AXD MEASUREMENTS AT SOLEIL

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Abstract

A first prototype of in-Air X-ray Detector (AXD) has been installed on the SOLEIL storage ring. An AXD simply consists of a scintillator, an objective and a camera installed in air behind the absorber of the bending magnet's synchrotron radiation layer. The radiation vertical profile analysis easily enables to retrieve the vertical beam size of the electron beam at the source point. This simple diagnostics opens large perspectives of beam size measurement all around the ring for an accurate characterization of the beam and improvement of its stability survey.

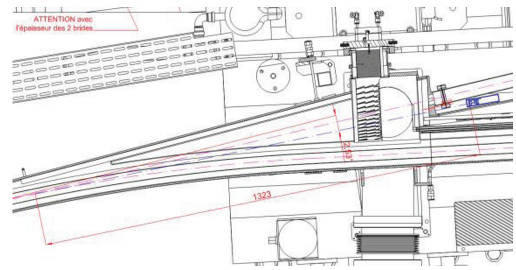
INTRODUCTION

An in Air X-ray Detector (AXD) has been installed at SOLEIL in August 2016 for vertical electron beam position and size measurements. An AXD consists of a scintillator and an imaging system [1] as illustrated in Figure 1. When the electron beam passes in the ring dipole field, it produces synchrotron radiation (SR) over a wide spectral range including hard X-rays. The synchrotron radiation in the X-ray range can pass through the absorber and the dipole vacuum chamber to reach the air in the tunnel. The X-ray SR layer distribution is then transformed into a visible light distribution by a scintillator. Finally, an imaging system enables to record this distribution on a camera. The analysis of the vertical profile of the light distribution enables to retrieve the vertical dimension at the source point, i.e. in the ring dipole. This paper summarizes the design and installation of the AXD at SOLEIL and presents its first measurements obtained in September 2016.

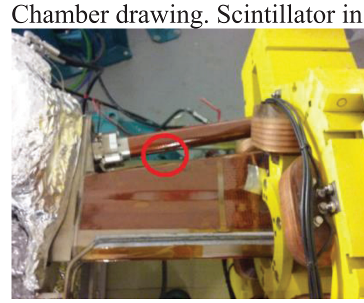
AXD SOURCE POINT

AXD Location

The AXD has been installed behind the second dipole of cell 12 at SOLEIL (C12-D2). The geometry of the C12-D2 vacuum chamber enables to mount the scintillator only 1.3 m downstream the source point inside the dipole (see Figure 2).



(a) Chamber drawing. Scintillator in blue.



(b) Chamber picture before AXD installation. Red circle: expected scintillator location.

Figure 2: C12-D2 vacuum chamber.

Beam Parameters at Source Point

The scintillator is in fact in between two vacuum chamber exit branches: the one for the 0° radiation and the one for the electron beam exit, corresponding to an extraction angle of 2.53°. The electron beam parameters at the 2.53° source point are given in Table 1.

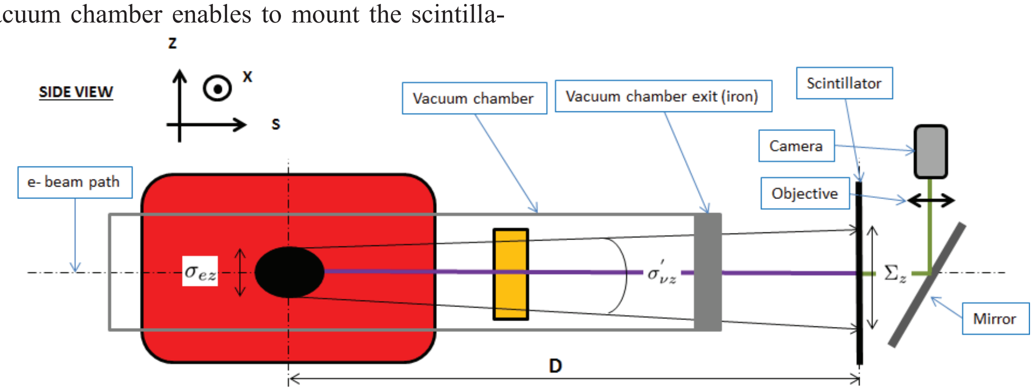


Figure 1: AXD schematic.

