DEVELOPMENTAL ACTIVITIES AT BARC-TIFR PELLETRON ACCELERATOR FACILITY

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Abstract

The 14 UD Pelletron Accelerator Facility at Mumbai has recently completed two decades of successful operation. The accelerator is mainly used for basic research in the fields of nuclear, atomic and condensed matter physics as well as material science. The application areas include accelerator mass spectrometry, production of track-etch membranes, radioisotopes production, radiation damage studies and secondary neutron production for cross section measurement etc. Over the years, a number of developmental activities have been carried out in-house that have helped in improving the overall performance and uptime of the accelerator and also made possible to initiate variety of application oriented programmes. Recently, a superconducting LINAC booster has been fully commissioned to provide beams up to A~60 region with E~5 MeV/A. As part of Facility augmentation program, it is planned to have an alternate injector system to the LINAC booster, consisting of 18 GHz superconducting ECR ion source, 75 MHz room temperature RFQ linac and superconducting low-beta resonator cavities. The development of an alternate injector will further enhance the utilization capability of LINAC by covering heavier mass range up to Uranium. The ECR source is being configured jointly with M/s Pantechnik, France, which will deliver a variety of ion beams with high charge states up to $^{238}U^{34+}$. This paper will provide detailed presentation of developments being carried out at this facility.

INTRODUCTION

The accelerator development in the Department of Atomic Energy set out in the fifties. One MeV Cockroft–Walton accelerator was commissioned at Tata Institute of Fundamental Research (TIFR), Mumbai in 1953. In early sixties a 5.5 MV Van de Graaff accelerator manufactured by High Voltage Engineering Corporation (HVEC), was installed at the Bhabha Atomic Research Centre (BARC), Mumbai that provided much-needed boost in accelerator based research in the country. In the late seventies, the only accelerator facility in medium energy range available in the country was indigenously developed Variable Energy Cyclotron at Kolkata. In order to meet the diverse requirements of nuclear physics community, a Medium Energy Heavy Ion Accelerator (MEHIA) project was conceived to accelerate ions right from proton to highest possible mass at intermediate energies. In 1982, the project MEHIA started, where a 14 UD Pelletron Accelerator was purchased from M/s NEC, USA and installed at Tata Institute of Fundamental Research campus, Mumbai. This accelerator was commissioned on 30th December 1988 and since then it has been serving as a major facility for heavy ion accelerator based research in India.

Since its inception, the accelerator has been continuously working with progressively increased efficiency (see Fig. 1) [1]. The accelerator upgradation was done by implementing following features; the original NEC accelerator has voltage grading based on corona needles that were replaced by resistances, a new terminal potential stabilizer was installed, two turbo-molecular pumps are introduced in the terminal to improve performance of gas stripper, development of negative ion beams for a wide range of species, a double harmonic drift buncher was introduced in the low energy injection path of the accelerator to obtain pulsed beam with a typical width of 1.5 ns, separation of 100 ns and a bunching efficiency of ~ 60%. The dark beam current between the beam bunches is swept away by a RF parallel plate sweeper situated at the exit of the accelerator, a Linux based control system consisting of a scanner and an operation interface (OIF) has been developed.

This paper will be providing an overview of the developmental tasks executed already (enabling the success of various application oriented programmes) at this facility, as well as the ones that are currently underway.

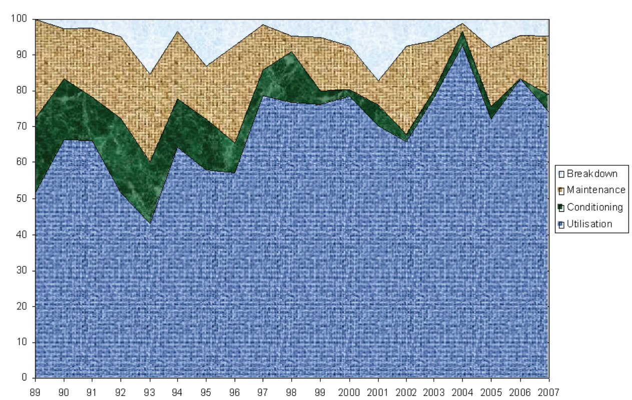

Figure 1: Performance Curve.

