COMMISIONING OF THE INDUS-2 STORAGE RING

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Abstract

An overview of the 2.5 GeV synchrotron radiation source, Indus-2, which has been set up at RRCAT, Indore will be presented with emphasis on commissioning details. The accelerator is used both as a booster and as a storage ring. Using an injection energy of 550MeV, the beam energy has been ramped up to 2.4 GeV. Two beam lines have also been installed, one for x-ray diffraction (XRD) and another for extended x-ray absorption fine structure (EXAFS) studies. To condition the vacuum chamber of the ring, regular operation has been restricted to 2 GeV. To test the XRD beam line, first diffraction pattern from a pyrolitic graphite sample was recorded with bending magnet synchrotron light with ring operating at 2 GeV. Indigenous technological base created in setting up Indus-2 would be used while participating in up coming international accelerator projects.

INTRODUCTION

A programme to build synchrotron radiation sources (SRSs) in the country was started in the eighties by the Department of Atomic Energy. A separate laboratory named Centre for Advanced Technology at Indore was created. The injector accelerators, namely, 20 MeV microtron and a 450-700 MeV booster synchrotron and the first 450 MeV storage ring Indus-1 were commissioned during the 90's. Originally, SRS Indus-2 was planned to be a 2 GeV ring. However, in November 1997, based on the advice of an International Panel, this energy was raised to 2.5 GeV. The design work on the new components, needed for the enhanced energy ring, was started in 1998 along with the civil construction of the building. Development of the prototype components and their large scale manufacture, partly in industry and partly in house, was spread over the next five years. The installation of the different subsystems was taken up from 2003-04 onwards. The complete assembly of Indus-2 & transport line (TL-3) connecting it to booster synchrotron, was finished by early 2005. Thereafter the evacuation of the ring and subsystem commissioning was taken up. By the end of 2005 we had started accumulating electrons in Indus-2 of ~450 MeV energy and the first signatures of the SR from Indus-2 were recorded using a CCD camera mounted over the sighting beam line. Over the past year beam energy ramping experiments were successfully completed, reaching up to 2.4 GeV in stages. In parallel work on building the beam lines for using the SR have also gone on. This paper will concentrate on the progress during the past year and a half. Main developments during the earlier periods have been described before [1].

INDUS ACCELERATOR PROGRAM AT RRCAT

Figure 1 gives a schematic view of the Indus Accelerator Complex and the present status of the machines and the transport lines. A sketch of Indus-2 lattice is given in figure 2 and Table 1 contains the parameters of the ring [1].

