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Synchrotron radiation sources INDUS-1 and INDUS-2*

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Abstract. The synchrotron radiation sources, INDUS-1 and INDUS-2 are electron storage rings of 450 MeV and 2 GeV beam energies respectively. INDUS-1 is designed to produce VUV radiation whereas INDUS-2 will be mainly used to produce x-rays. INDUS-1 is presently undergoing commissioning whereas INDUS-2 is under construction. Both these rings have a common injector system comprising of a microtron and a synchrotron. Basic design features of these sources and their injector system are discussed in this paper. The radiation beamlines to be set up on these sources are also described.

Keywords. Accelerators; synchrotron radiation; beam dynamics; x-rays; beamlines.

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1. Introduction

By late seventies, synchrotron radiation had already become well known as a powerful tool for basic and applied research in physics, chemistry, biology and medicine. Around that time, India also achieved a major milestone in accelerator technology when the 224 cm diameter Variable Energy Cyclotron built by the Bhabha Atomic Research Centre (BARC) at Calcutta became operational. Based on the experience gained in accelerator technology and considering the use of accelerators in various disciplines, the Department of Atomic Energy (DAE) appointed in 1979 a committee under the Chairmanship of Dr P K Iyengar, then Director, Physics Group, BARC to recommend a comprehensive long term programme to construct accelerators in India. After considerable deliberations, the committee recommended the construction of a synchrotron radiation facility in the first phase and a high energy proton accelerator in the second phase. This decision was based on the fact that a synchrotron radiation source will cater to the needs of a much larger and wider scientific community than a proton accelerator. In order to chalk out the specifications of the synchrotron radiation facility to be built, another committee headed by Mr C Ambasankaran, then Director, Variable Energy Cyclotron Centre and Electronics Group, BARC was constituted. This committee recommended that two synchrotron radiation sources one for vacuum ultraviolet radiation (VUV) and the other for x-rays should be built. After several discussions with potential users, it was decided to build two synchrotron radiation sources – first source, an electron storage ring of 450 MeV for the production of VUV radiation and the second one, a storage ring of 2 GeV energy for x-rays [1–4].

* Based on the keynote inaugural address delivered by Dr D D Bhawalkar at the XI NCAMP, 1997.

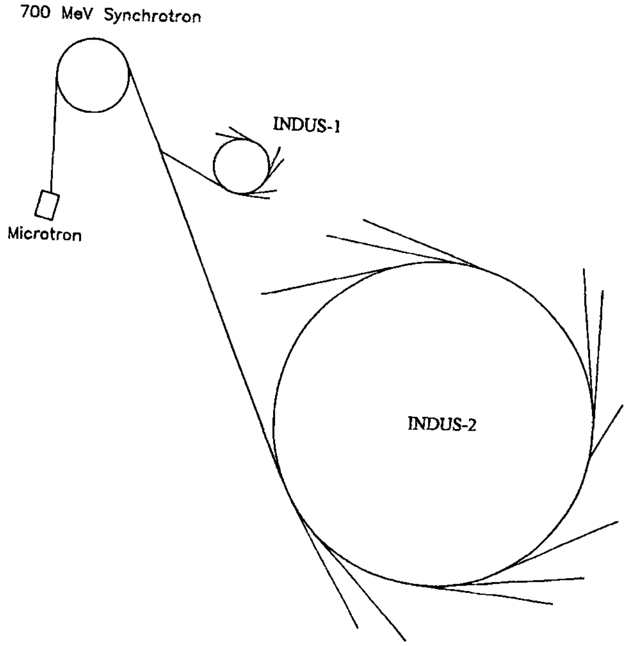

Figure 1. Schematic of synchrotron radiation facility.

These sources were named as INDUS-1 and INDUS-2 respectively. A decision was also taken by the DAE to establish a new research centre named Centre for Advanced Technology (CAT) at Indore to take up the construction of these two synchrotron radiation sources as well as further accelerators in future. It was also decided that the Centre for Advanced Technology will also take up a major programme on developing laser technology.

While planning these sources which are essentially electron storage rings, it was also decided to develop a common injector system for them. This injector system consists of a 20 MeV microtron and a 700 MeV synchrotron. A schematic of the synchrotron radiation facility is shown in figure 1. Many INDUS-2 users require the radiation of wavelength 1 Å or shorter. The flux and brightness of the radiation will be significantly higher, if the energy of INDUS-2 is increased to 2.5 GeV. This issue was discussed in the INDUS-2 International Advisory Committee held at CAT in November, 1997 and the committee recommended that the maximum energy of INDUS-2 be increased to 2.5 GeV. Presently, we are considering the possibility of increasing the beam energy by further increasing the magnetic field of magnets as this would involve minimum changes in the basic design of the storage ring.

The design work of all the accelerators and their subsystems has been carried out at CAT. All the major subsystems and components have been fabricated in the country; majority of them in CAT. In this paper, we discuss the design features and status of the injector system, INDUS-1, INDUS-2 and their beamlines.

2. Injector system

As already stated, the injector system consists of a 20 MeV microtron and a 700 MeV synchrotron. The synchrotron is designed to accelerate electrons from 20 MeV to a maximum energy of 700 MeV at a repetition rate of 1–2 Hz. Electrons are required to be accelerated to 450 MeV when they are to be injected into INDUS-1 and to 700 MeV when required for injection into INDUS-2. The injector system is shown schematically in figure 2.

2.1 *Microtron*

The microtron developed at CAT is of classical type. It is designed to give a 20 MeV electron beam with a current of 30 mA in pulses of 1 to 2 μs duration at a repetition rate of