DEVELOPMENTAL ACTIVITIES AND ASSOCIATED APPLICATIONS

Resistor Grading

An important consideration in high voltage design of an electrostatic accelerator is the potential grading system used to divide the terminal potential equitably (or as required) across the column or tube electrode gaps. Solid carbon or carbon film resistors were used in the early HVEC accelerators. These were bogged down with problems of frequent resistor failures either due to sparking damage or changes in the resistance values under application of high electric fields. However, development of very high values ceramic metal resistor technology has been found to be most suitable for use in high voltage grading chains. We have designed resistance chain to install 2 GΩ per gap in the column and 1 GΩ per gap in the accelerating tube (1 GΩ resistors; 1008 in columns and 924 in accelerating tubes). There are two charging chains in Pelletron Accelerator and each chain can transport more than 100 μA current, which is sufficient to go to 14 MV terminal voltage. The operation of accelerator, henceforth, became very stable particularly at lower terminal voltages, and it is now possible to deliver beam even at as low voltage as 2 MV.

New Terminal Potential Stabilizer

Onwards of 1995, a thrust was given to various application programs. Needless to say, Accelerator Mass Spectrometry program was on top of our agenda. At that point of time, accelerator beam used to be stable only in slit control mode and not in generating volt meter (GVM) mode. To attain the requisite terminal voltage stability, a new Terminal Potential Stabilizer (TPS) was procured from NEC, USA, especially for this programme. This has helped in a smoother control of the terminal potential in the Generating Voltmeter (GVM) mode, too. Accelerator Mass Spectrometry program took a leap forward and by 2005, ^{36}Cl based measurements could be performed, successfully. As the interfering isobar in the ^{36}Cl detection is ^{36}S, a segmented gas detector was developed in-house to circumvent the rather intense isobaric interference. The ratio obtained for standard sample is in agreement with the value specified by the Prime Lab within a statistical error of 12%. Such a good agreement obtained for direct measurement of ratio indicates that transmission for Cl isotopes through the accelerator is well optimized. Estimated detection limit is ~ 7 x 10^{-14} [2]. We are planning to extend this programme for ^{129}I in near future.

Recirculating Terminal Gas-Stripper

Gas pressure has a major role in getting intense and highly stripped ions, but at the same time bad vacuum conditions in accelerator tube causes loss of beam transmission due to charge exchange and scattering. The gas stripper system was originally installed with Titanium Sublimation pumps in high voltage terminal section. These pumps require periodic replacement of cartridges and pumping speed of these pumps used to come down with time. A new recirculation gas stripper system from NEC has been installed, consisting of two Turbo Pump (Varian make V 301 Navigator) in place of sublimation pumps. Our new installation of turbo pump is based on existing stripper housing (see Fig. 2). Table 1 shows vacuum condition inside accelerating tube at different canal pressure.

Recently BeO^- beam was injected in our accelerator and by using turbo based gas stripper system Beryllium $^9Be^{+n}$ beam was given to users [3]. Results are in displayed in Table 2.

Table 1: Vacuum across Accelerating Tube

	Base Vacuum	Terminal Turbo Pump on	@ 280 micron	@640 micron
IP-02-1	$2.4x10^{-8}$	$2.4x10^{-8}$	$2.4x10^{-8}$	$2.5x10^{-8}$
IP-D1-1	$6.5x10^{-9}$	$5.9x10^{-9}$	$2.1x10^{-8}$	$1.8x10^{-7}$
IP-T-1	$5.5x10^{-9}$	$4.8x10^{-9}$	$8.2x10^{-8}$	$1.8x10^{-6}$
IP-D2-	$2.2x10^{-8}$	$1.8x10^{-8}$	$3.8x10^{-7}$	$6.8x10^{-7}$
IP-03-1	$5.2x10^{-8}$	$5.2x10^{-8}$	$5.4x10^{-8}$	$6.3x10^{-8}$

Table 2: Be Beam Stripping Fraction

	Beam Current With Foil Stripper	Beam Current with Gas & Foil Stripper
Tank Top BeO^- yield	220 nA	220nA
Tank Bottom Be^{+n}, O^{+n} total yield	400 nA	610 nA
Be^{+3} analyzed yield	10nA	35 nA
@ Terminal Voltage – 10 MV, Beam Energy- 33.6 MeV ; Gas stripper Pressure 240 Micron		

