T.1: Development of indigenous technologies for upgradation of Indus-2 synchrotron radiation source

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Abstract

The Indus synchrotron radiation sources, Indus-1 (450 MeV, 125 mA) and Indus-2 (2.5 GeV, 200 mA), constituting a national facility, are operating in round-the-clock mode for more than a decade. The usage of Indus synchrotron radiation facility has exhibited steady growth over the years. Round-the-clock operation of Indus machines is ascertained through reliable and smooth operation of its various subsystems namely injector microtron, high power RF and microwave systems, ultra-high vacuum system, magnets, power converters, control system, beam diagnostic system, coolant system, and other auxiliary systems, through upgrades and with implementation of systems like beam orbit, betatron tune and instability feedback systems, beam based alignment and pinger magnet. The sub-systems of Indus-2 have been upgraded by developing and deploying improved technologies which are mostly based on indigenous efforts. This article describes some of the indigenous technology developments and their deployment in Indus-2.

1. Introduction

Indus-1 (450 MeV, 125 mA) and Indus-2 (2.5 GeV, 200 mA) are the two synchrotron radiation sources (SRS) indigenously designed, developed, commissioned and operated in round-the-clock mode at RRCAT. Six beamlines in Indus-1 and 16 beamlines (including 2 diagnostic beamlines) in Indus-2 are in operation. Both the sources are being used by a large number of users from R&D institutes, academic institutes and universities across the country. The usage of Indus synchrotron radiation facility has exhibited steady growth over the years. There has been a modest beginning of beamline usage by Indian industries and concerted efforts are being made to increase the number of industry users. With the consistent increase in the number of beamline users, it is imperative to enhance the performance of Indus facility in terms of beam quality and reliability. The sub-systems of Indus-2 have been upgraded by developing and deploying improved technologies which mostly are based on indigenous efforts. This has resulted in enhanced performance of Indus-2. The sub-system upgrades include injector microtron, high power RF and microwave systems, ultra-high vacuum system, magnets, power converters, control system, beam diagnostic system, coolant system and other auxiliary systems. Various feedback systems like beam orbit feedback, betatron tune feedback, multi-bunch feedback have been implemented to stabilize the electron beam which has resulted in delivery of stable photon beam to the beamline users. Beam based alignment (BBA) system has helped in the reduction of closed orbit distortion (COD) and hence improvement in beam lifetime. A pinger magnet with its associated systems has been recently installed in Indus-2. These upgrades have been deployed in Indus-2 in past 6-7 years in a phased manner optimizing the machine downtime. Some of the indigenous technology developments and their deployment in Indus-2 SRS are briefly described below.

2. Injector system

The injector system for Indus-1 and Indus-2 SRS is comprised of a 20 MeV injector microtron and a 450/550 MeV booster synchrotron. The upgrades carried out in it are briefly described below.

2.1 New 20 MeV injector microtron

A new 20 MeV injector microtron with improved design and manufacturing has been developed, tested and integrated as the new injector for Indus accelerators (Figure T.1.1), replacing the old microtron [1]. The main design parameters of the microtron are given below in Table T.1.1.

Fig. T.1.1: New 20 MeV injector microtron for Indus.

Table T.1.1: Main design parameters of the new microtron.

Parameter	Value
Beam energy	20 MeV
Pulse beam current	30 mA
Magnetic field	0.1780 T
RF cavity frequency	2856 MHz
Number of orbits	22
Pulse width	0.5 µs
Pulse repetition rate	1 Hz
Vacuum	2 X 10^{-7} mbar

The improved features include design for highly repeatable assembly, high geometrical accuracy and close control of material magnetic properties during manufacturing, beam extraction mechanism with 2-D motorized control, provision for cathode observation in operation, better vacuum conductance, multi-port diagnostics for magnetic field, rigid support structure with sliding trolley for magnet pole opening, etc. The microtron magnet assembly was manufactured by M/s Godrej and Boyce Pvt. Ltd. Mumbai as per RRCAT specifications. Various subsystems such as microwave, power converters, control, beam diagnostics, cooling, vacuum, magnetic coil elements have been developed by expert groups at RRCAT. In order to increase the beam current, face mounted magnetic coils were installed for adjusting individual beam orbit trajectories. The Indus facility has been operating trouble-free in round-the-clock mode with the new microtron.

2.2 Solid state modulator based 5 MW pulsed S-band microwave system

A new 5 MW peak power, S-band microwave system based on 'solid state modulator' technology for injector microtron to provide better pulse stability and higher component life time, is successfully installed. This has been tested for more than 4 MW RF peak power at 2856 MHz (Figure T.1.2) in installed condition. The existing waveguide transmission system was appended with necessary components like bends and straight sections for keeping provision of operating microtron with both new system and old system.

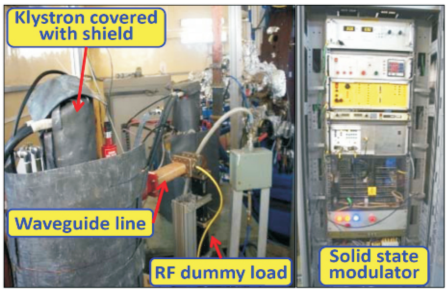


Fig. T.1.2: Solid state modulator and klystron.

