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OVERVIEW OF THE UNIFIED UNDULATOR SOLUTION FOR THE PolFEL PROJECT

J. Wiechecki†, National Synchrotron Radiation Centre SOLARIS, Kraków, Poland
P. Krawczyk, R. Nietubyć, National Centre for Nuclear Research, Otwock-Świerk, Poland
P. Romanowicz, D. Ziemiański, Cracow University of Technology, Kraków, Poland

Abstract

The PolFEL project, consisting of building a free electron laser, will be the first in Poland and one of the several sources in the world of coherent, tuneable electromagnetic radiation within the wide spectrum range from THz to VUV, emitted in pulses from femtoseconds to picoseconds, with high impulse power or high average power. The research infrastructure will include a free electron laser (FEL), a photocathode testing laboratory, end-stations, and laboratories necessary for the operation of the apparatus, and laboratories for users from the beamlines. The main FEL accelerator will consist of three independent branches, which will include chains of undulators adjusted to three different energy ranges: VUV, IR and THz. The main challenge was the unification of the final undulator solution, so that it could be applied to all three branches. The main goal of this approach was to save time, costs, human and material resources. The overview of issues and solutions related to the construction of undulators for the PolFEL project, and the challenges that had to be fulfilled to reach the final design, is presented in this publication.

PROJECT OVERVIEW

The PolFEL facility will be built at the National Centre for Nuclear Research in Otwock – Poland. The main goal of this infrastructure is to design, develop and build a free electron laser facility located in this part of Europe [1]. All activities will be supported by the largest research centres in Europe. This device will provide a wide wavelength range of electromagnetic radiation from 0.6 mm down to 60 nm. This will be possible since the linac will be split into three independent branches for different ranges: VUV, IR and THz.

Due to significant differences in the requirements towards the electron beam, which leads to the differences in geometry of the applied magnets, it is not possible to design a common solution for all three branches. However, to simplify the undulator design, increase safety, and reduce manufacturing and design costs it was assumed that the main frame for all undulators and drive systems would be unified.

BOUNDARY CONDITIONS

The PolFEL project requires three independent types of undulators with three different magnet configurations and quantities, as described in Table 1. This directly impacts the operating range of the undulators' girders and the forces acting on the i-beams. Each magnet must be settled on the girder within a certain position not exceeding the defined range of tolerances in the vertical direction and rotation.

On the other hand, each solution must be mechanically rigid, stable, and portable. The repeatability of the girder's movement and its position is the most critical factor that must be fulfilled to guarantee the stability of the electron beam. Furthermore, each undulator must have an opportunity to be aligned not only with the geological survey network but also to align its girders with the electron beam in real-time mode when the accelerator is fully operational.

Due to the huge amount of undulators that must be manufactured, each design must be reliable, simple, and cost-effective.

Table 1: Assumptions

Feature	VUV	THz	IR
Quantity	6	1	3
Period length [mm]	22	160	60
No. of effective periods per segment	73	8	25
Girder length [mm]	1644.5	1560	1605
Magnet material	$Nd_2Fe_{14}B$ $N_{45}UH$		
Magnet dimensions [mm] (W x H x L)	50/20 /5.5	100/100 /40	100/60 /15
Magnetic force acting on the beam in V direction [N]	300	4000	19000
Min / Max operational gap	8.5 / 13	100 / 200	22 / 60
Full open gap in [mm] where B=0 T	100	600	250
Vertical adjustment of the magnetic blocks [µm]	±100	±750	±450
Girders parallelism tolerance in z-axis (roll) [rad]	$<1.5\cdot10^{-3}$	$<1\cdot10^{-2}$	$<3.5\cdot10^{-3}$
Girders parallelism tolerance in x-axis (pitch) [rad]	$\pm5\cdot10^{-6}$	$\pm30\cdot10^{-6}$	$\pm15\cdot10^{-6}$
Girders parallelism tolerance in y-axis (yaw) [rad]	$\pm0.25\cdot10^{-3}$	$\pm0.5\cdot10^{-3}$	$\pm0.35\cdot10^{-3}$

CONSTRUCTION DETAILS

The high requirements put on each type of undulator forced an in-depth analysis. Many solutions have been taken into consideration [2-6], however, the most convenient and optimized idea was to unify the design of the undulators for all branches. This way, a common construction for all three devices has been designed, which

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† jaroslaw.wiechecki@uj.edu.pl

required only minor modifications related to the magnet holders and jaws. The main goal of this approach was to identify the worst-case scenario, which means the most demanding working conditions with maximum force values. The final unified design took into consideration the largest gap openings (which are required in the THz device) and the highest acting loading (which were observed in the IR device) [7].

