UNDULATORS FOR THE SWISSFEL

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Abstract

The proposed SwissFEL will provide both hard x-rays down to 1Å and soft x-rays with full polarization control at the rather small maximum electron energy of 5.8GeV. This continues the strategy of the medium energy synchrotron facilities, namely the SLS. The U15 and UE40 undulators are based on the experience with small period, small gap in-vacuum undulators and of APPLE II type respectively but are optimized for FEL operation. The undulator design including room temperature versus cryogenic principle, field optimization, materials and the demands for a series production will be discussed.

INTRODUCTION

The Paul Scherrer Institute is planning a free electron laser for x-ray wavelengths, the SwissFEL [1], to be in operation in 2016. This facility shall extend the capabilities of the third generation synchrotron light source SLS [2] in terms of peak brilliance and pulse length. At the SLS which started operation at PSI in 2001 time resolved experiments with 100 fs x-rays of 5 to 8 keV are produced already with a slicing technique [3]. Having a medium energy of 2.4GeV the SLS combined firstly full polarization control in soft x-ray with high brilliant hard x-rays up to 18 keV by using APPLE II type and short period, small gap undulators. The SwissFEL will follow the SLS concept.

The SwissFEL will generate electron bunches with a charge between 10 and 200 pC and a normalized emittance below 0.4μm in an RF photocathode gun. These bunches will be accelerated in a normal-conducting linear accelerator (linac) to a particle energy of up to 5.8 GeV and sent through up to three undulator lines. The overall length will be about 900 m. In the baseline design two undulators will be built with 15 and 40 mm period, respectively, where they radiate coherently at wavelengths between 0.1 and 7 nm. The repetition rate of this device will be 100 Hz initially, with an option to upgrade to 400 Hz. The baseline design foresees one electron bunch per RF pulse, but future extensions could allow for up to three electron bunches.

In the following the concept for the undulators for the SwissFEL will be presented, followed by the demands and boundary conditions given by the FEL beam dynamics to achieve saturation. The basic ideas to realize the undulators will be discussed in detail focusing on the magnet design including a discussion of the magnet materials. The engineering concept for a robust and cost effective manufacturing will be touched at the end.

UNDULATOR LINES

The basic idea in the layout of the undulators is to combine in the soft x-ray wavelength range the tunability of the undulators with a switchable extraction energy. An undulator with 40 mm period length in combination with extraction energies of 2.1 and 3.4 GeV is capable to cover the entire wavelength range from 200 eV to 2 keV. The exact photon energies depend on the maximum undulator parameter $K = 0.934 \cdot B[\mathrm{T}]\ \lambda_U[\mathrm{cm}]$ in the various modes of operation: Linear polarization continuously changeable from $0 - 180°$ and circular and are listed in table 1. The maximum K value varies between 3.5 and 2.3. The extraction point is located at 3.4 GeV. For operation at 2.1 GeV, parts of the RF system is not triggered and the beam is transported beyond 2.1 GeV through empty cavities till the extraction point.

It is planned to accelerate up to three bunches within a macro-pulse. In case of a 3.4 GeV extraction for the soft - xray all 2 (3) undulator lines can be served with the full repetition rate of 100 Hz. In case of a 2.1 GeV extraction, however, the injections have to be distributed which reduces the repetition rate for the individual undulator. The timing will be adjustable according to the demands of the current experiments.

In the hard x-ray regime the energy tune will be achieved by tuning of the electron energy from 2.2 GeV up to the maximum electron energy of 5.8 GeV. In order to allow the photon energy of 12.4 keV or the wavelength of 1Å with such a relatively small electron energy the undulator will have a small period of 15 mm at the small K - value of 1.2. This allows only small tuning of the output wavelength because the minimum K should be above K = 1 for a good FEL efficiency. However, some tunability by the gap of the undulator modules (i.e. for tapering or variation of the photon energy around a absorption edge) will be possible (table 1). As an upgrade it is planned to increase the electron energy to 6.4 GeV which allows to reach the Mössbauer line at 14.4 keV. The minimum K value is determined by FEL interaction and is assumed to be at a K of 1.

In the baseline design is also envisioned a seeding option for the soft x-ray beamline, either by HHG [4] or by the recently proposed EEHG [5]. Therefore beside the three main undulators, there is at least one small undulator. This influenced the naming of the undulators to Aramis (hard x-

