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Fast Corrector Magnets for Fast Orbit Feedback System of Indus-2 Synchrotron

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Abstract: Synchrotron users in Indus-2 require stable photon beams for performing various scientific experiments. At the source points of the photons, typical requirement of the beam position stability is ≤ 10 % of the r.m.s size of the electron beam. This stability requirement demands correction of beam orbit disturbances in the range from DC to 100 Hz. The existing slow corrector magnets in Indus-2 are used for correction of very slow disturbances e.g. thermal drift. Therefore a separate set of combined function corrector magnets of high bandwidth were developed for correction of short term perturbations (from low to high frequency up to 100 Hz). These fast corrector magnets have relatively weak kick strengths of ≥ ± 50 µrad at ±15 A DC. The magnetic measurements show no appreciable attenuation in the field strength of these magnets up to 200 Hz. The design, development of the fast corrector magnets and the results achieved by using them in the fast orbit feedback system of Indus-2 will be discussed in this paper.
Keywords: fast correctors, synchrotron, air core magnets, beam stability, feedback system.

I. Introduction

Indus-2, a 2.5GeV Synchrotron Radiation Source (SRS) is located at Raja Ramanna Centre for Advanced Technology (RRCAT), Indore, India, delivering X-rays to various beam line users. At present, the photon radiation of critical energy of 6.235 keV from the bending magnets of Indus-2 is only used by the users. Five insertion devices (IDs) e.g. undulators and wigglers are also planned for Indus-2 to meet the demand of radiations with different characteristics which are not available from the bending magnets. Beam line users require highly stable photon beam to avoid any compromise in the intensity of the beam. The stability of the photon beam is directly related to the stability of the source point i.e. the stored electron beam. For Indus-2, the most stringent tolerance for the electron beam position stability turns out to be ~ 3 µm in the vertical direction (Δy) at the long straight sections of the ring (location of Insertion Devices). The sources of perturbation to the electron beam orbit can be categorized in time scale as : (i) very slow (hours/days) - change in temperature due to beam induced heat load , air and water cooling effect, (ii) slow (seconds/minutes) - gap /phase change in undulators (IDs), activities in surrounding areas e.g. crane movement in experimental hall, (iii) fast (< second) - ground vibration, operation of booster synchrotron (~1 Hz at Indus complex), mains (50 Hz) and its harmonics. Some of the above mentioned perturbations can be minimized, but cannot be avoided totally. Therefore, a feedback mechanism is needed towards the stabilization of electron beam positions in Indus-2 for the entire range of perturbations (from DC to ~100 Hz) for the correction of beam positions. The existing combined function corrector magnets are placed on aluminum vacuum chamber and is suitable for correction of long term orbit disturbances (DC). A fast orbit feedback correction system is planned for installation in Indus-2 storage ring to mitigate (short term) fast orbit disturbances in order to provide a better beam stability at the photon source points. For this, fast corrector magnets are used to stabilize the time dependent electron beam orbit at all the source points from where the photon beam is emitted. The beam positions will be corrected using 40 fast corrector magnets distributed over the perimeter of Indus-2 ring.

Existing corrector magnets′ response in Indus-2: The field strength of the existing combined function (horizontal & vertical) magnets [i] for closed orbit beam corrections in Indus-2 is ~ ± 1.2-1.3 *mrad* and the independent corrector magnets' strength is ~ ± 1.5 *mrad*. These existing corrector magnets (steel-cored) in Indus-2 are placed over the aluminum vacuum chambers. Figure 1 shows one such corrector magnet placed in Indus-2 ring. The response of the magnet with aluminum vacuum chamber is measured and also simulated using Opera-3D software [ii]. Figure 2 shows the experimental results where

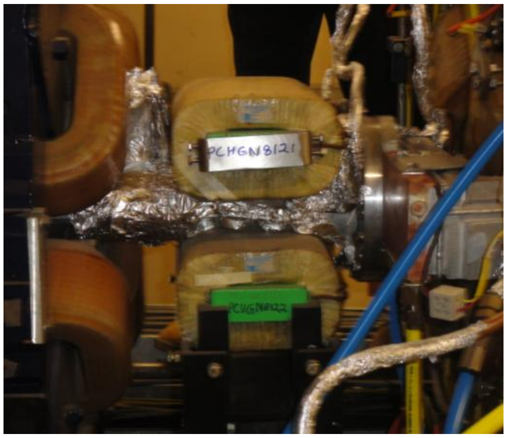

Figure 1: Combined function steel cored corrector magnet in the ring.

