

ORBIT CONTROL FOR INDUS-2 STORAGE RING

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ABSTRACT

Indus-2 is a 3rd generation synchrotron radiation source under pre-commissioning phase at CAT, Indore. Other than the control system hardware and software common for all sub-systems, it uses an interactive orbit control package developed in MATLAB [5], which provides for orbit control and simulation just by drag and drop. Implementation of orbit control requires handling matrix calculations efficiently. Well known for its powerful mathematical and graphic routines, MATLAB is an ideal choice as the mathematical engine for orbit control. The package provides support for number of orbit control algorithms and powerful and intuitive graphical display, simulation mode, commissioning and ramping support, orbit database and device control. The orbit control package along with control system hardware and software for magnet power supply systems and beam diagnostic systems constitute the complete system for orbit correction. The paper describes the scheme for slow global orbit control for Indus-2 and the use of the software package developed for the same.

INTRODUCTION

Indus-2 control system has three layered architecture (Fig. 1), where the first layer is UI (User Interface) layer with SCADA (PVSS), MATLAB and other software, the second layer is the SC (Supervisory Control) layer with network enabled VME based CPU boards acting as PROFI master and layer three is the EC (Equipment Control) layer with VME based CPU boards, acting as PROFI slaves and various I/O cards.

Electron beam revolving inside the storage ring may not always pass through ideal orbit due to various factors affecting its stability. Orbit correction is provided through the above control architecture, in which the correction algorithms run at first layer on MATLAB platform. The orbit is sensed using the Beam Position Monitors (BPM) spread across the whole of the ring. The actual orbit is calculated by applying certain calculations to the measured values and certain machine lattice specific constants. The orbit control package not only provides support for orbit correction and orbit bump but can also be used as tool for learning accelerator physics concepts practically. For orbit correction, Indus-2 has 56 BPMs throughout the ring, 48 horizontal and 40 vertical corrector magnets to steer the beam with desired kicks. Each BPM measures beam position and interfaces with the EC layer to which SC layer communicates and finally this BPM data is stored in database on PVSS SCADA at UI layer with a refreshing rate of about 4Hz. Orbit correction package, which can provide both manual and automatic operation, takes these distorted orbit data from BPMs there and then application of correction algorithms on it yields corrector strengths (for horizontal and vertical separately) which are then passed similarly on to the correctors.

ORBIT DISTORTIONS AND CORRECTION REQUIREMENTS

Global Slow Orbit Correction

Orbit distortions can be broadly classified into two categories. First is generally of static nature, which comes into picture due to magnet misalignments and magnetic field errors of dipole, quadruple and sextuple magnets. Such distortion is more precisely described as closed orbit distortion (COD). The COD has different values at different locations around the ring, which depends on the beam optics. As predicted by statistical calculations random errors in Indus-2 elements may give a maximum COD of 9.7 mm in horizontal plane and 10.5 mm in vertical plane. Temperature variations of the ring tunnel (cause variations in the structural components and magnets) and cooling water also