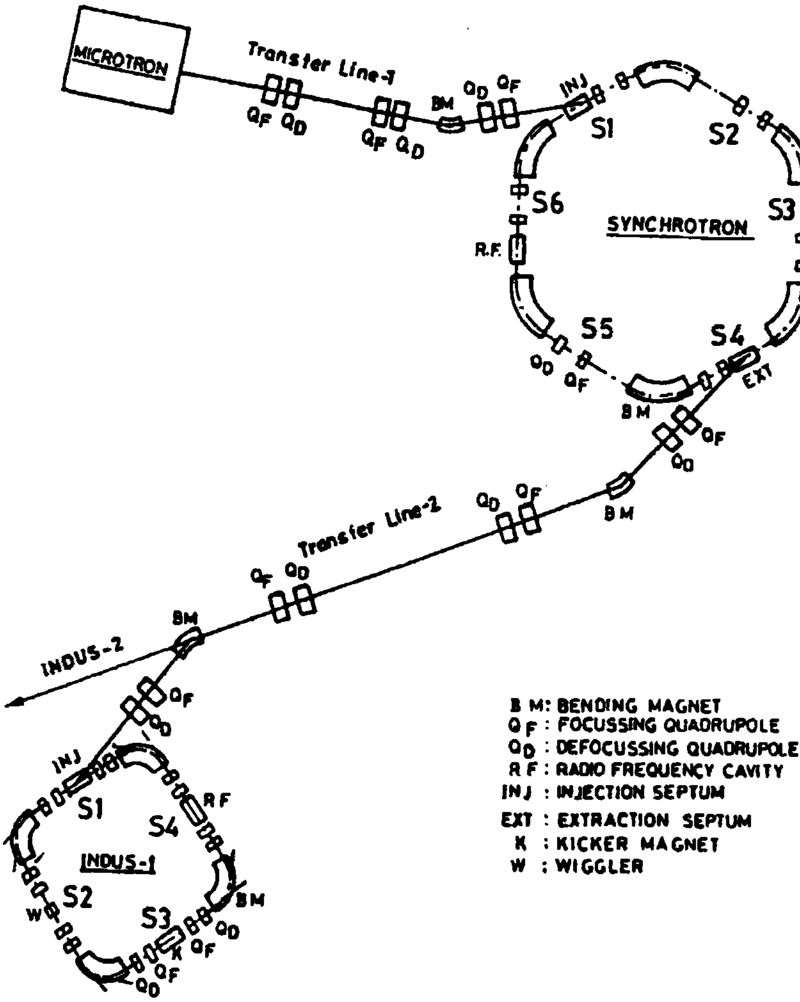

Figure 2. Schematic of injector system and INDUS-1.

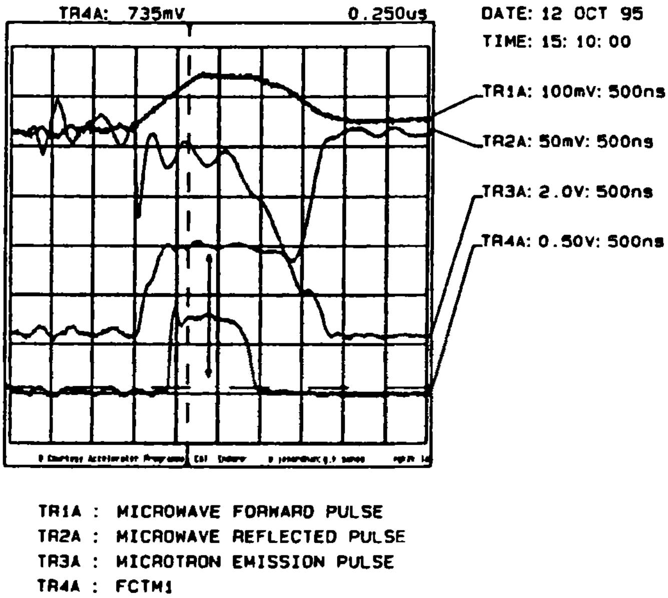

Figure 3. Various pulses for microtron. (Beam current 24 mA at the cursor.)

1 to 3 Hz. The expected emittance of the electron beam from the microtron is 1π mm.mrad (horizontal) and 3π mm.mrad (vertical) and energy spread is 0.2%. The microtron has a dipole magnet of 1.4 m diameter, which produces a nominal field of 1.2 KG with a uniformity of 0.2% over a diameter of 0.8 m encompassing 22 orbits of the accelerating electron. The acceleration occurs in a microwave cavity energised by a 5 MW klystron at 2856 MHz. A LaB_6 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 A is used as an electron emitter. The electrons emitted from the emitter are accelerated to 20 MeV in 22 orbits using the Type II injection scheme as discussed by Kapitza and Melekhin [5]. The vacuum in the microtron is better than 10^{-7} mbar.

The microtron was commissioned over three years ago. Since then it has been regularly operated to deliver 20 MeV electrons at a 20–30 mA pulse current. The pulse current is measured by means of a fast current transformer. A typical oscilloscope trace showing the current pulse (TR4A) and other parameters such as forward microwave power, reflected power and emission current is given in figure 3.

2.2 *Synchrotron*

The 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. The length of the straight section in the unit cell has been decided on the basis of the space requirement for various components such as kicker magnets, steerers, beam diagnostic devices and vacuum ports. The circumference of this accelerator is 28.44 m. The stability of the orbit at different field strengths of quadrupoles has been studied and the lattice shows stability over a wide range. From the point of view of injection and extraction, the operating tune point has been chosen to be (2.25, 1.22).

The injection into the synchrotron is carried out with a 20 MeV electron beam from the microtron. The beam is transferred to the synchrotron through the transfer line-1 which connects the microtron to the synchrotron. The beam matching requirements at the injection point of the synchrotron have been taken care of by using three quadrupole doublets and a bending magnet in the line. The electrons are injected into the synchrotron by adopting a multiturn injection scheme in which a 1 μs long electron beam pulse constitutes 11 turns in the synchrotron. Presently, the electrons are injected at a repetition rate of 1 Hz. The injection scheme involves a compensated orbit bump which is produced by means of three kicker magnets located in the straight sections S1, S2 and S6 indicated in figure 2. The electrons are accelerated in the synchrotron at a rate of 2000 MeV/s by ramping the magnetic field of the dipole magnets, quadrupoles and steering magnets. The additional energy required for acceleration and for compensating the loss due to synchrotron radiation is provided by a radio frequency cavity operating at 31.613 MHz. The accelerated beam circulates in the synchrotron in the form of three bunches having an inter-bunch spacing of 30 ns. The accelerated beam is extracted from the straight section S4 by deflecting it by a fast kicker located in the straight section S2. The rise time of the kicker magnetic field is 45 ns, this allows extraction of two out of three bunches from the

