HEAVY ION ACCELERATOR AND ASSOCIATED DEVELOPMENT ACTIVITIES AT IUAC

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Abstract

A Vertical 15UD Pelletron electrostatic tandem accelerator having highest terminal voltage tested up to 16 MV has been in regular operation at Inter-University Accelerator Center (IUAC) for more than two decades. It has been providing consistently various ion beams in the energy range from a few tens of MeV to 270MeV for scheduled experiments. A superconducting linear accelerator (LINAC) booster module having eight niobium quarter wave resonators has been designed, fabricated and installed successfully. It is fully operational for scheduled experiments. The LINAC module has been tested and used to accelerate energetic heavy ion beams from 15 UD Pelletron. A new type of high temperature superconducting electron cyclotron resonance ion source (HTS-ECRIS) has been designed, fabricated and installed successfully. It has been in regular operation as future source of highly charged ions having higher beam current for the alternate high current injector (HCI) system for the superconducting LINAC. A radio frequency quadrupole (RFQ) accelerator is being developed to accelerate highly charged particles (A/Q ~ 6) from HTS-ECRIS to energy of 180 keV/u. The beam will then be accelerated further by drift tube linacs (DTL) to the required velocity for injection of the ion beams in to the existing superconducting LINAC booster. A low energy ion beam facility (LEIBF) having permanent magnet ECRIS on high voltage platform and a 1.7 MV Pelletron are being used for regular experiments. Details of various developmental activities related to the heavy ion accelerator and associated systems at Inter-University Accelerator Centre (IUAC) are presented.

ACCELERTOR AND RELATED SYSTEMS

The 15UD Pelletron electrostatic accelerator [1-4] having compressed geometry tubes for 16MV terminal potential has been in regular operation at IUAC for more than two decades. It has been upgraded by using resistor grading for accelerating tubes and support posts, installing two turbo molecular pumps based re-circulating gas stripper at high voltage terminal, two foil strippers on either side of the analyzing magnet, multi harmonic buncher, multi-cathode sputtered negative ion source, external chiller for cooling the re-circulating SF_6 gas, and by adding accelerator mass spectrometry beam line having off-set Faraday cup and Wien filter. Figure 1 shows the foil stripper before the analyzing magnet along with other beam handling and diagnostic components. There is an off-set quadrupole triplet after the Gas/Foil Stripper followed by a matching quadrupole triplet in the high voltage terminal. This combination is used to select the ions having the desired charge state after the stripper, and then to match the ions of that charge state to the high energy section of the Pelletron. This helps in decreasing the loading of the charging system by removing the ions in other charge states at the terminal itself. It also makes the analysis of the charge states of ions stripped of electrons again at higher energy by the next foil stripper in the high energy dead section (located inside the tank after six of the fifteen accelerating units from the terminal simpler) simpler. The third foil stripper (figure 1) is located near the object plane of the analyzer magnet which is below the tandem accelerator tank. It is useful to strip the ions to very high charge states and to select subsequently the desired charge state by 1.8m analyzing magnet for accelerating them to much higher energy using the LINAC. The tandem accelerator has been operational round the clock seven days a week maintaining high uptime and delivering a variety of beams in the energy range of a few tens to a few hundreds of MeV (corresponding to ~ 1 to 8 MeV/nucleon) to users from all over India as well as from abroad. All types of developments and maintenance are carried out successfully by the accelerator personnel of IUAC. The integrated beam pulsing systems have been developed which are in regular use for various experiments and for accelerating beams through LINAC. The AMS facility has been tested successfully and user experiments have been carried out regularly. A compact 1.7MV Pelletron having fully automated Rutherford back scattering (RBS) and channelling facilities (figure 2) installed during December 2010 has been in regular use for experiments.

Figure 1: The new foil stripper near the object point of the 1.8m radius analyzing magnet of the 15 UD Pelletron.