2.3 Development of software for performance enhancement of booster synchrotron

In order to achieve a good accelerated beam current in the booster synchrotron, the operator has to manually optimize settings of more than ten parameters which is time consuming. To overcome this problem, a real coded genetic algorithm (RCGA) based system has been developed and implemented for the automatic optimization of microtron and Transport Line-1 (TL-1) parameters. The electron beam current from the microtron is optimized by controlling the cathode emission, and the transmission efficiency of the TL-1 is improved by monitoring of the beam current and optimization of the setting of nine steering coils. The scheme of the RCGA system is shown in the Figure T.1.3. The system has proved to be very useful in reducing the manual efforts to maintain good booster beam current.

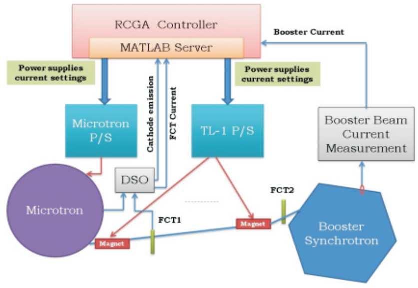


Fig. T.1.3: Schematic diagram of RCGA based system for booster beam current enhancement.

3. RF system

Indus-2 RF system had been substantially upgraded with indigenous technologies like high power solid state RF amplifiers (SSPA), digital low level RF control (DLLRF) systems, OFE copper RF cavity and high power circulator at 505.8 MHz. Indus-2 has six RF stations feeding RF power to six RF cavities. Four out of the six are 60 kW high power solid state RF amplifiers, fifth is klystron based RF amplifier and sixth is 60 kW Inductive Output Tube (IOT) based RF power system. In all, DLLRF system of the six RF stations [2] have been installed and commissioned giving better flexibility, adaptability, good repeatability and reduced long term drift errors, as compared to analog system. In recent years following RF technologies have been developed for Indus-2 RF system.

3.1 505.8 MHz, 60 kW IOT based RF power system

Assembly of IOT based RF amplifier system with driver amplifier, 36 kV high voltage beam supply, PLC based control, monitoring and interlocking systems, air and associated cooling water system was done. Testing of the RF power system for maximum required RF power out of 60 kW at the operating frequency of 505.8 MHz on dummy load was done. Integration of complete RF amplifier system along with all interlocks for RF cavity and RF amplifier is done. The RF cavity was tested up to full operating cavity gap voltage of 375 kV and the system is deployed for Indus-2 operation (Figure T.1.4).

Fig. T.1.4: 60 kW IOT amplifier at 505.8 MHz.

3.2 Solid state RF amplifiers@505.8 MHz

High power solid state RF amplifiers (SSPA) [3] of 60 kW each feeding to 4 out of 6 RF cavities, including one indigenous RF cavity, have been developed, installed and commissioned in Indus-2, making total installed SSPA capacity of 240 kW (Figure T.1.5).

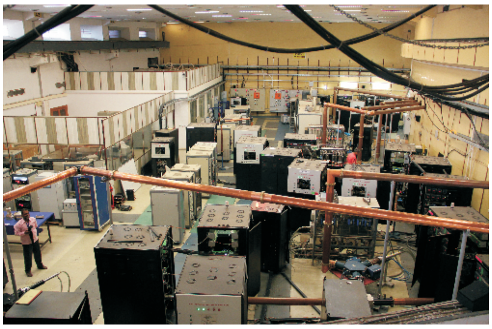


Fig. T.1.5: High power SSPA installed in Indus-2.

3.3 505.8 MHz OFE copper RF cavity

Initially, Indus-2 was commissioned with four RF cavities at 505.8 MHz procured from foreign sources. With requirement of additional RF cavities for operation of insertion devices in the Indus-2 ring and to cater to aging issues of RF cavities, indigenous RF cavity was developed and installed in Indus-2 (Figure T.1.6) [4]. Presently total six RF cavities providing total RF voltage in excess of 1700 kV are used in round-the-clock mode in Indus-2 for 2.5 GeV operation.

Fig. T.1.6: 505.8 MHz OFE copper RF cavity installed in Indus-2.

3.4 RF circulator at 505.8 MHz

Recently, a high power Y-junction RF circulator of 60 kW CW at 505.8 MHz, designed using strip line coupled to a magnetically biased ferrite material, was developed in-house. After electromagnetic simulation and RF design, mechanical design was optimized.

