2. ACCELERATOR AUGMENTATION

2.1 HIGH CURRENT INJECTOR

2.1.1 ECR ION SOURCE

A. Performance of 18 GHz HTS ECR Ion Source

In the last academic year, the output power measurements have been caried out by the RFA group to test the power delivering capabilities of the 1.7 kW klystron generator. An air-cooled, 2 kW dummy load was coupled to the klystron using a combination of rigid and flexible waveguides along with a directional coupler. During these measurements, a variable attenuator in the forward power path was found far from its actual value. The attenuator was re-adjusted, along with control card settings to arrive at a correct power level delivered to the dummy load. The power level was measured with external digital power meter with directional coupler (loop type) up to 100 W due to low power rating of the directional coupler. These measurements were again repeated in this academic year and the attenuator setting was again re-adjusted for output power up to 700 W by comparing the voltages values with the old data which had been taken when the klystron was working fine. Due to the limitations of power capabilities of flexible wave guide and directional coupler, it was not possible to adjust the attenuator setting for the output power levels beyond 700 W.

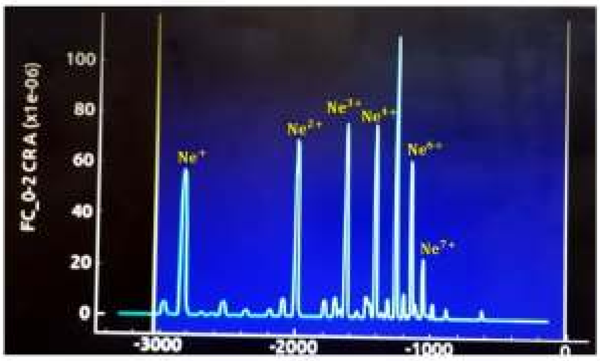

Fig 1. (CSD of Ne at 510 W after klystron output power issue was rectified.

The ion source performance improved after the variable attenuator settings were rectified by the RFA group. The maximum intensity of N^{5+} that could be extracted was 4 e□A at 850W when the klystron was being used with misaligned settings of the variable attenuator. After rectification of the output power issues of the klystron generator but not fully, the intensity of N^{5+} got enhanced to 40 e□ A at 500 W. The source parameters were systematically tuned for high intensity of Ne^{6+} at 510 W and a charge state distribution was recorded to compare the performance of the ion source with the older tuning data. The charge state distributions (CSD) of Ne after klystron output powering issue was rectified, is shown in figure 1. From figure 1, it can be seen that only 64 e□ A of Ne^{6+} could be extracted and it was still far from the older source performance data where it was 100 e□A or even better with excellent source tuning conditions and more favourable for even better performance.

B. Beam bunching using the 12.125 MHz Multi-Harmonic Buncher

The multi-harmonic buncher (MHB) was successfully operated to bunch 8 keV/A N^{5+} ion beam repeatedly to few ns FWHM for testing the remaining DTL cavities. The RF power required was found to be within a few watts. The MHB has been conditioned for more than 4-5 days for stability checks and the saw tooth waveform generated at RF gap was stable without any significant degradation. The water chiller of MHB was also adjusted at a nominal water flow rate sufficient to cool the tank circuits. The buncher has been routinely used and as a result of acceleration of bunched beams through the RFQ and DTLs, we were able to test up to DTL3 cavity with energy gain of 0.85 MeV/A.

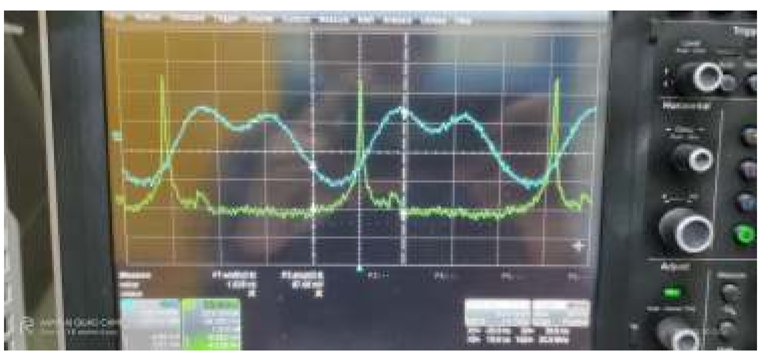

Fig 2. Bunched beam of FWHM of 2 ns (in green) measured at Fast Faraday cup positioned 3 m from the 12.125 MHz multi-harmonic buncher.

C. Electronics development related activities

Work of re-wiring and placement of bias and oven power supplies and associated control electronics on 30 kV platform was undertaken in the last academic year to accommodate these power supplies. The activity included placement of the 2 kV isolation transformer for operation of oven power supply. Bias and oven power supplies control were tested remotely with extraction potential varied from zero to 15 kV. Due to short circuit in – 1 kV bias power supply, a -10 kV, 10 mA power supply was instead installed. Light link interface modules have also been developed for controlling the equipment on 30 kV high voltage platform for electric isolation of signals at different potentials. These modules (transmitter/receiver) are based on voltage to frequency (V/F) and Frequency to voltage (F/V) mechanism using I.C.s AD650 (V/F, F/V) and encapsulated photo diodes HFBR1523 & photo sensor HFBR 2523.

