MAGNETIC TUNING OF FLASH2 UNDULATORS

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Abstract

The present fixed–gap undulator system for FLASH1 and the new FLASH2 undulators will share the same electron beam accelerator, thus 12 variable gap undulators are needed in order to provide radiation of different wavelengths to both experimental halls independently. Each of the 12 devices has a length of 2.5m. The magnet structure with a period length of 31.4mm provides a maximum field of 0.96T with an effective K-parameter of 2.81 at minimum gap. Phase, vertical and horizontal trajectories have been tuned based on Hall probe and stretched wire measurements. Remaining multipoles were optimized with moderate gap dependence by using magic fingers. At some magnet structures, shims were placed to correct gap dependent field integrals. All undulators have an rms vertical and horizontal trajectory flatness <6Tmm^2 for all gaps corresponding to an rms trajectory roughness (at 1GeV) along the structure of ~2µm. The rms phase error is below 2° over the entire gap range.

INTRODUCTION

In the last years, the FLASH facility has been steadily improved and its wavelength range extended. The enhanced number of requests for user beam time was an important reason to extend the facility with an additional undulator line.

The second undulator line has been built into a separate tunnel and the new experimental hall will double the number of user end-stations which can be operated simultaneously. Supplied from the same accelerator as for FLASH1, 12 variable gap undulators segments will provide radiation with an independently tuneable energy to the FLASH2 experiments. Behind the last accelerating module, the beam can be switched between the present fixed-gap undulator line of FLASH1 and the new variable gap undulator FLASH2.

UNDULATOR DESIGN

Each of the 12 undulator segments for FLASH2 has a length of 2.5m and a period length of 31.4mm. The end field termination has a 1:¾:¼ configuration. The magnet structure is a hybrid design consisting on NdFeB magnets and vanadium permendur poles. The maximum field provided by these magnets is 0.96T corresponding to a maximum K-value of 2.81 at minimum magnetic gap of 9mm. In Table 1, the undulator parameters are summarized.

The mechanical design of FLASH2 insertion devices (IDs) has been improved with respect to the PETRA3 undulators. Also the drive system has been changed from a four- to a two-axes configuration [2].

Table 1: Parameters of the FLASH2 Planar Undulators

FLASH2 IDs	
Structure	Antisymmetric, hybrid
ID length L (m)	2.5
Period length λ_U (mm)	31.4
Magnet width (mm)	50
Pole width (mm)	30
Minimum magnetic gap (mm)	9
Peak field B_0 (T)	0.96
Deflection parameter K	2.81

MAGNETIC TUNING

While manufacturing of the undulator support frames and the magnet modules was done by commercial companies, final assembly, magnetic measurements and tuning in order to meet the specifications was performed in the DESY undulator measurement lab.

The structures were mechanically aligned parallel to the measurement bench by means of Hall probe measurements. Hence yaw and pitch angle were adjusted within a margin of 7µrad and the roll angle for the entire device was levelled better than 80µrad. Using the new tuning mechanism for roll angle of the individual magnet girders, the transverse taper was aligned to be smaller than 50µrad at the minimum gap. Via the drive system, the longitudinal taper could be easily adjusted to show a maximum difference between up- and downstream gap on the 1µm scale. To guarantee a well-defined and precise initial state of the magnet structure all poles have been positioned 100µm above the magnet surfaces. This initialization served to have a good starting value for the tuning procedure as well as to reduce the iterations of pole adjustments. The fine-tuning of the magnetic field was realized by shifting and tilting each pole individually. Each pole could have been shifted by ±300µm and tilted by ±2mrad (which produces a vertical and horizontal field integral of up to 300mTmm and 30mTmm, respectively), but since large positive pole shifts would limit the minimum gap, the adjustments were restricted to +120µm.

