THE PROTOTYPE OF NEW VARIABLE PERIOD UNDULATOR FOR NOVOSIBIRSK FREE ELECTRON LASER

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Abstract

To improve the parameters of the second stage Novosibirsk free electron laser one plans to replace the existing electromagnetic undulator by permanent-magnet variable-period undulator (VPU). The VPUs have several advantages compared to conventional undulators, which include wider radiation wavelength tuning range and an option to increase the number of poles for shorter periods with constant undulator length. Both these advantages will be realized in the new undulator under development in Budker INP.

The idea of the permanent-magnet VPU was proposed just several years ago and it has not been properly tested yet. There are some technical problems, which have to be solved before this idea can be implemented in practice. To check the solution of these problems we designed and manufactured a small undulator prototype, which has just several periods. In this paper, the results of mechanical and magnetic measurements of this undulator prototype are presented and compared with simulations.

INTRODUCTION

The VPU for the NovoFEL under development at Budker INP has a remarkable feature which is the possibility to change the number of periods. The new undulator will replace the electromagnetic one used in the second stage FEL. The old undulator has the period λ_u 120 mm and the field amplitude B_0 varying from zero to 0.13 T .It is installed on the bypass of the second horizontal track [1]. The tuning range of the existing FEL is 35 to 80 microns. Application of the VPU will allow shifting the short wavelength boundary to 15 microns [2].

The available free length for the undulator is four meters. Electron energy at the second stage FEL is 22 MeV. One can find most important parameters of the VPU in Table 1.

Table 1: Basic Undulator Parameters

Parameter	Limits
Undulator period λ_u (mm)	48 - 96
Radiation wavelength (μm)	15 - 70
Number of periods	40 - 80
Filed amplitude on the undulator axis (kGs)	0.94 – 1.9
Deflection parameter	0.42 – 1.79

UNDULATOR GEOMETRY

To ensure low diffraction losses at maximum radiation wavelength, the diameter of the circle inscribed into the aperture of undulator was chosen to be 50 mm. As field amplitude B exponentially decreases with growth of g/λ_u, where g is the undulator gap, one can obtain the limitation that λ_u should not be too small compared to g, so we chose minimum λ_u to be 48 mm. [2]

Each undulator block consists of one permanent magnet and two iron plates. The permanent magnets are made of NdFeB. In simulations we used a permanent magnet with a remanence of 1.3T. We optimized the dimensions of the magnets and iron plates to obtain a maximum field amplitude with a minimum period.

The transverse cross-sections of the iron plate and permanent magnet with final dimensions are presented in Fig. 1. The longitudinal sizes (thicknesses) are 20 mm for the magnets and 2 mm for the iron plates.

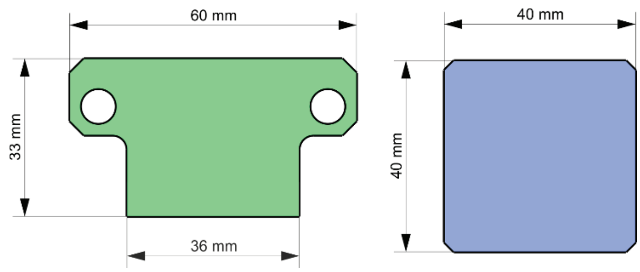

Figure 1: Transverse cross-sections of the iron plate and permanent magnet.

The opposite plates of two blocks adjacent in the longitudinal direction form one pole. Each couple of the right and left blocks at the top is combined in one unit, which can move as a whole, as can be seen from the Fig. 2. Each couple of the right and left blocks at the bottom also forms a similar movable unit.

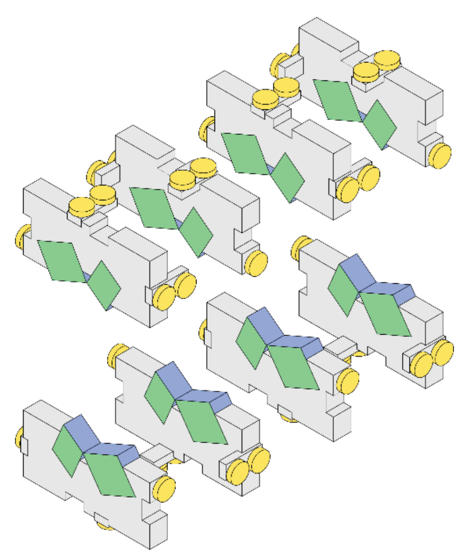

Figure 2: Undulator units disposition.