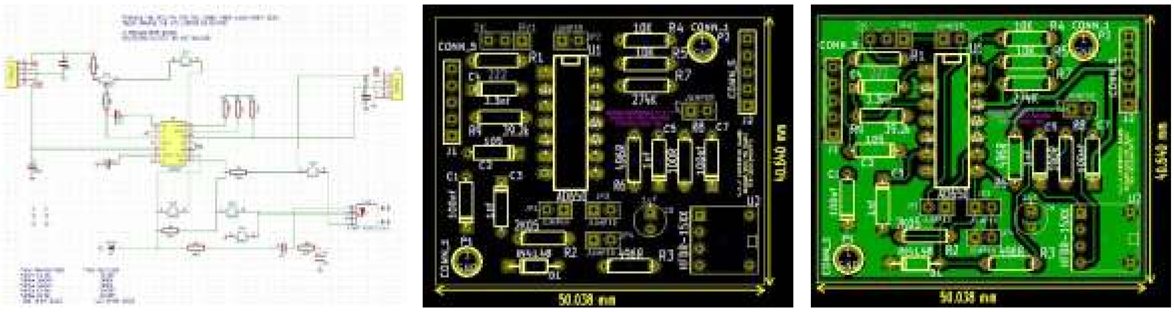

Fig 3. (Left) Light link interface circuit diagram ; (Right) PCB layout of light link interface modules.

D. Grounding problems on 200 kV high voltage platform

During normal operations with the ion source and low energy beam transport, it was observed that some grounding problems cropped up which inhibited us from operating the ion source and associated systems further on the 200 kV high voltage platform for safety reasons. In order to identify the problem due to loose connections, faulty grounding or faulty cables, the entire cabling was removed and re-done carefully for each of the devices on the high voltage platform. Additional grounding was incorporated for ease of operation. It was also observed that many of the cables were lying unused and were removed. As the high voltage platform is continuously prone to a spark environment, both visual and non-visual occurrences, it is of prime importance to ground every device to the nearest ground point on the high voltage platform. In this scenario, few modules operating inside the VME crate (used for control of various devices on the high voltage platform itself) went bad since they were not properly grounded. This has been rectified to make sure that proper grounding is well taken care of. A view of the grounding layout on the high voltage platform is shown in figure 4 below.

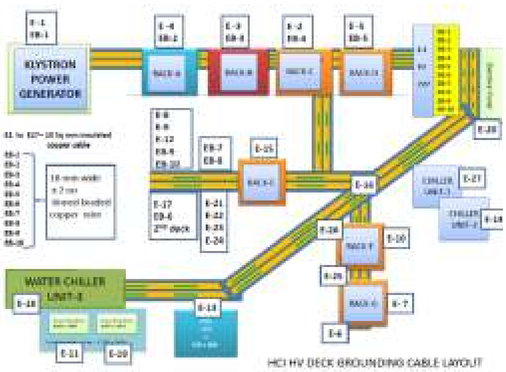

Fig 4. Grounding layout of various sub-systems on the 200 kV high voltage platform.

E. Beam tuning/acceleration results

The 18 GHz HTS ECR ion source has been in continuous operation for the beam acceleration tests through the RFQ and DTL cavities. The ion source was only shut down during the lockdown period due to COVID-19 pandemic. After the lockdown period, the performance of the systems prior to the shutdown was re-established and this took a huge amount of time - almost two months. During the beam acceleration test runs, we have observed that the beam was not stable in LEBT section. Few high voltage connectors of Electrostatic Quadrupole Triplet (EQT) were found broken while diagnosing the problem. The faulty connectors of EQT were replaced with new ones. Additionally, it was observed that the beam steerer before EQT was tilted with respect to the beam co-ordinate system. These were finally rectified and the beam was more stable throughout all the acceleration test runs. In the end of the academic year, all the beam tuning/acceleration results up to DLT2 were achieved which were done in the last academic year also. All the beam tests have been carried out using N^{5+} beam of energy 8 keV/A. The boosted energy achieved from RFQ, DTL1 and DTL2 are 180 keV/A, 317 keV/A and 550 keV/A respectively.

The beam acceleration test has been carried out for DTL3 to confirm the boosted energy 850 keV/A. The beam transmission was optimized by transverse beam tuning and also by optimizing the phase and amplitude of all the DTL cavities, RFQ, MHB and spiral buncher. After optimization of the phase and amplitude of the devices, the beam intensity increased further from 300 enA to 1.4 e□A at the exit of the DTL3 cavity. The beam was analysed between achromats but it was observed at the analysing filed of 3800 G and 3350 G with intensity 30 enA and 5 enA respectively, instead of a single beam at the required field of 4280 G. To get the beam at the energy 850 keV/A, the achromat field was ramped from 3800 G to 4280 G in steps of 50 G and at each step, only phases of the all devices from RFQ to DTL3 were again optimized to maximize the beam intensity. The final beam intensity of N^{5+} achieved was more than 100 enA. To further improve the transmission, all the beam tuning parameters (Quadrupoles and steerers), phase and amplitude of the devices needed to be optimized. Figure 5. shows the analysed beam profile of N^{5+} of energy 850 keV/A at the BPM placed between the dipoles of the achromat. It should be noted here that the observed fields are systematically off by 100 G for the achromat and conforming well to the calculated values.

