DESIGN AND CONSTRUCTION OF COMPACT ELECTROMAGNETIC UNDULATOR FOR THz RADIATION PRODUCTION*

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Abstract

The goal of this research is to design and construct a compact electromagnetic undulator. This insertion device will be installed at the PBP–CMU–LINAC system of Chiang Mai University (CMU), Thailand, to produce THz radiation. The undulator magnet is designed by using 2D POISSON and 3D RADIA computer code to optimize the magnet dimensions. The width of iron pole (W) should be 12 mm. The length of iron pole (L) should be about 80 mm long and the thickness of return yoke (d) should be more than 10 mm. The magnet design, the in-house construction of the magnet, and the measurement results will be presented.

INTRODUCTION

An undulator is a spatially periodic magnetic structure and can be viewed as pack of dipole magnets making alternating direction of magnetic fields. For a planar type or a plane harmonic undulator, the magnetic field is in the form of $B_z(y) = B_0 \cos(2\pi y/\lambda_u)$, where λ_u is period length of undulator.

An electromagnet undulator is easy to construct and the required magnetic field can be adjusted by changing the input current. The magnet consists of iron yoke, iron pole, and copper coil wrapped around the iron pole. Its schematic diagram is shown in Fig. 1 (W = pole width, d = return yoke thickness, L = pole height, H = space for coil, and g = air gap). The driving current (I) is put into the copper coil to generate the required magnetic field through the iron pole. The iron yoke carries the return magnetic flux [1, 2].

When an electron passes through such magnetic fields, it will undergo a sinusoidal path with a certain period length and release synchrotron radiation as the electron changes its direction. This radiation has high intensity and the radiation concentrates into a narrow band spectrum at the fundamental wave length of [1]

$$\lambda_w = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}+\gamma^2\theta_0^2\right), \quad (1)$$

where λ_u is period length of undulator, γ is Lorentz factor, and θ_o is observation angle. The undulator parameter K, representing the undulator strength, is defined by

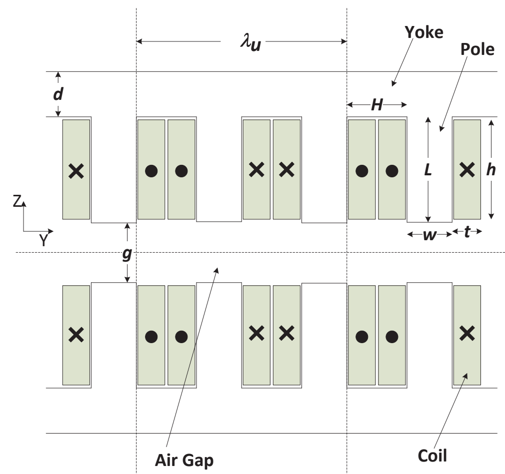

Figure 1: Schematic diagram of an electromagnetic undulator showing its dimension.

$K = 0.934 B_0[T]\lambda_u[cm]$, where B_0 is magnetic field at the undulator mid-plane in Tesla and λ_u is period length of undulator in centimeter .

A planar electromagnetic undulator was constructed at the Plasma and Beam Physics (PBP) Facility, Faculty of Science, Chiang Mai University (CMU). The undulator will be installed in the PBP-CMU-LINAC system [3] to produce THz undulator radiation. TeraHertz (THz) is an electromagnetic spectrum with the frequency ranging between 3GHz to 3 THz (100 – 1000 μm) [4]. This THz radiation can be used as a source of the THz imaging system and THz spectroscopy.

DESIGN OF ELECTROMAGNETIC UNDULATOR

One period of the undulator consists of 4 copper coil cross-sections and two iron poles as shown in Fig. 1. Consider the fundamental radiation wavelength (λ_w) in a forward direction (θ_o = 0), a practical undulator period length (λ_u) of 64 mm can produce radiation wavelength varying from 125 μm at K = 1.0 (B_0 = 0.167 T) to 87 μm at K = 0.3 (B_0 = 0.05 T) with 10 MeV electron beams.

Dimensions of the undulator with the period of 64 mm is optimized by using 2D POISSON [5] and 3D RADIA [6]. The undulator geometry in RADIA code is shown in Fig. 2. Figure 3 shows magnetic field at the mid-plane of air gap for various pole width (W). For small pole widths,

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iron saturation due to magnetic flux are visible. The pole width of around 12 mm gives good linearity and compactness. Figure 4 shows magnetic field at the mid-plane of air gap for various pole length (*L*). Note that the longer pole length also contains more turns of coil. From the result, we choose the pole length of 80 mm as it can provide the magnetic field intensity higher than 1.5 T while using low current density and still having linear relashionship.

