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PHYSICS AND TECHNIQUE OF ACCELERATORS

Commissioning the First Free Electron Laser Based on a Variable-Period Undulator

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Abstract—Variable period undulators (VPUs) have a number of advantages over conventional undulators, but until recently they have not been used in free electron lasers (FELs). In the summer of 2021, such an undulator was installed on the second track of the Novosibirsk free electron laser, and lasing in the spectral range of 15–120 μm was obtained. This article describes the design of this undulator and presents the results of measurements of the radiation parameters.

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INTRODUCTION

Undulators have found wide application both in free electron lasers (FELs) and in modern sources of synchrotron radiation (SR) [1, 2]. One important characteristic of these sources is the wavelength tuning range. The wavelength of the first harmonic of the undulator radiation is given by the formula [1, 2]

$$\lambda = \frac{\lambda_w}{2\gamma^2}\left(1 + \frac{K^2}{2}\right), \quad (1)$$

where λ_w is the undulator period, $K = 93\,\mathrm{V}(\mathrm{Tl})\,\lambda_w(\mathrm{m})$ is the undulator parameter, and γ is the relativistic factor of electrons. It can be seen from (1) that the wavelength depends on the electron energy, the amplitude of the magnetic field, and the period. The idea for the variable period undulator (VPU) implemented in the Novosibirsk FEL undulator was proposed in [3]. An original modification of this design, a helical VPU, was created and experimentally studied at the Korea Atomic Energy Research Institute [4].

Tuning the wavelength by changing the period has a number of advantages. In particular, a decrease in the period in the VPU does not lead to a strong decrease in the field amplitude; therefore, using such an undulator, one can obtain a larger wavelength tuning range than in a conventional undulator. Undulators with a continuously variable period have not previously been used in existing installations. The Novosibirsk FEL [5] is the world's first example of the successful use of an undulator of this type. The undulator was installed on the bypass of the second track of the Novosibirsk FEL accelerator in the summer of 2021; in September of the same year, generation was obtained and a record wavelength tuning range of 15–120 μm was reached.

DESIGN OF THE UNDULATOR

In the design that was used for the Novosibirsk FEL, the undulator is composed of separate identical magnetic blocks (see Fig. 1a), which are mounted on a guide and can move freely in the longitudinal direction. Each block consists of a permanent magnet *1* and iron pole pads *2* attached to it. As can be seen from the figure, such an undulator is a conventional hybrid undulator [2], the poles of which consist of two identical parts (pole plates) separated by an air gap. A repulsive force (magnetic field pressure) acts between adjacent blocks, which, in the absence of friction, leads to the uniform longitudinal distribution of blocks in the middle part of the undulator.

The body of the undulator is made of 6061-T6 aluminum alloy (see Fig. 2). There are grooves inside the case, along which cassettes with magnets installed in them can move freely (Fig. 1b). Cassettes are based on bearings. Each cassette contains two magnets 40 × 40 × 20 mm in size based on NdFeB alloy with a coercive force of 13 kOe. Steel pole plates 2 mm in thickness are installed on the magnets. A detailed description of the magnetic field calculations and optimization of the undulator geometry is presented in [6].

