Operation of INDUS-1, India's First Synchrotron Radiation Source

PradeepKumar, V.Bhatanagar, A.A.Fakhri, P.Fatnani, A.D.Ghodke, R.K.Gupta, P.R.Hannurkar, P.Kant, M.G.Karmarkar, S.Kotaih, M.Pravin Kumar, G.K.Sahoo, R.S.Saini, A.Sharma, S.K.Shukla, Gurnam.Singh#, B.Singh, H.C.Soni, D.S.Thakur, D.K.Vats and S.K.Prajapati

Centre for Advanced Technology, Indore-452013, INDIA

ABSTRACT

INDUS-1 is a 450 MeV electron storage ring for the production of Synchrotron Radiation in Visible Ultra Violet (VUV) range with a critical wavelength of 61 A°. The ring was commissioned in June 1999. Since then it is in regular operation. This Synchrotron Radiation Source (SRS) facility consists of a 20 MeV injector microtron, a 450 MeV booster synchrotron and a storage ring. In this paper operation aspects of INDUS-1 SRS facility will be presented.

INTRODUCTION

Electromagnetic radiation by bending the path of electrons moving at speed close to that of light is called Synchrotron Radiation. Considering widespread utility of Synchrotron radiation it was decided to build two Synchrotron radiation sources at Centre for Advanced Technology, Indore (India). These sources are INDUS-1, a 450 MeV electron storage ring for production of VUV radiation and INDUS-2, a storage ring of 2.5 GeV for X-rays. In the first phase, the development of Synchrotron radiation source (SRS), INDUS-1 was taken up.

INDUS-1 project involved the development of a 450 MeV electron storage ring and also an injector system which supplies electrons to it. The injector system consists of a 20 MeV Microtron and a 450 MeV Booster Synchrotron. The INDUS-1 SRS facility is shown in figure1.

The electrons are generated and accelerated to 20 MeV in the Microtron. After extracting the beam from the Microtron, it is injected into the Booster Synchrotron; in which the energy of the electrons is increased from 20 MeV to 450 MeV. After acceleration to 450 MeV, the electrons are extracted from the synchrotron and then transported to the storage ring INDUS-1. This process of production, acceleration and injection is carried out every one second till the stored current becomes 100 mA. In INDUS-1, the electron beam keeps circulating for few hours emitting synchrotron radiation continuously in the dipole magnets. This ring was successfully commissioned in June 1999 and since then it has been routinely operated.

OPERATION OF INDUS-1

The operation of INDUS-1 starts at 900 hours in the morning and up to 2300 hours in night everyday in two shifts. In one shift there are five members for the operation. The members are trained and well qualified.

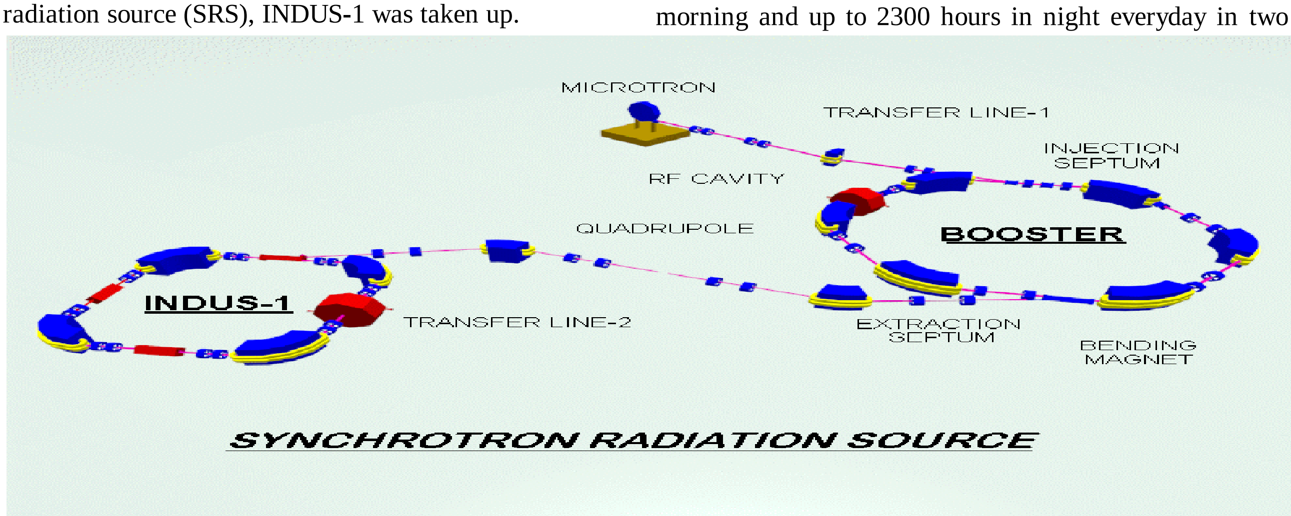

Figure 1: INDUS-1 Synchrotron Radiation facility at CAT, Indore (India)

