A.2: Indus-2 up-gradation: Installation and commissioning of APPLE-2 undulator

In our continuous endeavour to enhance the performance of Indus-2, an APPLE-2 (Advanced Planar Polarized Light Emitter) type undulator has been successfully installed and commissioned. This undulator is different from the two earlier installed planar undulators and can generate synchrotron radiation (SR) with adjustable polarization. The circular polarized synchrotron radiation from this undulator will be used for the study of magnetic materials by carrying out X-ray Magnetic Circular Dichroism (XMCD) experiments in a dedicated beamline. Furthermore, the undulator will enhance the brilliance of SR by orders of magnitude in the spectral region from 300 eV to 2000 eV including higher harmonics.

The undulator consists of four standard Halbach-type permanent magnet rows with two rows situated above and two rows below the plane of electron orbit. Two diagonally opposite rows are coupled and are moved longitudinally with respect to the other two diagonally opposite fixed rows (causing phase shift), in order to change the state of the polarization of SR. Depending on the phase shift, SR of linear, circular and elliptical polarization states are generated. Design parameters of the undulator are given in Table A.2.1.

Table A.2.1: Design parameters of the APPLE-2 undulator

Parameters	Values
Configuration	Pure Permanent Magnet
Peak magnetic field	~0.529 T (vertical)
Magnet assembly length	1.95 m
Energy of SR from undulator	300 eV to 2000 eV (Linear polarization, including higher harmonics) 350 eV to1000 eV (Circular polarization, 1^{st} harmonic)
Gap range (pole gap)	24 mm to 220 mm
Undulator period length (λ_u)	56.41 mm

In order to keep control over the undesirable effect of undulator on closed orbit, betatron function and dynamic aperture etc., the tolerances on magnetic field integrals were limited to maximum values listed in Table A.2.2.

Table A.2.2: Field integral tolerances

Field Integrals	Values
1^{st} vertical magnetic field integral	± 50 G - cm
2^{nd} vertical magnetic field integral	±8000 G-cm^2
1^{st} horizontal magnetic field integral	±50 G-cm
2^{nd} horizontal magnetic field integral	±8000 G-cm^2

The energy of synchrotron radiation emitted from the undulator can be tuned by changing the pole gap from 24 mm to ~70 mm and the polarization state can be changed by varying the phase shift from 0 mm to ±0.5λ_u. The design spectral brightness of synchrotron radiation from the undulator and dipole magnets for the Indus-2 storage ring are shown in Fig. A.2.1.

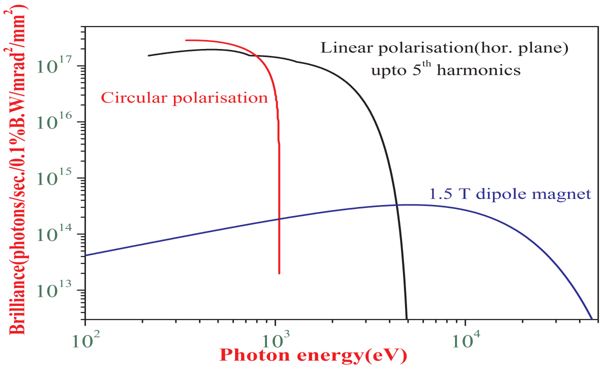

Fig. A.2.1: The design spectral brightness of the SR from APPLE-2 undulator and dipole magnets.

After receiving the undulator from the manufacturer, the basic operations were performed including movement of the poles after connecting the system to the control rack, using the local touch panel. Remote control functionality and interlocks of the device were tested and verified to be as per the specifications. Beam dynamical studies were carried out on the measured magnetic field data of the undulator for its smooth commissioning and operation, which include control of tune point, orbit distortion, beta function and other beam parameters. The magnetic field data were analyzed and the field quality was found to be acceptable. After the successful completion of the offline tests, this undulator weighing 7.2 MT was precisely placed at the designated location in Indus-2 ring, within the various constraints in the machine. Precision survey measurements were done before opening the ring to record the present working positions of the position-sensitive components in the designated section, and then the undulator was installed within linear accuracy of ± 0.1 mm. Fig. A.2.2 shows the section of Indus-2 storage ring housing the undulator.

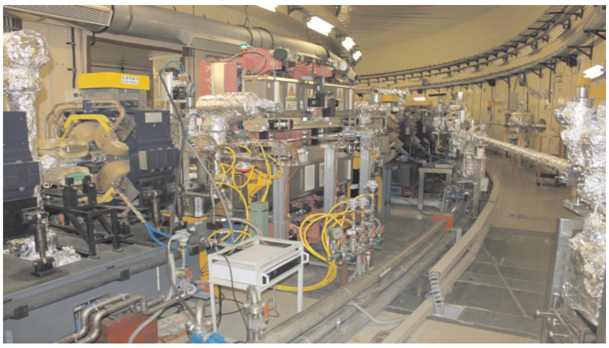

Fig.A.2.2: APPLE-2 Undulator installed in Indus-2

The non-evaporable getter (NEG) coated vacuum chamber was installed inside the pole gap of the undulator along with the peripheral components like beam position indicators for insertion device (IDBPI), taper chambers, corrector chambers and RF-shielded bellows. The assembly has been isolated with two RF sector valves from the rest of the Indus-2 ring. This undulator vacuum segment was leak-tested and baked, followed by NEG coating activation and the ultimate vacuum of 1.4 x 10^{-10} mbar was achieved in this segment without beam.