The existing low energy facility (LEIBF) developed using ECRIS on a high voltage (up to 300kV) platform is being shifted to the new Low Energy Ion Building (LEIB). In its new location it is put on a 400kV platform with three beam lines (figure 3) for carrying out experiments in atomic physics, materials science and soft landing of highly charged ions. Design and fabrication of different optical elements viz., dipoles, quadrupoles, steerers and scanner magnets, power supplies for the magnets, high voltage power supplies for electrostatic beam transport elements are successfully carried out.

Figure 2. The 1.7 MV of Pelletron with Rutherford back scattering (RBS) and channelling facilities.

The first module of the superconducting linear accelerator is shown in figure 4. It has been operational for boosting the energy of the ions from the 15UD Pelletron accelerator. The LINAC system [[3-8] comprises of a superbuncher cryostat having a single niobium quarter wave wesonator (QWR) followed by three accelerating modules (having eight QWRs and a superconducting solenoid each) and a rebuncher cryostat housing two QWRs. The prototype QWR and the first batch of twelve QWRs were designed and fabricated by IUAC personnel in collaboration with Argonne National Laboratory (ANL, USA). A few novel features were incorporated in the new design. Instead of niobium bonded to copper which was used in ANL's split-ring resonator, a niobium quarter wave resonator (QWR) jacketed in a stainless steel outer vessel was developed. The superconducting resonator fabrication (SRF) infrastructure at IUAC has been operational since 2002. At present, this is the only facility in India for fabrication, test and operation of superconducting niobium resonant cavities. The QWRs fabricated using these facilities have performed excellently.

The QWRs for cryostats 2 and 3 are indigenously developed using in-house facilities e.g., electron beam welding (EBW) machine, high vacuum annealing furnace and surface preparation laboratory. These indigenous resonators will be installed in the last two cryostats after cold tests in test cryostat.

At initial stage of operation of LINAC there were some problems which were rectified by damping the microphonics picked up by the resonator from its ambience, changing the design of the SS-jacket to increase the buffer volume of liquid helium at the top of the resonator, modifying the design of the power coupler, and making the fixture of the mechanical tuner more rugged.

Different beams starting from ^{12}C to ^{107}Ag have been accelerated and delivered to conduct scheduled experiments with the Hybrid Recoil mass Analyzer and the National Array of Neutron Detectors.

A lot of developments have been carried out for automation of operation of LINAC. An alternate tuning mechanism using piezo-actuator has been developed and tested successfully on superconducting resonator. The control system of LINAC is integrated with the Pelletron in the same control room (figure 5) for ease of operation

Figure 3: The new low energy ion beam facility (LEIBF) having ECRIS on a 400kV platform and three beam lines.

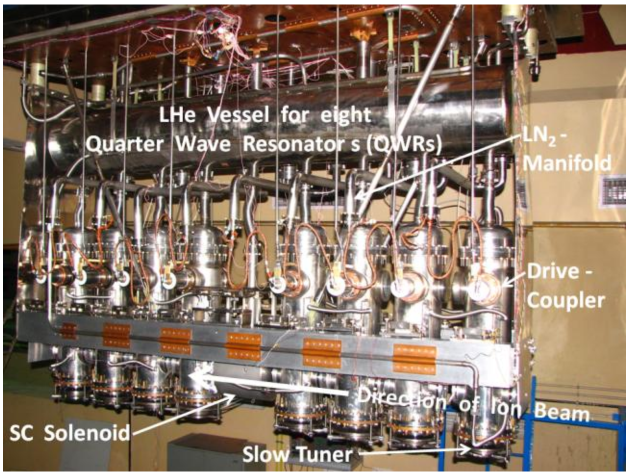

Figure 4: The first LINAC module consisting of eight superconducting niobium quarter wave resonators (QWRs) and superconducting solenoid.