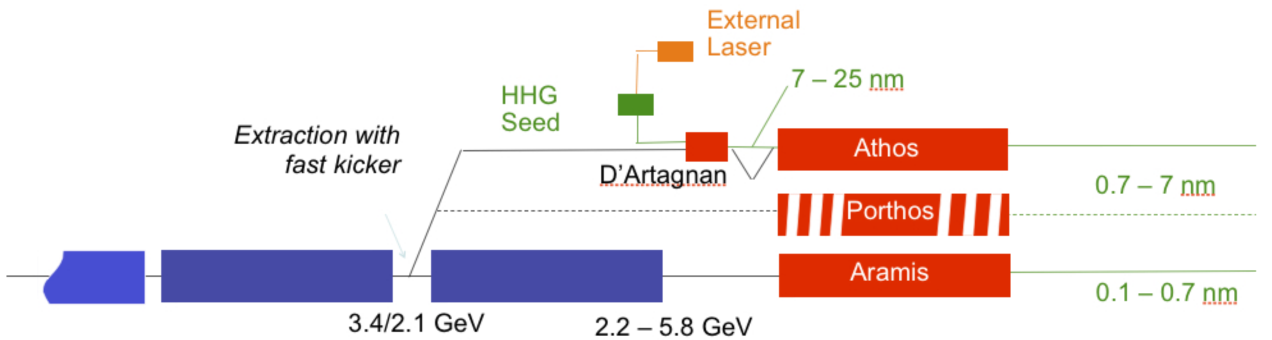

Figure 1: SwissFEL undulator concept: two soft x-ray undulators with variable gap can be served by 2.1 or 3.4 GeV electron energy, the hard x-ray line will be tuned mainly by electron energy variation. Seeding in the soft x-ray is envisaged as well.

Table 1: Photon energy range for the soft and hard x-ray undulator lines of the SwissFEL. In the soft x-ray the energy is tuned by variation of gap and shift of the APPLE II undulator UE40. Because the K value is not enough to cover the entire soft x-ray range on the fundamental, the electron can be extracted with two different electron energies. The maximum K values depend on the polarization: LH linear horizontal, LV linear vertical, Circ circular and L_{min} is at the minimum photon energy in linear inclined mode. For the hard x-ray line the photon energy is tuned by variation of the electron energy mainly. A small tuning range mainly for tapering is foreseen also by a gap change. The design K value is 1.2.

	Mode	LH	Circ	LV	L_{min}	K_{min}
	K_{eff}	3.5	3.3	3.0	2.3	1
	2.1 GeV					
Athos	E[eV]	146	164	193	294	700
UE40	λ[nm]	8.5	7.6	6.4	4.2	1.8
	3.4GeV					
	E[eV]	383	430	506	771	1830
	λ[nm]	3.2	2.9	2.4	1.6	0.7

Aramis	**U15**		
Energy		K	
[GeV]	1.4	1.2	1.0
		E [keV] / λ_{ph}[Å]	
2.2	1.6 / 8	1.8 / 7	2.0 / 6
5.8	10.7 / 1.15	12.4 / 1	14.2 / 0.87
6.4	13.1 / 0.95	15.0 / 0.82	17.2 / 0.72

ray), Athos (soft x-ray I) and Porthos (soft x-ray II, not in the baseline) and d'Artagnan[1]. Figure 1 shows the layout of the undulator concept for the SwissFEL.

[1] figures in the famous novel *the three musketeers* from Alexandre Dumas [6] published in 1844

REQUIREMENTS

FEL Optimization for 1Å *Operation*

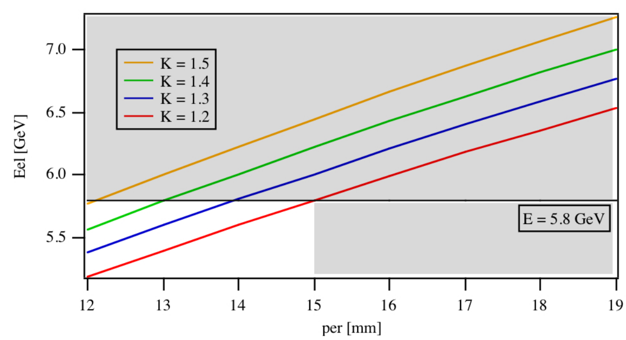

Figure 2: Possible periods and related K values to meet the specifications for the hard x-ray undulator With a maximum electron energy of 5.8 GeV and a minimum K value of 1.2 the maximum allowed period length is 15 mm. All possible options are in the white area at the left bottom side.

The SwissFEL is designed to reach a wavelength of 1Å in the hard x-ray regime with the lowest electron energy compared to other projects: SwissFEL 5.8 GeV, SCSS 8 GeV, LCLS 13.6 GeV and European X-FEL 17.5 GeV. The low energy is mandatory to allow a compact design and therefore affordable for Switzerland. As a result of the optimization process for 1Å a undulator period of 15 mm with a K - value of 1.2 is optimum. Although challenging, the undulator technology allows small period undulators with enough magnetic field at reasonable gaps. Figure 2 shows the periods - K value combinations which are possible to achieve 1Å with a maximum electron energy of 5.8 GeV and a minimum K value of 1.2. The 15 mm period is the maximum period length allowed. Figure 3 shows calculations of the gain length as function of K, wavelength and energy. Increasing the electron energy and the K value (for 1Å) while keeping the period fixed at 15mm lowers the saturation length slightly and increases the saturation power but for the price of higher rf power or longer accelerating

