APPLE-II AND TESLA FEL UNDULATORS AT DANFYSIK A/S

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Abstract

Danfysik A/S [1] has recently designed and produced a high-performance Apple-II type insertion device for the Australian Synchrotron Project, with low variation of the first integrals versus gap and phase, and minimal phase error. Thanks to software assistance, and an unconventional keeper design, the total time spent on magnet mounting, shimming and extensive final magnetic testing was reduced to 5 weeks. Furthermore, in order to negate the second-order tune effect of the insertion device on the dynamic aperture of the synchrotron, ESRF-type tune shims were designed and installed.

Danfysik is manufacturing and assembling one of three undulator prototypes for the TESLA FEL project at DESY. The prototype is based on a design made by DESY, but with changes implemented by Danfysik. A major part of the project is to make an industrial study that will recommend where design efforts on the next prototype generation shall be focused.

INTRODUCTION

Danfysik has historically been strong in the planar undulator business, providing end users with both high performance in-vacuum devices as well as regular planar devices for FEL applications [2]. With successful completion of our first Apple-II type device, Danfysik is now in the position to supply all the main types of insertion devices with tight performance requirements. Our software development allows us to quickly scale up the production and meet the most demanding requirements of many insertion devices in a short time.

ASP APPLE-II UNDULATOR

Figure 1 shows the undulator made for the Australian Synchrotron Project. The carriage is of the c-frame type, i.e. it is open at one side. This design is based on the ESRF type of Apple-II but increased in length and modified to allow movement of all four magnetic arrays. RADIA calculations [3] of a full length model device were used to optimize the periodic design. Of large importance is the design of the end section. We used an ESRF-type end design [4] for the device, and re-optimized the air gaps and magnet dimensions of the 3 end magnets, such that we could minimize the variation of the first integral with undulator phase, and undulator gap. This could be achieved by means of a simulated annealing algorithm in RADIA, where the end section was fully parameterized, including parametrized air gaps, and magnet block thickness.

A performance summary of the Apple-II undulator is shown in Table 1.

For the Apple-II device, it was decided to adopt a magnet module system, with two modules per period, The positive and negative poles are clamped together with a horizontal magnet, in a M3 module and the M1 module consists of a single horizontal magnet. The magnet modules are shown in Figure 2 together with the end section. This provides us with the following immediate advantages

- Reduction of magnet measuring time
- Swift magnet mounting
- More relaxed demands on positional accuracy of modules on girder.
- Better clamping of modules, which eliminates block tilting during phase movement.

However, we sacrifice a degree of freedom, as it becomes difficult to individually shim poles, vertically and horizontally, to provide first integrals for trajectory shimming, as described in [5]. Instead, module-swapping was used. In a few cases, it was elected to dismount M3 modules and perform horizontal or vertical shimming of the poles in the keeper. This could be achieved without completely disassembling the M3 module. We treated the device as a regular planar undulator, during magnet mounting and shimming, i.e. both right and left girders were mounted simultaneously.

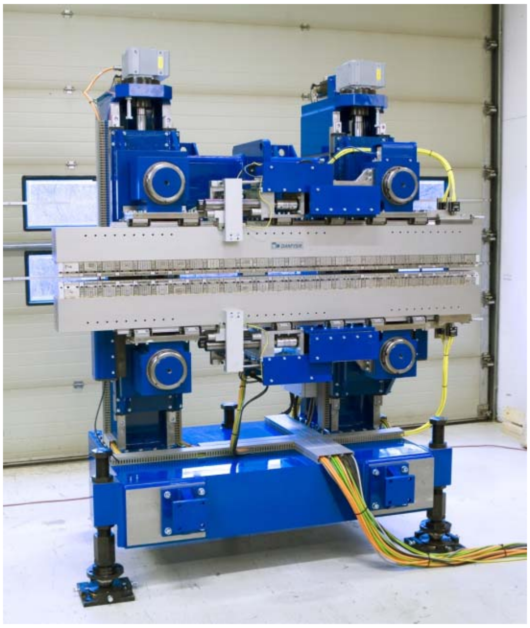

Figure 1: The Apple-II undulator for ASP.

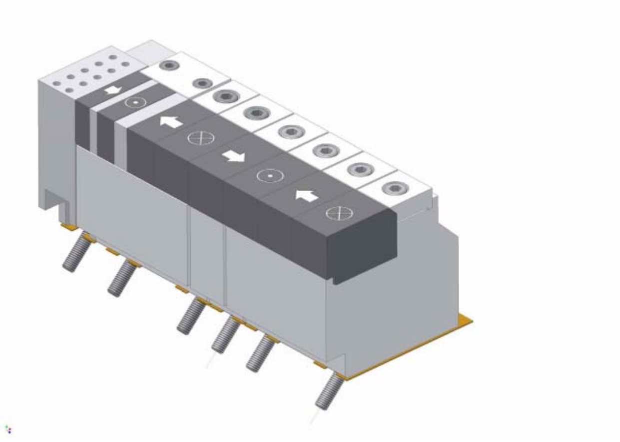

Figure 2: Apple-II termination and module definitions with end Module (EM), M1- and M3-module.

