HELICAL UNDULATORS FOR COHERENT ELECTRON COOLING SYSTEM*

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Abstract

In this paper, we present the description and results of the magnetic measurements and tuning of helical undulators for the Coherent electron Cooling system (CeC). The FEL section of the CeC comprises three 2.5-m long undulators separated by 40-cm drift sections, where BPMs and phase-adjusting 3-pole wigglers are located. We present design, tuning techniques and achieved parameters of this system.

INTRODUCTION

Coherent electron cooling proof-of-principle (CeC PoP) experiment is conducted at relativistic hadron collider (RHIC) in the Brookhaven National Laboratory (USA) to test the basic physical principles underlying coherent electronic cooling [1]. The coherent electron cooling is based on the electrostatic interaction between electrons and hadrons, when density modulation of the electron bunch induced by the hadrons is amplified by a high-gain single pass free-electron laser (FEL) structure and is subsequently used to reduce the energy spread of the hadron beam [2].

The requirements on the wiggler parameters shown Table 1 are defined by the CeC PoP physics and are set to obtain high gain in the FEL. The high gain requirement contributed to the choice of the helical undulator as well. The undulator have fixed gap which simplifies design, manufacturing and tuning.

The undulator gap is rather large to accommodate hadron beams circulating in RHIC. The hadron beams have vertical separation of 10 mm at the location of the FEL to prevent their collision. Therefore, we decided to make undulator vacuum chamber square and rotated by 45º. Although gap is fixed the undulator design should provide capability for opening for insertion the vacuum chambers.

Table 1: Undulator Specifications

Parameter	Value
Wiggler parameter, a_w	0.5 +0.05/-0.1
Undulator gap	32 mm
Period	40±1 mm
RMS Phase Error	< 1° (3° peak-to-peak)
1st field integral	< 30 Gs·cm
2nd field integral	< 300 Gs·cm^2

DESIGN AND MANUFACTURING

The undulator body was made from the aluminum alloy, which has sufficient stiffness and no magnetic properties. Its magnetic structure is pure permanent magnet [3]. A design allows for the correction of the magnetic field at any point of the undulator.

The magnetic structure of the undulator comprises of two types of magnets. The first one has longitudinal magnetization, and the second type has transverse magnetization. Since a magnet with longitudinal magnetization has zero first integral, the error correction can be performed only by a magnet with transverse magnetization. The size and configuration of magnets with transverse magnetization is chosen such that a magnetic force of 10 kg pushes them out of the groove and presses the magnet to adjusting screws, and magnets with longitudinal magnetization are pushed back against the cassette slot with a force of 6 kg (see Fig. 1).

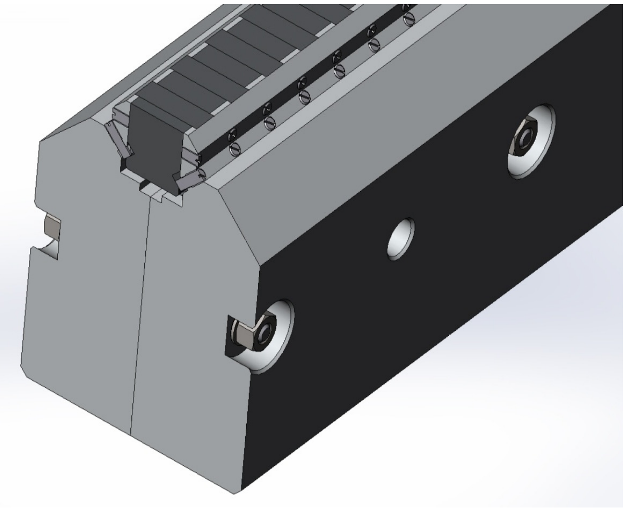

Figure 1: Cassette design. Cassette comprises two precisely machined halves bolted together. The magnets are inserted after cassette assembly and are hold in place with adjusting and fixing screws made of the stainless steel.

At the entrance to the undulator has such a distribution of the magnetic field that the electron beam, when entering the regular structure of the undulator, begins to perform symmetrical oscillations with respect to the longitudinal axis of the undulator. Figure 2 schematically shows the arrangement of magnets that satisfies this requirement as well as magnetic field and its integrals.

