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PHYSICS AND TECHNIQUE OF ACCELERATORS

Design and Results of Magnetic Field Calculations for a Variable-Period Helical Undulator

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Abstract—At the Budker Institute of Nuclear Physics, Siberian Branch, Russian Academy of Sciences, work is underway to create a new flat undulator with a variable period and an enlarged aperture. The magnetic blocks of this undulator can also be used to create a variable period spiral undulator. This article presents the results of calculations of the magnetic field of such a spiral undulator.

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INTRODUCTION

A free electron laser (FEL) on an electronic storage device is being developed at the Budker Institute of Nuclear Physics, Siberian Branch, Russian Academy of Sciences. One of the main nodes of the FEL is the undulator. Because the higher harmonics of spontaneous undulator radiation cause the additional heating of the mirrors of the FEL optical cavity, it is preferable to use a spiral undulator for an FEL on an electron storage ring [1]. In this case, most of the spontaneous emission power goes outside the cone with an opening angle of $1/\gamma$, where γ is the relativistic factor of electrons. Therefore, in order for all the radiation to exit the vacuum chamber of the undulator, the aperture of the latter must be large enough. In addition, the large aperture allows for a greater vacuum conductivity and, hence, pumping speed from a long pipe.

To change the wavelength of undulator radiation, it is proposed to use a relatively new type of construction, i.e., an undulator with a variable period [2–4].

MAGNETIC FIELD OF AN INFINITE SEQUENCE OF IDENTICAL BLOCKS

Consider a magnetic field created by an infinite sequence of magnetic blocks in which each subsequent block is obtained from the previous one by displacement along the longitudinal z axis at distance a and

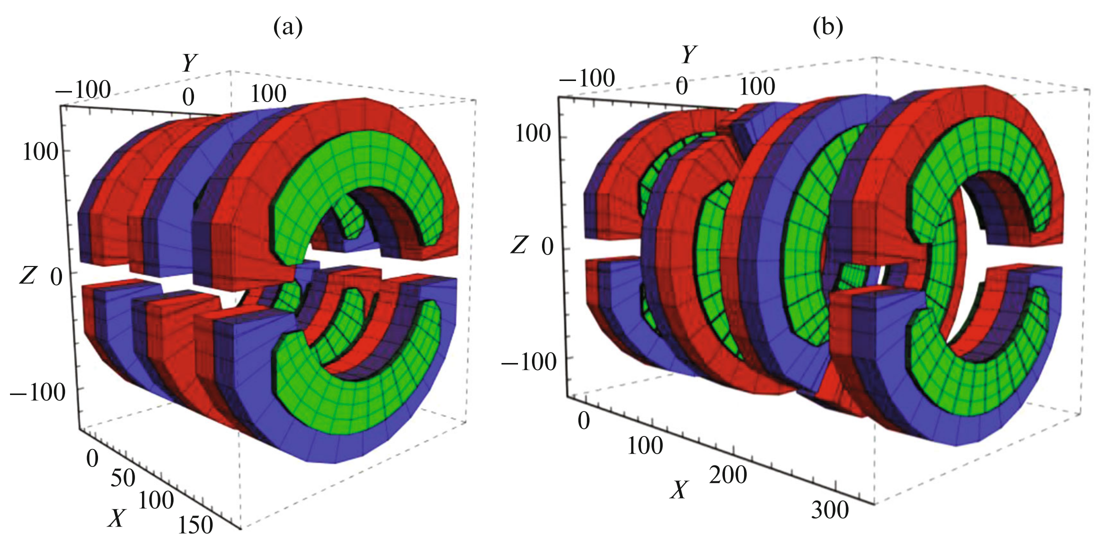

Fig. 1. Examples of undulators built from separate identical blocks: (a) flat undulator and (b) spiral undulator.