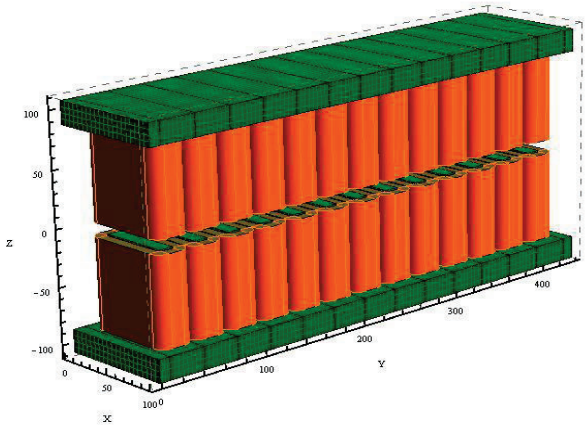

Figure 2: 3D geometry of the undulator in RADIA code.

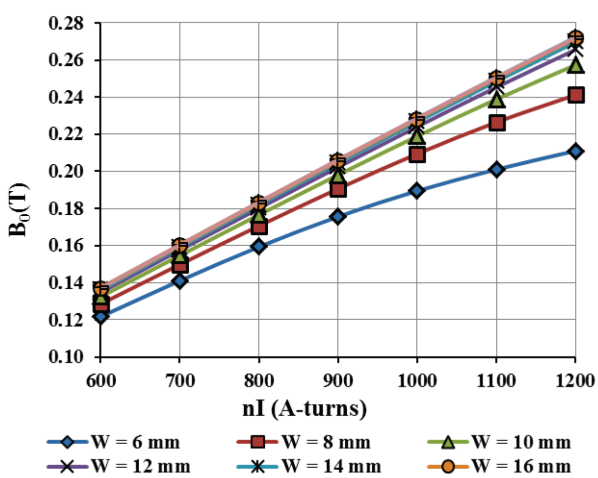

Figure 3: Magnetic field at the mid-plane of air gap for various pole width (*W*) from 2D POISSON output. (undulator dimension: *L* = 80 mm, *g* = 10.5 mm)

The thickness of return yolk (*d*) is also considered and adjusted using 2D POISSON and 3D RADIA program. The simulation results are displayed in Figure 5 showing that increasing the thickness makes the magnetic field increases. The magnetic field reaches the maximum value and stays constant when the thickness (*d*) is more than 10 mm. Along x-direction (transverse to the electron path), the magnetic field should be constant covering the chamber dimension (20 mm). Simulation with RADIA suggested that the lateral width of the pole (*T*) could be 60 mm.

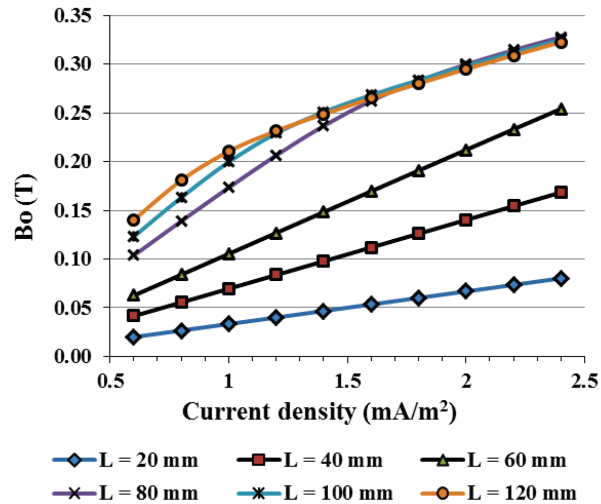

Figure 4: Magnetic field at the mid-plane of air gap for various pole length (*L*) from 2D POISSON output. (*H* = 16 mm, *g* = 10.5 mm, *W* = 12 mm.)

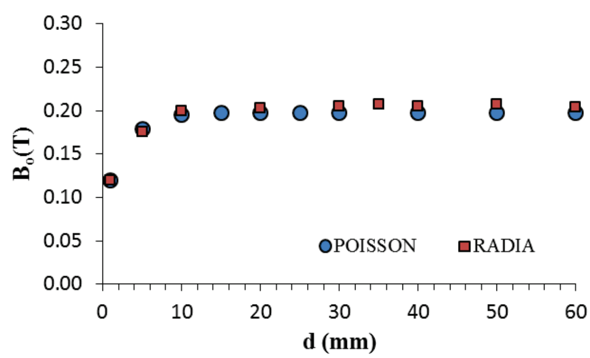

Figure 5: Magnetic field at the mid-plane of air gap for various thicknesses of return yoke (*d*). (*L* = 80 mm, *H* = 16 mm, *g* = 15 mm, *W* = 12 mm.)

