RECENT AND FUTURE ACCELERATOR ACTIVITIES IN INDIA

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1. Introduction

Accelerator activities started in India in late 40's when Prof. Meghanad Saha took up the construction of a 38" cyclotron similar to the cyclotron at Berkley. Since then India has constructed a number of accelerators for research, the important ones being the 224 cm Variable Energy Cyclotron Centre at Kolkata operational since 1977, the 14 UD Pelletron at Tata Institute of Fundamental Research, Mumbai and the 15 UD Pelletron at Nuclear Science Centre, Delhi, both of which became operational in the 80's.

The recent activities include adding super conducting linacs to the two pelletrons to increase the energy of the ions. Another important milestone is the commissioning of India's first Synchrotron Radiation Source, 450 MeV Indus-1 in July, 1999 at Centre for Advanced Technology, Indore and subsequent commissioning of two beam lines to utilise this radiation source. The construction of a 2.5 GeV Synchrotron Radiation Source, Indus-2 is currently in progress and is expected to be commissioned in 2003. A 142cm Superconducting Cyclotron is also under construction at Variable Energy Cyclotron Centre at Kolkata which is expected to be commissioned in 2005. India has also planned design and construction at Centre for Advanced Technology of a proton accelerator starting in 2003 which will have a 100 MeV linac as an injector and a 10-20 Hz, 1 GeV Proton Synchrotron with the average power of the proton beam being about 100 KW. This proton synchrotron will be used for pulsed spallation neutron source and initial experiments on ADSS.

2. Recent Accelerator Activities

2.1 SRS Indus-1

The Synchrotron Radiation Source Indus-1 was commissioned at Centre for Advanced Technology (CAT), Indore in July, 1999 and is now regularly in operation. Indus-1 is a 450 MeV storage which produces synchrotron radiation in VUV range with a critical wave length of 61 Å. A maximum beam current of 200 mA has been accumulated in the ring. The beam life time at 100mA is 75 minutes at present. The parameters of Indus-1 are shown in Table-1.

The details of Indus-1 are being presented in this conference by Mr. A.D. Ghodke et.al (TUSM06) hence only a brief description of Indus 1 will be given here.

Table 1 : Parameters of Indus-1

Energy	450 MeV
Current	100 mA (achieved 200 mA)
Bending Field	1.5 T
Circumference	18.96m
Operating point	1.69, 1.31
Beam Emittance εx	1.5×10^{-7} mrad
εz	1.5×10^{-8} mrad
Beam Size σx σz	0.28 mm 0.07 mm
Energy spread	3.85×10^{-4}
Momentum compaction	0.235
Chromaticities (ξx,z)-1.9,-0.3 (measured -2.6,+3.1)	
Revolution frequency	15.82 MHz
Harmonic number	2
Power loss	$0.36kW^a$; $0.05kW^b$
[a] Bending magnet; [b] high field wiggler (3T)	

Indus-1 and Indus-2 have a common injection system which consists of a microtron and a booster synchrotron. The microtron injector developed at CAT is a classical type microtron which gives 20 MeV electron beam with a current of 30mA in pulses of 1 to 2 μs duration at a repetition rate of 1 to 3 Hz. The designed emittance of the microtron is 1 πm.rad (horizontal) and 3π m.rad (vertical) with an energy spread of 0.2%. The microtron has a dipole magnet of 1.4 meter diameter which is designed to produce a nominal field of 2 KG with a uniformity of 0.2% over a diameter of 0.8m encompassing 22 orbits of the accelerating electrons. The acceleration occurs in a microwave cavity energized by a 5 MW klystron at 2856 MHz. LaB6 pin of 3mm diameter mounted in a flat face of the cavity and with a capability to provide peak emission current of more than 3 Amps is used as an electron emitter.

The booster synchrotron has a separated function type magnetic lattice which consists of six super periods, each having a dipole magnet, and a focusing and a defocusing quadrupole for tuning the ring. Injection to synchrotron is carried out at 20 MeV from the microtron by multiturn injection process. Although the booster synchrotron has been designed to accelerate electrons to energies upto 700 MeV, for INDUS-1 electrons are accelerated to 450 MeV and extracted for injection in storage ring Indus-1.

