MAGNETIC MEASUREMENTS OF THE FLASH INFRARED UNDULATOR

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Abstract

The FLASH free-electron laser at DESY, Hamburg, has recently been equipped with an infrared electromagnetic undulator, providing radiation in the range 1-200 μm. It will be used both for electron beam diagnostics purposes and as a powerful source synchronized to the VUV and soft X-ray pulses of the FEL. The undulator was constructed at the Joint Institute of Nuclear Research (JINR). This paper summarizes the extensive magnetic measurements that where performed both at JINR and DESY prior to installation of the undulator.

INTRODUCTION

An important feature of the beam formation system of FLASH is the possibility to produce ultra-short (below 50 μm) electron bunches. Such short bunches produce powerful coherent radiation with multi-megawatt power level. Generation of two-colors by a single electron bunch reveals unique possibility to perform pump-probe experiments with VUV and IR radiation pulses [1,4]. Coherent radiation produced by the electron beam in the IR undulator strongly depends on the bunch profile, thus allowing the use of the device for longitudinal profile diagnostics

UNDULATOR MAGNET DESIGN

The undulator (Figure 1) magnetic system [2,3] consists of two ferromagnetic girders with 22 poles each. The exciting coils are set on poles. The coils of the top and bottom girders are connected sequentially and powered by a single electrical supply. Each main coil consists of four layers, and each layer consists of 16 turns. The windings are made of a square-shape copper pipe (8.5x8.5 mm^2) with a cooling channel of 5.3 mm diameter. The maximum current in the winding is 435 A (current density 8.7 A/mm^2). Each regular coil has an additional correction winding to provide fine regulation of the magnetic field. The number of turns in the correction winding is 270, and wire diameter is 1 mm. The corrector winding allows to regulate the number of Amper·turns within 2% of maximum value of the main winding. The correction coils permit to compensate a perturbation of the magnetic field related to an imperfection of magnetic system at its construction. The coils of two end poles differ from the coils of regular periods, and consist of 8 and 36 turns for the first and the second pole, respectively. End-pole coils have also a correcting winding for fine adjustment of the magnetic field.

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Figure 1: View of the infrared undulator on the DESY magnetic field measurement bench

SCOPES OF THE MAGNETIC FIELD SHAPING

Undulator magnetic field measurements and correction were provided at the first stage in JINR (Dubna) and finally in DESY (Hamburg). At both sites a Hall probe magnetometer was used for the field measurement. The probe head was moved and controlled in three dimensions by stepping motors and a high accuracy linear encoder (~ some μm). The magnetic field monitoring was realized by reference Hall or NMR probe. During the magnetic field measurement campaign the following goals were realized:

- the first and second total integrals are I_1<200 G·cm and I_2<200 kG·cm^2;
- the first integral in each regular undulator period is I_1<200 G·cm;
- magnetic field reproducibility and long time stability for the first and second total integrals are I_1=±50 G·cm and I_2=±5 kG·cm^2;
- flat beam orbit;
- using one power supply for regular correction coils and as few as possible power supplies for the edge correcting coils.

The above undulator requirements have to be fulfilled in the range of the main coil excitation currents Io = 0 (remanent field) – 435 A (Bo=11000 G).

To achieve those goals, a large amount of simulation work was done at the initial stage of the project design by different codes (POISSON, ANSYS, TOSCA, RADIA) [2]. Those simulations have resulted in a flexible magnetic system with the possibilities to achieve the design goals.

UNDULATOR MAGNETIC FIELD AND ITS CORRECTION

The measured magnetization curve (central field, pole 4) has shown full correlation of this data with the simulation results by the TOSCA code (Figure 2).

To achieve a minimal first field integral in the regular undulator periods we have realized an iterative correction of the field integral by tuning the values of the correction coils shunt resistors. All regular undulator pole correctors (3-20) were excited by one power supply. The best correction was done first for the main coil current Io=200 A (Figure 3). For other main coil currents the correction was done by tuning the corrector current value. The initial value of the first field integral in the regular periods has achieved 1500 G·cm. The results of the regular periods first integral tuning are shown in Figure 4.

