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DESIGN OF A COMPACT HYBRID UNDULATOR FOR THE THz RADIATION FACILITY OF DELHI LIGHT SOURCE (DLS)

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Abstract

A compact Free Electron Laser (FEL) facility to produce coherent THz radiation is in the development stage at Inter-University Accelerator Centre (IUAC), New Delhi, India [1-3]. The facility is named the Delhi Light Source (DLS). It is planned to produce an 8-MeV electron beam from a photo-cathode RF gun, and the electron beam will be injected into a compact undulator to generate the radiation. To produce THz radiation in the range of 0.15 to 3.0 THz, the electron beam energy and the undulator gap will be varied from 4 to 8 MeV and 20 to 45 mm, respectively. The variable-gap undulator of 1.5-m length will consist of NdFeB magnets with vanadium permendur poles. The magnet design and dimensions are optimised by using code 3D RADIA [4]. The detailed design of the compact hybrid undulator is presented in this paper.

INTRODUCTION

The compact light source project at IUAC named as Delhi Light Source (DLS) is in the developmental stage [2]. In the first phase (Phase I) of the DLS, a normal conducting (NC) photocathode electron gun will be used to generate the pre-bunched electron beam which will be injected in to a compact undulator magnet to produce THz radiation. The layout of the facility is shown in Figure 1. Permanent magnet technology, both pure permanent magnet and hybrid design, is most common for undulators of several-cm period length, while electromagnetic devices are usually built for longer period length. For DLS, we decided to go for a hybrid permanent magnet design as it will provide the biggest magnetic field. It is, however, a little more demanding in terms of field tuning than a pure permanent magnet structure due to the nonlinear behaviour of the iron poles.

THE 50 MM HYBRID UNDULATOR

An undulator is a spatially periodic magnetic structure and can be explained as pack of dipole magnets making alternating direction of magnetic fields. The magnetic field in a planar undulator is of the form $B_0 \sin(2\pi y/\lambda_u)$, where λ_u is the period length of the undulator.

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 wavelength of

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}+\gamma^2\theta^2\right),$$

where λ_u is the period length of the undulator, γ is the Lorentz factor, and θ is the observation angle. The undulator parameter K, representing the undulator strength, can be written as $K = 0.934 \times B_0[\mathrm{T}] \times \lambda_u[\mathrm{cm}]$, where B_0 is magnetic field at the undulator mid-plane.

The undulator for the Delhi Light Source (U50-DLS) has a period length of 50 mm in an antisymmetric configuration and optimised using the code RADIA. The undulator has magnet block of 80 mm wide, 55-mm high and 19-mm thick with 5 mm × 5 mm square cuts at the corners for clamping the block with the holders. The vanadium permendur poles are 60-mm wide, 45-mm high and 6-mm thick. The end sections are designed and optimised with the configuration of 1/4 : 3/4 : 1 in terms of end pole strength [5].

A full five-period model undulator is shown in Figure 2. The end section consists of two magnet blocks and two end poles separated by air spaces. The inner 2nd last end magnet block has the same shape as the full-size blocks but the thickness is reduced to 75% of the thickness of the full-size blocks while the last end magnet has 25% of thickness as compared to regular magnet block. There is an air space between the second last magnet block and the second last end pole as well as between last magnet & last pole. The shape of both end poles is the same as for the full-size poles. In Table 1, the specifications of U50-DLS are summarised.

Table 1: Specification of U50-DLS Undulator

Technology	Hybrid planar, anti-symmetric
Magnet	Permanent NdFeB magnet (B_r =1.21T)
Pole	Vanadium permendur
Magnetic gap	20 - 45 (mm)
Period length	50 mm
No of Periods	28 (full)
Magnetic field	0.62 - 0.11 (T)
Undulator parameter (K)	2.89 - 0.61
Device length	~1.5 m

