SUPERCONDUCTING LINAC BOOSTER TO NSC PELLETRON

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Abstract

Nuclear Science Centre (NSC) is an autonomous organization of the University Grants Commission to provide accelerator based research facilities to universities and associated institutions. It has been running as a user facility since July 1991 with a 15 million volt tandem Pelletron accelerator. The user community presently comprises of 48 universities and large number of colleges and other institutions. Phase II augmentation of facilities consists of injecting the Pelletron beams into superconducting heavy ion booster linac modules. Niobium quarter wave resonating structure for the New Delhi booster linac has been developed as a joint project with the Argonne National Laboratory (ANL) in the U.S. A prototype cavity has been completed and operated at 4.2 K at accelerating gradient of about 4 MV/m. Resonators for a linac module having 8 QWR are under fabrication in ANL with parallel efforts for indigenous fabrication. RF instrumentation, computer control, cryostat etc. are designed and some fabrication jobs are completed. Closed loop liquid Helium reliquefication system of 600 watt at 4.5 K and a closed loop liquid nitrogen reliquefication system of 5000 watt at 82 K are commissioned. Accelerator augmentation plans for future are to have a high current injection system for linacs.

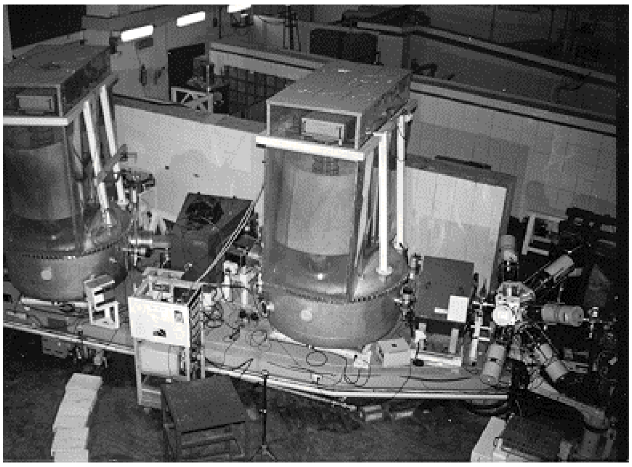
1 INTRODUCTION

Nuclear Science Centre (NSC) is established [1] by the University Grants Commission as an Inter-University Centre for accelerator based research in various disciplines. A 15 MV tandem Van-de-Graaf accelerator was commissioned in its first phase along with some state of the art experimental facilities e.g. a Recoil Mass Spectrometer, a Gamma Detector Array and a dedicated beam line for Materials Science studies with Swift Heavy Ions. During the calendar year 1997, the NSC facility was operated round the clock for 6580 hours with an uptime of 95% (similar to the preceding years) delivering a large variety of heavy ion beams of different energies as required for different research programmes. The users include nuclear physicists as well as scientists from other disciplines like materials science, atomic physics, radiobiology and radiation chemistry. In the year 1997 56% of the accelerator beam time was utilized for nuclear structure and reaction studies, 34% for materials science and 10% for other areas. Nuclear physics users await higher energies and most materials science projects need heavier projectiles of higher energies. A superconducting linac booster has been planned to augment the accelerator facilities, which will presently consist of 4 modules, each having 8 quarterwave resonators operating at 97 MHz. This will enable us to provide beams up to mass number 100 at an energy of about 5 MeV per nucleon and heavier ions of ~600 MeV. The resonator is developed as a joint project with the Argonne National Lab, USA and resonators for one module are presently being fabricated there. Cryostats, RF instrumentation, computer control, cryogenics etc. is being done indigenously. The first module is expected to be commissioned towards the end of next year.

