CAT NEWSLETTER

T.1 Synchrotron Radiation Source Indus-1

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1. Introduction

Electromagnetic radiation generated by bending the path of electrons moving at speeds close to that of light is called synchrotron radiation. It has emerged as a powerful tool for research in several areas such as material science, chemistry, biology, medicine and semiconductor technology. The increasing use of synchrotron radiation is attributed to its unique characteristics, which include high intensity, natural collimation, wide wavelength range, and high polarization and pulsed time structure.

Considering its widespread utility, it was decided to build two synchrotron radiation sources at Centre for Advanced Technology, Indore [1-3]. These sources are Indus-1, a 450MeV electron storage ring for production of VUV radiation and Indus-2, a storage ring of 2.5GeV for x-rays. In the first phase, which began in 1987, the development of the synchrotron radiation source Indus-1 was taken up. This project involved the development of a 450MeV electron storage ring and also an injector system which supplies electrons to it. The injector system consists of a 20MeV microtron and a 450/700MeV synchrotron. This injector system will also serve as the injector for Indus-2.

The synchrotron radiation source Indus-1 thus consists of a 20MeV microtron, a 450MeV synchrotron and a storage ring Indus-1. The layout of the Indus facility is shown in fig. T.1.1. The electrons are generated and accelerated to 20MeV in the microtron. After extracting the beam from the microtron, the beam is transported to the synchrotron through Transfer Line-1 (TL-1). A long pulse of 1µs is injected in to the synchrotron; the energy of the electrons is increased from 20MeV to 450MeV. After acceleration to 450MeV, the electrons are extracted from the synchrotron and then transported to the storage ring Indus-1 through the Transfer Line-2 (TL-2). This process of production, acceleration and injection is carried out every second till the stored current is 100mA in the storage ring Indus-1. In the storage ring, the electron beam keeps circulating for a long time emitting synchrotron radiation continuously in the dipole (bending) magnets.

The synchrotron radiation source Indus-1 was commissioned in May 1999. Five beamlines have been set up on it. Presently, users from various laboratories are using it.

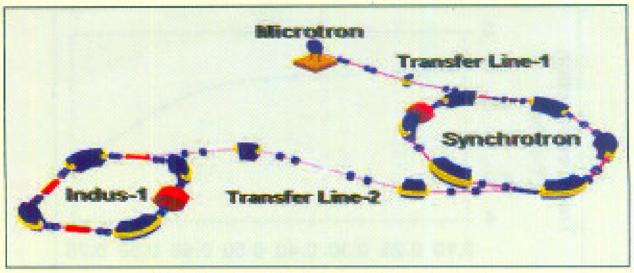

Fig.T.1.1 Schematic layout of synchrotron radiation source Indus-1

2. Accelerator Details

2.1 Injector System

2.1.1 Microtron

The microtron is designed to give a 20MeV electron beam with a current of 25mA in pulses of 1µs duration at a repetition rate of 1-2Hz. It is a classical microtron having a dipole magnet of 1.4m diameter, which produces a magnetic field of 1.8kG with a uniformity of 0.2% over a diameter of 0.8m encompassing 22 orbits during which electrons are accelerated to 20MeV. The acceleration occurs in a microwave cavity energised by a 5MW pulsed klystron at 2856MHz. A LaB_6 pin of 3mm diameter mounted on a flat face of the cavity is used as the electron emitter. The vacuum in the microtron is better than 10^{-7}torr. The main parameters of the microtron are given in Table T.1.1 and the photograph of the microtron and part of the Transfer Line-1 is shown in fig. T.1.2.

Table T.1.1

Parameters of the microtron	
Energy	20MeV
Pulse current	25mA
Pulse duration	1µs
Repetition rate	1-2Hz
Accelerating frequency	2856MHz
Energy spread	0.2%

Fig. T.1.2 The microtron and part of Transfer Line-1

2.1.2 Synchrotron & Transfer Lines

The beam from the microtron is transported to the synchrotron through Transfer Line-1 (TL-1), which has a length of about 14m. It has 3 quadrupole doublets and one dipole magnet to take care of the beam parameters as required by the injection process [4]. One 45° dipole magnet is provided to divert the 20MeV electron beam for some other experiments.