A high current injector (HCI) as a versatile injection system having higher current at high charge state is being developed for injection of heavy ion beams directly to the LINAC bypassing the 15UD Pelletron. A high temperature superconducting 18 GHz ECR ion source (HTS-ECRIS) PKDELIS[9-10] requiring simpler single-stage cryostat and air-cooled cryo-cooler has been designed, developed and installed successfully (figure 6). The performance of the source is as per the design goal. Analysed beam current of more than one milli-Amperes for nitrogen, neon, argon are obtained from this source. The HTS coils have been operational without any problem since 2002. The cryogen-free HTS-ECRIS is most suitable for operation on a high voltage platform as required for our HCI program. The two axial coils are cooled by two single-stage Gifford McMahon type refrigerators to 23K for optimum operation. The performance of HTS-ECRIS is found to be excellent. The power and cooling requirements of this type of ECRIS is decreased by a factor of about 10 as compared to conventional ECRIS using copper coils.

Figure 5. Control Room for 15UD Pelletron and superconducting LINAC.

Various developmental activities of the PKDELIS have been carried out as a part of the HCI programme. Emittance measurements has given important inputs for optimizing the design of RFQ, DTL and low beta cavities. The emittance can be matched with the acceptance of the accelerators by varying the emittance parameters. X-ray Bremstraahlung studies of ECR plasma shows that it is a diagnostic tool to optimize the production of highly charged ions. The ion optics through the low energy beam transport section has been carried out to optimize the transmission.

To reduce the loading of the high voltage power supply which biases the high voltage platform and the accelerating tubes across the platform and ground, a large acceptance analysing magnet having 80mm pole gap is placed on the high voltage platform to pre-select ions from the ECR source before acceleration across the high voltage platform. The main design goals for the analysing magnet are large acceptance, minimum weight, air-cooling and reasonable mass resolution. The geometrical aberrations due to higher order terms are minimized by suitably incorporating multipole field components. The vertical focussing is obtained by incorporating increasing sextupole field components at the entrance and exit of the magnet. This is achieved by incorporating cylindrical pole shape at entrance and exit with negative radius of curvature. The horizontal focussing is obtained by introducing decreasing sextuple field component in the radial plane at the middle of the magnet.

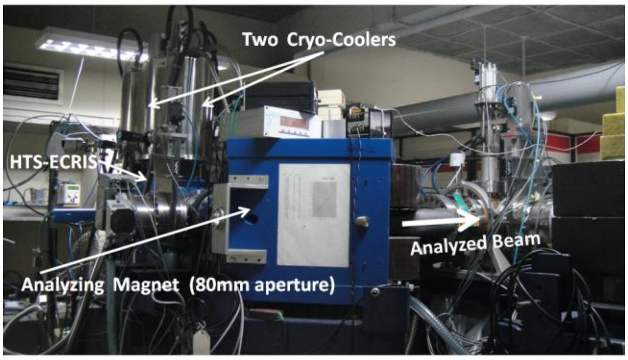

Figure 6: The HTS-ECRIS with analyzing magnet

A prototype unmodulated 48.5 MHz radio frequency quadrupole (RFQ) has been developed initially to have a detailed understanding of the various issues involved in the mechanical design, beam optical design and tests. The electrodes are in the form of four-rod structure. The bore radius and length of the electrodes are 4 mm and 1.17 meters respectively. An automated bead puller system is used to test the performance of the prototype RFQ. The prototype is a full-scale model of the final design. The design parameters like RF frequencies, shunt impedance, water cooling, tunability, mechanical vibrations and stability have been investigated with this prototype. After successful bead pull tests of unmodulated prototype RFQ, modulated vanes are fabricated (figure 7). The radio frequency quadrupole (RFQ) accelerator will accelerate highly charged particles (A/Q ~ 6) to an energy of 180 keV/u. The beam from RFQ will then be accelerated further by drift tube linacs (DTLs) to the required velocity for injection of the beams to the LINAC booster.

Six Inter-digital H type RF resonators operating at 97 MHz are being designed and developed at IUAC in collaboration with TRIUMF, Canada to accelerate ions from 180 keV/u to 1.8 MeV/u. Prototype DTL cavity with stems, ridges and cooling mechanism is shown in figure 8. A bead pull test has been carried out to measure the voltage profile across the gaps of the first prototype cavity. The voltage profile is found to be quite satisfactory. The prototype cavity having an inner diameter of 85 cm and length of 38 cm has been fabricated using SS304 material. The vacuum test has been performed successfully. The machining of the ridges, stems and drift tubes has been carried out at IUAC using the vertical machining centre (VMC) and associated facilities. Water cooling channels have been made in each of the stems and in the end walls of the cavity. Design of the chamber for the first DTL has been made and the order is placed with the vendor for manufacturing under the supervision of IUAC personnel.