Electrons of 700 MeV energy will be injected in Indus-2 where they will be accelerated to 2-2.5 GeV and stored.

The magnetic lattice of the storage ring INDUS-1 consists of four super periods, each having one dipole magnet with a field index of 0.5 and two doublets of quadrupoles. Besides providing enhanced tuneability the present lattice design also gives improved beam emittance. For injecting electrons in the storage ring, a scheme using one kicker magnet is used. Current is built up in INDUS-1 through successive injection of electron bunches from the booster synchrotron.

The first electrons were stored at 450 MeV in INDUS-1 on 21st April 1999. After optimisation of the tune points, injection and storage of electrons in INDUS-1 became routine and the stored current gradually increased. On 8th June 1999, a stored current of 100 mA was achieved which was the design value. As with every SRS, when electrons are stored, the vacuum degrades due to synchrotron radiation induced photodesorption of adsorbed gases. This adversely affects both the life of the stored electrons and the number of electrons that can be stored for a given injector current. With time the vacuum improved and a half life of nearly 1 ½ hours could be achieved for stored current of 100 mA. With improving vacuum it was also possible to store even larger current and on 16th April 2001 200 mA was stored in INDUS-1.

Although INDUS-1 storage ring has four magnets, beamlines can be drawn only from three bending magnets since the fourth bending magnet is close to the injection septum and the transport line from the booster synchrotron. Each dipole magnet vacuum chamber has two ports thus permitting six beamlines on INDUS-1. Keeping in mind the potential users, it was decided to construct in the first phase, the following five beamlines:

1. Radiometry beamline
2. Angle-integrated photoelectron spectroscopy beamline
3. Angle-resolved photoelectron spectroscopy beamline
4. High resolution spectroscopy beamline
5. Photophysics beamline

Of these, the first beamline was to be developed by CAT, the second by the Inter-University Centre at Indore and the remaining by Bhabha Atomic Research Centre, Mumbai. The first two beamlines were commissioned in November 2000, and the third beamline is presently being commissioned. The remaining two beamlines are under various stages of completion.

When construction of INDUS-1 was started it was decided to develop most of the technologies required for INDUS-1. There were two reasons for this. First, due to embargo, importing of many of the components was becoming difficult. Secondly, developing indigenously these technologies would not only raise India's technological capabilities but will also allow us to take up construction of even larger accelerators in future. Thus it was decided to take up development of technologies of ultra high vacuum, magnets, RF and microwaves, ferrites, precision power supplies etc. and develop and manufacture all components of INDUS-1 indigenously.

2.2 SRS Indus-2

Indus-2 is a 2.5 GeV storage ring. Table-2 gives the major parameters of Indus-2. While the work on Indus-2 started in 1996 as a 2 GeV storage ring, the proposed energy was increased to 2.5 GeV in 1998 as per the recommendations of International Advisory Committee of the project. The RF frequency was also increased from 189 MHz to 505 MHz as per the recommendations of the RF experts in the committee. Subsequently all the subsystem designs were modified and work started afresh. An expanded chasman green lattice has been selected and optimised for Indus-2. The magnetic structure of the storage ring is given in Figure-1. The storage ring has 8 unit cells providing 4.5 m long straight sections. The unit cell has two 22.5^0 bending magnets, a triplet of quadrupoles for the control of dispersion in the acromat section, two quadrupole triplet for the adjustment of beam sizes in the long straight section and four sextupoles in the acromat section for the correction of chromaticities. With the pressure in the vacuum chamber in which the beam circulates less than 10^{-9} mbar the beam life time is estimated to be 24 hours. The details of each subsystems as well as their present status is presented separately in the invited talk on Status of Indus-2 in this conference by Mr. A.S. Raja Rao (MOD01). The installation and commissioning of the ring is expected to be completed by middle of 2003.

