A relook at the observatory at Varanasi

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The observatory at Varanasi is believed to be established in 1717. It houses six instruments and appears to be a precursor of the much larger instruments in other places, viz. Delhi, Jaipur and Ujjain. Here is a relook at the observatory. An attempt is made to check the instruments as recorded by Robert Barker in AD *1749. One of the instruments, the Chakra Yantra is discussed here; its definition in various texts is extended to understand the instrument bearing the same name here as a possible precursor to the present-day equatorial mounts. There is another unidentified structure whose purpose remains mysterious. Here we discuss the possibility of that being used as a Dhruvabhramaka Yantra.*

The instruments and the Chakra Yantra

The instruments of the observatory are the large Samrat Yantra, the small Samrat Yantra, Nadivalaya, Dakshinottara Bhitthi, Digamsha Yantra, Chakra Yantra and an unknown instrument. All these are described in great detail and the accuracies have been verified[1]. The ground plan of the observatory is shown on a plaque in the premises and is reproduced here in Figure 1.

The Chakra Yantra is described as '… supported by two oddly shaped columns of masonary and stone … This Yantra is a circular dial of metal pivoted along its diameter parallel to the axis of the earth. The instrument is quite rugged in construction. It is fabricated out of solid beam of iron $3.5 \times 5\ \text{cm}^2$ in cross section and one meter in diameter. The beam supports a 0.5 cm thick brass strip on one side, on which a measuring scale is engraved. The scale is divided into four quadrants … perpendicular to the axis of Chakra Yantra around its pivot point to the south is a circular scale engraved on a fixed slab of stone. The diameter is 29.5 cm. The scale is parallel to the equatorial plane and divided into degrees which have been left unmarked'[1]. The instrument is shown in Figure 2. A closer inspection (not clear in the photograph) shows an arrow on the central metal dial pointing to the north.

Robert Barker visited the observatory in 1749. He reported[2] that the purpose of the 'Chakra Yantra' instrument was to measure azimuth and altitude – 'a brass circle, about 2 ft in diameter, moving vertically upon two pivots between two stone pillars having an index (hand) turning around horizontally on the centre of this circle which is divided into 360 parts: but there are no counter-divisions on the index to subdivide these on the circle. This instrument appears to be made for taking the angle of a star at the setting or rising or for taking the azimuth or amplitude of the Sun at rising or setting'.

A glance at the instrument shows that it is capable of reading the hour angle and declination directly. This gives a clue about the purpose of the instrument. The rest of the instruments measure altitude and/or azimuth, while this one is capable of measuring the hour angle and declination directly.

Figure 3 shows the definition of the coordinates, hour angle and declination. The meridian transit of the sun, for example, can be easily noted when the dial casts its shadow as a line on the ground (otherwise, it is an ellipse). The reading on the circle on the southern pier will then be zero. The reading on the circular metallic dial itself will be the declination. Prior to and after the transit, the diurnal motion of the sun will be parallel to the celestial equator.

The advantage of measuring hour angle directly was perhaps realized in the middle of 18th century in Europe. This angle is essential for the derivation of sidereal time and/or for the calculation of rise and set timings using the simple formula:

$$\cos z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos H, \tag{1}$$

where the symbols have the usual meanings.

Since the diurnal motion of all celestial bodies will be always parallel to the equatorial plane, their tracking by telescope can be achieved with a single motor if the telescope is mounted along the polar axis. The conventional alt–azimuth mounts need two motors for tracking since both altitude and azimuth vary continuously. Because of this advantage, the equatorial mounting is widely used in many observatories.

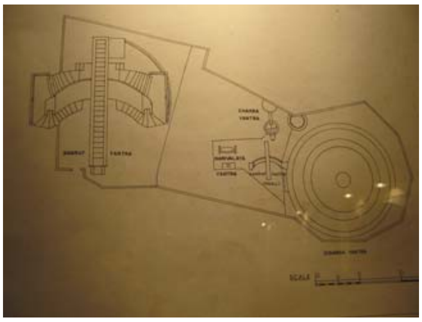

Figure 1. The ground plan of the observatory.

Figure 2. The Chakra Yantra.

