UNDULATOR SYSTEM FOR A SEEDED FEL EXPERIMENT AT FLASH*

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Abstract

A seeded free-electron laser (FEL) experiment at VUV wavelengths, called sFLASH, is being prepared at the existing SASE FEL user facility FLASH [1, 2, 3]. Seed pulses at wavelengths around 30 nm from high harmonic generation (HHG) will interact with the electron beam in sFLASH undulators upstream of the existing SASE undulator section. In this paper, sFLASH undulators are described.

INTRODUCTION

FLASH is a free-electron laser based on the SASE principle, comprising a 1 GeV superconducting electron linac and a 27 m long undulator, producing EUV pulses of sub-10 fs duration [4]. 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 [4]. 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 of the 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 (30 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 [1, 2, 3]. In Table 1, sFLASH parameters are listed. In the first row the maximum electron-beam energy that sFLASH can operate parasitically is given. Electron-beam transverse sizes (rms), normalized emittance, bunch length (rms) and peak-current (after installation of 3^{rd} harmonic cavity) are given next. The following row is the FEL parameter. In the last two rows the HHG power at the entrance of the undulator section and the Rayleigh length are given.

Table 1: sFLASH Electron- and Pphoton-Beam Parameters

Energy (MeV)	850
$r_{x,y-beam}$ (μm)	100
$\epsilon_x = \epsilon_y$ $(mm.mrad)$	2
σ_l (μm)	80
$\hat{I}$ (kA)	1.5
ρ	1.5×10^{-3}
P_{seed} (kW)	50
Z_{rayl} (m)	1.55

sFLASH UNDULATORS

sFLASH comprises a 10 m long undulator section. Unlike the present FLASH undulators, these will be variable gap devices. Three 2 m long U32 will be followed by a 4 m long U33 undulator. The latter is a previously decommissioned device which can be reused for sFLASH after refurbishment as described below. 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 will be installed in the beginning of the seeding section. In Table 2 undulator parameters are listed. In order to control and optimize the overlap of photon and electron beams, diagnostics blocks will be installed in the three intersections between the undulators. Undulator vacuum chamber uses the achievements of XFEL [5] (see Fig. 1). Taking into consideration the vertical size of the vacuum chamber (8.6 mm) and the minimum desired undulator gap size (9 mm), a sophisticated support and holder system is prepared to adjust and maintain the position of the chamber within the undulator gap.

Table 2: Parameters of sFLASH Undulators

	U32	U33
Min. gap (mm)	9.0	9.0
Period length (mm)	31.4	33
No. of poles	120	240
Length (m)	2	4
Peak field (T)	1	1.07

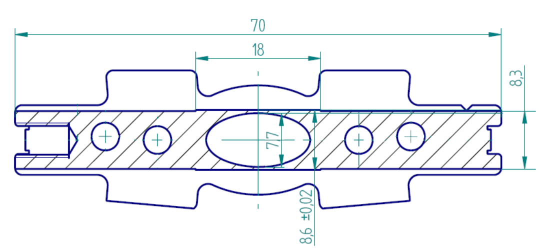

Figure 1: Cross-section of the undulator vacuum chamber.

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U32 Undulators

The development on undulators for PETRA III [6] has been adapted for U32 undulators. A well established procedure of shifting and tilting individual poles is performed for magnetic tuning of the trajectory. Figure 2 shows a set of preliminary magnet data which resulted in a trajectory straightness (rms) of $4\ \mu m$ at 850 MeV electron beam energy. Two air-coils will be used to compensate for the remaining gap-size dependent field integrals. The control system is based on off-the-shelf standard components for industrial automation. The gap drive consists of two independent servo axes for each magnet girder to allow for maximum flexibility, e.g. for tapering or beam height adjustment. Each of the axes is equipped with a multi-turn absolute rotary encoder to provide operational reliability even after a loss of power. The deformation of the support structure due to varying magnetic forces while changing the gap has been characterized carefully by an external gauge. This data is being used to correct for these gap deviations. In order to improve the accuracy to values within $\pm 1\ \mu m$, additional linear encoder systems will be mounted at the up- and downstream end of the magnet girders.