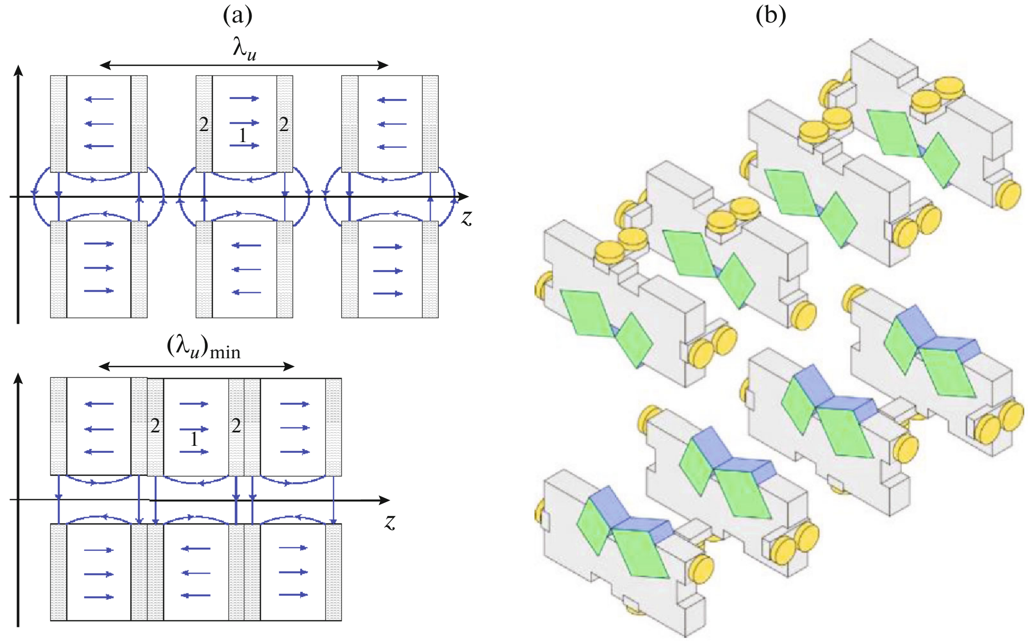

Fig. 1. (a) General scheme of an undulator with a variable period for two different periods: (1) permanent magnet and (2) iron plate. Blue arrows show the direction of magnetic induction. (b) 3D model and arrangement of cassettes. Blue shows permanent magnets, green shows iron pole strips, yellow shows ball bearings, and gray shows aluminum cassette housings.

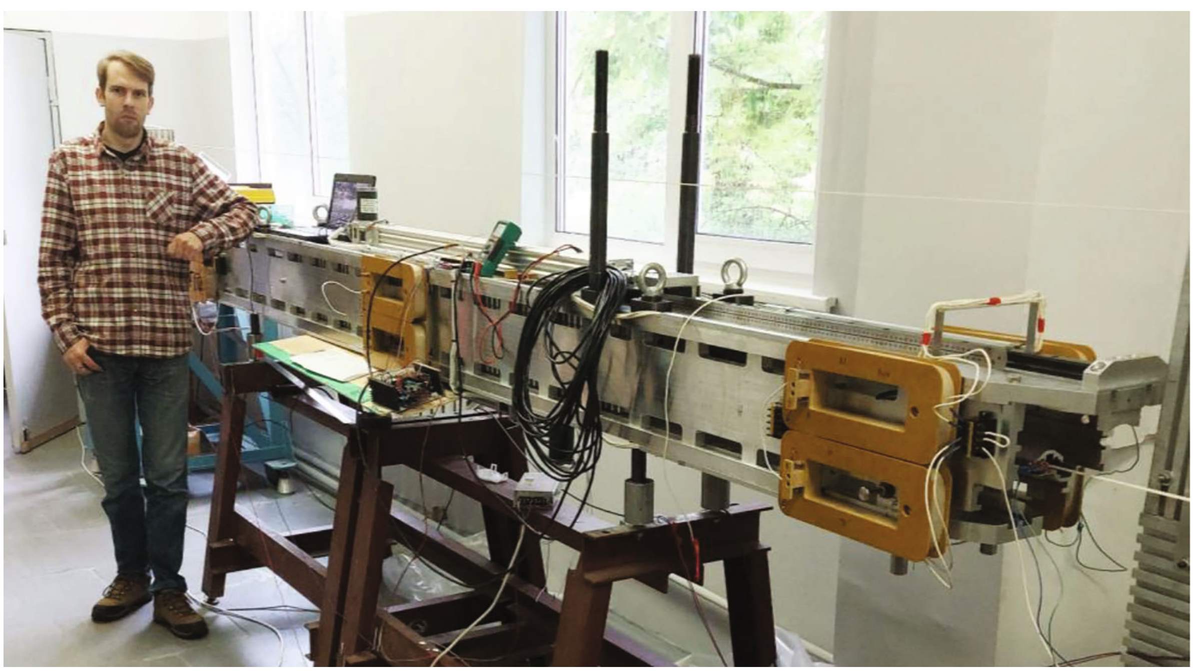

Fig. 2. Photo of the undulator installed on the stand for magnetic measurements. Magnetic field correction windings are visible in the middle and at the ends of the undulator.