All components like shell, ferrite support plates, RF port outer conductors were fabricated out of aluminium alloy. Strip line central conductor, the transitions and inner coaxial parts were fabricated from naval brass. The central conductor was

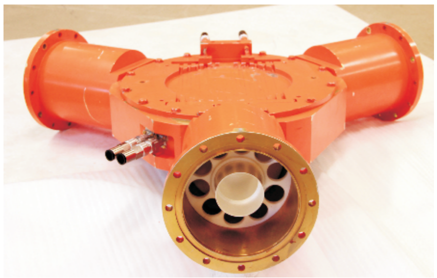


Fig. T.1.7: Assembled view of circulator.

fabricated from brass with groove to accommodate cooling tubes. Upper and lower ferrite plates were machined with twelve parallel groves to accommodate 6.5 mm OD copper tubes. The aluminium parts were given chromate conversion coating for better oxidation resistance whereas the brass parts were silver plated for better conductive longevity. The mechanical assembly of circulator cavity, coaxial ports and cooling circuits was completed, followed by fixing of permanent magnet and biasing coils on both sides symmetrically to the central conductor. A photograph showing assembled view of circulator is shown in Figure T.1.7. Low power RF characterization followed by high power RF test was conducted at 505.8 MHz. After testing at high power in one of the RF stations, the circulator was connected to the RF cavity and was commissioned as per the requirements of Indus-2 RF system operation.

4. Ultra-high vacuum (UHV) system

Indus-2 consists of 172.43 m long UHV system to provide UHV environment (dynamic pressure in 10^{-10} mbar range) for circulating electron beam for achieving the required beam lifetime. It is the largest UHV system of the country comprising of ~600 nos. of UHV components and instruments and running continuously in 24x7 mode since commissioning in the year 2005. Over the years several upgradations of the system were done to accommodate various new devices including three undulators and two RF cavities in the ring. Some of the upgrades in UHV system are described below.

4.1 Upgradation of large coating setup in UHV lab

With an aim of indigenous technology building for NEG film coating of long UHV chambers, a vertically oriented large coating setup (LCS) with overall size of 1300 mm x 1200 mm x 5500 mm height was developed, installed and commissioned in UHV Lab in 2017. This coating system, based on DC magnetron sputtering technique [5], will be used for NEG film coating of long UHV chambers required for undulators in Indus-2 and future high brilliance synchrotron radiation source for UHV pumping requirement and TiN coating of vacuum chambers of accumulator ring of future Indian Facility for Spallation Research for low secondary electron yield requirement. Vacuum chambers with external diameter up to 290 mm and length up to 3500 mm can be accommodated for coating in this set up. During last two years, the coating setup has been augmented with computer based bake out and activation controller and data acquisition system for in-situ bake out and coating activation and acquisition of process parameters. Gas dosing system of the setup has been also upgraded with electro-polished SS316L tubings, dew point sensors, in-line gas purifier and mass flow meter for delivery of pure gas inside the chamber under coating. Recently, one 2700 mm long chamber made of Al alloy AA6063-T6 was successfully coated using this setup as described briefly in the following section. This chamber has been tested in a stand-alone mode for use as a spare undulator chamber in future.

4.2 Development of NEG coated UHV chamber utilizing LCS

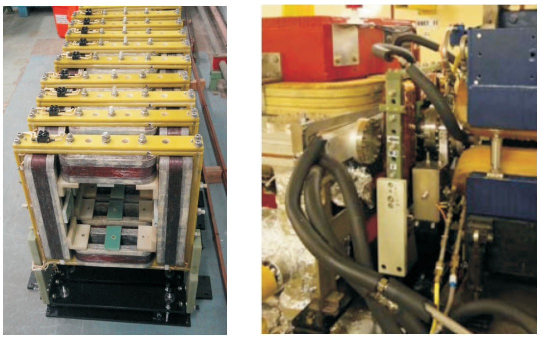
NEG coated UHV chamber as spare for undulators in Indus-2 was designed and developed in-house using raw material from Indian industry. Chamber height of 21 mm is limited due to 23 mm minimum pole gap of undulators. Material of construction of chamber is AA6063-T6 [6]. Molecular flow conductance of the 81 mm(W) x 17 mm(H) x 2700 mm(L) chamber is 6 l/s/m. Lower conductance of the chamber poses difficulty in achieving UHV condition by conventional lumped UHV pumps. This problem was surmounted by application of novel technology of NEG coating on inner surface which provides large distributed pumping speed after activation and facilitates realisation of UHV condition [7]. Nominal composition of NEG coating is 30% Ti, 30% Zr, 40% V (Atomic %). More details are given in Accelerator Report A.7 of this issue. Development of the technology of NEG coated UHV chamber is a very vital accomplishment towards self-reliance and import substitute for future high brilliance synchrotron radiation source.

5. Magnets

Magnetic elements are essential part of an accelerator and are required in large numbers. All the electromagnets of Indus-1, Indus-2, booster synchrotron, microtron and transfer lines were designed and characterised by using the in-house facilities of the Centre, while manufacturing was done by Indian industries. So far, more than 400 magnets have been developed for Indus accelerators. Following is a brief account of new developments carried out in magnet technology for Indus-2.

