CONSTRUCTION OF SHORT PERIOD APPLE II TYPE UNDULATORS AT SOLEIL

F. Briquez, C. Benabherrahmane, O. Chubar, M.-E. Couprie, T. El Ajjouri, C. Kitegi, F. Marteau, A. Mary, K. Tavakoli, J. Vétéran, Synchrotron SOLEIL, France.

Abstract

We present here the conception, construction and magnetic measurements of APPLE II type undulators of 44 and 36 mm period at SOLEIL.

Such short period undulators are difficult to design and construct because of the reduced dimensions of the magnets, leading to small support structures which are more easily bent by the magnetic forces. The design of the support structures consists in individual aluminium holders grouped in assemblies of three or five magnets called modules and fixed on the girders using dovetails. Special extremity modules are designed to reduce field integrals of the undulator. The magnets are independently measured using Helmoltz coils, sorted and assembled in modules. Then the modules are measured using Hall probes and bodyless coil, and sorted to assemble the undulator. After assembling, a shimming process is performed to correct radiation phase errors and field integrated multipoles, and a final correction of the integrated effects is made by little extremity magnets called "Magic Fingers". For each step of sorting, we use the home-made IDBuilder software, based on genetic algorithms. Short period undulators are of interest for the 4th generation sources ARC-EN-CIEL project, which considers APPLE II with a 30 mm period.

INTRODUCTION

Various fourth generation Linac based Free Electron Laser projects such as FERMI at ELLETRA [1], SASE3 of the EXFEL [2], BESSY FEL [3], ARC-EN-CIEL [4], 4GLS [5] aim at providing femtosecond duration pulses with variable polarisation down to the VUV-soft X ray range for scientific applications [6, 7] such as magnetism, exobiology… Radiation is generated in undulators providing variable helical magnetic field using various configurations: besides crossed undulators [8, 9] or electromagnetic devices [10, 11, 12], Helios type undulators [13] with the vertical and horizontal field generated independently, APPLE II undulators with two rows of magnets which can be translated on each girder [14] are commonly used. A system with three rows of magnets per girder enables to avoid the discontinuity between the different magnets seen by the electron beam [15]. The so-called APPLE-III systems with modified orientation of the magnetic fields have been proposed in order to enhance the peak field of the insertion [16, 17]. Coupled to intermediate electron beam energy, short period and high field variable polarisation undulators enable to design more compact and cheaper FEL sources, aiming at about 1 nm. For example, APPLE II undulators are foreseen with 62, 50, 28.5 mm periods on BESSY-FEL, 30 mm periods on ARC-EN-CIEL, 45 to 145 mm periods on 4GLS and 50 mm periods on FERMI [18].We report here on the construction and tests of short period APPLE-II undulators for the SOLEIL third generation light source in France. Table 1 summarizes the APPLE II undulators planned to be built and in operation at SOLEIL, and their main characteristics. The construction strategy was to start with large periods (80 mm) and to reach progressively short periods (44 and 36 mm).

Table 1: The different types of SOLEIL APPLE II type undulators, their main characteristics, the number of installed ones (Inst.) and the total number to be installed. B_x is the horizontal field and B_z the vertical one. K_x and K_z are the corresponding deflexion parameters.

Name	Period [mm]	Gap [mm]	B_x [T]	B_z [T]	K_x	K_z	Inst./ Total
HU80	80	15.5	0.75	0.96	5.60	7.17	3/3
HU60	60	15.5	0.60	0.86	3.36	4.82	1/2
HU52	52	15.5	0.52	0.76	2.53	3.69	2/2
HU44	44	15.5	0.45	0.67	1.85	1.85	1/2
HU36	36	11	0.53	0.75	1.78	2.52	0/1

DESIGN

The SOLEIL APPLE II type undulator design is based on modules fixed with a dovetail on a motorised carriage. The modules were designed so as to ease each step of the construction of the undulator and to enhance its performances. The carriage is driven by homemade electronics taking into account accuracy and material securities, and based on Berger Lahr motors and TR Electronics absolute linear encoders.

Carriage mechanical design

Carried out by ELETTRA, the design of the carriage is made up of two girders, each composed of two jaws, one of which is mobile along the undulator axis direction and the other static. Each girder is vertically movable, thanks to two independent motorised systems, in order to change the gap. With these two motors, we can correct the taper of the undulator. Changing the phase, corresponding to the horizontal position of mobile jaws with respect to fixed ones, makes it possible to change the magnetic field characteristics and consequently, the polarisation of the emitted radiation. Two modes are possible: the so-called parallel mode and the anti-parallel one. In the first case, the upper and lower mobile jaws move in the same direction, leading to helical polarisation. In the second case, the jaws move in opposite directions, producing tilted linear polarisation. When the phase is null, horizontal linear polarisation is obtained as in the case of basic planar undulators. Finally, with a phase equal to half the period, the undulator generates purely vertical linear polarisation.

