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TRANSVERSE AND LONGITUDINAL BEAM DIAGNOSTICS AND CHARACTERIZATIONS AT IUAC-HIGH CURRENT INJECTOR

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Abstract

The High Current Injector features normal-conducting Radio Frequency Linac structures intended to accelerate various ion species with a mass-to-charge ratio of up to 6, achieving a maximum output energy of 1.8 MeV/u. It can deliver an intense analyzed beam up to 100 enA/q at the target. In order to maintain beam transmission and quality from the ion source to the target, as well as to enhance the performance of RF cavities, both destructive and non-destructive, fast and precise transverse and longitudinal beam diagnostics are deployed at various locations. Recently, during 20 Ne^{9+} beam test, the beam energy was confirmed to be 1.8 MeV/amu using the existing Surface Barrier Detector. We also observed a notable energy spread of approximately 1 %, which led to the pronounced debunching and a complete loss of signal in the downstream Beam Profile Monitors. To reduce the energy spread, slits have been installed at the image plane of the fourth achromatic bending magnets. It was found that optimally adjusting these slits can reduce the spread by more than 50 % while maintaining satisfactory current intensity. This paper will discuss the most recent measurements, challenges encountered and future plans.

INTRODUCTION

The High Current Injector (HCI) is a forthcoming Heavy Ion Beam Accelerator Facility at Inter-University Accelerator Centre (IUAC) in New Delhi. It has been specifically designed to produce the beam currents in the dynamic range of tens of enA to tens of eμA. This will overcome the beam current limitation of the existing Pelletron -an electrostatic accelerator. This will also act as an alternative beam injector to the existing superconducting linear accelerator (SC-Linac) at IUAC (Fig.1). The increased current intensity and higher charge state will enable the exploration of previously unexplored areas in the experimental and research fields of high energy physics. The higher current intensity will also enable the nuclear physics researchers to investigate and perform the low cross-section reactions. HCI comprises of an 18 GHz High Temperature Superconducting Electron Cyclotron Resonance ion source referred to as PKDELIS, a 48.5 MHz four rod structure Radio Frequency Quadrupole (RFQ), and six Inter-digital H-type structure Drift Tube Linacs (DTL) functioning at 97 MHz [1,2].

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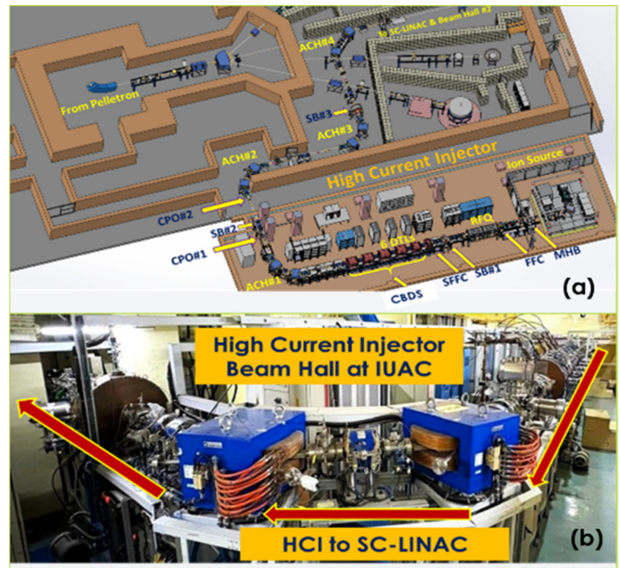

Figure 1: (a) Schematic layout of HCI to SC-LINAC with various transverse and longitudinal beam diagnostic devices. (b) Actual beam hall showing the beam direction from HCI Ion source to SC-Linac beam line via Achromatic Bending Magnet#1.

To ensure synchronization with the master clock, the RF structures within the HCI are engineered to function at frequencies that are harmonics and subharmonics of the operating frequency of the existing SC-Linac, which is 97 MHz. The RFQ receives an ion beam of 8 keV/amu from the ion source and boosts it to 180 keV/amu. Subsequently, the downstream accelerators, referred to as DTLs, further accelerate the ions from 180 keV/amu to 1.8 MeV/amu. This accelerated beam then advances to the SC-LINAC for an additional increase in energy. In order to diagnose the various beam parameters, HCI primarily includes Faraday Cups (FC), Beam Profile Monitors (BPMs), Compact Beam Diagnostic System (CBDS), Coaxial Fast Faraday Cup (FFC), Strip-line FFC (SFFC), Capacitive pick-offs (CPOs), and Surface Barrier Detectors (SBD). They are employed to measure the transverse and longitudinal beam parameters such as beam current, profiles, phase, bunch length, Time of Flight (ToF), beam energy, and the associated energy spread.

