electronics has been developed thanks to a joint effort of SOLEIL and Instrumentation Technologies, it is the so-called Libera electronics. Each Libera delivers a signal that can be used in an interlock system in order to eventually dump the electron beam. The interlock signal is set within a millisecond whenever the electron beam position in the horizontal or the vertical plane on any BPM trespasses one of the predefined thresholds. At SOLEIL, the interlock signals of 32 BPMs out of the 120 that equip the Storage Ring have been used as early as the commissioning in the vertical plane in order to avoid possible damage to the narrow vacuum chambers of the machine straight sections. Most active interlock thresholds are set to ±0.8 mm; this is to protect with confidence the machine from orbits shifts above ±1 mm. There is no wish to tighten any further the thresholds for avoiding unnecessary beam losses. After the Storage Ring commissioning, the Soleil Beamline Frontends have been progressively equipped with 26 X-BPMs (X-ray Beam Position Monitors). Seven more are ready to install or in construction. An upstream absorber called mask in the following, protects the X-BPMs from accidental orbit shifts that could result from power supply failures. In case of orbit distortions that do not trigger the interlock system, the XBPMs, their mask, and the other machine absorbers must sustain the power and power density of the photon beam. At some point, it was realized that this machine safety strategy was different from what has been previously implemented for the bending magnet crotch absorbers and the Beamline Frontends. This paper details the design of the XBPMs and their masks from the machine safety point of view. It shows in addition that for the new hard X-ray canted Beamlines the new machine safety strategy required to enlarge the previously intended aperture sizes of the bending magnet crotch absorbers.

POSSIBLE POWER SUPPLY FAILURES

Failures of the main magnet power supplies (bending magnets, quadrupoles and sextupoles) would lead to a quick beam loss without damage to the machine. However, a corrector or a set of correctors can trigger relatively modest orbit distortions that drive the ID powerful photon beams onto machine parts unable to stand it. High photon beam power densities are produced by in-vacuum undulators. The parts at risk are the crotch absorbers, the XBPMs and their mask for electron beam orbit shifts in the undulators. Although such accidents are unlikely, it would seriously affect our users' beam availability. Simultaneous failures in both H and V planes would damage the XBPM blades, but such event is very unlikely and was not considered.

X-BPM AND MASK APERTURES

All ID X-BPMs need an upstream protection mask. It helps to keep constant the XBPM temperature necessary for an accurate and stable monitoring. The manufacturer recommends a 100 W maximum power on the head assembly. The instrument would not be damaged with more power, but it cannot resist the high power of the soft X-ray beamlines or the power density of the hard X-ray beamlines.

Most hard X-ray beamline Frontends have two X-BPMs in order to accurately monitor beam angles as well as position. Only one X-BPM equips the soft X-ray frontends because the second one could not be installed far enough from the first one in order to be useful for angle monitoring. The present Soleil X-BPMs are based on the photo-emission phenomenon on copper blades in the bending magnet frontends and on tungsten blades in the ID ones. They were built by the FMB company.

Standard U20 Hard X-Ray Frontends

The short straight sections hard X-ray Frontends were the first to be equipped with X-BPMs. The mask aperture stays in the crotch absorber shade of the ID light in horizontal direction, but not in the vertical one. For the sake of simplicity we assumed that all vertical orbit deviations are possible within a ±1 mm interlock thresholds set on the undulator adjacent BPMs only. Using the SRW simulation code [1,2], the maximum power on the mask has been estimated to 600 W with a 22 W/mm^2 power density. The mask also needs to intercept the bending magnet radiation that amounts to 150 W.

The mask and X-BPMs are safe, but further downstream of the Frontend, the so-called "fixed absorber" needed protection that could be guaranteed with a ±1 mm interlock in the horizontal plane set on the nearby BPMs. Then, the BPMs adjacent to the U20 IDs set a ±1 mm interlock in both planes.

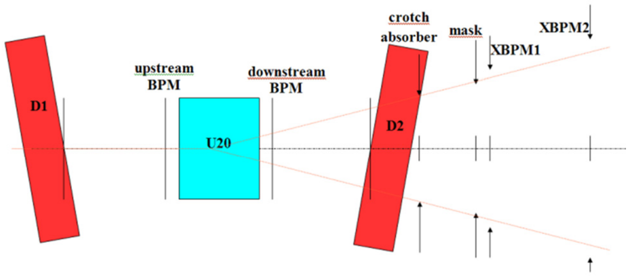

Figure 1: Top view of a short straight section hard X-ray Frontend. The "vertical" scale in the drawing which actually represents the machine horizontal plane is exaggerated in order to clearly see the angular apertures.