Table 1: Results for the Apple-II undulator. The field integrals and phase error is the maximum value at all specified gaps, and phases.

		Specified	Obtained
Undulator period	(mm)	75	75
Gap range	(mm)	16 - 100	16 - 100
Specified min. gap	(mm)	16.0	16.0
Undulator length	(mm)	-	2151
Number of poles		52	52
Vertical peak field, 16mm gap (HP Mode)	(T)	-	0.72
First integrals		≤ 0.1 Tmm	≤ 0.04 Tmm
RMS phase error	(º)	≤ 5	≤ 3
Material		Sm_2Co_{17}	Sm_2Co_{17}

Figure 3 shows the horizontal and vertical first field integrals, obtained for the finished device, after trajectory shimming and magic finger corrections. We see only a small change in the integrals as the phase of the undulator is moved, thereby eliminating the need for correction coils mounted on the device. We found that the change in first integrals observed was primarily driven by the end section. We didn't see any evidence of pole tilting during phase movement.

Table 2 shows a summary of the integrated multipoles, obtained using flip coil measurements. We see a change of 0.0041 T in the normal quadrupole, as the phase is changed from the VP mode to the CP (circularly polarized+) mode. The rest of the multipoles show minor changes as the phases of the undulator is changed.

After shimming and verifying the performance of the device, we added L-shaped ESRF-type tune shims, in order to negate the second order effects that the device has on the stored beam. The size of the tune-shims was optimized using RADIA. We cannot measure the second order effect in our laboratory, but the effects of the tune-shims becomes apparent as a normal quadrupole component, that was found to be in good agreement with the calculations.

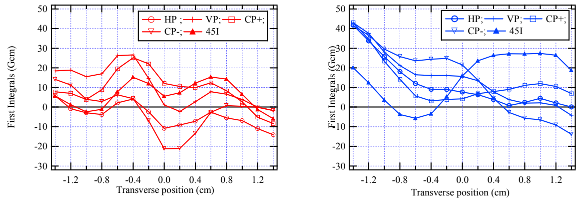

Figure 3: The horizontal and vertical first field integrals, measured at minimum gap, at all phases for the Apple-II device.

The electron trajectory can be simulated, based on measurements with a 3D Hall probe. The results in Figure 4 shows that as the undulator phase is changed, the trajectory straightness is preserved.

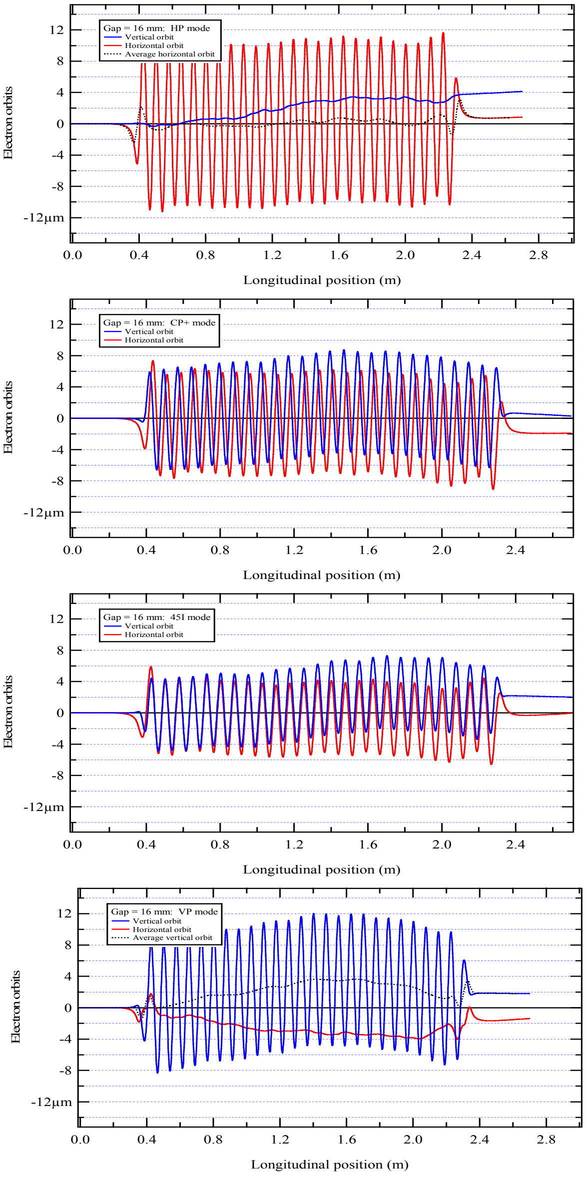

Figure 4: Electron trajectory at 16 mm gap, for the 4 different phases of the Apple-II undulator. The HP mode, CP+ mode, 45 degree inclined mode, and VP mode are shown.

