T.1 Indus-2 beam diagnostic systems

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Introduction

Indus-2 is a 2.5GeV, third generation dedicated synchrotron radiation source, which has been commissioned at this centre. It has a photon critical wavelength of about 2Å. It is aimed at delivering high photon flux of 1x 10^{13} photons / sec. milli-radian (H). 0.1% band width. Commissioning trials of the machine began with the transportation of 450MeV electron beam up to the beam dump in Transfer Line3 in May 2005. Four-turn circulation in the storage ring was achieved on August 27, 2005. Presently a beam current of 26mA at 2GeV energy has been achieved. This article provides an overview of the beam diagnostic systems installed in the ring and the results obtained so far.

Diagnostic systems are crucial and essential part of an accelerator, which play an important role during its commissioning and regular operation. Various beam parameters that need to be monitored are beam position, beam profile, instantaneous and average beam current, betatron tune value, bunch length etc. During the initial beam injection and commissioning stage, diagnostic devices such as fluorescent screen type beam profile monitors, wall current monitors, septum hole monitors and sighting beam line helped the beam physicists to transport the beam optimally through the beam transfer line and achieve beam circulation and accumulation in the storage ring. In the current stage of near routine beam operation, the main focus has shifted to the measurement of beam parameters with the objective of improving beam current and lifetime. The systems used during this phase are beam orbit monitoring system, tune measurement system, DC current transformer (DCCT) and scrapers. Users of synchrotron radiation require high photon flux and stable beam for their experiments. This necessitates the use of beam orbit correction system. Beam diagnostic devices can be classified as interceptive and non-interceptive depending on the extent to which they disturb the beam. They can also be classified as electron beam based and synchrotron radiation (SR) based, depending on whether electromagnetic field associated with the beam or synchrotron radiation is used for the observation. Table T.1.1 summarizes the diagnostic devices installed in Indus-2. A brief description of individual system and the obtained results follows.

Beam Profile Monitor

Beam profile monitor (BPM) is an interceptive type of diagnostic device. It is helpful during commissioning of machine. It is used for visual observation of transverse shape, orientation and position of the beam in transfer line and the storage ring. The BPM uses a fluorescent screen made of chromium-doped alumina, which can be inserted into the beam path at an orientation of 45° with respect to the beam axis. The spot of fluorescent light generated by the beam can be viewed by a CCD camera placed vertically above the beam plane. Keeping the beam spot in view, the machine physicist can achieve optimal setting of the beam trajectory and spot size. The video signals from various BPM are multiplexed by VME bus based video multiplexer card and transported to the control room for observation on a monitor. Interface units are used near each BPM to convert the high-level control commands into the actuating signals for pneumatic components of the BPM. Some salient features of the BPM design are: minimum beam coupling impedance in the retracted position, full remote operation from the control room and easy maintainability of the fluorescent screen. The photograph of a BPM is shown in Fig. T.1.1 and the inset

Table T.1.1
Beam diagnostic devices in Indus-2.

S. No.	Name of diagnostic device	Total number	Function
1	Beam Profile Monitor	19	Visual observation of beam profile and position
2	Wall Current Monitor	5	Observation of instantaneous bunch signal
3	DC Current transf ormer	1	Measurement of average beam current
4	Beam Position Indicator	56	Measurement of beam position, closed orbit distortion
5	Stripline	6	Tune measurement and Beam signal observation
6	Sighting Beam Line	1	Observation of synchrotron light during machine commissioning
7	Horizontal and vertical Scraper	3	Measurement of beam intensity profile along horizontal & vertical axes
8	Thick and thin Septum Hole Monitors	2	Visual observation of the injected beam at the septum mouth.

Fig.T.1.1 Beam profile monitor installed on Indus-2 storage ring. Inset shows the electron beam profile.

shows a typical electron beam profile observed. It is also possible to capture the beam profile using frame grabber for image processing.

