COMMISSIONING OF STRONG TAPERED UNDULATOR DEVELOPED FOR IFEL ACCELERATOR

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Abstract

Here we describe the manufactured KIAE-2p planar undulator designed for the Inverse Free Electron Laser experiment at the University of California in Los Angeles. New technology enabled to fabricate the installation responding to the stringent requirements on mechanical construction accuracy and magnetic field strong tapering. Results of the magnetic field measurements by different methods are given. The obtained magnetic field maps were used for final simulations of the acceleration process. It is shown that for nominal electron beam and laser beam parameters up to 30% of electrons can be captured and accelerated from initial 14 MeV up to 52 MeV. Special analysis of the undulator acceptances for these parameters is made. It is shown that the acceleration is possible up to energies >30 MeV for rather wide ranges of laser pulse energy, Rayleigh length and e.b. emittance.

INTRODUCTION

The KIAE-2p undulator was designed and manufactured for the UCLA – Kurchatov Institute IFEL project [1,2]. Physical requirements for the undulator and simulations results of the design were given earlier [3]. The main particularity of the undulator is strong tapering of both magnetic field periods and strength of the fields as well. This tapering is required since the projected Inverse FEL should be driven by a high power CO2 laser beam focused inside the undulator by a lens with rather small focus distance. The nominal Rayleigh length (3.6 cm) is relatively small in comparison with the size of the IFEL installation so diffraction of the laser beam should be taken into account. This diffraction dominated regime was carefully investigated in a series of numerical simulations [4–7] results of which were used in the designing of the undulator.

UNDULATOR CONSTRUCTION

Technical problems followed from the undulator requirements could not be solved without new technologies unusual for routine undulator production. To make the problem of magnets and poles supports less complicated a new type of support construction was suggested and used (Fig. 1). The basic array of poles is made as a frame from titanic (non magnetic) side blocks (2) and profiled permendure (magnetic) central block melted in one block. Windows between poles were cut out

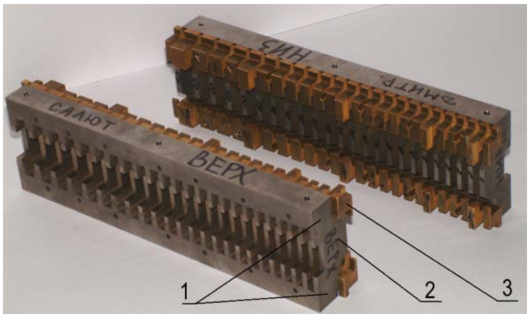

Figure 1: Photo of the melted block systems: 1 – non-magnetic side blocks; 2 – permendure central block; 3 – magnets fixation.

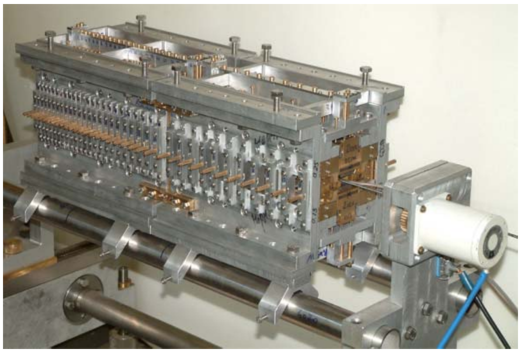

Figure 2: Common view of the KIAE-2p undulator with the Hall probe stepmotor driver.

by electroerrosion method, enabling to provide the required high accuracy of the shaped construction.

Higher fields in comparison with routine hybrid undulators were needed. Enhancement over Halbah limits of the fields was required. For this purpose new cone shape of poles (2) were used. Not equal magnetic field fluxes of two neighbouring magnet cells required by strong tapering were achieved by using coneshaped side magnets with specific support systems. Common view of the assembled two section undulator is shown in Fig. 2.

Two sections of the undulator were mounted on tube rails as a support. Alignment of the two sections mounted on the rails was performed with using a granite table. Small slopes have been got. The first section axis gives deviation <0.012 mm on the total section length. The second section was aligned up to <0.003 mm and the slope between two undulator section axes gives <0.003 mm misalignment.