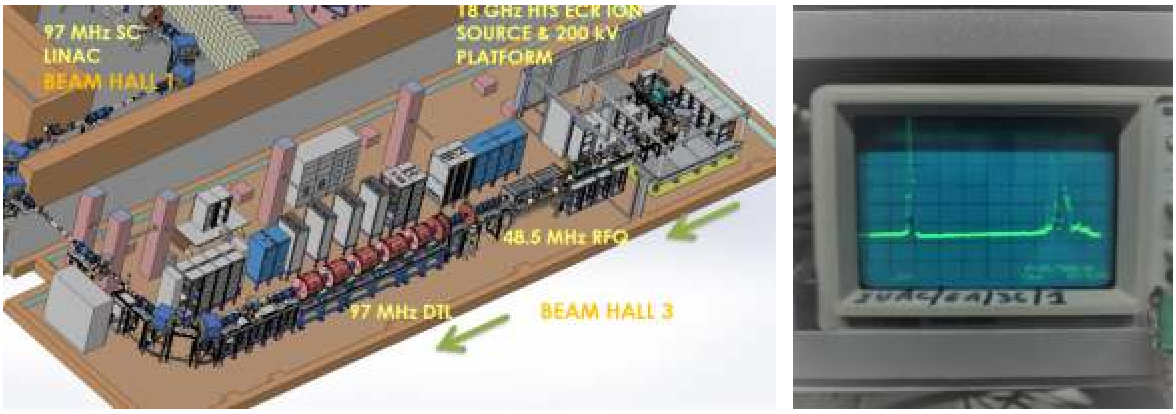

Fig 5. (Left) Schematic view of the HCI beamline ; (Right) The analysed beam profile of N^{5+} of energy 850 keV/A from 97 MHz, DTL3 cavity measured at the BPM placed between the dipoles of the achromat.

F. Development of metal beams using a micro-oven

As part of the developmental activity for extracting metal beams, development of Al beam was initiated by using an aluminium wire (99.9% pure) in the micro-oven. Presently the micro-oven used for the 10 GHz NANOGAN ion source was used to gain experience. Initial extraction of Al beam shows promising developments. A view of the installed micro-oven at the injection side is shown in figure. Due to insufficient time for further development arising due to the scheduled beam tests with gaseous ions through the DTL cavities for measuring the energy gain, it is envisaged that further tests will be continued when time permits. The larger capacity oven for the 18 GHz PKDELIS ECR ion source will be used utilised for long term beam tests

Fig 6. (Left)View of the 30 kV high voltage platform; (Right) View of installed micro-oven.

G. Design of a modified 40 kV high voltage cabinet

Presently, the 30 kV platform which houses power supplies floating at source potential utilises Perspex sheets for isolation. A 40 kV isolation transformer is used to power the bias tube and a 3 kV isolation transformer is used to power the micro-oven and the sputtering unit. In order to accommodate the power supplies for micro-oven and sputtering unit, a more spacious cabinet with proper electrical insulation is essential for smooth operation at 30 kV extraction. A modified HV cabinet has been designed as shown in Fig. 7. The outer dimensions and the dimensions of the racks have been chosen to provide sufficient spacing between the devices and to have easy access for servicing. The complete cabinet will be fabricated using non-magnetic steel using G-10 insulators.

Fig 7. Model of modified 40 kV high voltage cabinet.

2.1.2 BEAM ACCELERATION TEST OF THE RADIO FREQUENCY QUADRUPOLE (RFQ) ACCELERATOR

Sugam.Kumar, C.P. Safvan, R. Ahuja, A. Kothari

2.1.2.1 Beam Acceleration Test:

An interim beam acceleration test has been completed with the RFQ and three DTL tanks. The test facility included 90° achromats bending magnet and Faraday cup along with the BPM installed at the end of the diagnostic chamber for the energy, current, and beam profile measurement. The background pressure was maintained at around 5.6510^{-7} mbar along the whole system. The RFQ was operated in cw mode at 19kW power for the beam of N^{5+} (A/q=2.8) which has been accelerated successfully with three DTL tanks powered and other DTLs as drift. Beam current was optimized as a function of RFQ vane voltage and RF phase for the bunched beam from a multi-harmonic buncher.

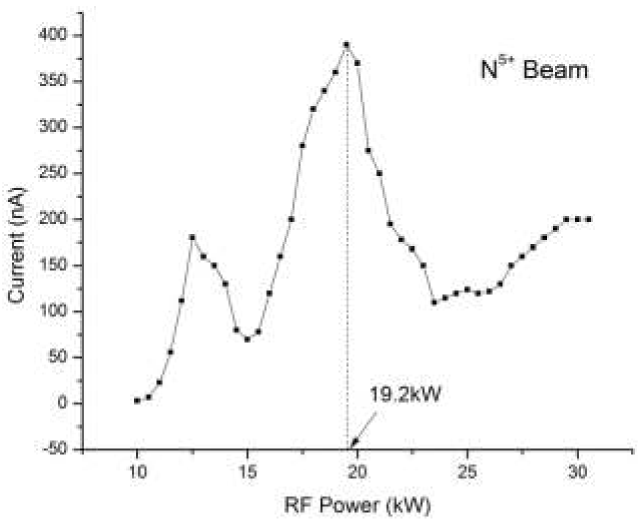

Fig 1 Transmitted current through the RFQ after acceleration as a function of the RF power.

The beam acceleration tests have been performed by injecting 112keV of the N^{5+} ion beam into the RFQ. The output beam energy of 180keV/A just after RFQ with DTL tanks switched off is estimated from the momentum spectrum of the beam, which was taken with the 90° achromat's bending magnets. The input and output beam currents were measured with the Faraday cups and a transmission of 60% was obtained for an input of 700 nA. Output energy from DTL 1, DTL 2 and DTL 3 is also confirmed. The beam current of 110nA has been measured with Faraday cup after achromats magnets, further beam current optimization is going on.