Main Support System

The main body of the undulator has a typical L-shaped frame that holds two movable girders with neodymium magnets (Fig. 1). Each of them is driven by two independent drive systems, consisting of servomotor, worm gear, and shaft with a nut attached to the girder. Four sets of rails with carriages placed on the side of the vertical beams are responsible for guiding both jaws with magnets in the vertical direction. The frame will be manufactured from standard S235JR construction steel grade, whereas two girders used as an undulator's jaws are made from aluminium. Elements that have direct contact with a strong magnetic field are made from stainless steel.

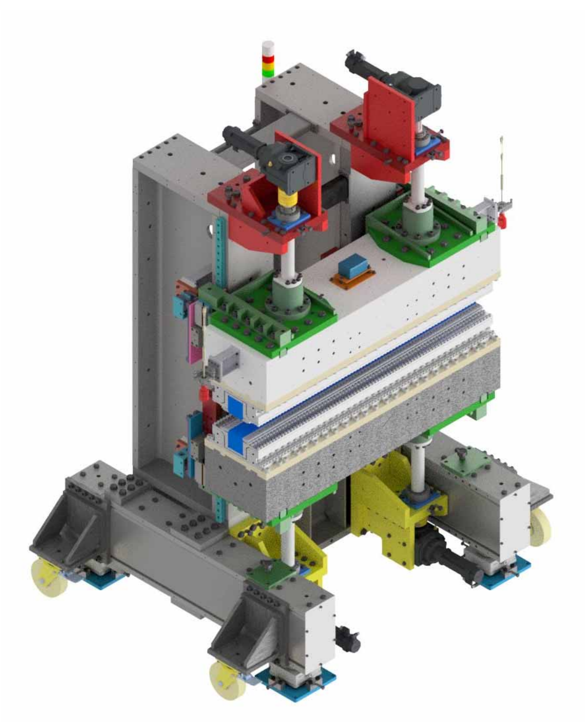

Figure 1: Undulator overview.

Four dismountable transportation wheels have been foreseen on the side planes of the frame, to facilitate movement in hard-to-reach areas. In its final position, each undulator will be placed on the alignment feet and anchored to the floor to protect against any unwanted movements.

The main supporting frame consists of two vertical pillars, settled on the horizontal H-shaped basis frame. Both pillars are shifted towards the centre of the construction due to the high demand for gap opening. This impacted the drive system's final location, which could not be placed in line with the vertical pillar and the horizontal perpendicular beam.

Magnet Keeper

The magnet keepers are the only elements that could not be fully unified. The wide range of forces, varying sizes of magnets, and various quantities of neodymium magnets impacted the design of the undulator. As presented in Table 1, there are many similarities between THz and IR magnets. Therefore, one common solution for both cases has been worked out based on the idea, that the single magnet block is placed in the centre of the aligning structure (Fig. 2). It is settled in the inner frame, which is susceptible to changes in position relative to the outer frame. Both collaborating elements are mutually positioned and fastened with four mounting screws, two of which also have an additional function to change the inner's frame and magnet position. The magnet block is secured at the top with additional handles (so-called fingers), which protect it against any unwanted movement under the influence of the interacting forces.