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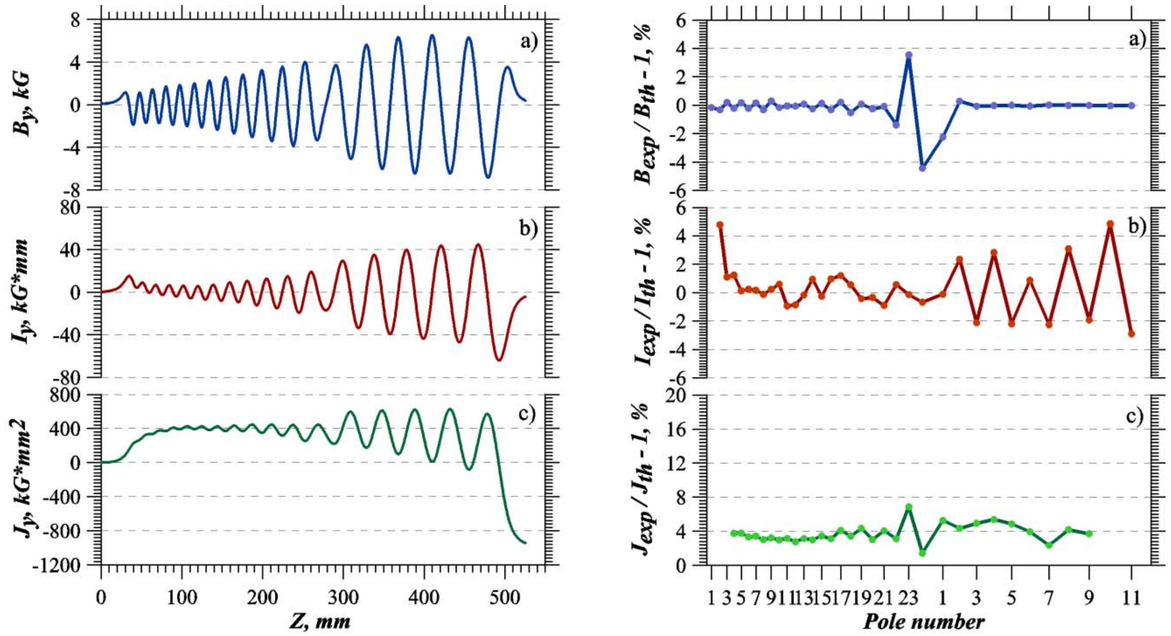

Figure 3: Magnetic fields directly measured by the Hall probe (a) and following from (a) the first (b) and the second (c) field integrals of KIAE-2p undulator (left graph). Deviations from projected ones respectively (right graph).

MAGNETIC FIELD TESTS

During tuning and commissioning the undulator magnetic fields were measured with high accuracy and by different methods. Some special measures were used to get high precision. A unit was manufactured for automatic scanning by the Hall probe. So it was possible to make measurements in many (from 60 to 200) points per one period length. For the same reason of getting high precision very small Hall probe crystal was used ($0.5\times1.0\times0.38$ mm^3) with very high (10^{-5}) stability of the current supply. Hall probe voltage was measured with accuracy ±0.1 μV. Calibration of the Hall probe was made with using a special reference magnet. As a result the Hall probe mean response ratio was found to be 7.9 μV/G. For more higher precisions corrections on nonlinearity of this response has been taken into account. The Hall probe was fixed on a special nonmagnetic carriage which could be moved by a stepmotor driver (Fig. 2) along the undulator axis in the gap keeping the Hall probe just on the undulator axis. Total accuracy of the magnetic field measurements ±0.1 G was achieved. Tuning of the undulator fields was made by moving side magnets or small moveable pieces of the poles. In extreme cases the basic magnets and (or) side magnets interchanged positions in the frames what gives some kind of sorting.

After the first stage of tuning magnetic field profiles became similar to that found in simulations [7] within ±0.08%. At the same time for the second integral of the field deviations were not so small. An additional tuning was needed to improve the field integrals. It was made by admitting some larger field deviations. The final results of the field tuning using Hall probe are given by Fig. 3. Deviations of the measured magnetic fields, first and second field integrals from the projected ones are also given. The field deviations here are ±0.4%, and grow up to 4% in the intersection gap caused probably by small geometrical changes in this gap. The second integrals coincide with the theoretical ones within 5%.

