REVIEW OF ALIGNMENT ACTIVITIES FOR INDUS-1 & 2 AT CAT

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1 INTRODUCTION

Survey and alignment activities at CAT are related to two accelerator projects called INDUS-1 and INDUS –2. Former is a 450 MeV SRS and latter is a 2.5 GeV SRS. Both the machines use a 450/700 Mev booster synchrotron and 20 MeV pre-injector microtron for injection. A paper titled 'Construction and Alignment Experience of INDUS-1 SRS in CAT'[1] was presented in fourth IWAA-95. Indus-1 was commissioned with 100 mA stored beam current in May 1999. Indus-2 is under construction and expected to be commissioned within next 4 years. Survey and alignment work of booster synchrotron & Indus-1 (storage ring) was accomplished using optical surveying techniques with erstwhile software ECDS-2 of Kern. That was possible due to small size of machines of Indus-1. For Indus-2 with circumference of 172.47 m, the network surveying and alignment scheme has been planned. Indus-2 is a high brilliance machine and this puts more stringent requirements on alignment. This paper describes methodology and performance results of Indus-1 alignment and strategy for Indus-2.
Abbreviations used in the paper:

BR – Booster Ring,	SR- Storage Ring,	Indus-1 – Microtron, BR and SR
TL1- Transport line 1	TL2- Transport line 2	TL3- Transport line 3

2 INDUS-1

Strategy of complete alignment and construction features of INDUS-1 was reported first time in IWAA-95 alongwith alignment results of BR. At that time, beam was just accelerated upto 450 Mev in BR. In the mean time, components of SR machine of Indus-1 were assembled and alignment procedure as reported in IWAA-95 was followed. We used four theodolites to cover complete machines Booster synchrotron or storage ring one at a time in single setting of theodolites and determined co-ordinates using ECDS-2 and later on Axyz™ co-ordinate determination software.
Results of the final alignment of SR carried out in Feb'99 are given in the Table-1. Following this, Indus-1 has been commissioned with stored current of 100 mA in May'99 with lifetime that is limited by vacuum level.
We can now say that small machines like Indus-1 can be aligned using co-ordinate determination systems in single setting with a lot of flexibility and satisfactory results.

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3 INDUS-2

The circumference of synchrotron radiation source Indus-2 is 172.47 meter. For a good performance of the machine all its magnetic components, vacuum envelopes and beam diagnostic components will require high accuracy in installation and alignment with respect to the theoretical electron beam trajectory. The main magnetic components for alignment are 16 nos. dipoles, 72 nos. quadrupoles and 48 nos. sextupole magnets. The relative alignment tolerances for magnetic elements and main parameters of specification of Indus-2 are given in Table-2 and Table-3 respectively.

For following reasons, a network approach of alignment is followed:

1) Indus-2 machine is larger than Indus-1 machines
2) Complete machine can not be surveyed in single setting of theodolites because it is enclosed in an over-ground ring tunnel.
3) Alignment requirements are more stringent compared to Indus-1.

In network surveying approach, there are two survey networks namely 'primary' and 'secondary'**.** Fig.1 shows layout of accelerators in CAT and these networks.

3.1 Primary survey network

The injection system for Indus-2 includes Microtron, TL-1, Booster Synchrotron, TL-2 and TL-3. Since the basic reference for positioning of Microtron, TL-1 and TL-2 has been taken from BR, hence for TL-3 and Indus-II also; BR will be taken as basic reference.

The machine will be housed in an over-ground circular tunnel of concrete structure. So the measurement for whole of the ring must be referenced to a number of internal control points. For this a well-structured reference network of monuments has been created to act as primary control points. The monuments are in the form of 40 cms. diameter concrete pillars with a stable and isolated base. These monuments will have forced centering sockets to facilitate mounting of theodolites, optical targets as well as invar wire holder. The coordinates of these points will be determined by distance and direction measurements. The measurements will be carried out at different hours in a day and over several days. To come at the final coordinates, these measurements will be treated by least square adjustment program. This network will act as fundamental frame for fixing and stability checking of secondary control points and to link between successive survey setups to control absolute positioning of components

3.2 Secondary network (Internal survey control points)

Using primary control network, a large number of secondary control points will be fixed inside the ring tunnel to facilitate alignment of components in local setups. The correlation of primary and internal control points will be determined by repeated measurements of angle and distance and then applying least square adjustment. The measurement will be carried out before any major installation work in the SRS ring tunnel. These points will have flexibility for mounting optical targets, Taylor-Hobson sphere and invar wire holder. The density of secondary points is well enough to orient measuring instruments freely in the surrounding of any object to be aligned.

Besides acting as frame these points will also act as large scale for base length calculation in Axyz surveying and triangulation-trilateration by invar wire distance measurements.

As alternative to invar wire, we are contemplating using Laser Tracker. However, it being an expensive thing, we are looking for a collaborating laboratory to share the instrument with us.

3.3 Measuring instruments:

Measuring instruments presently available with us for surveying and alignment are as following:

a) Angle measurement: Precision digital theodolites KERN E-2 (3 nos.) & a Leica Total Station TDM-5000
b) Distance measurement: KERN-Distometer with calibrated invar wire, Laser Interferometer with self aligning reflector, & co-ordinate determination by Axyz™ software. For millimetric precision electro-optical distancer of total station TDM 5000 can be used.
c) Leveling: Wild N3 Optical Level.
d) Tilt: Electronic Inclinometers Lieca Nivel-20

For further improvement in the distance measurements for the primary control network or internal control network, use of more accurate devices like Leica Laser Tracker may be required. In order to expedite the leveling exercise one more N3 will be added to our existing instruments.