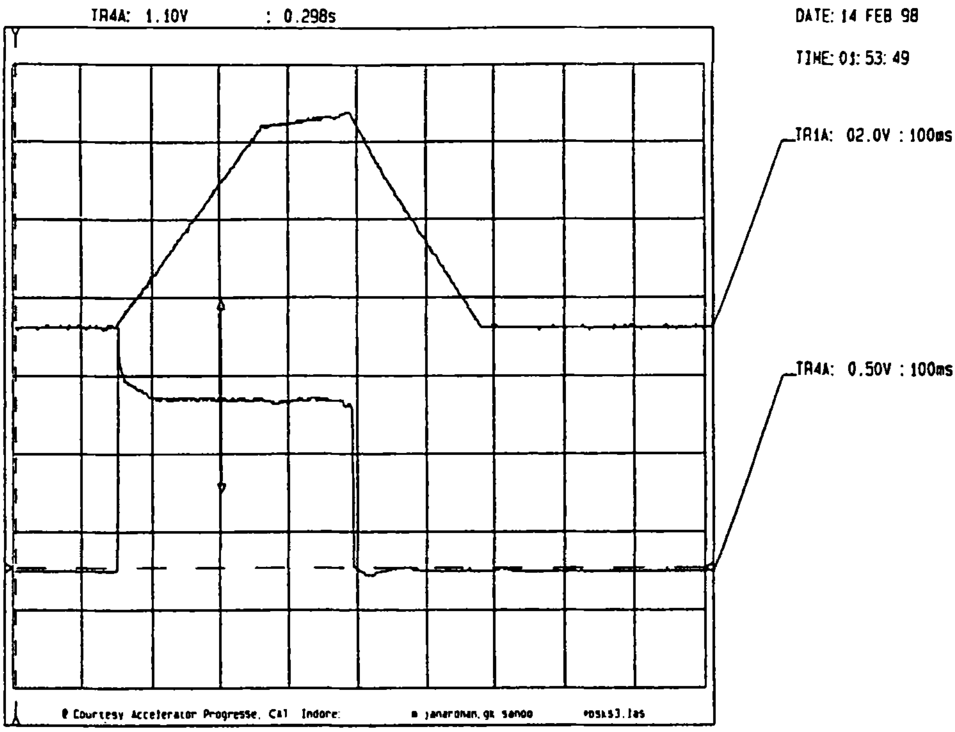

Figure 4. Beam current with dipole field ramp in synchrotron. (Beam current 11 mA at the cursor.)

synchrotron. The extracted bunches are transferred to the storage ring INDUS-1 through the transfer line-2 (TL-2), which has four pairs of quadrupole doublets and two bending magnets besides several steering magnets. For transferring electrons to INDUS-2, part of the TL-2 will be extended up to the storage ring INDUS-2.

In the synchrotron, the electrons have been accelerated to 450 MeV and the beam current of 11 mA has been achieved at this energy. The current of this magnitude was achieved after making several experiments which involved optimizing the dipole, quadrupole and steering magnet currents in the synchrotron and in the transfer line 1. Figure 4 shows the accelerated current as measured by a DCCT along with the dipole magnet ramp pulse. When the accelerated current became more than 2 mA, experiments were done to extract the beam by varying the extraction magnet current and its triggering time. Two electron bunches out of three bunches are now successfully extracted as envisaged in the design specifications. The extracted electron bunches have been transferred to INDUS-1 storage ring through the TL-2. Presently, studies are being carried out to enhance the accelerated current in the synchrotron.

3. INDUS-1

INDUS-1 is a 450 MeV electron storage ring with four bending magnets of field 1.5 Tesla and bending radius of 1 meter. The circumference of the storage ring is 2/3 of the

Table 1. Parameters of INDUS-1.

Energy	: 450 MeV
Current	: 100 mA
Bending field	: 1.5 T
Critical wavelength (l_c)	: 61.38 Å (BM)[a]
	: 30.69 Å (W)[b]
Circumference	: 18.96 m
Typical tune point	: 1.88, 1.22
Beam emittance ε_x	: 7.3×10^{-8} m.rad
ε_y	: 7.3×10^{-10} m.rad
Electron beam size and divergence	
Centre of bending magnet σ_x, σ_y	: 0.28, 0.07 mm
$\sigma_{x'}$, $\sigma_{y'}$	: 0.30, 0.01 mrad
Centre of Wiggler section σ_x, σ_y	: 0.70, 0.03 mm
$\sigma_{x'}$, $\sigma_{y'}$	: 0.14, 0.03 mrad
Photon flux[c]	: 7.2×10^{11} (BM)[a]
	: 3.2×10^{12} (W)[b]
Brightness[d]	: 7.2×10^{11} (BM)[a]
	: 3.0×10^{12} (W)[b]
Bunch length σ_l	: 11.3 cm
Beam lifetime	: 1.8 hours
Energy spread	: 3.86×10^{-4}
Revolution frequency	: 15.82 MHz
RE frequency	: 31.613 MHz
Harmonic number	: 2
Power loss	: 0.36 kW (BM)
	: 0.05 kW (W)

[a]BM: bending magnet; [b]W: high field wiggler (3T); [c]Flux in photons/s/mrad horz./0.1%BW; [d]Brightness in photons/s/mm^2/mrad^{2}0.1%BW.

circumference of the synchrotron from which electrons will be injected at 450 MeV into the storage ring. The magnetic lattice of the ring consists of four superperiods, each having one dipole magnet with a field index of 0.5 and two doublets of quadrupoles. Each superperiod has a 1.3 m long straight section. Two such straight sections will be used for beam injection. One section accommodates the septum magnet and the other diametrically opposite to it accommodates the injection kicker. A single kicker scheme similar to SOR, Japan will be used for beam injection. Of the remaining two straight sections, one is used for the RF cavity and the other to be used later for a 3 Tesla wiggler.

Besides having a wide tunability, the present lattice also provides a fairly low beam emittance. The chromaticity of the ring will be corrected by installing sextupoles in each straight section. The specifications of INDUS-1 are given in table 1 and the lattice functions are shown in figure 5. The ring has a provision to accommodate a wiggler as mentioned above. The radiation flux and brightness from the bending magnets and wiggler are shown in figure 6. The critical wavelength of radiation from the bending