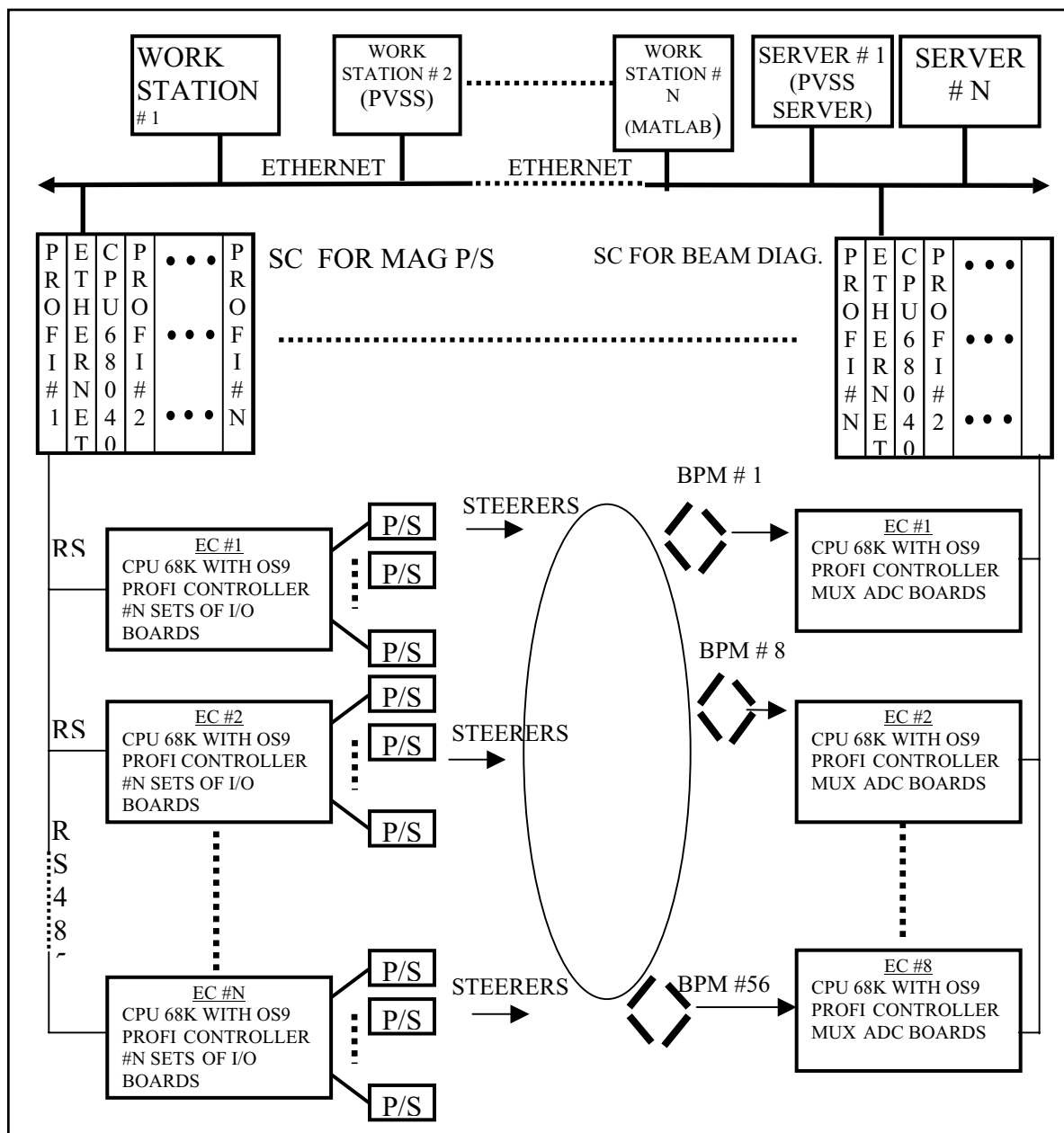


Figure 1: Indus-2 Control System Scheme

cause orbit distortions with time. These have to be therefore corrected at certain interval of time. The requirement is to correct this COD to a value less than 1mm in both transverse planes. Using slow orbit correction scheme, we aim to correct the orbit against these sources of distortions.

Local Fast Orbit Correction

The equilibrium closed orbit of the electron beam in a storage ring can not be held perfectly stable due to time varying errors introduced into the magnetic guide fields. There are many vibration sources, which affect the beam in the storage ring. Some of the main sources of vibrations may be ground motion, local traffic, rotary equipments and cooling water flow. Spectrum of such distortions may be up to 100 Hz while most of the frequencies may be located below 25 Hz. The most stringent requirement of orbit control comes from the spectral brightness of the photon beam from an undulator. Stability of the photon beam source point against faster distortions should be of the order of 10 % of that of the beam size. Typically, beam size variations have to be kept under 72 microns for horizontal plane and 9 microns for vertical Plane. So correction of the order of a few microns is expected from fast correction scheme. For correction within such tight tolerances, accurate, digital

feedback system is must. By measuring the position and angle of the photon beam downstream, the orbit of the electron beam can be corrected locally. A local correction system deflects the electron beam only over a limited position of closed orbit, without affecting the rest of the orbit. This is called generating a local orbit bump. With four magnet bump it is possible to independently control both the position and the angle of the beam at source point using photon beam position monitors at two locations in the beam line. Two corrector magnets placed in the downstream region and two corrector magnets placed in the upstream region of the insertion device are required to correct the beam motion up to 50 Hz. We have plans to implement such a digital local fast correction later. Below we describe the global slow orbit correction system for Indus-2.

HARDWARE

The control system hardware at layer 3, i.e. the EC layer caters to the characteristic requirements of the system. The measurements of beam positions involve the beam diagnostic sub-system and the application of corrections involves the magnet power supply sub-system. The power supply sub-systems use VME 16 bit DAC and ADC boards for setting and reading the steering power supplies, while VME 16 bit ADC boards with 4 channel multiplexer serve to read the BPM data under the beam diagnostic sub-system. One such board is used for each BPM. The signals on the four channels correspond to the four buttons on the BPM. Hence such 56 boards are placed in the 8 EC racks spread across the ring. Provision is also made for averaging out a number of samples to mitigate the noise effects and get acceptable readings. There is a status indication available from each BPM electronics unit indicating its health. Other front-end electronics is also deployed for selecting, handling and conditioning of the fast signals, which are in the RF range. BPM calibration constants are taken into considerations in software at layer1.