5.1 Development of fast corrector magnets for fast orbit feedback system

Synchrotron users in Indus-2 require stable photon beam for performing various scientific experiments. This is achieved through the implementation of orbit feedback system in which corrector magnets are used as actuator elements. The existing slow corrector magnets placed over aluminum vacuum chamber in Indus-2 are used for correction of very slow disturbances e.g. thermal drifts. Therefore, a separate set of combined function fast corrector magnets (FCMs) of high bandwidth were developed for correction of short term perturbations (from low to high frequency up to 100 Hz) [9]. The design of FCM is finalized with the consideration of having (a) air cored (low inductance to reduce the compliance voltage) and air cooled magnet type to mount over the stainless steel (SS) bellows in the limited available space (~100 mm), and (b) high bandwidth to correct the high frequency perturbations up to ~100 Hz. The initial phase of implementation of local and global fast orbit feedback (FOFB) system for Indus-2 using limited numbers of fast corrector magnets and beam position indicators (BPIs) have showed encouraging results. The system successfully brings down the beam position variations in vertical plane within ~3 µm rms for perturbations of frequencies up to 50 Hz. In the final phase of global FOFB system for Indus-2, total 56 BPIs and 40 FCM will be used. The development and magnetic characterization of all 40 correctors have been successfully completed (Figure T.1.8).



(a) *(b)*

Fig. T.1.8: Photograph showing (a) series of FCMs, and, (b) FCM installed in Indus-2.

5.2 Development of combined function harmonic sextupole magnets

In order to improve the dynamic aperture of Indus-2 by suppressing the non-linearities induced from the existing chromatic sextupole magnets, it is planned to install a set of 32 harmonic sextupole magnets. Due to the limited space in Indus-2, it has been decided to go for compact combined function harmonic sextupole (CFHS) magnets having integrated additional windings to generate horizontal and vertical dipole fields for beam orbit corrections and skew quadrupole field to reduce the coupling between the two transverse planes. The CFHS magnets [10] have an aperture radius of 60 mm and overall length of 250 mm. The design of the CFHS magnet has been done using POISSON-2D and

OPERA-3D codes. The magnet has the integrated field strengths of 17 T/m for the harmonic sextupole (SP) and 0.1 T for the skew quadrupole (QP) and 1.333 T-m for both the horizontal (H) and vertical (V) steering dipole (DP) fields. All the magnets have been developed and characterized. The magnetic field measurement results satisfy the specified field quality requirements. The magnets are kept ready for installation in Indus-2 (Figure T.1.9).

(a) (b)

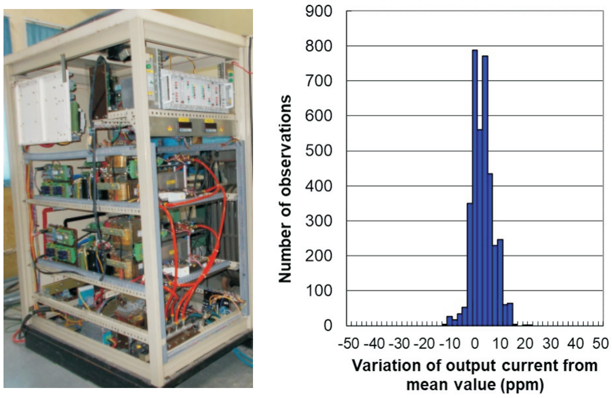
Fig. T.1.9: Photographs showing (a) series of CFHS magnets, and, (b) a CFHS magnet on test setup bench.

6. Power converters

Output-current-controlled power converters (PC) with very high output current stability are operational round-the-clock to energize a large number of electromagnets. Some of these power converters have been in service for more than two decades and approaching end of life. Therefore, a comprehensive programme for phase-wise replacement of these power converters was taken up and some of the power converters in microtron (those for LH/RH, VSC/HSC coils), TL-1, TL-2, Indus-1 were upgraded [11-13]. The advancement in the field of power electronics (devices and topologies) and the accumulated experience in design, development, installation, operation and maintenance of PCs have facilitated in the development of new PCs using switch mode power converter technology with better performance as well as better reliability. In addition to upgradation of existing power converters, new power converters and pulsed power supply have been developed to cater to new requirements. These developments are briefly described below.

6.1 Upgradation of Indus-2 quadrupole power converters

Eleven power converters for quadrupole magnets in Indus-2 have been upgraded using input-parallel output-series (IPOS), two-switch forward converter (TSFC) configuration [14]. The quadrupole magnets of Q1, Q2 and Q3 families in Indus-2 ring are energized with 170 A power converters with compliance voltage of 80 V, 120 V and 100 V, respectively. Output current stability of these power converters is required to be better than ±50 ppm. For better maintainability of these PCs it was thought to develop a standardized converter that would cater to the PCs of the three types. Two sections of TSFC, which are driven by the common duty cycle command, have inherent load sharing capability. The IPOS configuration also helps in distributing the losses that result in lowering of the stress on the components and switches. The two sections are operated in phase-staggered manner, which helps in reducing ripple at the output. Figure T.1.10 shows inside view of the PC and a histogram showing typical output current stability performance.



(a) (b)

Fig. T.1.10: (a) Inside view of the power converter for Indus-2 quadrupole magnet. (b) Typical output current stability performance.

