UNDULATORS OF THE sFLASH EXPERIMENT *

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Abstract

The Free electron LASer in Hamburg (FLASH) at DESY has been upgraded recently [1]. Besides increasing the maximum energy to about 1.2 GeV and installation of a third harmonic rf cavity linearizing the longitudinal phase space distribution of the electron bunch, an FEL seeding experiment at wavelengths of about 38 nm has been installed [2]. The goal is to establish direct FEL seeding employing coherent VUV pulses produced from a powerful drive laser by high-harmonic generation (HHG). The project, called sFLASH, also includes a newly installed variable gap undulator section which will be described in this paper.

INTRODUCTION

FLASH is a free-electron laser based on the SASE principle, comprising a 1.2 GeV superconducting electron linac and a 27 m long undulator, producing EUV pulses of sub-10 fs duration [3]. Starting up from noise, the SASE radiation consists of a number of uncorrelated modes resulting in reduced longitudinal coherence and shot-to-shot intensity fluctuations of about 18% rms [3]. One possibility to reduce these fluctuations is to operate the FEL as an amplifier of injected seed pulses from a high-harmonic generation (HHG) source. In this way, high shot-to-shot stability at GW power and pulse duration in order of 20 fs can be expected. The natural synchronization between the FEL output and an external laser source will make pump-probe experiments insensitive to inevitable bunch jitter. Furthermore, the longitudinal coherence is expected to be greatly improved. sFLASH is an experiment to study the feasibility of seeding at short wavelengths (38 nm and below). sFLASH eventually aims at reliable seeding operation for a dedicated photon beamline, while SASE pulse trains are simultaneously delivered to the present beamlines [2].

sFLASH UNDULATORS

sFLASH comprises a 10 m long undulator section. Unlike the FLASH undulators, these are variable gap devices. Three 2 m long U32 undulators are followed by a 4 m long U33 undulator. The latter is a previously decommissioned device which is reused for sFLASH after refurbishment [4]. Since proper interaction of the HHG laser with the wiggling electron beam in the undulators is among the main milestones of the project, the new U32 undulators are installed at the beginning of the seeding section. Undulator parameters are listed in Table 1. Both types are hybrid structures built with NdFeB magnets and Vanadium Permendur poles. An intersection of 700 mm length is placed between the undulators which contains the quadrupole, diagnostic components, an ion getter pump, and a compact electromagnetic phase shifter. The latter corrects the K value, i.e. gap dependent phase advance from one undulator to the next. Additionally, a set of small air coils is located upstream of all undulators in order to compensate residual field integrals. Table 2 shows the specification in magnetic field errors of the undulators which are required to drive the seeding process efficiently.

Table 1: Parameters of sFLASH Undulators

	U32	**U33**
Min. gap [mm]	9.0	9.8
Period length [mm]	31.4	33
No. of poles	120	240
Length [m]	2	4
K value	2.72	3.03

Table 2: Field Error Specification of Undulators

Trajectory straightness	10 μm / 30 Tmm^2	(rms)
Residual kick	10 μrad / 30 mTmm	(rms)
Phase error	10 $^\circ$	(rms)

MAGNETIC MEASUREMENTS

Magnetic tuning was performed at a measurement bench in a climatized room with a temperature stability better than 0.5 K. Vertical field maps were measured by a Hall probe, while the horizontal field component was simultaneously measured by a small search coil. Tuning of trajectory and phase error was performed at minimum gap. The field integrals and their transverse dependence were determined by a stretched wire probe for all gaps. The reproducibility (rms) of these measurement methods was about 70 μT for the Hall probe, 1 μT for the search coil, and 10 mTmm for stretched wire field integrals.

To improve accuracy, each measurement was repeated 10 times and averaged values were used for progressive tuning. Though Hall probe and stretched wire data show the same field integral contours, only the wire data provide reliable absolute values.

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TUNING OF U32s

The strength of each pole of the U32 undulators can be regulated individually [5]. Each pole can be adjusted in height by about ± 300 μm and tilted by ± 2 mrad, which produces a vertical kick of up to ± 250 mTmm and horizontal kick of ± 40 mTmm. In general, pole movements are limited to a maximum variation of 100 μm along the magnet structure in order to preserve the minimum gap specification.

The applied pole tuning procedure optimizes both flatness of the local K parameter and the horizontal trajectory. Using properly measured field signatures of pole tilt and shift, only one iteration is required to tune the device to a phase error (rms) well below 2 degrees. All U32 devices exhibit this small error over the entire gap range (Fig. 1). Consequently, the corresponding trajectories are almost perfectly flat as it can be seen in Fig. 2. At 9 mm gap, the roughness of 2^{nd} field integral is 16 Tmm^2 rms, which is only marginally above the ideal trajectory minimum value of 15 Tmm^2 caused by the pure beam oscillation. A straight progression of the horizontal trajectory is obtained at all gaps (see Fig. 3 for one of the U32 devices). For clarity, data have been averaged over one period length here. Figure 4 displays the straightness of the horizontal and vertical trajectories in terms of rms values of 2^{nd} field integral as a function of gap for all devices. For the horizontal 2^{nd} field integral, values of 2 Tmm^2 have been achieved, i.e. of about 10% of the transverse beam excursion. These results are well within specifications defined by simulation results [6]. Within the gap range used for sFLASH operation, this also holds for undulator U33 which overall, however, provides considerably larger field errors discussed below.