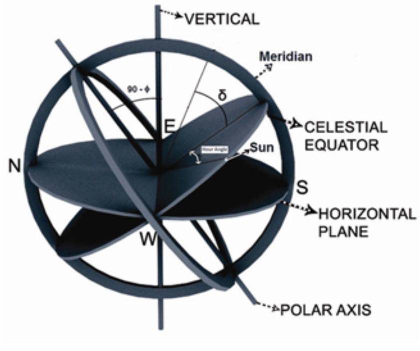

Figure 3. Definition of the coordinates, hour angle and declination.

The equatorial mount is also popular among amateur astronomers who aim at long exposures for their astro-photos. Special devices are used so that the tracking can be achieved manually. Experienced amateurs achieve very high accuracies and are able to track for exposures as long as an hour without a motor.

The telescopes used in the early years after the death of Galileo were mounted on alt–azimth mounts. Figure 4 shows a comparison of the two types of mounts in the simplest form. The demand on long intervals of tracking during observations necessitated the evolution of the equatorial mount. The introduction of this is attributed to James Short in about 1749 (ref. 3) around the same time when Barker was visiting Benaras. However, Christian Scheiner seems to have attempted it in 1620 and it was perfected by the Jesuit Christopher Grienberger much later (see Appendix 1). Therefore, this may have been the reason for Barker being unaware of a revolution that was incorporated in the making of telescopes.

The idea of developing the equatorial mount owes its origin to the instruments used in China[4]. The instrument described by Needham[4] (figures 2 and 2 *a*) is similar to the Chakra Yantra. He describes a ;simplified' instrument as the forerunner of equatorial mountings. He also describes many instruments similar to the ones seen in Jantar Mantar. It is interesting that Needham identifies the 'time-determining instrument' as the equatorial dial of the simplified instrument. The figure shows a dial similar to the one on the south pier of the Chakra Yantra in Varanasi.

It is difficult to assess whether the 'simplified instrument' was influenced by the Chakra Yantra or vice versa, since the communication among the two civilizations dates back to more than 2000 years.

Thus it is clear that the purpose of the Chakra Yantra at Varanasi is not to measure the altitude and azimuth, but to get the hour angle which can be read out on the south dial and the declination on the circular wheel itself (Figure 5).

Descriptions by Barker[2] and Sharma[1] refer to a sighting tube which is not available now. The central pivot hole, however, confirms its use. People have searched for a device like a vernier which perhaps would have improved the accuracy in reading the angle. In a supplementary note, Pearse[5] wrote 'I had forgotten an instrument for taking the declination of the Sun, etc., which consists of a circle of iron … The divisions are very much inferior to those on the stone.' Here he is comparing the accuracy to the measurements made on the Samrat Yantra.

Chakra Yantra as described in texts

There are varieties of Chakra Yantras described in several astronomy texts; these are discussed extensively by Ohashi[6]. They are all circular graduated rings hung vertically. Aryabhata mentions about two holes for aligning with the sun so as to get the zenith distance. It is to be noted that the text states 'the nadis elapsed' can be ascertained using this instrument, which is not straightforward as it appears, but demands a second graduated circle as an accessory. If the graduated circle is in the horizontal or vertical plane, the calculations are to be made using the formulae for sundials to get the local time. The procedure requires corrections which vary from season to season. On the other hand, if the circle is along the equatorial plane, the angles directly reveal the time from or to the meridian transit. None of the texts mentions the use of such a graduated circle; perhaps, this was implied and therefore not explicitly mentioned.

The Bhagana Yantra of Lalla is more closer to the 'Chakra Yantra' of the Varanasi observatory. This is the dial on the southern pier of the Yantra, which has graduations in degrees. When the chakra or the central wheel is aligned with the sun, it is effectively a stick or rod, and the shadow cast on the southern wheel will record the hour angle. At the latitude of Varanasi it is unlikely that the shadow will ever miss the southern wall. Thus the instrument called Chakra Yantra is not the one described by Aryabhatta, and Varaha Mihira, but is a combination of Chakra with Bhagana Yantra. This was modified to Nadivalaya Yantra by Bhaskara II. It may be seen that the Nadivalaya Yantra can read only the hour angle and not declination.