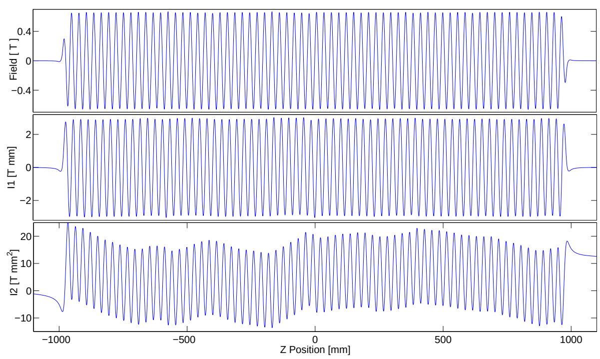

Figure 2: Preliminary Hall-probe measurements for U32 (12 mm gap) and corresponding field integrals.

U33 Undulator

After more than 10 years of operation in the PETRA II ring its undulator U33 was disassembled in 2007. The magnet structure corresponds to the standard undulator used at APS while a mechanics was used for this undulator which was originally developed for the DORIS III wigglers. At each side of the support frame one left-right-handed thread spindle is used which were mechanically coupled to a single motor. Adjustment of the taper could have been performed only manually. The gap measurement system was based on a rotary encoder connected to one of the gear-boxes. In the absence of a real-gap measurement system and no feed-back loop for real-gap, irreproducibility can be expected. After the decision of using this undulator for sFLASH, investigations on necessary modifications have been started. Four displacement gauges with micrometer precision were installed at the corners of two jaws. By introducing gap size changes, displacements were recorded. The mean value of four recorded displacements is considered as half real-gap change. The deviation from the mean value in each corner is plotted in Fig. 3. Deviations as large as $80\ \mu m$ from nominal half-gap can result in unacceptable deformation strength from one run to the other. Genesis [7] simulation results show that due to this irreproducibility, at the downstream end of U33 the seeded FEL radiation power can vary from run to run by one order of magnitude. Depending on the direction of gap change, different displacement curves are observed. Moreover, deviations from the mean gap change are not reproducible even coming from the same direction. Therefore a throughout modification of the mechanics was indispensable. In Fig. 4 a photo from the modified U33, based on two motors, is shown. In the proposed design a real-gap measurement tool will be used to reach the same level of accuracy as described for U32s (see reference [6]).

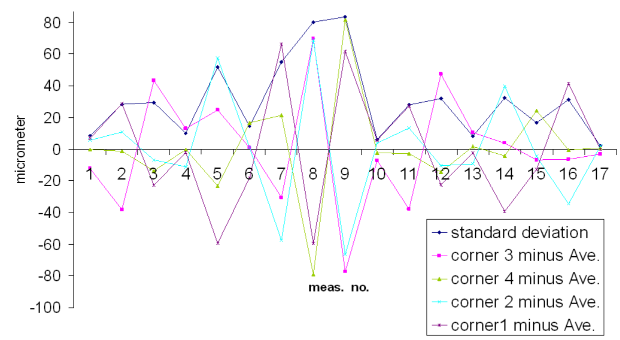

Figure 3: In several steps the gap size has been changed and the half gap displacement were measured with micrometer precision gauges. The average gap change is defined by the mean value of four measured displacements. The deviations in each corner with respect to the mean value is shown in the plot.

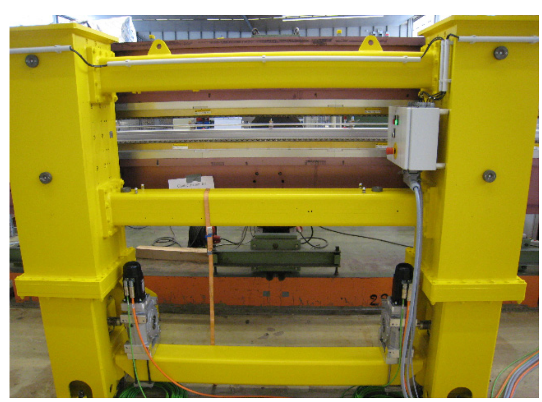

Figure 4: U33 with new mechanics and control.