6.2 Power converters for BBA system

BBA is a technique for measurement of offset between electrical center of BPIs and magnetic center of the nearest quadrupole magnet (QP) using electron beam itself [15]. Measurement of this offset is required to reduce COD which leads to better beam life time, reduced tune variation, reduced corrector strength and ease in commissioning of small aperture insertion devices (ID). BBA requires independent setting of all QP magnets. The BBA system is comprised of special power converters called active shunts (AS) and control system (described in section 7.4) to adjust the current remotely. Brief details of AS are given below. In Indus-2 ring, each group of the series connected quadrupole magnets is powered by a precision current source (I_M). In order to perform BBA, the magnetic field of each quadrupole magnet is varied independently by a few percent (±3.5% max) of I_M (170 A full scale), by putting an active shunt (±6 A/±80 V) across it as shown in Figure T.1.11. The true four-quadrant active shunts with regenerative utility interface have been indigenously designed and developed. The active shunt has a pulse width modulated rectifier (PWMR) as its input followed by a four quadrant converter (FQC) at the output. The regenerative utility interface has increased power transfer efficiency, which in turn has simplified the task of thermal management.

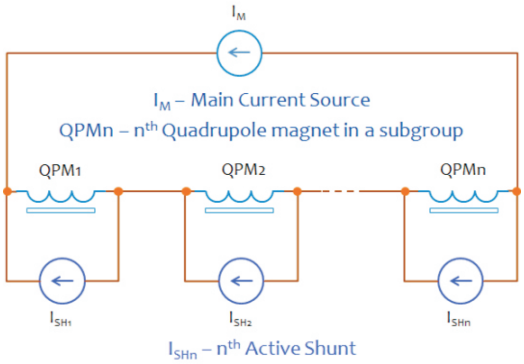
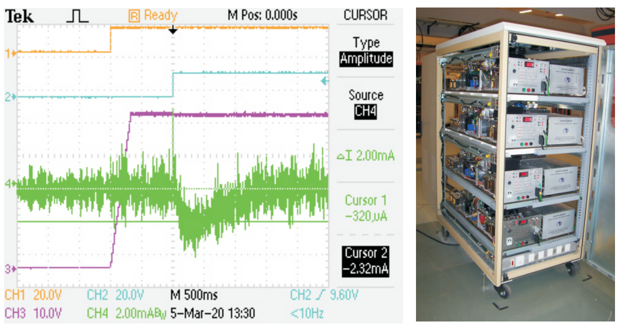


Fig. T.1.11: Circuit configuration: active shunts (I_{SH}), main current source (I_M), and quadrupole magnets.

The operation of multiple current sources with several quadrupole magnets in series offers a great challenge in meeting the performance parameters, like turn on/off transients to limit disturbance to the beam current, output current stability during normal operation, sensitivity of main current source to active shunt and vice versa, isolation, etc. The performance of the active shunt can be best described with the following data arrived after conducting various tests on a number of units: turn on transient in current < 500 ppm (Figure T.1.12(a)), ripple < 25 ppm, sensitivity to main power supply < |±6| ppm, and stability better than ±50 ppm. Figure T.1.12(b) depicts a photograph of the active shunts installed in a rack.



(a) (b)

Fig. T.1.12: (a) Turn on transient in load current (green) (2 mA/div, 12A FS); current loop closure command (blue). (b) Photograph of active shunt for BBA.

After the COD correction with BPM offsets obtained through BBA, the rms COD was reduced from 1.3 mm and 0.43 mm to 0.45 mm and 0.2 mm in horizontal and vertical planes, respectively. This helped in beam operation with reduced vertical aperture of new vacuum chamber at the undulator. Beam lifetime also increased by 3 hours when Indus-2 operated in user mode using the minimum COD achieved after BBA [15].

6.3 Fast pulse power supply for pinger magnet

Fast pulse power supply to energize vertical pinger magnet (described in section 9) delivers a half-sine wave current pulse of peak current 5.5 kA in the load with a pulse width of less than 1 µs. Delivering large peak current with a high di/dt, half sine current pulse, large working voltage and low jitter were technical challenges in the development of this power supply. The power supply was indigenously developed, installed in Indus-2 ring, integrated with the magnet load and remote control system. Commissioning of the power supply was carried out with remote interface and desired performance parameters were achieved. More details are given in Accelerator Report A.4 of this issue.

7. Control system

Indus-2 control system continues to provide supervisory control and data acquisition (SCADA) functions for the entire Indus-2 and its beamline front-ends in 24x7 operation mode. Data of more than 12,000 parameters are logged every second in the central database and history data are available for offline data analysis. Some of the major recent enhancements carried out are as follows.

7.1 Orbit feedback controller improvements

The orbit feedback correction schemes viz. SOFB and FOFB restrict the perturbations occurring in the electron beam due to various noise sources to the acceptable levels. Earlier, the SOFB system was implemented with proportional integral derivative (PID) based feedback controller with corrections applied every 20 seconds [16-17]. A new SOFB controller has been developed over LabVIEW RT platform to incorporate advanced features in SOFB system like predictive and interactive orbit manipulation, predictive orbit movement, simulation, reference tracking, move reverting and constrained model predictive control for disturbance rejection mode [18]. Figure T.1.13 shows a GUI with reference orbit, actual orbit and predicted orbit in SOFB ON state. Also the system architecture has been enhanced to improve the correction rate to 1/3 Hz.