Device Control

Indus-2 control system uses an architecture that has intelligence distributed over three layers. These three layers are User Interface Layer (L1), Supervisory Control Layer (L2), and Equipment Control Layer (L3). Ethernet and TCP/IP interconnect L1 & L2, whereas L2 & L3 are interconnected by Profibus over RS485. L2 uses Motorola 68040 processors and runs on real time operating system OS-9. At L2, one process continuously polls L3 over Profibus and updates online database in RAM with latest device information and another server process handles communication with L1 using TCP/IP sockets. Various inter-process communication mechanisms have been used at L2 to pass, share and synchronize data/events among these processes. At L1 a Java Client takes corrector magnet kicks from the MATLAB environment and transfer them to server process running at L2, which writes these kicks at L3. Another Java Client takes orbit data and corrector magnet read backs from the L2 server and passes it onto MATLAB the environment.

We have used JAVA to provide connectivity of MATLAB with PVSS through Ethernet. Special protocols are made to process the request from the MATLAB client.

SOFTWARE: MATLAB BASED GLOBAL ORBIT CORRECTION PACKAGE

The interactive orbit control package developed in MATLAB, which provides for orbit control just by drag and drop is the core of the correction software. The package provides support for number of orbit control algorithms like Singular Value Decomposition (SVD), least square minimization, constrained correction, orbit bumps etc. Indus-2 lattice has been simulated in this package using Accelerator Toolbox [4]. An operator can visualize all orbit related information and can foresee the effect of corrections, before its actual application. The highlights of the package are powerful and intuitive graphical display, simulation mode, commissioning and ramping support, orbit database and device control. This package is fully equipped to provide complete graphical access to its features for users. One can opt to either work in offline mode (for learning or testing the software) or online mode (with machine actually providing data). Offline mode of software operation is possible through incorporating Accelerator Toolbox.

The Graphical User Interface

All orbit related information is displayed on single screen. This screen shows electron beam orbit, corrector strengths and spectrum of singular values. The orbit display (Fig.2 top graph) shows measured (a), predicted (b), reference (c) and desired (overlapping with the reference orbit) orbits. Small rectangles indicate individual Beam Position Monitors (BPMs). Clicking on BPM icon, displays the orbit information on the screen. In toggle mode, BPM icons can be toggled on/off to control which BPMs enter the calculations. In drag mode, BPM icons can be dragged to define desired orbit and subsequent calculations will try to achieve that desired orbit. The corrector display (Fig.2 bar chart) shows measured (thick bar) and predicted (thin bar) corrector strengths. Clicking on the corrector bar displays the information pertaining to that corrector onto the screen. In toggle mode, corrector icons can be graphically toggled On/off to specifically exclude them from the correction procedure. Since orbit correction will be mainly based on SVD of the response matrix, so plot of singular values is also displayed (Fig 2. bottom left). By graphically moving the icon in this display, operator can define cutoff singular value for SVD algorithm and can immediately see the predicted orbit and its root mean square (RMS) value, if selected singular values are used. And on release of mouse button, predicted corrector strength is also displayed.