De-Magnetization Accumulated at PETRA II

Previous investigations into the radiation-induced de-magnetization of permanent magnets similar to those of the

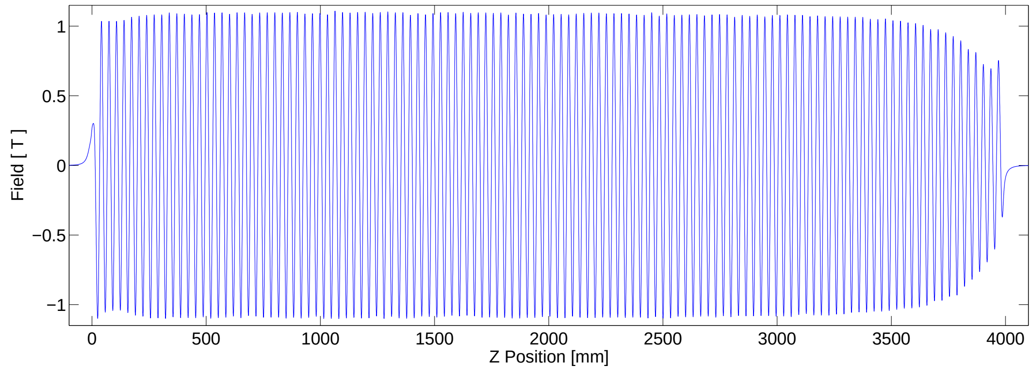

Figure 5: Field decay of up to 40% is observed at the edges of U33. This is a measurement with 9 mm gap size.

PETRA II insertion device produced varying results [8, 9]. In order to make an early enough decision on the way to handle U33 in terms of its magnetic field, its old control and mechanics were re-commissioned. This was followed by various Hall-probe scans at different gap size. An unexpected field decay at both ends of the undulator was observed. The responsible process for demagnetization of U33 is beyond the scope of this paper. Here, only the measurement results are reported. In Fig. 5 the field decay of up to 40% at the edges of U33 is visible for 9 mm gap. The field decay stretches over a length of about 1 m at the former upstream end of the magnet structure. The relative field decay remains the same for larger gaps. Thus, this effect cannot be explained in terms of gap non-uniformities due to stronger magnetic force in small gaps (see Fig. 6). In order to illustrate the influence of such a decay a Gen-

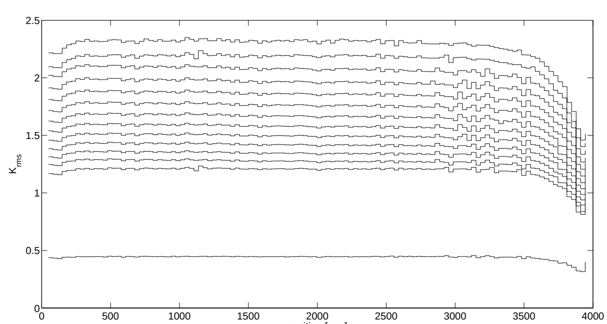

Figure 6: Measured B_y is used to plot variation of the undulator parameter K_{rms} along the device for different gaps. The top curve is for 9 mm gap size, the next curves are for larger gaps increasing in 0.5 mm steps up to 15 mm, the last one corresponds to 25 mm.

esis simulation result is shown in Fig. 7. Here, the HHG seed is introduced at the entrance of the undulator. Considering the present field distribution of U33 the output power reduces by a factor of two compared to the ideal case, i.e. sFLASH loses almost one gain length.

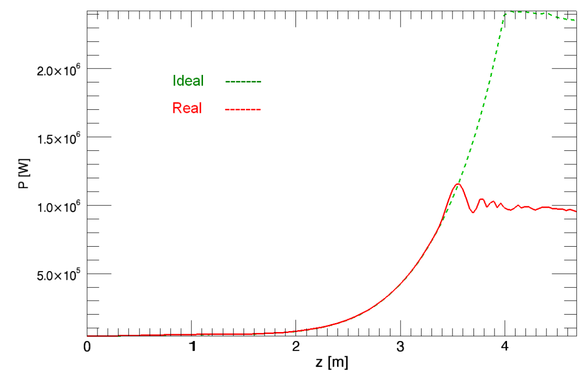

Figure 7: Simulated power gain curve for an HHG seed to the electron beam at the entrance of U33. For presently deteriorated field, the output power is affected by a factor of two with respect to the ideal case.

Re-Magnetization to Cure U33

The demagnetized parts of the magnet structure have to be repaired to assure full performance of sFLASH. It has been demonstrated in the past that a remagnetization of radiation-damaged undulator magnets can successfully regain their full magnetic strength [8]. Therefore, the magnet structure will be partly disassembled, then the affected magnets will be remagnetized individually. After remounting, a throughout magnetic tuning will be necessary to achieve the required field specifications.

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