CONSTRUCTION & ALIGNMENT EXPERIENCE OF INDUS-1 SRS IN C.A.T.

P.K. Nema, V. Prasad, S.C. Joshi, R.K. Sahu, Dr. S.P. Mhaskar, M.G. Karmarkar
Accelerator Programme, Centre for Advanced Technology, Indore-452 013, India.

Abstract :

A 450 MeV Synchrotron Radiation Source, Indus-1 is being constructed at Centre for Advanced Technology at Indore in central India. A new site for this machine was developed from 1986 onwards. The machine building and most of components were ready by Dec. 1992. A 20 MeV pre-injector microtron and 450/700 Mev booster synchrotron were progressively commissioned from June 1994 onwards. The 450 MeV storage ring is partially assembled by now; and in the meantime, commissioning experiments with booster synchrotron continue (Sep. 95) to get electron beam accelerated up to 450 MeV.

This paper narrates our experience in construction & alignment of synchrotron machines which was first of its kind for most of us. Careful design, planning and execution of the work yielded modest results so that alignment accuracies between 0.1 to 0.3 mm could be achieved (in booster synchrotron) and, which have proved to be adequate up till now.

The building of the SRS complex was constructed such that machine rings have their foundations isolated from rest of the building. A number of 100 x150 mm size steel plates were embedded in the concrete of floor and walls to serve as base for reference surveying marks which were established later. The pre-injector & booster ring are enclosed in a radiation shielding zone with separate ventilation system. An overhead crane serves for handling of shielding concrete blocks and heavy magnets in the two synchrotrons.

Dipoles, quadrupoles and a few sextupoles were fiducialised during their field mappings; on a CNC Hall-probe manipulator for dipoles and on rotating coil measuring machine for others. Fiducials were of two types- sticker type as well as accurately reamed holes to receive a precision target for alignment measurements with optical instruments.

Due to small size of entire machine zone, we decided & used precision surveying method of using ECDS-2 coordinate determination system of KERN (now, Leica) and micrometer type N3 level of WILD. Additionally, accurate spirit levels (01/20 micron per m.) for preliminary leveling and an interferometer to calibrate CNC Hall-probe manipulator were also used. We faced some problems due to instrument failures which were circumvented by mixed use of KERN & WILD theodolites and hand feeding angular readings in the ECDS-2. This helped in continuing and completing the alignment activities without much delay.

Of late, the booster synchrotron experiments have established acceleration up to 480 MeV albeit, with very weak current, about 2 mA and first synchrotron light emission was directly observed on 26th Sept. 1995.

CONSTRUCTION & ALIGNMENT EXPERIENCE OF INDUS-1 SRS IN C.A.T.

P.K. Nema, V. Prasad, S.C. Joshi, R.K. Sahu, Dr. S.P. Mhaskar, M.G. Karmarkar
Accelerator Programme, Centre for Advanced Technology, Indore-452 013, India.

1. INTRODUCTION :

Centre for Advanced Technology at Indore is located in the central Indian province of Madhya Pradesh. This Institute was established in 1984 by Department of Atomic Energy, Govt. of India for development of indigenous know-how in Laser & Accelerators. The project site development for Accelerator Programme's Indus-1 project began in 1986.

Indus-1 project consisted of a 20 MeV microtron pre-injector, 450/700 MeV booster synchrotron and 450 MeV synchrotron radiation source (SRS ring). The booster synchrotron is designed for 700 MeV peak energy so that it can also be used as injector for a 2 GeV SRS ring to be constructed later. Main parameters of pre-injector, booster and SRS ring are given in Table-I, II & III respectively [1]. A composite layout of all these machines is shown in figure-1.

The microtron pre-injector was developed and fabricated in CAT; its commissioning experiments began in late 1992 and by early 1994, it yielded good quality electron beam of desired parameters as listed in Table-I.

Planning & construction of accelerator building began in 1988 and so also construction of machine magnets. All the magnets were fabricated in CAT. Dipoles of booster ring and all quadrupoles and sextupoles were fabricated from CRGO steel laminations and only dipoles of SRS ring were made from steel forgings accurately machined and assembled into C-shape.

General layout of machine building is shown in the figure-2. Microtron & booster ring are housed in a completely shielded enclosure, but only local shielding by concrete slabs will be provided around storage ring. Removable concrete slabs are provided over booster ring area for crane approach-whenever required for handling equipment inside the enclosure,

Construction features of Machine Building

Indus-1 machines are housed in a building which is roughly 78 meters long & 53 mctcrs wide. Geologically, the region around Indore is considered very stable & few seismic activities here are known. In view of this, only precaution taken against ground vibrations is to structurally isolate the machine bases of booster & SRS ring from rest of the building. The floor joints between machine base and building are sealed with a commercially' available bitumen mix. In our opinion, this design was adequate to isolate machine from vibrations originating at air handling unit (AHU) motors, pumps in the LCW plant and overhead crane movement. Typical floor joint design is shown in figure-3.