At the edges of the undulator, the cassettes are held by pushers, which are driven by drives mounted on the top and bottom covers of the undulator.

The design of the undulator makes it possible to relatively quickly change the number of periods by adding or removing cassettes. With a minimum

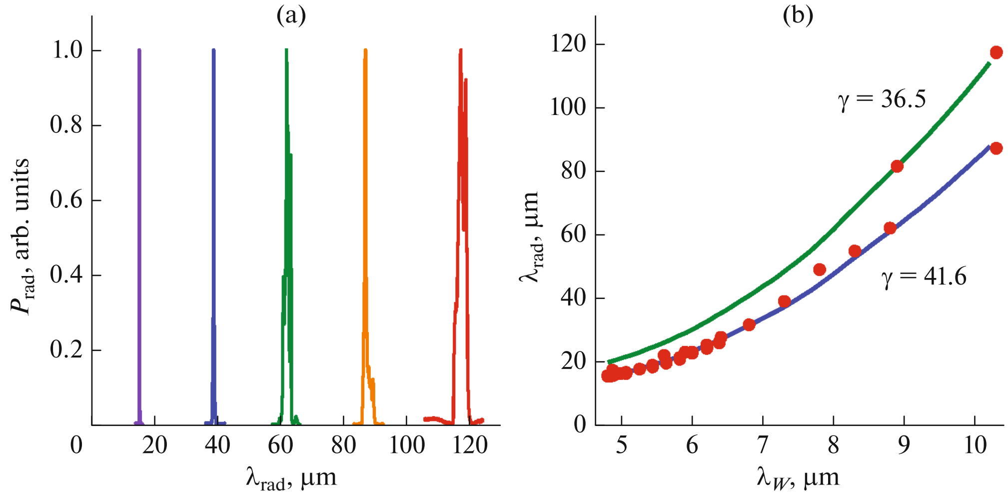

Fig. 3. Measured emission spectra in different regions of the tuning range (a) and measured dependence of the wavelength on the period of the undulator (b). The solid line shows the theoretical dependence of the wavelength on the period for two different electron energies.

period, the maximum allowable number of periods is 70, which makes it possible to have a sufficiently high gain of the FEL; this is necessary to obtain generation in the short-wavelength region of the spectrum.

OBTAINING GENERATION AND MEASUREMENT OF RADIATION PARAMETERS

The undulator was installed on the bypass of the second track of the Novosibirsk FEL in the summer of 2021, and the first generation with a wavelength of 26 μm was obtained on September 14 of the same year. Within a relatively short period of time, modes were tuned for the generation in the short and long wavelength regions of the spectrum and, in the end, the wavelength tuning range was 15–120 μm, which turned out to be better than the expected range of 15–85 μm.

Figure 3a shows the emission spectra measured in different regions of the tuning range. Accurate measurements of the absolute radiation power have not yet been carried out, so the spectra are normalized to the maximum. Figure 3b shows the measured dependence of the wavelength on the period of the undulator, which agrees well with theoretical formula (1).

In addition to the spectral characteristics at the minimum-obtained wavelength of 15 μm, the gain of the FEL (7.2%) and the radiation loss per pass in the optical cavity (3.8%) were measured. The measurements were carried out in the power modulation mode [7] using a fast detector. The gains and losses were determined from the rise and fall times of the radiation power measured by the detector.

CONCLUSIONS

Obtaining generation on an undulator with a variable period is an important achievement in terms of improving the parameters of the Novosibirsk FEL installation; expanding the wavelength tuning range opens up new opportunities for users. At the same time, this achievement is of great importance from the point of view of prospects for creating new undulators of this type, because it demonstrates the operability of these devices.

It should be noted that the minimum period of the described undulator (48 mm) is less than its aperture (50 mm). Because the amplitude of the magnetic field does not change with a change in all dimensions of the system with permanent magnets, for modern synchrotron radiation sources with apertures of less than 10 mm, it is possible to use a VPU of a similar design with a period of less than 10 mm.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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