SIMULATION OF ELECTROMAGNETIC UNDULATOR FOR FAR INFRARED COHERENT SOURCE OF TTF AT DESY

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Abstract

A perspective extension of the FLASH ("F"reie-Elektronen-"LAS"er in "H"amburg) user facility at DESY is infrared coherent source on the base of electromagnetic undulator. The undulator consists of 9 periods, period length is 40 cm long, and peak magnetic field is up to 1.1 T. With the energy of electron beam of 500 MeV maximum radiation wavelength is about 200 μm. An important feature of the beam formation system of the FLASH is the possibility to produce ultra-short, down to 50 μm electron bunches. Such short bunches produce powerful coherent radiation with multi-megawatt power level. FIR coherent source operates in a parasitic mode utilizing electron beam passed VUV undulator. Generation of two-colors by a single electron bunch reveals unique possibility to perform pump-probe experiments with VUV and FIR radiation pulses. In this report we present simulations of the undulator magnetic system and beam dynamics.

INTRODUCTION

The pump–probe technique is one of the most promising methods for application of a high power FIR source [1]. The FLASH at DESY is a facility producing sub-picosecond electron pulses for the generation of VUV or soft X-ray radiation. The nearest plans of the facility upgrade include installation in 2007 of an electromagnetic undulator for production of powerful, coherent infrared radiation [2]. FIR undulator will be installed behind the VUV undulator, and will operate in a “parasitic” mode not interfering with the main mode of the FLASH operation. Coherent radiation produced by the electron beam in this undulator strongly depends on the bunch profile and charge:

$$\varepsilon_{coh} = \pi \cdot e^2 A_{jj}^{\ 2} \omega_0^2 K^2 / [c(1+K^2/2)] \cdot [N + N(N-1)|\overline{F}(\omega)|^2],$$

where ε_{coh} is the energy radiated by electron bunch, N is the number of electrons per bunch, $\overline{F}(\omega)$ is the Fourier transform of the bunch profile function, ω_0 is the resonant frequency of the first undulator harmonic, $A_{jj}=[J_0(Q)-J_1(Q)]$, J_0 and J_1 are the Bessel functions and $Q=K^2/[4(1+K^2/2)]$. At the wavelengths longer than bunch length the bunch form factor tends to the unity, thus leading to enormous growth (by a factor of N) of the radiation power with respect to the power of incoherent radiation. An additional application of the FIR undulator is electron beam diagnostics [3].

INFRARED UNDULATOR

The infrared undulator is a planar electromagnetic device with 9 full periods, each of 40 cm long. The peak magnetic field is up to 1.1 T. Location of the undulator integrated into the FLASH tunnel is shown in Figure 1. The parameters of FIR coherent radiation source based on FIR undulator [2] are given in Table 1.

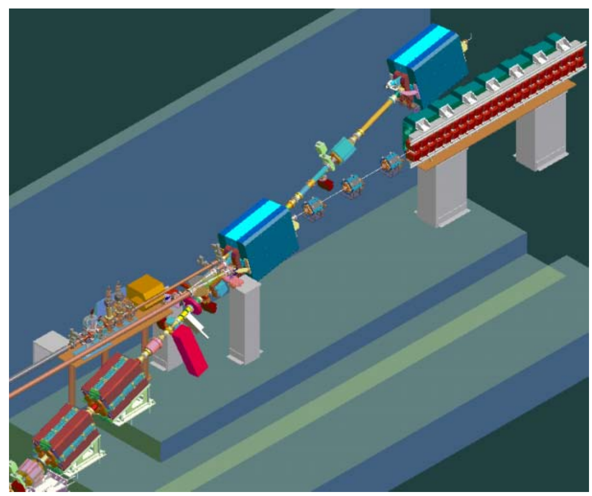

Figure 1: 3D-view of the FIR undulator in the FLASH tunnel.

MECHANICAL DESIGN

The undulator magnetic yoke consists of two girders with the poles. Transverse dimensions of the pole chamfers are 27 by 80 mm. The transverse chamfering permits to increase the undulator magnetic field up 1.1 T at a small yoke thickness of 150 mm. Material for the yoke and poles is 1010 type carbon steel. The material for girders of a yoke is a steel with low carbon content. The pole position accuracy of 0.1 mm with respect to the girder is provided during manufacturing. The accuracy of undulator girder mechanical production is better than 0.1 mm on a length of 4.3 m. The undulator weight is 4.5 tons.

The yoke of a magnet system (Figure 2) consists of two ferromagnetic girders with 22 poles in each of them. The exciting coils are set on poles. The coils of the top and bottom girders are connected sequentially and powered by single electrical supply.