The machine base was provided with some steel plates in the form of embedded parts over which the equipment support stands would be resting/clamped. A central monument was provided with its independent foundation for each of booster & SRS rings. There were no special efforts to locate centres of these monuments accurately nor any fiducials on them during civil works; rather, accuracies of only few mm. were maintained. This method of construction resulted in accuracy up to 3 mm in height & about 5 mm in X-Y plane for location of these features in concrete works.

2. SUPPORT & ALIGNMENT FEATURES :

Booster Dipoles

These sector type, zero-gradient magnets were assembled from blocks made of CRGO laminations. The laminations had a rectangular slot at top edge. Centre plane of this slot coincided with the vertical plane through S-axis of magnet assembly. Magnet core blocks were assembled over a thick steel plate which rested on magnet support structure. Relative movement of blocks by sliding over steel plate in X-Y plane on support structure was possible by means of screws. This arrangement is shown in figure-4.

The magnetic field in these magnets was checked by means of a Hall-probe mounted on 2-axis CNC machine. This machine itself was calibrated by a laser interferometer ZLI-150 of Spindler & Hoyer make. Coplanarity of magnet pole faces was measured by means of N3 WILD level. Relative displacement & twist was noted between adjacent blocks, but the magnetic field characteristics were found to be in acceptable range in case of all dipoles. Coplanarity range was determined within ± 0.2 mm in all the dipoles. The planer X-Y alignment fiducials were derived from accurately located target holders in the slot; this slot was also used as reference to generate curved stacking of each block during laminations assembly.

SRS Dipoles

SRS dipoles were assembled from symmetric top & bottom halves which were machined out from forged rings. These magnets have similar screw mechanisms to make adjustment during alignment as the booster dipoles.

These magnets were also fiducialised on the 2-axis CNC machine. Top flat surface of these dipoles was provided with a pair of locator holes on each end. Line joining these locators on either side was parallel to the entry or exit direction of particles in the machine orbit. The locators at these fiducials are the target holders with reamed holes of 6.36 mm dia. into which shank of optical targets from Hubbs Inc. would snugly fit.

Quadrupoles & Sextupoles

All the quadrupole magnets were splittable about the mid-horizontal plane of symmetry & these were provided with dowel pins to achieve repeatable accurate assembly geometry. There was marked shift in the mechanical & magnetic centres in prototype quadrupoles. Therefore, it was decided to use magnetic centre line & its fiducials for alignment. These fiducials were located on the magnet body by surveying during magnetic axis determination by a rotating line-integral coil method.

Each quadrupole was provided with two reamed holes at top plate as fiducials, a precision ground level plate at top & two adhesive targets on the sides. These fiducials were generated by using E2 theodolite & N3 level after first bucking them into line of the axis of rotating coil & then fixing the fiducials. No tight control was required on azimuthal location of these magnets in the machine.

All these magnets have screws to provide X, Y, Z movements and turning along axes. These movements would be unmeasured on their drive points, so, a constant monitoring or measurements during adjustment procedure were required.

3. ALIGNMENT PROCEDURE :

Reference marks surveying

Taking rough reference from the points established during civil works, average centre of the booster synchrotron and rough shape of machine foot print (hexagon) was determined. Then, centre of an adhesive target fixed at average centre of central monument was taken as origin for X, Y & Z. Line joining this centre to an apex of machine hexagon was chosen as arbitrary line of X direction in horizontal plane. At a calculated distance in this line, first apex target was located using linear measurements by ECDS-2 tooling and instruments. This apex was again an adhesive target on a level plate that was attached to an embedded fixture. Top of this level plate was maintained horizontal within the accuracy of a Wyler make precision spirit level which had resolution of 20 **μm** per meter. The reference target marking system is shown in figure-5. Similarly, points were fixed at other apexes by taking direction from basic x-axis & using an E2 theodolite in plumb line above central target. On verifying the coordinates of these apex targets by ECDS-2, they were within an error circle of 0.5 mm diameter.

Targets representing foot-print of each straight section line of booster synchrotron were marked on both sides of apex targets and also on the walls of the room. It was then possible to “buck-in” two theodolites above a line and at the ends of any straight section, and then, install & align dipoles, quadrupoles etc. into the established line of sight.