The gap dependence of residual first field integrals is minimized by appropriate tuning of the poles in the end modules. The remaining gap-dependent end kicks are in the order of ± 0.1 Tmm (Fig. 5 and 3). They are corrected by a pair of air coils installed at each undulator intersection generating up to ± 0.2 Tmm horizontal and vertical kick [5].

After tuning the poles for phase error and trajectory, multipoles are adjusted by placing shims at the ends of the magnet structure. Because of the small vacuum chamber aperture of just ± 5 mm, only few shims at each side are required to flatten the transverse dependence below ± 20 mTmm for 1^{st} field integral and ± 50 Tmm^2 for 2^{nd} field integral (Fig. 6). For U33, values of ± 60 mTmm and ± 160 Tmm^2 have been achieved, respectively.

TUNING OF U33

This device is an upgraded undulator which had previously been used at PETRAII. To make it viable for sFLASH, the motion control had to be upgraded towards a two-axes drive. Besides, a severe radiation damage induced demagnetization of about one third of the magnets had to be cured [4]. As the U33 structure is different from

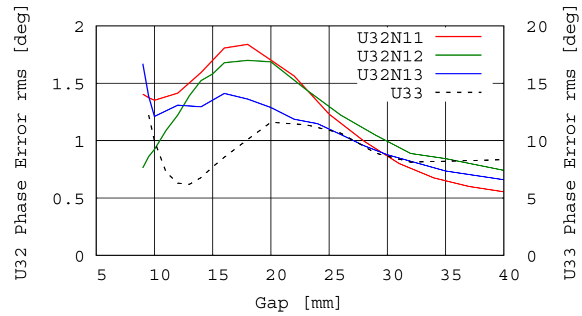

Figure 1: Gap dependence of the phase error (rms) for U32 (left) and U33 (right) undulators.

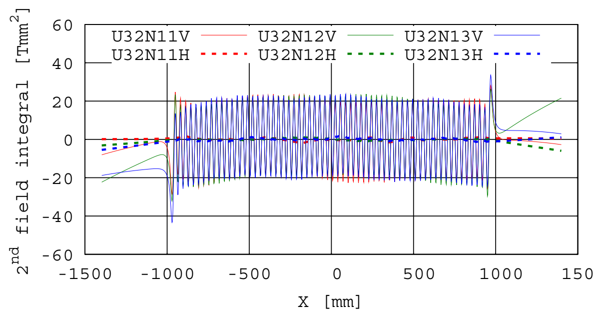

Figure 2: Vertical (solid) and horizontal (dashed) 2^{nd} field integrals of U32 undulators at 9 mm gap.

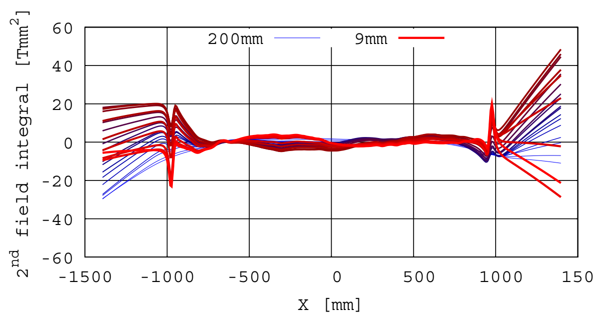

Figure 3: Lambda-filtered U32 trajectory for different gaps.

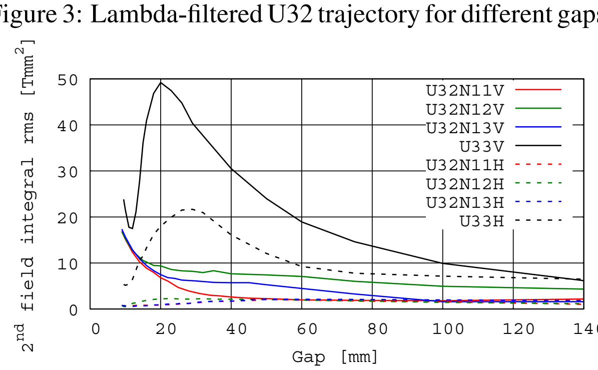

Figure 4: Second field integral rms value as function of gap, indicating the trajectory straightness. Values should be compared to the ideal trajectory rms value of 16 Tmm^2 related to the intrinsic oscillating motion at minimum gap.