The top and bottom units are not connected. Blocks in one unit are tilted relative to each other, therefore the free aperture is a rhomb. This configuration provides field

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amplitude growth with distance from the central axis in all directions. As a result, this undulator will focus the electron beam both horizontally and vertically. This feature is important because of the low (22 MeV) electron energy and, consequently, strong focusing by the undulator field.

Each unit has set of bearings that provide sufficient coefficient of friction to avoid significant undulator period tapering [2].

PROTOTYPE MECHANICAL DESIGN

Two prototypes of the VPU were manufactured in order to examine magnetic and mechanical undulator properties. Carcasses of undulators are made of aluminum and allow installing up to 8 units in row. One prototype has both upper and lower arrays of units and another one has just upper array and a metal plate in the horizontal symmetry plane that provides proper boundary conditions. One can see sketches of prototypes in Fig. 3. The first one is suitable for magnetic measurements and the second one is convenient to conduct mechanical measurements. Both prototypes have pusher screws in one side and stoppers in the middle, which allows changing the number of units and undulator period. There are deeperings in the inner side of frames for bearings.

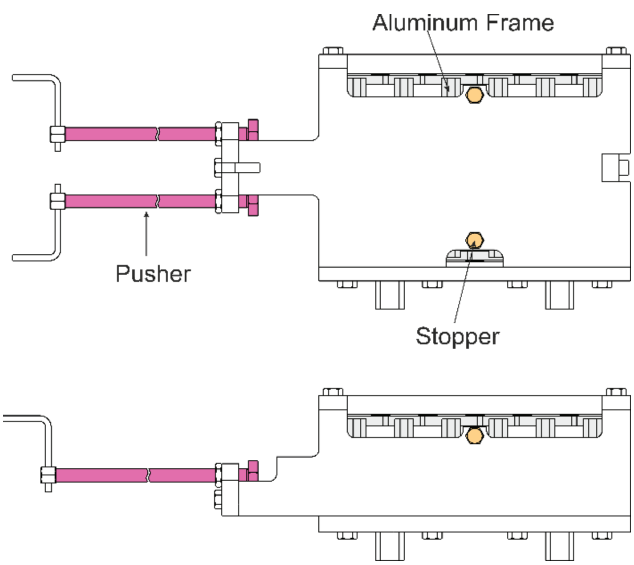

Figure 3: Sketches of VPU prototypes.

As it was said before undulator units consist of two magnets, four metal plates aluminum frame and set of bearings, as it is shown on Fig. 4. Bearings positions are optimized to avoid tilts of the unit.

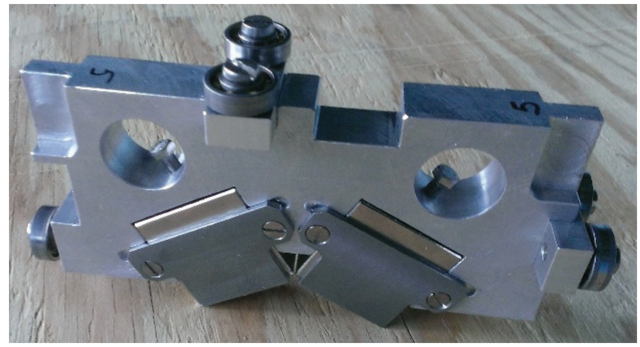

Figure.4: Undulator unit.

MAGNETIC MEASUREMENTS

To check results of three dimensional computer simulations of the field distribution in the undulator several mechanical and magnetic measurements were made.

One can measure the value of magnetic field produced by a single undulator unit at a given point with help of Hall sensor, as it is shown in Fig. 5. So one can compare magnetization of different units with value used in simulations.

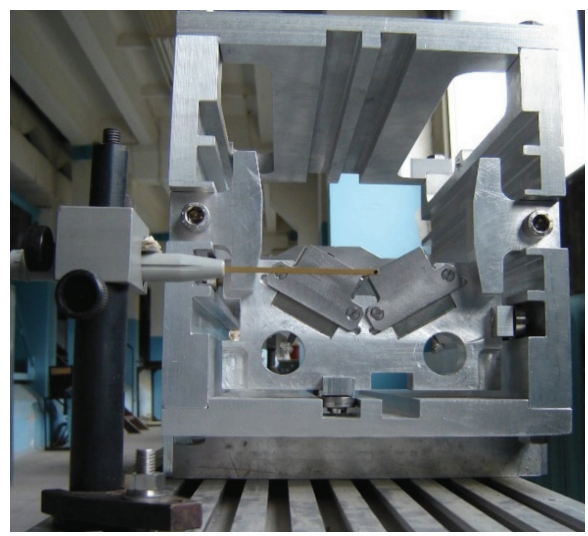

Figure 5: One point magnetic field measurement.