CONSTRUCTION OF ELECTROMAGNET UNDULATOR

The magnet poles were pre-cut and put at the specify position on the return yoke [Fig. 6(a)]. Then, the yoke and pole together were final machined by the CNC (Computer Numerical Control) machine. Figure 6(b) shows one piece, after CNC machining, consisting 5 poles. For this prototype, we constructed 13 poles undulator by combining 5-pole-piece, 2- pole-piece and 6-pole-piece as shown in Fig. 6(c-d). The coil was constructed with 515 turns of SWG 19 gauge copper wire. Figure 7 shows the completed undulator magnet.

MAGNETIC FIELD MEASUREMENT

Correction of the end pole field has been carried out using 2D POISSON and 3D RADIA program. Once the calculated current of the end pole was known, the required current can be obtained by adding a proper resistor in parallel to the coil. A Hall probe was then used to measure characteristic magnetic field of the undulator.

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Field measurement at the current of 1 A along x-axis is compare to the magnetic field from RADIA and both of them are shown in Fig. 8.

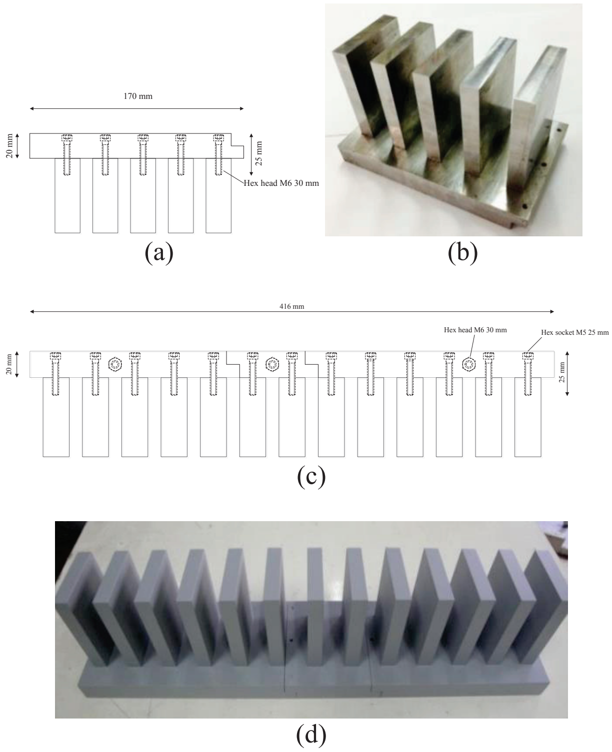

Figure 6: (a) diagram of 5-pole-piece (b) photograph of 5-pole-piece after CNC machining (c) diagram of the combined pole piece (d) 13 poles after combing.

Figure 7: completed undulator magnet.

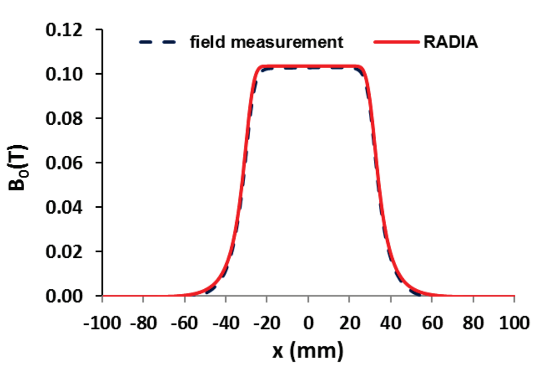

Figure 8: Magnetic field distribution along x-axis from RADIA and measurement.

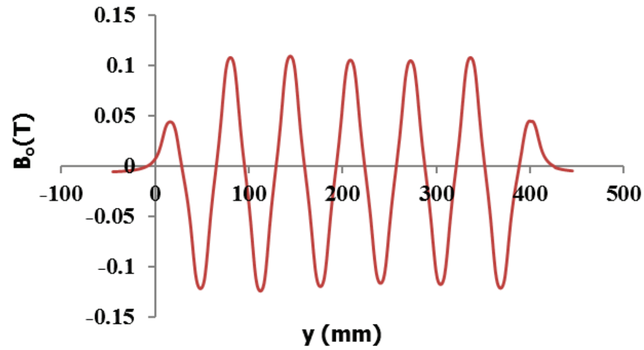

Figure 9: Magnetic field distribution along y-axis from measurement.

The magnetic field is constant in x-direction covering 50 mm along x axis. The measurement of harmonic field in y-direction is shown in Fig.9. The adjustment of end pole compensation is still in progress. Further analysis of the filed quality will also be conducted.

CONCLUSION

A compact electromagnetic undulator for THz radiation production at the PBP facility, Thailand, was designed and constructed. The design employs 2D POISSON and 3D RADIA code. The construction was done by CNC machining of each set of few pole pieces attached to the iron yoke. Magnetic field measurements by Hall probe show good field quality. With this undulator with the period length of 64 mm and a 10 MeV electron beam, it is expected to produce THz radiation varying from 125 μm at K = 1.0 (B_0 = 0.167 T) to 87 μm at K = 0.3 (B_0 = 0.05 T).

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