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# Results of test of prototype of variable period undulator

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ABSTRACT

The development of the permanent-magnet variable-period undulator (VPU) is aimed at improving the parameters of the Novosibirsk free electron laser (FEL). The key features of this design are the possibility of increasing the number of poles for shorter periods with constant undulator length and wider radiation wavelength tuning range as compared with conventional undulators. As the idea of the permanent-magnet VPU has not been properly tested yet, there are several issues to be solved before THE manufacture of the device. Two short prototypes of the VPU were made for the purpose of testing solutions to existing problems. We present here the results of mechanical and magnetic measurements of the undulator prototypes and compare the characteristics of the prototypes with those predicted by simulations.



## 1. Introduction

Increasing the radiation tuning range is an important goal in the FEL design optimization as the wavelength tunability is the main advantage of FEL over quantum lasers. A common way to vary the radiation frequency is changing the undulator parameters. Along with the electromagnetic (EM) and permanent magnet variable gap undulators (VGU), a concept of a device with alterable period was proposed in [1,2], which has not found many implementations so far [3]. The VPU for the Novosibirsk FEL under development at Budker INP is similar to the conventional hybrid undulator [4–6], in which the iron poles are divided into two halves (see Fig. 1). Such a VPU is composed of separate magnet blocks, which can move freely along the longitudinal axis. Each block includes one permanent magnet and two iron plates. With fixed positions of the outer blocks, due to the repulsive forces, the inner blocks are distributed evenly in the longitudinal direction and the period of this distribution can be adjusted via shift of the outer blocks. This design has a remarkable feature of the variable number of periods, which enables one to increase the number of magnet blocks for shorter periods with a fixed space allocated for the undulator [7,8].

The new undulator will replace the electromagnetic one, which is used in one of the Novosibirsk FELs. The old undulator is four meters long; it has a period $\lambda_u$ of 120 mm and a field amplitude $B_0$ varying from zero to 0.13 T. It is installed on the bypass of the second horizontal track [9]. The tuning range of the existing FEL is 35 to 80 μm.

The advantage of the VPU becomes evident from comparison of the small-signal gain of the Novosibirsk FEL calculated for different wavelengths and different types of undulators. In Fig. 2 one can see the dependence of the gain on the radiation wavelength with the currently installed EM undulator, as well as a VPU plot and a plot for a hypothetical VGU with a comparable tuning range. The gain was calculated for the following electron beam parameters: an energy of 22 MeV, an energy spread of 0.5%, and a peak current of 40 A; the calculation for the VPU case takes into account the increase in the number of periods for shorter wavelengths. The round trip radiation losses in the existing optical cavity [10] are shown as well. Thus, the application of the VPU will allow widening of the tuning range of the Novosibirsk FEL wavelength and shifting the short wavelength boundary towards 15 μm [7,8].

## 2. Novosibirsk FEL VPU design

At the simulation stage, the undulator parameters were optimized to provide the necessary wavelength tuning range and meet all the requirements. The hybrid undulator scheme was modified, a combination of two inclined magnet blocks used instead of solid magnet bars. Thus, the undulator has a rhomb-like free aperture as shown in Fig. 3. This configuration provides field amplitude growth with shift from the central axis in both transverse directions. As a result, such an undulator is capable to focus the electron beam horizontally and vertically. This feature is important because of the low (22 MeV) electron energy and, consequently, strong focusing by the undulator field. There are two iron poles adjacent to each NdFeB magnet. Each couple of the right and

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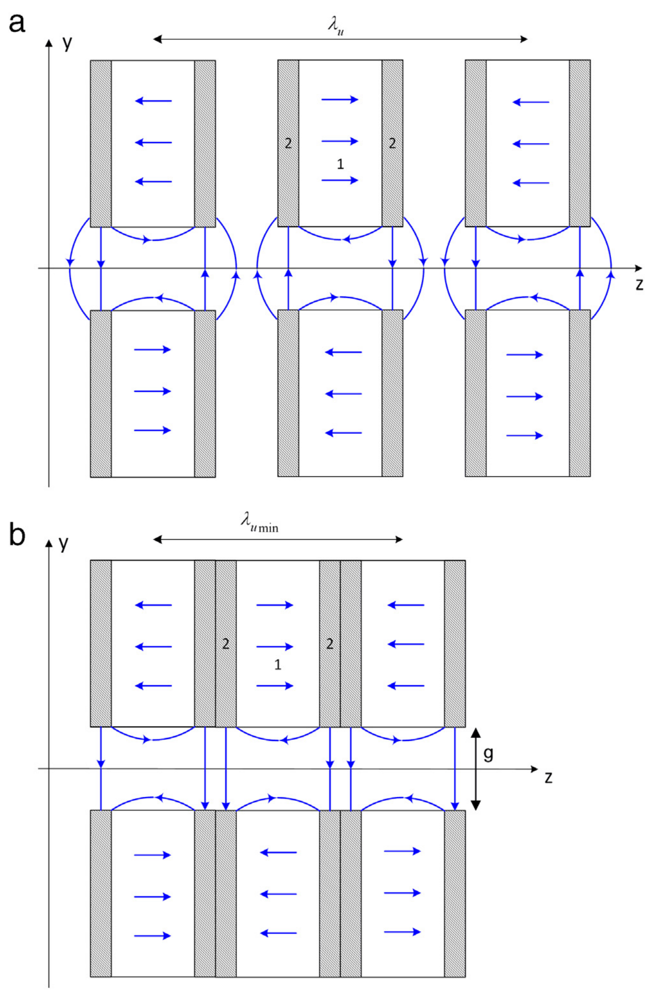


**Fig. 1.** Scheme (sagittal section) of variable-period permanent-magnet hybrid undulator, proposed in paper [2]. (a) is an arbitrary period; (b) is the minimum one, with which the VPU becomes a common hybrid undulator. The iron poles are hatched. The arrows indicate the magnetic induction direction.