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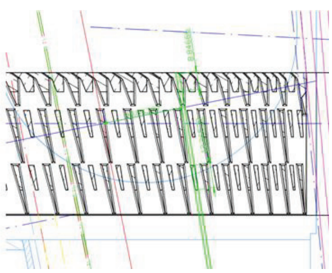
Table 1: Beam Parameters at the 2.53° Exit of C12-D2

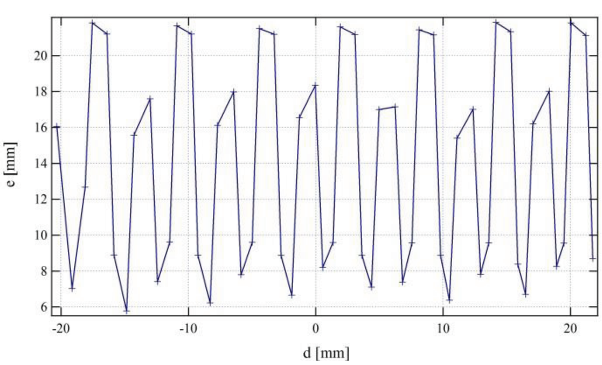
Parameter	Symbol	Unit	Value
Energy	E_e	GeV	2.75
Hor. Emitance	ε_x	nm.rad	4.0
Energy dispersion	σ_e	-	0.001025
Vert. beta function	β_z	m	12.026
Vert. alpha function	α_z	m	0.552
Vert. beam size	σ_{ez}	µm-rms	21.93
Vert. beam divergence	σ'_{ez}	µrad-rms	2.08

The Absorber

Inside the SOLEIL dipole vacuum chambers are installed absorbers to block the synchrotron radiation which is not used by a beamline. Those copper absorbers, called crotchs, do not present a constant thickness of copper. They are made of series of teeth (see Figure 3a) to optimize the power deposition, which results into a periodic shape of the transverse thickness (see Figure 3b). The thickness varies between 6 and 22 mm along the X axis. For the following calculations, we will assume that the copper density is 8.96 g/cm^3.



(a) Crotch drawing in the XS orbit plane. Top view.



(b) Crotch thickness profile along X.

Figure 3: Characteristics of SOLEIL absorbers (crotch).

The Vacuum Chamber Exit

The AXD is located in the middle of the dipole vacuum chamber, where a gap appears between the 0° exit branch and the electron beam exit branch. The dipole vacuum chamber is made of stainless steel, i.e. essentially iron. For the following calculations, we will assume that the chamber is only made of iron, with a density of 7.874 g/cm^3. The thickness of the chamber on the SR path towards the AXD is changing rapidly in the transverse direction as shown in Figure 4. We will assume that at the scale of the scintillator, i.e. 10 mm, it is constant and equal to 20 mm. The left part of the X-rays will also intercept the 0° branch exit flange. It is there 25 mm thick and is also made of iron.

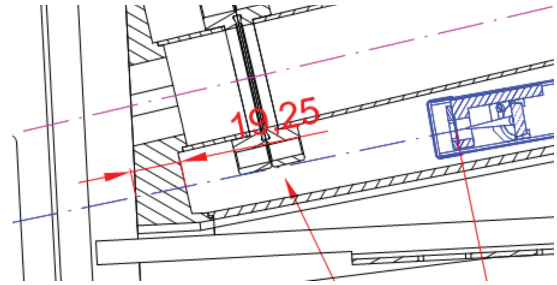


Figure 4: Dipole chamber exit. Scintillator in blue.

SIMULATION OF THE AXD

Analytical Calculations

The synchrotron radiation layer rms vertical size at scintillator can be calculated analytically according to the following formula:

$$\Sigma_z = \sqrt{{\sigma_{ez}}^2 + D^2({\sigma'_{\upsilon z}}^2 + {\sigma'_{ez}}^2)} \qquad (1)$$

σ_{ez} and σ'_{ez} are respectively the electron beam vertical size and divergence (rms) and $\sigma'_{\upsilon z}$ the photon beam vertical divergence (rms). D is the distance between source point and scintillator. For a photon energy E_υ of 100 keV: Σ_z = 46.3 µm.

SRW Simulations

The analytical calculation assumes that the photon beam is mono energetic, which is far from being the case. SRW simulation enables to simulate the 3D radiation distribution emitted by the dipole which should provide a much more accurate estimate of the expected vertical size.

The electron beam is simulated using parameters of Table 1. The dipole field is simulated using its longitudinal profile with a plateau at 1.71 T. The 3D radiation distribution (E_υ, X, Z) is extracted at the scintillator location, i.e. at 1323 mm downstream the 2.53° exit of the dipole. The 3D distribution is then filtered in E_υ using the transmission profile of the crotch, of the vacuum chamber, and the absorption of the scintillator.