Wall current monitor

Wall current monitor (WCM) is a non-interceptive beam diagnostic device, which monitors the image current flowing through the inner surface of the beam pipe. An electrical break is imposed in the wall current path by introduction of a ceramic ring in the beam pipe. The wall current is diverted to flow through a number of bridge resistors distributed over the circumference of the ceramic gap. The voltage developed across these resistors due to the flow of wall current is taken out by a coaxial cable for further processing and observation. Ferrite rings surround these resistors in order to reduce part of image current flowing through the metal housing which encloses the WCM. Use of ferrite rings also reduces the possibility of external noise currents affecting the output of wall current monitor. Beam transportation through the transfer line is optimized by monitoring bunch signals from four WCM located along transfer line-3. Typical beam signals are shown in Fig. T.1.2. One WCM is installed in short straight section (SS-8) of the storage ring, which is used to observe beam injection and circulation in the ring. Fig. T.1.3 shows a typical beam bunch pattern observed on a digital storage scope.

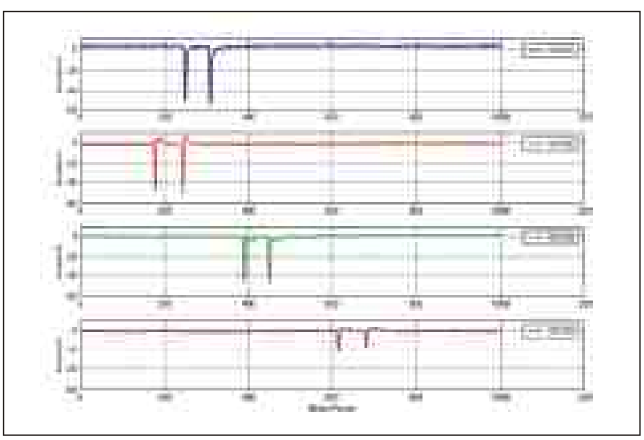

Fig. T.1.2 Beam transport through TL-3 as seen on WCMs.

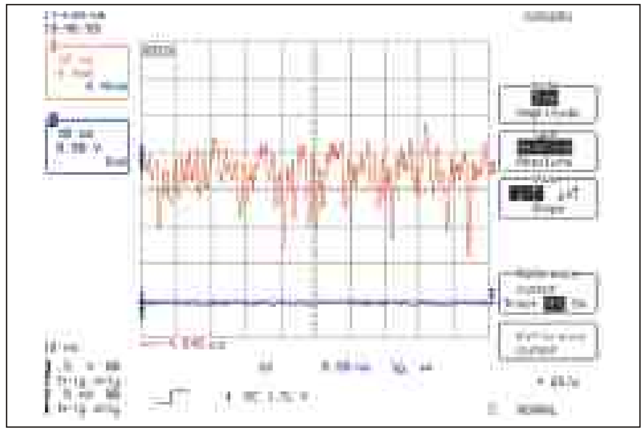

Fig. T.1.3 WCM output showing beam bunch pattern in storage ring.

DC Current Transformer (DCCT)

DCCT is used for measuring stored (average) beam current circulating in the storage ring. It consists of a toroidal core mounted on the vacuum chamber. An insulating gap is

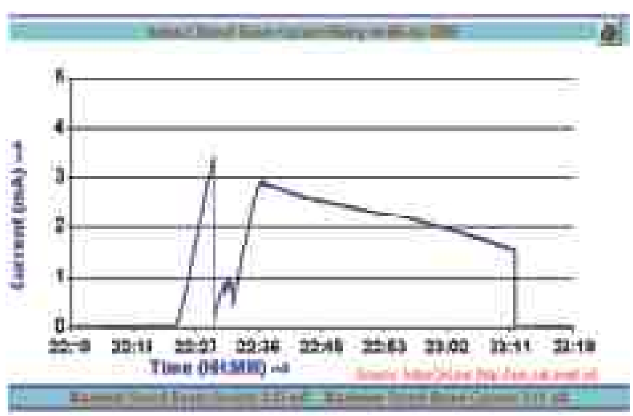

Fig. T.1.4 Typical stored beam current in Indus-2.

provided in the vacuum chamber to prevent the flow of dc and low frequency currents in the vacuum chamber wall passing through the core. The insulating gap is bypassed with capacitors to provide low impedance path for high frequency currents. This prevents the core from getting exposed to high frequency electro magnetic (EM) field of the beam and resulting heating of the core. To protect the sensor against stray magnetic fields, a two layer magnetic shield is provided. The output of the DCCT is digitized and displayed on computer as current v/s time graph. The core temperature is monitored and an alarm is generated if the temperature exceeds the limit. The DCCT has a measurement range of 0-1000 mA and resolution of 5 microamperes. Figure T.1.4 shows the typical beam current history of a machine shift as monitored by the DCCT.