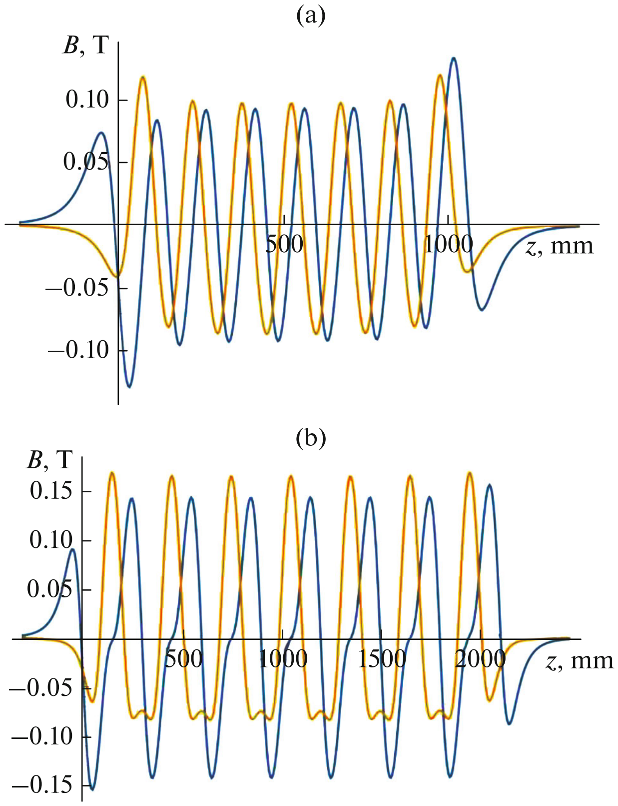

Fig. 2. Dependence of the vertical and horizontal components of the magnetic field on the longitudinal coordinate in the spiral undulator at the minimum (150 mm) and maximum (300 mm) periods.

turn around corner φ around this axis. Obviously, the scalar potential of this field satisfies the symmetry condition

$$\psi(r,\alpha,z) = \psi(r,\alpha-\varphi,z-a). \tag{1}$$

Here, (r,α,z) is point coordinates in cylindrical coordinate systems. Expanding the potential in a Fourier series in terms of α and taking into account (1), we obtain the following expression (2):

$$\begin{aligned}\psi(r,\alpha,z) &= \sum_{n=-\infty}^{\infty} U_n(r,z)\exp[in\alpha] \\ &= \sum_{n=-\infty}^{\infty}\sum_{m=-\infty}^{\infty} v_{mn}(r)\exp\left[in\left(\alpha-\frac{\varphi}{a}z\right)+im\frac{2\pi}{a}z\right].\end{aligned} \tag{2}$$

It is taken into account here that $U_n(r,z)\exp(in\varphi z/a)$ is the periodic function in z with period a. Imposing additional symmetry conditions on the potential

$$\begin{gathered}\psi(r,\alpha,z) = \psi(r,-\alpha,-z), \\ \psi\left(r,\frac{\pi}{2}+\alpha,z\right) = -\psi\left(r,\frac{\pi}{2}-\alpha,-z\right),\end{gathered} \tag{3}$$

from (2) one can easily obtain the following final expression:

$$\begin{aligned}&\psi(r,\alpha,z) \\ &= 2\sum_{n=1}^{\infty}\sum_{m=-\infty}^{\infty}\left\{v_{m,2n-1}\cos\left[(2n-1)\left(\alpha-\frac{\varphi}{a}z\right)+m\frac{2\pi}{a}z\right]\right\}.\end{aligned} \tag{4}$$

For potential (4) to be a periodic function z, it is necessary to fulfill the condition $\varphi = 2\pi p/q$, where p and q are whole numbers. In this case, the period $\lambda_w = qa$.

Near the undulator axis, from (4) for the potential, we obtain the expansion

$$\begin{aligned}&\psi(r,\alpha,z) \\ &\approx r\sum_{m=-\infty}^{\infty} B_m\cos\left[\alpha+\left(m-\frac{p}{q}\right)\frac{2\pi}{a}z\right],\end{aligned} \tag{5}$$