4. INSTALLATION PROCEDURE :

Booster Synchrotron Dipoles

Dipoles (for both, booster & SRS) have their own sturdy support structure on which the magnet core can be adjusted in X-Y plane including rotation. Below the structure are screw jacks which are used to adjust level. All dipoles were first installed in rough location by means of overhead crane. Each magnet in turn was aligned first in the leveling by means of N3 level and a reference bench mark in the shielding wall. Thereafter, it was aligned in X-Y plane by sighting with two precision theodolites which were “bucked-in” over the straight section extension lines. While adjusting the dipole in X-Y plane, some variation in Z position was noticed and it was compensated and re-checked with N3 level. In this, manner, all dipoles were aligned to fine positions. Then, in a single setup of ECDS-2 coordinate surveying these magnet fiducials were found within 0.05 mm repeatability. Errors in the positions of fiducial targets in dipoles were explainable in terms of imperfections in their fabricated geometry. Being zero-gradient dipoles and in use for a booster synchrotron, the errors shown in the final dimension layout of figure-6 were acceptable to our accelerator physics.

Booster Synchrotron Quadrupoles

Quadrupoles have their individual X-Y-Z adjusting fixtures and each is located on a fabricated frame of steel extending along straight section. The base of quadrupole fixture was welded on the frame in a mean position and height. Here also, level of the quadrupole was adjusted in the beginning. For this, the two adhesive targets on the sides were leveled by using N3 level.

There are two alignment targets on top flat surface of each quadrupole. These were aligned by E2 theodolite previously bucked into the line of a straight section. In this case, the theodolite was centred over a point on the extended line of straight section and then the sighting direction was line (or plane) containing end points of the nearest and next dipole magnet (which were already located accurately). The alignment conditions of a quadrupole were achieved when two top sighting targets were brought in the direction of straight section and the two side ones were in horizontal plane. The precision ground plate at the top of quadrupole was also checked to lie in horizontal plane by means of Wyler level. Tolerance allowed was ±0.05 mm in leveling and elevation of side targets. The X-Y alignment was checked by angular variation in horizontal circle scale and within ±0.001 gon (1 gon = 9/10 degree arc) from the established line of sight.

Thus, adjacent dipoles were used as reference and quadrupoles were aligned in the local coordinate system. After completing each straight section containing two quadrupoles, the alignment was rechecked by ECDS-2 coordinate determination. The alignment in X-Y plane at fiducial target location was maintained within ±0.1 mm in most cases. All six straight sections were aligned in this manner.

The fiducial target system of quadrupoles was also used later on the bodies of injection and extraction magnets. The procedures of their alignment were also similar.

After making connections for cooling water and electrical power feeding, all the magnets were surveyed once again by the ECDS-2 coordinate measurement. This alignment read out of quadrupoles is shown in Table-IV.

Microtron & Transport Line TL-1

The entire foot-print of the TL-1 trajectory was marked by means of adhesive targets on the machine building floor. The starting point was the intersection of straight line foot-print with machine orbit's at injection septum position. The quadrupoles in the injection line were aligned using procedure similar to that described above.

The extraction tube of microtron was aligned by means of small plugs with hole inserted into its two ends and projecting a laser beam through the eyepiece of E2 theodolite. The alignment within ±1 mm was considered adequate here, since steering magnets were used near the microtron exit to obtain beam in desired location and orientation.

Transport Line TL-2

Procedure similar to that used for TL-1 was adopted to mark the line foot-print, except that this line passed through a 1.2 m thick concrete wall. The line was projected outside using ECDS-2 coordinate measurements. This marking accuracy was somewhat coarse; in the range of ±1 mm. All the equipment in TL-2 are presently in rough location.

SRS Ring

The SRS ring Indus-1 is smaller in size compared to the booster synchrotron. The surveying for the foot-print mark of SRS ring has been completed. This ring has four straight sections. The central reference point and four apex targets were fixed by means of theodolite surveying and checks by ECDS-2 had been done. In this ring, the dipoles and quadrupoles have been roughly located. However, in order to achieve the complete integrity of vacuum envelope by repeated bakeouts, leak checks, repair etc. the upper half of all straight section magnets have not been assembled yet. We plan to resume final surveying of SRS ring sometime in the March-April next year. The procedure similar to that adopted in booster synchrotron will be applied, but, with more careful observations and full use of ECDS-2 coordinate measurements.

5. RESULTS :

In the commissioning trials of booster synchrotron, the injected electron beam of 20 MeV energy and peak current of 20 mA from microtron was accelerated to 480 MeV and final beam current of about 2 mA. The synchrotron radiation emitted by this accelerated beam in the booster ring was observed first time on 26th September, 1995. The magnet alignments have not been disturbed for over last 6 months during which commissioning trials were carried out.