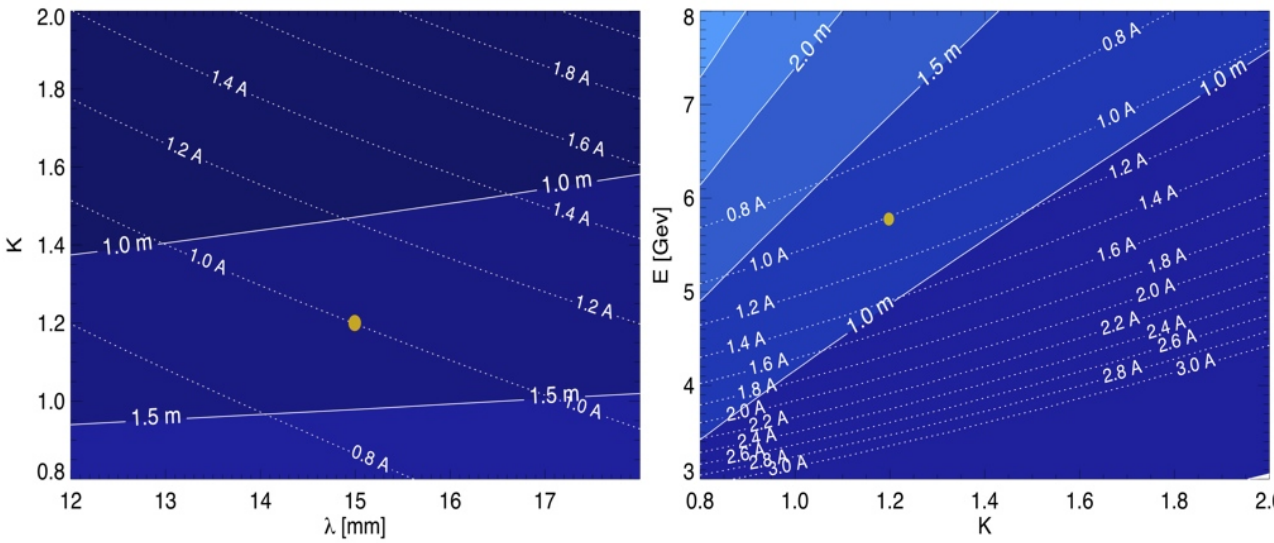

Figure 3: SwissFEL hard x-ray undulator working point. Optimization based on the Ming Xie model [7]. The plots show the gain length for various wavelength around 1Å due to variations of period, K and electron energy.

structures. Keeping the energy at 5.8 GeV and reducing the period combined with a higher K value reduces also the saturation length but without changing the saturation power and with a more challenging undulator as discussed later. And smaller periods combined with smaller electron energy keeping the K value at 1.2 would reduce the saturation power which is already lower in comparison to other projects due to the compact design of the SwissFEL.

Undulator Length

The basic difference in undulator operation in a storage ring in a linear accelerator based FEL is the need of the very long undulators. Saturation lengths of 40m or larger cannot be build with a single undulator because of the need to focus the beam inside the undulator which is difficult to integrate into the sinusoidal field and because of difficulties of magnetic measurements in long structures. Hence the undulators for the SwissFEL will be built up of modules with 4m length separated by short intersection of 0.7m. These intersections have to be filled with focusing, steering, phase adjustment, electron beam diagnostic and the vacuum components bellow, sector valve and pumps. The module length exceeds also to the gain length which is for all undulator lines between 2.5 and 1m depending on the photon energy in the 200pC mode. Within a single module there is in most cases several gain length which will be helpful for the commissioning. The maximum expected saturation length will vary between 50m for the U15 at 1Å and 40m for the UE40. The total undulator length will have 50% contingency. For the soft x-ray undulator it is planned to build all undulator modules of the APPLE II type. In SASE mode it is sufficient to have only the last two or three modules with variable polarization whereas the FEL amplification leading up to saturation can be done with planar undulator, inducing the micro bunches in the beam current. But for the planned seeding option the saturation length is shorter and all modules must provide the same polarization [12]. Having all modules of APPLE II type will give the highest flexibility. Depending on the experience with the first soft x-ray undulator Athos unnecessary APPLE II modules can be used for the second soft x-ray line Porthos.

Commissioning

For the commissioning of the FEL the undulator will be brought into resonance module by module. The remaining modules shall be kept. with zero or vanishing field. Therefore for both undulator types the gaps will be opened. In order to keep the undulators reasonable small, the gap open position will be limited to a K-value of 0.1. This is for the in-vacuum undulator U15 a gap of 20 mm which fits into the vacuum vessels used so far.

In case of the APPLE II undulator UE40 a gap drive is not mandatory. For full polarization control all 4 magnet arrays have to be shiftable [13], which allows the undulator to be operated at a fixed gap like the UE44 for the SLS [14]. However the field errors do not vanish so that for the commissioning of the FEL undulator with its up to 15 modules it seems to be preferable to implement also a gap drive. Gap open with K = 0.1 will be at a gap of 50 mm.

