AN IN VACUUM WIGGLER WSV50 FOR PRODUCING HARD X-RAYS AT SOLEIL

O. Marcouillé, P. Brunelle, O. Chubar, M-E. Couprie, J-M. Filhol, C. Herbeaux, J-L. Marlats,

A. Mary, K. Tavakoli, Synchrotron SOLEIL, Gif-sur-Yvette, France.

Abstract

SOLEIL is a medium energy storage ring (2.75 GeV) operating since 2006. The production of intense high energy photon beams requires Insertion Devices (ID) with high magnetic field and large number of periods. To cover the 20 - 50 keV range, an in vacuum wiggler has been preferred to a superconducting wiggler. This choice results from a compromise between photon flux, investment and running cost. Deep studies have been performed to find the optimum magnetic field and period producing the maximum flux in the dedicated spectral range (20-50 keV). The wiggler is composed of 38 periods of 50 mm producing 2.1 T at a 5.5 mm minimum gap. To minimize the high magnetic forces acting between the magnet arrays (10 tons), a compensation system has been designed. It consists of two series of 40 amagnetic springs reducing the forces down to 1 ton over the whole range of the magnetic gap variation. This paper presents the spectral performances of the wiggler compared with an optimized superconducting wiggler, the mechanical and magnetic design of the wiggler and the first tests of the compensation system.

INTRODUCTION

The production of high photon energy in medium energy storage ring is driven by the construction of insertion device (ID) with high magnetic field and a large number of periods. Superconducting IDs allow to operate with photons above 50 keV even with small period [1], but induce important running costs and are maintenance time consuming. SOLEIL has decided to investigate in the in-vacuum technology to reach the high photon energy domain though the construction of a small gap wiggler with a large number of periods and producing a relative low magnetic field.

CHOICE OF THE PERIOD

The in vacuum wiggler (WSV50) is constructed for the PSICHE beamline [1]. This beamline is the dedicated to experiments under extreme conditions in terms of temperature and pressure. The required opening angles are the full emission angle in vertical direction and 8 mrad in horizontal direction. The main limitation comes from the total deposited power which must not exceed 25 kW on the front end at the nominal 500 mA stored current. Figure 1. presents in contours the maximum angular flux produced by IDs versus the period and the reachable magnetic field at photon energy of 50 keV. The maximum acceptable power of 25 kW, is taken into account in the length of the IDs.

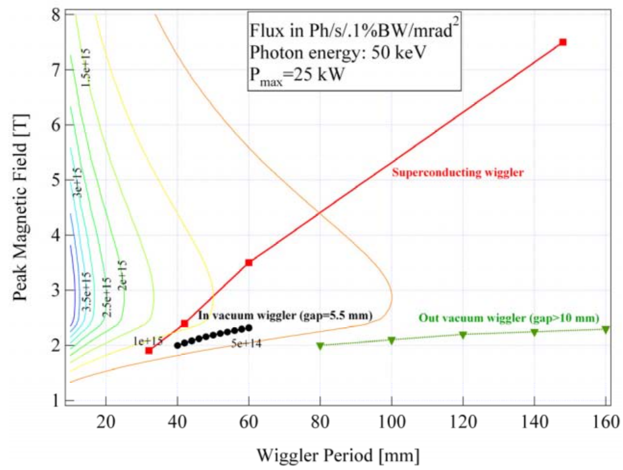

Figure 1: Angular flux versus field and period. Solid lines: existing Superconducting IDs. Dashed lines: proposed IDs for SOLEIL. Black bullet: designed in-vacuum wiggler.

The maximum flux at 50 keV is attained for a 50 mm period corresponding to 70 % of the maximum flux of a superconducting wiggler

MAGNETIC DESIGN

The wiggler WSV50 is composed of 38 periods of 50 mm.