#Corresponding Author, Email: gurnam@cat.ernet.in

The shift operation starts with the operation of injector Microtron. The microtron consists of a dipole magnet of 1.4 m diameter, which produces a magnetic field of 1.8 Kilo Gauss. The acceleration of electrons occur in a microwave cavity energized by a 5 MW pulsed klystron at 2856 MHz. A lanthanum hexaboride (LaB_6) pin of 3 mm diameter mounted on a flat face of the cavity is used as the electron emitter. The electrons emitted from the emitter are accelerated to 20 MeV in 22 orbits. The vacuum in the microtron is better than 10^{-7} Torr. Microtron gives a 20 MeV electron beam with current of 20 mA in pulses of 1 μs duration at a repetition rate of 1 Hz. The paramerters of microtron are given in Table 1.

Table 1:Parameters of microtron

Energy	20 MeV
Pulse current	25 mA
Pulse duration	1 μs
Repetition rate	1-2 Hz
Acceleration frequency	2856 MHz
Energy spread	0.2%

The electron beam from the microtron is transported to the booster synchrotron through transfer line-1 (TL-1), which has a length of about 14 m. It has three quadrupole doublets and one dipole magnet to take care of beam parameters as required for the injection process. The parameters of Booster synchrotron are given in Table 2.

Table 2: Parameters of Booster synchrotron

Energy	450 MeV
Current	30 mA (11 mA achieved)
Circumference	28.45
Superperiod	6
Max. dipole field	1.32 Tesla
Tune point	2.25, 1.22
Momentum Compaction	0.151
Revolution frequency	10.5 MHz
Harmonic number	3

Booster synchrotron consists of six super periods, each consisting of a dipole magnet and a pair of focusing and defocusing quadrupole magnets. The maximum magnetic field of the dipole is 1.32 T. The circumference of synchrotron is 28.44 m. The electrons from microtron through TL-1 are injected in to the synchrotron by adopting a multi-turn injection scheme. A compensated bump producing maximum amplitude near the injection septum is produced using three injection kickers. After injecting the beam the electrons are accelerated to 450 MeV in nearly 200 ms following a linear ramp using the Radio Frequency (RF) cavity operating at 31.619 MHz. Fields in the dipole, quadrupole and storage ring 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 of 45 ns. As the separation between two bunches is 30 ns, during the extraction process, one out of three bunches is lost and two bunches are extracted. These two bunches are then transported to INDUS-1 storage ring through transfer line-2 (TL-2). The synchrotron operates at 1 Hz till 100 mA current is filled in INDUS-1 ring. The vacuum pressure in the synchrotron is better than 10^{-6} Torr. The transfer line-2 (TL-2) is about 25 m length. It has four quadrupole doublets and two dipole magnets to match the beam parameter at the injection point in INDUS-1.

The parameters of INDUS-1 are given in Table 3.

Table 3: Parameters of INDUS-1 storage ring

Energy	450 MeV
Current	100 mA(200 mA achieved)
Bending field	1.5 T
Operating point	1.69, 1.31
Beam emittance (ε_x) (ε_x)	1.5×10^{-7} m.rad 1.5×10^{-8} m.rad
Beam Size at center σ_x Of Bending magnet σ_z	0.28 mm 0.07 mm
Energy spread	3.85×10^{-4}
Momentum compaction	0.235
Chromaticities $\xi_{x,z}$	-1.9,-0.3 (measured -2.6,3.1)
Harmonic number	2
Power loss	0.36 KW (from BM)

The ring shown in figure 2 consists of four super periods, each having one dipole magnet and two doublets of quadrupoles. Each super period has a 1.3 m 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. The remaining two straight sections, one is used to accommodate an RF cavity. The circumference of INDUS-1 ring is 18.96 m.