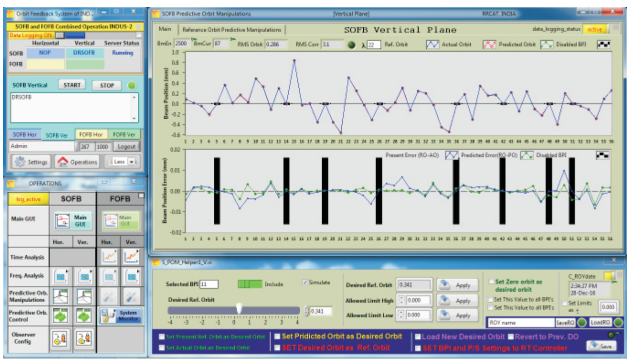


Fig. T.1.13: GUI showing reference orbit (blue), actual orbit (red) and predicted orbit (green) in SOFB ON state.

7.2 Machine interlock system enhancements

Several important enhancements in this computer based interlock system were recently completed with the aim to reduce the spurious trips, capture transient trip events, and increase the reliability through incorporating measures of self-diagnostics and redundancy. Developments include different types of hardware boards and modules, modified data acquisition scheme to improve process response time and changes in software, viz. firmware of Real Time Operating System (RTOS) OS9, SCADA GUIs and database. More details are given in Accelerator Report A.6 of this issue.

7.3 Ramping and cycling verification system

Cycling the output current of magnet power supplies (MPS) ensures repeatable and history-free magnetic field profile which in turn ensures repeatability of operation. Verification of the correctness of cycling operation for all 138 MPS which is nearly a 30-minute process is an important aspect of regular machine operation. This verification has been automated using a software application consisting of multiple modules developed in Matlab and WinCCOA SCADA. This involves checking the deviation beyond tolerance limits for the key parameters and also to detect presence of any spikes and glitches in the reference and read-back signals and reporting it just after completing the cycling process. This has resulted in identification of cycling related faults at the early stage of beam injection cycle and thus increased the machine availability.

Similarly, electron beam energy in Indus-2 is ramped to 2.5 GeV by synchronously ramping magnetic fields of all 117 participating magnets. The overall ramping process is implemented on multi-layer and distributed control system of Indus-2. This involves ramp data generation for each power supply based on user defined profile and then synchronously setting these profiles as per user defined clock rate. Any deviation in this may be one of the causes of beam-loss/partial beam-loss, orbit distortion or tune shift. A system for software based analysis and verification of the correctness of ramping of all MPS participating in energy ramping of Indus-2 has been developed using WinCCOA SCADA and Matlab modules. Figure T.1.14 shows the flow of overall ramping verification process. The current read-back of each MPS is recorded and analyzed to verify that all MPS have participated and followed the standard or desired current ramp profile without any tracking error. The overall application works based on events without user intervention and informs the success or deviation results to the operator along with a detailed report containing plots of analog reference signal, digital signal reference and read-back current signal profiles of all MPS.

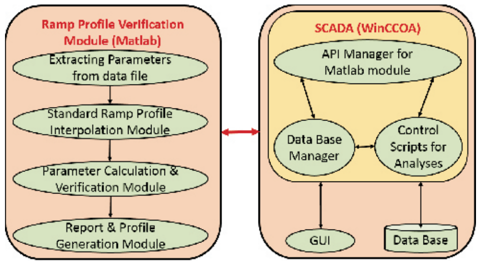


Fig. T.1.14: Overall ramping verification process.

7.4 Control system for BBA

Control system provides 16-bit accurate bipolar reference using Equipment Controllers (Figure T.1.15) interfaced as per 3-layer control system architecture of Indus-2 for all 72 AS and a software application implementing the BBA algorithm automating the complete process. Control system along with the BBA system has been gradually built up over last few years with limited number of AS. BBA is now regularly done after every machine shutdown. Full capacity of 72 AS along with its control system is now in advanced stage of commissioning which will lead to finding offsets of all BPIs in one go and also allow them to be used for experiments of linear optics by closed orbit (LOCO).

Fig. T.1.15: VME equipment control station to control active shunts for performing BBA.

7.5 Enhancements of Indus-2 timing control system for pinger magnets control

Indus-2 timing control system has been enhanced to accommodate the new control requirements for horizontal and vertical pinger magnets. These pulsed pinger magnets need monitoring and control of different input/output (I/O) signals of respective pulsed power supplies and trigger pulses synchronized to Indus-2 revolution clock (1.73 MHz), with timing jitter < 1 ns. New VME I/O boards and trigger board are developed and installed in existing Equipment Control Station. Software for all the three layers of control system is developed to support the enhancements. Figure T.1.16 shows a snapshot of the GUI for pinger magnet operation.