3.4 Alignment procedure and alignment features of magnets :

All machine elements required to be aligned will be equipped with proper fiducials. A database describing the position of fiducial marks with respect to theoretical trajectory for each element will be prepared. This will facilitate the absolute as well as relative positioning of elements in the ring and analysis of alignment errors.

3.4.1 Alignment of Dipoles:

Each dipole is planned to be equipped with four fiducial posts, which can hold optical targets as well as invar wire holder. The correlation between position of these fiducial posts and magnetic axis will be established during magnetic field characterization of magnet on CMM.

After installing at approximate positions these magnets will be aligned accurately within the given tolerances by using fine movement mechanism provided in the magnet support. Coordinate measurements for alignment of each dipole will be carried out with respect to nearby internal control points in local setups. These coordinates will be transformed into ring frame of reference to get the relative and absolute alignment accuracy. To establish confidence level, the measurements will be carried out several times. The final coordinates of fiducials will be calculated by least square adjustment of these measurement. Once dipoles will be in the correct position, fiducial marks on these will act as secondary control points for alignment of components in straight sections.

3.4.2 Alignment of the Quadrupoles, Sextupoles and other elements

Each quadrupole and sextupole will be equipped with two fiducial posts with flexibility for mounting either T-H sphere or optical targets and one grinded plate for positioning of precision 2-axis level at the top. The straight line passing through the center of the two fiducials will be parallel to the magnetic axis and the grinded plate will be parallel to the median plane of the magnet.

These quadrupoles, sextupoles and other elements will be pre-aligned accurately over long girder in the laboratory. The loaded base girder will be then properly fiducialized with respect to common magnetic axis. Such individual girder will be carefully shipped into ring tunnel where only the precision alignment of the girder will be carried out.

After installing all the machine magnets with the best possible measurements of their location and orientation, total re-surveying runs will be performed to establish the confidence level of procedures. That will also provide estimate of the total error envelope for the aligned machine.

The smoothing analysis would be required to find out the extent of relative alignment errors in various parameters of alignment tolerance. These will be maintained within the specified range of relative tolerances given in table-2.

4 CONCLUSION:

In the commissioning trials of Indus-1 more than 100 mA current could be stored in the SR many times. With the procedure and instruments described above we feel it will be possible to align and adjust the entire Indus-2 ring and would like to welcome suggestions from all in this field.

5 ACKNOWLEDGEMENTS:

Alignment of BR was our first time experience in this field. Alignment of SR was needed in closer tolerances and we could do it based on the experience of BR. Now, alignment tolerances for Indus-2 are still finer and different from Indus-1. Our project manager Mr. A. S. Rajarao is providing us able guidance and keeping our morale high.

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Reference:

(1). Construction and alignment experience of Indus-1 SRS in C.A.T. P.K.Nema et.al., IWAA-95
(2). Technical report of Synchrotron Radiation Source Indus-2.September 1998.

Table-1

Alignment Check for Quadrupoles of SR

Co-ordinate System: Electron beam direction +S
Radially outside from centre +X Upward +Z
Nomenclature : QF = focusing quadrupole ; QD = defocusing quadrupole

Component Name	Point Name	Δx	Δz	Remark
SRQF1	F11	0.04	0.04	Section-1
	F12	-0.016	0.03	(Section with
SRQD1	D11	-0.019	0.03	injection point)
	D12	0.005	0.02	
…………….	……………….	……………….	……………….	……………….
SRQF2	F21	0.05	0.03	Section-2
	F22	0.02	0.14	
SRQD2	D21	-0.05	0.11	
	D22	-0.04	0.05	
SRQF3	F31	0.08	0.07	
	F32	0.06	0.16	
SRQD3	D31	-0.06	0.08	
	D32	0.15	0.15	
…………….	………………….	……………….	……………….	……………….
SRQF4	F41	0.04	-0.01	Section-3
	F42	0.01	-0.01	
SRQD4	D41	0.11	0.00	
	D42	0.09	0.01	
SRQF5	F51	-0.10	0.01	
	F52	-0.02	-0.01	
SRQD5	D51	-0.01	0.02	
	D52	0.05	0.02	
…………….	………………….	…………………	……………….	……………..
SRQF6	F61	0.04	-0.02	Section-4
	F62	-0.07	-0.02	
SRQD6	D61	0.02	-0.09	
	D62	0.01	0.00	
SRQF7	F71	0.02	0.11	
	F72	0.08	0.11	
SRQD7	D71	0.04	0.02	
	D72	-0.04	……	
…………….	………………..	……………….	……………….	……………….
SRQF8	F81	-0.042	0.06	Section-1
	F82	-0.041	0.07	(section with
SRQD8	D81	-0.059	0.02	injection point)
	D82	-0.056	0.00	

Table-2

Alignment tolerances for Indus-2

Object name	ΔS(along - orbit)mm	ΔX(radial) mm	ΔZ(azimuth) mm	$\Delta\theta_S$ mrad	$\Delta\theta_x$ mrad	$\Delta\theta_z$ mrad
Dipole	0.2	0.2	0.2	0.2	1.0	1.0
Quadrupole	0.3	0.1	0.1	0.2	1.0	1.0
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

Table-3

Specification of Indus-2

Energy		=	2.5 GeV
Current		=	300 mA
Bending Field		=	1.502 T
Circumference		=	172.4743 m
Beam emittance:	ε_x	=	5.81×10^{-8} m.rad
	ε_y	=	5.81×10^{-9} m.rad
RF Frequency		=	505.812 MHz