Remote operation of undulator is facilitated from Indus-2 control room through network communication over ethernet link using client server software components. A beam dump signal is generated to abort the electron beam by way of position interlock from IDBPI at entry and exit of the undulator.

The effect of undulator action on the orbit stability with low beam current at 2.5 GeV was studied. There was no significant distortion of the orbit during magnet pole gap and phase movement. The basic performance of the undulator was demonstrated using scanning wire monitor (SWM) and beam viewer mounted on the zero degree port of the downstream dipole magnet chamber as shown in Fig.A.2.3.

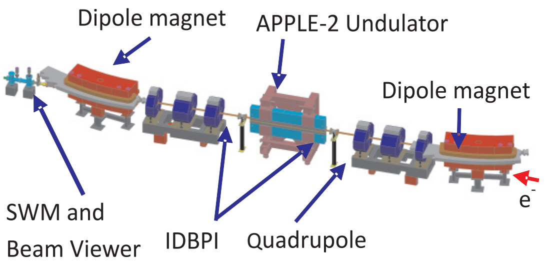

Fig.A.2.3: A schematic of the section of the storage ring housing APPLE-2 undulator

The photo-electron current profiles measured using SWM for different pole gaps is shown in Fig. A.2.4. It is seen that the peak current increases as the undulator pole gap is reduced.

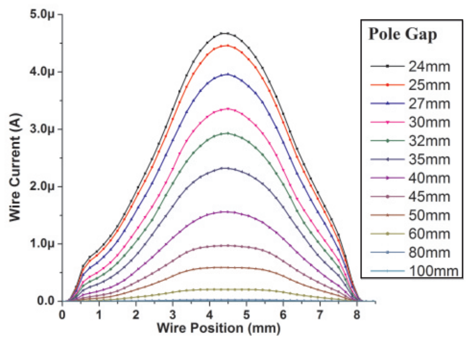

Fig.A.2.4: Photo-electron current measured using scanning wire monitor for different pole gaps.

Experimentally observed variation of the peak current with pole gap is found to be in good agreement with the theoretical calculations as shown in Fig.A.2.5.

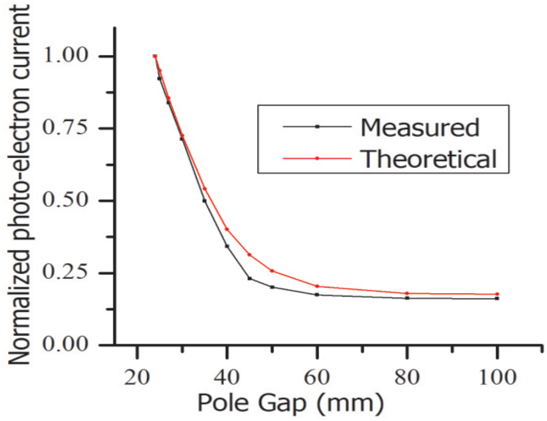

Fig.A.2.5: Normalized current signal of SWM v/s pole gap (theoretical and measured)

The beam images of the SR coming from the undulator for 0 mm, $0.32\lambda_u$ and $0.5\lambda_u$ phase shifts corresponding to linear polarization in horizontal plane, circular polarization and linear polarization in vertical plane respectively, were recorded using beam viewer as shown in Fig.A.2.6. The observed beam profiles show a trend that matches with the theoretical prediction.

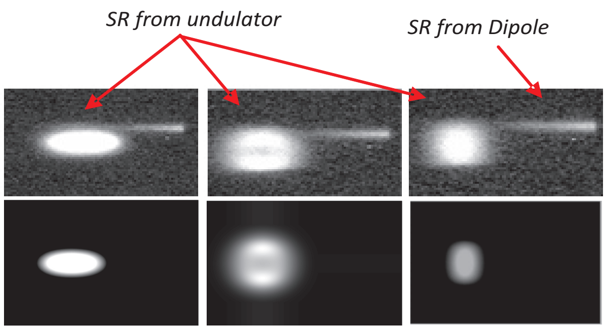

Fig.A.2.6: Beam profiles of the synchrotron radiation from APPLE-2 undulator for: (a) 0 mm phase shift (b) $0.32\lambda_u$ phase shift (c) $0.5\lambda_u$ phase shift. Top row: observed profiles. Bottom row: theoretical profiles.

In the case of $0.32\lambda_u$ phase shift (Fig.A.2.6 b) when circular polarization is expected, flux from the first harmonic is only present on the axis and all the higher harmonics get canceled out. Therefore, the SR beam intensity is lower on the axis compared to that off axis.

To summarize, the APPLE-2 undulator has been successfully installed in the Indus-2 ring and its basic performance demonstrated.

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