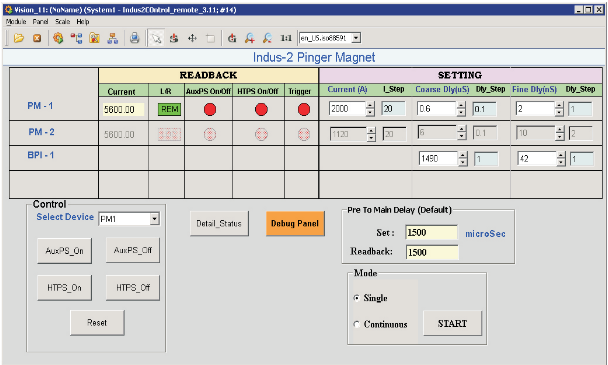


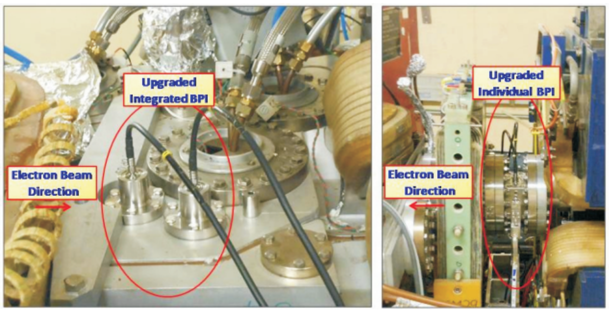
Fig. T.1.16: GUI for pinger magnet operation.

8. Beam diagnostics system

In Indus-2, a number of UHV compatible beam diagnostic devices are installed for the measurement of important beam parameters. These devices were installed ~ 15 years back and have been operating since then. Some of these devices were showing aging affect, due to which a plan was made to replace these devices in phased manner with their upgraded version having improved design features. Development of some of the upgraded diagnostic devices is briefly described below.

8.1 Beam position indicator

In Indus-2 ring, 56 beam position indicators (BPIs) of four-button electrode type are installed in a distributed manner to provide electron beam position for various activities like closed orbit measurement and correction, orbit feedback systems, and coupled bunch instability feedback system. Out of these 56 BPIs, 40 individual type BPIs are installed in the long and short straight sections, and 16 integrated type BPIs are integrated in the vicinity of each dipole vacuum chamber at its downstream side. Upgraded version of BPIs have been designed and developed [19-22] and these are being installed replacing the old BPIs in Indus-2 in phased manner during the planned major shutdowns. Till now, upgraded version of 25 individual type and 4 integrated type BPIs have been installed in Indus-2. The remaining upgraded BPIs are ready and will



(a) (b)

Fig. T.1.17: (a) Upgraded integrated BPI, and, (b) upgraded individual BPI installed in Indus-2.

be installed in line with the planned shutdown in near future. Figure T.1.17 shows upgraded version of individual type BPI and integrated BPI installed in Indus-2.

8.2 Beam position indicators for insertion device sections

For precise monitoring of electron beam position at the entry and exit of the three IDs installed in Indus-2, low gap type BPI, named as insertion device BPI (IDBPI) having internal race track profile having aperture 17 mm (V) x 81 mm (H) same as of vacuum chamber of ID, have been designed, developed, and installed [23-25]. IDBPI signals are also being used for implementation of beam position interlock system. Figure T.1.18 shows the installed IDBPI assemblies at the upstream end and downstream end of U-3 undulator in Indus-2.

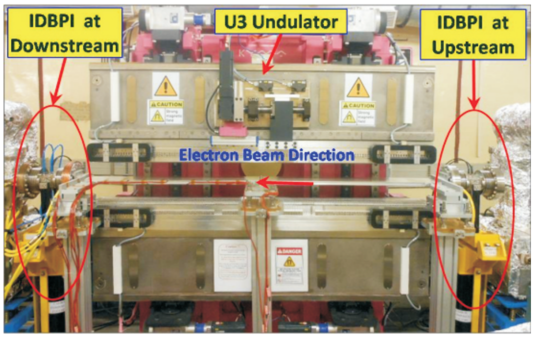


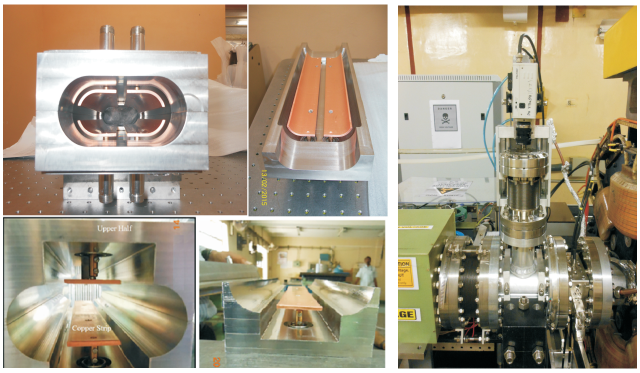
Fig. T.1.18: Installed IDBPI assemblies at the upstream end and downstream end of U-3 undulator in Indus-2.