2.1.2.2 Development of o-ring based high power RF Coupler:

To be able to operate the RFQ at higher RF power, that is required for accelerating the accelerator at design A/q = 6, the existing coupler, made from off the shelf, water cooled CF35 ceramic feedthrough is not expected to be sufficient. Therefore, a new specially designed RF coupler with a 20mm thick alumina disc is proposed to be built in house. Its water-cooled inductive loop can withstand up to 120kW power in CW operation at 48.5MHz. The coupling factor of the RF coupler insertion and rotation inside the coupling cell have been analyzed in CST microwave studio for different effective loop areas. The shape of the loop has been adopted in order to increase the coupling coefficient. The loop is made of two concentric copper pipes one of diameter 12mm and the other of diameter 6mm. The loop has several bends which were introduced in order to optimize the coupling coefficient. One end of the inductive loop is brazed to the central conductor of the feedthrough and another end is brazed onto a rotatable CF150 flange. Machining of the inner and outer conductor is successfully done at IUAC workshop. Procurement of the ceramic window is under process. Assembly of the parts and high-power testing will be started in couple of months.

2.1.3 STATUS OF DRIFT TUBE LINEAR ACCELERATOR AND COMPACT BEAM DIAGNOSTIC SYSTEM OF HCI

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2.1.3.1 Introduction

High Current Injector (HCI) facility is an upcoming accelerator facility at IUAC, New Delhi. This will be an alternate injector to the existing superconducting LINAC. The HCI consists of six numbers of IH-Drift Tube Linear accelerator cavities (DTL) operating at 97 MHz to accelerate the heavy ions from 180 keV/A to 1.8 MeV/A energy having mass to charge ratio A/q ≤ 6. There are five compact beam diagnostic system (CBDS) commissioned at the entrance of DTL#2 to DTL#6 cavities. Each one of the CBDS consists of Faraday cup and slit scanner Beam Profile Monitor for the current and profile measurements. Last year, we were able to accelerate the N^{5+} pulsed beam up to DTL#2 using Multi-Harmonic Buncher (MHB), Radio Frequency Quadrupole (RFQ), Spiral Buncher (SB), DTL#1 and DTL#2 cavities ON. This year, we achieved another milestone and succeed to accelerate the N^{5+} pulsed beam through DTL#3 cavity. The status of DTL cavities performances and its associated diagnostics are recapitulated here.

2.1.3.2 Status of the DTL cavities

(A) RF High Power Conditioning of DTL Cavities with Amplitude, Phase and tuner controller

Last year, all the six DTL cavities were conditioned and powered up to 6kW RF power but it was done without the frequency tuner i.e. in open loop and the frequency optimization had been done manually. This year, the high power RF conditioning started in closed loop with the help of the RF Amplitude/phase and frequency tuner controllers. It was planned to start the acceleration of N^{5+} beam having A/q =2.8 and the power level required by DTL #1, DTL #2, DTL #3, DTL #4, DTL #5 and DTL #6 cavities for N^{5+} were calculated to be about 1.1 kW, 2.4 kW, 3.9 kW, 3.9 kW, 5.3 kW and 5.5 kW respectively to get the designed energy gain. DTL #1, DTL #2, DTL #3 and DTL #4 cavities were powered to 5 kW each and these cavities were left running overnight at this level to get properly RF conditioned. DTL #1, DTL #2, DTL #3 and DTL #4 cavities were kept ready for the beam acceleration whereas the other two cavities DTL #5 and DTL # 6 were still under high power conditioning and require some more time to increase the RF power to the required power level (about 5.3 kW and 5.5 kW respectively) for the present beam acceleration.

(B) N^{5+} Pulsed Beam (A/q =2.8) Acceleration and Energy gain validation through DTL cavities:

This year, we successfully achieved another milestone of getting pulsed beam accelerated by DTL #1, DTL #2 and DTL #3 cavities keeping the MHB, RFQ and spiral buncher operational. The designed energy gain (0.85 MeV/u) through DTL#3 cavity was achieved in the very first shot. The designed energy gain of DTL#1 and DTL#2 were also verified which were 0.32 MeV/u and 0.55 MeV/u respectively just before the energy gain validation of DTL#3 cavity. The transmission efficiency of the accelerated pulsed beam was calculated for first three DTL cavities pulsed N^{5+} beam having A/q=2.8 to be approximately 97%, 91% and 48% respectively. However, we are still working on maximizing the transmission efficiency by optimizing the phase and amplitude in the cavities. Though the beam acceleration and required energy gain through first three DTL cavities has been achieved, we are continuing the high-power RF conditioning of the remaining three DTL cavities and beam tuning in HCI. The required energy gain by DTL cavities are represented in Fig. 2.1.2.1 whereas the designed parameters and experimental results observed for power required and energy gain of all cavities during the recent beam test in HCI, are tabulated in Table.1.

(C) Commissioning and Read back of Water and Temperature sensor controllers for DTL cavities.

The temperature and water cooling in the various sub-sections of DTL cavities are very important during the RF conditioning and increasing the RF power. Continuous monitoring of these parameters play a significant role in the operation of DTL cavities during the RF field stabilisation inside the cavity. The supply water flow rate in the different sections of the cavities need to be optimised to maintain the temperature of the return water. We need to keep an eye on these two parameters to operate the DTL cavities in stable condition. RF amplifier can trip due to VSWR in case of any increment in the temperature beyond certain limit ($\Delta T \geq 5$ °C). The six water /temperature sensors controllers have been commissioned with each of the six DTL cavities and mounted on the DTL stand near to each cavity with the help of aluminium clamps. Initially these parameters were being monitored individually and manually but now the dedicated pages are added in the HCI control console. The water flow rate and temperature are now monitored regularly during the DTL operation.