Table 2 : Parameters of Indus-2

Maximum Energy	2.5 GeV
Lattice Type	Expanded Chasman Green
Superperiods	8
Circumference	172.4743 m
Maximum Current	300 mA
Beam Emittance εx	5.81×10^{-8} mrad
εy	5.81×10^{-9} mrad
Available Straight Section for insertion devices	5
Maximum Straight length available for insertion devices	4.5 m
Beam Size σx (Cen.of bending magnet) σz	0.234 mm 0.237 mm
Beam envelope vacuum	< 1 $\times 10^{-9}$mbar
Beam life time	24 Hrs
RF Frequency	505.812 MHz
Critical Wavelength	1.98 Å Bending Magnet
	0.596 Å (High Field Wiggler)

Indus-2 has provision for 22 beam lines from dipoles and 5 beam lines from insertion devices in the straight sections. Six beam lines are expected to be fully operational by 2005.

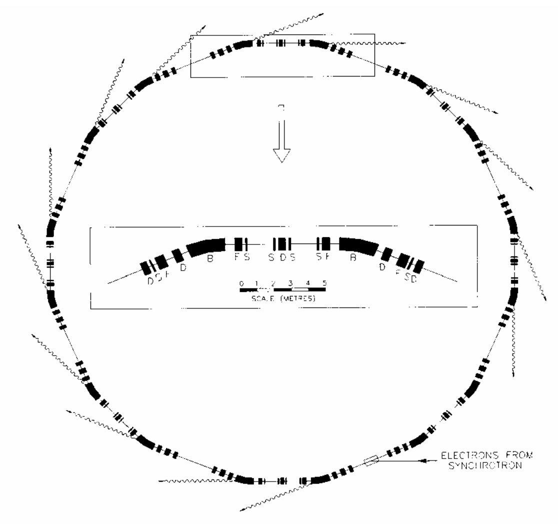

Fig-1: Layout of Indus-2

2.3 Superconducting Cyclotron

A room temperature cyclotron with K=130 is operating at the Variable Energy Cyclotron Centre (VECC) at Kolkata as a national facility for nuclear physics and allied research since 1980. The cyclotron now accelerates heavy ion beams that are produced by a 6.4 GHz electron cyclotron resonance (ECR) heavy ion source which was indigenously developed and commissioned in 1998. Low energy ions from the source are injected axially into the cyclotron. At present beams of neon and oxygen ions are accelerated.

With users demanding a higher energy cyclotron, VECC initiated a project to develop a superconducting cyclotron with K = 500.

This cyclotron will accelerate light ions to 80 MeV/Nucleon and heavy ions to 10 MeV/ Nucleons. A cross-section of this cyclotron and its main parameters are given in fig 2. and table 3. respectively.

The diameter of the superconducting main magnet is 142 cm. The superconductor is niobium-tin strands embedded in copper. This magnet is designed to give maximum hill field of 5.8 T and maximum valley field of 4.3 T. An Indian manufacturer developed a coil winding machine for this magnet. The cyclotron has three Dee's each phased 120 electrical deg. apart and each fed by a 100 kW RF amplifier in the frequency range of 9-27 MHz. The Dee voltage is 80KV maximum giving energy gain of 240 kV/turn. Heavy ions are produced in a high performance 2β mode Electron Cyclotron Resonance (ECR) heavy ion source operating at 14.5 GHz.

