PRODUCTION OF HIGH FLUX HARD X-RAY PHOTONS AT SOLEIL

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Abstract

The production of high photon fluxes in the hard X-rays region is a major issue on medium energy storage rings. At SOLEIL, developing a small gap in vacuum wiggler has been preferred to ordering a multipole superconducting wiggler, because the latter reveals to be maintenance constraining, much more complex and more expensive than the permanent magnet technology. The in vacuum wiggler is composed of 38 periods of 50 mm, encompassed in a compact magnetic system producing in a limited space a magnetic field of 2.1 T at a magnetic gap of 5.5 mm. An auxiliary counterforce system based on non-magnetic springs has been built in to compensate for the huge magnetic forces (up to 8.5 Tons) acting on the magnet arrays. The gap between the jaws and the mechanical deformations have been controlled and corrected. Magic fingers corrections have been also implemented to reduce the integrated multipoles and to minimize the 2nd order integrals resulting from the tight width of the wiggler poles. This paper presents the design of the wiggler, the construction, and the results of the measurements after magnetic corrections.

INTRODUCTION

SOLEIL is operating at medium energy (2.75 GeV) and produces routinely stored beam current of 400 mA. However, providing high fluxes in the hard X-rays region on medium energy machine requires building Insertion Devices (IDs) with high magnetic field and a large number of periods. SOLEIL has investigated in the pure permanent magnet technology to build an in-vacuum wiggler delivering high photon flux up to 50 keV. With the constraint of fitting within a short straight section of the storage ring, the optimum was found with a 50mm period, 2m long device. The 2.1T high magnetic field allows pushing up to high photon energy but the large number of periods produces high power on front ends. A trade-off had to be made to define the pole width, as decreasing the pole size reduces the high attractive forces between magnet arrays, but generates non linear effects acting on electrons. A counter force system has then been chosen in order to simultaneously reduce the force acting on the girders and to enable keeping the pole size relatively large.

MAGNETIC DESIGN

The wiggler is composed of 38 periods of 50 mm and is foreseen to operate during on-beam operation between a minimum gap of 5.5 mm and a maximum gap of 70 mm [1, 2]. Wiggler operation up to 100 mm can be also performed for magnet installation. The field is produced by a periodic sequence of magnets of high quality (magnetization B_r=1.25 T, coercivity H_{cj}=2230 kA/m) and vanadium poles of high saturation level (2.35 T). The design has been performed using RADIA code [3] and cross-checked with the Vector Field code [4] on a short model of three periods. Special attention has been taken in the design of the poles to maximize the field without saturating them and limiting the dynamic acceptance. At each extremity of the magnet system, magic finger magnets (cylindrical permanent magnets) can be installed to correct the magnetic defaults of the wiggler.

The predicted peak field roll-off is presented in Fig. 1. The peak field at the minimum gap (5.5 mm) reaches 2.1 T and remains very homogeneous over the range +/- 20 mm (within 1.25%). Beyond this area, the field dramatically drops, resulting in a reduction of the energy acceptance of the ring. Indeed, crossing the wiggler, the electrons experience important second order kick angles [5]. This effect is equivalent to the effect of a multipole magnet producing a strong transverse variation of the vertical field integral (dynamic field integral).

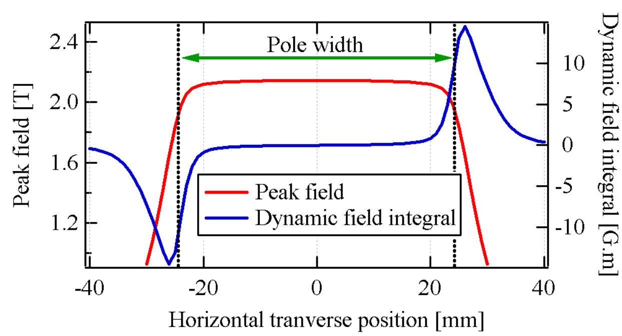

Fig. 1: Transverse field and dynamic field integral variation at minimum gap.

CALCULATED EFFECTS ON THE ELECTRON BEAM

The calculations have been achieved for the nominal bare lattice [6], using the TRACYII code. To evaluate the effects on beam dynamics, the magnetic system has been represented by a second order kick map (Fig. 1) and a 1st order field integral map have been calculated with RADIA respectively for the wiggler and for the magic fingers at minimum gap (see Fig. 7 for the total field integral). We remind that the wiggler is located in a short straight section where the horizontal betatron function β_x-function is large (18m). The vertical tune shift due to focusing is +6.10^{-3} at minimum gap. There is no additional focusing due to the field roll-off.

The effect of the wiggler on the on-momentum dynamic aperture (Fig. 2) is not drastic. The effect of the roll-off occurs at x=25mm in the short straight section (see Fig. 1) and the corresponding horizontal amplitude in the injection straight section (x=19.5mm) is very close to the physical aperture of the septum. Then, no injection efficiency reduction is expected.