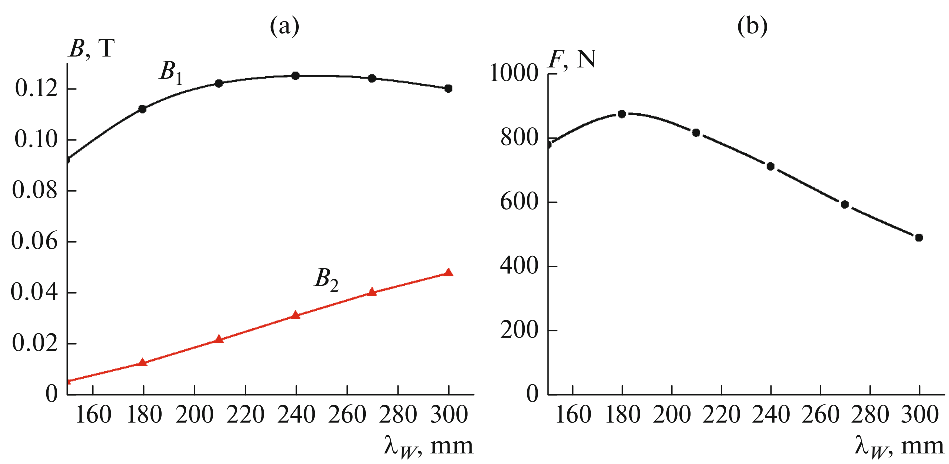

Fig. 3. Dependence of the amplitudes of the first and second harmonics of the magnetic field (a), as well as the repulsion force acting between neighboring blocks (b), on the period.

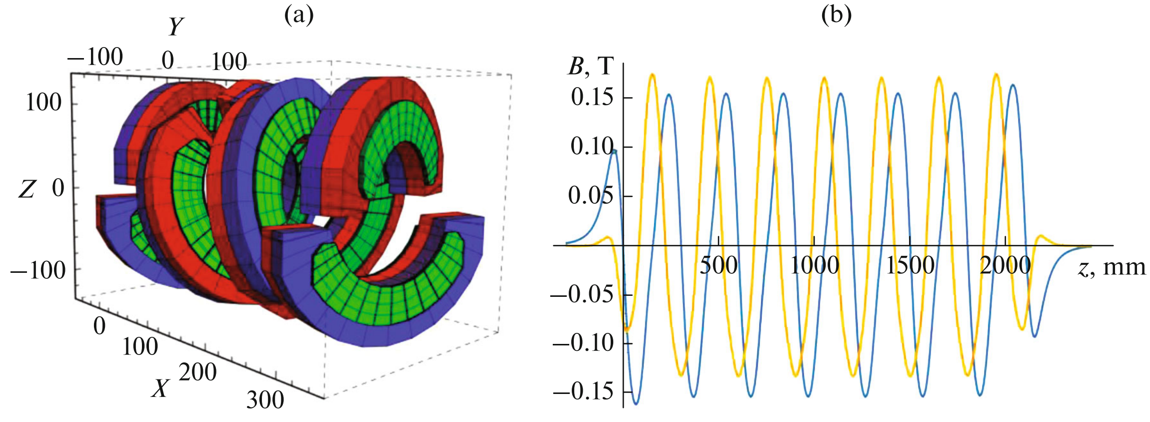

Fig. 4. Compensation of the second harmonic by turning the upper and lower halves of the magnetic block relative to each other in the case of large periods: (a) optimized undulator geometry; (b) field distribution on the axis. For a maximum period of 300 mm, the amplitude of the second harmonic can be reduced from 40 to 15%.

from which one can easily find the field on the axis

$$B_r(0,\alpha,z) = \sum_{m=-\infty}^{\infty} B_m \cos\left[\alpha + \left(m - \frac{p}{q}\right)\frac{2\pi}{a}z\right]. \quad (6)$$

In a particular case, when $p = 1$ and $q = 3$, field (7) is obtained from (6), the first harmonic of which has circular polarization and period $\lambda_w = 3a$ and the next is the second harmonic with the opposite direction of polarization.

$$B_r(0,\alpha,z) = B_0 \cos\left(\alpha - \frac{2\pi}{3a}z\right) + B_1 \cos\left(\alpha + 2\frac{2\pi}{3a}z\right) + B_{-1}\cos\left(\alpha - 4\frac{2\pi}{3a}z\right) + B_2 \cos\left(\alpha + 5\frac{2\pi}{3a}z\right) + \dots. \quad (7)$$

NUMERICAL SIMULATION OF THE UNDULATOR FIELD

The Radia program [5] was used for modeling. The results are presented in Figs. 1–4.

CONCLUSIONS

The design of the undulator, based on the use of separate identical magnetic blocks, turned out to be very flexible. Using this approach, it is possible to construct an undulator with a variable period and a variable number of periods, as well as an undulator with an adjustable magnetic field polarization. The design of such an undulator is easily scaled to smaller periods, so it can be used in undulators designed for short-wavelength radiation sources.

Some technical issues remain to be resolved. These include the minimization of higher harmonics and more accurate consideration of repulsive forces. Another problem that needs to be solved is the development of a mechanical structure that ensures the rotation of the blocks.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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