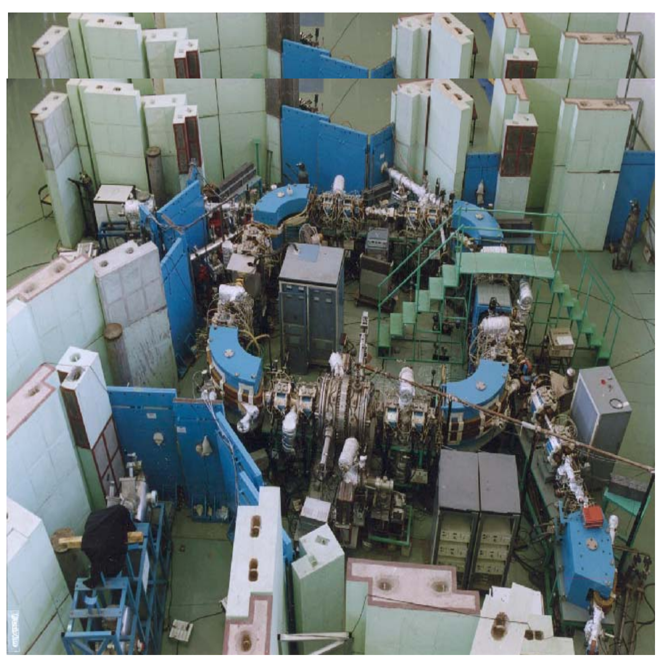

Figure 2: INDUS-1 ring with initial part of beam lines

The RF frequency of 31.619 MHz provides the electron beam with the additional energy equivalent to the energy radiated by the electrons in the form of Synchrotron radiation. It keeps the electrons moving on a fixed orbit with a fixed energy. The vacuum pressure in INDUS-1 ring is better than 10^{-9} Torr.

CONTROL SYSTEM

INDUS-1 main control room area is 17×8 m^2 and consists of ten PCs with Window 98 loaded and display monitors. The operation of Microtron, Booster Synchrotron and INDUS-1 ring is controlled remotely from main control room.

The control system is a distributed processor network comprising personal computers serving as intelligent workstations and a number of microprocessor based device controllers dedicated to the task of data acquisition, monitoring and control. Each device controller has an autonomous capability to control the subsystem to which it is connected. The control system is distributed hardware wise over three layers. At the bottom is the front-end instrumentation which conditions the output from an equipment directly connected to the machine into standard electrical signals. The front-end instrumentation is connected upward to intelligent Supervisory Control and Data Acquisition System (SCADA). The output from these controllers is connected to a workstation situated in the main control room.

The operation of the control system is divided in to two major tasks: (i) informing the operator about various aspects of the operation of the accelerator. These are the values of various parameters such as magnet currents, vacuum pressures, temperatures, frequency, voltages, currents, power, beam positions, time delays, radiation levels, status of interlocks, status of pumps, etc.

(ii) Conveying the messages and commands issued by the operator to the concerned devices.

The hardware of the control system is based on a 16 bit microprocessor; Motorola 68000 family is chosen as the standard. The hardware is modular based on VME bus. The SCADA crate consists of a master processor board based on the 68000 microprocessor and the necessary input/output modules. I/O modules handle a variety of analog and digital signals.

RESULTS

The variation of magnetic field with time during ramp of booster synchrotron is shown in figure 3. The timing system pluses of extraction kicker of booster synchrotron, injection kicker of INDUS-1, two extracted bunches at the end of TL-2 and stored bunches are shown in figure 4. . Filling of current in INDUS-1 ring with time is shown in figure 5. Everyday shift operation data are recorded and written in logbook register available in the main control room.