In all these descriptions a graduated dial is not specified. Therefore, it appears quite likely that the name Chakra Yantra in the Varanasi observatory may be misleading; it is possible that all the versions of the Chakra Yantra in various texts[6] assumed a dial in the equatorial plane. This requires a rethinking on the definition of the Chakra Yantra. For example, in the version suggested by Aryabhata, two diametrically opposite holes are specified; but whether it should be hung freely or fixed on an already existing 'mount' like the one in Varanasi specifically prepared for the latitude is not clear. In case the latter instruction was implied it is a special Chakra Yantra; the one in Varanasi belongs to this class.

The Yantras described by Varaha Mihira are of a different category, since they need two plumb lines also hung from the Chakra.

The unidentified instrument

Sharma[1] identified all the instruments in the observatory, except one. This instrument is constructed on a platform 18 cm

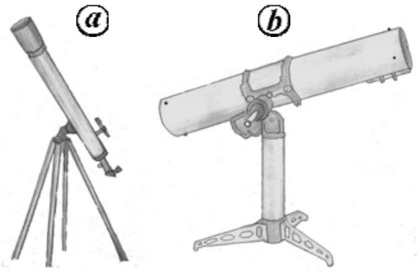

Figure 4. Simplest examples of (***a***) alt–azimuth and (***b***) equatorial mounts.

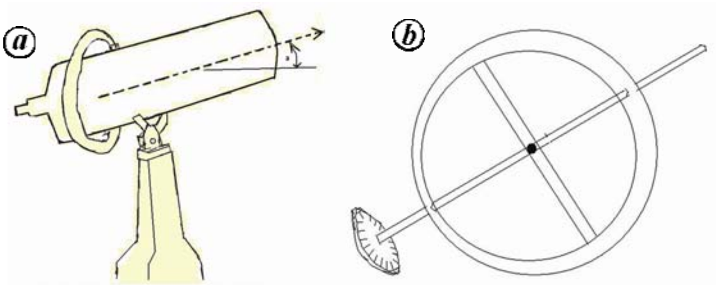

Figure 5. The equatorial mount (***a***) and comparison to Chakra Yantra (***b***).

above the floor of Digamsa and half a metre above that of the Chakra Yantra. 'Of this instrument only a circular channel 7–8 cm wide and about 4 cm remains … An iron pin is embedded in the lime plaster at the center of the channel. The function of the structure is unknown.'

We have yet another indirect reference in Barker's report. The instrument is recorded in the drawing prepared by Campbell, accompanying Barker's report as 'item C'. However, the description for C matches with that of the Chakra Yantra. There seems to be some inconsistency in the drawing, since the only instrument visible behind the small Samrat Yantra appears different from the Chakra Yantra (and is not described in the text). The instrument has a horizontal platform and supported by four small pillars. The Chakra Yantra itself is missing in the drawing. Therefore, it is possible that the instrument (or the platform) existed at the time of Campbell, even though Barker's report does not mention anything about it.

A more recent report on the instrument by Bapudeva Shastri (1866) is cited in Sharma[1] as follows: 'Towards east of this north-south wall Dashinottara Bhitti Yantra, there is an adjacent plane with breadth equal to that of the wall and length equal to seven hands. Although it was initially leveled like a water surface, but now it has become uneven. On this plane there were fixed two pegs of iron with holes at the top. These are fixed along eastern direction determined by the two gnomons on the wall. At present only one of them in the east exists. Quite near this plane, there is a leveled circular plane made of lime bricks and with diameter equal to one hand, 9.25 angulas. There is also another one (second) leveled circular plane made up of stones and having diameter equal to two hands and seven angulas. Nearby this plane there is a leveled square with side equal to one hand and 11 angulas. The graduation on these two circular platforms and the square are erased now. But it seems that earlier these were made to determine the gnomonic shadow and the azimuth.'

It is possible that they were the simplest instruments to mark the azimuth. A simple horizontal sundial with the standard 12 angula gnomon would have fitted precisely for the square platform of side one hand and 11 angulas, which is approximately the length of the gnomon itself. Ohashi[6] has described these as Palabha Yantra (vertical sundial) and Shanku Yantra (horizontal sundial). Such instruments are found in Ujjain and Jaipur. Hence Shastri opines that the instruments existed in Varanasi too, but may have got tilted and broken down.

In this context it is worth recalling that there are two columns in the Delhi Observatory close to the Mishra Yantra, the purpose of which has not been discussed so far anywhere.