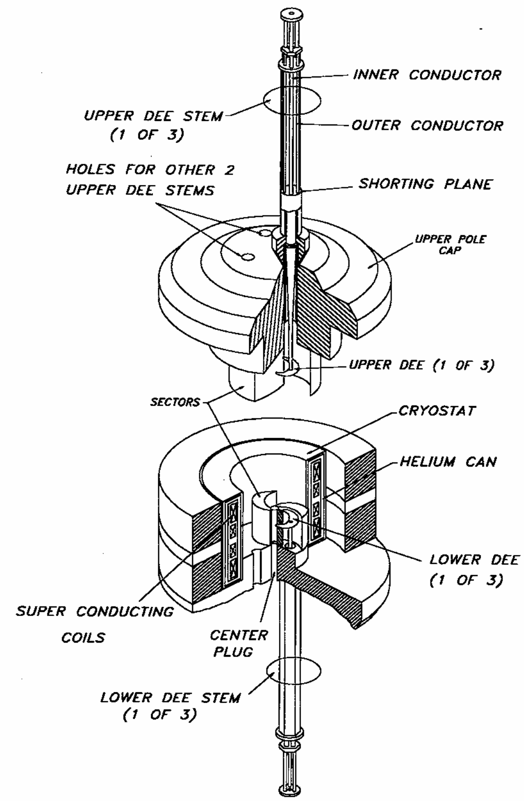

Fig. 2 : Schematic of Superconducting Cyclotron

Table 3 : Parameters of Superconducting Cyclotron

Max. Energy of Ions Light Ions Heavy Ions	 80 MeV/nucleon 10MeV/nucleon
Pole diameter	142 cms
Extraction radius	67 cm
Hill field (Max)	5.8 Tesla
Valley field (Max)	4.3 Tesla
Weight of magnet	100 Tons
RF frequency	9-27 MHz
Dee angle	3.53^{o}
Number of Dees	3
RF power	2×80 kW
Dee voltage	80 kV
Energy gain	240 kV/turn
Ion source	External ECR
Injection	Axial injection
Vacuum	10^{-7} Torr

The superconducting cyclotron is expected to be commissioned during 2005. Since Dr. R.K. Bhandari is giving a talk at this conference on this superconducting cyclotron, only a brief description is given above.

2.4 Radioactive Ion Beam

An ISOL-post accelerator type of Radiative Ion Beam (RIB) facility is presently being built at VECC, Kolkatta.

The project received approval and first level of funding in August 1997 for the phase-1. This phase is the R & D phase and will be completed by the end of the year 2002 or early 2003.

In the present scheme nuclei will be produced inside a thick target using the proton and α particle beam from the K= 130 variable energy cyclotron at VECC. The radioactive atoms diffusing out from the thick target will be ionised to q = 1+ in the integrated target-ion-source and then transported to an on-line ECRIS where q = n+ RI Beams will be produced in a novel two-ion-source mode. Alternately, in the case of gaseous activity, the radioactive atoms will be directly transported to the ECRIS by mean of a transfer tube. The desired RI Beam with an energy of 1.5 keV/u and q/A=1/16 will be separated in the low energy beam transport line after the ECRIS and will be accelerated to 80 keV/u in a heavy-ion Radio Frequency Quadrupole (RFQ) linac. Subsequently, the RI Beams will be accelerated from 80 keV/u to the desired final energy in a heavy-ion Inter digital-H linac. In phase-I RI Beams up to about n .4 MeV/u will be produced.

The major thrust in phase-1 will be in completing the R & D on the individual components of the RIB facility viz. the thick-target integrated ion-source, on-line ECRIS, the two-ion-source the pre-buncher and the RFQ and linac post-accelerators. These components will form the main building blocks of the final facility. A considerable amount of progress has been achieved in the development of the various sub-systems.

2.5 Folded Tandem Ion Accelerator

A folded tandem ion accelerator (FOTIA) has been set up at Bhabha Atomic Research Centre, Mumbai . The first beam on target was delivered in April, 2000 and was of carbon 12 ions with an energy of 12.5 MeV. The accelerator has the capability to accelerate heavy ion beams upto A~40 and beam energy upto 66 MeV with a maximum terminal voltage of 6 MV. These beams will be used for research in the field of nuclear physics, astrophysics, material science, accelerator mass spectrometry, atomic spectroscopy, and others.

The construction of FOTIA involved development of the state of the art technologies of several vital components such as high voltage generator, sulphur hexafluoride gas handling system, electrostatic lenses and advanced electronic systems.