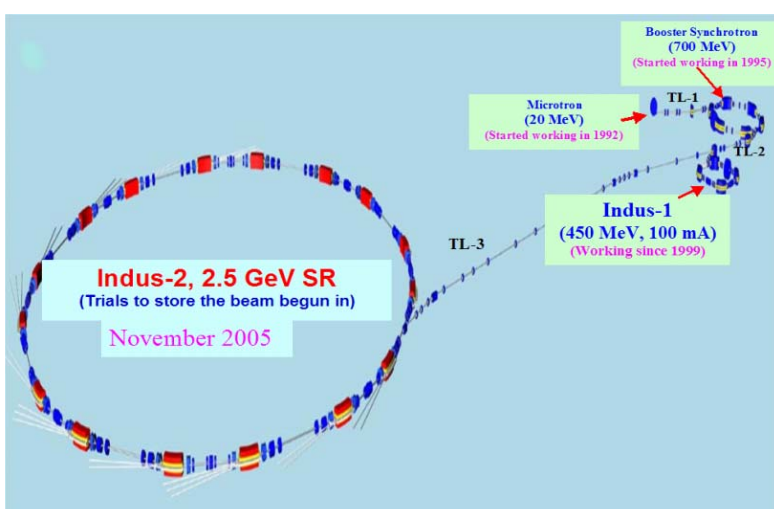
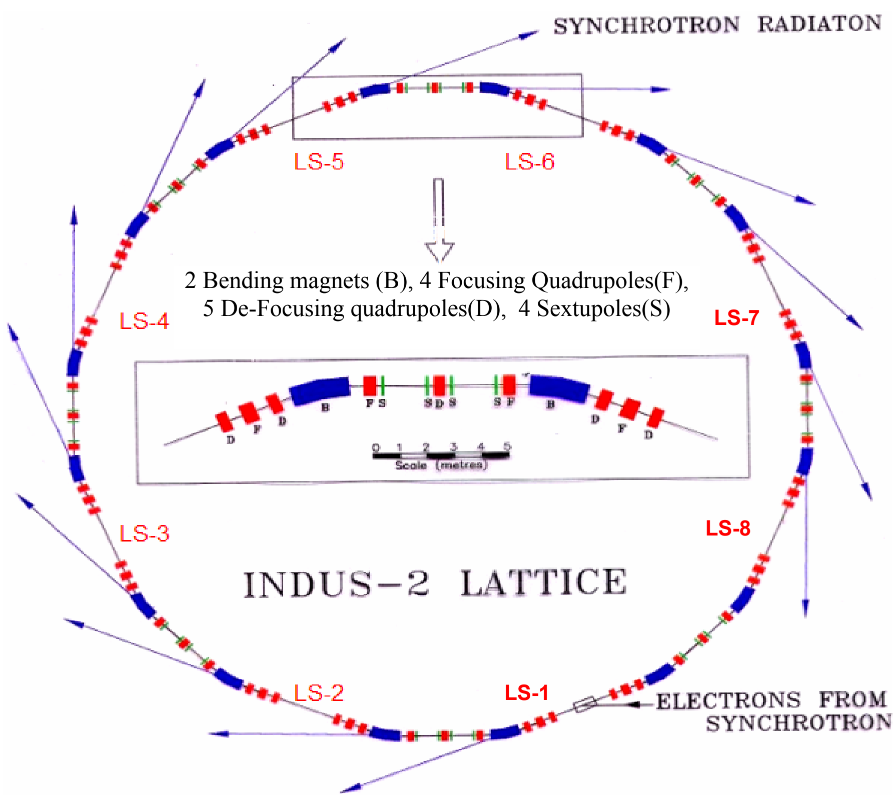


Figure 1: Schematic view of the Indus Accelerator Complex.

Table 1: Parameters of INDUS–2.

Maximum Energy	2.5 GeV
Maximum Current	300 mA
Lattice type	Expanded Chassman Green
Superperiods	8
Circumference	172.4743 m
Bending magnet field	1.502 T
Typical tune points	9.2, 5.2
Beam emittance, ε_x	5.81 x 10 $^{-8}$ mrad
ε_y	5.81 x 10 $^{-9}$ mrad
Available straight section for insertion devices	5
Maximum straight length available for insertion devices	4.5 m
Beam size σ_x	0.234 mm
(Centre of bending magnet) σ_y	0.237 mm
Beam envelope vacuum	< 1 x 10 $^{-9}$ mbar
Beam life-time	12 hrs
RF frequency	505.812 MHz
Critical wave length	1.98 Å (bending magnet)
	0.596 Å (high field wiggler)
Power loss	186.6 kW (bending magnet)

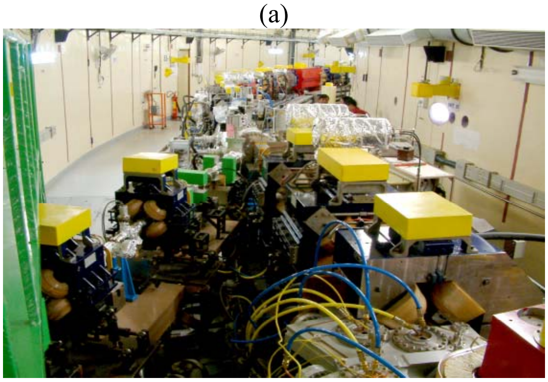
Main subsystems of the ring viz the magnets (dipoles, quadrupoles and sextupoles, septums & kickers) their power supplies, vacuum chambers, RF transmitters, control systems etc were developed at our Centre in Indore. After fabrication, field mapping was done on each of the magnets. Since there was some spread in their measured field profiles (as compared to the design values), we used simulated annealing algorithm to find the optimized locations for the magnets. With the best placement of the magnets in the ring, errors of different magnets compensated one another to obtain good overall performance from the machine. This optimization enabled us to bring down the closed orbit deviations in the electron trajectories by about a factor of 3. Figures 3 shows some of the pictures of Indus –2 inside the tunnel. For more details see [2].