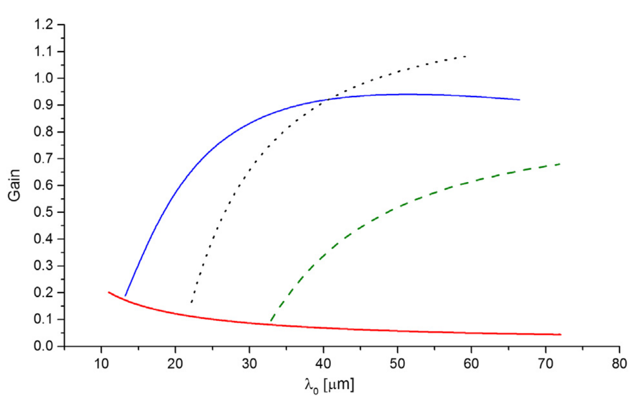


**Fig. 2.** FEL gain (solid line: VPU; dotted line: VGU; dashed line: EM undulator) and optical cavity losses (red line) for different radiation wavelengths [8].

left blocks at the top is combined in one unit, which can move in the longitudinal direction as a whole. The units that contain the magnet blocks are made of duralumin. Pole plates of low-carbon steel fix the magnet blocks inside a unit. Each couple of the right and left blocks at the bottom also forms a similar movable unit. Each unit has set of bearings that provide low friction for smaller undulator period tapering. The top and bottom units are not connected.

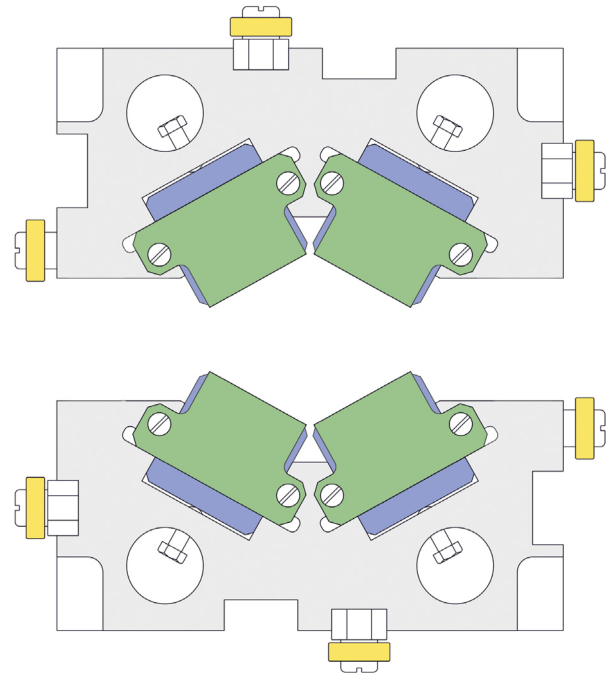

**Fig. 3.** Front view of undulator mechanical design described in [7].

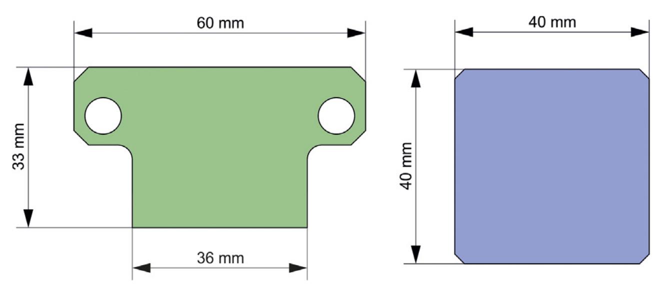


**Fig. 4.** Transverse cross-sections of the iron plate and permanent magnet (see [7]).

In the simulations, the permanent magnets were assumed to have a 1.3 T remanent magnetization. The dimensions of the magnets and iron plates were optimized for maximum field amplitude at the minimum undulator period. The transverse cross-sections of the iron plate and permanent magnet are presented in Fig. 4. The longitudinal sizes (thicknesses) are 20 mm for the magnets and 2 mm for the iron plates.

The diameter of the circle inscribed into the aperture of undulator was chosen to be 50 mm for provision of low diffraction losses at the maximum radiation wavelength. The undulator period $\lambda_u$ should not be too small as compared with the gap g between the upper and lower poles as the magnetic field amplitude exponentially decreases with growth of $g/\lambda_u$, so we have chosen the minimum period to be 48 mm. [7,8]

The units can freely move in the longitudinal direction inside the undulator frame. For the friction coefficient to be small, they are placed on bearings. The vertical positions of the pole plates are defined by precise grooves in the unit body. The period is varied remotely using a special mover [2,7,8].

One can find the most important parameters of the VPU in Table 1.

## 3. Prototype design

Fig. 5 shows sketches of two VPU prototypes that were manufactured for examination of the undulator magnetic and mechanical properties. The carcasses of the prototypes are made of aluminum and have