8.3 Stripline kickers

In Indus-2, a transverse bunch-by-bunch feedback system is implemented to suppress coupled bunch instabilities [26]. Stripline kickers, one each for vertical and horizontal plane respectively, are part of this feedback system. These are fed with RF power for providing transverse correction kick to the electron beam. With a view to enhance the performance of the feedback system and hence improved beam stability, design and development of upgraded version of UHV compatible stripline kickers has been done [27] (Figure T.1.19(a)). The upgraded kickers have improved features such as higher transverse shunt impedance ($\geq$ 20 kΩ for vertical plane and $\geq$ 10 kΩ for horizontal plane), optimum coupling impedance and higher RF power handling capacity of up to 125 W by minimizing the heating of the kicker due to beam.

8.4 Beam profile monitor

Fluorescent screen based beam profile monitors are used in TL-3 and Indus-2 for monitoring of the electron beam profile. Upgraded version of beam profile monitor (Figure T.1.19(b)) has been developed having enhanced design features such as improved actuation and guiding mechanism and fail safe operation. Five numbers of upgraded beam profile monitors have been installed in Indus-2.



(a) (b)

Fig. T.1.19: Upgraded version of (a) horizontal and vertical stripline kicker and (b) beam profile monitor installed in Indus-2.

9. Pinger magnet

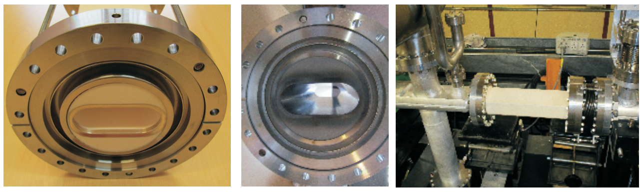
A pinger magnet system is an advanced diagnostic tool for probing the linear and nonlinear dynamics of the beam by way of generating betatron oscillations in the stored beam [28]. The system consists of two types of fast pulsed magnets namely horizontal and vertical pinger (kicker) magnets, which are energized by two separate fast pulse power supplies and control system for operating the pinger assembly from main control room. During the recent planned shutdown of the machine the vertical pinger magnet system was installed in SS-7 straight section of Indus-2 in the first phase. Development of vertical pinger magnet and alumina ceramic UHV chamber for its mounting in Indus-2 ring are described below. Fast pulse power supply and timing control system for pinger magnet are described in sections 6.3 and 7.5, respectively.

9.1 Vertical pinger magnet

A vertical pinger magnet was designed, developed, characterized and installed in SS-7 of Indus-2 ring. The window type geometry has been chosen to achieve better field uniformity in pole aperture, low leakage flux and to minimize the overall size of the magnet as space was a prime constraint. The magnet consists of single turn copper coil and high frequency Ni-Zn ferrite as core material. The magnet produces half sinusoidal magnetic field for pulse width of less than 1 µs having peak value of 650 G at 5.5 kA peak current, which is able to deflect the 2.5 GeV electron beam by 2 mrad in vertical direction. More details are given in Accelerator Report A.3 of this issue.

9.2 Development of Ti coated alumina ceramic UHV chamber for vertical pinger magnet

For mounting the pinger magnet in Indus-2 ring, a UHV compatible alumina ceramic vacuum chamber with Ti coating on vacuum exposed surface was designed, indigenously developed and installed inside fast pulsed vertical pinger magnet in SS-7 straight section. The chamber is made of high purity (99.7%) alumina tube brazed with an intermediate Kovar® ring which is in turn laser welded with SS316L flange. Alumina is used as vacuum chamber material to mitigate the issue of eddy current effect in case of metallic chamber. A Ti coating of 0.5 m thickness provides electrical continuity for the image current and it is thin enough not to generate significant eddy currents which might distort the applied pulsed magnetic field of pinger magnet. A novel active brazing technique was used for direct brazing of Kovar® to alumina joint. Precision and uniform Ti coating of the alumina tube was developed in-house using magnetron sputtering facility at UHV lab. Subsequent to installation and after bake-out, ultimate vacuum ~5 x 10^{-10} mbar was achieved in the ring. Figure T.1.20 depicts end views of chamber before and after Ti coating, and the chamber installed in Indus-2.



(a) (b) (c)

Fig. T.1.20: Chamber end view (a) before and (b) after coating. (c) Alumina ceramic UHV chamber installed in SS-7 straight section of Indus-2.

10. Conclusion

The upgradations carried out in its sub-systems have enhanced the performance of Indus-2 in terms of stable and smooth operation of the machine, better SR photon beam stability and increased beam lifetime. The enhanced performance is evident in the steady increase in the total number of hours made available to beamline users over the years, reflecting in increase in the number of publications per year based on the experiments conducted using Indus-2 beamlines. The expertise developed through indigenous technology development in the field of high power solid state RF amplifier and microwave system, high stability dc and high current pulsed power supplies, magnets having high field homogeneity, UHV technology, controls and beam diagnostics will not only help in the development of sub-systems for future accelerators such as high brilliance synchrotron radiation source but also will ensure long time sustained performance of Indus machines. Many of these technologies have been developed with the participation of Indian industries. Development of infrastructure like large coating facility is a very vital accomplishment towards self-reliance and import substitute for NEG coated UHV chamber.

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