The U20 standard Beamline Frontend configuration is shown in Figure 1 and the apertures of the X-BPMs and their mask in Figure 2.

It can be noticed that the apertures are circular. This shape was suggested by the manufacturer. But since the H and V orbits are independent, a rectangular shape was preferred for the X-BPM and its mask at the time of the next X-BPM orders.

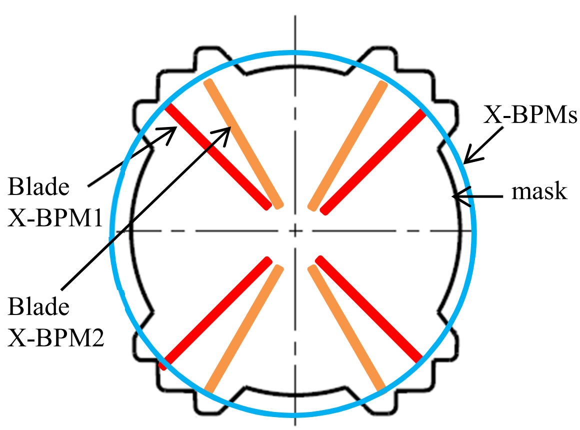

Figure 2: The mask shades the XBPMs from the ID light. This view is a conical perspective, looking from the ID center. Both X-BPMs are seen with the same aperture although the second one has actually a larger diameter. The second monitor blades are set in order to receive the ID light without being in the shade of the first X-BPM blades. The four notches in the mask edge are for keeping the base of both X-BPMs blades into the photon flux during the calibration process that consists in translating the whole X-BPM successively in the H and V plane.

New Canted Beamline on Long Straight Section

A long straight section is going to house two new canted beamlines (Nanoscopium and Tomography) powered by in-vacuum undulators. The same method with SRW was used for estimating the power deposit on the mask. We chose the largest rectangular dimensions of the X-BPM aperture that do not put any part of the blades into the shade of the crotch absorber for every possible position of the elements within their tolerances. The mask aperture is slightly smaller than the X-BPM in the H and V directions but leave the base of the blades into the photon flux. A 1000 W power and 90 W/mm^2 power density coming mainly from the downstream bending magnet could reach the mask in case of bad orbit. In the power calculation process it became clear that the bending magnet crotch could be badly damaged in case of bad orbit drifts. The crotch absorber issues are discussed in a subsequent paragraph.

Other Frontends

The Apple II undulators of the soft X-ray Beamlines deliver powerful photon beams in the machine Frontends. Like in the previous case, the mask total power and power density characteristics are defined using the SRW code and taking into account the photon beam going through the crotch absorber and can possibly reach the mask in all cases beam orbits that are not interlocked. The upstream mask is designed for not letting more than 100 W on the XBPM. The simulations are quite tedious because many polarizations need to be considered for each undulator at its minimum gap. Most soft X-ray Beamlines have a set of two undulators that can be used at the same time. As an example, the undulator set HU256 + HU80, for the Pleiades Beamline, can deposit 6500 W on the X-BPM mask with a 70 W/mm^2 maximum power density. The highest power density, 128 W/mm^2, occurs with the undulator set HU80 + HU44 that equip two Beamlines (Tempo and Sextant).

CROTCH ABSORBERS

The dipole crotch absorbers intercept most of the 15 kW photon beam emitted in a bending magnet. In addition to its power requirements, the absorbers can sustain the high power density (450 W/mm^2) occurring downstream of the bending where the emission point is the closest to the absorber. The absorbers need openings for the bending magnet and Insertion Device (ID) Beamlines. Initially, the ID opening sizes were calculated for keeping the total power and power density within the design limits of the absorber during normal machine operation. It means that one considered the ID photon beams to be always centered on their absorber openings and did not add more power to the absorber than the bending magnet radiation power going through the openings. The power density requirement was no problem since the high power density IDs that equip hard X-ray beamlines are well focused and a well centered electron orbit will not lead to significant power and power density deposit on the edges of the crotch absorber openings.