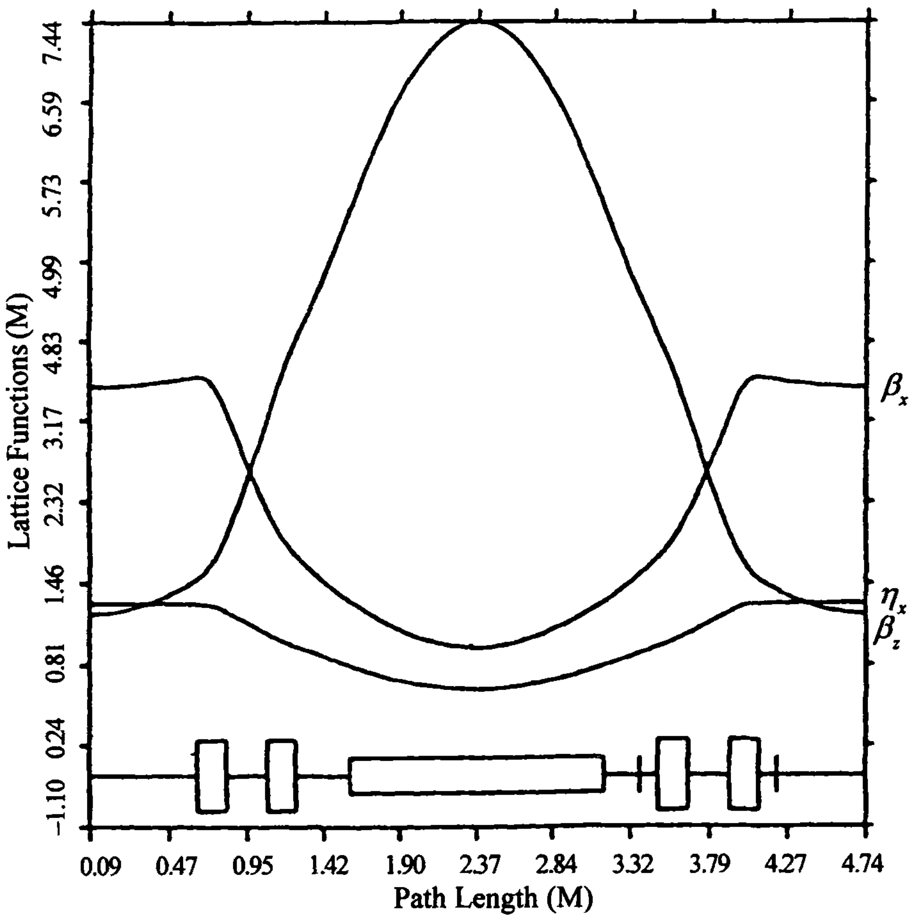

Figure 5. Lattice functions of INDUS-1.

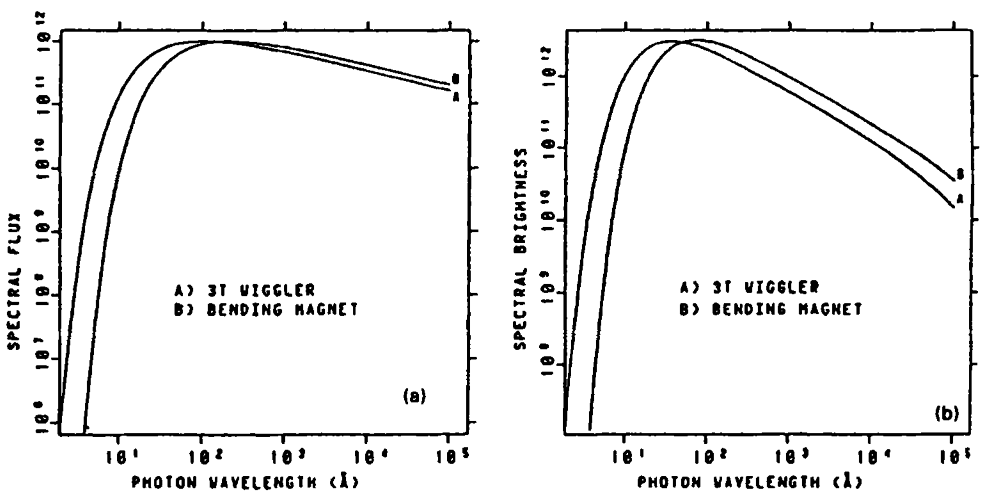

Figure 6. (**a**) Flux and (**b**) brightness versus photon wavelength for INDUS-1.

magnets will be 61 Å, whereas the wiggler will produce harder radiation having critical wavelength of 31 Å.

Presently, the injection kicker is not yet installed in the ring. However, to test the septum and other magnets in the ring, electrons were injected. By varying the current of the magnets, electrons could be circulated for 6 turns. These observations were made with the help of a wall current monitor. The injection kicker will be installed soon and subsequently, trials will be made to accumulate current in the ring.

4. INDUS-2

INDUS-2 is a high brightness x-ray source with a beam energy of 2 GeV. It is designed to accommodate a number of insertion devices and therefore an expanded Chasman Green lattice has been chosen and optimized for it. The storage ring consists of 8 unit cells each providing a 4.5 m long straight section. The magnetic structure of the storage ring INDUS-2 is shown in figure 7. Its unit cell has two 22.5° bending magnets, a triplet of quadrupoles for the control of dispersion in the achromat section, two quadrupole triplets for the adjustment of beam sizes in the long straight sections and four sextupoles in the achromat section for the correction of chromaticities. An additional advantage of this lattice is that the two 2 m gaps between the focusing and defocusing quadrupoles in the achromat section provide a lot of space for accommodating beam diagnostic and vacuum devices. The design parameters of the source are given in table 2. A similar structure with a gradient in bending magnets has been adopted for the synchrotron radiation source ELETTRA at Trieste, Italy. Though the gradient has some beneficial effects on the beam optics, we have chosen normal parallel edged magnets to avoid fabricational problems associated with gradient magnets. Of the eight 4.5 m long straight sections, one will be used for beam injection and two for RF cavities and the remaining five for insertion devices. Presently, two wigglers are planned to be installed in the ring. The remaining

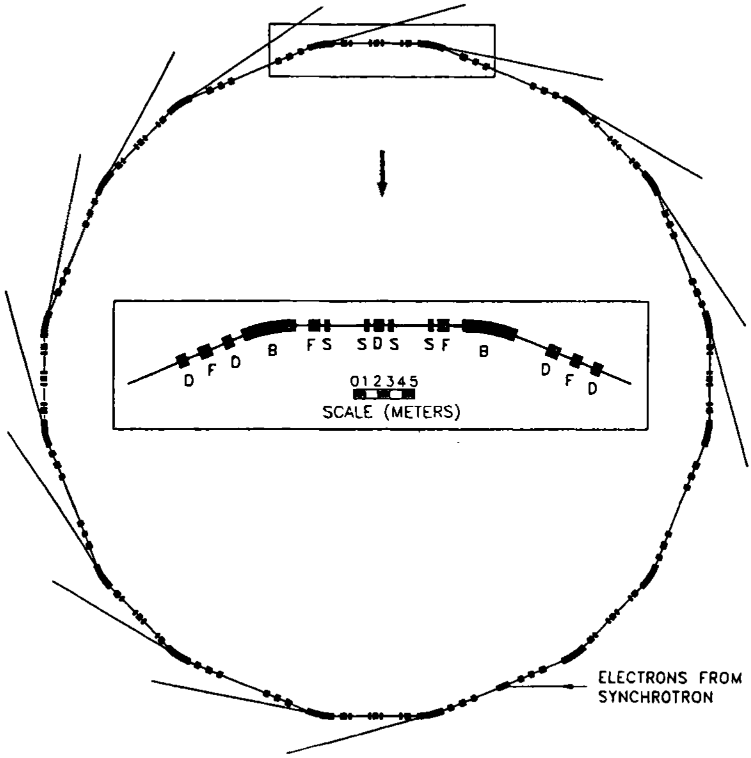

Figure 7. Magnetic structure of INDUS-2. Inset highlights a unit cell with bending magnets (B), quadrupoles (F and D) and sextupoles (S).

three straight sections will remain unused for some time leaving some scope for further development of the machine.