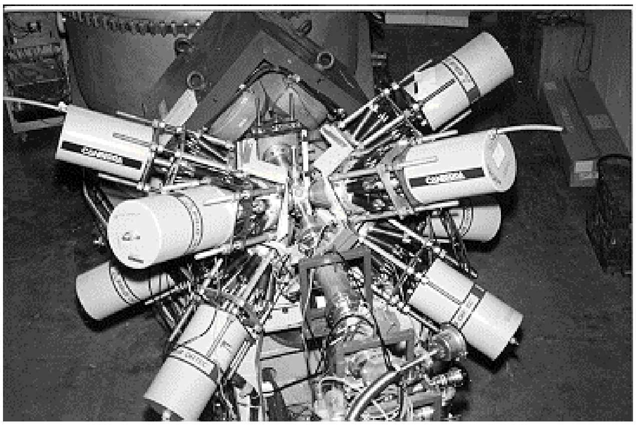
2 PELLETRON ACCELERATOR

The centre has commissioned a 15 MV tandem accelerator, the Electrostatic International Incorporation (EII). USA model 15 UD Pelletron, with compressed geometry tubes [2][3]. The Pelletron has been operating since July 1991 with better than 90% uptime. The highest and lowest terminal voltages achieved so far have been 16 MV and 2.9 MV without shorting of any unit or change of gas pressure by replacing the corona points by resistor network. Some other modifications and upgradations made are incorporation of a gap-lens before the first unit, pick-up loop for chain movement monitoring, and modifications to pulsing system. In order to achieve higher terminal voltage gas handling system is being augmented to increase the gas pressure. An appropriate differential pumping system is being installed inside the terminal to improve the machine performance during the use of gas stripper.

The Pelletron beams are predominantely used for the study of nuclear structure and reaction dynamics near the Coulomb barrier using two state of the art experimental facilities. The Heavy Ion Reaction Analyser (HIRA) is a Recoil Mass Separator with the electromagnetic configuration of QQ-ED-M-MD-ED-QQ equipped with focal plane detection system for the identification of reaction products[4][5]. A Gamma Detector Array (GDA) is commissioned [6][7] with 12 HPGe detectors with compton suppression and 14 BGO detector multiplicity filter. A Charged Particle Array (CPA) is being added to GDA which is nearing completion. Other facilities available for nuclear spectroscopy work include, Recoil Distance Measurement set-up, Mini-Orange spectrometer, Perturbed Angular Correlation system. A facility HiGrasp [7] for high energy gamma ray studies exist for Giant Resonance studies. A special stand has been installed at the target position of HIRA for mounting the gamma detectors and now HIRA-GDA are configured together, Fig.1, for nuclear spectroscopy of tagged nuclei.[8]



a) Front view of the facility



(b) Closer view of the detectors

Figure. 1: HIRA-GDA combined facility

Majority (60%) of the user community is in the area of materials science. The basic theme of research in this area [9] is electronic excitations induced modifications of the properties of the materials in which heavy ions of high energies are required. A dedicated beam line with a scattering chamber, cryogenic ladder and facilities for on-line measurements, and one UHV chamber for in-situ surface studies provide for user requirements which includes Elastic Recoil Detection (ERD) studies. There are also some users in the area of atomic physics and radiobiology. For atomic physics there is an on-line facility to measure coincidences between the recoil ions and the scattered projectiles called SCORPION [10]. Most of the research projects now need higher energies. This requirement is planned to be met by injecting the Pelletron beams into superconducting linac modules to boost the energies.

3 SUPERCONDUCTING LINAC BOOSTER

The development of superconducting linac booster for the NSC Pelletron accelerator is in progress [11] which at present aims to achieve the goal of accelerating heavy ions upto mass 100 above the Coulomb barrier. The subsystems of the project: basic accelerating structures, buncher, rf instrumentation, control and cryogenics are described.