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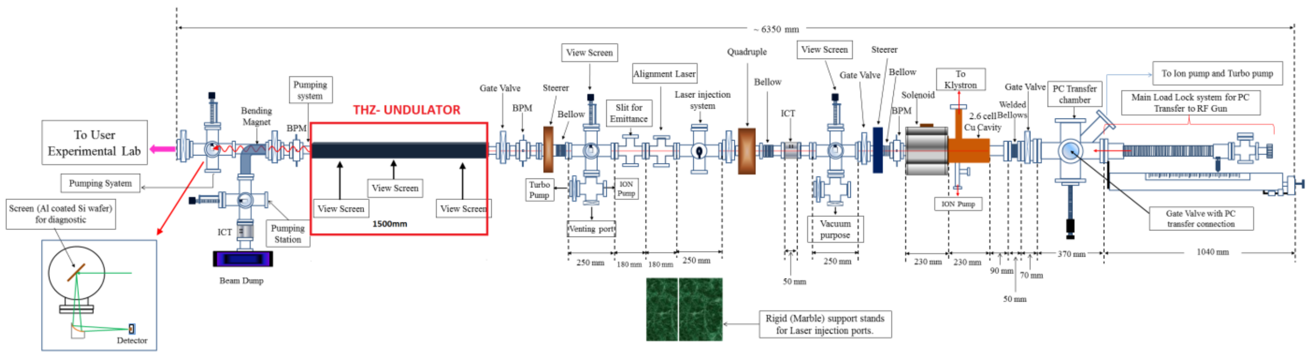

Figure 1: The beamline layout of Phase-I of DLS.

The mechanical design for the magnet/the pole holders and the support body system is in progress. For magnets and poles, we will design period holders that will be mounted on aluminum girders. The girder movement will be done by a system of two motors. To achieve accuracy in µm level while adjusting the gap, we will use absolute linear encoders.

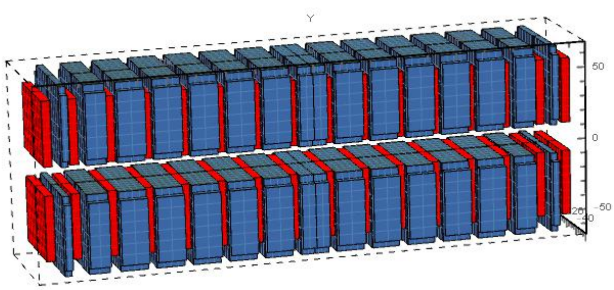

Figure 2: RADIA model of full five period U50-DLS.

RESULTS AND DISCUSSION

The design and optimisation of the hybrid undulator to be developed for DLS has been done with RADIA [4]. The magnetic field profile for the minimum gap (20 mm) as well as for the maximum gap (45 mm) is shown in Figure 3. The undulator has been designed in an anti-symmetric configuration, i.e. the ends have opposite sign, so that their nonlinearities and errors will cancel as good as possible. While the first field integral will cancel to zero in an ideal magnet structure, the second field integral needs to be zeroed by proper configuration of the end field termination. The vertical second field integral will change with the undulator gap as we can see for maximum and minimum gaps in Figure 4. A further optimisation can still reduce this small trajectory offset. Final remaining kick errors of the real device will be corrected by small air coils on both sides of the undulator. Small trim magnets (magic fingers) at the end structures will be applied for correction of multipole errors.

The transverse field roll-off depends strongly on the transverse width of the undulator. A flat transverse roll-off reduces the higher order integrated multipoles over the good field region and reduces the effect of dynamic field integrals. In this design the width of the magnet and pole has been selected to assure a good-field region of ±10 mm about the central axis of the undulator as recommended by the beam optics calculation. The percentage of the roll-off with respect to the on-axis field at transverse positions of ±5 mm, ±10 mm, and ±20 mm is 0.05, 0.25, 2.92 and 0.30, 1.39, 8.74 percent at the closed (20 mm) and open (45 mm) gaps, respectively. Figure 5 shows the transverse roll-off over the full undulator width at (a) the minimum gap of 20 mm and (b) the maximum gap of 45 mm. The field variation of magnetic field B_0 over the working gap range 20–45mm is plotted and is shown in Figure 6.