The length of the straight section between the focusing quadrupole and the defocusing quadrupole of the achromat has been adjusted to obtain a good decoupling of beta functions and a small beam emittance. The lattice functions at the tune point (9.2, 5.2) are shown in figure 8 in which a beam emittance of 3.72×10^{-8} m.rad is achieved with zero dispersion in the insertion section. It is found that the emittance can be reduced if one relaxes dispersion in insertion section. For the correction of chromaticities, two families of sextupoles are used per superperiod. Dynamic aperture calculations have been done using computer program RACETRACK [6]. The dynamic aperture in the presence of chromaticity correcting sextupoles is adequate from the considerations of beam injection and beam storage.

The electron beam extracted from the synchrotron will be injected into INDUS-2 through the transfer line-3 (TL-3). Besides part of TL-2, TL-3 consists of 4 FODO cells, two achromatic bends and six independent quadrupoles to match the beam parameters at the injection point of INDUS-2. Total length of TL-3 is $\sim$ 90 metres.

The synchrotron will provide two bunches each around 1 ns long separated from each other by nearly 30 ns at the required energy at a repetition rate of 1–2 Hz. After injecting

Table 2. Parameters of INDUS-2.

Energy	2 GeV
Current	300 mA
Bending field	1.2 T
Critical wavelength (l_c)	3.88 Å (BM)
	0.93 Å (Wavelength shifter)
	2.59 Å (MW)
Circumference	172.2781 M
Typical tune point	9.2, 5.2
Beam emittance ε_x	3.72×10^{-8} m.rad
ε_y	3.72×10^{-9} m.rad
Electron beam size and divergence	
Centre of bending magnet σ_x, σ_y	0.187, 0.190 mm
$\sigma_{x'}$, $\sigma_{y'}$	0.287, 0.050 mrad
Centre of insertion section σ_x, σ_y	0.722, 0.086 mm
$\sigma_{x'}$, $\sigma_{y'}$	0.052, 0.043 mrad
Bunch length $2\sigma_l$	3.00 cm
Beam lifetime	20.0 hours
Energy spread	7.2×10^{-4}
Revolution frequency	1.740 MHz
RF frequency	189.678 MHz
Harmonic number	109
Power loss	76.3 kW (BM)
	4.3 kW (WSH)
	5.2 kW (MW)

BM: Bending magnet; MW: Multipole Wiggler (1.8 T); WSH: Wavelength shifter (5 T).

several pulses at 700 MeV to accumulate 300 mA, the beam will be accelerated to 2 GeV by slowly increasing the magnetic field of the bending magnets. The beam will be injected in the horizontal plane via two septum magnets (one thick and another thin one) by a multiturn injection process in one of the 4.5 m long straight section by employing a compensated bump which will be produced by means of four kickers.

As an x-ray source, INDUS-2 is envisaged to provide radiation from bending magnets and wigglers. Its beam energy of 2 GeV is adequately high to produce powerful x-rays from these devices. The magnetic field in a bending magnet at 2 GeV will be 1.2 T which will generate radiation of critical wavelength 3.87 Å. One wiggler will be a 11 pole electromagnet with a magnetic field of 1.8 T. This will provide radiation of critical wavelength 2.6 Å and flux and brightness an order of magnitude higher than the bending magnets. The other will be a superconducting wavelength shifter with a peak field of 5 T. The critical wavelength of its radiation will be 0.9 Å and this device will provide a good flux and brightness even up to much shorter wavelengths say 0.2 Å. The spectral flux and brightness for these devices is plotted in figure 9. A coupling constant of 10% has been taken into consideration. When the coupling constant is lower, the brightness will be higher. It is possible to operate INDUS-2 at any energy between 700 MeV and 2 GeV. At lower energies, the emittance of the ring will be much lower and source can be used to produce radiation of much higher brightness.

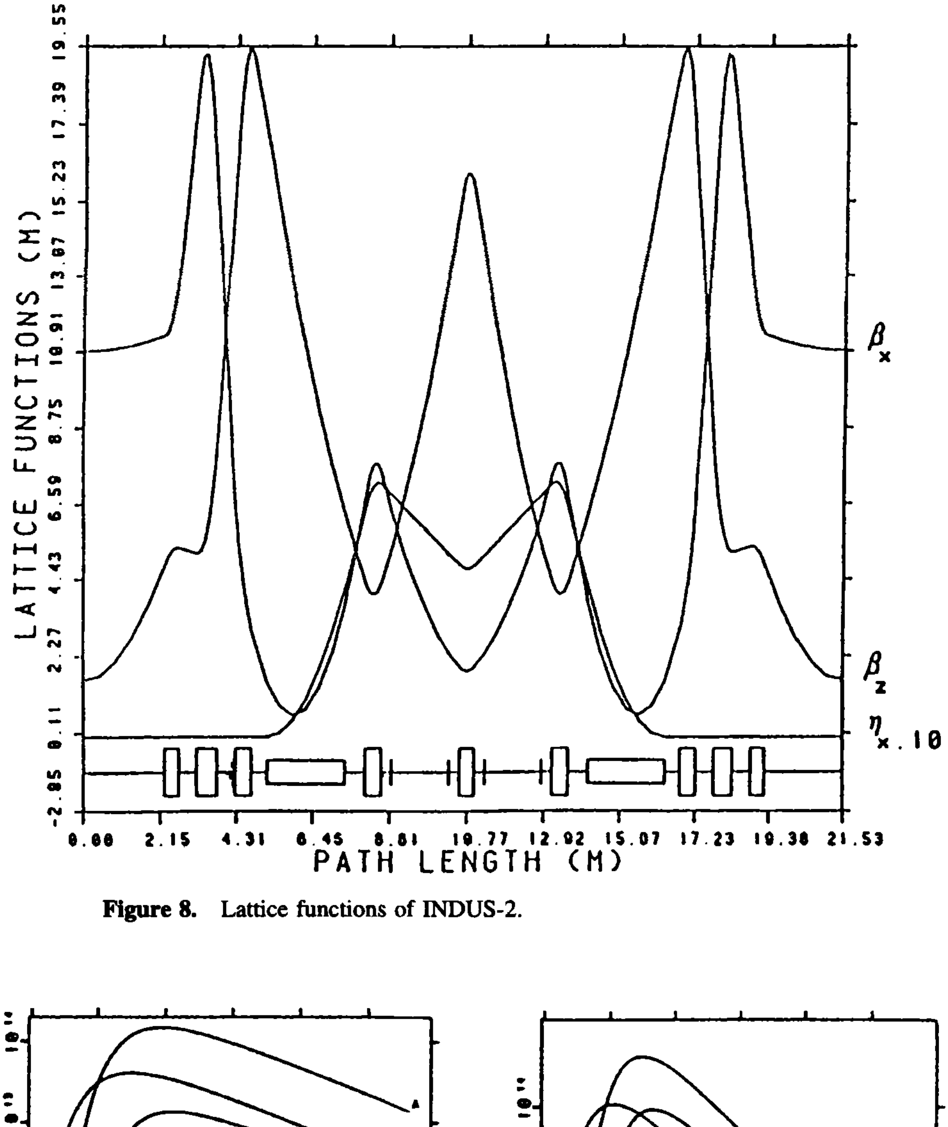

Figure 8. Lattice functions of INDUS-2.

