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DESIGN AND COMMISSIONING OF THE FLASH2 UNDULATORS

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Abstract

This paper reports about aspects of design, manufacturing, and commissioning of the 12 FLASH2 variable gap undulator segments. The accuracy of gap drive and encoder systems was tested by magnetic measurements; changes in the phase error proved to be a highly sensitive probe to verify a reproducibility of 1 µm. After magnetic tuning of the IDs, the remaining gap dependence in the field integrals could be successfully compensated by corrector coils. Inconsiderate handling of components during assembling necessitated an elaborate demagnetisation process before the tuning could start.

INTRODUCTION

In order to double the number of user experiments which can be operated simultaneously in the XUV and soft X-ray regime, DESY's free-electron laser (FEL) facility FLASH has been upgraded. Within the scope of the FLASH II project [1], a second experimental hall and a second undulator line have been built. They share the same accelerator [2]. This paper describes some aspects of the manufacturing and the commissioning of the 12 2.5 m long variable-gap undulator segments. This comprises the accuracy of the gap drive, the unintentional magnetization of mechanical components and the active compensation of gap dependent, residual magnetic field integrals.

MECHANICAL DESIGN

The mechanical design of both, the support and the magnet structure is based on the PETRA III insertion devices. In comparison with these, the girder cross-section has been modified from 550×100 mm^2 to 400×130 mm^2 in order to improve the lateral stiffness while keeping the vertical deflection due to the magnetic forces at the same level. In contrast to a storage ring like PETRA III, for a linear accelerator like FLASH the required good-field region (less than 0.1% field roll-off) is only ±2 mm, thus the width of poles and magnets could be reduced by 20 mm to 30 mm and 50 mm, respectively. By these means, the dynamic load changes due to magnetic forces during gap movements could be limited to 15 kN. Nevertheless, finite element calculations show that elastic deformations of up to 50 µm are to be expected due to these forces.

In order to achieve a positioning accuracy for the magnet girders of better than 1 µm, linear encoder systems like large sliding callipers have been mounted on both ends of the girders, measuring their distance (similar to [3]). Although the encoders are optical non-contact systems, an additional rail to guide the encoder head with respect to the scale is required. The expected movements of the heads while tapering the girders or due to unintentional rolling would otherwise exceed the positioning tolerances for a proper operation of the encoder system. In order to avoid any kind of Abbé error, the transverse positions of the encoder scale, the guide rail for the read-head, and the transmission point for the movement of the bottom girder were chosen to be the same as the beam position (see Fig. 1).

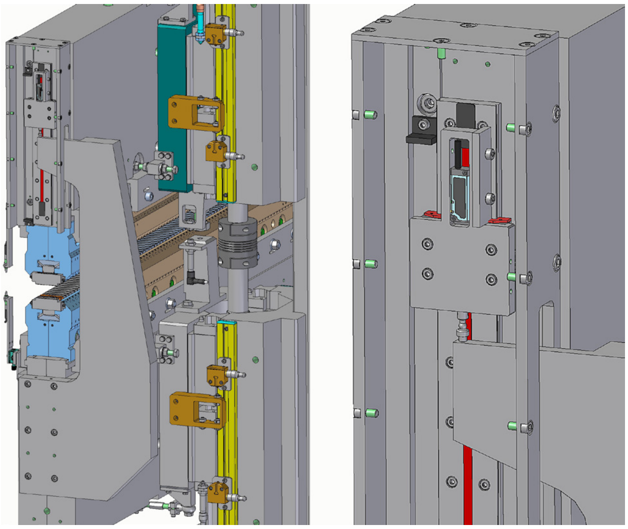

Figure 1: Encoder system mounted to the ends of the magnet girders. Close-up on the right shows the additional guide rail for the read-head and the transmission of movements from the bottom girder.

ENCODER PERFORMANCE

Before mounting, the encoder systems were tested with a laser-interferometer and were proven to have an accuracy and a hysteresis of better than 1 µm. Their performance at the ID with the control system was tested using magnetic measurements as a reference. The phase error σ_Φ is both, strongly correlated to the spectral performance of an undulator, and very sensitive to relative positioning errors of the two undulator axes, which would cause a tapering of the magnet structure. From the definition of the phase advance in a periodic magnet structure like an undulator, it is evident, that a tapered positioning of the magnet girders would cause a parabolic behaviour of the phase error along the longitudinal coordinate.

