

# PRECISE SURVEY AND ALIGNMENT OF SYNCHROTRON RADIATION SOURCE INDUS-2

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### Abstract

The 2.5GeV third generation synchrotron light source Indus-2 at RRCAT, which is in advance stage of commissioning, demanded a high precision of survey and alignment of all its components. In particular, we had to control the transverse and azimuthal positions of all quadrupoles and dipoles within a relative accuracy of 0.1 mm and overall circumference within 2.5 mm. This required a tight control over all the sources of errors starting from fiducializations, survey of networks, final alignment and smoothing. We have successfully accomplished this task by adopting the triangulation-trilateration technique of survey and alignment along with indigenously developed software for online survey data collection, least square adjustment of redundant measurements and error analysis. The accuracy of alignment was reflected from the successful circulation and storage of electron beam in the machine with a very small closed orbit distortion. This paper, in brief, presents the methodology adopted for survey and alignment and final accuracies achieved.

### INTRODUCTION

Indus-2 with a circumference of 172.4743 meters consists of 16 dipole magnets, 72 quadrupoles, 32 sextupoles, 48 steering magnets, 56 beam position monitors and some special components like injection septums, kickers and RF cavities. The relative tolerances for alignment of magnets are given in table-1. These are the total error budgets in the placement of components including ambiguities in knowledge of the magnetic axis and errors in fixation of fiducials etc.

Table 1: Alignment tolerances.

Object name	$\delta S$ mm	$\delta X$ mm	$\delta Z$ mm	$\theta_s$ mrad	$\theta_x$ mrad	$\theta_s$ mrad
Dipole	0.1	0.2	0.1	0.2	0.5	0.5
Quadrupole	0.1	0.1	0.1	0.2	0.5	0.5
Sextupole	0.5	0.1	0.1	0.2	1.0	1.0
Steering Magnet	1.0	1.0	1.0	2.0	2.0	2.0

Figure-1 shows the general layout of accelerators at RRCAT. The already existing Booster Synchrotron acts as injector for Indus-2. Hence before start of construction of building for Indus-2, it was necessary to mark the centre of building and fix the central monument with respect to Booster synchrotron.

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During building construction the embedded plates for mounting girder jacks, embedded pipes for synchrotron beam lines, primary control network monuments etc. were fixed at their designed positions/orientations and elevations with in a fair accuracy. Since Indus-2 is housed in a narrow over-ground tunnel of 5.2meter width, the visibility of machine is limited to a very small zone. So we decided to adopt a network approach of alignment for controlling the overall shape and size of the machine and at the same time to align all components within specified tolerances [1]. For this we established three control networks, namely Primary Control Network, Secondary Control Network and Elevation Control Network.

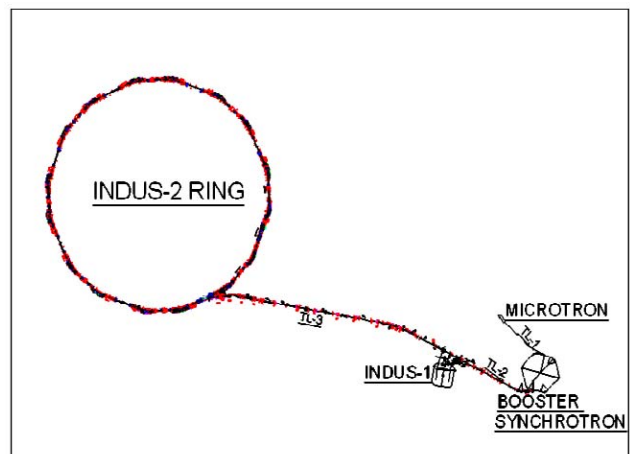


Figure 1: Layout of Accelerators at RRCAT.

### SURVEY CONTROL NETWORKS AND FIDUCIALIZATION

#### Primary Control Network

The primary control networks are in the form of 400 mm diameter concrete pillars (monuments) with forced centering sockets over them for mounting survey instruments and optical targets [Figure 2]. Out of 11 monuments, the locations of 4, that lie in the tunnel, were decided in such a way that the whole machine is divided into four approximately equal parts. Holes have been provided in the inner wall of the tunnel, to facilitate direct measurements of distances and directions between them. The primary control network defines the coordinate system of Indus-2 and acts as a reference for the secondary control network. The coordinates of these monuments have been determined by least square adjustment of repetitive redundant distance and direction

measurements, using a Distinvar™ with calibrated invar wires and a Leica TDA5005™.

### Secondary Control Network

The secondary control network is in the form of 42 uniformly distributed brackets fixed with the inner and outer wall of the tunnel [Figure 2]. These brackets are equipped with conical bases for mounting survey instruments and optical targets. Their locations were decided after considering the parameters like focusing (magnification) distances of theodolites, visibility of components, uniform positional strength (error ellipses) in all directions etc. The coordinates of these network points have been determined by repetitive distance and direction measurements [2] using a calibrated TDA5005™ and a TM5100™.