Beam Position Indicator

Beam position indicator (BPI) is a non-interceptive type diagnostic device, which is used to measure the position of the charge centroid of the electron beam circulating in the accelerator vacuum chamber. In Indus-2, four-button electrode beam position indicator is used. There are 56 BPI in the ring, 7 in each unit cell. Out of these, 40 BPI are of individual type, which are installed in the straight sections and 16 are integrated type. One integrated type BPI is embedded in each dipole chamber. Using these beam position indicators, the position of the equilibrium beam orbit and closed orbit distortion (COD) is obtained. This data is used by the control system to correct the COD. The device consists of four button shaped electrodes mounted symmetrically in the cross section of the accelerator vacuum chamber. The electrode connection is brought out of the vacuum chamber by means of vacuum feed through coaxial connector. The signal induced on an electrode depends on the proximity of the beam to that electrode. The beam position, with reference to the geometric center of the device is obtained by detecting the four electrode signals and applying a suitable position algorithm.

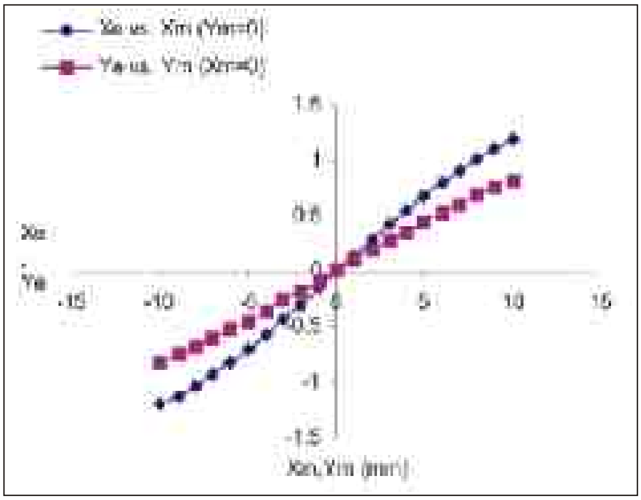

Fig.T.1.5 *BPI response curves.*

Individual type beam position indicators were calibrated on a calibration bench before installing in the ring. In the calibration setup, an antenna fed from a RF source simulates the beam electric field. The antenna is moved in horizontal and vertical directions using PC controlled stepper motors. Response curve is drawn from the calibration data. In simple terms, a response curve is a relationship between electrical coordinate (*Xe,Ye*) and mechanical position in horizontal or vertical plane (*Xm and Ym*). The electrical coordinates are calculated using diagonal difference algorithm. By analyzing the response curves we estimate the linear behavior of electrodes with respect to position of beam. Figure T.1.5 show the typical response curves obtained from calibration data of Indus-2 BPI. The BPI signal processing modules are installed in eight electronics racks distributed symmetrically on the equipment gallery. The output of the processing electronics is acquired by 4-channel, 16 bit ADC cards and the acquired data is transferred to the control room, where beam position is calculated by using position algorithm. Figure T.1.6 shows a typical display of beam orbit in the main control room.

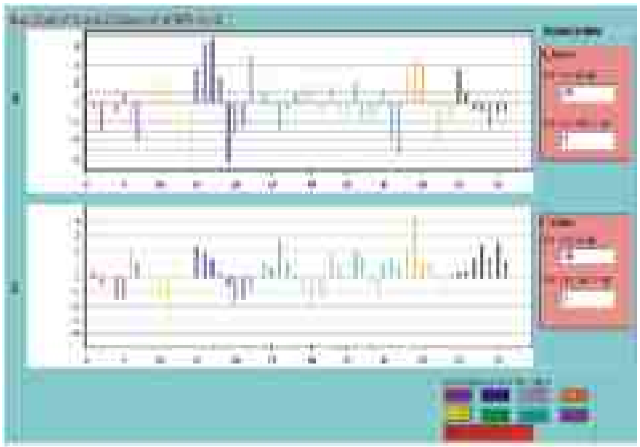

Fig.T.1.6 *Beam orbit displayed in the control room.*

Tune Measurement System

In an electron storage ring, a particle displaced transversely from its equilibrium orbit executes betatron oscillation about the orbit. The number of periods of oscillation in one complete turn around the machine is called betatron tune. The measurement of tunes in horizontal and vertical plane and knowledge of their dependence on certain beam and machine parameters are very important for the

