India's first synchrotron radiation source Indus-1: A historical perspective

Because of its unique properties such as broad spectrum extending from far infrared to hard X-rays, small beam size and divergence resulting in high brightness, short pulse duration and possibility of getting polarized beam even in X-ray region, synchrotron radiation has emerged as a powerful tool for pure and applied research in almost all branches of science and technology as well as for applications in industries. No wonder, research with synchrotron radiation is the fastest growing area of research today. Most of the western countries either already have synchrotron radiation source (SRSs) or are building newer and more powerful SRSs. Many manufacturers of integrated circuits or Micro Electro Mechanical Systems (MEMS) have their own SRSs either for production line use or for development of new products or for research.

India's first SRS, Indus-1, became operational at the Center for Advanced Technology (CAT), Indore, in early 1999. Indus-1 is a 450 MeV storage ring which gives synchrotron radiation extending up to about 20 Å in the vacuum ultraviolet/soft X-rays. To use synchrotron radiation from Indus-1 for various experiments, six beamlines with associated experimental stations are planned. Of these, two beamlines were commissioned in November 1999 and the third one is in the final stage of commissioning. The remaining three beamlines are also expected to be ready within a few months. With the commissioning of Indus-1 and its beamlines, Indian scientists now have access to this modern tool.

Development of accelerators started in India in late forties when a project was undertaken by Meghnad Saha to develop a 37-inch cyclotron at the Institute of Nuclear Physics, Calcutta which is known as Saha Institute of Nuclear Physics. Later on, a 1 MeV Cockroft–Walton generator was commissioned at the Tata Institute of Fundamental Research (TIFR), Mumbai in 1953. In 1962, a 5.5 MeV Van-de-Graff was installed at the Bhabha Atomic Research Center (BARC), Mumbai. Though the accelerator was imported, the beam transport system and switching magnets were developed indigenously. However, accelerator development in India took a great leap in 1978 when a 224 cm diameter variable energy cyclotron was made operational at Variable Energy Cyclotron Centre (VECC) at Kolkata. Although, for this cyclotron, the design of the 88″ cyclotron at Lawrence Berkeley Lab. was adopted, all the components and sub-systems were developed and fabricated indigenously. In addition to these accelerators, several smaller accelerators were installed during this period at several universities and national laboratories.

Realizing the importance of developing accelerators in India, the Department of Atomic Energy, appointed in 1979, a committee under the Chairmanship of P. K. Iyengar, then Director, Physics Group, Bhabha Atomic Research Centre, to recommend a comprehensive long-term programme of construction of accelerators in India. After considerable deliberations, the committee recommended constructing a synchrotron radiation facility in phase-I and a proton accelerator in phase-2. This decision was based on the fact that synchrotron radiation source caters to the needs of a much larger and wider scientific community than a high energy proton accelerator.

To concretize the first phase of the recommendation of this committee, another committee was constituted under the Chairmanship of late C. Ambasankaran then Director, Electronics and Instrumentation Group, BARC, to evolve specifications of the synchrotron radiation facility. The committee conducted several workshops to survey the requirements of potential users of these sources in the universities and various national laboratories. Indian scientists had opportunities to work in several laboratories in the western world and use synchrotron radiation. Their experience and interest thus covered a wide spectrum, from surface studies requiring UV radiation to X-ray crystallography using hard X-rays. The committee, after considering these requirements of potential users and keeping in view that these accelerators have to be designed and constructed indigenously, prepared a report in December 1982 recommending construction of three SRSs with their energies in increasing order in a phased manner such that the infrastructure of the technology built up during the construction of one would be used for the next. The SRSs to be constructed under this programme, were storage rings with energies of 450 MeV, 800 MeV and 2.5 GeV. The programme also envisaged the development of a 700 MeV synchrotron as injector for the three sources. This proposal was submitted to the Government of India which approved it. Financial sanction for the entire project was received in March 1987 when work on the development of the accelerators started in full swing.

In the meantime, in 1981, the Government of India approved a proposal of the Department of Atomic Energy to establish a new research centre, namely the Centre for Advanced Technology (CAT) to take up construction of these SRSs as well as further accelerators in future and also take up a major programme on developing laser technology. A site selection committee chaired by Raja Ramanna selected the picturesque site at Indore around

Sukhniwas lake and palace which was a weekend resort of Holkars, the Maharajas of Indore. The State Government and Indore Municipal Corporation extended full support and soon the process of acquisition of land was initiated. On 19 February 1984, President Zail Singh inaugurated construction of CAT, although till then even the land acquisition was not complete. Construction of some houses, roads and a shed was initiated in 1984–85 and by the end of 1986 about 80 persons including scientists, engineers, technical and administrative staff were posted to CAT.