2.6 Pelletron Facilities

A 14 UD 15 MV pelletron accelerator at Tata Institute of Fundamental Research, Mumbai is in operation since 1988. A 15 UD, 16 MV pelletron accelerator at Nuclear Science Centre, Delhi is also in operation since 1990. These medium energy heavy ion accelerators are capable of providing beams of accelerated nuclear particles such as protons, alpha particles and different types of heavy ions at energies sufficiently high for conducting nuclear research in a variety of new and interesting regimes. Upgradation work was taken up for both the pelletrons to add superconducting linacs to the two pelletrons to increase the energy of the ions. The linac booster for 14 UD pelletron at Mumbai consists of 7 modules each having 4 superconducting quarter wave resonator (QWR) to achieve an energy gain of 14 MeV/Q. These superconducting QWR are made of OFHC copper coated with Pb. All the 7 modules of the linac will be commissioned by the end of 2001. The linac booster for the 15 UD pelletron at Delhi has similar construction but uses Nb in place of Pb for the superconducting material. This is also expected to be commissioned during the year 2002.

3. Future Accelerator Activities

3.1 Spallation Neutron Source

Planning is now underway for a major accelerator, the spallation neutron source which will have a 100 MeV linac as an injector and a 10-20 Hz, 1 GeV proton synchrotron. The average power of the proton beam will be about 100 KW. Work is expected to start on this project in the year 2003 at Centre for Advanced Technology, Indore. The project has been approved in principle by the Indian Government and conceptual design is under progress. The 100 MeV proton linac will be designed for 5 mA CW current. In such a mode this linac can inject the proton beam into a superconducting linac to accelerate the protons to 1 GeV nominal energy. This could then be used for transmutation of radio active wastes or for a nuclear reactor based on accelerator driven subcritical system. India is particularly keen to use such a scheme for using its vast thorium resources .

Currently the following configuration is being explored. An ion source sill produced H+ and H- ions of 50 keV energy. The beam current for H- ions will be >20 mA. A low energy beam transport will transport this beam to a RFQ. The RFQ will have a 4 wane cavity made of OFHC copper. The operating frequency will be 350 MHz. The RFQ will accelerate protons to 4.5 MeV energy. In CW mode, a current of about 10 mA is expected from the RFQ. The proton beam from RFQ will be coupled to a DTL structure through a suitable beam transport line. The DTL section will consist of 2 tanks each having three segments, will accelerate the proton beam to 20 MeV energy. The radiofrequency of DTL section which will accelerate the protons to 100 MeV.

The 100 MeV proton beam will be injected in a proton synchrotron which will accelerate them to 1 GeV energy. The proton synchrotron will have a FODO lattice with super-periodicity of 3. The circumference of the synchrotron will be 147 m. The lattice will have 24 dipoles, 48 focussing and defocusing quadrupoles, 21 sextupoles and 6 harmonic sextupoles. The dipole field at injection will be .257 T and at extraction will be 1 T. The RF frequency at injection will be .875 MHz and at extraction 1.75 MHz. The peak RF voltage will be 100 kV giving a maximum energy gain per turn of 25 keV.

The synchrotron will be pulsed at 10-20 Hz and will give an average proton beam power of about 100 kW.

It is also proposed to construct a 30-50 MeV superconducting cyclotron to accelerate proton and or $_2H^+$ beams with ~5 mA beam current at VECC, Kolkata. The purpose of taking up these projects is to establish some technical base for developing high current proton accelerators to be used for spallation neutron sources, ADSS and ATW.

4. International Collaboration

The Department of Atomic Energy, India has major international collaboration with CERN, the European Council for Nuclear Research, Geneva in the construction of the Large Hadron Collider . India has committed to contribute in kind US$ 25 million to the large Hadron Collider (LHc) Project. CAT is coordinating this activity. So far commitments have been entered into to deliver nearly 2000 superconducting sextupole and decapole corrector magnets, nearly 3000 quench protection system power supplies, nearly 7000 precision magnet positioning jacks as well as development of software. In addition 40 man years of man power is being provided for magnet measurements. With successful collaboration with CERN, India is looking forward to similar collaboration with Asian countries in the construction of large accelerators.