ISBN: 978-3-95450-179-3 doi:10.18429/JACoW-FEL2017-MOP046

PROGRESS OF DELHI LIGHT SOURCE AT IUAC, NEW DELHI*

S. Ghosh†, B. K. Sahu, P. Patra, J. Karmakar, B. Karmakar, S. R. Abhilash, D. Kabiraj, V. Joshi, N. Kumar, S. Tripathi, G. K. Chaudhari, A. Sharma, A. Pandey, S. Kumar, G. O. Rodrigues, R. K. Bhandari, D. Kanjilal,
Inter University Accelerator Centre (IUAC), New Delhi, India
A. Aryshev, S. Fukuda, M. Fukuda, N. Terunuma, J. Urakawa,
High Energy Accelerator Research Organization, KEK, Tsukuba, Japan
U. Lehnert, P. Michel, Helmholtz Zentrum Rossendorf Dresden (HZDR), Dresden, Germany
V. Naik, A. Roy, Variable Energy Cyclotron Center, Kolkata, India
M. Tischer, Deutsches Elektronen-Synchrotron (DESY), Germany
T. Rao, Brookhaven National Laboratory, USA

Abstract

The first phase of the pre-bunched Free Electron Laser (FEL) based on the RF electron gun, has been initiated at Inter University Accelerator Centre (IUAC), New Delhi. The photoinjector-based electron gun made from OFHC copper was fabricated and tested with low power RF. The beam optics calculation by using ASTRA and GPT codes are performed and radiation produced from the pre-bunched electron bunches are being calculated. The high-power RF system was ordered and will be commissioned at IUAC by the beginning of 2018. The design of the laser system is being finalised and assembly/testing of the complete laser system will be started soon in collaboration with KEK, Japan. The initial design of the photocathode deposition system has been completed and its procurement/development process is also started. The first version of the undulator magnet design is completed and its further improvements are underway. The initial design of the DLS beam line have been worked out and various beam diagnostics components are being finalised. Production of the electron beam and THz radiation is expected by 2018 and 2019, respectively.

INTRODUCTION

A typical Free Electron Laser (FEL) accelerator is either based on the principle of oscillator or seeded amplifier or Self Amplified Spontaneous Emission. The length of most FEL facilities is extended to a few tens of metres which make the system complex as well as expensive. To reduce the length of the machine and, hence, to minimise the cost and complexity, the pre-bunched FEL [1,2] based on the photoinjector RF electron gun was planned to be developed at Inter University Accelerator Centre (IUAC), New Delhi. The name of the project is Delhi Light Source (DLS) [3] and it is divided into three phases. In the first phase, a photocathode based electron gun will produce low emittance electron beam with maximum energy of ~8 MeV which will be injected in to a compact, variable gap undulator magnet to produce the coherent THz radiation in the range of 0.15 to 3.0 THz. During the second phase, a superconducting RF photo-injector will be developed and the electron beam will produce THz radiation with higher average power by an undulator magnet. In the third phase, the energy of the electron beam will be increased from 8 to 40 MeV and it will be injected in to longer undulator magnets to produce far-infrared and infrared radiation. The electron beam will be also used to produce soft X-rays by colliding it with a laser beam. Presently, the first stage of the DLS project is about to be commissioned at IUAC.

† ghosh64@gmail.com
* The work is supported by Board of Research in Nuclear Science, India and Inter University Accelerator Center, India

DEVELOPMENTAL STATUS OF MAJOR COMPONENTS OF PHASE-I OF DLS

A class 10000 clean room has been commissioned to accommodate the Phase-I of DLS. In addition to that, the photocathode deposition mechanism and all the experimental stations to perform experiments with electron and THz beam will be also installed inside the clean room. The stages of developments for various subsystems of the compact FEL is given in the following sections:

Simulation of Beam Optics and Radiation Production from the Undulator

The beam optics simulations are performed with the help of ASTRA [4] and GPT [5] code. In the first phase of DLS, the single laser pulse responsible to produce electron bunches will be split in to 2, 4, 8 or 16 micropulses. The maximum separation between 2, 4, 8 or 16 micropulses of laser and hence electrons will be ~ 6.6 ps, 2.2 ps, 950 fs or 333 fs respectively so that the total span of the microbunch train will occupy less than about 6.6 ps in an RF cycle of 2860 MHz. If the RF pulse width is adjusted to be at 3 μsec, then 15 electron microbunch trains, each separated by 200 ns containing 2, 4, 8 or 16 micro-bunches will be accommodated within a RF pulse whose repetition rate is ~80 msec. For the case of 16 laser micro-bunches, a total number of 3000 electron micro-bunches (16×15×12.5) will be produced. If 15-pC electron charge can be accommodated inside a micro-bunch, the total charge of a macro-

ISBN: 978-3-95450-179-3 doi:10.18429/JACoW-FEL2017-MOP046

bunch will be 240 pC. The beam optics calculation is done to cover the desired range of radiation frequency (0.15 to 3 THz) and the parameters like charge per microbunch, electron bunch width, solenoid field, position and field of the quadrupole singlet, laser spot size, etc. are adjusted to restore the beam quality and to avoid the overlapping of the microbunch structure. The important parameters of the beam optics calculation are tabulated in Table 1.

Table 1: Parameters of the Beam-Optics Calculation [6].

Range of radiation frequency (THz)	0.15	3
Accelerating field (MV/m)	58.5	110
Launching phase (deg)	30	30
Electron Energy (MeV)	4.1	8.1
Energy spread (%)	1.1	0.43
e-beam FWHM @ cathode (fs)	200	200
Total charge (pC)/microbunch	15	15
Number of microbunches	2	16
Av. microbunch separation at undulator's entrance (ps)	6.6	0.345
Peak Current (A) at und. entrance	20	75
$\sigma_{x,y}$ (mm) at undulator's entrance	0.25, 0.19	0.27, 0.17
Emittance (x, y) π mm-mrad at undulator's entrance	3.5, 0.04	0.2, 0.01

The simulation of the radiation produced from the undulator is calculated by the analytical formula by using Lienard-Wiechert's equation [6]. The total photon energy from a single 16 microbunch train for the frequency of 3 THz has been calculated as 12 μJ [6] on a square area of 30 mm × 30 mm at a distance of 0.5 metre from the exit of undulator.

The Copper Cavity as the Electron Gun

The electron gun of the FEL will be a 2.6 cell copper cavity with a resonance frequency of 2860 MHz. This cavity has been fabricated and tested in collaboration with KEK, Japan and a quality factor of ~15,000 has been measured during the low power RF test. The field profile of the cavity was measured by the bead pull method. The picture of the cavity and the match between its field profile from simulation and bead pull data is shown in Figure 1. The cavity is waiting to be installed in the beam line of DLS and currently under evacuation at IUAC inside a clean room of class 100.

The RF System of DLS

The RF system of DLS comprises of a Low-Level RF section and high power RF system consisting of klystron and modulator to power the RF cavity. Specifications of the high-power system are summarised in Table 2.

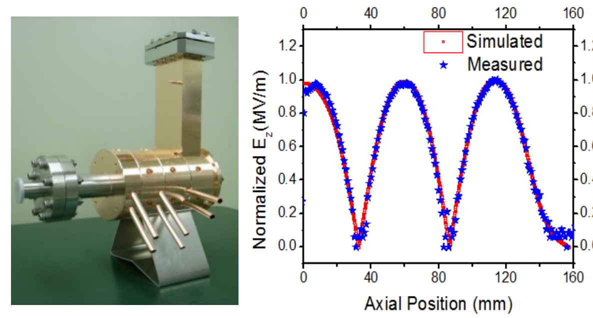

Figure 1: 2860 MHz copper cavity and its field profile.

Table 2: Main Parameters for Klystron & Modulator.