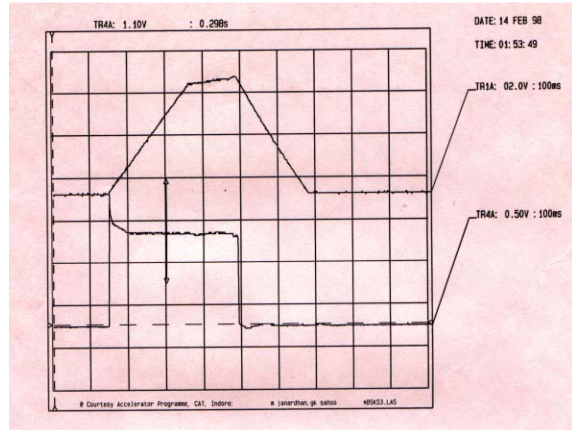

Figure 3: Ramping of magnetic field & DCCT signal

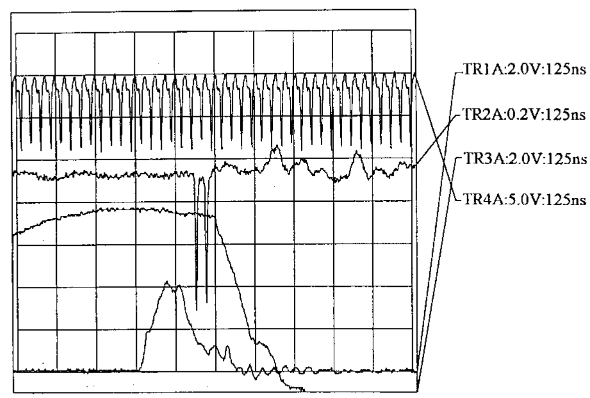

Figure 4: Timing pluses at the time of current accumulation in INDUS-1

TRA1: Booster extraction kicker pulse

TRA2: Wall Current Monitor at end of TL-2

TRA3: Injection Kicker in Storage ring

TRA4: Wall Current Monitor showing train of pulses in storage ring section 3

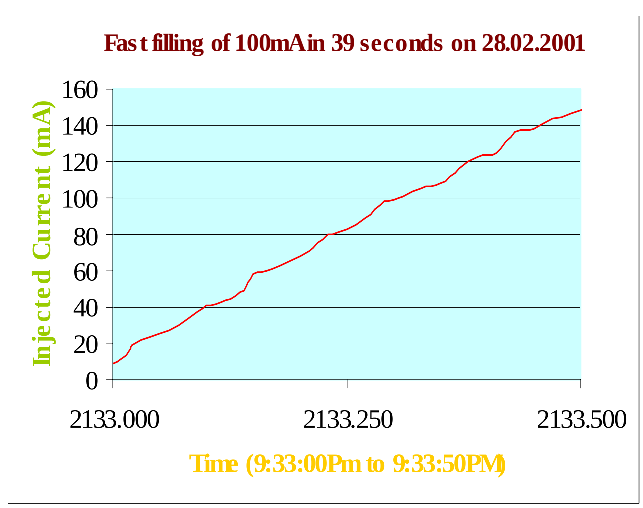

Figure 5: Filling pattern during injection in INDUS-1

The INDUS-1 operation record (stored current Vs time) during one day is shown in figure 6.

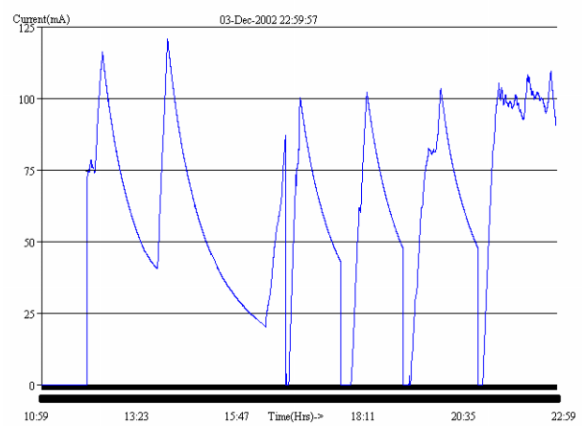

Figure 6: One day INDUS-1 operation

Radiation levels

Ionising radiation produced due to interaction of electron beam with stainless steel vacuum chamber and residual gas molecules present in it. Based on radiation hazards existing in INDUS-1, the entire area is divided in to three zones:

Zone-1 (normally accessible area < 0.1 mRem/hr)

Zone-2 (restricted entry area < 1 mRem/hr)

Zone-3 (entry prohibited area > 10 mRem/hr)

Dose rate measured near INDUS-1 storage ring with 100 mA stored current is shown in Table 4. Radiation level outside the shielding around the storage ring during the storage is well within the permissible limits.

Table 4: Radiation dose at 100 mA stored current

location	Source of radiation	Dose (mRem/hr)
Main Control room	Bremsstrahlung	0.01
Experimental Station	Bremsstrahlung	0.02

Neutron flux is negligible.

CONCLUSIONS

INDUS-1 storage ring was commissioned in june 1999. Since then it is regularly operated. Initially beam lifetime at 100 mA stored current was 20 minutes later on it was increased up to 75 minutes by using ion clearing electrode voltage in the ring. The vacuum mainly determines the beam lifetime in INDUS-1 ring. The lifetime will improve further as the ampere-hour operation increases. The beam is in use for four beam lines, which are already commissioned.

ACKNOWLEDGEMENTS

We thank WAO-2003 organisers, Dr D.D.Bhawalkar, Director CAT and Sh. S.Kotaih Project Manager, INDUS-II for their support to participate in Workshop on Accelerator Operation (WAO-2003) at KEK Japan. We also like to mention the valuable contributions made by Sh K.K.Thakkar, Sh Haridas and Sh M.Nayak on radiation monitoring near INDUS-1 ring and main control room area.

REFERENCES

[1] G.Singh, V.Bhatnagar, A.A.Fakhri, P.Fatnani, A.D.Ghodke,R.K.Gupta, P.R.Hannurkar, Pradeep Kant, M.G.Karmarkar, S.Kotaiah, , M.Pravin Kumar, Pradeep Kumar, G.K.Sahoo, R.S.Saini, A.Sharma, S.K.Shukla, B.Singh, H.C.Soni, D.S.Thakur and D.K.Vats “Synchrotron Radiation Source INDUS-1”, Proceedings of the DAE-BRNS Indian Particle Accelerator Conference-2003 (InPAC-2003) pp 8-11.