The alignment of the undulators is planned to provide with a remote controlled cam shaft mover system which has been developed for the SLS girders. This rigid system allows 5 degrees of freedom: displacement in vertical and horizontal direction and all angles, tilt, roll and yaw. It has been used successfully for the SLS in-vacuum undulators but it will be even of higher importance for the APPLE II undulator because of tight alignment tolerances in vertical and horizontal direction (see below).

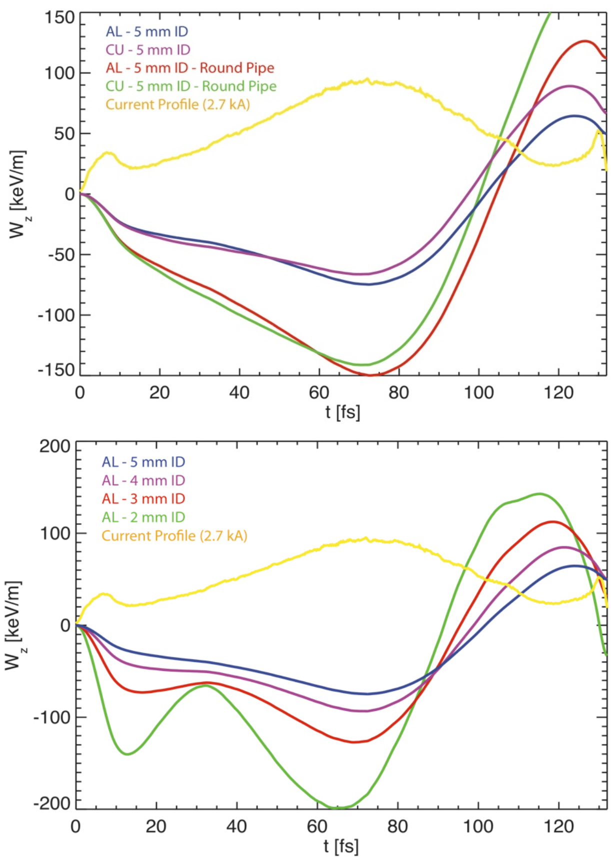

Figure 4: Impact of gap and vacuum chamber material on the current profile. The top graph shows the influence of aluminum and copper in a 5 mm vacuum chamber with horizontally flat and round profile. The material does not matter. The bottom graph shows a flat chamber with gaps between 2 and 5mm. Below 4mm oscillations across the current profile become larger. For the vacuum chamber of the UE40 an elliptical chamber profile with a gap of 5 mm would fit best to the current profile and in case of the in-vacuum undulator U15 the minimum gap should be at 4 mm.

Wakefield Effects

The impedance of the vacuum chamber has an impact to the current profile and can even compensate variations along the current profile. Figure 4 shows calculations for the wakefield effects using the Stupakov-Bane model [8]. For horizontally flat surroundings like in the in-vacuum undulator, the gap should be above 4 mm. In an in-vacuum undulator the magnets are covered by a 50μm thin Ni foil which has been covered by $50\mu m$ copper. To the sides there is no limitation which permits the excellent pumping speed. In case of the fixed gap vacuum chamber an elliptical chamber with a gap of 5 mm would be reasonable. The choice of the material has no impact.

Operational Aspects

The undulator will be tapered from module to module to compensate for the energy losses. In addition, the soft x-ray undulator UE40 shall have the possibility to taper the magnetic field within a single module. Such a taper can be used to increase the photon intensity after reaching the saturation [15]. For the hard x-ray undulator such post saturation is not useful.

The gap variation of both, the UE40 and the U15 requires phase matching units between all undulator modules which will be permanent magnet structures similar to an undulator but with only half a period.

Table 2: Tolerances for the undulators. The tolerances depend on the FEL bandwith and the dimension of the optical mode. The tolerances for the U15 refer to a field variation of $1\cdot10^{-4}$. The temperature stability is meant over a single module.

	U15	UE40
FEL bandwith ρ	$2.5-5\cdot10^{-4}$	$1\cdot10^{-3}$
optical mode σ	$20\mu m$	$40\mu m$
gap setting g	$<1\mu m$	$<1\mu m$
position y	$\pm30\mu m$	$\pm50\mu m$
position x	$\pm200\mu m$	$\pm50\mu m$
trajectory straightness	$1\mu m$	$5\mu m$
phase error ϕ	$10°$	$10°$
temperature ΔT	$0.1°$	$0.1°$

Tolerances

Important constraints to the undulators are the tolerances, which are summarized in table 2. The tolerances are not significantly stronger compared with the tolerances given to the third generation storage ring undulators. The main difference lies in the alignment tolerances of the long undulators. The magnetic field errors are related to the FEL bandwith ρ by

$$\frac{\Delta\lambda}{\lambda} = \frac{K^2}{1+\frac{K^2}{2}}\frac{\Delta B}{B} < \rho.$$

The main tolerances are summarized in table 2. Compared to the other hard x-ray FELs the parameter for the SwissFEL have to be more stringent, i.e. the normalized emittance ϵ_N has to be small with a small electron energy γ to keep the emittance smaller than the wavelength λ:

$$\epsilon \leq \frac{\lambda}{4\pi} \text{ and } \epsilon = \frac{\epsilon_N}{\gamma}.$$

The same applies also for the trajectory straightness. The lower the electron energy, the weaker the beam and the smaller have to be the trajectory distortions.