We have plans to improve the machine current in the near future and install extraction magnets in the booster ring thereafter. In the meantime, components preparation work of SRS ring continues.

6. ACKNOWLEDGMENT:

Design and development of accelerators have been first time experience for most of the staff in CAT. We faced many problems and uncertainty during the machine construction phase, so much so that some are still unresolved. Our project leader Mr. S.S. Ramamurthi, who retired recently from service, provided us able guidance in the project. His relentless zeal in ensuring ultimate success and keeping morale high in the events of failure had impressed us all. We are also indebted to Russian collaborators from BINP, Novosibirsk in working shoulder to shoulder with us.

* * *

REFERENCES :

[1]. Status of Indus-1 & Indus-2- S.S. Ramamurthi; Proc. of the Int. Conf. on Synch. Rad. Sources, Indore, 3-6 Feb. 1992.

Specifications of Machines in Indus-1

Table- I

1. Injector Microtron :

1.1	Energy	:	20 MeV
1.2	Pulse current	:	20-30 mA
1.3	Pulse duration	:	1 μsec.
1.4	Pulse repetition	:	1 Hz.
1.5	Beam emittance	:	1 x 10^{-6} m.rad (horiz.)
		:	3 x 10^{-6} m.rad (Vert..)

Table- II

2. Booster Synchrotron :

2.1	Inj. Energy	:	20 MeV
2.2	Max. Energy	:	450/700 MeV
2.3	Orbital current	:	30 mA
2.4	Circumference	:	28.44 m.
2.5	Max. BM field	:	1.32 Tesla
2.6	RF frequency	:	31.613 MHz.
2.7	Harmonic number	:	3
2.8	No. of dipoles	:	6
2.9	No. of quadrupoles	:	12
2.10	Beam emittance (Horiz)	:	8.8 x 10^{-8} m.rad. @ 450 MeV
		:	2 x 10^{-7} m.rad. @ 700 MeV

Table- III

3. SRS Indus-1 ring :

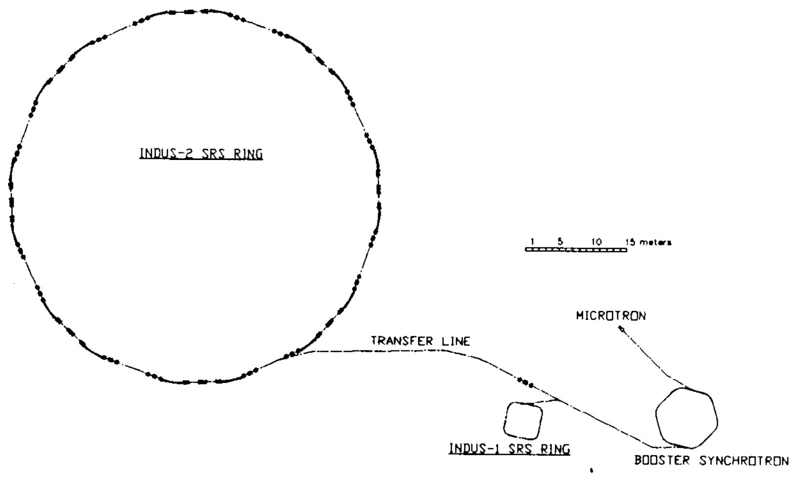
3.1	Inj. Energy	:	450 MeV
3.2	Max. current storage	:	100 mA
3.3	Bending magnet field	:	1.5 Tesla
3.4	Circumference	:	18.96 m.
3.5	RF frequency	:	31.613 MHz.
3.6	Harmonic number	:	2
3.7	No. of dipoles	:	4
3.8	No. of quadrupoles	:	16
3.9	No. of sextupoles	:	8
3.10	Beam emittance (Horiz)	:	7 x 10^{-8} m.rad.