Fig. T.1.7 *Stripline monitor.*

understanding of a storage ring. Betatron tune is measured by applying a transverse excitation to the beam. This causes the beam to execute coherent betatron oscillation. A beam position monitor is used to observe the resulting beam response. Stripline electrodes (Fig.T.1.7) are used as kicker and position monitor. The stripline electrodes are designed for 50Ω characteristic impedance. A block diagram of the tune measurement system is shown in Fig.T.1.8. The measurement system employs a spectrum analyzer equipped with a tracking generator. The spectrum analyzer is interfaced to a PC through GPIB bus. A VME bus based horizontal/vertical plane selector card allows the user to remotely select measurement of either horizontal or vertical tune. The tracking generator RF output, after splitting and

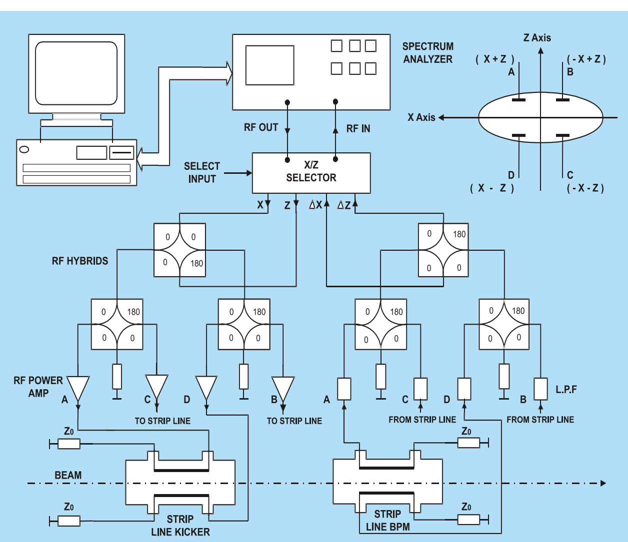

Fig.T.1.8 *Block diagram of betatron tune measurement system.*

amplification, is fed to a stripline kicker. Another stripline located downstream in the storage ring is used as a beam position monitor. The four strip line electrode outputs are used to produce real-time X and Z delta signals proportional to the beam position in horizontal and vertical plane. The position signal is then applied to the RF input of the spectrum analyzer. During the frequency sweep, when the excitation frequency passes through the betatron side band, amplitude of the oscillation grows and it is displayed as a peak on the spectrum analyzer. From the frequency of the peak, tune value is calculated and displayed on the monitor. With this system, fractional tune value can be measured with a resolution of $1X10^{-3}$.

Betatron tunes in both horizontal and vertical planes are being routinely measured using this system. Table T.1.2 gives typical tune data measured during beam energy ramp on June 16, 2006.

Table T.1.2
Measured fractional betatron tunes at different beam energy

E (GeV)	I_{beam} (mA)	V_x	V_z
0.550	4.3	0.320	0.215
1.0	3.4	0.298	0.135
1.56	2.6	0.303	0.117
2.01	1.7	0.325	0.110

Sighting Beam line

Sighting Beam line (SBL) is primarily used to observe the synchrotron light spot during commissioning of the machine. It is installed in 10^o extraction port of beam-line BL-27 of Indus-2 dipole DP-11. A photograph of SBL is shown in Fig.T.1.9. The inset shows the first synchrotron light observed on December 2, 2005. SBL is completely situated inside the radiation-shielding wall. The total length of beam line is 4 meters from the extraction port. It consists of a water-cooled slit located at a distance of 2.93 meters from source to define horizontal aperture of the synchrotron radiation fan. Slit aperture of 20.6mm (H) and 25mm (V) define 7.3mrad horizontal opening angle with a natural vertical opening angle of synchrotron radiation emission. SBL has a photon beam position monitor also known as staggered pair monitor (SPM) to monitor the vertical beam position with a resolution of 1 micron. It works on the principle of photoelectron emission. SPM has four copper blades that measures the asymmetrical currents induced on

