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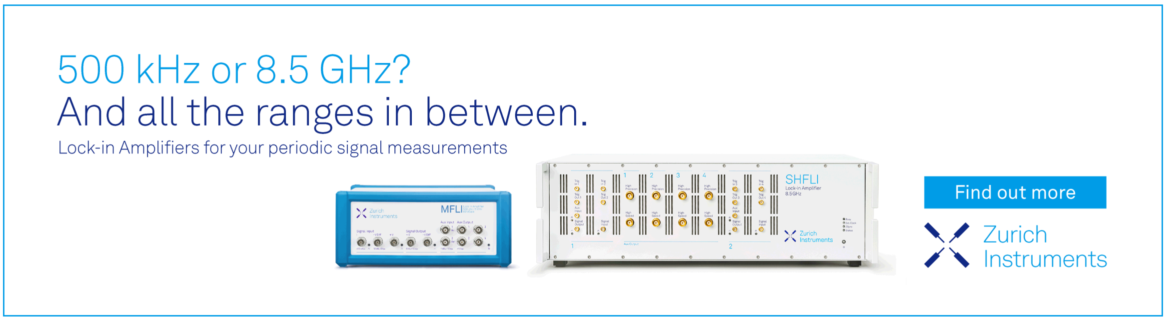

Production of High Energy Photons With In Vacuum Wigglers: From SOLEIL Wiggler to MAXIV Wiggler

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Abstract. Small gap wigglers become more and more attractive to produce high photon fluxes in the hard X-ray photon range. They use magnet blocks of high magnetization which resists much better to heating (baking, synchrotron radiation) than in the past, produce high magnetic field with numerous periods and are very compact. They also are a very good alternative to superconducting technology which requires special infrastructure, heavy maintenance and is not running cost free. SOLEIL, operating presently at 2.75 GeV has designed and built an in-vacuum wiggler of 38 periods of 50 mm producing 2.1 T at a minimum gap of 5.5 mm to delivered photon beam between 20 keV and 50 keV. Already in operation, further improvements are presently in progress to push photons towards higher energy, in particular thanks to the operation at lower gap (4.5 mm). MAX IV and SOLEIL, in the frame of collaboration, ave built an upgraded version of the existing SOLEIL wiggler with the target to extend the spectral range at high energy (above 50 keV) but also at low energy (4 keV) with the same insertion device. The design of the existing magnetic system has been modified to reach 2.4 T at a minimum gap of 4.2 mm and includes taper operation to avoid undulator structure in the radiated spectrum at low energy.

INTRODUCTION

Scientific users from Synchrotron facilities are more and more demanding of photons well above 50 keV. Photons of high energy are usually produced by high field wigglers using permanent magnets [1,2] or superconducting technology [3,4] . However they also generate large amount of useless power and have a strong impact [5,6] on the beam dynamics (tunes shift, horizontal emittance and dynamic aperture). The effects of the magnetic field on the beam lifetime get more and more pronounced as the particle energy gets lower [7]. This is the reason why it is preferable to build rather moderate or low magnetic field wigglers on intermediate energy storage rings. Decreasing the magnetic period of wiggler can be a solution to decrease the magnetic field. Although the angular flux produced by each radiating pole of the wiggler is lower the total flux is kept constant and even increased because the number of radiating pole increases. This enables to produce similar flux with lower radiated power.

The solution adopted at SOLEIL is to use permanent magnets (PPM) to produce high energy photons. The technology of permanent magnets, mature for 20 years, offers grades of high magnetizations [8] and coercivities [9]. SOLEIL, operating at 2.75 GeV and a current of 500 mA has constructed an in-vacuum hybrid PPM wiggler [10] dedicated to the High Pressure studies beamline (PSICHE) with a relatively short period. The wiggler (WSV50) is composed of 38 periods of 50 mm generating 2.1 T over a magnetic length of 2 m and produce photons between 20 keV and 50 keV. It is in operation for 8 years but a spectral extension up to 70-80 keV has been demanded by the beamline users. Tests of flux increase are in progress and will be presented here. Following the installation of the in-vacuum wiggler MAXIV and SOLEIL signed a collaboration contract to build a similar wiggler with higher field for the BALDER beamline of MAXIV operating between 4 keV and 40 keV. Technical changes have been brought to

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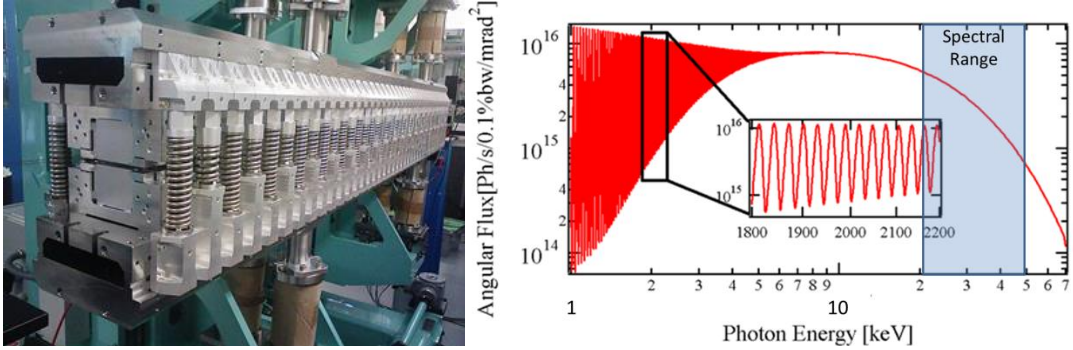
increase the field and to avoid undulator structure present in the spectrum at low energy. The technical evolutions of the wiggler will be presented in the paper.