magnetic field is lagging w.r.t. the excitation current. Figure 3 shows the amplitude (relative to 1Hz) and phase lag variation with frequencies. The poor response of these magnets to high frequency corrections was mainly due to eddy current effect as these were placed on the aluminum chambers at various locations of Indus-2.

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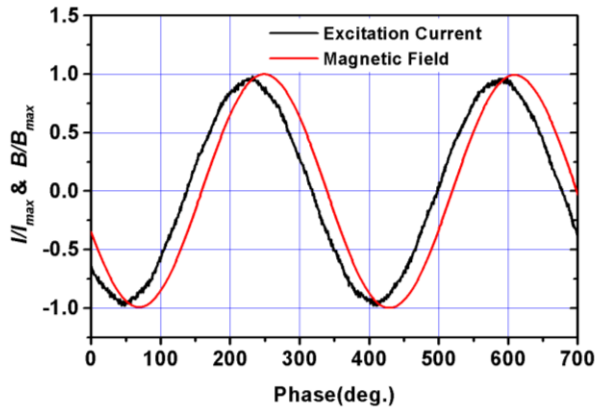

Figure 2: Vertical magnetic field (red line) lags excitation current (black line) by ~23.8^0 at 5Hz.

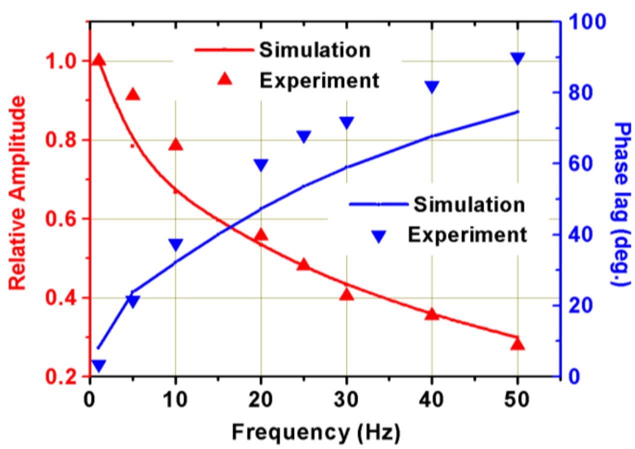

Figure 3: Amplitude variation and phase lag Vs frequency.

As shown in figure 3 above, the existing corrector magnets have limited bandwidth, suitable for only slow orbit feedback (DC) corrections and not suitable for fast orbit beam corrections. There are multiple stainless steel (SS) bellows present in the ring connecting different sections of aluminum vacuum chambers and as adopted in SOLEIL, these spaces can be used for the fast correction of the beam positions [iii]. Therefore, a separate set of corrector magnets with high bandwidth are required which will be placed at the locations where stainless steel bellows are present in the Indus-2 ring. The thicknesses of the stainless steel (SS) bellow (0.2mm) and the Be-Cu strips (0.3mm thick) inside the SS bellow for RF shields [iv] are much less than the skin depth at 1kHz. .

II. Methodology and Materials

Design and development of fast corrector magnets: The length of SS bellow over which these fast corrector magnets are to be placed is about 100 mm. Hence, the overall length of each corrector (along the beam orbit in Indus-2) has to be designed within 100 mm. Also, these fast correctors have to be of combined function magnets to generate both horizontal and vertical magnetic fields which will be required to correct the fast orbit disturbances up to ~ 100 Hz in both planes. The design of fast corrector magnet is finalized with the consideration of having (a) air cored (low inductance to reduce the compliance voltage) & air cooled magnet type to place/mount over the stainless steel (SS) bellows, (b) high bandwidth (kHz) to correct the high frequency perturbations up to ~ 100 Hz, and (c) relatively weak strength (± 50-60 μrad @ 15 A). The technical challenge involved is to install these correctors over stainless steel bellows in the limited available space (~ 100 mm) of Indus-2. Based on the above mentioned requirements and space constraints, the fast corrector magnets are designed to have four air-cooled coils (two coils in each case for producing horizontal and vertical magnetic fields) and feasible to clamp/fix the coils in horizontal and vertical positions within the narrow space as available in Indus-2 ring. The mechanical design of the fast corrector magnets has been done after consideration of the above mentioned issues and initially developed a prototype magnet.