Table- IV

ALIGNMENT CHECKS FOR QUADRUPOLES

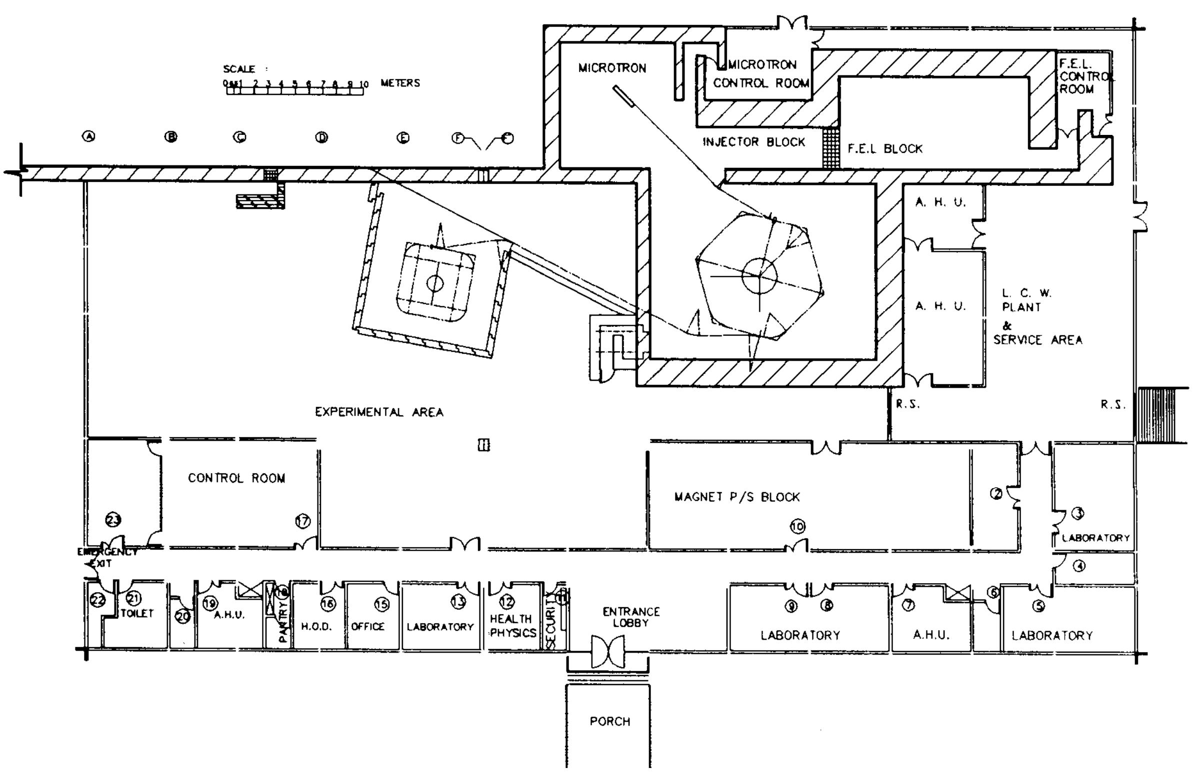
(Booster Synchrotron Ring)

S.No.	Quad. Identity	Fid. name	δ X	δ Z	Remarks
1	BOQF- 1	F 1 1	0.03	-0.12	Focussing Quad. in
2	BOQF- 1	F 1 2	0.10	-0.05	first straight
3	BOQD- 1	D 1 1	0.09	0.00	Defocussing Quad. in
4	BOOD- 1	D 1 2	0.16	0.00	first straight
5	BOQF- 2	F 2 1	0.04	-0.01	Focussing Quad. in
6	BOQF- 2	F 2 2	0.03	-0.01	second straight
7	BOQD- 2	D 2 1	0.02	0.03	Defocussing Quad. in
8	BOOD- 2	D 2 2	0.03	0.08	second straight
9	BOQF- 3	F 3 1	0.16	-0.04	Focussing Quad. in
10	BOQF- 3	F 3 2	0.16	-0.04	third straight
11	BOQD- 3	D 3 1	0.02	-0.12	Defocussing Quad. in
12	BOQD- 3	D 3 2	0.11	-0.17	third straight
13	BOQF- 4	F 4 1	-0.17	0.10	Focussing Quad. in
14	BOQF- 4	F 4 2	-0.05	0.03	4th straight
15	BOQD- 4	D 4 1	0.11	0.04	Defocussing Quad. in
16	BOQD- 4	D 4 2	0.17	0.04	4th straight
17	BOQF- 5	F 5 1	-0.01	-0.06	Focussing Quad. in
18	BOQF- 5	F 5 2	-0.01	0.02	5th straight
19	BOQD- 5	D 5 1	0.03	0.00	Defocussing Quad. in
20	BOQD- 5	D 5 2	0.11	-0.06	5th straight
21	BOQF- 6	F 6 1	0.02	-0.10	Focussing Quad. in
22	BOQF- 6	F 6 2	0.14	-0.01	6th straight
23	BOQD- 6	D 6 1	-0.06	-0.01	Defocussing Quad. in
24	BOQD- 6	D 6 2	0.08	0.00	6th straight