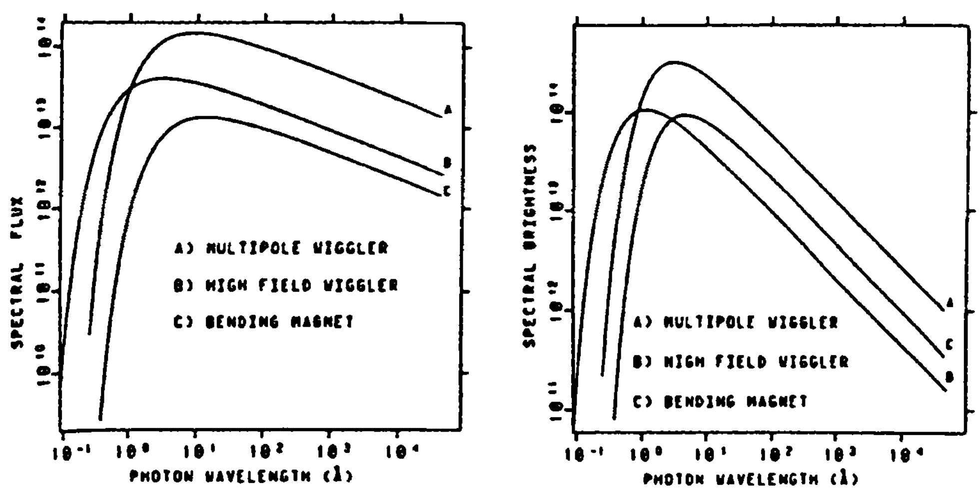

Figure 9. (a) Flux and (b) brightness versus photon wavelength for INDUS-2.

5. Subsystems

5.1 *INDUS-1 and injector system*

In this section, we briefly discuss the basic features of magnets, RF system, vacuum system, controls, power supplies and beam diagnostics used in the microtron, synchrotron and INDUS-1. All the subsystems and components have been designed at CAT. While most of them have been fabricated at this centre, some of them have also been fabricated in other organizations in India including private industries.

Dipole magnets of INDUS-1 are made of forged steel blocks and that of the microtron of carbon steel. All other dipoles, quadrupoles and sextupoles have been made from 0.35 mm thick laminations of cold rolled grain oriented (CRGO) silicon steel. For septum magnets, 0.1 mm thick laminations of Ni–Fe alloy were used. Kicker magnets of the synchrotron and the storage ring INDUS-1 have been fabricated using different types of indigenously developed ferrites. For characterization of these magnets, a PC/CNC based magnetic field mapping system has been developed.

Regulated power supplies have been made for dipoles, quadrupoles, sextupoles and steering magnets. In the storage ring, DC current regulated power supplies are used to energise the magnets to get stable constant magnetic fields. In the synchrotron, the magnetic fields of dipole, quadrupoles and steering magnets are varied with time following trapezoidal wave shape. The power supply used for the dipoles in the synchrotron provides a waveform in which the current increases from 20 A to 1000 A and due to inductive effects the overall voltage also increases from 6 V to 1.6 KV. The stability required for dipole and quadrupole power supplies is $\sim 10^{-4}$. Pulsed power supplies required for the septum and injection kicker magnets are voltage regulated and their currents are sine wave of half periods of few tens of microseconds with peak currents of hundred amperes repeating at 1 Hz. The extraction kicker power supply delivers a fast current pulse with a rise time of 45 nsec and a peak current of 800 A.

Two RF cavities having an operating frequency of 31.613 MHz, one for the synchrotron and the other for the storage ring INDUS-1, have been made. These are fed by two 12 kW RF power sources which mainly consists of a frequency synthesizer, a 200 W solid state driver amplifier and a power amplifier. Both the amplifiers have been built using indigenous components. The RF cavity of the microtron has an operating frequency of 2856 MHz. Several such cavities were made to optimize the performance of the microtron.

The vacuum system has been designed to maintain a pressure less than 10^{-9} mbar in INDUS-1 and 10^{-7} mbar in the synchrotron, the transfer lines and the microtron. The vacuum pumps used in these accelerators include turbo molecular pumps (TMP), sputter ion pumps (SIP) and titanium sublimation pumps (TSP). All vacuum chambers are made of stainless steel. The vacuum chambers for dipole magnet sections of INDUS-1 have a box type design with two tangetial ports, one for tapping synchrotron radiation and other for a distributed ion pump. The chambers for the straight sections of INDUS-1 have been fabricated using SS tubes. For the synchrotron, to avoid magnetic field distortion due to eddy currents, SS, bellow type chambers with a wall thickness of 0.3 mm have been developed. There was no need to construct the vacuum chamber for the microtron. In this case, the beam chamber is formed by employing a suitable construction of magnet poles.

The design of the control system for these accelerators is based on a modular and distributed architecture. The control system is a distributed processor network comprising personal computers serving intelligent work stations and a number of microprocessor based device controllers dedicated to the task of data acquisition, monitoring and control. As for the beam diagnostic devices required for the operation of this facility, fluorescent light monitors and current transformers have also been developed at CAT. The beam position monitors have been developed in collaboration with BINP, Russia. A DCCT for DC current measurements was procured from Bergoz, France.

A separate building has been constructed for INDUS-1. This building will also house the radiation beamlines and their user laboratories. It has a floor area of 3700 m^2. The main hall housing INDUS-1 and the synchrotron has a 10 MT capacity EOT crane with about 8 m clear headroom under the crane hook, while the rest of the area will provide 4.5 m headroom. A low conductivity water plant has been installed in the north side of the building. RCC foundation have been provided for the installation of dipole magnets. The entire building is air conditioned to maintain a clean environment and stable temperature conditions (25 ± 1°C, 50% RH).

5.2 *INDUS-2*

The dipole magnets will be fabricated from low carbon steel having carbon less than 0.1% and all other impurities to the minimum possible levels. Since the magnets are to be ramped, the magnet core will comprise of several 40 mm thick plates stacked together with interplate insulation. Quadrupole and sextupole magnets will be made from laminations. The material for stamping is CRGO silicon steel of 0.35 mm thickness. Septum magnets will be laminated and will be made from nickel iron stampings, whereas kickers will be made of high frequency ferrites.