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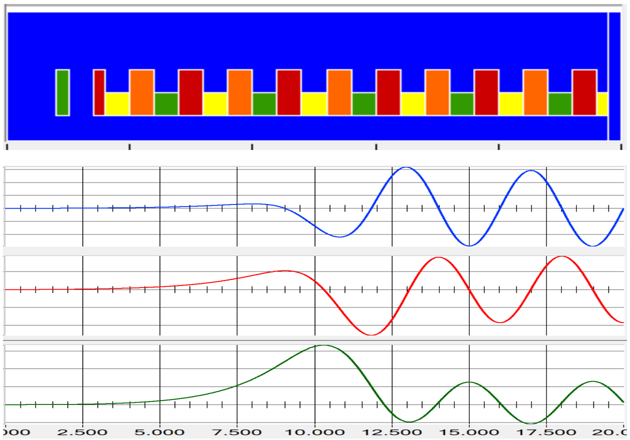

Figure 2: Magnetic structure of the undulator entrance. Red and orange magnets have vertical magnetization, and yellow and green longitudinal magnetization. Blue curve shows vertical component of the magnetic field, red curve corresponds to the first integral, and the green curve corresponds to the second integral.

The beam leaving the undulator should not have a transverse mixing and has zero angle with respect to the central axis. Figure 3 schematically shows the longitudinal distribution of magnets at the exit from the undulator and the longitudinal distribution of the vertical field, as well as the first and second integral of the magnetic field at the output from the undulator.

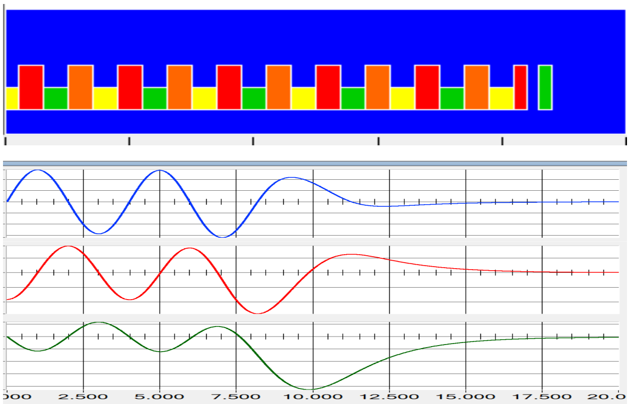

Figure 3: The magnetic structure of the undulator exit. Red and orange magnets have vertical magnetization, and yellow and green longitudinal magnetization. Blue curve shows vertical component of the magnetic field, red curve corresponds to the first integral, and the green curve corresponds to the second integral.

Before choosing the final design of helical undulators, a short prototype with a length of 0.5 meters was built. It served also for verification of the procedure for the fine tuning of the undulator after its assembly.

The prototype is shown in Fig. 4. Four cassettes are hold in the aluminum frame. The undulator gap can be closed and opened with a help of the manually driven lead screws. Gap is established by the inserts between the frame and the cassettes. Helicity of the undulator is provided by the longitudinal shifts of the cassettes.

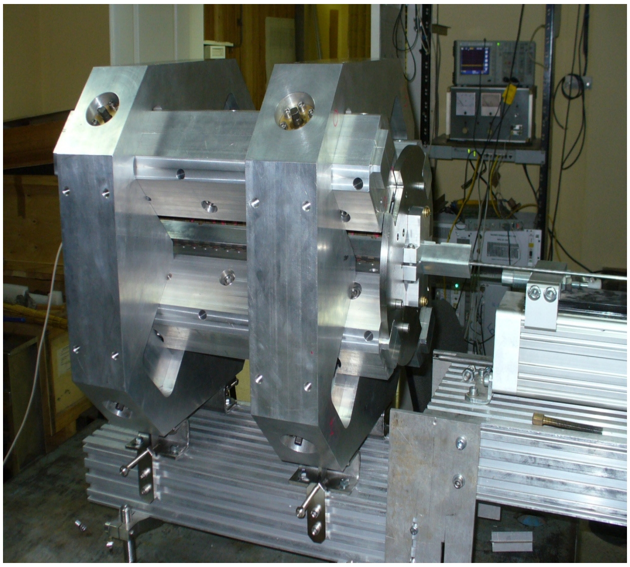

Figure 4: Undulator prototype has 10.5 periods. It shown on the stand for pulsed wire measurement.

During the production of undulator in the shop particular attention was paid to the accuracy of manufacturing long cassettes. In addition to machine precision, since the ratio of the cross-sectional dimensions of the cassette to their length was small the residual deformation has a strong effect on their straightness after removing the cassettes from the machine. The final measurements of the cassettes showed that the deviations from straightness along the entire length of the cassette did not exceed 20 microns.