Materials: The fast corrector magnets are of air cored type to eliminate the effect of remnant magnetic fields. Air cooled excitation coils (current density ~ 1 A/mm^2) are used, wound from 10 SWG enamelled copper wires and impregnated with F-Class epoxy resin. The material for magnet assembly structures is made from G-11 (NEMA Grade) glass fiber reinforced epoxy resin material and all the mechanical fasteners used for assembly are of non- magnetic stainless steel grade (SS 316).

The coils of prototype magnet is wound from enamelled copper wires with 200 turns and all the wound coils are epoxy resin

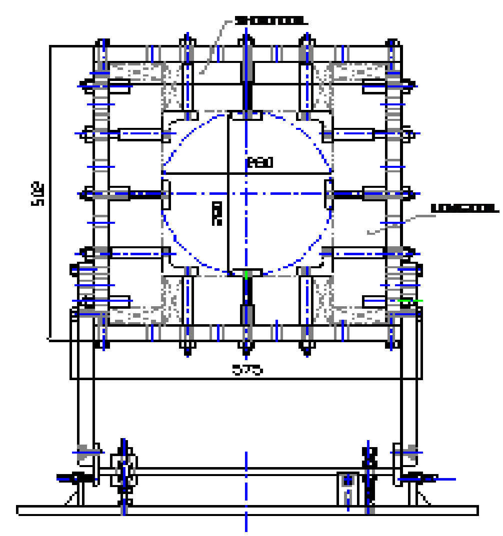

Figure 4: Prototype fast corrector magnet.

impregnated under vacuum. The four coils of the corrector magnet assembly were mounted perpendicular to each other (two coils in horizontal & two in vertical) using a square support structure/frame of glass reinforced epoxy resin. Figure 4 shows the details of fast corrector assembly. The mechanical and electrical parameters of the impregnated coils were checked before their assembly in the magnet. The prototype magnet is tested with and without placement of central SS bellow and the

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field measurement results (magnet response) are found satisfactory.
A corrector magnet assembly placed over SS bellow vacuum chamber in the measurement bench is shown in figure 5.

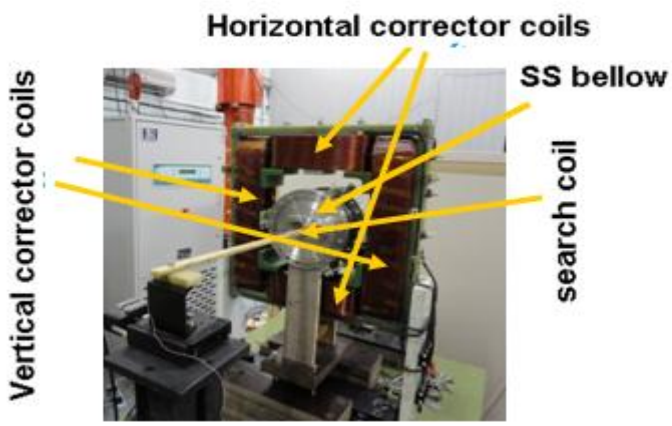

Figure 5: Corrector magnet with SS bellow in the measurement bench.

The DC integral magnetic field strengths (horizontal and vertical) have been measured using a rotating coil. The DC integral field strengths and corresponding angular kicks for a 2.5 GeV electron beam in the current excitation range of ± 15A are shown in figure 6 and 7 respectively. The maximum angular kicks of ~ ± 60 μrad (for vertical correction) and ~ ± 50 μrad (for horizontal correction) @ ±15 A have been achieved in the magnet.