COMPACT PPM WIGGLER AT SOLEIL

WSV50 is a wiggler made of 38 periods of 50 mm. Each period is composed of sequence of NdFeB magnets with a remanence of 1.26 T and vanadium permendur poles. Magnets and poles are coated with a 10 µm thick layer of Al. Magnets can be baked up to a temperature of 125 °C to insure a low level of pressure when operating under vacuum. The minimum magnetic gap is 5.5 mm corresponding to a field of 2.1 T (deflection parameter K of 9.8). Despite the moderate level of the magnetic field the attractive forces between magnet arrays reaches 8 tons. The usual carriage used at SOLEIL, SPring8 or ESRF are equipped with external girders and internal girders [11]. The increase of the thickness of internal or external girders could fix the problem of beam deformation but cannot be applied in the case of SOLEIL because of the limited height of the tunnel roof (2.4 m). Compact solution avoiding external girders have been integrated in the design and completed by a counter force system made of springs (Figure 1.a).



(a) (b)

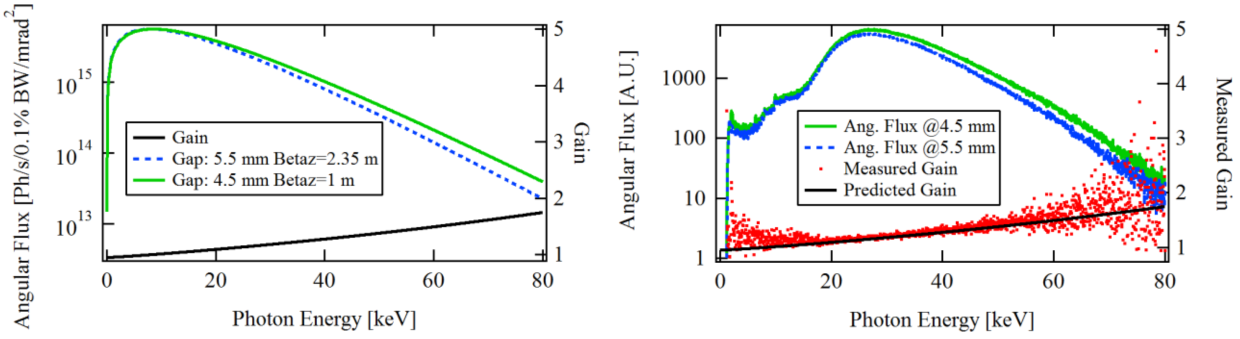
FIGURE 1. WSV50 without vacuum chamber (a) and angular flux(b) calculated at gap of 5.5 mm (K=9.8).

The strength and length have been controlled and paired with spacers to optimize locally the force compensation. The gap can be changed from 70 mm down to 4.5 mm via 2 motors. The residual force is 500 kg over th full gap range. A taper between entrance gap and exit gap can be applied in the limit of 300 µm without carriage deformations. There is presently no need to use tapering to broaden the spectrum. The wiggler is operating well above the undulator regime limit (Figure 1.b). However the flux above the initially required spectral range (20-50 keV) drops dramatically. A spectral extension up to 70 keV-80 keV has been proposed to users via the operation at lower gap (4.5 mm). The machine optics has been modified to take into account the gap reduction: the vertical betatron function β_z has been changed from 2.35 m to 1 m. However the change of optics changed also the horizontal emittance (Table 1).

TABLE 1. Horizontal and vertical emittances variation versus the vertical betatron function.

β_z [m]	Magnetic gap [mm]	Peak Field [T]	Effective Field [T]	Horizontal Emittance [nm.rad]	Vertical Emittance [pm.rad]
2.35	5.5	2.1	1.901	4.24	51.4
1	5.5	2.1	1.901	4.65	51.7
1	5	-	-	4.7	50.4
1	4.5	2.3	2.058	4.8	49.5

The angular flux has been measured on the beamline at three gaps mentioned in Table 1 and various β_z. Figure 2 compares the measured flux and the predictions using SRW code [12] for two gaps.