	Parameter – RF system	Value
1	Peak output power	≥ 25 MW
2	Average output power	≥ 5 kW
3	Operating frequency	2860 MHz
4	Bandwidth (-1 dB)	± 1MHz
5	RF pulse duration	0.2 μs to 4 μs
6	Pulse repetition rate	1-50 Hz
7	Pulse top flatness	±0.3%
8	Rate of rise and fall of modulator output voltage	200-250 kV/μs
9	Long term stability	±0.05 %

The Photocathode Deposition System to Produce Photocathode Plug

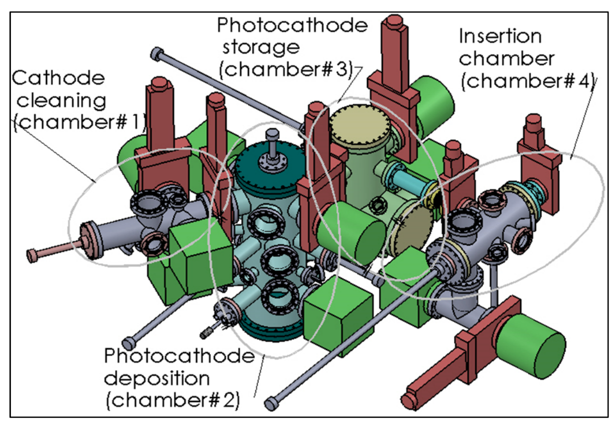

Figure 2. The photocathode deposition mechanism

In the photocathode based RF gun, initially, electrons will be produced from the copper photocathode by illuminating it with the laser beam. The copper photocathode has been fabricated along with the cavity and is ready to be installed inside the copper cavity. An ultra-high vacuum chamber with a few vacuum manipulators to insert the copper photocathode inside the copper cavity has been designed and presently is being fabricated. However, to increase the electron yield from the accelerator, semiconductor photocathode e.g. Cs_2Te and K_2CsSb will be used in future. To develop the deposition facility of the semiconductor photocathode on metal substrate, the complete de-

ISBN: 978-3-95450-179-3 doi:10.18429/JACoW-FEL2017-MOP046

sign of the deposition system consisting of four dedicated vacuum chambers along with numerous accessories is frozen (Figure 2) and the initiative to fabricate the device has been started. In this deposition system, while preparing the thin film of Cs_2Te, the metal substrate will be loaded in the cathode cleaning chamber and the surface to be deposited will be cleaned by the laser beam. After cleaning, the substrate will be brought to the deposition chamber and it will be deposited first by Tellurium and then by Caesium with a constant measurement of Quantum efficiency (Q.E.). Then the photocathode will be shifted to the storage chamber where there will be a provision to store six photocathode plugs and any one of them can be inserted in to the cavity through the insertion chamber. The complete system will be working at an expected vacuum level of 5 x 10^{-11} mbar and the movement of the photocathode plugs will be done by various load locks and vacuum manipulators.

The Laser System to Produce Electrons from the Photocathode

The oscillator frequency of the Yb doped fiber laser system (Table-3) will have 130 MHz to produce 1030 nm as fundamental mode which will be synchronised with the master clock (2860 or 1300 MHz). The repetition rate will be reduced by AOM to 5 MHz to avoid laser pulse loading (Figure 3). Then after stretching and amplification through the PCF fiber, the laser pulses will be transported through the pulse picker to pick up the pulses in the ~3 microsecond RF window with 12.5 Hz rep rate. Two burst amplifiers will be added subsequently to increase the pulse energy. After amplification, the splitting mechanism will split each laser into 1-16 pulses but it's location is still uncertain and can be placed before amplification. Finally, after fourth harmonic conversion, the UV laser will be delivered to the photocathode. With 0.1-µJ pulse energy, we can produce maximum of 200-pC charge from Cs_2Te photocathode. The pulse energy in the UV can be increased up to 10 µJ if the laser system is operated at transient amplification region which can be used mainly due to lower quantum efficiency of Cu photocathode.