Figure 2 shows the change in phase error along the beam-axis implied by a taper (difference in magnetic gap

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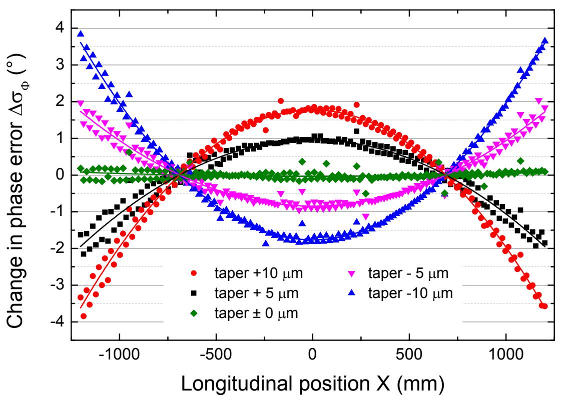

Figure 2: Parabolic behaviour of the phase error along the beam axis due to tapering the magnet structure.

between up- and downstream end of the undulator) setting of ±5, ±10 and 0 µm. The coefficient for the second order polynomial term in the fits to the measured data changes by -3.75×10^{-7} per 1 µm taper.

The referencing procedure for the incremental linear encoder systems has been repeated three times, in order to test its reproducibility. The results can be seen in Fig. 3. The maximum change which could be observed in the phase error was equivalent to a taper of 0.27 µm. For comparison, plots for the expected changes for a taper of ±1 µm have been added to the graph. This proves the reliability of the encoder systems to be significantly better than 1 µm.

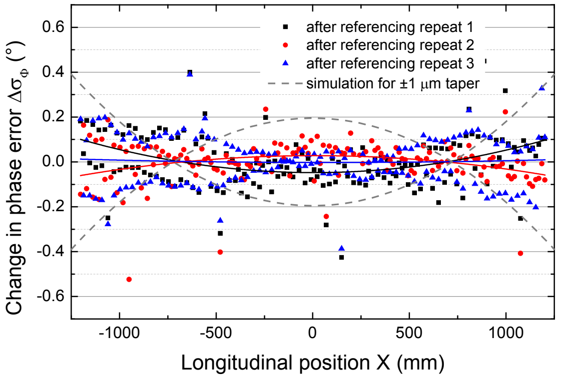

Figure 3: Change in phase error after several repeats of the referencing procedure for the linear encoders.

PERFORMANCE OF MECHANICS

The same tool as for testing the repeatability of the encoder systems was applied for testing the drive mechanics. The measurement of the phase error was done at a magnetic gap of 10 mm and repeated after several full open/close cycles of the device. For testing the hysteresis of the mechanics, the same gap value was approached twice from opposite directions, once from larger values and once from smaller values. Any deviations from the first measurement would indicate a different positioning of either of the two axes.

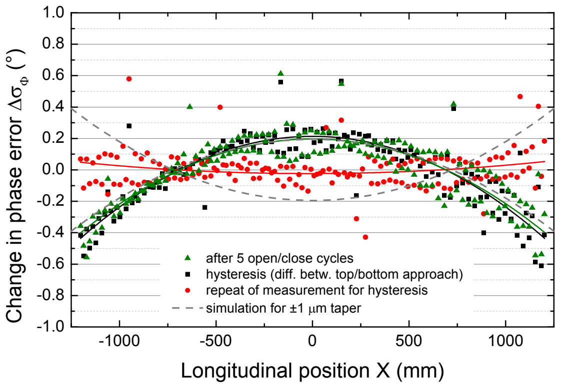

Figure 4: Change in phase error after several full open/close cycles and the hysteresis test of the ID.

The results are shown in Fig. 4. The maximum changes in the phase error, which could be observed for the mechanical hysteresis tests of the entire system, were equivalent to a taper of 1.2 µm. Repeating this measurement confirmed these results, with a deviation of only -0.14 µm.

COMPENSATING END-KICKS

The end-poles of the FLASH2 magnet structure have been designed in a 1:¾:¼ - configuration; the size and the positions of the end-poles and -magnets have been optimized for minimum gap dependence of the remaining field integrals. Typically these values are well below 0.1 Tmm, corresponding to a deflection of 30 µrad at an electron beam energy of 1 GeV. A dedicated set of corrector coils is mounted to the vacuum chamber up- and downstream of the magnet structure in order to compensate for these field integral changes during gap movements.

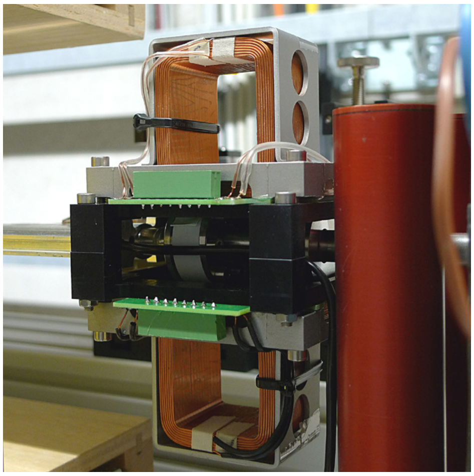

Figure 5: A compact pair of horizontal and vertical corrector coils (nested) for compensation of gap dependent changes in the field integrals, mounted to the vacuum chamber.