The mean value of longitudinal magnetic field measured by Hall detector at the 90 mm distance from unit is 97.8 Gs, while the magnetic field calculated in CST Studio software [3] in the same scheme is 97.3 Gs. It means that magnetizations of manufactured magnets are very close to project value 1.3 T. One can see deviation from the mean value of magnetization for all units in Fig. 6.

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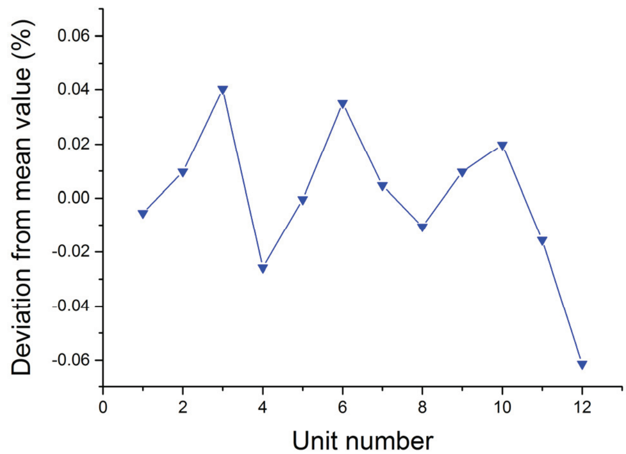

Figure 6: Variation of units field measured at given point.

MECHANICAL MEASUREMENTS AND COMPARISON WITH SIMULATIONS

Attraction force between upper and lower units placed in the magnetic field H can be described by Maxwell's stress tensor [4]. The vertical force can be found as integral of stress tensor over horizontal symmetry plane between two units. Using magnetic field distribution from simulations one can find the vertical attraction force and compare it to the measured one.

Figure 7: Measurement of the vertical attraction force.

One can see scheme of the experiment in Fig. 7. Lower unit was fixed and upper unit could be moved only vertically. The measured force was 60.42 N and the weight of the unit was 9.92 N, thus, attraction force is 50.5 N.

The force obtained from numerical calculation of simulated field is 50.85 N. Claimed error of the dynamometer is 0.1 N, measuring distance between units could also add error.

The prototype construction allows to fix outside units. In order to avoid errors related with displacement of inner units it was decided to measure longitudinal repulsive force using just three units: two fixed in the ends and one that we can shift in the middle, Fig. 8.

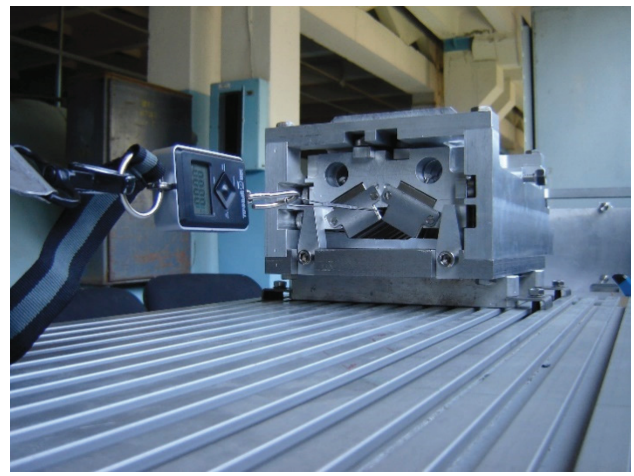

Figure 8: Measurement of longitudinal repulsive force.

One can see the dependence of repulsive force on the displacement of the middle unit in Fig. 9. In such a scheme, behavior of the force is almost linear due to absence of next unit with same magnetization.

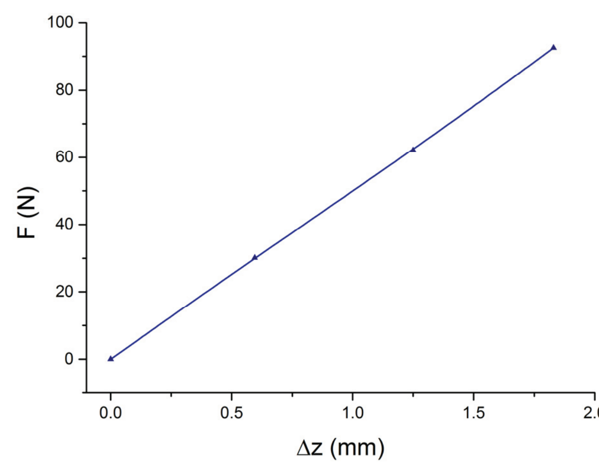

Figure 9: Dependence of repulsive force on the displacement.