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Table 2: Summarizing table of multipole content, at minimum gap

Gap	Mode	Multipole	Skew	Normal
16 mm	**HP**	2-pole (Tmm)	$-5\cdot 10^{-3}$	$6\cdot 10^{-3}$
		4-pole (T)	$-2\cdot 10^{-4}$	$-7\cdot 10^{-4}$
		6-pole (Tmm^{-1})	$2\cdot 10^{-5}$	$7\cdot 10^{-5}$
16 mm	**VP**	2-pole (Tmm)	$9\cdot 10^{-3}$	$13\cdot 10^{-3}$
		4-pole (T)	$-14\cdot 10^{-4}$	$-9\cdot 10^{-4}$
		6-pole (Tmm^{-1})	$8\cdot 10^{-5}$	$-2\cdot 10^{-5}$
16 mm	**CP +**	2-pole (Tmm)	$18\cdot 10^{-3}$	$4\cdot 10^{-3}$
		4-pole (T)	$-4\cdot 10^{-4}$	$5\cdot 10^{-4}$
		6-pole (Tmm^{-1})	$8\cdot 10^{-5}$	$16\cdot 10^{-5}$
16 mm	**45°**	2-pole (Tmm)	$12\cdot 10^{-3}$	$13\cdot 10^{-3}$
		4-pole (T)	$9\cdot 10^{-4}$	$32\cdot 10^{-4}$
		6-pole (Tmm^{-1})	$-9\cdot 10^{-5}$	$-1\cdot 10^{-5}$

TESLA FEL UNDULATOR

Danfysik was awarded the contract for one of the prototype undulators for the European X-ray laser project (XFEL). The preliminary design was made by DESY, and further optimized by Danfysik. During production and assembly further potential improvements were identified, which are described in a thorough industrial study report that is an essential part of the project. The industrial study will thoroughly describe where it will be favorable to continue the effort to optimize the design, both with regard to better performance but also to reduce the cost of the devices.

The device is a hybrid undulator, with a minimum gap of 9.5 mm and a period of 29 mm. The novelty of this device consists of the adjustable poles. The poles can be adjusted vertically and rotated around the beam axis for easy trajectory shimming. This capability, together with high quality magnets from the supplier [6], eases magnet mounting and trajectory shimming.

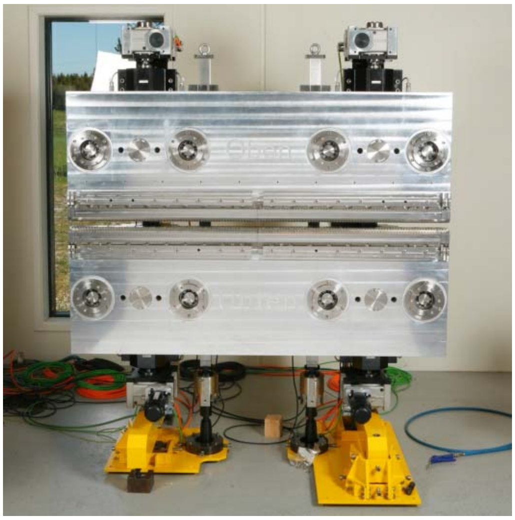

Figure 5: The undulator for the TESLA project .

SOFTWARE AND AUTOMATION

As mentioned in [2], we have developed a unique software package for the assistance and automation of this processes running in Igor Pro [7]. We have implemented a functionality which provides assistance during magnet mounting and during the shimming phase. This is based upon first measuring the magnet modules with an integrating coil system, and afterwards loading them into an Igor Pro project. For the Apple-II device, a magnet "module" was defined as both right and left sides of the 1.6 mm gap between adjacent girders.

As the magnets are mounted, flip coil measurements are performed after each period is mounted. The software then automatically searches the coil-data of the remaining magnets in the database for the next best set of magnets, until the end of the device is reached. After magnet mounting, the device is shimmed by software-assisted block swapping. The software is used to efficiently suggest the magnet block swap that gives the largest magnetic performance improvement and keeps track of the magnet positions during the swapping phase.

The magnetic measurements on the finished device are run fully automated one undulator gap and phase at a time using flexible batch programs. Each data is analyzed with one simple command macro that generates report ready graphs. The analysis macros are built-up around B2E from ESRF [8].

With our new software development we can produce insertion devices faster with tight performance specifications. Thus we are in a good position to scale up for the large scale insertion device production that is needed for many ERL and FEL projects, as well as AppleII type devices.

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