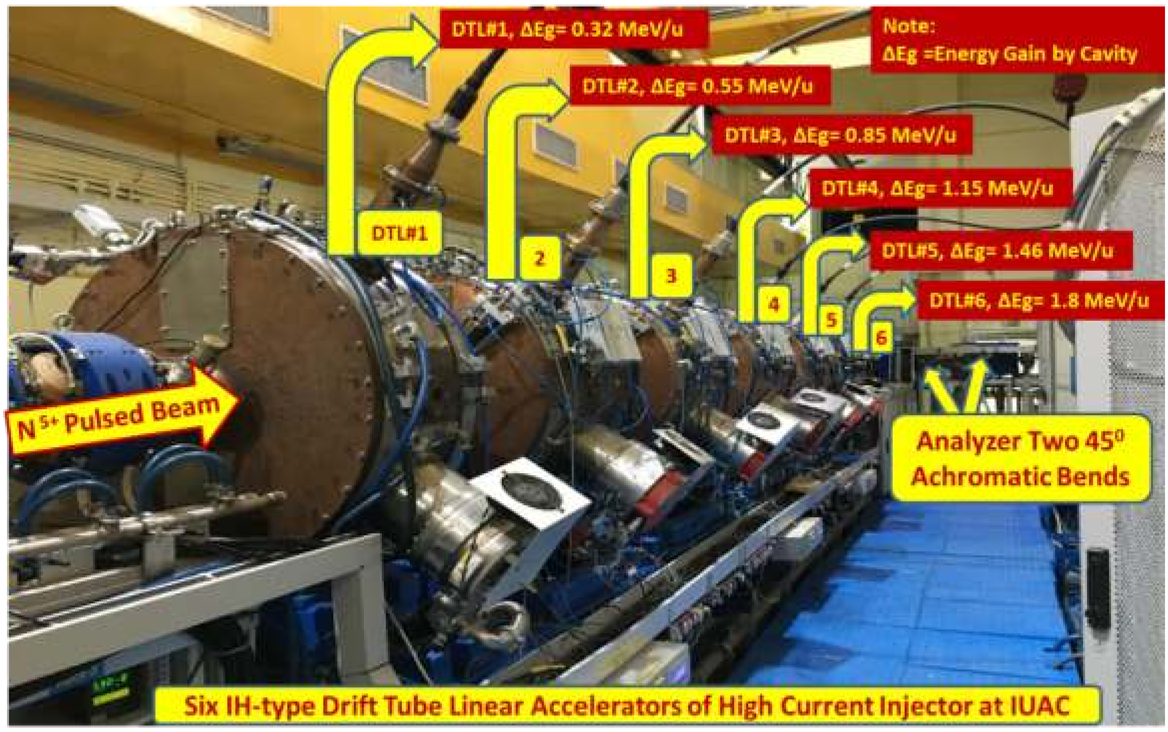

Fig 2.1.2.1: Showing design energy gain required by DTL cavities. Here, the design values of energy gains have been validated through DTL #1, DTL #2 and DTL #3 cavities for N^{5+} Pulsed beam (A/q=2.8).

Table1: Design parameters and experimental results of DTL cavities.

Cavity	DTL #1	DTL #2	DTL #3	DTL #4	DTL #5	DTL #6
Power Required for A/q=6	5 kW	11 kW	18 kW	18 kW	24 kW	25 kW
RF Power Required for A/q = 2.8 (calculated for N^{5+} beam)	1.1 kW	2.4 kW	3.9 kW	3.9 kW	5.3 kW	5.5 kW
Design Energy Gain	0.32 MeV/u	0.55 MeV/u	0.85 MeV/u	1.15 MeV/u	1.46 MeV/u	1.8 MeV/u
Energy Gain for N^{5+} Beam	4.48 MeV	7.7 MeV	11.9 MeV	16.1 MeV	20.44 MeV	25.2 MeV
Analysing Mag. Field of Achrom. Bend (Calculated for N^{5+} beam)	2683 G	3517 G	4373 G	5086 G	5731 G	6364 G
Present Status of DTL cavities (for A/q =2.8)	**Energy gain verified**	**Energy gain verified**	**Energy gain verified**	Beam Tuning Underway	Conditioning Underway	Conditioning Underway

(D) Uniform connections of water supply and return channels and their labelling:

The water supply and return connections in the various sub-sections of DTL cavities have been verified and cross checked. It was found that there was no water connection in the exit plate of DTL#1 cavity and it was stopped earlier due to water leakage through the top reservoir on the exit plate. It was also observed that there were few sharp bends in the supply and return connections of DTL#4, DTL#5 and DTL#6 cavities. The old connectors have been changed to new connectors and water connections re-established in DTL#1 cavity. All the sharp bends have also been removed by connecting the new water pipes. The water supply and return connections have been re-arranged to make all the connections uniform in all the DTL cavities. The labelling of all connections in various sub-sections were also performed to avoid any confusion in future.

2.1.3.3 Status of Compact Beam Diagnostic System (CBDS)

CBDS is an integral part of the DTL cavities in HCI. This is required to measure the beam current and beam profile at the entrance of DTL cavities using indigenously developed Faraday cup and slit scanner BPM. Last year, the CBDS along with two controllers were commissioned with DTL cavities and tested successfully with various beams. This year, all the controllers were kept ready and commissioned with each of the DTL cavities from DTL#2 to DTL#6. CBDS and stepper motor controller commissioned with DTL cavities in HCI are shown in Fig. 2.1.2.2. The interface and new cable connections were made from the HCI console to the respective controllers near each of the DTL cavities. All the interfaces and connections were checked from the console. There is a dedicated stepper motor controller for each of the BPM. The controller was mainly based on the IDX 7505 stepper motor controller module made by Trinamic Motion Control GmbH & Co., Germany. Initially, the design of controller was started with the RS485 to RS232 adopter/converter which was required to interface and communicate the slit scanner from the computer one by one. Recently, the design of the controller has been modified and the converter was removed from the controller. In this case, the current signals are received on console through VME whereas the slit scanner BPM are controlled through a separate USB/RS485 interface from the console. It will be transferred on TCP/IP very soon to ease the remote-control operation. A single GUI program has been written in python for beam profile scanning and read back for all BPMs from BPM#2 to BPM#6. The controllers have separate address byte and we need to mention the BPM number in GUI for beam scan at that particular location. BPM Controllers for DTL#2, DTL#3, DTL#4, DTL#5 and

DTL#6 have been assigned the address byte A, B, C, D and E respectively. The BPM at particular location will only work when the address byte matches in the control program. All the controllers are tested successfully with N^{5+} beam during HCI beam operation.