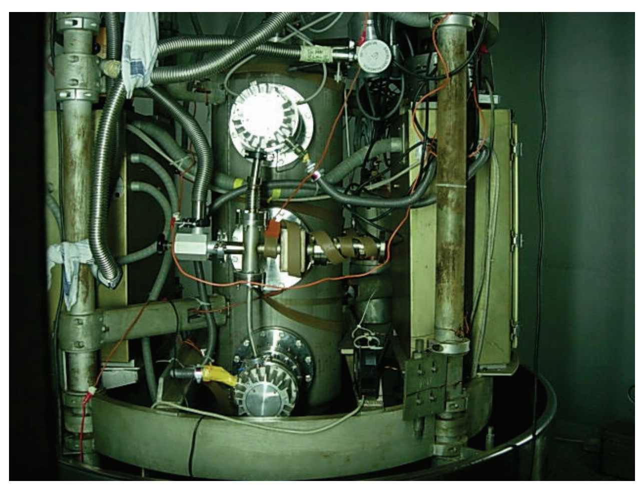

Figure 2: Terminal Gas Stripper System.

A Linux based Control System

A new Linux based control and monitoring software has been written for the Pelletron Accelerator. This software has a graphical User Interface (GUI) through which the operator can interact and control the accelerator. The GUI incorporates features like software assignable meters and slider controls. This will obviate the need for shaft encoders and assignable meters that were in use for the past twenty years. The control system software is relatively more reliable and user friendly compared to the old system that is DOS based and has been in use for twenty years.

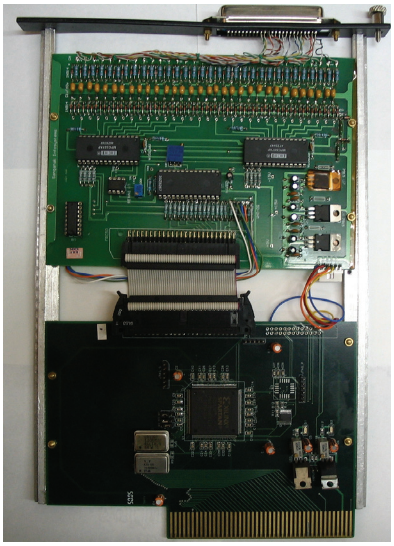

Figure 3: FPGA based CAMAC ADC module.

The Pelletron control system hardware is CAMAC based. The CAMAC interface modules are more than twenty years old and are now facing end-of-life issues. To ensure continuity of the CAMAC platform, general purpose FPGA based CAMAC modules like ADC/DAC modules and digital input/output modules have been designed and developed at the Pelletron accelerator (see Fig. 3). All the modules have been tested [4]. Of these, a 16 channel, 12 bit CAMAC ADC module has been installed and is currently in continuous use.

Beam Profile Monitor

In order to facilitate measurement and monitoring of position and focusing parameters during beam tuning, beam profile monitors (BPM) are used at various places in the accelerator. A two channel, PCI based FPGA compatible BPM digitizer along with the associated GUI has been designed and developed at the accelerator (see Fig. 4).

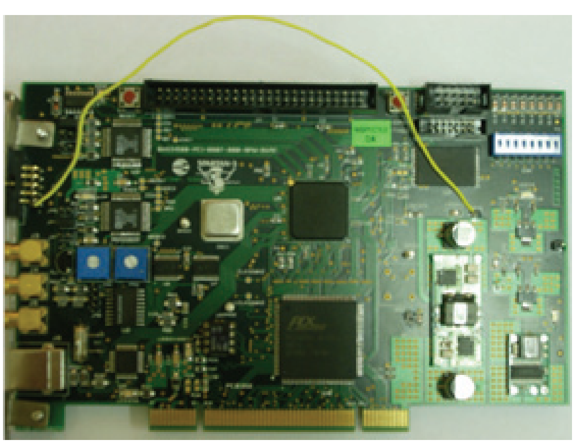

Figure 4: BPM digitizer.

The digitizer can display two BPM waveforms simultaneously. These waveforms can also be filtered and archived. Data archival helps in comparison and monitoring of the BPM waveform and aids the beam tuning process. The digitizer card can also function as a general purpose platform for testing various FPGA based designs. It can also function as a general purpose PCI interface card. The card has been tested [5].