3.1 Accelerating Structure

The first part of the linac will be composed of 32 superconducting niobium quarter wave resonators (QWR) in four linac cryostats. The resonator has been developed through a joint collaboration with Argonne National Laboratory, USA [12-15]. The resonator will

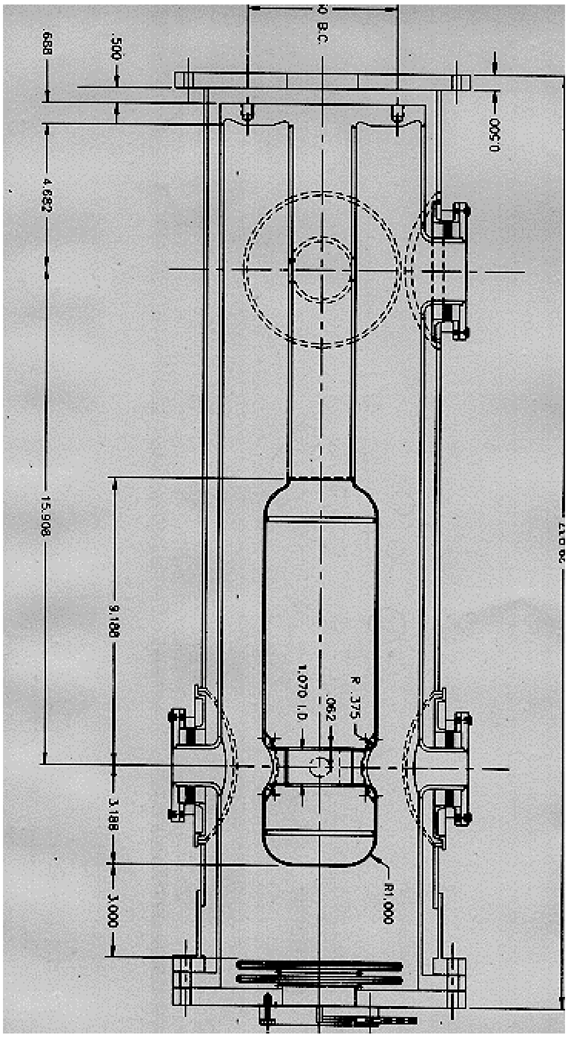


Figure. 2: Sketch of Coaxial Line quarter wave cavity for linac booster

operate at a frequency of 97 MHz and is optimized for particle velocity, β=0.08, but has a broad enough velocity acceptance that a single resonator geometry can be used for the entire booster linac, as presently envisaged. The cavity is formed entirely of niobium rather than bonded niobium-copper composite. Figure 2 shows the two-gap resonant cavity. The high voltage end is of larger diameter which shortens the cavity and also improves mechanical stability. The niobium cavity is closely jacketed in an outer vacuum vessel of stainless steel, which contains the liquid helium. A small amount of niobium - stainless steel bonded composite material is used to provide welding transition where beam and coupling ports penetrate the stainless steel jacket. A novel pneumatic slow tuner in the form of a niobium bellow provides a tuning range of approximately 100 KHz. In cold tests the resonator exceeded the design goal of 3 MV/m at an RF loss of 4W. It has achieved a field of 4.2 MV/m at 4W and 5 MV/m at 8W of RF input. The slow tuner bellows assembly has been tested at low temperatures and perform satisfactorily, providing the expected range of motion resulting in a frequency tunability of about 70 KHz and causing no observable performance degradation at high field levels.

3.2 Multiharmonic Buncher and Beam Sweeper

The existing single harmonic buncher with the Pelletron is being replaced by a single gap multiharmonic buncher of ANL design, built as a collaborative project between NSC and ANL. An efficiency of about 65% is expected from this buncher, and rest of the dc beam would be spread as dark current between two adjacent peaks separated by the bunch repetition interval of 82.5 ns (frequency of 12.125mhz). This dark current would be removed by the use of a sweeper operating at 6.06 MHz to be installed after the analysing magnet of the Pelletron.

A spiral cavity phase detector [16] installed in the beam line after the analysing magnet of the Pelletron has been providing a stable reference pulse for timing experiments and would be used for the reference phase.

Since the phase acceptance of the linac is only around 5 deg which translates to a time width of about 140 ps, the injected beam should have a time width smaller than this value. As the pre-tandem buncher would provide bunch widths of around 1 ns, further time compression will be done with a superconducting buncher using one niobium QWCL cavity housed in a cryostat.