The effect of the wiggler on the negative energy acceptance occurs in large and medium straight sections and in achromats. The addition of magic finger magnets almost restores the nominal energy acceptance at these locations and as a consequence the beam lifetime (Fig. 3).

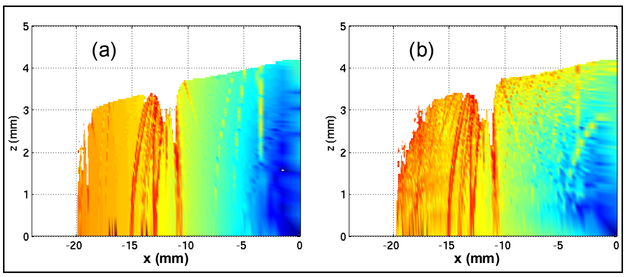

Fig. 2: On-momentum dynamic aperture at injection point. (a): Bare machine. (b): Wiggler effect.

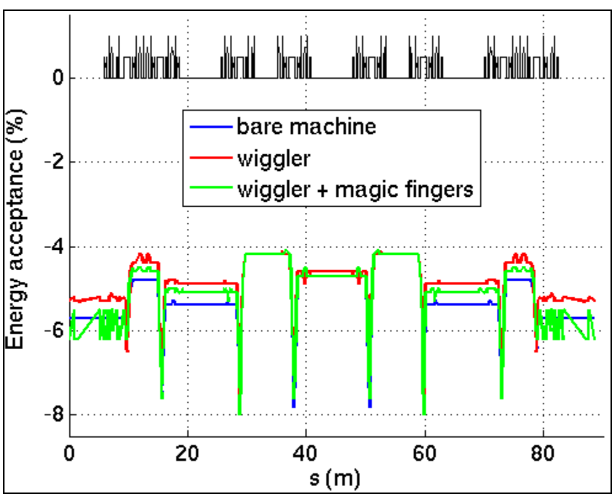

Fig. 3: Calculated negative energy acceptance along one period of the machine.

CONSTRUCTION OF THE WIGGLER

The pole and magnet supports are mounted on 2 stainless steel girders. Each girder is water cooled during wiggler operation. The opening and closure of the gap (5.5 mm to 70 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 mechanical centring once 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 end flanges. The total capacity of pumping is 4600 l/s distributed among 4 ionic pumps of 150 l/s, one ionic pump of 500 l/s, 6 Titanium sublimator pumps of 250 l/s and 2 NEG cartridges. The baking temperature is 120 °C on magnets during 15 days.

Counter Force System

The magnetic system generates attraction forces up to 8.5 Tons. This force cannot be supported by the carriage the capability of which is limited to 6 tons. A counter force system has been designed and installed on the magnetic system. It is composed of two types of Inconel springs, short and long ones, installed on both sides of the magnets. Long and short springs operate respectively from 22 mm and 10 mm to the minimum gap, allowing the forces to be linearly compensated by part (Fig. 4).

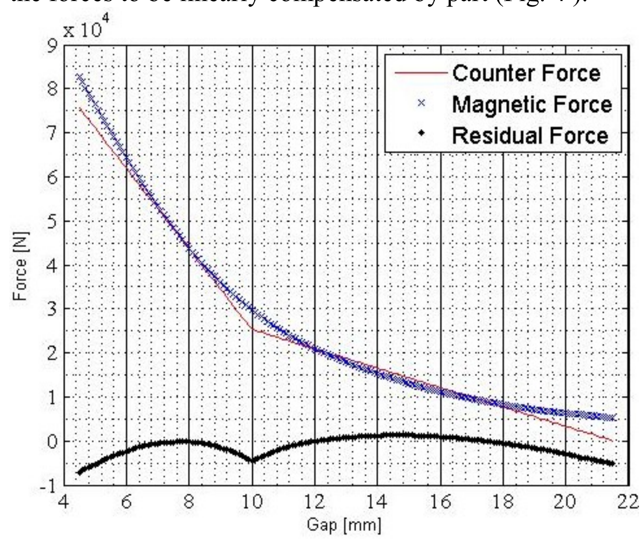

Fig. 4: Two-step linear counter-forcing system compensating exponential magnetic forces.

The rigidity constant and the length of the springs have been measured and equipped with additional shims in order to compensate the applied force difference between springs. Their installation on the girders has been performed step by step during the magnets and poles assembling (Fig. 5).

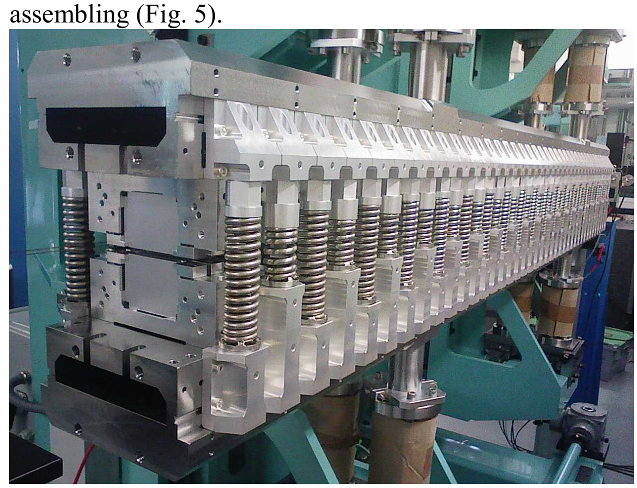

Fig. 5: Full Magnetic system (at minimum gap) equipped with the compensation force system.