Ion Source and Beam Development

To produce a wide range of negative ions, sources such as SNICS (Source of Negative Ions by Cesium Sputtering) and Alphatross are commonly used in tandem accelerator facilities. An ion source test bench was set up to meet the increasing demand of intensity and quality of beams at Pelletron Accelerator Facility. The sputter-characteristics of the cathodes are optimized using the ‘cooking systematics’ generated in our lab. Different types of composite-sputter cathodes, gas feed-sputter cathodes and disc covered-gas feed-sputter cathodes have been developed and tested at our test bench, with particular emphasis given to the elements of user’s interest [6,7]. Composite-sputter cathodes development has led to a significant reduction in the down time of the accelerator by eliminating the beam changeover delays and enhanced ion source lifetime. Gas feed-sputter cathodes provide molecular negative ions of low electron affinity elements. Disc covered-gas feed-sputter cathodes are developed to generate negative ions of the rare earth elements without impairing the ionization efficiency of ionizer. Over the years, various versions of high intensity negative ion sources based on cesium sputtering i. e. SNICS, Gas feed-SNICS, MC-SNICS (Multi Cathode-Source of Negative Ions by Cesium Sputtering) have been developed, in house [8, 9]. Recently, ^{9}Be beam has been accelerated through Pelletron Accelerator Facility, successfully. Given to the toxicity of beryllium, a dedicated ion source was used and stringent safety requirements were followed as recommended by the Particle Accelerator Safety Committee (PASC), BARC, at different levels of production, acceleration, and utilization [10].

Track Etch Membrane Set Up

Microporous membranes with well defined and uniform pore size and pore density, uniform thickness, high tensile strength and inertness to toxic environments are in good demand for growing number of scientific and technological applications. Heavy ion accelerators provide greater flexibility to produce Track Etch Membrane (TEM) of a wide range as they can provide various heavy ions of different atomic number (Z), kinetic energy (E) and particle flux. Pore densities of the order of 10^6 to 10^8 pores/cm^2 and pore size of the order of 0.2 to 1.0 micron are required for many applications. A magnet was used to scan the heavy ions from the accelerator in horizontal direction and the polymer film was moved in vertical direction using a roller mechanism. The scanner magnet gives a peak magnetic field of 1.35 Kgauss [11].

To get larger deflection higher charge states of the desired ions are produced using post stripper. The deflection, at the exit of the scanner is few centimeters, which is then widened using a horn chamber of one metre length. At the end of the scanner deflection up to 25 cm is achieved. The film is wound on a perspex shaft of 19 mm diameter and is continuously unwound on to another roller that is driven by a D.C motor from outside the chamber. Coupling is done using a vacuum rotary feedthrough. The linear speed of the film is kept at 60 cm/min. The beam is defocused in vertical direction to get almost uniform particle distribution. These membranes are being used by Radiation Medicine Centre, Mumbai to immobilize antibodies against specific analyte and are also used for purification of gases, in separating various Actinides and metals.

High Current Irradiation Set Up

Drift space above analyzing magnet is modified to accommodate a Proton Beam Irradiation Setup at 6 meter level at this facility (see Fig. 5). This setup is capable of delivering proton beam in the energy range of 2 MeV to 26 MeV and current in µA range. The shielding at this level is such that radiation is within permissible limit when proton beam with high energy and high current is accelerated. In order to study radiation effects on metals at a higher temperature a hot target assembly is developed which can go up to 500 ^{0} C. Radionuclides such as ^{52}Mn, ^{67}Ga, ^{96}Tc, and ^{236}Pu are produced for radio-pharmaceutical applications.

Figure 5: Irradiation Setup.

Radiation Biology Set Up

A thin window (20µm) of Titanium is placed at 30^0 N beam line to bring out ion beam in air. Various users have used this facility. A large area proton beam of size 25 mm to 40 mm diameter in air was made available to Indian Space Research Organization for testing their on-line electronic devices.

FUTURE PROGRAMME

ECR-RFQ based Positive Ion Injector

An alternate injector system (see Fig. 6) comprising of a superconducting ECR (Electron Cyclotron Resonance) source, room temperature RFQ (Radio Frequency Quadrupole) and superconducting low-beta resonator cavities is planned, to enhance the utilization capability of LINAC booster, enabling the study of reactions above the Coulomb barrier even for very heavy system like U+U [12]. Prior to injection into Superconducting LINAC, the ion beam needs to be accelerated to 12-14 MV/q.