### Elevation Control Network

The elevation control network is also in the form of wall brackets (24 no.) fixed with inner and outer wall of the tunnel. They are also equipped with conical bases for mounting optical targets. Elevation of each bracket has been determined by their repetitive survey using a Leica N-3™ optical level.

### Fiducialization

All quadrupoles and sextupoles are fitted with two fiducial posts and one level plate. These fiducial posts were fixed during their magnetic characterization on harmonic bench using laser and quadrant diode. However for controlling the position along beam, reference with respect to mechanical mid section was established by using Axyz® system. All dipoles are fitted with four fiducial posts and one level plate. The magnetic

measurements of dipole magnets were carried out by hall probe manipulating CNC machine and during this the fiducial posts were welded and their relationship with respect to magnetic axis was established by using Leica industrial measuring Axyz® system. For alignment in the tunnel, the coordinates of all these fiducials were transformed into Indus-2 machine coordinate system, based on the final sorted locations of dipoles and multipoles and axial as well as radial positions.

## INSTRUMENTS AND SOFTWARES

Following measuring instruments are being used for survey and alignment of Indus-2:

- Angle measurement: Precision digital theodolites Leica TDA5005, TDM5000 and TM5100.
- Distance measurement: Distinvar® with calibrated invar wire, Laser Interferometer with self-aligning reflector, TDA5005 and TDM5000.
- Levelling and elevation: Wild N3 Optical Level.
- Tilt: Electronic Inclinometers Leica Nivel-20, Wyler precision spirit levels.
- Softwares: SNAAPS[3] (in-house developed) for survey data collection, their least square adjustment, on-line coordinate measurements, alignment error analysis, curve fittings, coordinate transformations, stake out, resection etc, Axyz™ for online coordinate measurements.

In order to ensure the accuracy of distance measurements by TDA5005, they were calibrated by using laser interferometer. Calibration files having the coefficients of Fourier fitting were prepared and used for online correcting the distances measured on site.

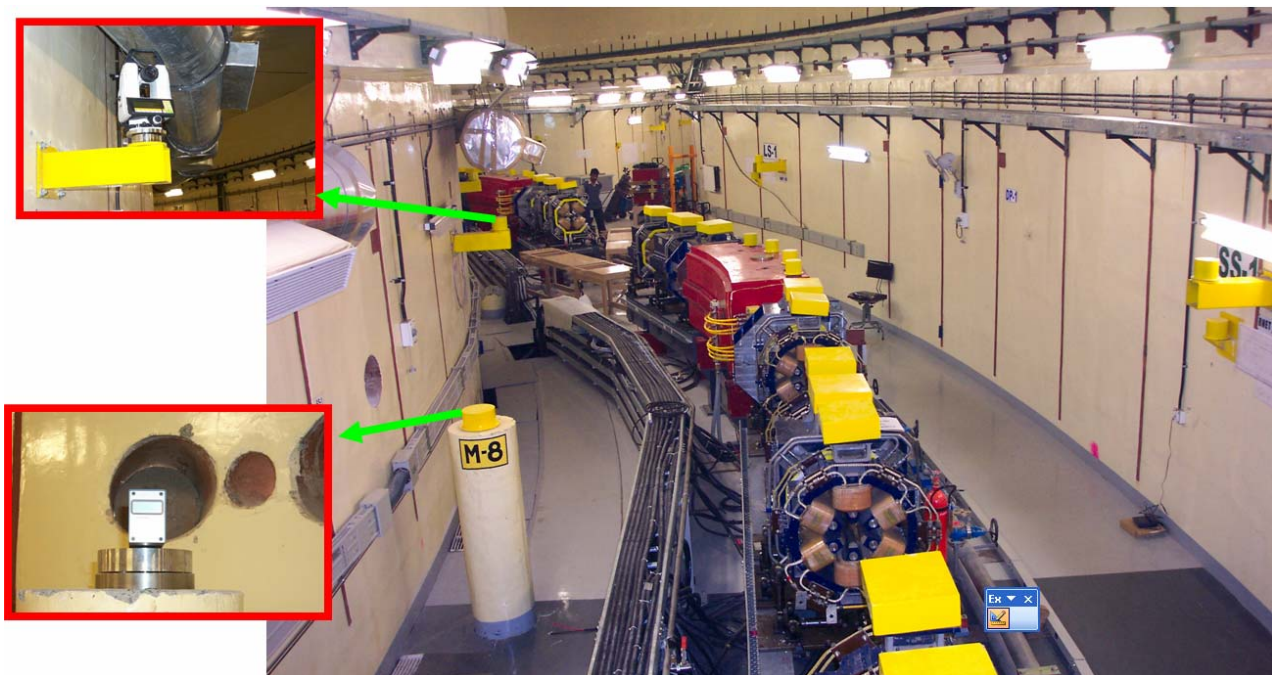


Figure 2: Indus-2 tunnel showing primary control network monument, secondary control network brackets and magnet fiducials protected by yellow coverings.