In March 1987, when the financial sanction for construction of Indus-1 was issued, CAT did not have any laboratories or infrastructure such as workshops, glass blowing shop, etc. However, work was initiated in Sukhniwas Palace, and in a temporary shed which was ready by then. Temporary power connection was given by MP Electricity Board but this power was insufficient even to test a single dipole magnet of Indus-1. In spite of these handicaps, there was tremendous enthusiasm amongst the scientists and engineers and soon prototypes of various sub-systems of some of the components of Indus-1 were taking shape.

While constructing Indus-1, CAT has been maintaining constant dialogue with prospective users. It soon became clear that the demand for X-rays was growing fast and the X-ray community was keen to have the SRS for X-rays much earlier than envisaged originally. In 1988, the steering committee of CAT reviewed the entire programme again and after taking into consideration user requirement it decided to construct only two SRSs of 450 MeV and 2 GeV energies. These were named Indus-1 and Indus-2 respectively. The injector system was to be common to both the SRSs.

Another decision taken was 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 ultrahigh vacuum, magnets, radio frequency (RF) and microwaves, ferrites, precision power supplies, etc., and develop and manufacture all components of Indus-1 indigenously.

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 30 mA 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 π mrad (horizontal) and 3 π mrad (vertical) with an energy spread of 0.2%. The microtron has a dipole magnet of 1.4 m in diameter, which is designed to produce a nominal field of 2 kg with a uniformity of 0.2% over a diameter of 0.8 m 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 3 mm 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 up to 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-1 where they will be accelerated to 2–2.5 GeV and stored.

The magnetic lattice of the storage ring Indus-1 consists of four superperiods, 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 21 April 1999. After optimization of the tune points, injection and storage of electrons in Indus-1 became routine and the stored current gradually increased. On 8 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 absorbed 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 1.5 h could be achieved for stored current of 100 mA. With improving vacuum it was also possible to store even larger current and on 16 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 as the fourth one 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 (IUC) at

Indore and the remaining by BARC. The first photo-electron spectrum was recorded using the IUC beamline on 9 November 2000 (see Figure 1), although the beamline was not optimized at that time and hence there was considerable noise on the spectrum. A few days later on 27 November 2000, CAT beamline also was optimized and commissioned and the first monochromatic X-ray spectrum was recorded. A week later, the first reflectivity spectrum of a platinum carbon multi layer was recorded (see Figure 2). The remaining beamlines are in various stages of completion.

Design, construction and commissioning of Indus-1 has been a team work involving a large number of scientists, engineers and technicians. There has been some criticism about the time taken to complete Indus-1. It must be remembered that when the project to construct Indus-1 was sanctioned in 1987, CAT did not have any infrastructure – neither laboratories nor workshops. The first 3–4 years were required for constructing laboratory building, workshop buildings and equipping them. Since it was decided to develop as many technologies required for construction of Indus-1 as possible, some time was spent also on these efforts. Further, sufficient power even to test dipole magnets of Indus-1 was available only in February 1994. Considering these difficulties and the fact that this is the first synchrotron ever built by the team, the delay is not inordinate. I may also comment about the time-schedule of Indus-2. Design of Indus-2, the 2 GeV storage ring was completed by 1995 and work on development of some of the components was initiated. It was decided by DAE that the design of Indus-2 should be reviewed by an international advisory committee. Accordingly, an international advisory committee consisting of SRS experts from several countries was constituted and the first meeting convened in November 1997. The committee strongly recommended major changes in Indus-2, namely, increasing the energy from 2 GeV to 2.5 GeV and increasing the RF from 189 MHz to