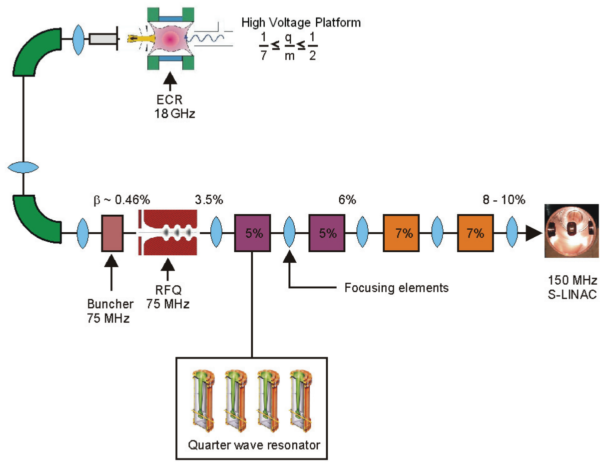

Figure 6: Alternate Injector Layout.

The superconducting ECR ion source (ISIS) operating at 18 GHz frequency is being configured jointly with M/s Pantechnik, France, which will deliver a variety of ion beams with high charge states including up to $^{238}U^{34+}$ with emittance <1 π mm-mrad and beam current up to 3eµA. The ECR will be mounted on a 300 kV platform with mass selection feature on it. This source will also have an arrangement of varying the B_{min} via an independent third coil. It is proposed to operate the ion-source in two modes. In one mode it will inject ions at 10 keV/A into the RFQ. In the other mode, it will be a stand-alone facility, directly delivering ions, right from protons (at 300 keV) to U^{34+} (at 10.2 MeV), to users for experiments in atomic physics, material science, etc.

The RFQ will be operating at 75 MHz and will accelerate ions up to 575 keV/u (β~3.5%). The beam dynamics studies were performed using LIDOS [13] and the resonant structure design was carried out by employing SOPRANO module of OPERA 3D [14]. The Table 3 summarizes the final RFQ parameters.

Recently, the RFQ vanes, stems and base plate are machined from ETP (Electrolytic Tough Pitch) copper (see Fig. 7). The prototype RFQ is undergoing RF tests, currently. The physics design of superconducting low-beta resonator cavities have also been initiated.

Table 3: RFQ Parameters

q/m	1/7, U^{34+}
Ein / Eout, keV/u	10 / 575
Frequency, MHz	75
Kilpatrick Factor	1.4
Focussing Parameter (B)	4.26
Intervane Voltage, kV	16*m/q
Mean Aperture Radius(r_0)	8.0 mm
Minimum Aperture (a), mm	8.0-4.51
Current (I), mA	0.1
ε (input, norm.) π mm mrad	1.0
Modulation (m)	1.0 - 2.3
Synchronous Phase (ϕ_s)	-90^0 to -20^0
Number of cells (n)	167
Length, m	4.62
RMS Long. Emitt., keV/u*ns	0.3
Transmission	87%

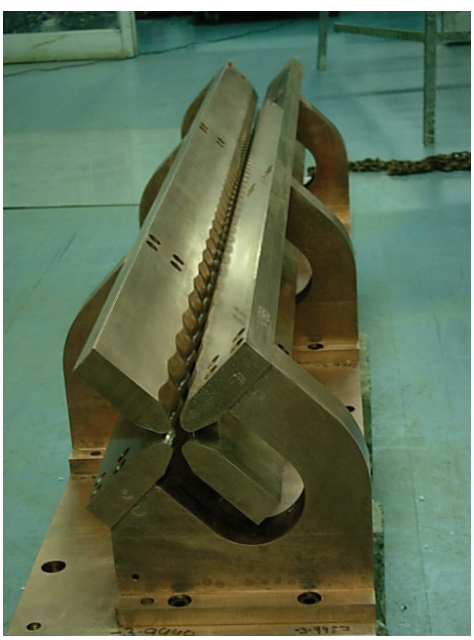

Figure 7: RFQ Assembly.

CONCLUSIONS

Developmental work carried out over the past two decades has resulted into increased uptime as well as enhanced utilization of the Pelletron Accelerator Facility. Pelletron Accelerator stand-alone and the ECR based injector shall cover elements across periodic table to meet the requirements of research in basic science and applications of departmental interest, essentially.

ACKNOWLEDGEMENT

The authors thank their colleagues of Pelletron Accelerator Facility for their contribution. We are also thankful to Dr S. Kailas for his keen interest and constant support for the accelerator based progarammes.

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