B-Bending magnet; F/D-Focussing / Defocusing quadrupole; S –Sextupole,
LS-1: used for injection; LS-2 to LS-6: for insertion devices. LS-7: Unusable; LS-8: for RF cavities

Figure 2: Indus – 2 lattice & its components.

(a)



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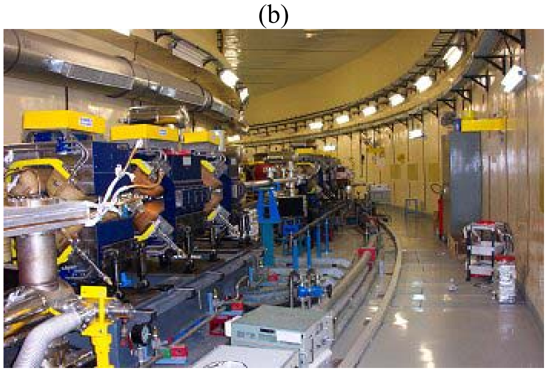

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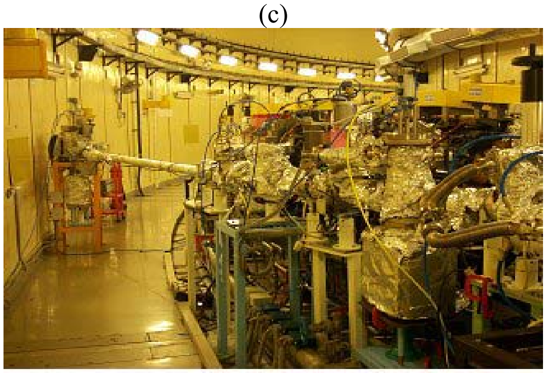


(d)

Figure 3: a) RF Cavities Commissioned in Indus – 2 Ring, b) TL-3 Joining on to Indus-2, c) Long Straight Section Assembly, d) front end of a typical bending magnet beamline as it is linked to Indus-2.

In May 2005 the electron bunches of 450 MeV energy were transported through TL-3, and, as desired by AERB, experiments were conducted to confirm that beam loss was minimal. In August 2005, electrons were injected for the first time into the storage ring and, after optimization of magnetic lattice elements, the beam circulated for four turns (Figure 4), without the kicker and the RF power being turned on [2]. After reaching this milestone, we went through an exhaustive evaluation of various sub-systems, particularly the timing of the kicker magnets and the RF power system. Then in early December 2005, with the kicker magnets and the RF system turned on the beam circulated for ~1 second in the storage ring. The first synchrotron light out of Indus-2 as recorded through the CCD camera mounted on the sighting beam-line on December 2, 2005 as shown in Figure 5.

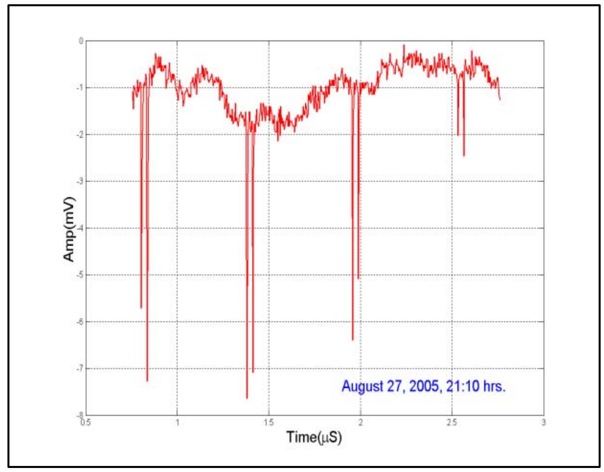
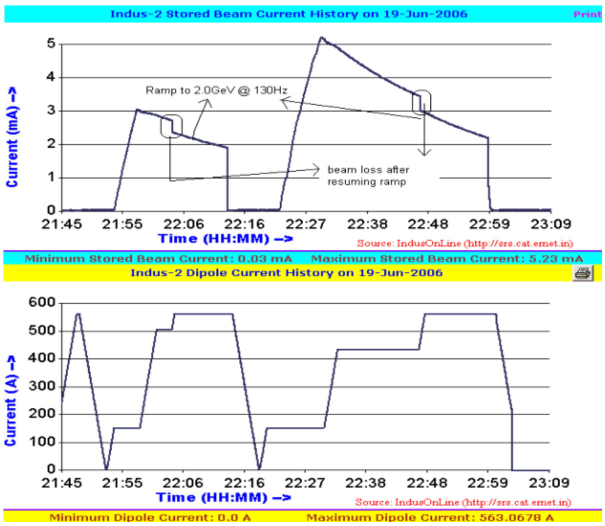


Figure 4: Four turn beam circulation seen on wall current monitor on 27th August, 2005.