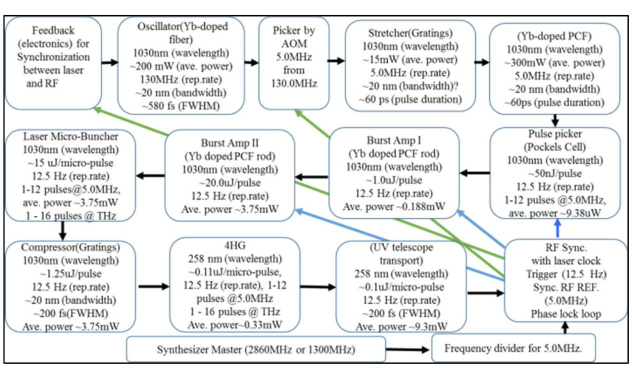

Figure 3: Block diagram of the fiber laser system.

Table 3. A Few Specifications of the Fiber Laser System

Energy/ Pulse @ 258 nm @cathode	Number of micro-pulses	Pulse-width micro-pulses	Photo-cathode & expected Q.E.	Charges produced from each micro-pulses	MaxCurrent (15×16 bunch structure at 12.5Hz rate)
10µJ, transient amp. state	1	200fs	Copper, 0.0014%	20 pC	3.8 nA
0.1µJ, steady state	1-16	200fs	Cs_2Te, 1%	200 pC	600 nA

The Design of the Compact Undulator

To produce the THz radiation in the range of ~0.15 to 3 THz, a compact hybrid Undulator magnet consisting vanadium-permendur poles with a period length of 50 mm has been designed [7] with the code RADIA [8]. Initial beam optics calculation suggested that the device length will be 1.5 meter. The end-field termination is designed to follow 1: 3/4 : 1/4 configuration. There will be 28 full periods (56 poles and 56 magnets) and the end structure will consist of 2 poles and 2 magnets on both sides. The working gap range of the undulator is 20–45 mm corresponding to the range of magnetic field of 0.61–0.11 T. The undulator with full five periods and its magnetic field plots is shown in Figure 4.

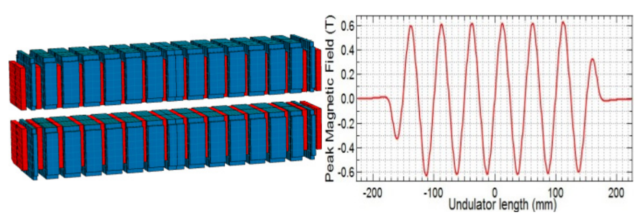

Figure 4: Miniature model of the 16-pole undulator (asymmetric structure) and its field plot at the gap of 20 mm.

PRESENT STATUS

A project to develop a compact THz radiation facility in the range of 0.15 to 3 THz based on pre-bunched FEL has been initiated at IUAC, New Delhi. The electron gun to produce 8 MeV of electron beam has been fabricated and tested. The suitable RF system to power the electron gun will be installed and operated at the beginning of 2018. The state of the art fiber laser system is going to be developed in collaboration with KEK, Japan. The design of the photocathode deposition system to produce the semiconductor photocathode is frozen and will be developed or procured

ISBN: 978-3-95450-179-3 doi:10.18429/JACoW-FEL2017-MOP046

shortly. The first phase of the design of the undulator is done and it is going to be developed in collaboration with a reputed magnet company. The solenoid to focus the electron beam is ordered and will be delivered to IUAC within a few months. The design and development of the other electromagnets, e.g. dipole, quadrupole and steering magnets will be started soon.

The beam line design of the THz facility is almost frozen and the various components of the beam line are being procured or developed. The demonstration of the electron beam and THz radiation are expected to happen by the end of 2018 and 2019.

REFERENCES

[1] S. Liu and J. Urakawa, in *Proc. FEL'11*, Shanghai, China, 2011, pp. 92-95.

[2] M. Boscolo *et al., NIMA* vol. 577, p. 409-416, 2007.

[3] S. Ghosh *et al. NIM-B* vol. 402, p. 358-363, 2017.

[4] K. Flöttmann, ASTRA, www.desy.de/~mpyflo

[5] General Particle Tracker, available at: http://www.pulsar.nl/gpt/index.html

[6] V. Joshi *et al*, presented at FEL'17.

[7] S. Tripathi *et al.*, presented at FEL'17.

[8] RADIA, available at: http://www.esrf.eu/Accelerators/groups/Insertion Devices/Software/Radia