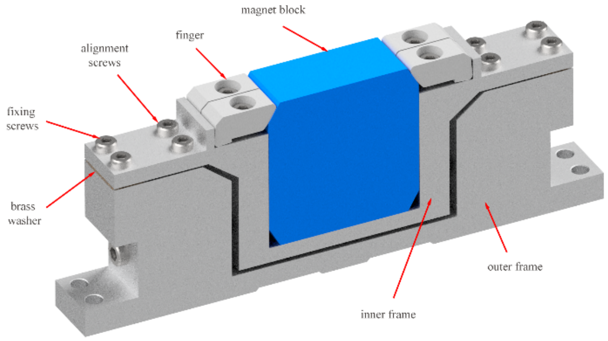

Figure 2: The concept of the magnet keeper (THz magnet keeper).

The positioning of the magnet block is done in two-stage sequence: rough adjustment by means of outer brass washers (located between inner and outer frames) and fine alignment using four inner mounting screws. Adjustment with the screws located closer to the magnet allows the magnet to tilt and adjust the vertical position within the small range. If the range is not sufficient, the height can be changed by exchanging the washer under the outer screw. This solution offers many possibilities and allows adjustments for both large and small ranges.

However, the above-presented solution cannot be implemented for a single VUV magnet due to its small dimensions. On the other hand, the promising possibilities offered by the THz magnet keeper have been observed in the experimental phase. Due to this fact, it was decided to keep the existing solution and modify the VUV magnets in such a way that they could be installed in a similar positioning system. The only modification that must be carried out is glueing two subsequent magnets to form a thick monolith. In this way, the functionality of the handles and the scope of their operation are being kept.

Magnet Grouping

Each magnet block, once placed inside its keeper, must be safely transported onto the girder, and fixed in the defined spot. The transportation of each magnet separately is associated with an increased risk of device damage and human injuries. Therefore, a single sub-assembly of the keeper is grouped into larger sets of three or five elements to facilitate assembly and increase installation safety and simplicity. Each block is fastened to an additional plate - an adapter, which is mounted in series onto the undulator jaws. Transport between the place of assembly and the final location will be carried out using a dedicated manipulator. This solution is applicable to all three types of undulators.

Drive System

The drive system is built out of four identical sets located at the top and bottom of the frame. Each pair is responsible for the vertical girder's movement. The single set includes a servomotor, worm drive, clutch, bearing and drive shaft with nut (Fig. 3).

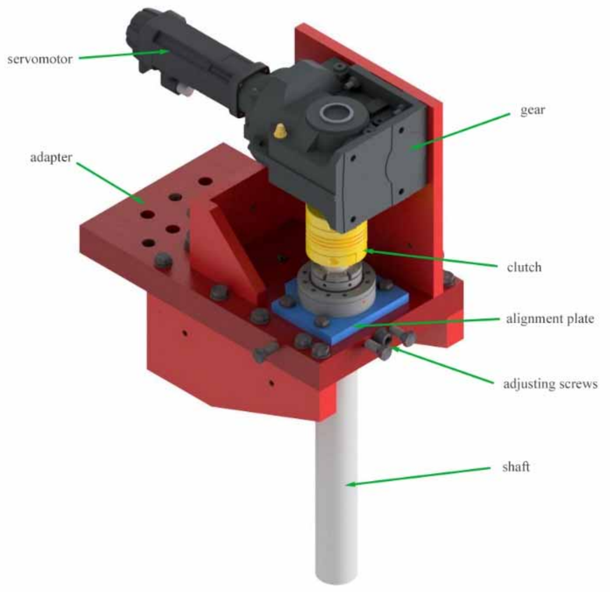

Figure 3: The layout of the drive system.

The sub-assembly will be settled on the adapter that allows position compensation in all 6 DOFs. For this purpose, an additional adjustable plate has been added that allows fine alignment of the screw position in the horizontal plane. The angular and vertical position compensation in small ranges can be modified using additional screws and washers. Through this solution, inaccuracies in manufacturing will be compensated and the lifetime of the drive system will be extended.

CONCLUSIONS

The PolFEL project turned out to be on many levels demanding and challenging project. Appropriate approach and planning of design work related to one of the most critical devices in the FEL infrastructure – the undulator, may contribute to the success of the entire project. Despite that work on undulators is still ongoing, a significant impact on cost reduction and timesaving can already be observed.

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