For the final testing of the second field integrals and focusing ability of the undulator the pulsed wire method was used. A BeCu wire of 50 μm diameter and 1.6 m long was used. Special optical detector provided sensitivity 247 μm/V at working range 60 μm. To get information about the focusing properties of the undulator the wire should be positioned parallel to the undulator axis in transverse (x or y) direction [8]. Fig. 4 shows measurement results for both the horizontal and vertical planes respectively. It is seen, that for the horizontal wire displacement curves remain parallel to the undulator axis showing absence of the defocusing in x-z plane. For the vertical wire displacement curves are inclined to the undulator axis showing that focusing in y-z plane takes place.

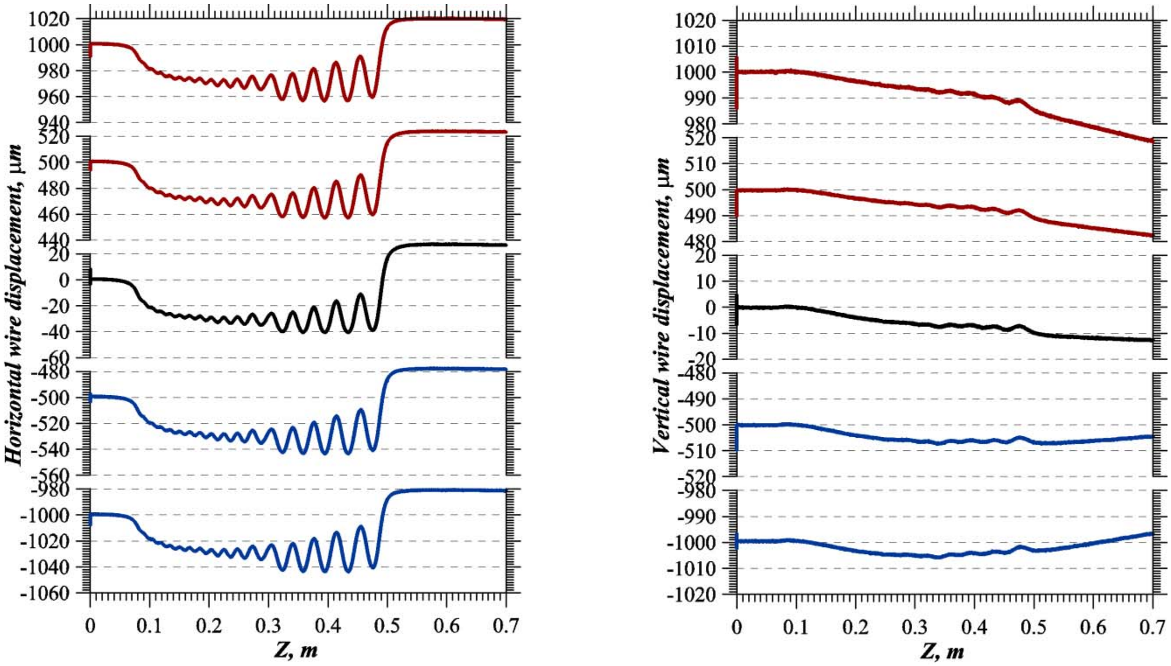

Figure 4: Illustration of the horizontal (left graphs) and vertical (right graphs) focusing properties of the KIAE-2p undulator measured by pulsed wire method.

ACCEPTANCE FOR THE LASER BEAM PARAMETERS PROVIDED BY THE UNDULATOR

As a final test of the tuned magnetic fields a new simulation of the acceleration process was made with using the measured magnetic field map (Fig. 3). Calculations of the maximum accelerated electrons energy γ_{max} and the capture ratio χ were made for different deviations from nominal ones in laser pulse energy, Rayleigh length z_r and laser focus position z_f. Results are summarized in Table 1.