New Nanoscopium Canted Beamline

Like for the X-BPMs and their mask, we looked at the power density deposited on the crotch absorbers in case of bad electron beam orbits. It became clear that the crotch absorber openings of the new canted Beamlines had to be widened in both H and V directions. The first approach for defining the new dimensions was to use only the interlock properties of the two BPMs adjacent to each undulator. It lead to very large openings that were impossible to implement. All BPMs possibly in the interlock system had to be considered, the most useful ones are located at high beta function points. The investigation result for the Tomography Beamline is shown in Figure 3.

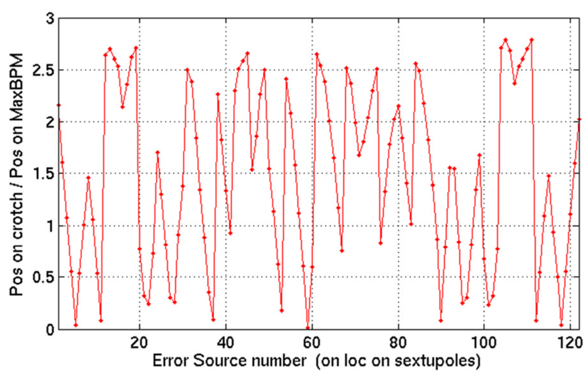

Figure 3: Ratio in the vertical plane between the maximum vertical deviation of the photon beam at the Tomography crotch and the greatest position read by the 122 BPMs. The ratio is computed for each corrector (corrector number is shown on the horizontal axis of the graph). There are only 56 power supplies actually implemented among 122 vertical correctors located in the sextupoles, but all 122 cases are represented here.

In the Figure 3 example, several cases of corrector failures (wrong power supply currents) can move the photon beam up (or down) by about 2.8 mm on the crotch absorber with vertical orbit drifts that stay within ±1 mm on all BPMs. The aperture opening of the absorber has been enlarged to ±7.25 mm in order to keep the power density within specifications. The top and bottom edges of the opening receive the photon beam in normal incidence which limits to 30 W/mm^2 the acceptable power density. The left and right sides of the opening are on the special tapered teeth of the absorber that can sustain 120 W/mm^2 in addition to the bending magnet photon beam power density. The ±7.25 mm vertical crotch aperture is appropriate. It needs to be greater than the sum of i) ΔP_{max}, the maximum photon beam deviation on the crotch (±2.8 mm from Fig. 3), ii) W_{beam}, the width of the photon beam of power density above 30 W/mm^2 at the crotch level (± 3.0 mm from SRW power density map), and iii) ΔP_{crotch}, the crotch position tolerance (±1 mm).

Other Hard X-ray Beamlines

The same exercise, done on the short straight sections equipped with U20s, showed the maximum power densities on the openings to be within specifications. Another hard X-ray Beamline, called PX2 is presently equipped with only one U24 undulator downstream of a canted straight section. A cryogenic U18 is foreseen lateron the upstream side. The horizontal openings are appropriately wide but not the vertical ones. It will be fixed when the second undulator is installed. A hard X-ray Frontend summary for the horizontal crotch absorber apertures is shown in Table 1.

Table 1: Minimum estimated crotch absorber apertures in the Horizontal plane and actual ones for the hard X-ray Beamlines. All dimensions are in mm.

Beamline	**U20 SDC**	**Nanoscopium U20**	**Tomography U18 cryo**	**PX2-A U24**	**PX2-B U18**
ΔP_{max}	±0.92	±1.25	±1.25	±0.93	±0.93
W_{beam}	±1.9	±2.77	±4.1	±2.14	±2.6
ΔP_{crotch}	±1	±0.5	±0.5	±1	±1
total=min aperture	±3.82	±4.52	±5.85	±4.07	±4.53
Actual aperture	±4	±5.3	±8	±4.5	±5.5

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CONCLUSION

The Libera interlock signals can be used in order to efficiently protect all machine and Beamline Frontend elements from the powerful SOLEIL undulator photon beams. A special attention for the hard X-ray in-vacuum undulators that equip a new canted Beamline resulted in enlarging the bending magnet crotch apertures initially foreseen in order to prevent possible damage in case of accidental corrector power supply failures. For good orbit interlock protection, all BPMs located at high beta function points in both vertical and horizontal planes are used.

REFERENCES

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