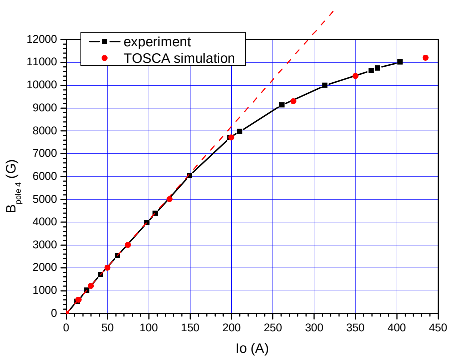

Figure 2: Undulator magnetization curve

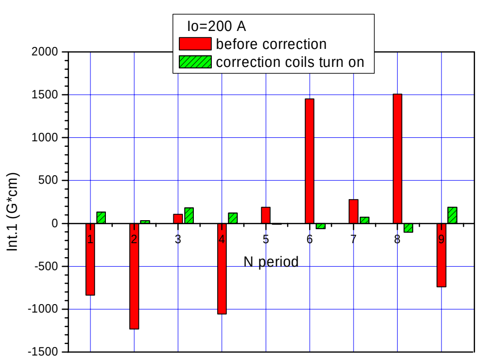

Figure 3: Distribution of the first field integral in the regular undulator periods (Io=200 A) before and after correction

The task of the total first and second field integral correction and minimization was successfully solved by careful tuning of the correctors currents for the pole 1, 2, 21, 22. The maximal correction current is 8 A for these poles. The final first and second field integral is presented in Figure 5 and 6. The corrector coils settings depending from the main coil current are presented in Figure 7. Second integral distributions along the undulator axis are shown in Figure 8 for the maximal main coil excitation currents.

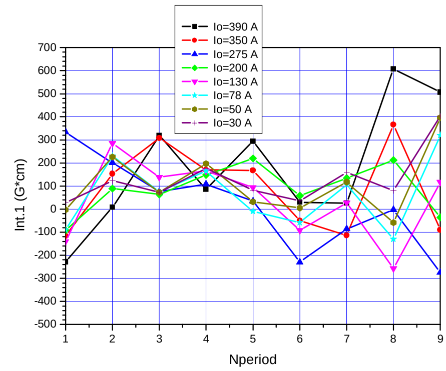

Figure 4: Distribution of the first field integral in the regular undulator periods for some excitation currents

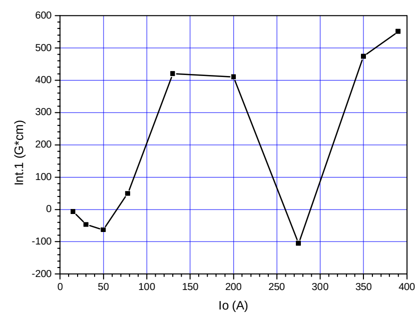

Figure 5: Final first field integral as function of the main coil excitation current

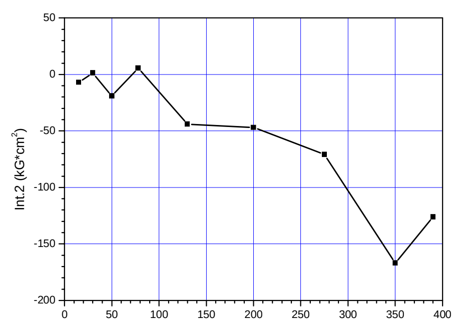

Figure 6: Final second field integral as function of the main coil excitation current

To investigate temperature effects of the undulator, a Fluke Ti45 thermography camera was used. Figure 9 shows an example of such thermographic images. The emissivity for calculating temperatures was taken as 0.95. From a series of such measurement, the coils are in equilibrium after about 30 minutes. The thermal coupling of the coils to the massive iron yoke and the support structure is weak, however, and a 6 hour time constant is found for the magnetic field.

The results of the reproducibility for the first and second field integral at some test runs are presented in Figure 10 and 11. The study of the undulator magnetic field variation during a 27 hour run at the maximum excitation current Io=435 A has shown that the undulator magnetic field integrals have reached equilibrium some minutes after the working regime setting. The results of the long term measurements are shown in Figure 12.