Integrating over E_υ, we obtain the 2D distribution of the visible light at the exit of the scintillator, as illustrated in Figure 6. The width of the field of view corresponds to the scintillator width. Three teeth should be visible on the scintillator. Their absolute position on the scintillator is not known, since we don't know the relative position between the crotch teeth and the 2.53° axis.

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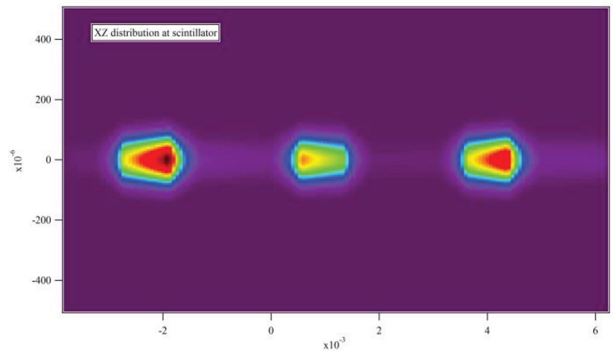

Figure 5: 2D distribution at the scintillator location. XZ grid: 151 x 151 over 10 x 1 mm. Initial photon distribution: 100 photons from 50 up to 200 keV. Fe thickness: 20 mm.

Integrating over XZ, we obtain the average spectrum of the X-rays transmitted to the scintillator, and the average spectrum of the light absorbed in the scintillator (see Figure 7). This gives an indication of the central wavelength of the X-rays that contributed to the visible pattern.

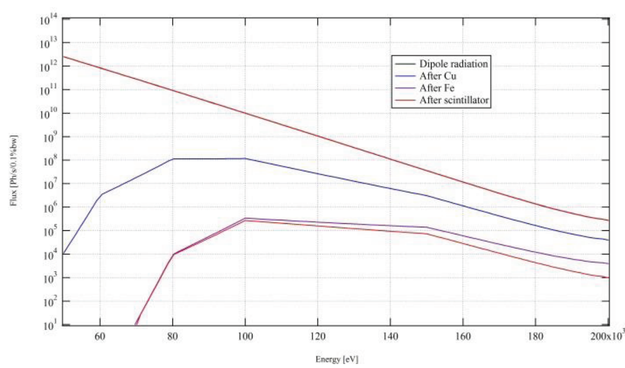

Figure 6: SR spectrum at various stages of the process. Integration over the 10 x 1 mm transverse window at the scintillator location. Fe thickness: 20 mm.

In the case of 45 mm iron thickness (case with the flange), the distribution is peaked at 130 keV (100 keV with 20 mm). It was difficult to predict how many teeth would be in the shade of the flange. But the teeth behind the flange should be significantly less intense than the others since the photon flux is more than one order of magnitude lower.

Expected Measurements

The crotch thickness changes the output spectrum of the radiation. At maximum thickness (22 mm approximately) the radiation reaching the scintillator will be of higher energy than at the minimum thickness (6.6 mm approximately). This means that the crotch thickness changes along the X axis the divergence of the photons reaching the scintillator and the scintillator response. To retrieve the electron beam size σ_{ez} from the layer size Σ_z, the vertical profile must be done on a narrow band for which we know the corresponding copper thickness.

For instance, the simulation in the case of 45 mm iron thickness gives:

- Σ_z = 41.29 µm at minimum crotch thickness (6.6 mm)
- Σ_z = 40.16 µm at maximum crotch thickness (21.6 mm)

The analytical calculation of Σ_z gives:

- Σ_z = 40.63 µm at 150~keV
- Σ_z = 41.6 µm at 140~keV
- Σ_z = 47.2 µm at 100~keV

Those results are in good agreement with the estimate from the average spectra of a median photon energy of 150 keV.

The crotch thickness changes sharply from "very thick" to "very thin". But it also changes within the "very thick/thin" regions. Inside a tooth ("very thin" region), the variation of copper thickness is typically of 2 mm per mm along X. According to the simulation, with an iron thickness of both 20 and 45 mm, the resulting Σ_z variation is about 1%, i.e. negligible. Consequently, to measure the electron beam size from Σ_z, we can use the vertical profile obtained from the projection in Z over one tooth. Of course, if the signal is enough, one should favour narrower integration in X.

DETECTOR DESIGN

The scintillator is a CdW04 crystal provided by Saint-Gobain. Its dimensions are 10 x 10 x 0.5 mm.