## INSTALLATION AND PRE-ALIGNMENT

In order to have the full range of movement of girder jacks during final alignment, all jacks were fixed at their designed locations within  $\pm 5\text{mm}$ . Subsequently the straight sections and dipole girders were installed and aligned. Each straight section girder is supported on three precision movement jacks. The dipoles were first to install on their girders. All dipoles were individually aligned by taking reference from nearby network points. After completion of alignment of all dipoles individually, they were surveyed together to determine the relative positions and overall shape. Based on the results of this survey, 5 out of 16 dipoles were readjusted to obtain better relative alignment and smooth shape of the machine. After this all dipoles along with secondary control network points were resurveyed. The absolute error ellipses of this survey are shown in figure 3. The results of this survey were within acceptable limit and no further refinement in positions of dipoles was attempted. The Over the straight section girder, quadrupoles and sextupoles are supported on six strut support system for their individual alignment. The upper half of all the quadrupoles and sextupoles were required to open for assembly of vacuum chamber. Before removing the upper half, these magnets were pre-aligned within  $\pm 1\text{mm}$  to facilitate the assembly of vacuum chambers. The Beam position monitors (BPM) and beam position indicators (BPI) are part of vacuum envelope and required a precise alignment. So before connecting to adjacent vacuum chambers, they were aligned and fixed.

## PRECISE ALIGNMENT

Precise alignment of multipoles started after completing the assembly of vacuum chambers and re-assembly of upper halves of multipoles. All quadrupoles and sextupoles on individual girder were first precisely aligned within the specified tolerances by using N-3 optical level, precision tilt level and two theodolites together, oriented in machine coordinate system by using the coordinates of nearby 5-6 secondary network points. For elevation control reference were taken from nearby elevation control network points. This helped us in not only controlling the relative alignment of multipoles on a girder within the specified tolerance but also the absolute position of girder in the machine. The same procedure was followed for all 16 straight sections. After this a full survey of the machine was carried out and approximately 1866 directions and 766 distances were measured by using motorized theodolite TDA5005. This data was processed by least square adjustment. During adjustment the coordinates of two primary control points, namely M1 and M3 which are in the tunnel, were assumed fixed. After adjustment the largest size error ellipse was found to have major axis of the order of 0.2 mm. The most probable coordinates obtained from this adjustment were used to analyze the overall shape of machine, orientation of straight sections with respect to each other and dipoles

etc. Based on the result of this survey three girders were realigned and again a complete survey run was performed. The results of this survey were quite satisfactory and the calculated circumference was deviating by only an amount of 0.4 mm from designed. Therefore we did not need any further refinement in the alignment condition.

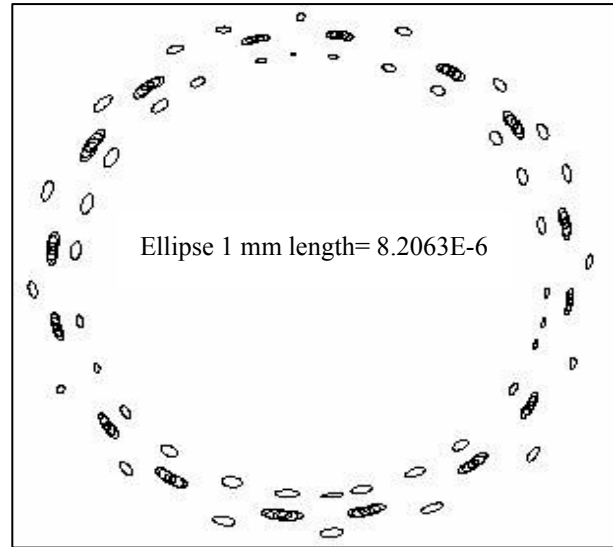


Figure 3: Absolute Error Ellipses (Dipoles & Secondary Control Network points).

## CONCLUSION

The commissioning trials of the machine started with the above conditions of alignment. After a few days of injection trials it was possible to circulate and accelerate the beam. The successful circulation and acceleration of beam verifies that there is no gross error in alignment. Afterward closed orbit distortions were also measured and they were closely agreeing with the designed values. Further refinement in alignment will be based on the operating condition of the machine.

## ACKNOWLEDGEMENT

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## REFERENCES

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