After the full mounting of springs, the residual theoretical force acting on the girders and on the frame does not exceed 500 kg. We have measured a maximum deformation of 30 µm on the girder at minimum gap.

Assembly of the Wiggler

Poles and magnets are mounted on two types of Al supports containing either only one magnet (the A-modules) or two poles and one magnet the (PAP-modules). The assembling was performed period by period using a genetic algorithm [7]. Using the magnetic field integrals (rotating coil measurements) in both transverse planes versus the horizontal position, the algorithm predicts the two A-modules and the two PAP-modules to be installed for the next period. The process of modules selection is based on the optimization of the global field integrals, the one-period field integrals and the half period field integrals. It avoids installing the best magnets at the entrance of the wiggler and the worse ones at the end.

MEASUREMENTS AND CORRECTIONS

At minimum magnetic gap the physical aperture has been checked along the axis of the wiggler by using a magnetic ball (3 mm diameter) as a target in order to evaluate the girder deformations. Due to the excess of counter forces at the extremities, the girders were found distorted in a parabolic shape. The magnetic gap was shrunk to 5.1 mm at the centre and was reaching 5.5 mm at the ends. The girders have been flattened by removing some springs at the extremities and by changing the thickness of some spring shims in order to compensate for the reduction of repulsive forces. This enabled the magnetic gap and the field now to remain constant along the wiggler axis within respectively 30 µm around the minimum gap of 5.5 mm and 0.05 % around the field of 2.07 T (Fig. 6). As a consequence, the phase error has been reduced from 19° to 4.2°.

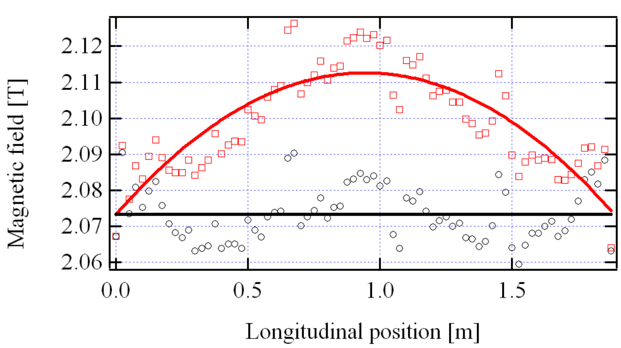

Fig. 6: Peak field variation along the wiggler axis before (red squares) and after (black circles) girder correction.

Fig. 7 presents the field integrals after implementation of the correction with magic fingers. The field integrals remain constant within +/-0.5 G.m in the range +/-15 mm. At the pole corner the vertical field integral (plain line) has been reduced significantly by a factor 2-2.5 (comparison between black plain line and dashed line). The vertical field integral has not been completely cancelled because the horizontal position of the magic finger magnets does not fit exactly with the position of the peaks of the dynamic field integral (the limitation comes from the step size in horizontal position of magic finger magnets).

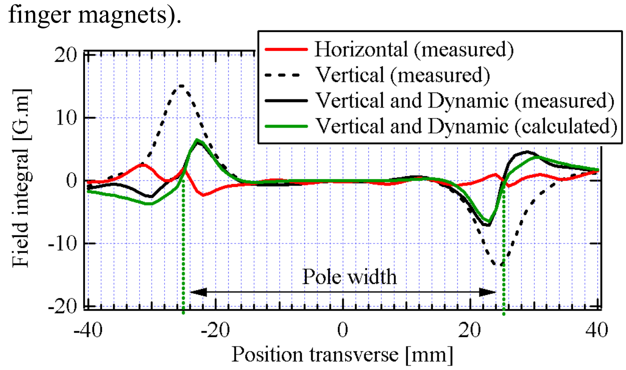

Fig. 7: Field integrals versus transverse position. The red circle, dashed line and plain line represent resp. the measured horizontal and vertical field integral and the vertical field integral cumulated with the dynamic one.

CONCLUSIONS

The wiggler is completely assembled with the counter force system, and the field integrals have been corrected with magic fingers. Dynamic field integral has also been taken into account in the magic finger corrections to reduce the impact on the energy acceptance of the ring. Despite the mechanical correction of the girders, the peak field is slightly under the required value (2.1 T) but can be enhanced by reducing the magnetic gap down to 5.3 mm. The pumping and baking of the wiggler are presently under progress. It will be installed in the storage ring at the beginning of June 2010.

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