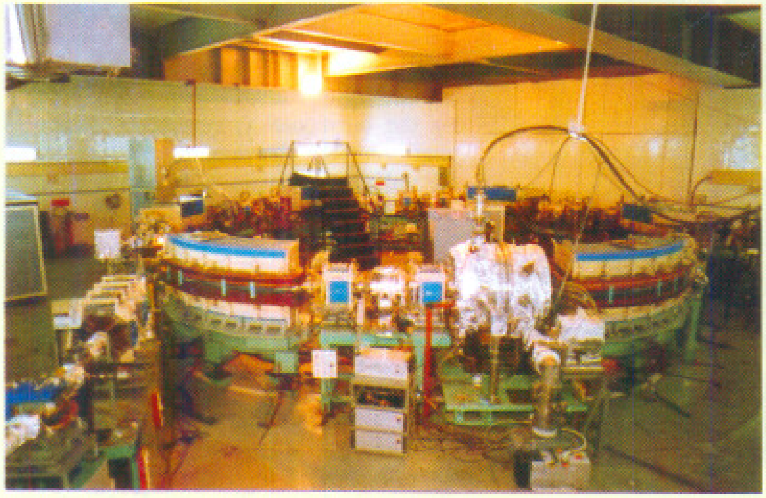

Fig. T.1.3 The synchrotron

The magnetic lattice of the synchrotron consists of 6 superperiods (repetition of magnetic structure), each consisting of a dipole magnet to bend the electron beam on a circular path and a pair of focussing and defocussing quadrupole magnets to achieve a wide stability range. The maximum magnetic field of the dipole is 1.32T. The circumference of the synchrotron is 28.44m. The main parameters of the synchrotron are given in Table-T.1.2 and fig. T.1.3 shows the photograph of the synchrotron. The electrons are injected into the synchrotron by adopting a multi-turn injection scheme using 1μs long electron beam pulse from the microtron at a repetition rate of 1Hz. A compensated bump with maximum amplitude near the injection septum is produced using three injection kickers.

After injecting the beam, the electrons are accelerated to 450MeV in nearly 200ms, following a linear ramp, using the RF cavity operating at 31.619MHz. Fields in the dipole, quadrupole and steering magnets are synchronously increased during the acceleration. The harmonic number of the ring is three; giving rise to three circulating bunches in the ring. The accelerated beam is extracted by deflecting it by a fast kicker magnet having a rise time 45ns. As the separation between two bunches is 30ns, during the extraction process, one out of three bunches is lost and two bunches are extracted. These two bunches are then transferred to Indus-1 through TL-2. The synchrotron operates at 1Hz till the desired current is filled in Indus-1. The vacuum in the synchrotron is better than 10^{-7} torr.

The length of the transfer line-2 is about 25 metres. The line has four quadrupole doublets and two dipole magnets to match the beam parameters at the injection point in Indus-1. One of the dipole magnets before Indus-1 will be kept off while transporting the 700MeV beam from the synchrotron to Indus-2.

Table T.1.2	
Parameters of the synchrotron	
Maximum energy	700MeV*
Current	30mA (11mAachieved)
Circumference	28.45m
Superperiods	6
Maximum dipole field	1.32T
Tune point	2.25,1.22
Momentum compaction	0.151
Revolution frequency	10.5MHz
Harmonic number	3

* 450MeV for injection into Indus-1

2.1.3 Indus-1 Storage Ring

Indus-1 is a 450MeV storage ring designed for providing radiation in the range of soft x-ray to far infrared. It is a small ring having a circumference of 18.96m. The critical wavelength (defined as a wavelength above and below which the power radiated is equal) of the radiation emitted from the bending magnet is 61Å. The flux and brightness curves for Indus-1 are shown in fig. T.1.4.

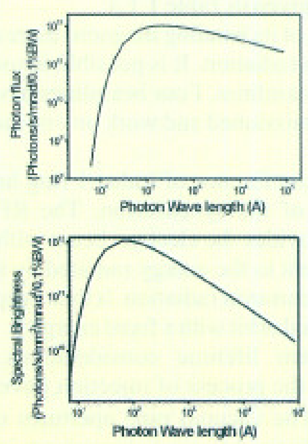

Fig. T.1.4 Photon flux and spectral brightness

Each superperiod has a 1.3m long straight section. Two such straight sections are used for beam injection; one section accommodates the septum magnet and the other diametrically opposite to it accommodates a pulsed kicker magnet. Of the remaining two straight sections, one is used to accommodate an RF cavity and the other can house an insertion device.