Table 1. Parametrs of FIR coherent radiation source

Parameter	Value
Electron beam parameters	
Electron energy, GeV	0.5-1
Bunch charge, nC	1
Rms bunch length, μm	50
Normalized emittance, π·mm·mrad	3
Rms energy spread, MeV	2.5
Undulator	
Period, cm	40
Number of periods	9
Magnetic field, T	0.1-1.1
Output radiation	
Wavelength, μm	50-200
Peak power, MW	100
Average power, W	50
Micropulse energy, mJ	1
Micropulse duration, ps	1-10

The undulator yokes are mounted on a C-shaped support allowing an easy access to the undulator gap. The support is made of a non-magnetic steel. Mechanical properties of the support are sufficient to keep strong ponderomotive forces, the gap change is less than 0.01 mm at a maximum field.

The main coil consists of four layers, and each layer consists of 16 turns. The windings are made of a squared-shape copper pipe (8.5x8.5 mm) with a cooling channel of 5.3 mm diameter. The maximum current in the winding is 435 A (current density 8.7 A/mm²). Maximum heat deposition per undulator period is 2.54 kW. 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 equal to 270, and wire diameter is 1 mm. The corrector winding allows to regulate the number of Amper·turns inside 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 the correcting winding for fine adjustment of the magnetic field.

MAGNETIC FIELD SIMULATIONS

3D-magnetic field simulations of the infrared undulator were performed by TOSCA (Figure 2), RADIA and ANSYS codes.

The undulator specification values of the first (Figure 3) and second integrals are of $I_1=2\cdot10^{-4}$ T·m and $I_2=2\cdot10^{-4}$ T·m^2.

Simulations show that the optimum yoke thickness for the field of 1.1 T should be within of 250-270 mm. However, the restrictions on the weight and the power supply do not permit to realize undulator construction at this yoke thickness. The undulator yoke thickness corresponds to 150 mm and as a result, the magnetic field in yoke steel is oversaturated up 1.9-2.1 T.

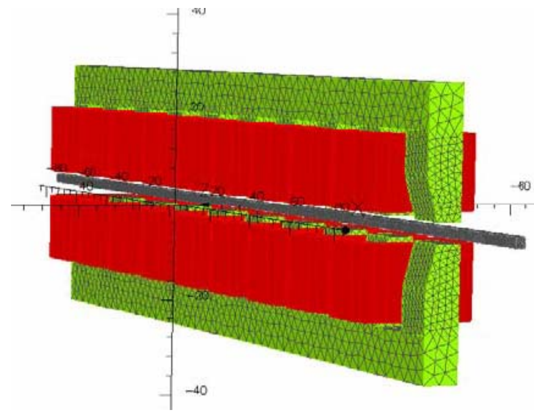

Figure 2:View of the undulator poles in TOSCA code.

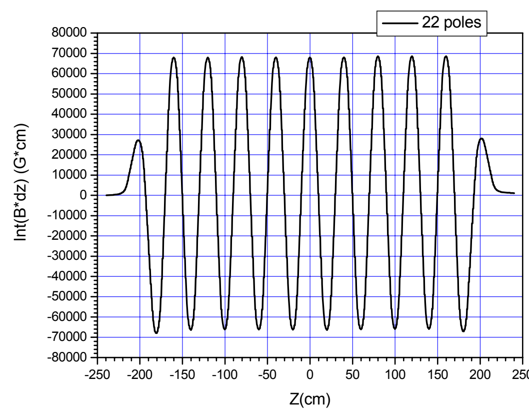

Figure 3: Simulated first integral of the undulator magnetic field.

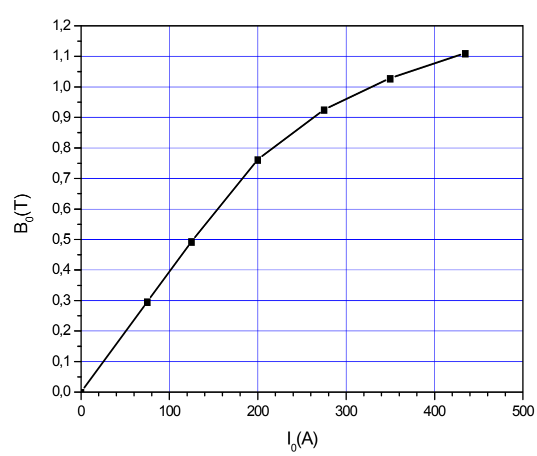

Figure 4:Dependence of magnetic field on coil current.