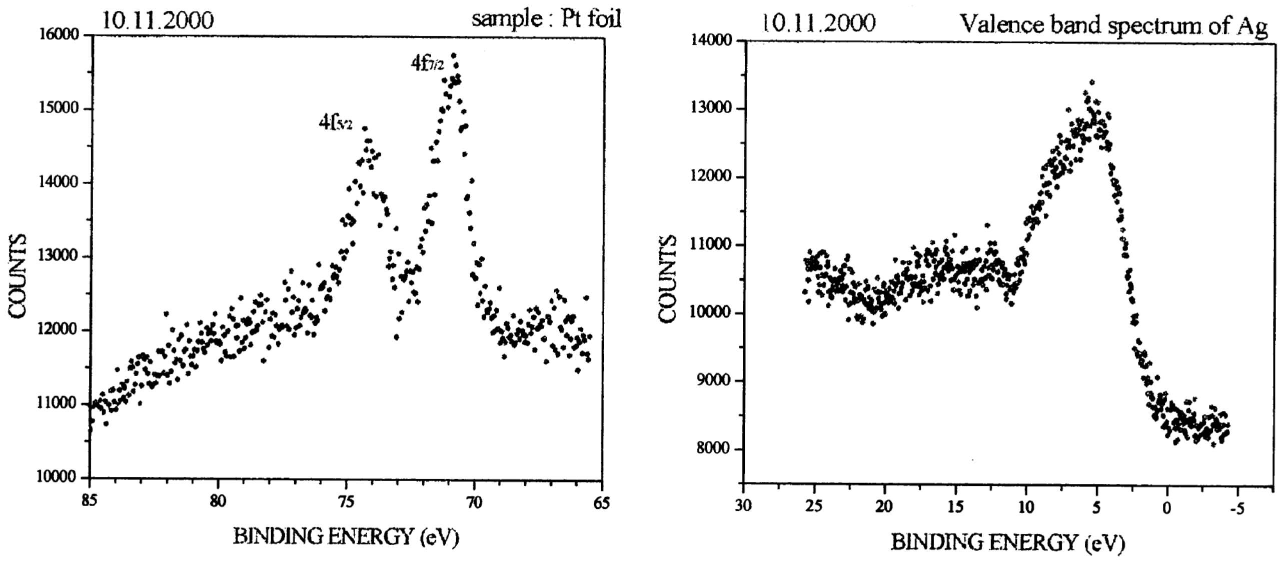

Figure 1. First photo-electron spectrum recorded using IUC–TGM beamline on 9 November 2000 at 8.20 pm.

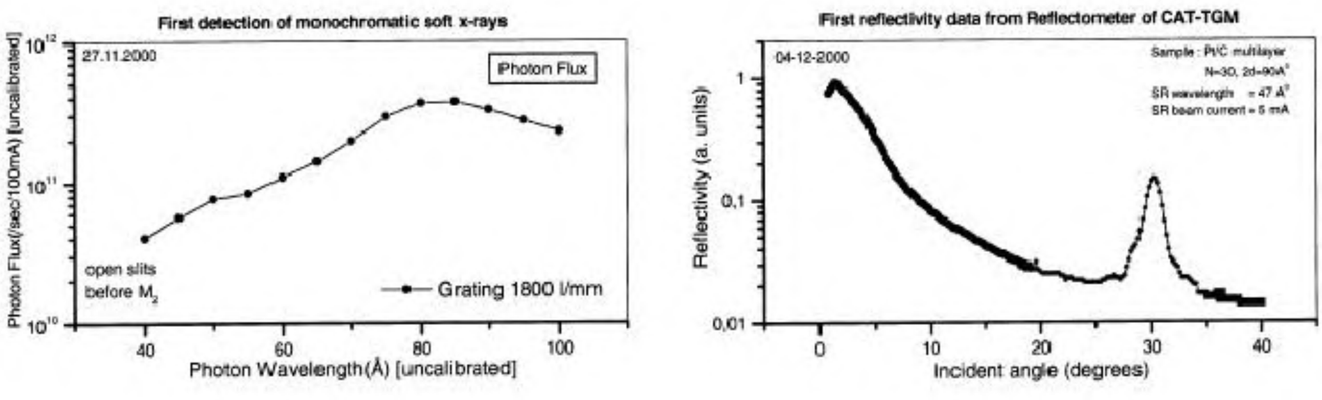

Figure 2. CAT–TGM beamline for reflectometry on Indus-1 commissioned in November 2000.

500 MHz. These recommendations were accepted by CAT and by DAE. This meant virtually redesigning the entire Indus-2 again including the lattice, magnets, RF systems and RF cavities, power supplies, vacuum systems and controls. In fact, the magnets of the 2 GeV Indus-2 were already designed, material procured and order placed with BHEL for fabricating them. This order was cancelled since with those magnets it would not have been possible to reach 2.5 GeV energy. Thus, it will be fair to say that the design and construction of the upgraded Indus-2 was started in November 1997. We expect to complete the fabrication and assembly of Indus-2 by March 2003, i.e. just over five years after recommendations of the International Advisory Committee were accepted. We expect to commission Indus-2 within a few months thereafter. This period is comparable to what is taken, for example, in Europe to construct such a synchrotron radiation source.

A few Indian scientists have been using synchrotron radiation abroad including Elettra, the 2 GeV SRS in Italy; SPring8, the 8 GeV SRS in Japan; BESSY-2, the 2 GeV SRS in Germany, etc. With the availability of Indus-1 and Indus-2, we will have facilities comparable to most of the SRS in the world. For effective use of Indus-1 and Indus-2, the number of scientists using them has to increase greatly. This can happen only when scientists become aware of the enormous potential of Indus-1 and Indus-2. The series of articles on Indus-1 and its beamlines in this issue is a beginning in this direction. I have no doubt these articles will generate interest in many potential users of Indus-1 and they will come forward to propose experiments on Indus-1.

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