3.3 Cryogenics

The cryogenic system consists of helium and nitrogen liquefiers, cryostats, helium purification system and cryogenic instrumentation.

A 600 W at 4.5 K helium reliquefier plant has been commissioned. In the first phase this system will provide 330 W cooling capacity without liquid nitrogen in the heat exchanger. It can also deliver 1200 watts at 60 K with the addition of another expansion engine in parallel to the warm engine. The reliquefier has been provided with two JT valves in series, to achieve 94% liquid and 6% vapour at the exit. A copper coil heat exchanger has been incorporated in the 1000 litre dewar to condense the balance 6% vapour. When used as a liquefier the machine can deliver 150 litres/hr of liquid helium. The machine is designed to respond to the dynamic load variation between 25% to 100% loads.

A helium gas purifier operating at 78K temperature along with a impurity monitor has been designed to purify helium gas obtained from the vendors before using in the refrigerator.

The closed loop liquid nitrogen reliquefier of capacity 5000 watts at 82 K, designed jointly by Nuclear Science Centre and M/s Stirling Cryogenics, the Netherlands, has been commissioned. It has delivered 5000 watts at 82K with a spare capacity of 15%. The machine efficiently responds to the dynamic load variation between 25% to 100% loads. When used as a liquefier, the machine has delivered 50 litres/hr of liquid nitrogen. The total electric power required to run the system is 35 kW.

The resonators are to be mounted in specially designed vacuum cryostats. Several such cryostats, viz, a test cryostat, buncher cryostat, magnet cryostat and the linac cryostat are designed and would be manufactured indigenously. A multipurpose test cryostat, 0.9 m in diameter and 1.8 m tall, has been fabricated in close interaction with the manufacturer and tested upto liquid nitrogen temperature. This is for cold tests of resonators and solenoids. The buncher cryostat will have a single QWCL cavity whereas the rebuncher would require two QWCL cavities. The acceleration process through a linac in the longitudinal phase focussing mode gives rise to transverse defocussing. Superconducting solenoid magnets will be employed for the transverse focussing of the beam. The linac cryostat would house eight cavities and a superconducting solenoid for transverse focussing. The cryostat design incorporates the support and alignment system for the resonators, the feed through design, cryogenic connections etc. Four such cryostats for linac modules are being planned to be installed in the beam line.

3.4 Control System for the Pelletron-Booster

A control system running on a network of PC/AT 486 or Pentium computers has been developed for the Pelletron-Linac system which supports multiple control console. The system is based on a client-server model and uses X-window software. The server is connected through a CAMAC serial highway to the accelerator. It maintains an online data base for all the client computers. However, only one client programme is allowed to access the data base at a time to avoid conflicting commands. All computers are connected via ethernet link. The computers which act as operator consoles have special hardwares which are interfaced via PC-ISA but for supporting assignable control knobs and meters for controlling and monitoring machine parameters. A CAMAC module is designed to take input from the beam profile monitors (BPM) and digitize them for computer processing. In one rotation of the helical wire for the BPM, which takes about 60 ms, 1000 samples are taken. RUN & READ commands are issued by the programme to the module, which then waits for a start signal from the BPM, digitizes a full cycle and goes to the READ mode. The fiducial information is also digitized. The computer thus has the full beam information for automatic beam control.

3.5 RF Instrumentation

Powering of superconducting resonators require special circuitry due to their high Q-factor. Several electronic modules are required to operate the linac. The resonator controller module has as inputs, the instantaneous RF field inside the resonator, amplitude reference, a master oscillator signal for the phase and frequency reference and a relative phase shift. It outputs the RF drive signal for the power amplifier which drives the resonator, a 25 KHz variable duty-cycle pulse for the PIN diode pulser module and the phase and frequency error inputs for the slow tuner module. The power amplifiers are designed for 200 W load. A clock signal distribution system to provide phase reference signals at 97 MHz and its subharmonics has been designed.