Oversaturated magnetic field in the yoke depends on the individual position of each coil. As a result, magnetic errors due to finite accuracy of manufacturing and positioning of the coils may become pronouncing.

Relevant simulations have been performed. Figure 5 shows an effect of random displacement of 1 mm amplitude for coil vertical positioning (Figure 6).

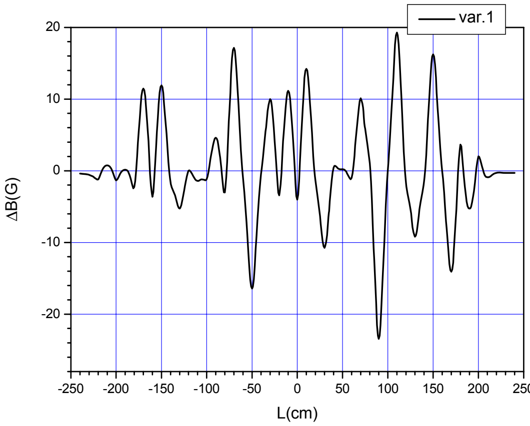

Figure 5: Magnetic field disturbance due to position coil.

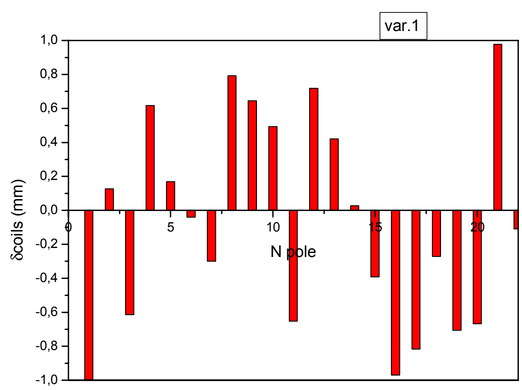

Figure 6: Set of vertical errors for excitation coils position errors.

The beam displacement is characterized by the uncompensated value of the second field integral on each undulator period (Figure 5). The beam displacement is of 0.6 mm for $I_2=10^{-3}$ T·m^2 and electron energy of 700 MeV. This value is by a factor of 5 larger than specification. Thus, we foresee an individual regulation of the vertical coil position within the range of 1 mm for compensation magnetic field errors (Figure 5).

The application of trim correctors in the first and the last pair of coils allows also to reduce the first and the second field integrals appearing due to imperfection of coil manufacturing. The speciation values of first and second field integrals correspond to the electron angle of $x' \approx 0.1$ mrad and electron trajectory displacement of $x \approx 0.1$ mm at the energy of 0.7 GeV.

ELECTRON TRACING IN UNDULATOR

Final topic of our analysis relates to the parameters of the electron beam at the exit of the FIR undulator. One of them relates to coherent deflection angle and beam offset in horizontal direction caused by uncompensated first and second magnetic field integrals. The uncompensated value of the second field integral of $2\cdot10^{-4}$ T·m^2 produces the coherent beam displacement of 0.1 mm (Figure 7). The second distortion relates to the increase of the emittance. This effect is caused by absence of full compensation of the first and the second field integrals along different electron trajectories at the full field integral compensation along the undulator axis. The beam size is increased by 50 µm at the undulator exit caused by an individual electron excitation in undulator field (Figure 7).

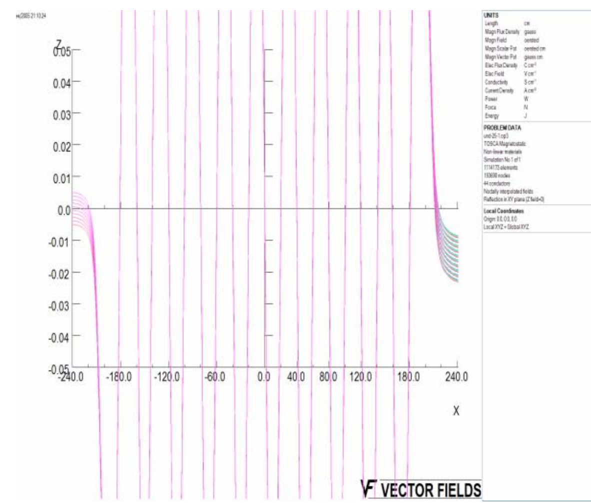

Figure 7: Beam tracing at undulator entrance beam size of 0.1 mm.

REFERENCES

[1] B. Faatz et al., NIM A 475 (2001) 363.
[2] E. A. Matyushevsky et al., JINR E9-2005-168, 2005.
[3] G. Geloni et al., NIM A528 (2004) 184.