Table 1. Simulation results

Laser and e-beam parameters	**Laser power, GW**		
	250	300	400
Nominal regime			
z_r = 3.6cm, z_f = 0 cm γ_o =28.5, ε =10 mm·mrad			γ_{max}=105, χ=34%
Not nominal regime			
z_r = 1.8cm, z_f = 0 cm γ_o =28.5, ε =10 mm·mrad	γ_{max}=42, χ=0%	γ_{max}=53, χ=1%	γ_{max}>95, χ=3%; γ_{max}>90, χ=4%; γ_{max}>85, χ=6%
z_r = 1.8cm, z_f = -2.0 cm γ_o =28.5, ε =10 mm·mrad	γ_{max}=50, χ=0%	γ_{max}>85, χ=2%; γ_{max}>80, χ=8%; γ_{max}>75, χ=9%	γ_{max}>85, χ=2%; γ_{max}>80, χ=8%; γ_{max}>75, χ=23%

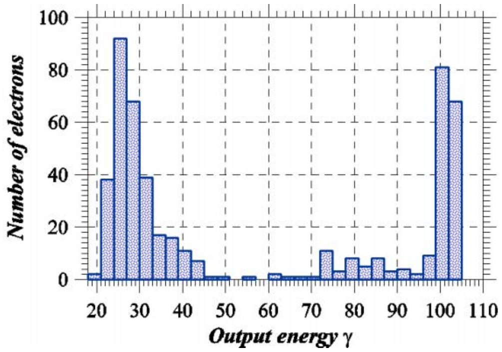

Figure 5: Energy distribution of the output electrons for the nominal regime.

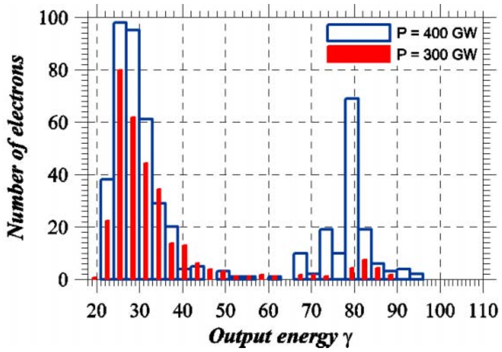

Figure 6: Energy distribution of the output electrons for the not nominal regime (z_r = 1.8 cm, zf = -2.0 cm).

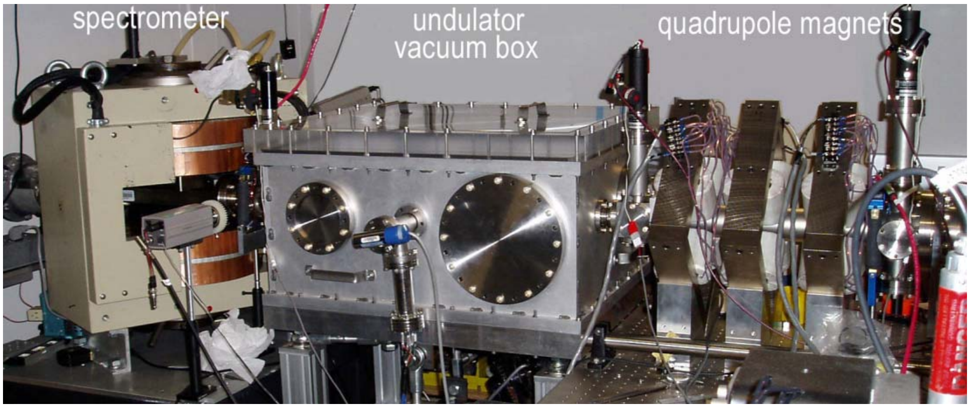

Figure 7: Photo of the IFEL beamline.

Maximum electron energy for nominal parameters is equal to 52 MeV (γ=105). Corresponding energy spectrum of the output electrons is shown in Fig. 5. Total capture ratio equals to 34±1%. All these data are adequate to the IFEL project requirements. The histogram of the output electrons energy for not nominal regime is shown in Fig. 6. Not nominal regime date given by Table 1 shows strong sensitivity of the whole acceleration process to the laser beam parameters (shape, power and focus position). On the other hand these data can be considered as rather wide acceptances for these parameters not stoping the acceleration process in the first undulator section.

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After commissioning undulator was placed in the special vacuum box. The box was installed on the IFEL beamline (see Fig. 7). Alignment of all beam line elements was made with accuracy 0.1 mm by using a reference laser.

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