The dipoles, quadrupoles, sextupoles and steering magnets will be energised by DC power supplies. The current of the power supplies will be slowly ramped as the energy of electrons is increased. INDUS-2 being a high brightness source, it requires a power supply with a stability of 5.10^{-5} for the dipole magnets and $\sim 10^{-4}$ for the quadrupoles. The dipole power supply energising all the dipoles connected in series will provide a current of 900 A at 850 V. Pulsed power supplies will be used for injection septa and kickers. The pulse shape for these will be half sine waves with a width of 200 µs for the thick septum, 20 µs for thin septum and 6 µs for kicker magnets. These pulsed power supplies will deliver currents of hundreds of amperes.

The RF frequency chosen for INDUS-2 is 189.678 MHz which is 6 times that of the synchrotron. However, we are in the process of changing the frequency to 505.4 MHz in view of the easy availability of the RF devices and technical knowhow at this frequency. The design details of 505.4 MHz RF system are being worked out. As regards the 189 MHz system, most of the details are known and in this case three RF cavities one producing a gap voltage of 750 KV and each one of the other two producing 375 KV will be required to store a beam current of 300 mA. These cavities will be capable of delivering 90 KW power to the beam.

A vacuum better than 10^{-9} mbar will be maintained in INDUS-2. The choice of material for the construction of the ring vacuum envelope including the bending magnet chamber is aluminium alloy AA-5083H321. The chamber design is optimized to keep the cross-section variation to minimum. Baking of the chamber is envisaged by circulating pressurized hot water. The pumping system comprises TMPs for roughing and baking, SIPs and TSPs for getting ultimate vacuum of the order of 10^{-10} mbar. Non-evaporable getter pumps are proposed to take care of the additional gas load due to synchrotron radiation.

The control system for INDUS-2 will be similar to that of INDUS-1. Control system architecture is a three layer system. The top layer consists of control room computers serving as user interface, operator consoles, file servers, data base managers and alarm computers. The middle layer consists of local process computers responsible to monitor and control various subsystems. The third layer is formed by equipment interface units (EIU). All these computers will be standard PC/AT 486 and Pentium with good graphics facilities. EIU will be realized by integrating different VME modules which will be developed in house. The computers are connected over two layers of network. The control system shall provide both audio and video communications.

The beam diagnostics being planned will meet all the beam physics requirements during commissioning and during smooth operation of the ring. A number of diagnostic devices such as beam position monitors, a radio frequency knock out device, synchrotron light monitors, stripline monitors, fluorescent screens, wall current monitors, a DCCT will be included in the ring.

A new building of about 12000 square meters is required to house accelerator systems of INDUS-2, its experimental beamlines and support laboratories. A 10 MT EOT crane will be installed inside the shielded ring. The open area, open to sky, is not accessible during accelerator operation. Adequate care has been taken in the structure to provide a high degree of stability for the components of the ring and experiments. The experimental hall is a polygon-near circular structure with a folded plate type roof. This hall provides about 18 m wide column free space for both the experimental beamlines and accelerator subsystems. A low conductivity water plant is being set up in a building adjacent to INDUS-2 building. The temperature inside the building will be maintained at 25 ± 1°C.

6. Beamlines

6.1 *INDUS-1 beamlines*

INDUS-1 storage ring has four bending magnets with a radius of 1 metre. Beamlines are drawn from only three bending magnets as the fourth bending magnet is close to the injection septum and the transport line. The beamlines which will be tapped from these three bending magnets [7] are shown in figure 10. The dipole magnet vacuum chamber has two ports, one at 10 degrees and other at 45 degrees. From each port two beamlines can be tapped and in all 9 beamlines can be laid down.

The front end of the beamlines consists of a fast acting shutter of closing time of $\sim$ 5 msec and a pneumatically operated slow closing gate valve (closing time $\sim$ 1 sec). In the initial stage it is proposed to operate two beamlines with one front end system. Thus three such front end systems are under construction.

Although nine beamlines can be extracted from these three bending magnets, initially only six beamlines are going to be commissioned. Inter University Consortium of the