Summary Constraints

Both undulator types for the SwissFEL shall be gap variable although both undulators could also be operated at a fixed gap because for the U15 the main energy variation will be done by electron energy variation and the UE40 could be tuned also as a fixed gap undulator. But for the commissioning and in case for the UE40 the optional seeding mode and post saturation taper option require the gap variation. In addition the operation of the SwissFEL can profit from a K - variation and a gap variation because both parameter are very demanding. With a maximum electron energy of 5.8 GeV the SwissFEL shall cover the wavelength down to 1Å with a desgn K value of 1.2. The module length shall be 4m each both for the U15 and the UE40.

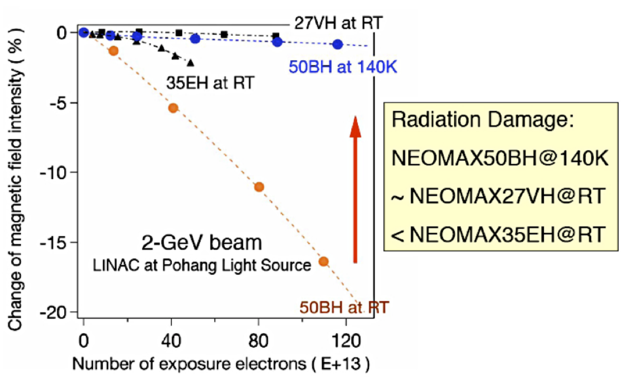

Figure 5: Degradation of various NdFeB magnet types due to exposure with 2 GeV electrons. The degradation is strongly correlated with the coercivity. 27VH is the material used for the SLS U19 undulators. 50BH has lower coercivity at room temperature and shows large degradation. But cooled down to LN2 temperatures increases stability drastically (courtesy of T. Bizen, SPring-8).

IN-VACUUM UNDULATOR

SLS Standard

For the SLS a series of small period, small gap in-vacuum undulators have been constructed in tight collaboration with SPring-8 [9]. These undulators emit spontaneous radiation on high harmonics (up to 13th for 18 keV photon energy) with a medium energy light source (2.4 GeV electron energy). The periods range from 24 over 19 to 14 mm with overall length of up to 2 m. Minimum gaps of 4.5 mm are used routinely in user operation. The use of such small gaps reduces the lifetime which is compensated by a continuously filling in the top-up mode. For the undulators this operaton requires beside a high remanence B_r also a high stability expressed by the coercivity Hc_j of the magnetic material used. Materials of choice are the rare earth permanent magnets made of $\mathrm{Sm_2Co_{17}}$ and NdFeB. Samarium cobalt has an excellent stability but limited strength while the neodymium iron boron magnets are stronger but not stable enough (see also figure 5). The stability of that magnets can be improved by replacing Nd partly with dysprosium Dy, also a rare earth material but with higher mass ($\mathrm{Nd_{31-x}Dy_xFe_{17}B}$). This increases the stability but because Dy has an opposite magnetic moment the strength is reduced. For the SLS U19 undulators $\mathrm{Sm_2Co_{17}}$ as well as stabilized NdFeB (NEOMAX 27VH) are used which have both the same strength. Important also for FEL operation is the fact that after 8 years of operation no demagnetization effects occur.

CPMU

The magnet technology limited the useable periods to about 20 mm at minimum gaps of 4 to 5 mm. Shorter periods became recently available by the cryogenic permanent magnet undulator [16] concept which makes use of the negative temperature gradient of both, the remanence and the coercivity as shown in figure 6. This enables the choice of NdFeB grades with higher remanence because in operation the increased coercivity prevents the magnets of degradation due to lost electrons (see i.e. 50BH at room temperature and at 130K in figure 5). The limit with this materials is given by the demagnetization due to magnet fields during assembling of the periodic structures at room temperature. The obligatory bake out for the in-vacuum undulators is also mandatory because at temperatures around 130K the magnet structure shows significant pumping. As the remance of the magnets has a maximum this is an ideal working point because there is no or very little temperature dependency.

From engineering point of view the CPMU requires only slightly modifications from the standard in-vacuum undulators. Two CPMUs have been built so far, one at ESRF and one in collaboration of SPring-8/Hitachi and PSI for the SLS. The U14 for the SLS will shift the photon energy range served with high brilliant x-rays from 20 keV to above 30 keV. With a proper design the magnetic field quality can be kept during the cool down process. The U14 will be installed into the SLS in 2010 together with the required modification of the beamline which is served so far by a wiggler.