Module mechanical design

The support structures are independent magnet holders assembled by modules of three or five magnets. The asymmetry between the two types of modules makes it more accurate to sum the field integrals of several modules in order to calculate the integrals of the whole undulator. The modules are designed to fulfil four conditions:

1. The holder has to be stiff enough to limit the magnet deflection versus gap and phase.
2. The module must ease the shimming operations. This is done by middle pieces inserted in the module between the magnet holders and the module basis. The middle pieces allow us to remove the magnet and its holder in a first time, and then to move the middle piece thanks to strippable shims. By this way, it is easier to operate the shimming, especially on the upper jaws.
3. The assembling or dismantling and mounting of the modules on the jaw must be easy. This is achieved thanks to screws within the module, and by the dovetail on the jaw.
4. The modules must be amagnetic to avoid hysteresis due to gap and phase changes. They are made of aluminium for the main pieces and stainless steel for the magnet clamps.

To assure the stiffness requirements, the magnetic forces exerted by the whole undulator on one magnet versus the phase and at minimum gap, have been computed using RADIA [19] code. The figure 1 shows the result for one HU36 undulator at gap 11 mm. For each component, the highest value is about 100N. The maximum resulting deflection on one magnet (computed with ANSYS [20] code), is about 20 µm. As magnets are theoretically separated by 0.1 mm gaps in order to make the shimming easier, this deflection is acceptable. The calculation model and results are presented in figure 2.

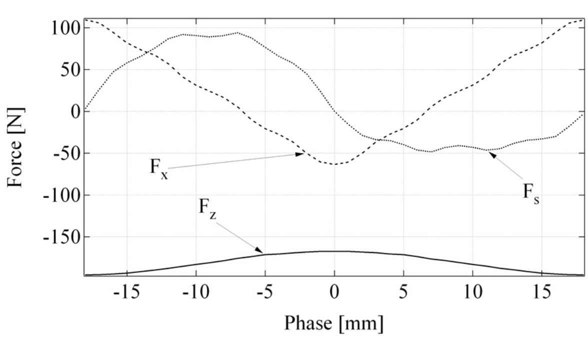

Figure 1: Force acting on one magnet versus phase. F_s is the component along undulator axis. F_x is the transversal component, and F_z the vertical one. In this model, a negative phase means the anti-parallel mode and a positive one the parallel mode.

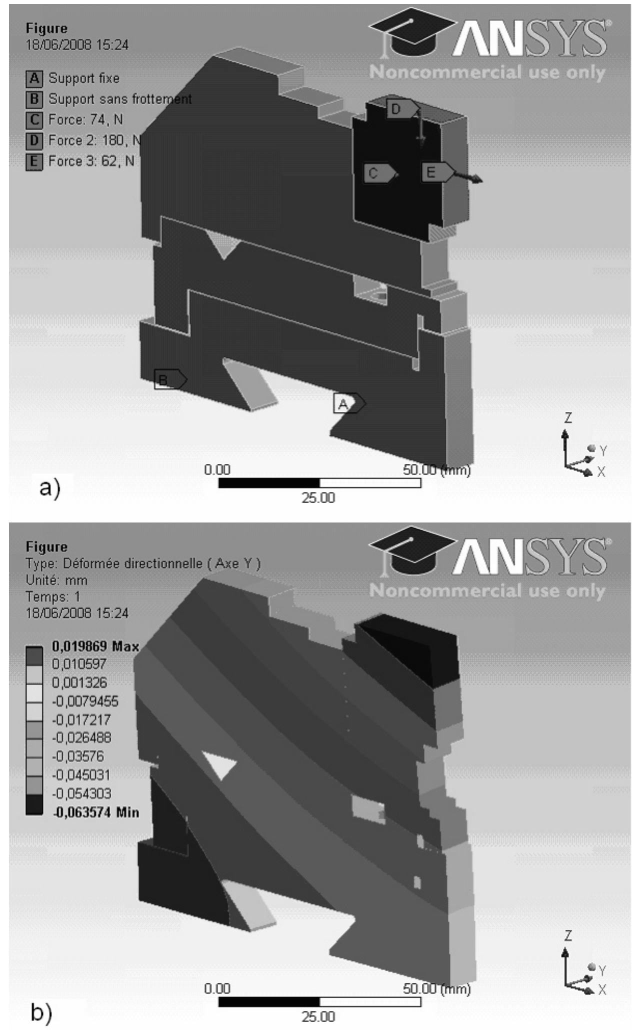

Figure 2: Calculation of the deflection using ANSYS code. a) 3D modelling of one magnet and its holder, b) 3D distribution of deflection intensity in transversal direction.