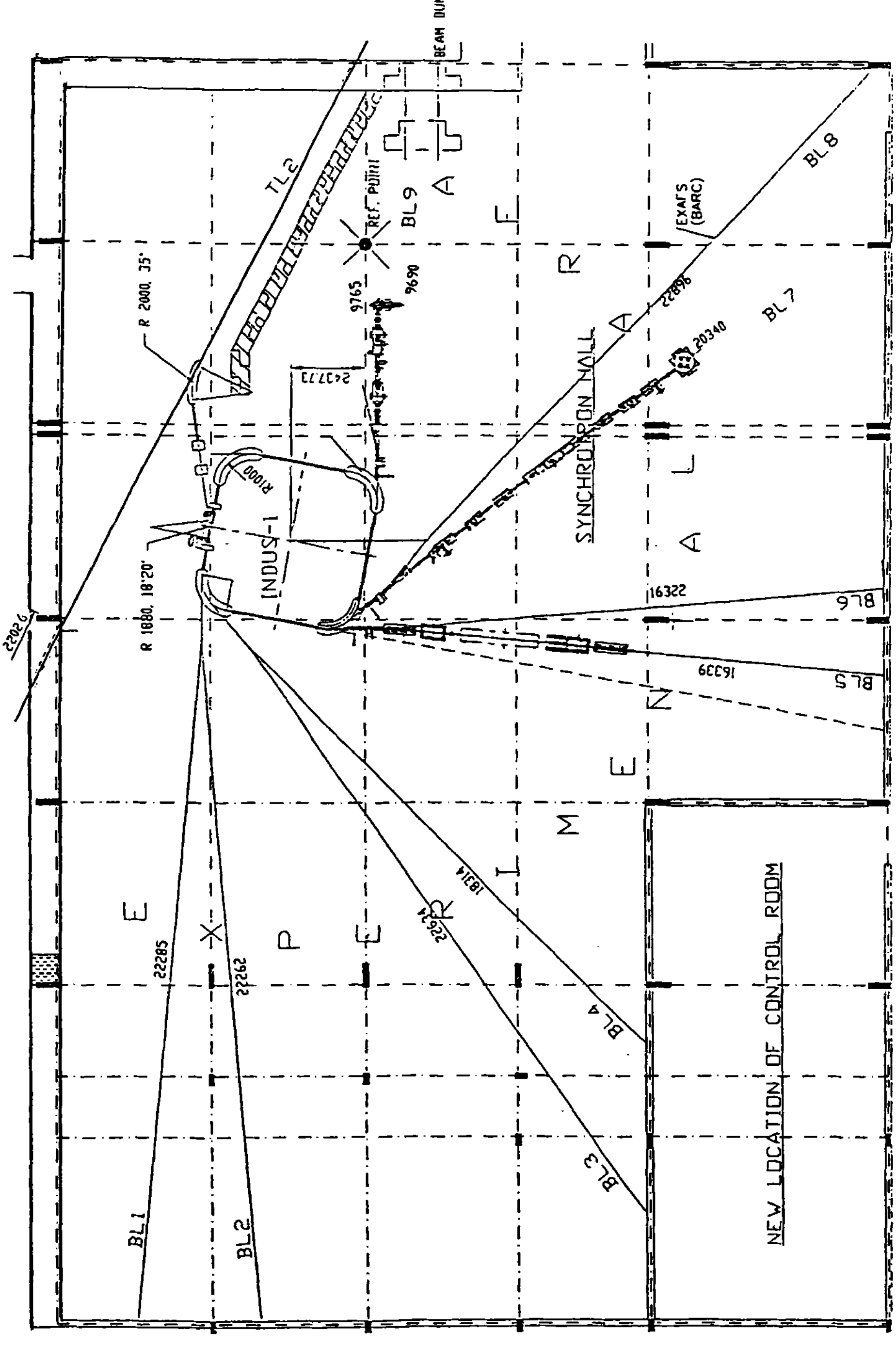

Figure 10. Schematic layout of beam lines in INDUS-1.

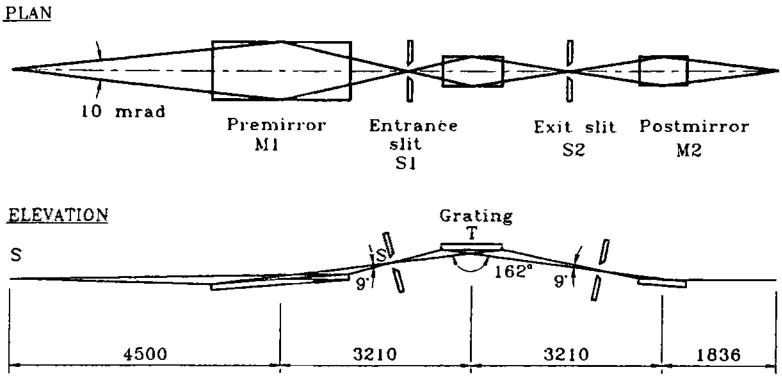

Figure 11. Optical layout of metrology beamline on INDUS-1.

University Grants Commission of India is building a beamline for the angle integrated photo emission beamline. The remaining five beamlines are being constructed by CAT/BARC. These beamlines are briefly described below:

6.1.1 *Metrology beamline*: This is a toroidal grating monochromator based beamline with toroidal mirrors as pre- and post-focusing optical components. The wavelength range that will be covered by this monochromator by using three interchangeable gratings is from 40 Å to 1000 Å with a moderate resolution of $\sim$ 500. This beamline will be a general purpose beamline and would have a reflectometer end station to check the reflectivity of optical elements like mirrors, multilayers components etc. The optical layout of this beamline is given in figure 11 [8].

The reflectometer chamber is 700 mm in diameter and 510 mm in height. A goniometer is fixed into this on which specimen will be mounted. The detector will have a soft x-ray detector (photo diodes with end cap removed). The sample and the detector will be moved in 0–20 geometry. The spectrometer will be controlled through a computer.

6.1.2 *Photo physics beamline*: This is a Seya Nomioka monochromator based beamline which will cover wavelength range from 150–3000 Å. The pre-mirror is a toroidal mirror installed at a distance of 2.5 metres from the source point. The acceptance angle of the mirror is 45 mrad horizontal and 6 mrad vertical. The 1 metre SM monochromator was fabricated in house with a designed resolution of 0.5 Å at 1000 Å with 100 micron slit width. The post focusing mirror is again a toroidal mirror which focuses a monochromatized beam of photon from the exit slit of the monochromator on to the sample in the sample chamber with an expected flux of 10^{10} ph/sec. This beamline will be used for time resolved spectroscopy.

6.1.3 *VUV spectroscopy beamline*: A 6.65 metre off axis Eagle mount spectrograph will be used as a monochromator. The pre-optics consists of three cylindrical mirrors to focus a 60 mrad (H) and 6 mrad (V) divergent beam to the entrance slit of the spectrograph. The beamline will cover the photon energy range from 4–40 eV with a resolution of $2 * 10^5$. The beamline is intended to be used to carry out high resolution studies of atoms and molecules. For these purposes, the sample in the vapor state will be kept in the absorption cells. To study refractory materials an absorption cell with a high temperature furnace is planned.

6.1.4 *Photoelectron spectroscopy beamline*: This is again a toroidal grating monochromator based beamline with toroidal mirrors as pre- and post-focusing optical elements. The monochromator has a focal length of 1414 mm. The wave length that will be covered by this monochromator will be the same as that of the metrology beamline. The photo electron spectrometer has been designed to perform experiments both in the angle resolved and the angle integrated modes. The angle resolved energy analyser is a 100 mm mean diameter hemispherical electrostatic analyser. This hemispherical analyser is coupled to a two axis goniometer placed in an ultra high vacuum chamber. The analyser can be rotated through 360° in both the planes, parallel and perpendicular to the sample. The rotation about either axis is independent of other. However in the actual set up the rotation in the parallel plane is restricted due to the presence of other hemispherical analyser to be used for the angle integrated photoemission spectrometry. The angle integrated analyser has been provided with an acceptance angle of 22.5° to facilitate collection of the photo electrons from the entire sample and with an expected resolution of 100 meV at 50 eV band pass energy. The ultra high vacuum chamber of the spectrometer is also provided with an LEED/Auger apparatus, an ion gun for sample cleaning, a sample preparation chamber and a sample transfer mechanism.

6.1.5 *Photo absorption spectroscopy beamline*: This beamline will be used to study L-edge absorption spectroscopy. The perfecting optics will be an elliptical mirror. A plane grating monochromator will be used as the dispensing element. The wavelength range that will be covered is from 20–1225 Å. The resolution is aimed at $\sim$ 1000.

6.2 *INDUS-2 beamlines*

In INDUS-2, four beamlines are planned in the first phase. These beamlines are for experiments in EXAFS, trace element analysis, diffraction and magnetic circular dichroism (MCD). The EXAFS and trace element analysis beamlines will be built on bending magnets. The diffraction beamline will be built on a high field wiggler and MCD beamline will be built on an elliptical undulator whose specifications are yet to be finalized.

7. Conclusion

The microtron and synchrotron have been fully commissioned. Initial trials for circulating electron beam in INDUS-1 in the absence of the injection kicker were successful. It is hoped that after installation of the kicker, it will be possible to store electrons in this ring and the ring will be available to users towards the end of 1998. Most of the INDUS-1 beamlines are ready to be installed on the ring. The development work on INDUS-2 is in full swing. The building is scheduled to be completed by 2000 and with the experience gained commissioning INDUS-1, this ring will be operational by 2002.

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