In order to measure the magnetic field at 130K the Hall sample measurement system had to be implemented into the vacuum vessel. This has been achieved by replacing the granite bench by a light rail system and correcting the x and y position of the Hall sample in a closed loop with a laser and position sensitive photo diodes [17]. This system is also useful for magnetic measurements of any undulator with closed H or O support structures.

Diffused Dysprosium

The cryogenic undulator technology has been assumed to be the technique of choice for the SwissFEL in-vacuum undulator and the SLS U14 is seen also as a prototype for the FEL. But end of 2008 Hitachi proposed an improved manufacturing technique for NdFeB magnets based also on Dy. The dysprosium is not added into the basic alloy but is diffused out of a gas phase into the ready made magnet. The dysprosium can only diffuse along the grain boundaries where it replaces the neodymium. This is enough to

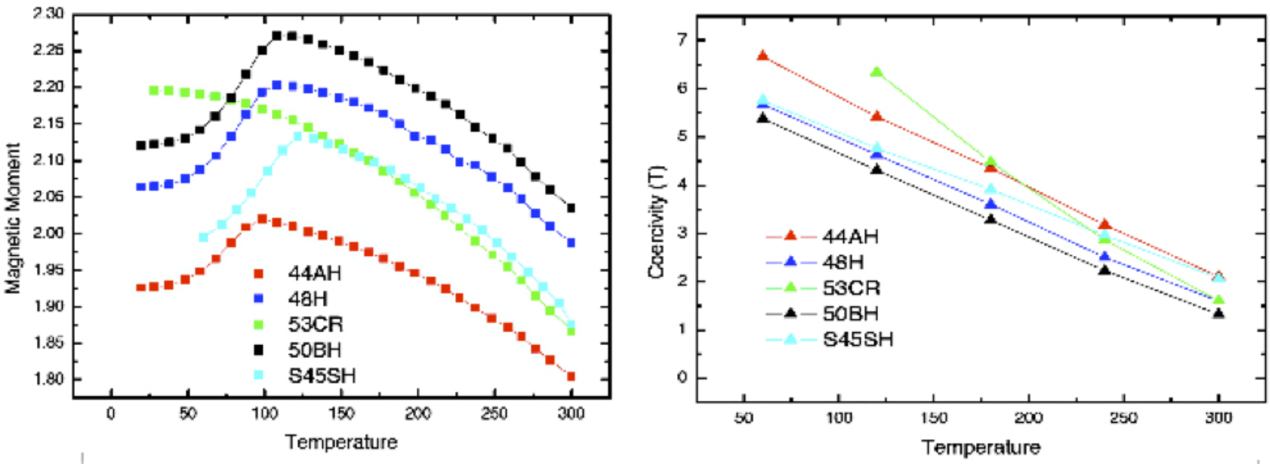

Figure 6: Concept of the cryognic permanent magnet undulator CPMU (courtesy of T. Tanaka SPring-8).

stabilize the magnet without changing the magnet strength. The diffusion process is effective only for thin magnets but the magnets needed for the U15 have only a thickness of about 2 mm. With this technique the coercivity can be increased at room temperature but the possible gain in remanence in combination with large enough coercivity is not as large as for the cryogenic magnets. The data are summarized in table 3.

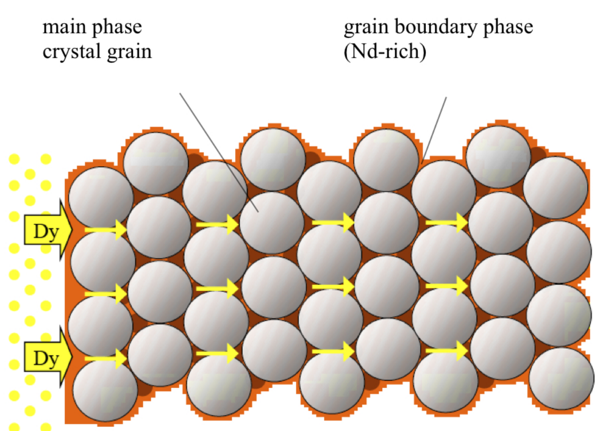

Figure 7: Increased coercivity of NdFeB magnets by diffusion of Dy into the ready made magnet. The Dy concentrates only at the grain boundaries (courtesy of Hitachi Metals Ltd.).

Table 3: Physical properties of permanent magnet materials

material	Sm_2Co_{17}		NdFeB	
grade		27VH	diff. Dy	CPMU
radiation hard	yes	yes	yes	yes
$B_r[T]$	1.1	1.08	1.25	1.5
dB/dT [%/K]	- 0.035		- 0.1	
permeability	1.01/1.04		1.06/1.15	
mech. prop.	brittle	ok	impr	impr
suitable for	UE40	UE40	U15	U15

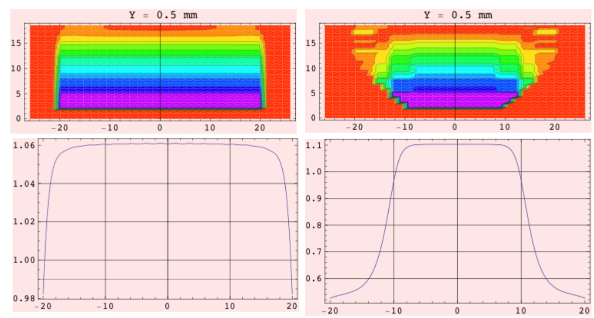

Figure 8: Field optimization by optimized pole profile.