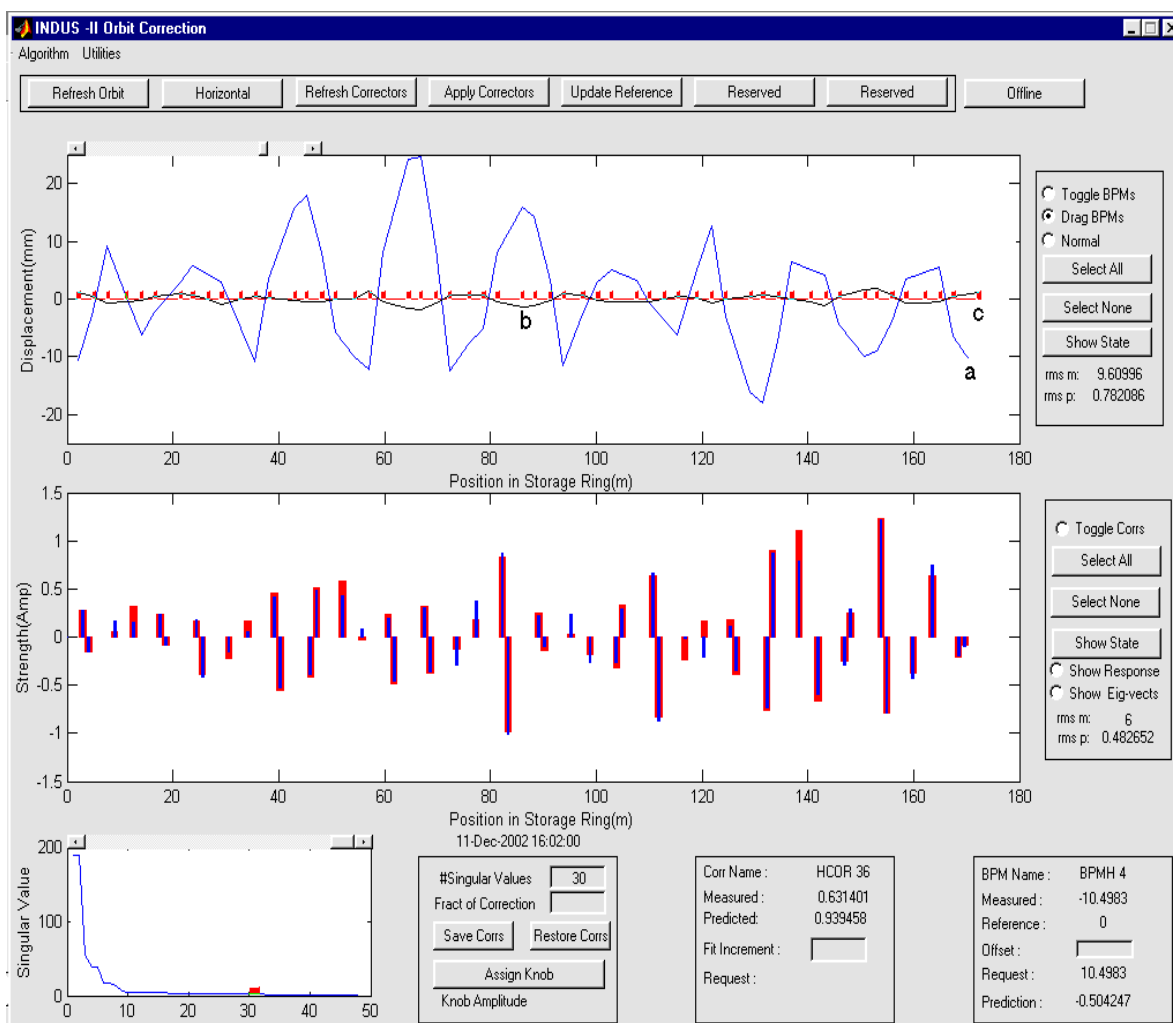


Figure 2: Main Panel of orbit control software

More on Graphical User Interfaces

There are pushbuttons with callbacks to refresh orbit and correctors, and each time data is refreshed corresponding RMS value is updated onto the screen. An operator can switch between orbital planes (Horizontal /Vertical) and machine modes (Online/Offline). There are radio buttons to show response matrix or eigenvectors. Show state button in BPM pane pops up another screen (Fig.3), which displays the details of electron beam orbit along with interactive lattice of Indus-2. Clicking on any lattice element brings up a dialog box showing all details about that element. Other buttons are to update reference, apply corrections, save and restore corrector magnet strengths etc. Desired algorithm for orbit correction can be selected from Algorithms menu. If an operator is going in for algorithms like constrained correction or orbit bump, the program graphically saves necessary parameters like region of interest or magnitude of orbit bump etc. Utilities menu has menu item to measure orbit response matrix.