Prior to the installation of permanent magnets into the cassettes, their magnetic parameters were measured with accuracy at the level of 10^{-4}. The scatter of the magnetization was found of the order of 6%, which is about an order of magnitude greater than magnets usually used for the production of magnets for accelerators. Based on the results of measurements, it was decided to employ a selective installation of magnets into the cassettes, since it greatly reduces the magnitude of errors in the distribution of the field in the undulator.

After insertion of the magnets into the cassettes, their vertical position is adjusted for equalization of the magnetic field amplitude over the entire length of the cassette. The magnetic field amplitude is measured with the Hall carriage with the magnetic mirror, and then the corrections for the field amplitude of each pole was calculated. The distance from the pole to the magnetic mirror at the time of measurement is equal to half the vertical gap in the undulator. This procedure took only a few hours. The combination of two individually pre-tuned cartridges greatly reduces the initial spread of the amplitudes and makes the magnetic potential in the undulator axis equal to zero, thus making the fine tuning of the undulator much easier.

The pre-tuning was followed by insertion of the cassettes into the frames and mounting them onto the support structure as shown in Fig. 5.

Figure 5: Assembled undulator. The extensions at the ends of the cassettes are installed for magnetic measurements.

TUNING

The tuning of the undulator field was done using a 2D Hall probe mounted on the special cartridge. The cartridge was pulled through the undulator with closed gap using saw-tooth plastic belt shown in Fig. 6. The cartridge position was monitored with laser interferometer. Custom-designed VME-based system for high-precision magnetic measurements with Hall probes was used for the tuning [4].

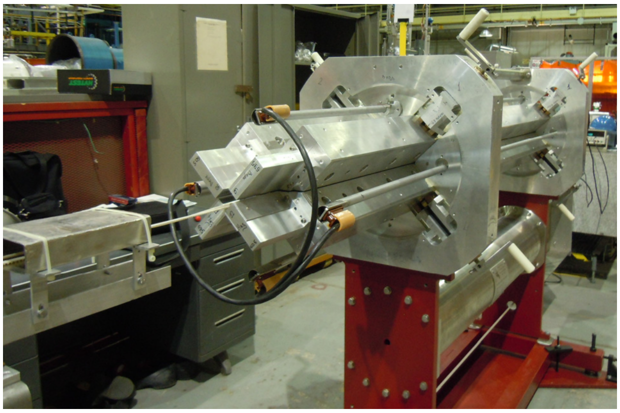

Figure 6: Assembled undulator during measuring of the magnetic field map. The extensions of the cassettes support the carriage during the scan of the undulator ends. On the left side, there is a zero-field chamber.

After the measurement of the magnetic field in the undulator is done two opposite cassettes are opened to provide access to the tuning screws. The carriage is the moved from pole to pole and field is adjusted by increment/decrement found from the scan. Then the operation is repeated with the orthogonal plane. It was found that due to the ambient temperature variations we need to relax and tight the lead screws prior each measurement to relax the mechanical tension in the system.

Having adjusted amplitude of the pole fields we need to correct the field integrals. The entrance position and angle were adjusted using matching section of the undulator. The second integral was adjusted by correcting one-two poles in the location where “orbit” receives the kick or start significantly deviating from the axis. The first integral was finally correcting with exit section. After the end of the magnetic measurements, the amplitude is repeatedly adjusted, but only of one sign, for example positive. At this stage, the amplitude adjustment should be done as accurately as possible. The field of all three tuned undulators is shown in Fig. 7.

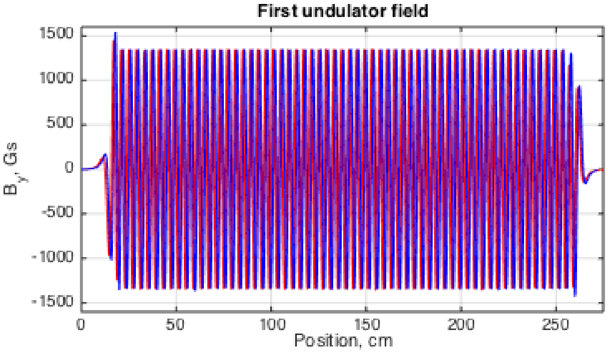

Figure 7: Field profiles of the first undulator after tuning. Two traces (blue and red) show fields for orthogonal planes. Other two undulators have similar fields with equal amplitudes.

CONCLUSION

We have successfully designed, built, and tuned three helical undulator for the coherent electron cooling proof-of-principle experiment. The tight requirements on the field quality were achieved with magnets having substantial distribution of field errors.

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