Field Optimization

Based on the SLS U14 undulator and with the different material options the magnet field has been optimized. The constraint of a good field integral region of $\pm 20mm$ as for the SLS is not required for the FEL. So the pole can be formed to concentrate the magnetic field in the center. This increases the on axis field and reduces the magnetic forces which depend on the integrated field under the pole. In addition the magnet volume can be reduced for a more economical design (see figure 8). The K values which can be achieved in an in-vacuum undulator with 15mm period and 4mm gap are given in table 4. With a chamfered pole with 15 mm pole tip and 30 mm wide magnets a maximum K value of about 1.5 is achievable at a gap of 4 mm using the diffused dysprosium enriched NdFeB magnets at room temperature. The design K value of 1.2 will be reached at a gap of 4.7 mm. With a CPMU the maximum K would be 1.75 and a K value of 1.2 would be achieved already at 5.3 mm gap. The field roll off allows a good field region (of $\pm 200 \mu m$). The focusing effect due to the horizontal field roll of is negligible.

Considering the boundary conditions discussed above a design of a U15 with room temperature in-vacuum technology using the new Dy diffused magnets seem to be reasonable and is in the baseline design (see also figure 9).

Table 4: K values for U15 at 4 mm gap for different materials and pole geometries. The height of the poles/magnets is 16.5/20.5 mm.

pole / magnet	52 / 42	20 / 30	15 / 30	10 / 30
B_r [T]		K		
1.08	1.23	1.27	1.29	1.31
1.25	1.42	1.48	1.50	1.51
1.5	1.69	1.73	1.75	1.78

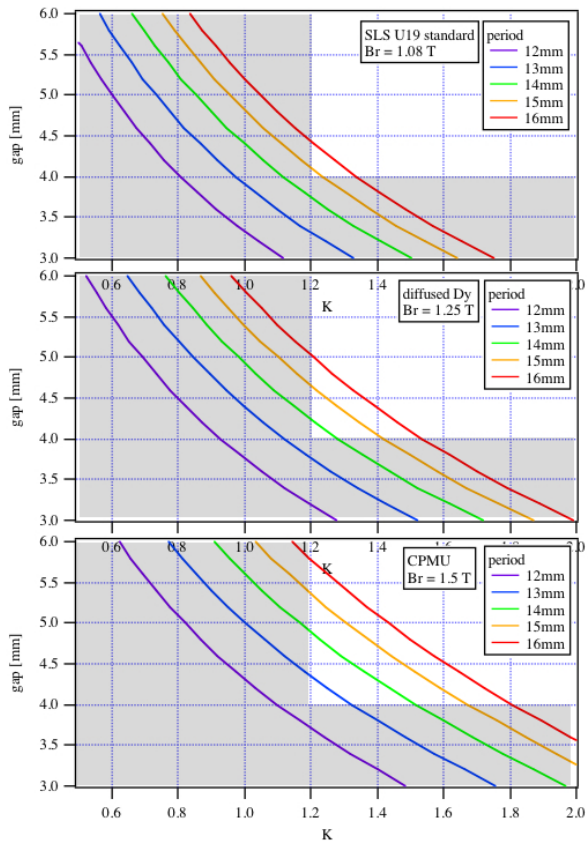

Figure 9: Gap versus K value for period length between 12 and 16 mm. The three graphs differ in the remanence of the magnets.

APPLE II

Again experience has been gained at the SLS in construction and operation of the APPLE II [10] type undulators. In close collaboration with BESSY two UE56 undulators and one UE54 have been constructed. Based on these undulators PSI has designed a 3.4 m long fixed gap APPLE II [11] UE44 with 44 mm period and a rather small gap of 11.4 mm [14]. This unduator is already close to the specifications of the UE40 for the SwissFEL, mainly with respect to the shift system of the magnet arrays. The gap drive can be taken from the UE56 respectively UE54. As already mentioned the vacuum stay clear aperture can be as small as 5 mm. For the SLS vacuum chambers the vacuum chamber wall thickness plus tolerances for planarity resulted in a 2.8 mm larger magnetic gap. However also the vacuum chamber for the single pass FEL can be smaller so that the minimum magnetic gap is assumed to be 6.5 mm. Therefore also the UE40 is a small gap undulator. But the development of a in-vacuum APPLE II undulator seems to be too demanding. Vacuum or even UHV compatible bearings suffer so far from precision. Instead a first prototype of a vacuum chamber with wall thickness well below 0.5 mm is under way. Nonetheless a high coercivity for the UE40 magnets is also recommended and can be of the type of the SLS standard magnet material for the U19 in-vacuum undulators that is either NdFeB or Sm_2Co_{17}. For the required K - value of 3.5 for the vertical field, the magnet transverse dimensions can be as small as 20 × 20 mm. The focusing effects of such an APPLE II is in the vertical and horizontal plane but is slightly smaller than the focusing of the U15 in the vertical plane.