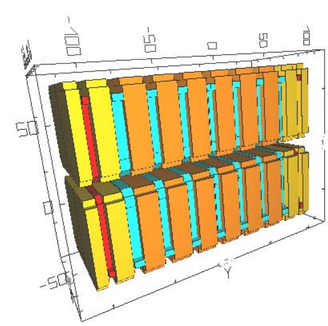

Figure 2: Magnetic design of a 3 period model: The main magnet are shown in orange, the main poles in light blue. The end terminations are composed of a sequence yellow magnets and red poles

The maximum field is 2.1 T at a minimum gap of 5.5 mm. The magnetic system consists of a sequence of NdFeB permanent magnets (VACODYM 872TP) of high remanence (B_r=1.22 T) and coercitive field

(H_{cj}=2000 kA/m) and Vanadium Permendur poles (VACOFLUX) of high saturation level (2.35 T). Both magnets and poles have been Al-coated to limit the corrosion of the material and the desorption. They have been assembled on individual supports of one magnet and on supports composed of a sandwich of two poles and one magnet, in order to shim the wiggler by vertical displacement of supports and poles. The wiggler has been designed using the RADIA [2] code and checked with Tosca 3D [3]. Figure 2 shows the magnetic design of a short version (3 periods of WSV50). The resulting magnetic field at minimum gap is plotted in figure 3.

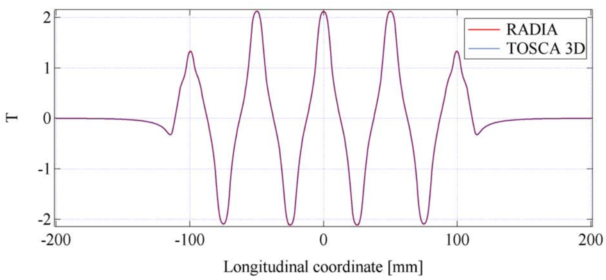

Figure 3: Magnetic field versus longitudinal position at minimum gap of 5.5 mm.

Special attention has been taken in the demagnetization resulting from the baking at 125 °C. Thermal stabilization at 140° C has been performed before complete measurement of magnet and delivery.

DESIGN AND NON LINEAR EFFECTS

The transverse size of the poles is a trade-off between magnetic forces acting between girders and non linear effect acting on beam dynamics and Touschek beam lifetime. The smaller the poles and magnets are, the weaker the magnetic attraction is but the stronger the non linear effects are. Table 1 presents the magnetic field, the transverse roll-off (relative variation of the field at x = 30 mm from the beam axis) and the Touschek beam lifetime calculated for the nominal operation mode. Note that the Touschek beam lifetime is 35.5 hours without the WSV50.

Table 1: Attraction force between magnets arrays and effect of the size of the poles on the beam life time

Gap [mm]	Pole size: 60mm	Pole size: 70 mm	Pole size: 80 mm
5.5	**7.5 Tons**	9.2 Tons	10.6 Tons
	ΔB/B: 54%	ΔB/B: 14%	ΔB/B: 1.2%
	τ=27.7h	τ=31.3h	τ=35.5h
4	10 Tons	11.5 Tons	13 Tons
	ΔB/B: 59%	ΔB/B: 13%	ΔB/B: 0.8%
	τ=24.8h	τ=29.7h	τ=35.4h

Poles of the smallest pole size (60 mm) have been finally selected.

MAGNETIC FORCE COMPENSATION

At minimum gap (5.5 mm), the attraction force between jaws reaches 7.2 Tons. Different counterforce systems have been envisaged. Firstly, by using permanent magnets such as already proposed at Spring8 [4] or by R. Carr [5]. Such magnetic system generates a repulsive force between top and bottom girders. This effect can also be produced by using non magnetic springs.

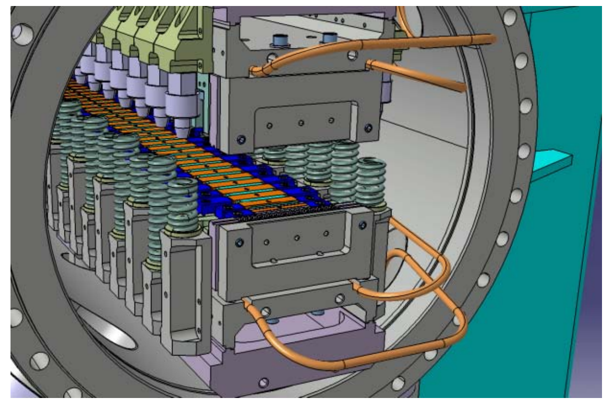

Figure 4: Magnetic system and compensation system installed in the vacuum chamber

Even if the first solution allows in the principle a total cancellation of forces, it is less compact than the spring solution and more expensive and sensitive to thermal demagnetization resulting from the baking.