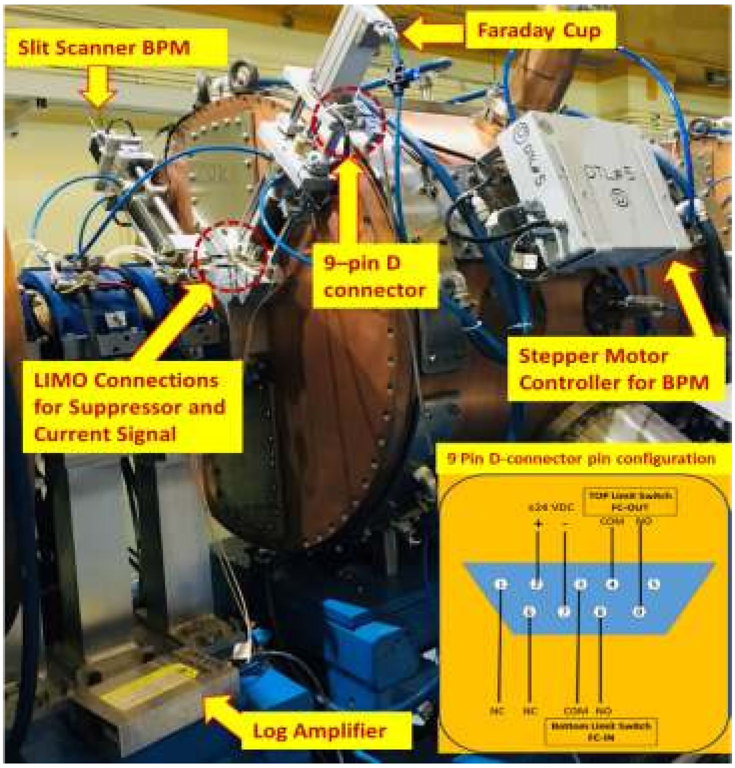

Fig 2.1.2.2 : Showing CBDS and stepper motor controller commissioning with DTL cavities in HCI.

2.1.3.4 Conclusion

This year was a productive year for HCI and we have completed the beam acceleration through DTL#3 cavity and achieved the design energy gain (0.85 MeV/u) along with the validation of DTL#1 and DTL#2 cavities. The indigenously developed compact beam diagnostic system with modified controller design has also been tested during the HCI beam operation this year and the results have validated its design parameters.

References:

[1] Beam optics and resonator design for the 97 MHz DTL at IUAC Ajith Kumar, B.P.; Zacharias, J.; Hariwal, R.; Mehta, R.; Safvan, C.P.; Laxdal, R.E., Proceedings of the DAE-BRNS Indian particle accelerator conference (InPAC), 2009.

[2] Rajesh V Hariwal et al, ; Design, Fabrication and Testing of Compact Diagnostic System at IUAC, 13th International Conference on Heavy Ion Accelerator Technology, Yokohama, Japan (2015), p.294.

2.2. COMMISSIONING AND TESTING OF THE SUBCOMPONENTS OF THE DELHI LIGHT SOURCE (DLS) AT IUAC

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[4]Variable Energy Cyclotron Center, Kolkata, India

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[7]High Energy Accelerator Research Organization, KEK, Tsukuba, Japan

2.2.1 INTRODUCTION:

A compact, pre-bunched Free Electron Laser facility named as Delhi Light Source (DLS) is presently being commissioned at IUAC [1]. Electron beam of energy of ~ 4 - 8 MeV produced by a photocathode based normal conducting RF gun operating at 2860 MHz will be injected into a compact undulator to produce THz radiation in the frequency range of 0.18 to 3.0 THz. The electron gun with the photocathode deposition system, the complete beam line, the undulator and the experimental stations for THz radiation as well as for pulsed electron beams are to be installed inside a class 10000 clean room. Recently the RF conditioning of the electron gun has been started and the first signature of the electron beam in the form of dark current has been demonstrated in the beam viewer equipped with YAG screen and a camera.

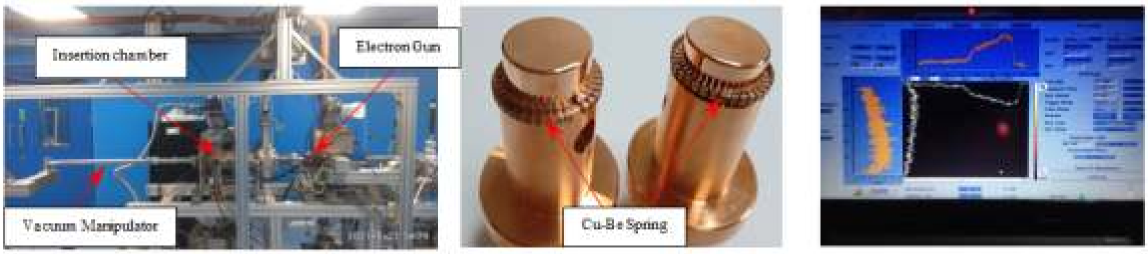
2.2.2 STATUS OF VARIOUS SUBSYSTEMS OF DLS:

The status and commissioning of the various sub-systems of the compact FEL are presented in the following sub-sections:

2.2.2.1. The electron gun and the high power RF system

The copper cavity to be used as the electron gun is a 2.6 cell S-band resonator with a resonance frequency of 2860 MHz. The cavity along with the solenoid magnet was installed in the beam line in the past. In the last year, the high power RF system (the klystron, the modulator and the waveguide up to the cavity) have been tested and conditioned with a dummy load and had gone upto its full capacity of 25 MW of peak power, 4 microseconds RF pulse period with a repetition rate of 50 Hz. After the successful testing, the RF system was connected with the copper cavity with another E-bend wave guide. The resonance frequency of the gun has been set at 2860 MHz by keeping the temperature of the water chiller at 35^{0}C with a temperature accuracy of 0.05^{0}C

The copper cavity is equipped with a copper photocathode (PC) plug mounted on the long vacuum manipulator (Figure 1(a)) which was installed at the back side of the Insertion chamber with the help of a port aligner. The Cu PC plug equipped with a Cu-Be RF spring (figure 1(b)) has been placed at the back side of the copper cavity prior to start of the RF conditioning. During the conditioning of the copper cavity, the current in the solenoid magnet is varied to check the trace of any electron beam in the YAG screen installed with a camera at about one meter downstream from the cavity. When the forward power going into the cavity was around 700 kW and the RF pulse width was kept at 4 micro-second, the first signature of the electron beam was recorded by adjusting the magnetic field of the solenoid magnet. The electron beam spot on the YAG screen recorded by the digital camera is shown in figure 1(c). Presently the RF conditioning is continuing in the electron gun and the higher reflected power for a duration of more than 50% of the RF pulse width is observed. The reason for the higher reflection power is being investigated. This limitation doesn't allow us to increase the RF forward power beyond ~ 1 MW due to the pre-set values of the interlock of the Klystron



(a) (b) (c)

Fig 1. (a) Long vacuum manipulator, Insertion chamber and the Cu cavity (b) Cu photocathode plugs with RF springs (Cu-Be) and (c) The first signature of the electron beam from Dark current.

2.2.2.2 Undulator

The design of the hybrid undulator for the production of THz radiation (0.18 to 3.0 THz) has been performed in the past [2]. However, a spare Undulator with almost identical specification has been offered by Helmholtz Zentrum Berlin (HZB), Germany. The performance of the undulator has been checked and validated with the fresh measurement of its magnetic field by using the Hall probe at HZB and with the help of Stretched wire method at Deutches Electronen Synchrotron (DESY), Germany. A few modifications of the magnets at the entry/exit of the undulator along with the installation of a few correction coils (to keep the electron beam on the magnetic axis and to eliminate the effect of earth's magnetic field) have been incorporated. Since the electron energy of the DLS facility to produce the THz radiation is on the lower side (4.0 to 8.0 MeV only), a pair of quadrupole correction coils to reduce the enhancement of beam emittance along the wiggling plane of the undulator are also incorporated. Figure 2 shows the correction coils at the entry, the long coils along the length of the undulator and the schematic design of the quadrupole correction coils to be attached on the vacuum chamber of the Undulator. The undulator has arrived at IUAC and soon will be installed in the beam line of DLS

Fig 2. Images show the end correction coils, long coils and the schematic of the quadrupole correction coils.

2.2.2.3 Final test of the Photocathode Deposition System

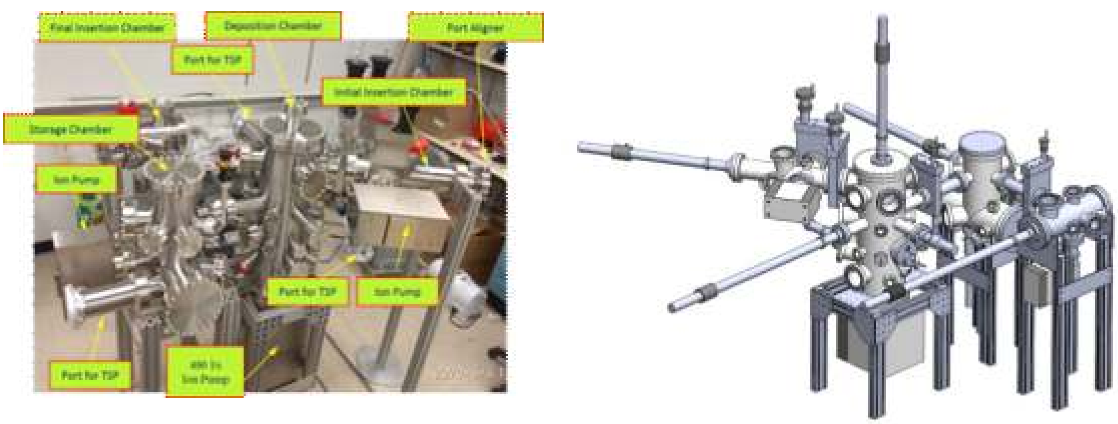


Fig 3. The photograph and the schematic shows the complete photocathode deposition system consisting of four chambers connected together.

The production of electron beam will be demonstrated first by striking laser beam on the Cu photocathode and subsequently on Cs_2Te photocathode. The photocathode deposition system to deposit Cs_2Te thin film on Molybdenum substrate had been designed at IUAC in the past [3]. Currently the complete system is at the final stage of fabrication at Brookhaven National Laboratory (BNL), USA. The system is almost ready and has been tested to check the functionality of its various aspects like movement of the photocathode substrate in vacuum from one chamber to another with the help of vacuum manipulators, establishment of XHV (10^{-11} torr) in the complete system, deposition of photocathode material like Te with thickness measurement calibration, etc. The complete system along with its all accessories is expected to be shipped from BNL by May-June 2021 and should arrive at IUAC by Aug.-Sept. 2021.