Figure 5: First synchrotron light from Indus-2 recorded on Dec. 2, 2005 with CCD camera on sighting beam line.

The beam accumulation experiments were started in January 2006 and first time few mA were stored in mid February 2006. The lattice optimization studies were continued over the next few months and successful energy ramping was achieved in May-June 2006. The data in Figures 6 & 7 shows energy ramping up to 2 GeV and 2.4 GeV respectively. The data in Figure 8 shows the improvement in the vacuum in the ring as a result of the conditioning of the vacuum chambers by the synchrotron radiation and the concomitant increase in the beam life time with 20 mA of current. In addition to energy ramping experiment we have used steering coils to carry out orbit correction to minimize COD (Figure 9).

While the work on installation and commissioning of the storage ring has been going on, parallel effort is also on towards setting up beam-lines meant for using the synchrotron radiation from Indus-2. Work is going on to build six beam lines of which two, namely, one for x-ray diffraction (XRD) and other for extended x-ray absorption fine structure (EXAFS) studies have been installed.



(a) shows current in Indus-2;
(b) shows current in the dipole magnets;
~150 A corresponds to 543 MeV;
~560 Amps corresponds to ~2 GeV

Figure 6: Successful energy ramping to 2 GeV (19/6/2006).

Figure 10 shows a picture of the x-ray diffraction beam-line in the experimental hall and figure 11 shows the first XRD pattern taken with pyrolitic graphite sample. Sadly, in the last quarter of 2006, a bad vacuum leak occurred in Indus-2 and the injectors due to a leak in the bellows. This was the result of large movements of Indus-2 dipole vacuum chambers due to eddy currents generated by power transients and the accompanying Lorentz force acting on the chambers. This problem has since been mitigated using a better arrangement to fasten the vacuum chambers. This has brought about a reduction in the movement of the vacuum chambers to below ~ 2mm (when current in the dipole magnet coils is suddenly turned off from ~550 A level to zero.) which is within the permissible limits of bellows. We also carried out improvements in the booster synchrotron in two ways. One was by replacing the old RF cavity (which had developed some pitting on the internal capacitor plates) with another cavity and other was to attend to better alignment of the extraction septum. The booster synchrotron and Indus-2 were made operational again by mid January 2007. While there has been an overall performance of the system, we have lost a good deal of time in fixing these problems. Some further work was carried out on the installation of PES beam lines and building hutch around the EXAFS beam line. Work is now planned to fine tune current in the steering coils to further bring down the closed orbit deviations (COD) of the beam in the ring. The work on enhancing the infrastructure is also in progress, which will enable us to increase the beam energy to 2.5 GeV in the coming months.

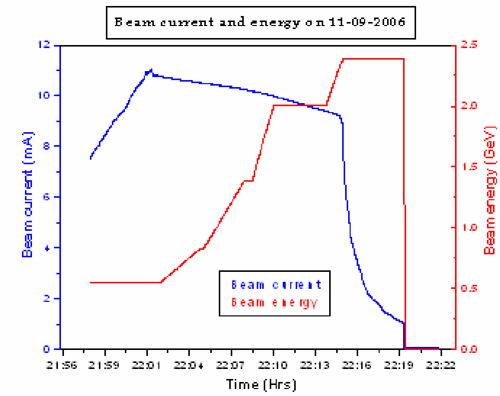


Figure 7: Successful energy ramping to 2.4 GeV.