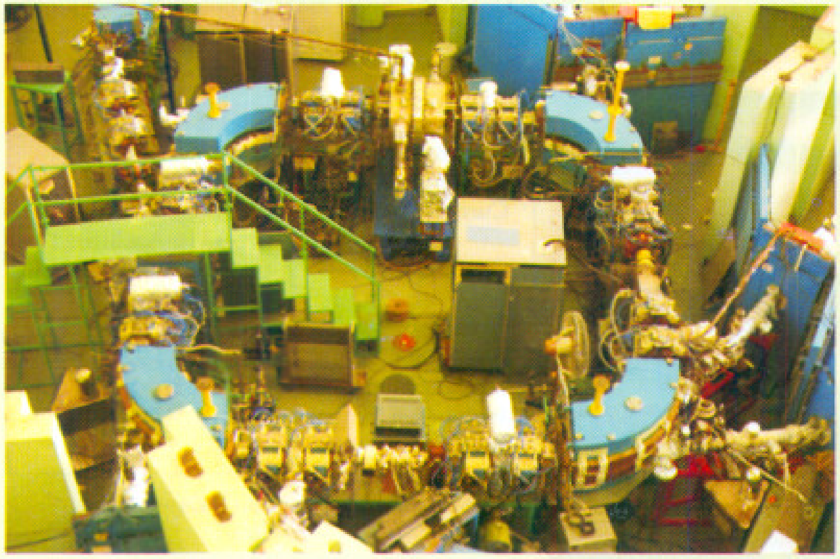

Fig.T.1.5 The storage ring Indus-1

The magnetic lattice of the ring consists of 4 superperiods, each having one dipole magnet with a field index of 0.5 and two quadrupoles doublets. The field index of 0.5 in the dipole magnets helps in achieving a larger stability range because it provides weak focussing in radial and vertical planes. To correct the natural chromaticity of the ring, a pair of sextupoles is used in each superperiod. The photograph of Indus-1 is shown in fig.T.1.5 and its main parameters are given in Table T.1.3.

On each of its bending magnets, there are two ports to tap synchrotron radiation. It is possible to use five ports for setting up the beamlines. Four beamlines have already been set up and commissioned and work on one more beamline is in progress.

The circumference of Indus-1 ring has been chosen as 2/3 of that of the synchrotron. The RF frequency of 31.619MHz provides the electron beam with the additional energy equivalent to the energy radiated by the electrons in the form of synchrotron radiation. It thus keeps the electrons moving on a fixed orbit with a fixed energy.

The beam lifetime considerations, closed orbit distortions and the process of injection govern the vacuum requirements. The vacuum pipe apertures of ±30mm and ±12.5mm in radial and vertical planes respectively are found to be adequate. Experimentalists want an uninterrupted supply of synchrotron radiation for few hours and this is possible only if the electron beam lifetime i.e. the duration in which the beam current decays to 1/e of its value, is few hours. In order to achieve such a beam lifetime, the pressure in the beam pipe or chamber in the presence of 100 mA electron beam has to be less than 10^{-9}torr.

The beam lifetime at 450MeV is mainly governed by the Coulomb scattering of electrons in a bunch (Touscheck effect) and the elastic scattering of the electrons with the residual gas molecules. The lifetime due to Touscheck effect increases with the energy aperture, the maximum value of which is governed by the horizontal (physical or dynamic) aperture. Thus the maximum value of the RF voltage (overvoltage factor) is decided by the aperture limitations.

The harmonic number of the cavity (defined as the RF frequency/revolution frequency) is chosen as 2 to reduce the ion trapping problems. Circulating electrons ionise residual gas molecules creating ions. The motion of some of these ions could be stable under certain beam conditions and they can get trapped. If the density of trapped ions is high, the motion of the electron beam can be perturbed and as a consequence, the lifetime of the beam is reduced. These ions can be removed by creating transverse electric field along the beam path. In Indus-1, 20% circumference is occupied with ion clearing electrodes.

There is a provision to apply ±1kV DC voltage on these electrodes. The effect of different DC voltages on the beam lifetime has been studied. It is found that the beam lifetime improves as the voltage is increased. In fig. T.1.6, the effect of ±1kV on beam lifetime with current is shown. The -ve voltage gives a higher beam lifetime compared to the same +ve voltage. The reason for this is not yet fully understood. The beam lifetime which is 40 minutes (with 0 voltage on ion clearing electrodes) is increased to 60 minutes with -1kV DC voltage on the ion clearing electrodes. The beam lifetime in Indus-1 is mainly determined by the vacuum of the ring and particularly that of the cavity section (BAG4). The lifetime will improve further as the ampere-hour operation increases. The earlier maximum lifetime achieved is 75 minutes [5]. This was achieved when the vacuum in the ring was better. The vacuum is monitored in each straight sections by four Bayard Alpert Gauges (BAG1-4) placed in four straight section of the ring and the vacuum corresponding to fig. T.1.6 is shown in fig. T.1.7. The vacuum in the 4^{th} straight section in which the RF cavity is placed is in 10^{-8}mbar range and this seems to be limiting the beam lifetime.