2.2.2.4 Fiber Laser system to produce electron beam from Cu as well as Cs2Te photocathode

A state of the art Fiber Laser system is being developed as a collaborative project between IUAC and High Energy Accelerator Research Organization (KEK), Japan. The laser system will produce very short laser pulses (a few hundreds of femto-seconds) at a frequency of 5-10 MHz and each laser pulse will be divided into maximum number of 16 micro-pulses with an energy of ~ 10µJoule/micro-pulse. The separation of the micro-pulses can be varied in the range of ~100µm to 2 mm which is instrumental to tune the frequency of the THz radiation in the two extreme frequencies of 3.0 to 0.18 THz respectively. Currently the Oscillator, Pulse picker, Pre-Amplifier and both the Amplifiers have been tested and integrated in the system. The laser pulses are also compressed upto ~400 femto-second (fs) and the measurement of the energy after the generation of the fourth harmonic is presently going on. The laser pulse compression < 200 fs, the enhancement of the peak power at UV (after FHG) and the splitting of the single laser pulse into 16 are presently going on and will be accomplished shortly.

2.2.2.5 Completion of the beam line design and its commissioning status

The beam line design and the 3-D drawing is made and shown in figure 4 [4]. The beam line has been commissioned upto the entrance of the undulator along with the Solenoid magnet, beam position monitor, integrated current transformer, beam viewer with digital camera, etc. The beam line magnets consisting of Bending, Quadrupole & dipole steering magnets are designed, developed and characterized at Bhabha Atomic Research Centre (BARC) and are received at IUAC. The design of the THz extraction chamber is done and is currently under fabrication at IUAC. The design of the THz transport line has been finalized and the appropriate detector to measure its power (the Pyroelectric detector) is being procured.

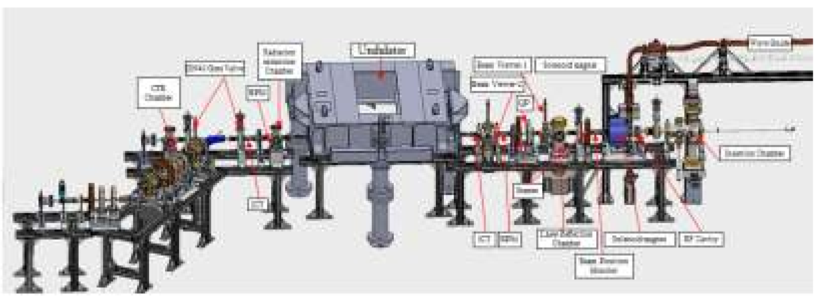


Fig 4. The schematic of the complete beam line for pre and post Undulator section.

2.2.2.6 Control Scheme for the FEL facility

Various aspects related to the control scheme and infrastructure for the control of FEL facility for regular operations has been finalised. The space for FEL control room near to existing accelerator control room is dedicated along with a separate entry from FEL control room to the facility. Physical layout of control modules along with distribution racks are finalised and some of the instrumentation racks are placed at appropriate locations. Eight number of modules for vacuum system control and read-back are being developed in house. The control signals/ wiring is planned to be identical to the other accelerator systems of IUAC. VME based control will be implemented for beamline control devices. All the magnet power supplies are planned to be housed in 3 racks inside the clean room along with RS232 based control server. Control and interlock requirements for high power RF system, LLRF system, beam diagnostics devices and undulator will be taken care of by the independent standalone control modules. EPICS based control scheme is planned for implementation in the FEL facility. Already EPICS based control has been tested with VME low level drivers. Gigabit Ethernet based camera for beam viewing is integrated with EPICS based control. The control of Klystron modulator, the LLRF and the beam diagnostic are made EPICS compatible. Efforts are being dedicated to make all other control modules as EPICS compatible. Development of client GUI interface will be taken up in near future.

2.2.3 INITIATIVE TO DEVELOP THE EXPERIMENTAL FACILITIES

Efforts are being dedicated to develop the experimental facilities in the fields of Materials Science and Biological Science to utilize the THz radiation. Many workshops and meetings were organised at IUAC in the past to develop the user community who will be the potential user in both these fields. Another two workshops to initiate more discussions are being planned in the summer of 2021. Based on the experimental proposals received so far and the equipment required for that, a couple of project proposals have been submitted to SERB, DST and DBT. It is planned to start designing the experimental beam line and the detail of the facilities in near future with the help of the dedicated personnel from IUAC and from the other institutes for the optimum use of this facility.

2.2.4 CONCLUSION

The compact Free Electron Laser is currently at the commissioning stage at IUAC. The RF conditioning of the electron gun has been started and the first signature of electron beam from the dark current has been demonstrated recently. The fiber laser system is at the final stage of development and is expected to be commissioned by the autumn of 2021. The undulator has arrived at IUAC and is about to be installed in the beam line. The photocathode deposition system to deposit the semiconductor photocathode has been tested successfully and will be installed in the beam line within a few months. Most of the beam line components to complete the beam line are ready and are being installed. It is expected that the electron beam from the copper photocathode by striking the laser pulses will be demonstrated by the end of 2021 and subsequently the production of the THz radiation will also be demonstrated.

Reference:

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[3] Abhilash S.R., et. al. Proceeding of Indian Particle Accelerator Conference, (InPAC2018), RRCAT, Indore, ID-52.

[4] P.Patra, et. al Proceedings of Indian Particle Accelerator Conference, IUAC, New Delhi, Nov. 18-21, 2019.