CONSTRUCTION

The construction of an undulator is performed in four steps:

1. Assembling of the magnets into modules,
2. Assembling of the modules on the jaws,
3. Shimming by magnet displacements,
4. Shimming by "Magic Fingers".

For each of these steps, we use the homemade software IDBuilder **[**21**]** based on genetic algorithm in order to sort the elements and to compute the required shimming.

Assembling of the magnets into modules

The magnets are measured with Helmoltz coils by the manufacturer to obtain the three components of the magnetic momentums. A first sorting is then accomplished to assemble the magnets into the modules, in such a way the magnetic defaults cancel each other.

Assembling of the modules on the jaws

When assembled, the modules are measured separately, with the same bench as the one which will be used to characterize the undulator. This bench was manufactured by ESRF and consists of one bodyless coil for field first integral measurements, and three Hall probes on one support for the local field measurements. The mounting of the undulator magnetic structure is made assembly per assembly, an assembly consisting in two periods, i.e. in eight modules. After each new assembly fixing, the whole undulator is measured and a new sorting calculated. With this method, we can follow and prevent the defaults generated by an incorrect mounting or by false measurements. All along the assembling, different parameters which have an influence on both emitted radiation and electron beam dynamics are followed by IDBuilder.

Shimming by magnet displacements

Once all the modules are fixed on the jaws, the shimming is processed in order to reduce the integrated

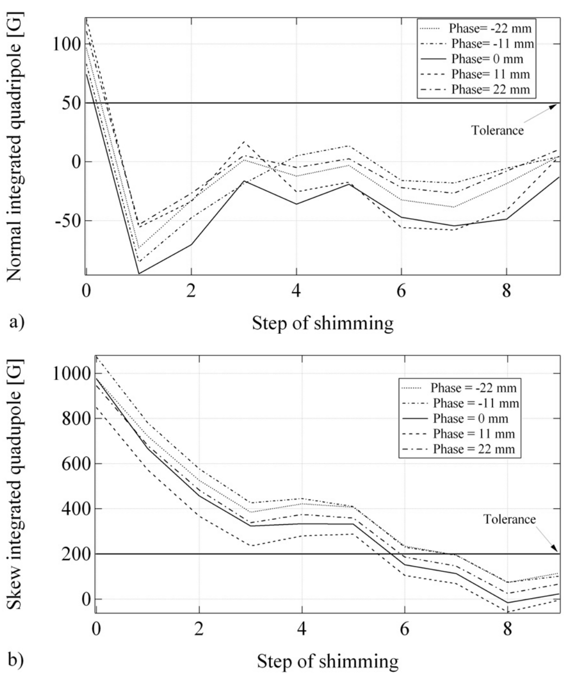

Figure 3: HU44 TEMPO a) normal and b) skew integrated quadrupole improving along shimming steps. These values are measured at minimum gap and for five different phases. Step 0 corresponds to assembled undulator without shimming. Steps 1 to 5 correspond to magnet shimming iterations, such as steps 8 and 9. Steps 6 and 7 correspond to Magic Finger shimming.

multipole components and to improve the emitted radiation phase error. Once again, IDBuilder is used to manage this. While other laboratories separate the shimming in different steps in order to improve different parameters the ones after the others, our method consists in to improving simultaneously all the parameters at the each steps. By fixing parameter weights in the software, we can choose some parameters to be improved more efficiently than the others. Not only the values of the multipoles (figure 3) but also their variations with phase are improved, as shown on figure 4. In this example, the