To achieve the initial longitudinal bunching of the beam originating from the ion source, a compact Multi-Harmonic Buncher (MHB) is utilized in the LEBT Section. The Coaxial Fast Faraday Cup (FFC) located upstream of the RFQ will measure the bunch length and supply the

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beam to the RFQ for further acceleration. Additionally, the spiral buncher#1, positioned upstream of DTL#1, is installed in the MEBT section to further bunch the beam before directing it into DTL#1. Another compact SFFC is also installed in the MEBT section for longitudinal phase measurements, while capacitive pickoffs are placed between achromatic magnets 1 and 2 in the HEBT section to measure the Time of Flight (ToF). Previously, various beams, including 14 N^{5+}, 20 Ne^{7+}, and 20 Ne^{9+}, were accelerated and transported from HCI to the SC-Linac entrance to validate its optical and electrical design parameters. This paper discusses some of the major beam diagnostic devices in detail.

TRANSVERSE BEAM DIAGNOSTICS

In addition to the standard FCs and BPMs, IUAC has developed indigenous CBDS for measuring beam current intensities and profiles prior to the DTL cavities. In this regard, some important diagnostics of different transverse beam parameters are analyzed and discussed here.

Compact Beam Diagnostics System (CBDS)

In order to maintain the transverse and longitudinal emittances and address the spatial constraints between the DTL cavities, an indigenous, economical, and compact multipurpose beam diagnostic system with a broad dynamic range (~ 10 epA-100 eμA) has been designed and developed, to measure the transverse beam characteristics, including beam current, position, profile, and spot size of the ion beam. The total length of CBDS is only 70 mm and attached directly at the entrance of each of the DTL cavities (Fig. 2). This mainly includes a versatile and compact diagnostic box, Faraday cup, and a slit scanner type beam profile monitor. The validation of designs for different diagnostics has been conducted by executing current, fiducials, profile calibrations, and test outcomes using various ions (such as C, N, O, and Ar ion) beams in the different beam lines and with different setup. An electronic control system based on a Python programmable stepper motor controller via RS 485 to USB interface and GUI, has been developed and used to control the motion of the stepper motor and obtain the data for beam profiles. The beam currents can be read in the main console using the VME. Five CBDS units have been installed at the entrance of each of the DTL cavities and have been successfully operational in HCI since last six years [3,4].

LONGITUDINAL BEAM DIAGNOSTICS

Longitudinal beam diagnostics play a vital role in the tuning, control, and optimization of particle accelerators by providing critical data regarding beam quality and stability. They measure important parameters such as longitudinal phase space, energy spread, and bunch shape, which are essential for enhancing beam intensity in HCI-Linac beam line and ensuring high-quality beam output. These data facilitate the resolution of challenges such as phase and bunching instability, as well as the optimization of accelerator components and operational parameters, thereby ensuring the effective performance of such advanced facilities. Here, some of the crucial devices are discussed.

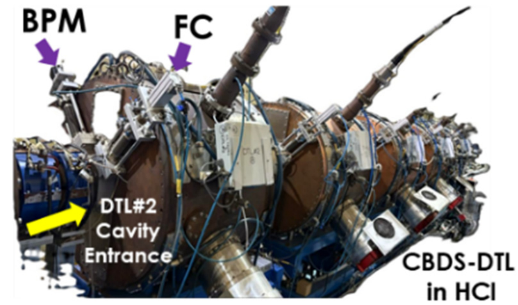

Figure 2: CBDS having FC, BPM and controller for each DTL cavity.

Strip-line Fast Faraday Cup (SFFC)

This discusses the development, performance, and testing of the longitudinal bunch shape monitor known as the SFFC. The SFFC is a device that operates invasively and is operated by a pneumatic cylinder, utilizing a strip line structure for its functioning principles. The longitudinal bunch shape was established by sampling a tiny section of the beam impacting the strip line via a beam aperture. The rise time of the detector indicates the bandwidth of the beam that is to be measured. The SFFC is positioned at the entrance of the DTL#1 cavity to maintain the beam quality at the DTL cavity's input. Ideally, the acceptance for bunch length in the DTL cavity is about 1 ns. MHB and Spiral buncher#1 are the RF structures employed to reduce the bunch length of the incoming beam. It was noted that when the spiral buncher was OFF, the bunch length measured roughly 6 ns, whereas it decreased by around one third after turning ON the spiral buncher (Fig. 3). The bunch length optimization is underway for the good quality beam output.