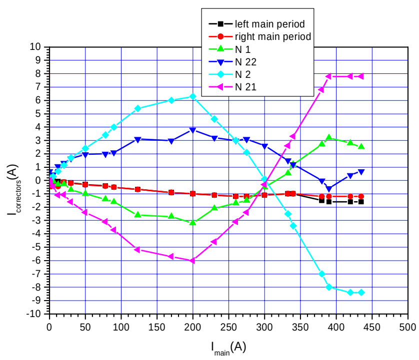

Figure 7: Correctors coils settings

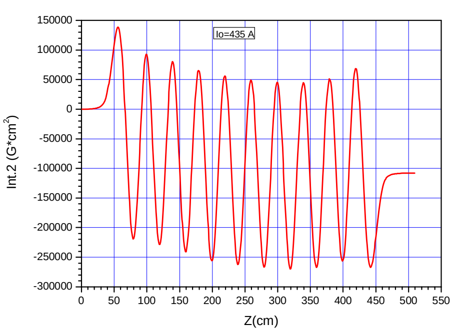

Figure 8: Magnetic field second integral for Io=435 A

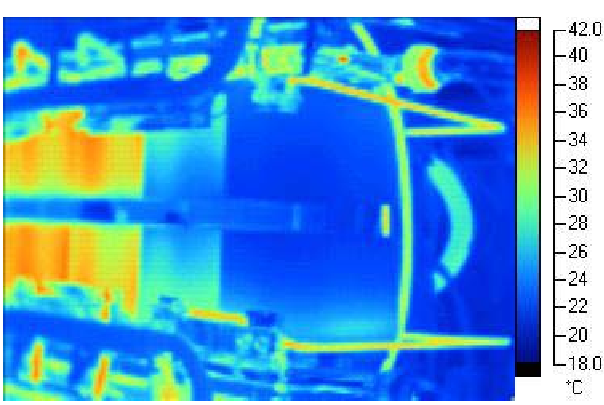

Figure 9: Thermographic image of the infrared undulator 60 minutes after switching on at 435 A current

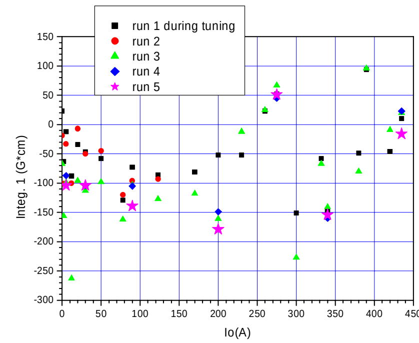

Figure 10: Reproducibility of the first field integral

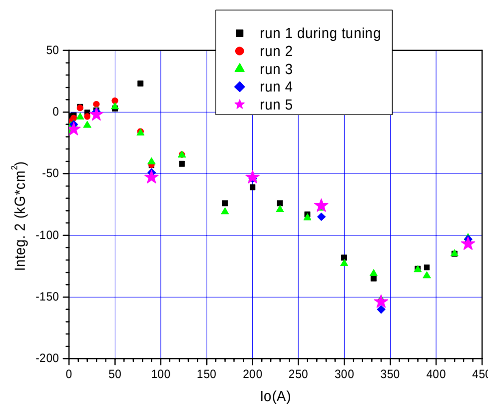

Figure 11: Reproducibility of the second field integral

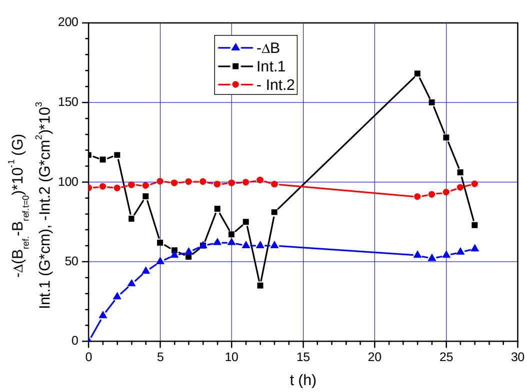

Figure 12: Data from the long test run of the undulator

CONCLUSION

The undulator magnetic field measurement and shaping campaign has approved the technical solution for the magnetic system design. The undulator has shown good stability and reproducibility of the basic magnetic field characteristics.

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