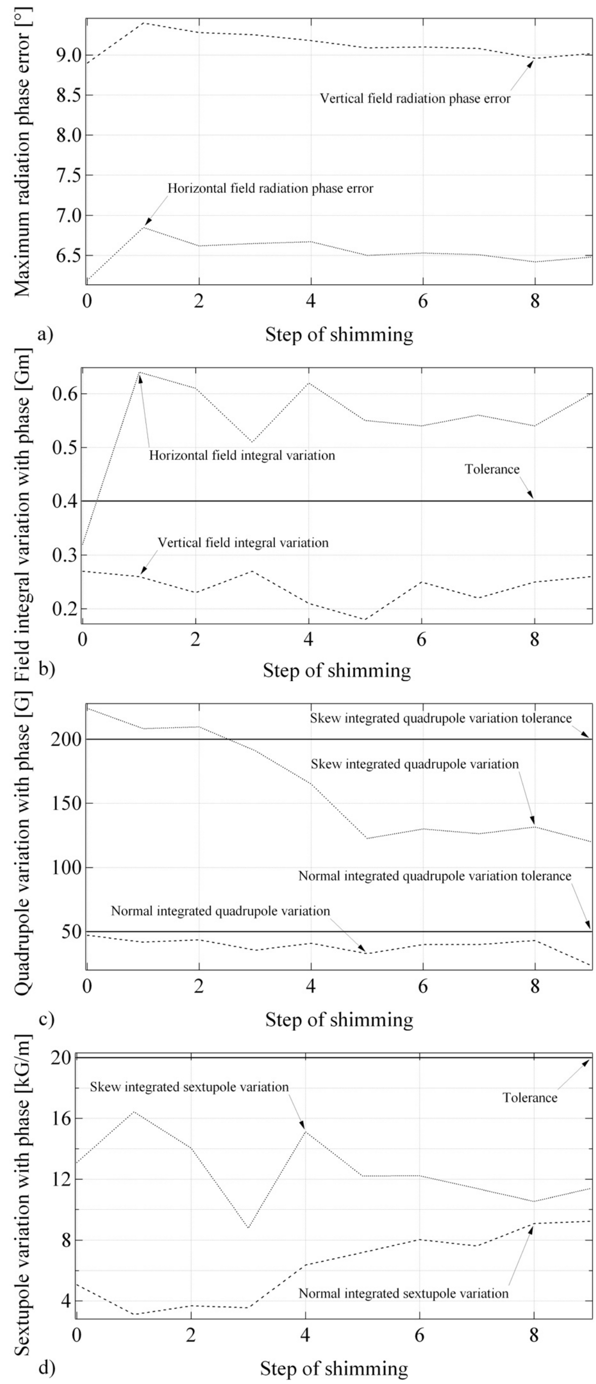

Figure 4: HU44 TEMPO main characteristic improving along shimming steps. Characteristics are maximum values measured at minimum gap: a) radiation phase error, b) on axis integral variation with phase, c) quadrupole variation with phase, d) sextupole variation with phase. Step 0 corresponds to assembled undulator without shimming. Steps 1 to 5 correspond to magnet shimming, such as steps 8 and 9. Steps 6 and 7 correspond to Magic Finger shimming.

vertical field radiation phase error still remains high after shimming, because the corresponding weights were chosen small, taking into account that only the first harmonics of radiation would be used with this undulator. It is the same point for the vertical field integral variation, which can be easily corrected by the embedded steering coils. The transverse variation of the vertical and horizontal field integrals are displayed on figure 5 at several steps of shimming. The two peaks of horizontal field integral remaining at the end are positioned at ± 26 mm, which is outside the vacuum chamber. Thus these peaks don't have any effect on the electron beam.

Shimming by "Magic Fingers"

The last step consists in final compensation of remaining integrated multipoles of the undulator. This is performed by a fine vertical tuning of small NdFeB magnets called "Magic Fingers" [22] distributed along three hole arrays on the horizontal axis, at both extremities of the device. In the case of HU44 for TEMPO beamline, the Magic Fingers enabled to reduce the skew quadrupole. Once done, additional magnet shimming steps wer carried out for further improvement.

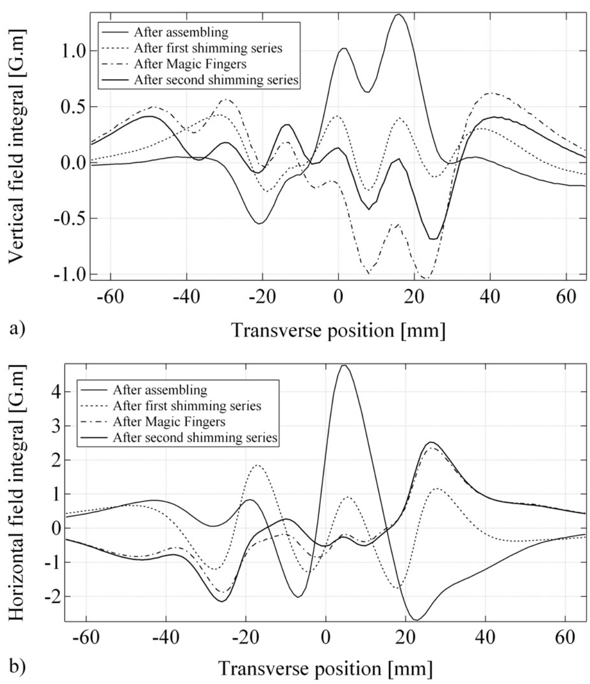

Figure 5: HU44 TEMPO a) vertical and b) horizontal field integrals versus transverse position, at minimum gap and phase zero, for several steps of shimming.

CONCLUSION

SOLEIL APPLE II undulators construction method is based on the high quality design of their various elements and on the multi-parameters shimming using IDBuilder. After seven undulators constructed, installed and commissioned in the storage ring, this method has been fully tested.

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