As the period of undulator changes, the repulsive longitudinal force on shifted unit changes too. Fig. 10 shows the dependence of three-unit system rigidity (repulsive force normalized on shift) on the period of undulator. The results of simulations differ from measured values on short periods, where the error of measuring force is higher.

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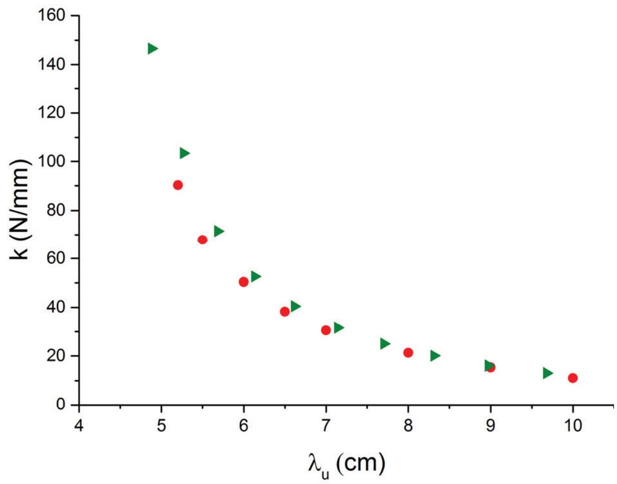

Figure.10: Dependence of three-unit system rigidity on the undulator period (green triangles – data from simulations, red dots – measured data).

In addition, prototype allow us to check the repeatability of the units distribution. Distances between units were measured in different periods several times.

Distribution of the units in different periods are shown in Fig. 11. Displacements of the units after the period change are shown in Fig. 12.

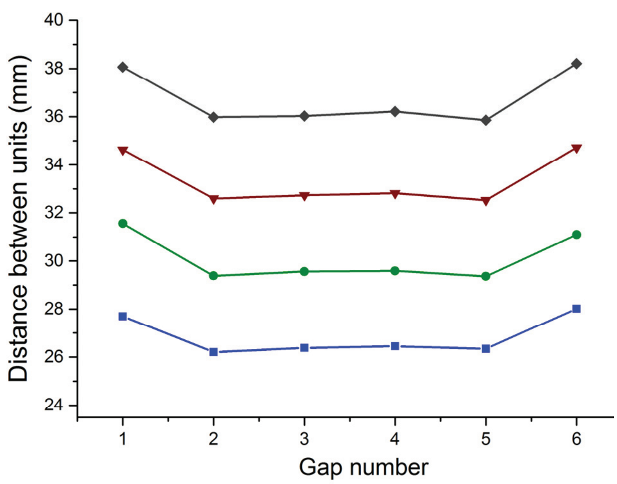

Figure 11: Distribution of the units in different periods.

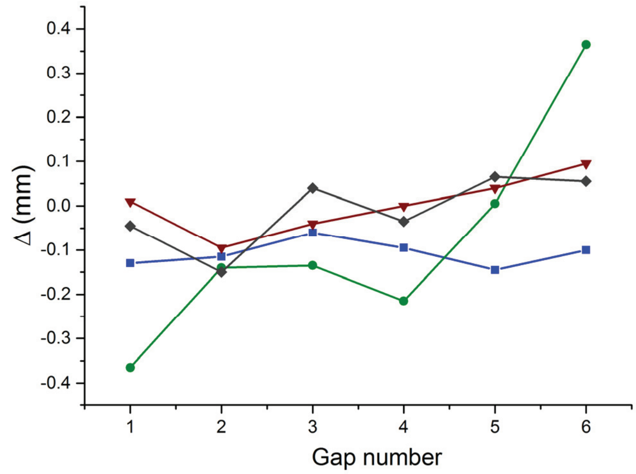

Figure 12: Displacements of the units after the period change.

CONCLUSION

Results of measurements obtained at VPU prototypes are in a good agreement with simulations. It confirms the feasibility of the variable period undulator concept. Valuable experience, which was obtained during prototype assembly, will be used for the full-scale undulator that is being designed and manufactured at BINP now.

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