The camera is a CCD from Basler, model Scout Series scA640-70gm, 494 x 659 pixels of 7.4 microns.

The specifications on the optics are the following:

- To locate the teeth, we first need a field of view of 10 mm, i.e. a magnification of 0.4.
- To measure the vertical layer size, we will need a resolution of Σ_z / 10, i.e. a magnification up to 1.8.

For high quality imaging, we chose to use an objective: a MVL6X12Z (6.5X) from Navitar. The magnification is variable from 0.26 to 1.69, which fits the requirements.

The mechanics of the detector is illustrated in Figure 8:

- The scintillator is hold between an aluminium piece and a peek piece.
- A 1/2 inch broadband metallic mirror is hold in an aluminium support to deflect the light upward.
- The camera is fixed on a motorized translation stage to enable remote controlled focussing.
- A manual stage enables to adjust the camera position in X within a +/- 3 mm range to select the zoomed area.
- The whole detector is hold by a massive post.

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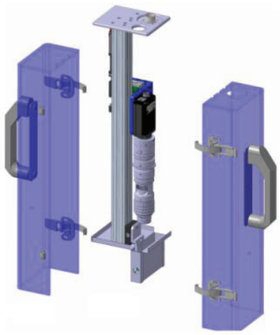


Figure 7: 3D view of the detector and its mechanics.

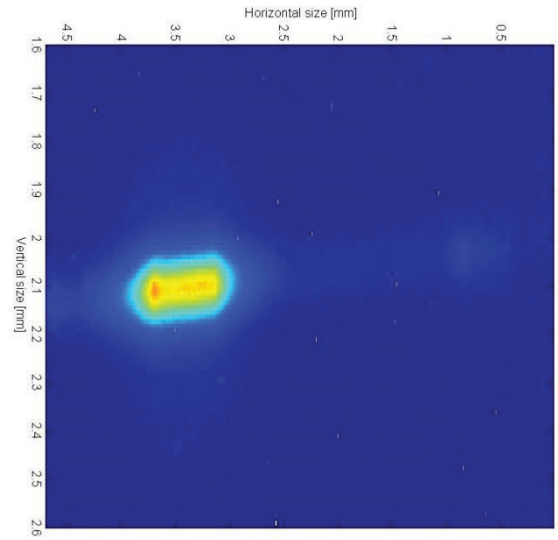
Shielding

The camera and the stage will be installed in a high radiation environment, requiring a heavy shielding. The whole detector is enclosed into a 5 mm thick lead box made of two pieces (see Figure 8).

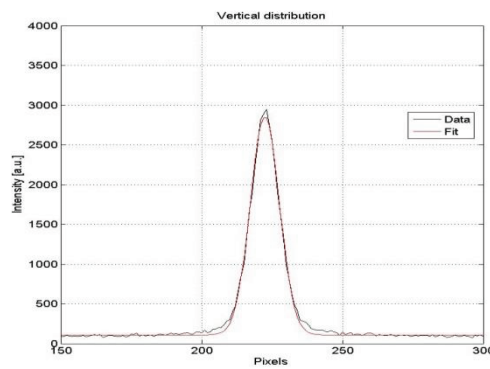
AXD FIRST MEASUREMENTS

Figure 8: AXD on C12-D2 (August 2016).

The AXD was installed in August 2016 (see Figure 8). And the first AXD observation was performed in September 2016. The magnification factor was set to 0.35 in order to visualize the whole scintillator area, and we could observe immediately at the machine restart one tooth on the scintillator. On the 5th of September, we increased the magnification coefficient up to 0.78 and therefore zoomed on the observed tooth (see Figure 9). We measured Σ_z = 50 µm-rms, i.e. slightly above the expected value probably because of the system resolution. Unfortunately we could not increase further the magnification due to mechanical constraints. We plan to modify the support by the end of October in order to reach the expected final magnification of 1.69.



(a) AXD image (part of the full field).



(b) Vertical profile.

Figure 9: AXD record of the 05/09/2016.

CONCLUSION

An AXD has been installed on C12-D2 at SOLEIL. It aims at the vertical position and size measurements of the electron beam inside one of SOLEIL's dipole ring. According to simulations, the AXD should be an accurate diagnostic once taken into account the peculiar geometry of the SOLEIL's absorber. The first measurements performed in September 2016 are very encouraging.

REFERENCES

[1] K. Scheidt, "Detection of hard X-rays in air for precise monitoring of the vertical position and emittance in the ESRF dipoles", Proc. of DIPAC'05, Lyon, France, May 2005, pp. 238-2.

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