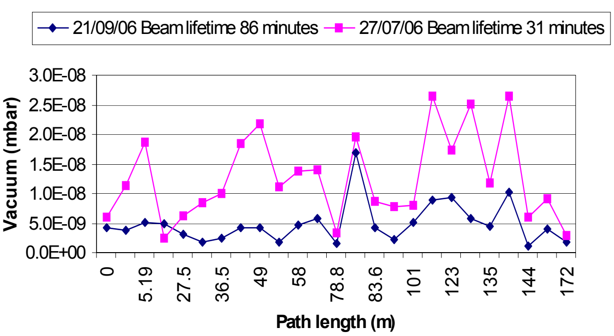
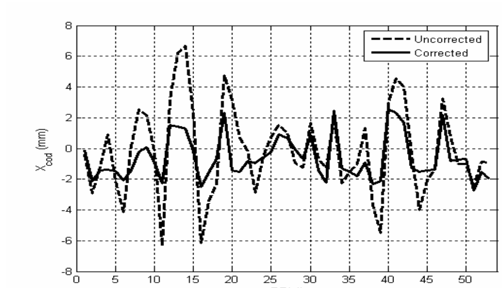


Figure 8: Vacuum in the ring and its influence on beam life time.



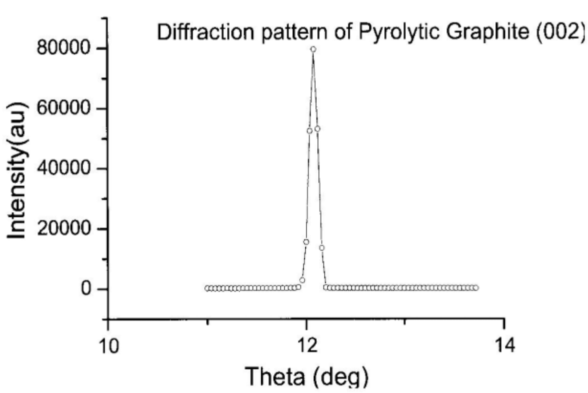
COD	Uncorrected	Corrected
Absolute Max (mm)	6.7	2.75
RMS(mm)	2.9	1.54

Figure 9: Reduction in closed orbit deviation brought about by use of steering coils.

Figure 10: Down stream view of the XRD beamline. The large chamber in picture houses the DCM.

CONCLUDING REMARKS

The paper describes the progress made on synchrotron radiation source Indus-2 which has been set up and commissioned at RRCAT, Indore. In the process of setting up Indus-2, a strong indigenous base has been created in the country. This should come in handy when India participates in up coming international accelerator projects, like, e+ - e- linear colliders, X-FEL, energy recovery linacs, SPL [3] etc. These projects are also of interest to India in so far as they can contribute to development of high intensity proton accelerator. BARC plans are to build Accelerator Driven Sub-critical reactors (ADS) (for details see ref. [4]) for nuclear waste transmutation studies, while RRCAT plans to set up a SNS for condensed matter research. These programmes have a strong overlap with SPL project [3] of CERN. Indian capability would be of value for such programs. A prototype 110kV, 24 A, 700 µsec pulsed modulator for SPL's injector & TL-2 for CTF3 are amongst the elements identified for Indian contribution. It is clear that the accelerator related developments in India have now entered a new phase and in the coming years these will integrate with the world wide efforts in this area.



Date : Sept 28, 2006 : Indus-2 beam energy was 2 GeV & current ~4 mA.

Figure 11: First record of the x-ray diffraction with SR from Indus-2 using beam line 12.

ACKNOWLEDGEMENT

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REFERENCES

[1] S. Kotaiah, A. Banerjee, A.G. Bhujle, P. Fatnani, P.R. Hannurkar, M.G. Karmarkar, A.K. Jain, A.M. Kekre, S.S. Prabhu, R.K. Mishra, M. Pravin Kumar, V.C. Sahni, R.S. Shinde, S.K. Shukla and Gurnam Singh, Proceedings of Indian Particle Accelerator Conference, p.65 (2005).

[2] V.C. Sahni, Pramana 67, 225 (2006).

[3] M. Vretenar (For SPL Study group), CERN –PS-2000-059-RF, LINAC2000-TU206, CERN-NUFACT-NOTE-040 (2000), Talk at the 20th International Linac Conference (Linac 2000), Monterey California, 21-25 Aug. 2000, eConf C000821 (2000) TU 2006, Physics/0008142.

[4] P. Singh, Proceedings of Indian Particle Accelerator Conference (InPAC 2005), p25 (2005).