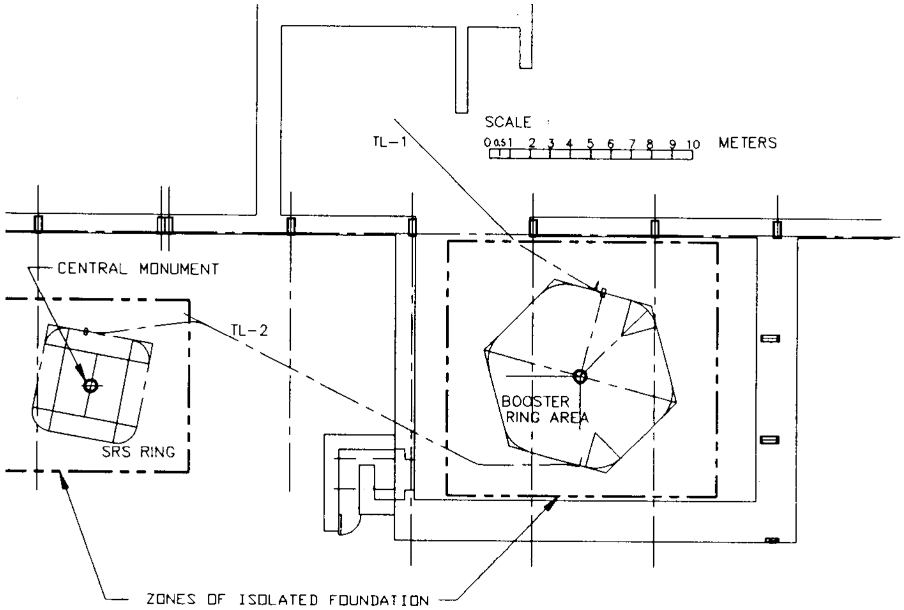
LAYOUT OF ACCELERATORS IN C.A.T.