Construction of two prototype low beta niobium resonators is taken up. The fabrication of two single spoke resonators for Project-X is in advanced state of completion. The first two 1.3 GHz single cell cavities performed quite well achieving high gradients. Two more improved single cell cavities are being built by RRCAT in collaboration with FNAL and IUAC. The first cavity is expected to be ready by the next few weeks. There are plans to develop 1.3 GHz 5-cell cavity and 650 MHz single cavity during next one year in a collaborative mode.

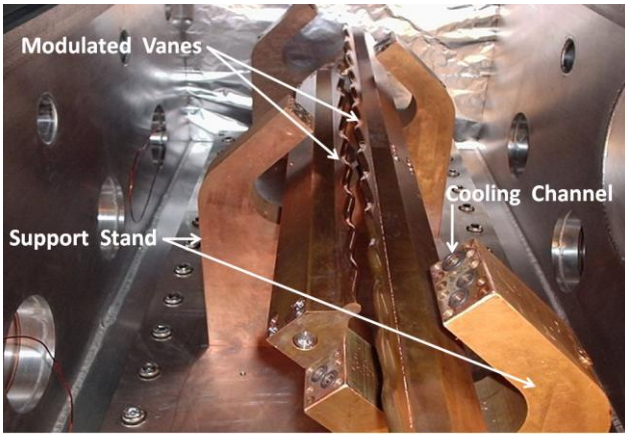

Figure 7. Modulated vanes of RFQ inside the chamber.

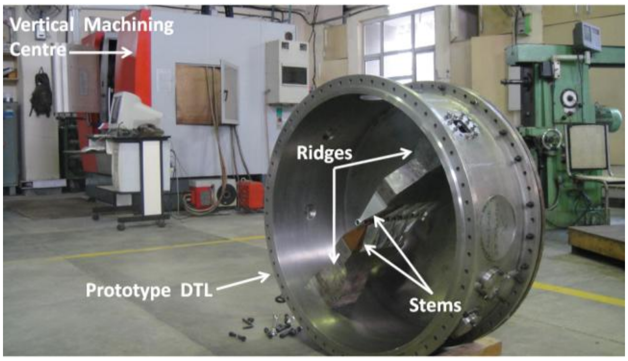

Figure 8. Prototype DTL cavity with stems, ridges, cooling mechanism, flanges.

CONCLUSION

At IUAC continuous operation and up-gradation of existing accelerators, and development of new accelerators and associated systems have been carried out successfully. The 15UD Pelletron, low energy ion beam facility (LEIBF), 1.7MV Pelletron, first module of the superconducting LINAC having eight quarter wave resonators (QWRs) are being used for this purpose. Beams from proton to gold in a wide range of energy starting from a few keV to hundreds of MeV are being delivered round the clock seven days a week for experiments in nuclear physics, materials science, atomic physics and radiation biology. Various beams from ^{12}C to ^{107}Ag from the Pelletron accelerator have been accelerated using this LINAC module for scheduled experiments. The remaining two cryostats are installed and aligned in the beam line. Off-line tests of the newly fabricated resonators for second module of LINAC are being carried out in the test cryostat. A frequency tuning mechanism using piezo actuator is developed successfully. A cryogen free high temperature superconducting ECR ion source (HTS-ECRIS) known as PKDELIS has been developed as future source of various ion beams at higher charge states as a part of future high current injector (HCI) of the superconducting LINAC. The RFQ and DTL are at an advanced stage of development as parts of the HCI. Development and fabrication of different types of superconducting resonators are being carried out for future up-gradation of existing accelerator facility as well as for collaborative projects with other national and international research laboratories.

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