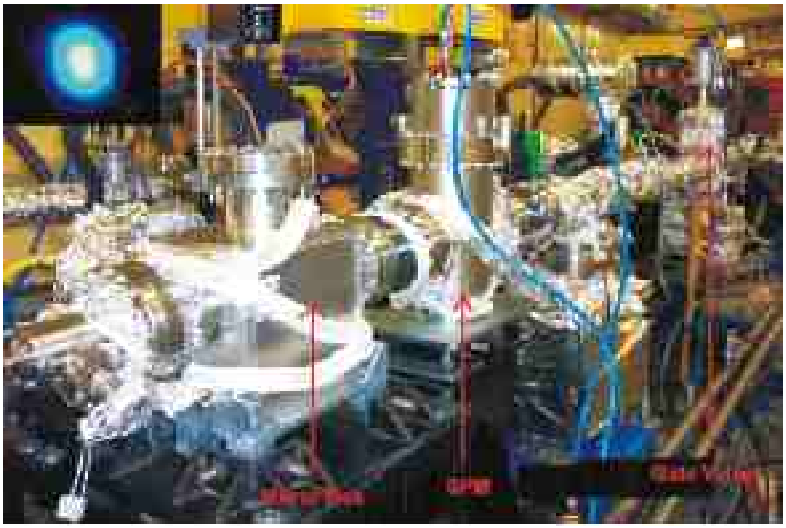

Fig. T.1.9 *Sighting beam line on Indus-2. Inset shows the first SR light observed on December 2, 2005 using this beamline.*

four blades as a result of soft x-rays striking the blades. The position measurement is performed by a difference-over-some photocurrent detection of each blade pair separated by a gap. A negative bias voltage is applied on the blades to avoid cross talk and space charge effect. Beam line also has a mirror chamber with a water-cooled gold plated copper mirror placed at 45^{o} to the beam path. Metallic mirror absorbs the x-rays and reflect the visible part of synchrotron radiation, which is observed with a CCD camera, and a video monitor placed in control room. Machine physicists are now routinely using SBL.

Scraper

Scraper is an interceptive type of beam diagnostic device, which is used to measure the intensity profile of the beam in the transverse plane. Scrapers installed in the storage ring consist of two thick stainless steel blades, which can be moved into the beam cross-section from opposite directions. Beam particles, which hit a scraper blade, are eventually lost from the beam. These blades remain out of the beam chamber during normal beam operation. During a scraper measurement, a particular scraper is selected and its blades are moved into the beam in precisely controlled small steps. A measurement of blade position as a function of surviving beam current (as measured on the DCCT) is used to obtain the beam intensity profile. Three scrapers, two horizontal and one vertical, have been installed in the storage ring. All these scrapers can be fully operated from the control room. A micro-controller based intelligent local controller unit controls the operation of the scraper. Interface units are connected to the host computer on a multidrop RS-485 serial link.

Septum Hole Monitor

The septum hole monitor is used to view the position of the beam at the entrance apertures of the thick and thin injection septum. The beam passes through an opening in a fluorescent screen mounted just a few millimeters upstream of the septum aperture. The dimensions of this opening match with the dimensions of the septum aperture. If the beam or part of the beam is traveling along a trajectory, which does not pass through the entrance aperture, it hits the fluorescent screen and shows up on the video camera. The hole monitor has been found to be very useful in steering the beam though the injection septum during initial beam injection into the storage ring.

Conclusion

Beam diagnostic systems of Indus-2 have been commissioned. They have proved to be very useful during initial beam injection and commissioning phase of Indus-2. Currently, exercises are being done to increase the beam current and energy and efforts are being made concurrently to study and improve the performance of diagnostic systems under different operating conditions. A preliminary exercise has been done to correct the orbit in horizontal plane using beam position data, which has shown positive results.