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ISBN 978-3-95450-132-8

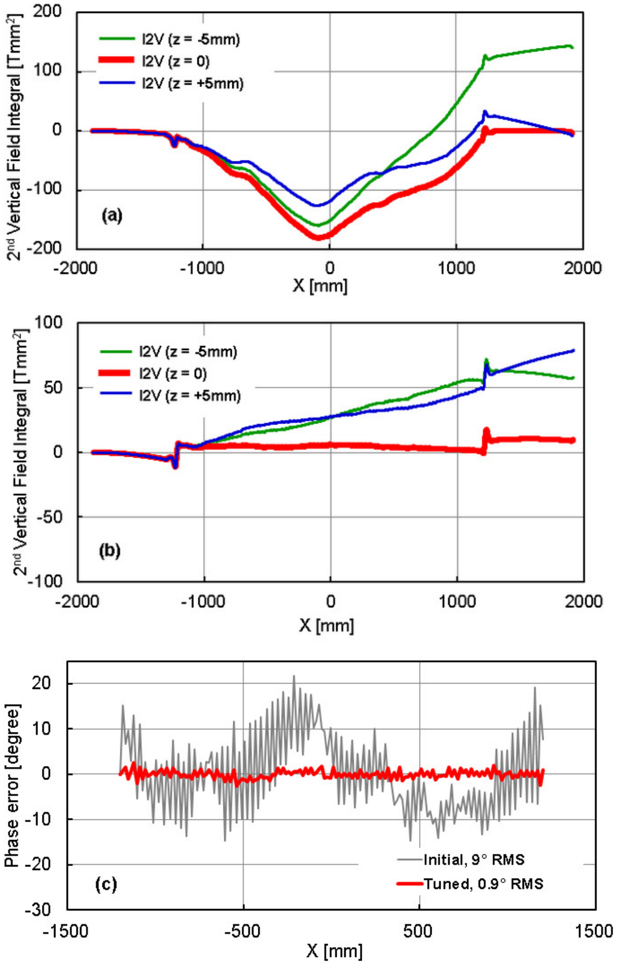

Figure 1: Exemplary tuning results for one of FLASH2 IDs. Second vertical field integrals (λ_U-filtered for clarity) in the initial state (a) and after tuning (b); the curves at transverse positions z=±5mm show that also the off-axis trajectories have been completely straightened. (c): Phase error after the final corrections in comparison to the initial state at 9mm gap.

Vertical and horizontal fields were measured by a Hall probe and a small pick-up coil, respectively. The related field integrals were used to ascribe any error to particular poles for which the according pole shift or tilt was calculated. The accurate initial setting of poles provided already reasonably straight trajectories and an rms phase error of about 10° only. In further simultaneously fine-tuning steps at minimum gap the vertical and horizontal trajectory straightness was improved to less than 6Tmm^2, the phase error was improved down to 1° rms and the maximum deflection parameter K achieved is 2.81. In Fig.1 the final result of this fine tuning is compared to the initial state. For better visibility, the 2nd vertical field integrals have been averaged over a period length (λ_U-filtered) and are shown without the oscillating behaviour. Also the off-axis trajectories have been tuned by a correction of local quadrupole components that were minimized by specific shifts or tilts of particular poles as described in [3].

A nonconforming, gap dependent kick in the trajectory was observed for a few undulators which also affected the phase error. This was corrected by shims which were placed on the pole and imposed a kick with opposite gap dependence. Shims of 15mm width and variable thickness were used. After placing the shim, the corresponding pole was retracted accordingly. As it can be seen in Fig.2, the signature of such a pole shim consists of two competing effects, the bare signature of the shim plate and a change in strength for the gap dependence of the shimmed pole due to its misplacement with respect to all other poles.

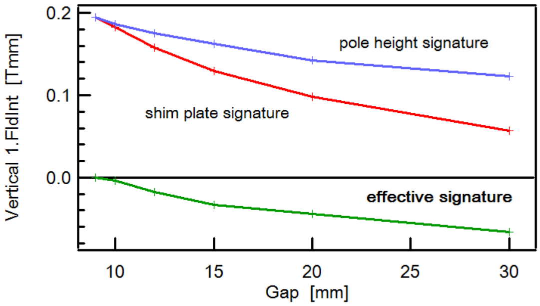

Figure 2: Shim signature for correction of gap dependent trajectory kicks.

For illustration, Fig.3 compares vertical 2nd field integrals for various gaps before and after applying a gap-shim. Within a transverse range of ±5mm, such a shim with 200μm thickness induces a small local sextupole of

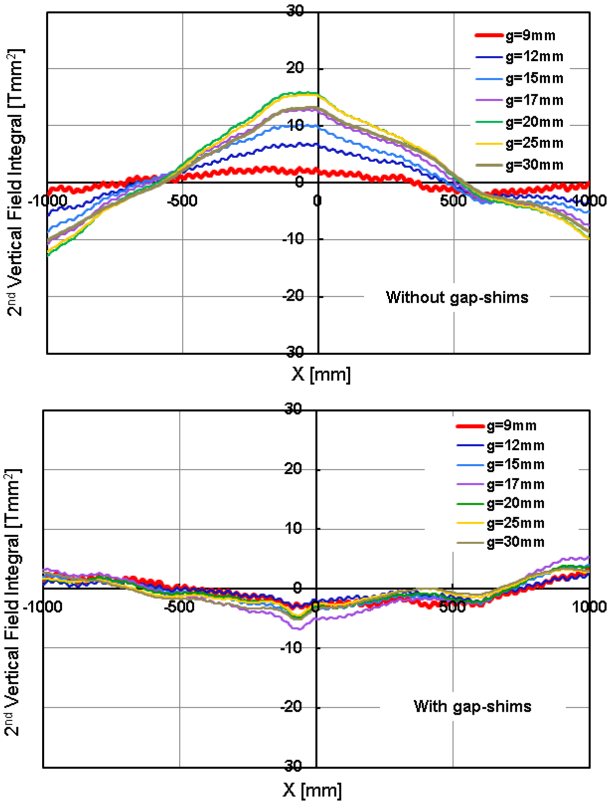

Figure 3: Gap dependence of second vertical field integrals before (top) and after applying a gap-shim (bottom).