The compensation system of the wiggler is composed of Inconel springs (μ=1.005) of different rigidity constant and length. The resulting repulsive force acting on the wiggler jaws is linear with the gap. The residual force is limited to 1 Ton maximum leading to mechanical deformations of girders to less than 50 µm. Figure 4 shows the compensation system installed on the both side of the magnetic system. The system can be replaced by the magnet compensation system, if necessary. The residual force versus gap is plotted in figure 5.

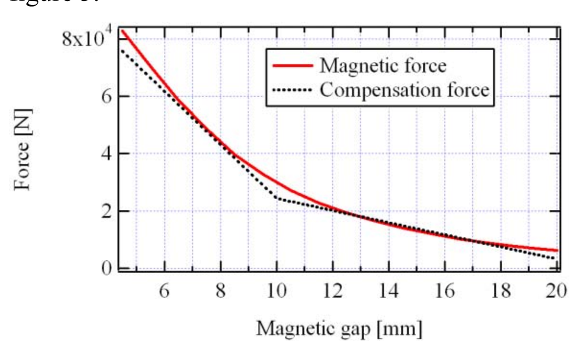

Figure 5: Magnetic and compensation Force versus the gap

Tests on springs have been performed. The main objective is to verify that both types of springs keep the same rigidity constant during 15 years of operation (5 000 cycles of compression) with or without baking

(140 °C during one week). The test bench (INSTRON) allows vertical motion with an accuracy of 2 μm and measures the applied force in the range of 1N to 2 kN. The first version of the spring system was equipped with a stainless steel axis to guide the motion. After few cycles under vacuum, the system blocked due to intense friction. A simplified version has been built and tested. From the experimental data, the rigidity constant remains steady within 0.5 N/mm. The results on the average rigidity K and the dispersion during the test are summarized in table 2. The rigidity constant does not evolve neither after a long compression time nor after a rather large number of cycles.

Table 2: Rigidity constant variation

Type of spring	Cycle number	Time	Rigidity K [N/mm]	σ_K [N/mm]
Long	1	170h	61	0.2
Long	190	2h	62	0.3
Short	1	170h	163	0.3
Short	500	5 s	164	0.5

CARRIAGE AND MOTORIZATION

The pole and magnet supports are mounted on 2 stainless steel girders. Each girder is water cooled during the baking. The opening and closure of the gap (5.5 mm to 100 mm) between the magnet arrays are accomplished by 2 Bergher Lahr VRDM3910 motors. The maximum speed between jaws is 2 mm/s. An identical additional motor installed on the base of the frame allows the whole carriage to be moved vertically within +/- 5 mm in order to perform centring when installed in the ring. Absolute linear encoders control the gap with an accuracy of 0.4 μm. The vacuum chamber is composed of one main vacuum vessel and two extremities. The total capacity of pumping is 2600 l/s distributed among 4 ionic pumps of 150 l/s, one ionic pump of 500 l/s and 6 Titanium sublimator pumps of 250 l/s. The baking temperature is 125 °C during 3 days.

MAGNETIC MEASUREMENTS

Magnetic measurements are planned to be performed at SOLEIL. The peak value of the field will control via Hall probe. The assembling will be based on genetic algorithm [6] and verified via a rotating coils at each step of the mounting. Pulsed wire technique [7] will be especially carried out to check the particle trajectory and to apply local magnetic corrections.

CONCLUSIONS AND OVERVIEW

The wiggler is in phase of construction. Magnets and poles have been built and assembled on the supports. The present minimum gap is limited to 5.5 mm. In the near future, we planned to reach smaller gap (~4.5 mm) to increase the magnetic field and consequently the flux at high photon energy. In addition, the recent experimental results on magnets operating at cryogenic temperatures are very promising [8] in terms of gain in magnetic field. The estimated increase of field is presently 20% making cryogenic in-vacuum wiggler competitive with superconducting wigglers.

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