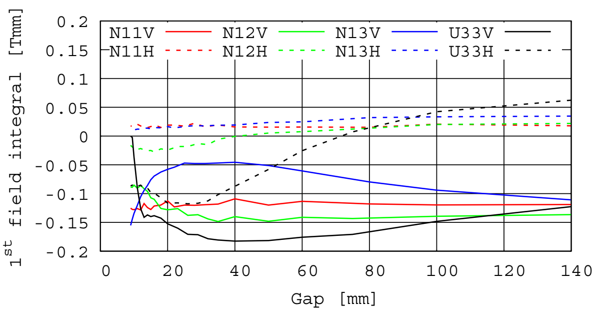

Figure 5: Residual gap dependence of vertical (solid) and horizontal (dashed) field integrals after adjustment of end poles. These kicks are compensated by corrector coils.

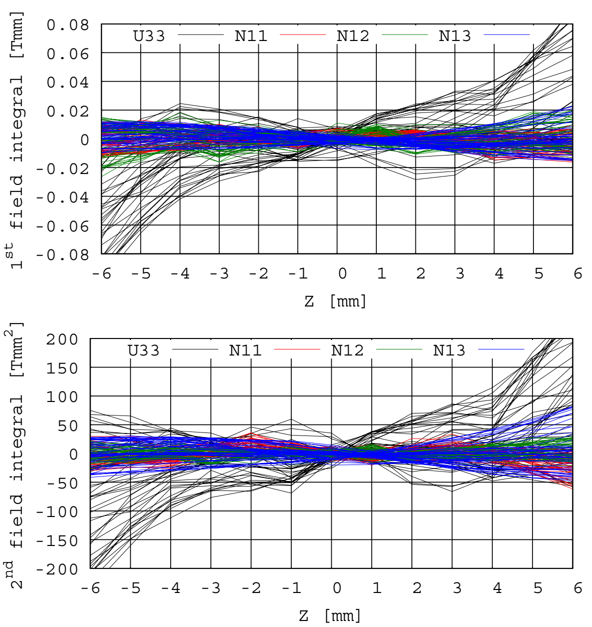

Figure 6: Transverse dependence of 1^{st} (top) and 2^{nd} (bottom) field integral values for different gaps measured by stretched wire (gap dependent dipole correction applied).

U32 in terms of mechanics it is impossible to tune each pole individually. Therefore, tuning of U33 has been performed in two steps. At first, the trajectory was tuned with magnetic shims placed aside of the poles (Fig. 7). Then the phase was tuned using mechanical shimming of magnet modules. The magnet structure consists of 5 modules. Measured phase error data were divided into 5 parts accordingly and a parabolical approximation was made for each part in order to calculate appropriate correction of gap and taper for each module. Figure 8 shows the significance of this concept.

Multipole shiming was made as for U32 undulators but shims had to be placed on top of the poles for stability reasons. This slight degradation of minimum gap does not matter. Having larger period length, U33 will require a gap of 10.4 mm to match the lasing condition for 38 nm when U32 undulators will operate at minimum gap of 9 mm.

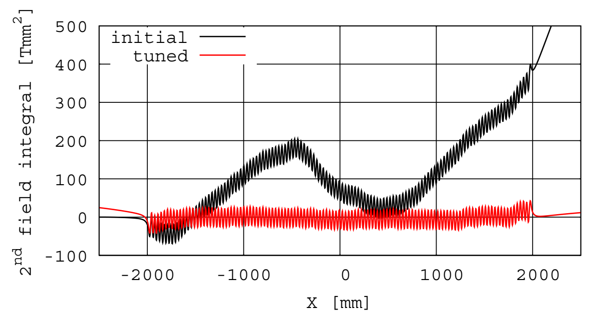

Figure 7: U33 trajectory correction.

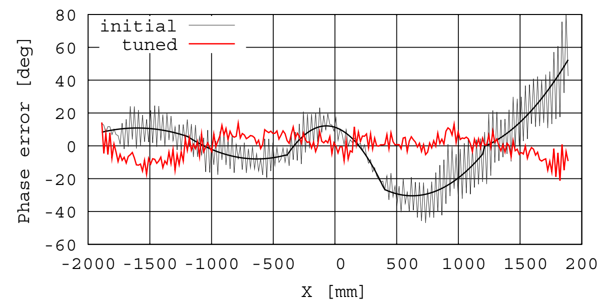

Figure 8: U33 phase error correction.

INSTALLATION

Regarding the order of the three U32 undulators, the one with the best magnetic field error properties should be placed in the beginning of the seeding section. In the present case, all U32 easily meet the magnetic specification. Differences in their field quality are largely insignificant in this respect. Therefore, the sequence of the devices has been chosen such that the gap dependence of the residual downstream kick of one undulator is at least partly compensated by the upstream kick of the following undulator. The remaining kicks are corrected by one set of steering coils shared by both devices. Owing to a slim design of the undulator vacuum chamber [4], chamber and undulator could be successfully aligned with respect to each other, even with a nominal space of only 0.15 mm at each side while preserving the minimum magnetic gap.

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