After tuning of the undulator magnet structure, the remaining horizontal and vertical field integrals have been measured with a stretched wire setup in the lab [4]. The data were separated into their up- and downstream components and thus a dataset for driving the power-supplies corresponding to each coil set was created. These compensating coils are driven by the undulator control system in a "feed forward" fashion. The results for a gap dependent field integral measurement with and without these coils activated are shown in Fig. 6.

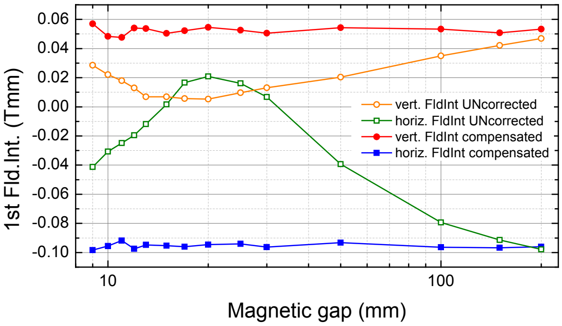

Figure 6: Gap dependence of residual field integrals after tuning the magnet structure with and without compensation by corrector coils.

The kicks applied by the correctors up- and downstream of the magnet structure (see Fig. 7) reduce the gap dependence of the remaining field integrals to values below 0.01 Tmm. These values can later be refined by orbit response measurements during gap movements, in order to correct for variations in the ambient field conditions between the accelerator tunnel and the lab.

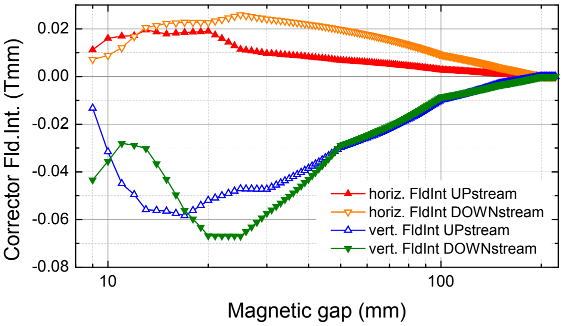

Figure 7: Feed forward tables for corrector coils.

DEMAGNETISATION OF COMPONENTS

The conical pins of the carriers for the magnet girders are crucial parts of the support structure and have to bear both, the attractive magnetic forces between the girders and their weight; they have therefore been manufactured from a high-strength steel (42CrMo4).

With the main focus on the mechanical strength of this part, the magnetic properties unfortunately were slightly disregarded. Thus, during the manufacturing process these pieces were handled with a lifting magnet and thereby magnetised considerably.

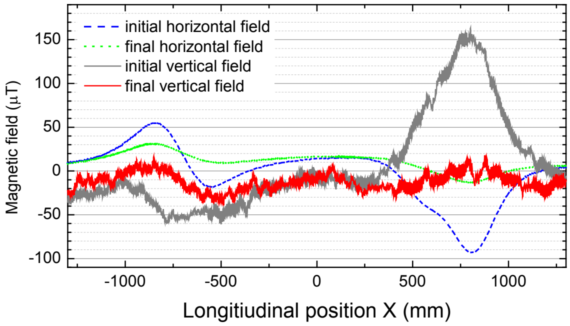

Figure 8: Magnetic field on the beam axis (without undulator magnet structure) before and after the demagnetisation process.

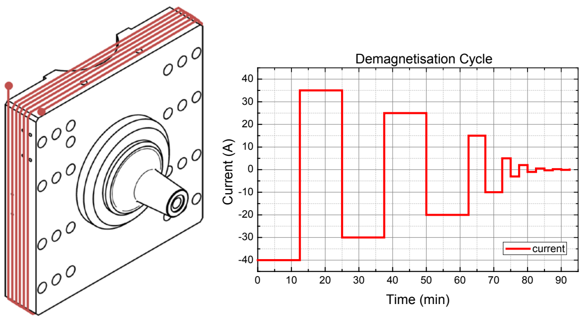

Figure 9: Carriers with pins for magnet girders and the applied demagnetization cycle.

This led to magnetic fields of up to 180 µT on the beam axis causing field integrals and thus perturbing kicks of up to 75 mTmm (see Fig. 8). By wrapping a coil with 190 windings around the carriers and applying an alternating current profile from -40 A down to +0.05 A (see Fig. 9), the remanent magnetic fields and corresponding integrals were brought down to a level of the ambient earth field (see Fig. 8).

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