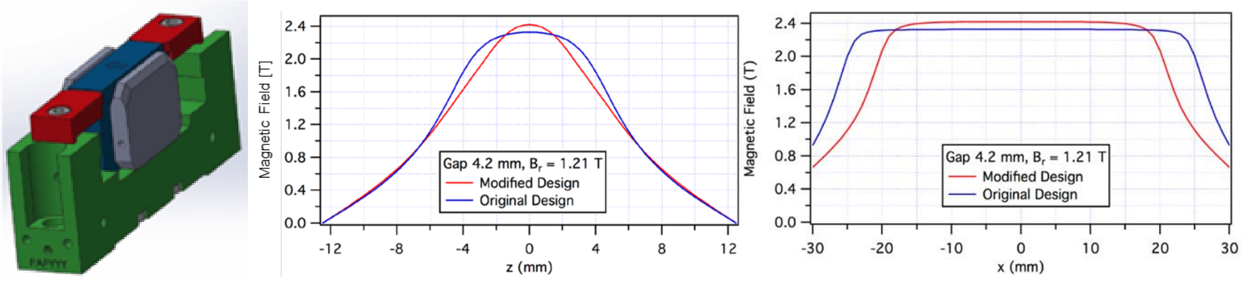
(a) (b)

FIGURE 2. Predicted (a) and measured (b) angular flux at gaps of 5.5 mm and 4.5 mm.

The measured angular flux drops below 20keV because of the filters of the beamline to avoid excessive useless power on the optics. The gain resulting from the measured flux is “noisy” but follows the predicted behavior. A gain of 1.8 is expected at 80 keV.

FROM SOLEIL WIGGLER TO MAXIV WIGGLER

The potentialities of the wiggler have been pushed further by adding slight changes in the design.



(a) (b) (c)

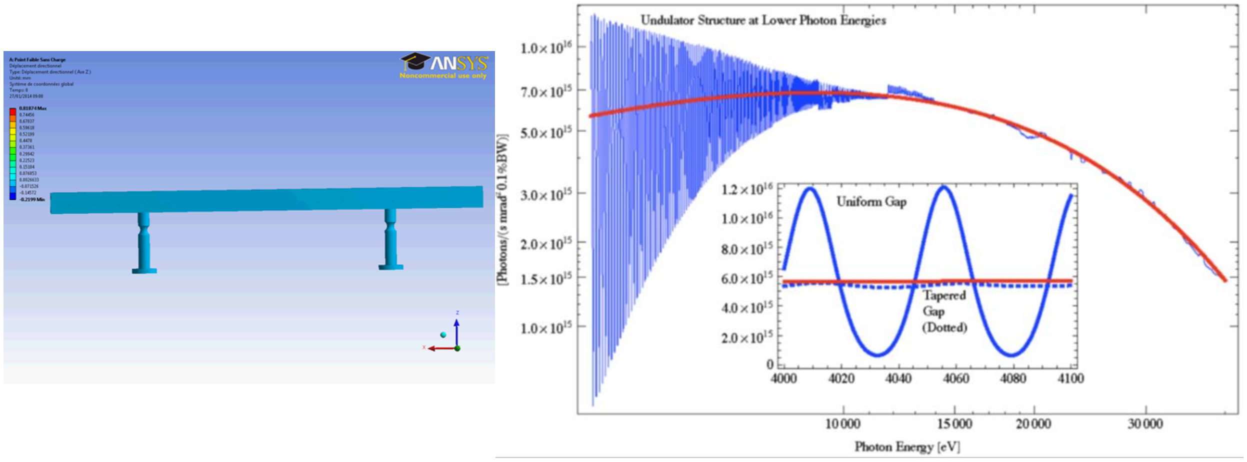
FIGURE 3. Modified poles (a), longitudinal profile of the field (b) and transverse variation of the field (c).

The period is the same. The magnet blocks have the same geometry. But the minimum gap has been reduced downto 4.2 mm, the pole width drops from 60 mm to 50 mm and longitudinal chamfers on the poles (wiggler axis) have been added (Table 2). The maximum field is 2.4 T assuming a lower remanence (1.21 T instead of 1.26 T for the SOLEIL wiggler). Figure 3 presents the magnetic field generated by the original design of the SOLEIL wiggler and the modified design for MAXIV.

TABLE 2. Comparison of technical characteristics of SOLEIL and MAXIV wigglers

Parameters	SOLEIL wiggler	MAXIV wiggler
Technology	Hybrid In-vacuum	Hybrid In-vacuum
Magnets	B_r=1.26 T	B_r=1.21 T
Magnet grade	NdFeB	NdFeB
Poles	Vanadium permendur	Vanadium permendur
Pole width	60 mm	50 mm
Minimum gap	5.5 mm	4.2 mm
Tapering	0	+/- 2 mm

However the required spectral domain of the MAXIV beamline extends more at low energy (4 keV) than at SOLEIL. Undulator structure appears in the spectrum below the critical energy (14.3 keV) but can be cancelled by applying a tapering between the entrance and the exit of the magnetic system.



(a) (b)

FIGURE 4. Supporting structure of the magnetic system (a) and predicted angular flux (b) at MAXIV.

The tapering is performed thanks to the entrance and exit motors. The original rods supporting the girders have been partially shrunk to create weak points (Figure 4.a) which limit the additional deformation of the girder (15 µm) during taper operation. With a taper of 2 mm (respectively 4.2 mm and 6.2 mm at the entrance and at the exit), the amplitude of the flux oscillations can be reduced by a factor 10 in the full spectral range (figure 4.b).

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