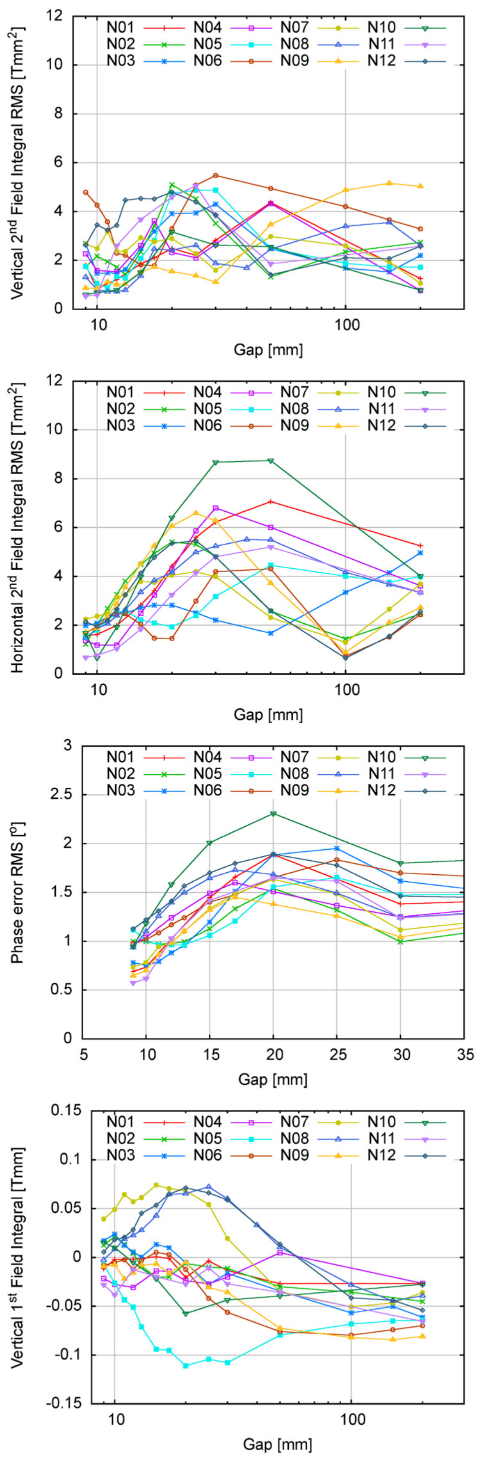

Figure 4: Compilation of magnetic tuning results for the 12 FLASH2 undulators; the rms values of the vertical and horizontal 2nd field integrals, the phase error, and the 1st vertical field integral are shown as a function of gap.

about 15G/cm which is less relevant for a single-pass machine, but is anyway compensated by magic finger magnets at the ends of the magnet structure. It has been found that a transverse misplacement of such a shim by 0.2mm induces a local quadrupole of about 10G. Similar shims were used for a local correction of other gap dependent normal or skew field errors.

Multipole components do usually not play a crucial role in FELs. Nevertheless it was decided to perform a moderate correction of the residual multipole components in a limited transverse range of ±5mm as a final tuning step. By means of the moving wire set-up, the horizontal and vertical, first and second field integrals were measured and the multipole contributions of the magnet structure have been investigated. While odd normal or skew quadrupoles have already been corrected locally along the magnet structure, remaining multipoles were corrected by using two pairs of magic fingers (an array of retainers for small cylindrical magnets with a diameter of 2mm and a length varying from 2 to 10mm) which are mounted on both ends of the undulator on the top and bottom magnet girders. The magnet configuration in these pairs is optimized such that the transverse dependence of both, vertical and horizontal components is reduced down to a variation of ~0.03Tmm in measured transverse range. The remaining gap dependence of the end-kicks is ±0.05Tmm and will be compensated with small (air) corrector coils which are designed to correct up to ±0.2Tmm [2].

CONCLUSIONS

The following graphs summarize the final tuning results of all the 12 FLASH2 undulators (Fig.4). For the vast majority of the IDs, the rms trajectory straightness is below 6Tmm^2 which corresponds to less than 2μm rms beam displacement at 1GeV. An rms phase error of ~1° at minimum gap (g=9mm) has been achieved throughout while for all other gaps a phase error of <2° was obtained. Currently, all the devices are installed in the tunnel and first commissioning steps are in progress already.

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