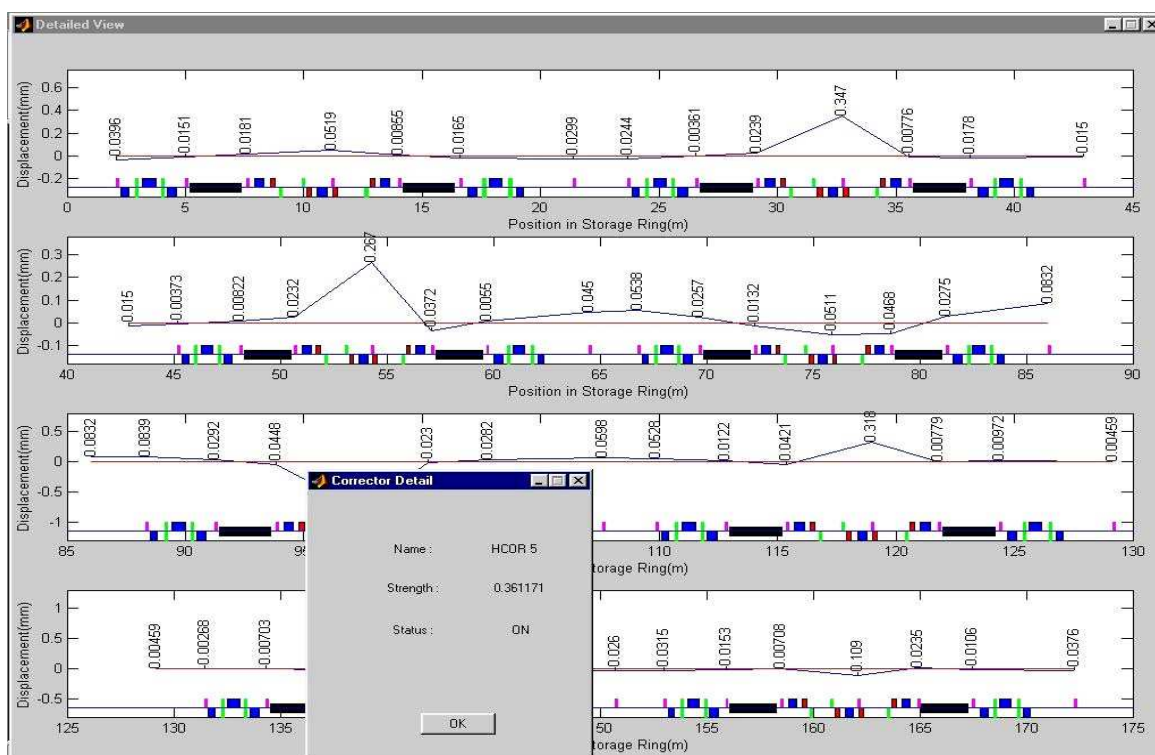


Figure 3: Detailed view of orbit with interactive Indus-2 lattice

Simulation Mode

Indus-2 has been simulated in this package using Accelerator Toolbox. In simulation mode corrections are applied to simulated machine, and predicted orbit is displayed, if satisfied with predicted orbit and calculated corrector strength, an operator can go online and apply corrections. If corrector strength exceeds the permitted value, alarm is sounded and correction is aborted. Package makes use of MATLAB based LOCO (Linear Optics from Closed Orbits) program in conjunction with AT to find errors and calibrate model of storage ring, so that predictions made by simulated machine are very accurate. Simulated machine can be used for beam dynamic studies.

Commissioning and Ramping Support

Package provides for orbit bumps, which are extremely useful during commissioning period, to look for vacuum chamber obstructions. During Commissioning, at each halt of ramping, program will calculate new set of corrections, so that beam is ready for further ramp. And based on planned increment in beam energy it can give signals to ramping hardware, so that correctors can be ramped in synchronism with beam energy.

Program Structure

Program Structure is modular. It has separate mathematical, data I/O and graphical routines. There are separate routines for BPM, corrector and SVD graphics. There are global data structures like BPM, COR, RES, BPM and COR data structures contain fields for name, value, status for fitting etc. BPM (1) and BPM (2) contain horizontal and vertical orbit data respectively, same is case for COR and RES. RES contains response matrix data.

Orbit Database

Package has an inbuilt database to store all orbit related information. This has been developed in Microsoft Access and it is connected to MATLAB using Java Interface and Java Database Connectivity (JDBC). Orbit and corrector status can be saved in Orbit database, and can be recalled at any future time to update reference or for application on the machine. Database browser (Fig.3) has been implemented using Java Swing Components, which have very good look and feel. Database can be queried very easily by specifying RMS or average electron orbit, RMS corrector strength, date, algorithm etc.

Pseudo Multi Tasking

Program performs sequence of operations in background like refreshing orbit, measuring response matrix, logging orbit data into database, applying corrections etc. Program uses (Windows) system timer calls and Java threads to implement pseudo-multitasking in single threaded environment like MATLAB.

Drag & Drop

All orbit control is by drag and drop. This drag and drop is not a regular feature of MATLAB. It has been implemented using C and Windows API programming. MEX files (MATLAB callable C programs) have been written, which take vital data from Windows operating system like screen width, screen height, mouse coordinates and mouse status (up/down) etc. BPM icons in orbit display are rectangles. In button-down function of these rectangles MEX files are called to get the status of mouse and if mouse is being dragged these coordinates are transformed into coordinates valid for orbit display axes and position of BPM icons is updated accordingly. In this way the desired orbit is defined by just drag and drop. Similar technique is being used to select the cut off singular value.

DISCUSSION

This module has been put to test in the simulation mode and the actual tests would be carried out soon. The machine is under pre-commissioning phase and the slow orbit control would be put to work after some initial trials with energy ramping.

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