Table T.1.3

Parameters of storage ring Indus-1	
Energy	450MeV
Current	100mA (200mA achieved)
Dipole field	1.5T
Field index	0.5
Critical wavelength	61Å
Spectral flux (λ_c)	$7.2 \times 10^{11\,a}$
Lattice type	Combined function
Circumference	18.96m
Superperiods	4
Tune point (ν_x,ν_y)	1.69, 1.31
Emittance (ε_x)	1.54×10^{-7}m.rad
Momentum compaction	0.235
Chromaticities(ξ_x, ξ_y)	-1.91, -0.345
Beam size in σ_x, σ_y	0.587, 0.102mm
(bend centre) $\sigma_{x'}$, $\sigma_{y'}$	0.290, 0.015mrad
Spectral brightness (λ_c)[b]	$1.03 \times 10^{12\,c}$
Bunch length2σ_l	302mm
Beam lifetime	2hours (75 minutes achieved)
Energy spread	3.8×10^{-4}
Damping times(τ_x, τ_y, τ_ε)	15.64, 15.64, 7.8ms
Revolution frequency	15.806MHz
RF frequency	31.613MHz
Harmonic number	2
Power loss	364W

[a] photons/s/mrad horz./0.1%BW ; [b] bending magnet
[c] photons/s/mm^2/mrad^2 horz./0.1%BW (10% coupling)

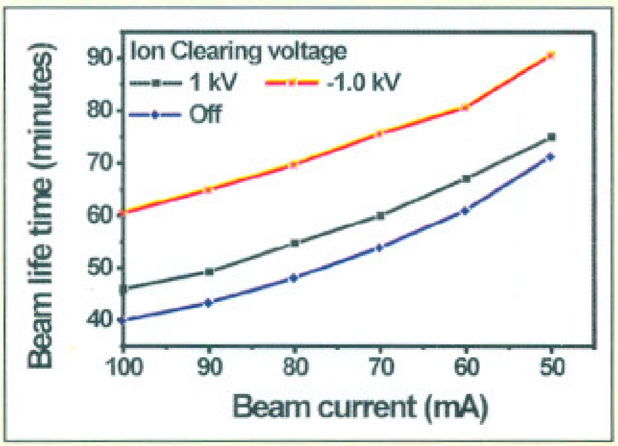

Fig. T.1.6 Beam current vs beam lifetime

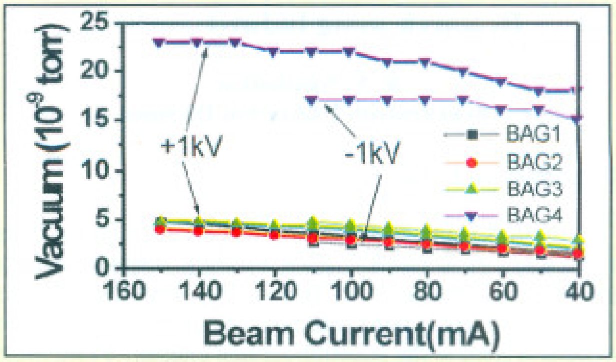

Fig. T.1.7 Beam current vs vacuum

Indus-1 is regularly operated every day from 9hrs to 23hrs on all working days and is regularly used by the users. As per the practice followed at other synchrotron laboratories, beam filling is done a few times during each day. The maximum current stored in a filling operation is normally decided by the requirements of the users. A typical operational behaviour of Indus-1 during a day is shown in fig. T.1. 8. It shows that the maximum stored current is 172mA, though the maximum current stored so far is 200mA[5].

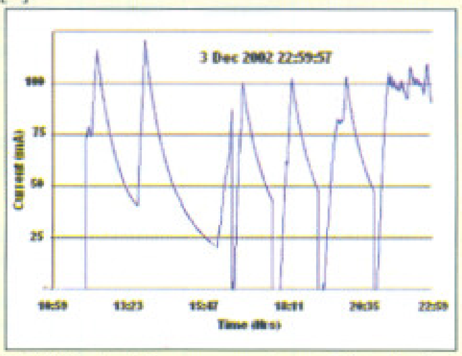

Fig. T.1.8 Typical beam current variation during a day

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