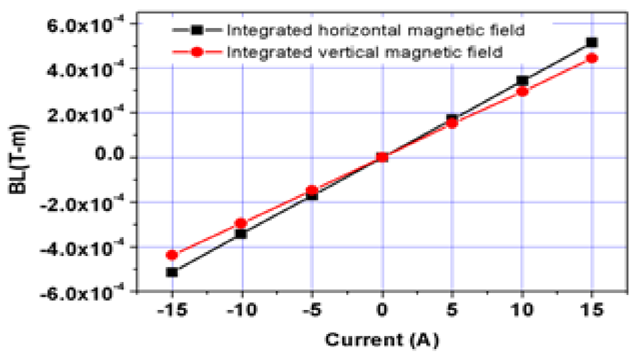

Figure 6: Integral field strengths (DC) of corrector magnet with excitation current

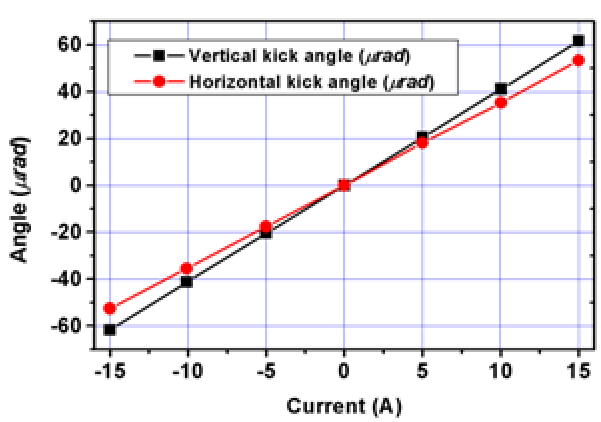

Figure 7: Angular kick strengths (DC) of corrector magnet with excitation current.

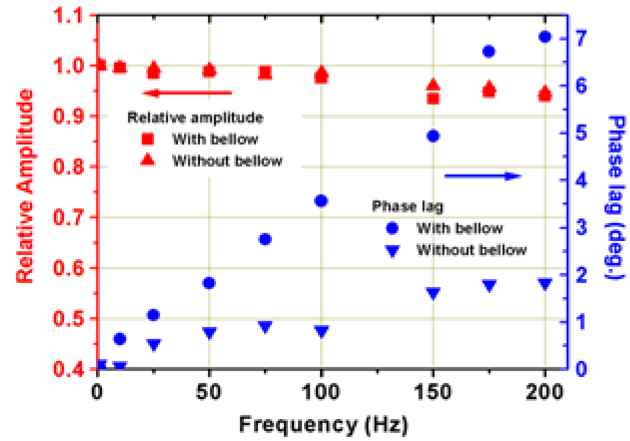

Figure 8: Relative peak amplitude and phase lag Vs frequency for vertical field component (amplitudes normalized w.r.t. the value of peak amplitude at 1 Hz without bellow).

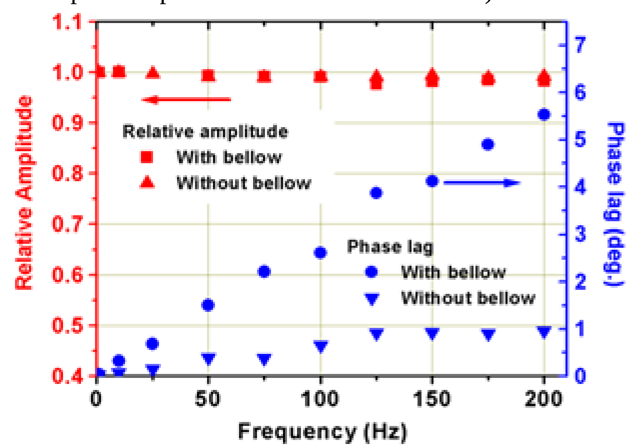

Figure 9: Relative peak amplitude and phase lag Vs frequency for horizontal field component (amplitudes normalized w.r.t. the value of peak amplitude at 1 Hz without bellow).