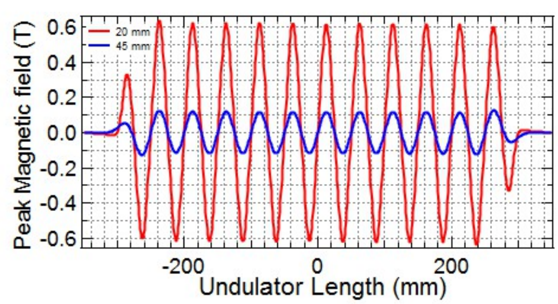

Figure 3: Field plot for the ten-full period model of U50-DLS at the minimum (20 mm) and maximum (45 mm) gaps.

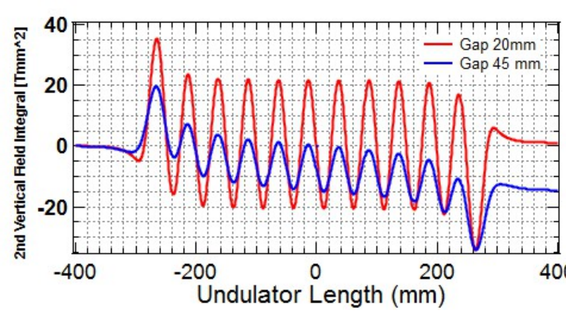

Figure 4: Vertical second field integral (trajectory) plots for the ten-full period model of U50-DLS at the minimum (20 mm) and maximum (45 mm) gaps.

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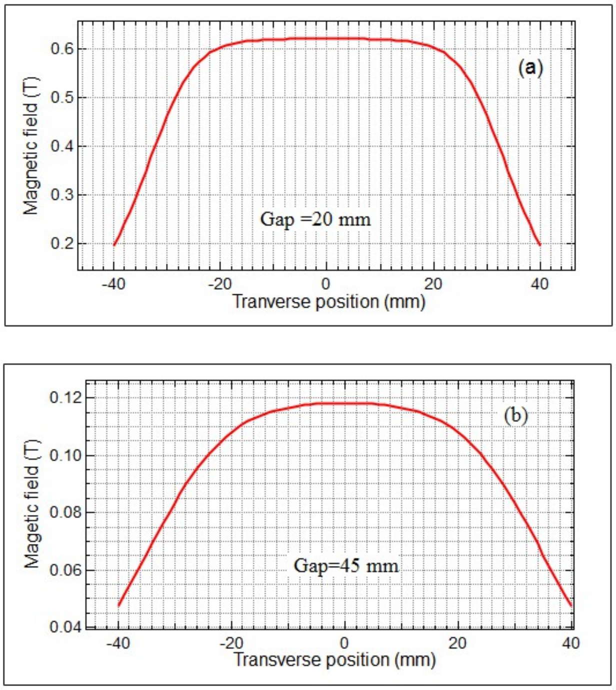

Figure 5: Transverse roll-off plot in magnetic mid-plane.

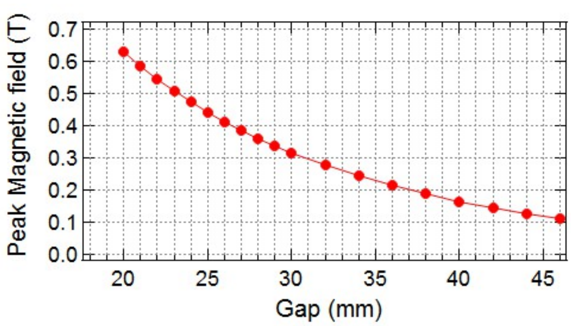

Figure 6: Variation of magnetic peak field as function of undulator gap.

CONCLUSION

A compact hybrid planar undulator for THz radiation production at DLS facility, New Delhi, is designed and optimised successfully with code 3D RADIA. The mechanical design of the undulator is going to be carried out shortly, and then the device will be fabricated, assembled and tested. As per the schedule of the DLS project at IUAC, the device should be installed in the beamline at the beginning of 2019 and the production of THz is expected to be demonstrated by the end of the same year.

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