Two resonator controller modules, two PIN diode pulsers, eight channels of slow tuners and one power amplifier have all been fabricated and tested with resonators on line at Argonne Tandem-Linac Accelerator System.

4 RIB FACILITY WITH HIRA

A simple radioactive ion beam (RIB) facility for a few light ions is being created using the HIRA (see Fig.3). Primary beams from the Pelletron will be used in inverse kinematic reaction at the production target position, the desired RIB species will be separated and transported to the second target position using HIRA. A distinguishing feature of the facility compared to similar single accelerator facilities is the flexibility to transport many charge states of RIB species (including that of primary beam); e.g. for the production of ^{18}Ne RIB species using the reaction ^{3}He (^{16}O, ^{18}Ne)n at E(^{16}O)=60 MeV, both 8^+ and 9^+ are equally probable. We find that while the difference in magnetic rigidity between $^{16}O^{8+}$ and $^{18}Ne^{8+}$ is less than 0.5%, the difference in electric rigidity is >10%, hence this facility should be able to provide much cleaner RIB species in such cases. We expect RIB species like ^{7}Be, ^{8}B, ^{8}Li etc. with intensity of 10^4-10^6 pps of high purity and on a spot of ~2mm diameter will be available.

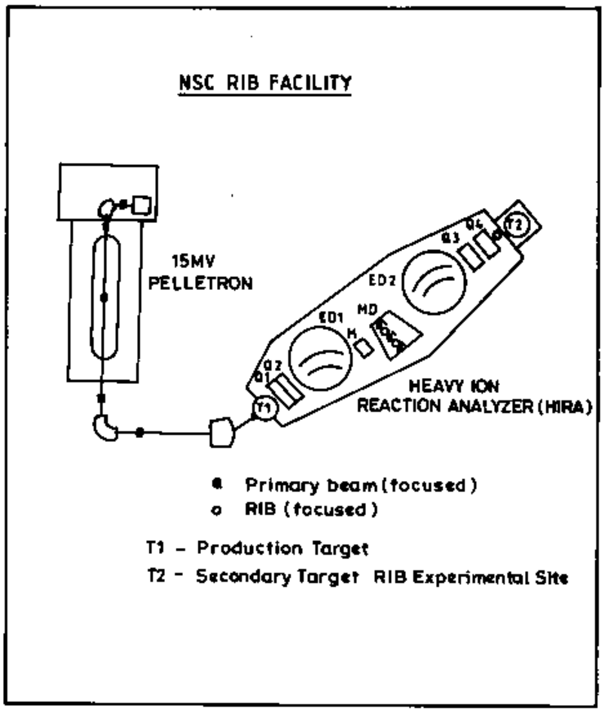


Figure. 3: Tandem accelerator based RIB facility using HIRA

5 FUTURE PLANS

The installation of 4 linac modules will enable nuclear physics experiments above the Coulomb barrier with targets right across the periodic table using the beams upto Ni in the normal kinematics mode. These beams will also provide possibilities to materials scientists to cross threshold values of electronic excitation in different class of materials. However, Pelletron linac combination has the limitation regarding the current which can be delivered. It is planned to have a high current injector to the linac in the next phase. This upgradation of the accelerator facility will consist of an electron cyclotron source, which is a copious source of high charged state ions followed by RFQ and/or low velocity resonant cavities. This acceleration before injection into linac is necessary to match the velocity profile of the transit time factor of the linac. The Pelletron will be able to provide stand alone facility for accelerator mass spectroscopy besides continuation of some projects which require lower energies/currents.

The user community is planning larger detector array and next generation recoil separator for research with augmented beams. Materials scientists are planning a dedicated beam line where stress will be on some dynamic measurements during ion irradiation and in-situ studies in UHV environment to study surface modifications in the materials produced by the electronic excitations.

6 ACKNOWLEDGEMENT

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