Figure- 1

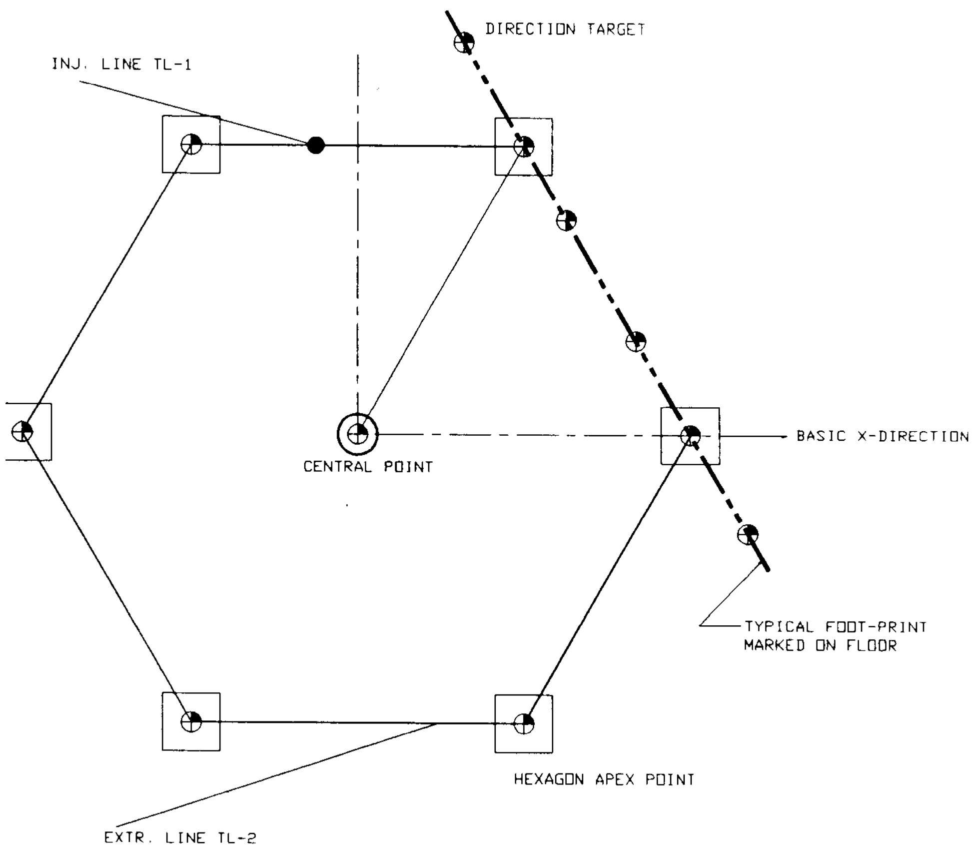


LAYOUT OF INDUS-1 BUILDING

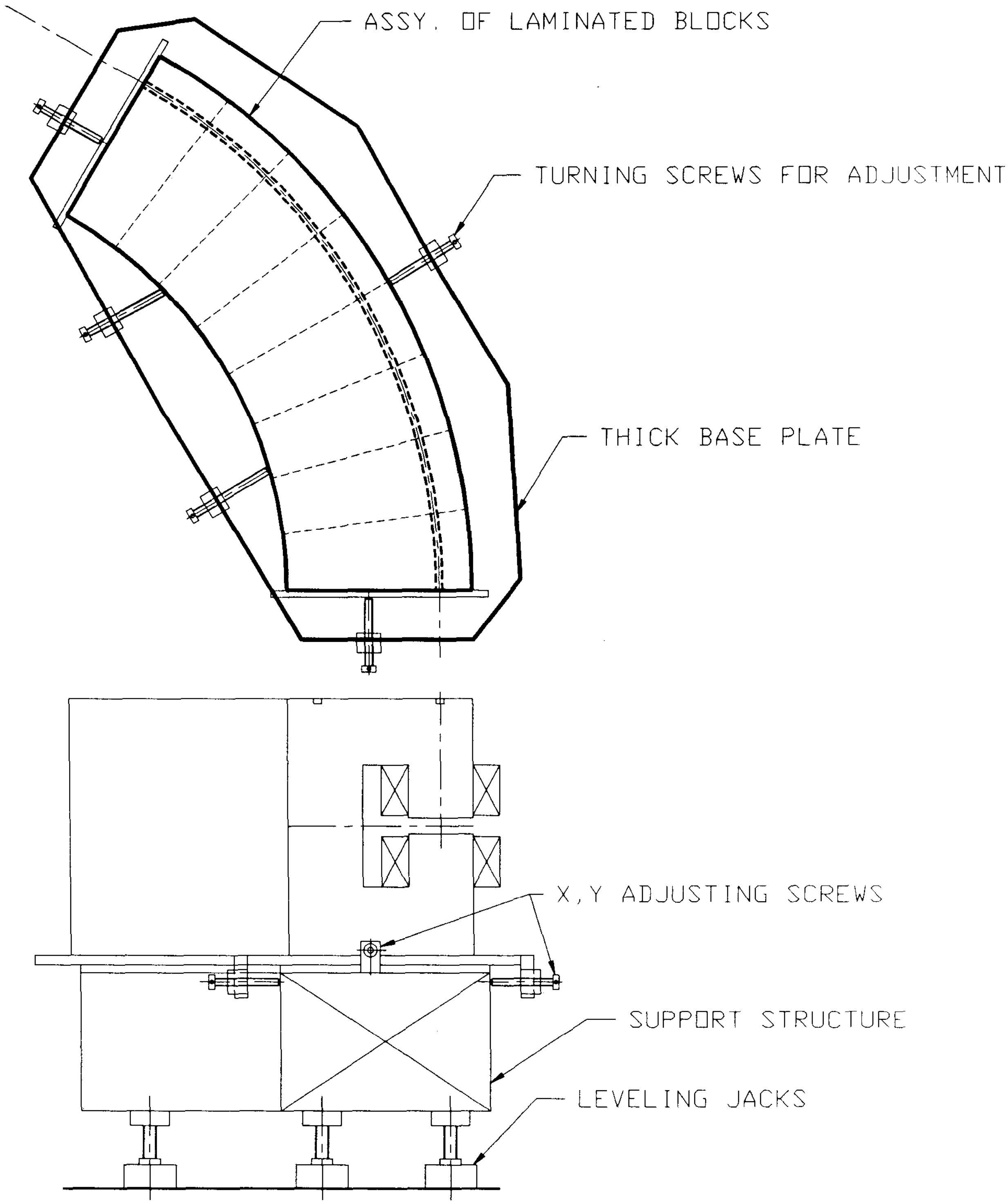
Figure- 2



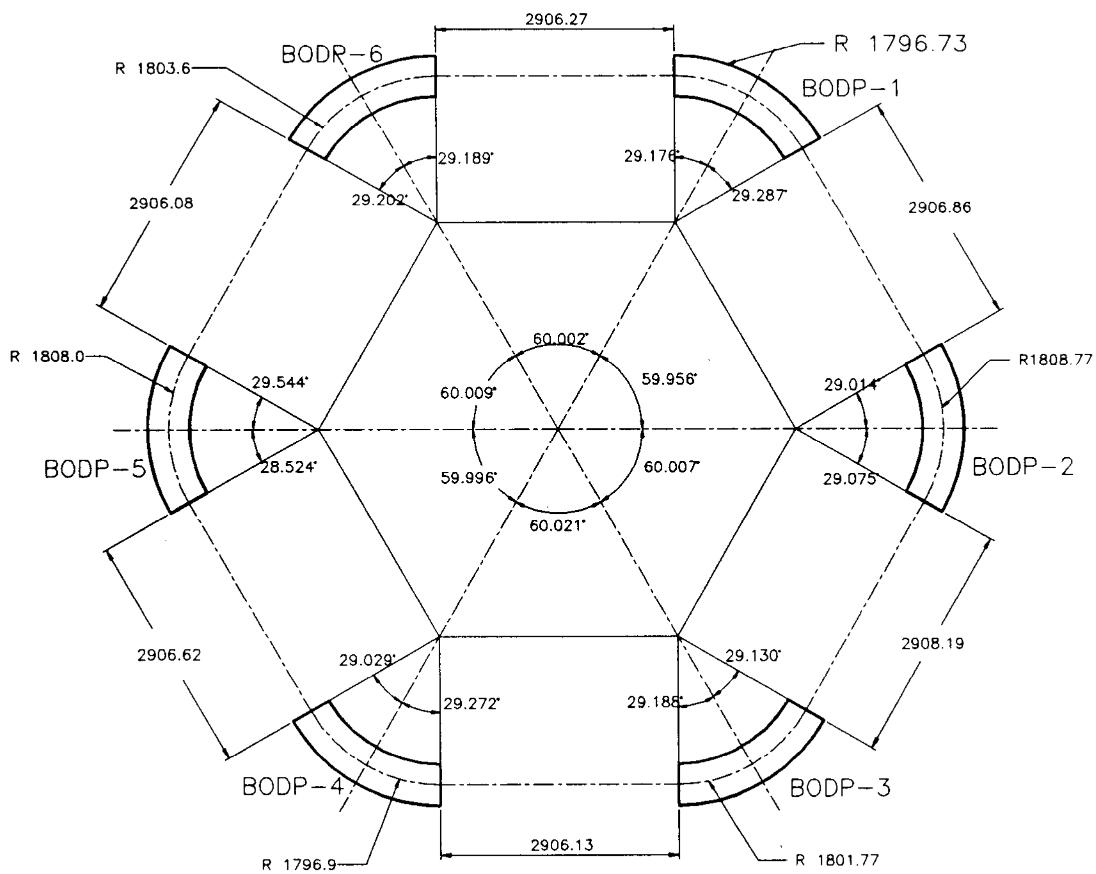
ISOLATION OF RING FOUNDATIONS
Figure- 3



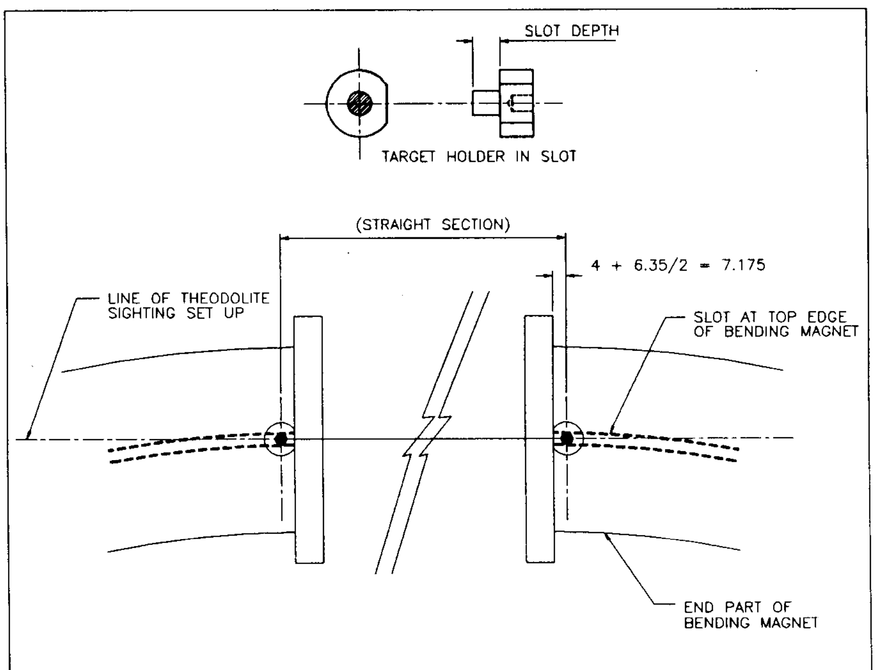
MARKING OF SURVEYING REFERENCES
(TYPICAL FOR ONE STRAIGHT SECTION)
Figure- 4



SCHEMATIC OF ALIGNMENT ADJUSTMENT SYSTEM
(BOOSTER RING DIPOLE)
Figure- 5



MEASURED GEOMETRY OF DIPOLE ALIGNMENT



ENLARGED VIEW OF TARGET POSITION

(NTS)

BOOSTER SYNCHROTRON ALIGNMENT RESULTS
Figure- 6