A search coil (as shown in figure 5) is used to measure the response of the magnet by changing the frequency of the excitation current. Figure 8 and 9 show the response of the vertical and horizontal magnetic field components with the frequency of the excitation current respectively. No appreciable attenuation is observed up to ~200 Hz. Phase lag of ~ 7^0 and 5.5^0 are found for the vertical and horizontal field components respectively at 200 Hz.
The magnet can be operated continuously at 15 A peak AC current (r.m.s 10.6A). The maximum coil surface temperature was observed as ~ 60^0 C.

III. Development of fast corrector magnets

Fast correctors for local orbit correction: To implement Fast Orbit Feedback (FOFB) system for Indus-2 in a phased manner, initially a trial operation is done on beamline-8 with local electron beam orbit corrections. For this, five numbers of combined function fast corrector magnets (needed four correctors at a time for experiment) were developed,

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characterized and installed at Indus-2 synchrotron. These corrector magnets along with beam position indicators (BPIs) are used for beam position control for local orbit corrections. The power supplies for the fast corrector magnets are rated as ±150V, ±15A and provided the current stability of ±50 ppm or better [v]. The bandwidth of the power supply is 500 Hz. Figure 10 shows the fast corrector magnet assemblies for local orbit correction experiment. Figure 11 shows the one such installed fast corrector magnet in the limited space over SS bellow in Indus-2 ring.

The initial fast orbit local correction results were encouraging and corrected the beam orbit variation within the required 3 μm in both the planes.

Figure 10: Fast corrector magnet assemblies for local orbit correction trails.

Figure 10: Fast corrector magnet assemblies for local orbit correction trails.

Figure 11: Installed fast corrector over SS bellow in the limited space at Indus-2 ring.

Fast correctors for global beam orbit correction: In the first phase of implementation of global Fast Orbit Feedback (FOFB) system for Indus-2, 16 series fast corrector magnets have been developed and characterized. During magnetic characterization, conical pins (fiducials) were fixed at the top and front face of each magnet to represent its magnetic axis. Also, each magnet is mounted with a compact movement mechanism to adjust / position the magnet at the desired location at Indus-2 ring site. Figure 12 shows the series developed fast corrector magnets for global beam orbit corrections.

Figure 12: Series fast correctors magnets for global orbit beam corrections for Indus-2.

All these 16 fast correctors along with 16 BPIs were used for the first phase of global orbit beam corrections in both the horizontal and vertical planes. The fast corrector with feedback system successfully brings down the natural occurring beam variations up to 50Hz in vertical plane to ≈ ± 3μm [vi].

In the final phase of global FOFB system for Indus-2, total 56 BPIs and 40 fast corrector magnets will be used for global fast orbit corrections. The development and magnetic characterization of all 40 correctors have been successfully completed. These magnets have to be installed in Indus-2 ring for full implementation of global FOFB system for beam orbit stability in Indus-2 synchrotron.

IV. Conclusions

The design and development of fast corrector magnets for fast orbit feedback system for Indus-2 is successfully completed. The first phase of global orbit beam corrections is done successfully at Indus-2 ring. The operation results of the beam orbit corrections with the fast corrector magnets are quite satisfactory. The implementation of final global fast orbit beam corrections in Indus-2 is in progress.

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1 Aug. 2017

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References

i. *G. Singh et al, "Status of indus-2 synchrotron radiation source - IUAC, www.iuac.res.in/event/InPAC11/proceedings/.../I-30/GurnamSingh.pdf*

ii. *Opera-3D version 12, Vector Fields Limited, 24 Bankside, Kidlington, Oxford OX5 1JE, England*

iii. *N. Hubert et al, "Commissioning of Soleil Fast orbit feedback System" EPAC,2008, p.3248-3250.*

iv. *S.K. Shukla, "Vacuum Systems of Accelerators at Indus Complex", IVS-2012 -February 15, 2012, VECC Kolkata.*

v. *Singh S.N et al, "Corrector magnet power supplies for Indus-2" InPac-2013, VECC, Kolkata, 19-22 Nov. 2013, pp 666-668.*

vi. *Pravin Fatnani et al," Status of Indus-2 Control system" Proceedings of PCaPAC2014, Karlsruhe, Germany, ISBN 978-3-95450-146-5, pp 138-140.*