The gap drive which has to be implemented because of the post saturation tapering option and the possibility to open the gap for commissioning allows in combination with the 4 axes shift system required for full polarization control [13] an advanced but simplified operation of the UE40. During the development of the UE40 fixed gap undulator it has been found that at the phase shift $\phi = 2\arctan(K_{z0}/K_{x0})$, the condition for full circular polarization in circular mode and the shift where the photon energy is minimum in the linear mode (with ϕ = diagonal shift and K_{z0} and K_{x0} = maximum K_z respectively K_x), an energy shift not results in a variation of the the energy but in a linear variation of the angle [18]. So with a combination of a gap drive and a 4 axes shift mode it is possible to operate the APPLE II in 1-dim modes: in circular mode the phase shift for the circular condition has to be set in symmetric mode and in a second step the energy can be set with a variation of the energy shift, a shift of the two upper magnet arrays versus the two lower arrays. In linear mode, the energy has to be set with a proper gap with the corresponding phase shift (which is gap dependent) but in assymetric mode and than the energy shift is used to vary linearly the angle.

Magnet Material

The permanent magnets have a permeability which differs slightly from 1. This results in nonlinearities which are the reason for a variation in the field integrals when shifting the magnet arrays and in distortions of the cosine behavior of the magnetic field which is responsible for small errors in the correct prediction of the energy and polarization behavior. Samarium cobalt shows smaller effects as shown in figure 10 which have to be actively corrected during operation because the permeability is closer to 1 (refer to table 3. In addition it shows a smaller temperature dependency so that samarium cobalt seems to be serious material although it is more delicate to handle because it is more brittle compared to neodymium iron boron.

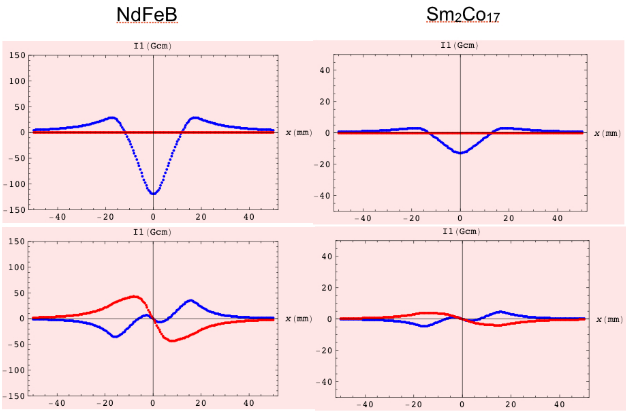

Figure 10: Multipoles distribution (transverse variation of the first field integrals or kicks) due to nonlinearity of the permanent magnet material in circular and linear mode for NdFeB and $\mathrm{Sm_2Co_{17}}$.

UNDULATOR SUPPORTS

For the support structures of the undulators the series production of the 2×15 undulators must be considered to get also a cost effective solution. Therefore in the current design status a common support structure for both, the in-vacuum and the APPLE II undulator is under consideration which will be made of cast materials (iron, Aluminum or even mineral). Although the APPLE II with its more complex forces in addition to vertical also longitudinal and horizontal requires a more rigid support than the in-vacuum undulator under series aspects a common design seems to be preferable. The vacuum chamber for the APPLE II will be part of the undulator similar to the vacuum system of the in-vacuum undulator which is mandatory for remote alignment with small tolerances between vacuum chamber and magnets. For a rather compact design the support structures shall have O - or H - structure. The higher symmetry of the closed structure is preferable in comparison to the standard C - structure but requires the integrated vacuum chamber and the integrated magnet measurement system.

OUTLOOK

For a user friendly hard and soft x-ray FEL PSI will provide the SwissFEL complementary to the SLS with the same high flexibility in terms of polarization control and wavelength tunability. The concept is based on state of the art in-vacuum and APPLE II undulator technology. The particular challenge will be the controlled, phased matched operation of the complex undulators.

Full size prototypes of the U15 and UE40 undulator modules will be build until 2012. The U15 will be implemented in a bypass of the the 250 MeV diagnostic line as the radiator in a echo enabled seeding scheme. Lasing at 50 nm is expected there. The roadmap for the SwissFEL foresees a conceptual design report in autumn 2009, the financing request to the Swiss parliament will follow in beginning of 2011. The technical design report is the next milestone in the end of 2011. If agreed, the construction will be done from 2012 to 2015 and starting operation will be beginning of 2016.

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