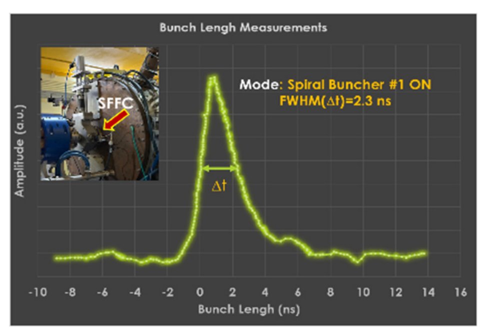

Figure 3: Bunch length measurement using SFFC at the DTL#1 entrance (Insight view).

Capacitive Pickoff (CPO) and Time of Flight (ToF) Measurements

Capacitive pick-ups, notably beam phase probes, are utilized for time-of-flight (TOF) measurements, especially to measure the particle energy and track the beam stability, by recording the duration required for a particle bunch to move between two probes. The CPOs are located in the

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HEBT section situated between ACH1 and ACH2. TOF measurements are employed to monitor the kinetic energy of ion beams. This is essential in the HEBT line of the HCI-LINAC for accurate tuning of the RF phase and amplitude of the RFQ and DTL cavities to reach the intended performance and optimal injection efficiency by adjusting longitudinal beam parameters such as a kinetic energy, energy spread and bunch length at the exit of the IH-DTL. ToF measurements in the ongoing beam run using CPOs are underway.

RF Pickups Amplitudes and Phase Measurements

In order to improve the beam intensity immediately after the DTL cavities, the phase and amplitude of all the cavities (MHB, RFQ, SB, and DTLs) need to be fine-tuned. In HCI, distinct Low-Level RF modules are set up for RFQ, SB, and each of the six DTL cavities, to monitor the phase and amplitude of pick-up signals. The phase and amplitude of various harmonics are essential for beam tuning and maintaining beam stability. Recently, we recorded the pickup voltage and phase (in voltage) signals while running the 20 Ne^{9+} beam. It was noted that these values remain constant and reproducible in every run (Table 1).

Table 1: Amplitude and Phases of the Cavity Pickup Signal

Cavity	RF Power [kW]	Pickup Volt [V]	Phase (Degree)
RFQ	10.0	0.010	98°
SB 1	0.2	0.028	97°
DTL1	0.7	0.023	87°
DTL2	1.4	0.008	116°
DTL3	3.1	0.009	128°
DTL4	3.3	0.033	112°
DTL5	4.2	0.037	136°
DTL6	4.8	0.016	21°

Energy Spread Measurements

The SBD installed downstream to ACH#4 and upstream to SC-Linac, was used to calibrate the energy first by using Pelletron Beam having the same output energy. The resolution of the detector was measured using 36 MeV 19 F^{3+} beam from Pelletron having an energy spread of 40 keV. The fourth achromat was operated in dispersive mode by switching off the quadrupole magnets in between. The ΔE measurement was carried out by closing the slits to ±0.7 mm in the dispersive plane. It was found that the energy spread has been reduced by more than 50 % after optimizing the slits opening (Fig. 4). The effectiveness of the double slit installed, in mitigating the energy spread has been studied.

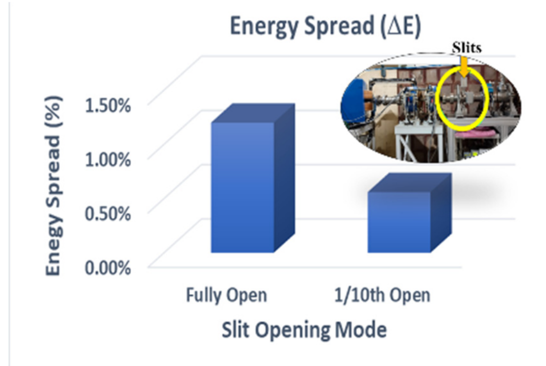

Figure 4: Mitigation of energy spread using slits after ACH#4.

CONCLUSIONS

To preserve the beam quality at different locations and assess the effective acceleration by the RF cavities, CBDS, FFC, SFFC, CPO and SBD are studied. FFC and SFFC results offer insights into the bunching capacity and efficiency of the bunchers. RF pickups and phases were measured and found stable throughout the beam run. The beam energy was confirmed using the SBD. A substantial energy spread was noted during recent beam test, and it was minimized using the slits. It was discovered that the energy spread can be decreased by more than 50 % through optimal closing of slits.

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