One of the possibilities of an instrument involving two platforms at unequal heights from the ground is Dhruvadarshaka Yantra[1,7]. This uses the idea that the pole of the rotation axis is along a straight line joining the two stars Alpha and Beta Ursa Minor. This requires that the instrument be mounted between two vertical planes so that its axis is aligned to the polar axis.

Unaware of the description of such an instrument, several years ago, the present author had designed a device for checking the polar axis alignment of equatorial mounts. This required a simple PVC pipe of about 8″ diameter approximately aligned to the polar axis. It has two circular dials as shown in Figure 6. The outer circle is graduated in angles and is immovable; the inner circle is rotatable. A small slot is cut along the diameter of the inner circle. When the pipe is aligned with the rotation axis, both Alpha and Beta Ursa Minor are seen through the slot. After sometime both stars would have moved out of the slot; they can be brought back to the field of view by rotating the inner circle. This can be achieved only if the alignment is exact. This was to be used with amateur telescopes for checking the polar axis alignment.

The two dials were graduated in degrees. The location of the pole star alignment at sunset was marked with a pointer. At any time in the night, the slot was turned to the position to see the two stars. The angle between the present position and the pointer can be converted to time from sunset. Thus the instrument turned out to be a useful device for keeping track of time in the night.

The instrument in the Jaipur collection as described by Sharma[1] has a dimension of 17.9×16.3 cm^2 and it is possible that a similar instrument was mounted on this platform. This requires a rotation in the vertical plane. However, the description and Campbell's drawing show a wheel for horizontal rotation. Whether the horizontal motion was translated into vertical

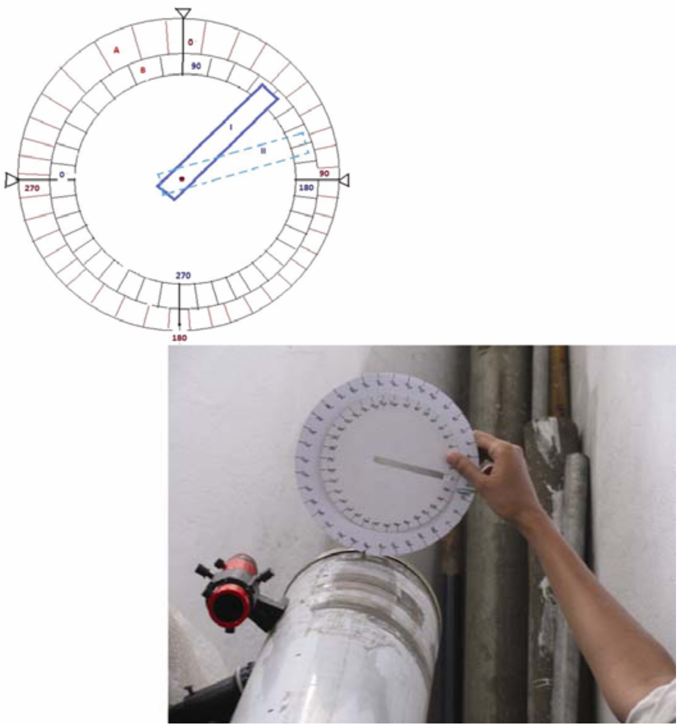

Figure 6. A device for helping amateur astronomers to assist in the alignment of (equatorial mount) telescopes. A modification connects this into a Dhruvabhramaka Yantra according to the description.

by some mechanical system is debatable in the absence of any proof. On the other hand, it might have been a simple trapezoidal platform to see the pole star. We do not have examples of the second kind, a simple trepizoidal plane, anywhere.

Among the instruments of the Peking Observatory sketched by Verbiest, as described by Cummins[8], there is one which is not extensively discussed anywhere in the text. It shows two circular rings placed one above the other and a conical frame connecting the two. Perhaps it was possible to steer it to any direction after making one ring perpendicular to the other. In essence, it was perhaps the 'parked' position of this Yantra. This bears a striking similarity with the unidentified instrument seen only in Campbell's drawing. The layout of the observatory at Peking, as provided by Cummins[8], also shows the instrument with two circular rings; again no description is available.

Conclusion

Here we report a possible clue on two of the lesser known instruments of observatory at Varanasi. One is perhaps a combination of two ideas and for the other, only a description by Aryabhata and other astronomers is available. This report therefore takes a new look at two instruments at the observatory in Varanasi. The name Chakra Yantra may be a misnomer and actually it is a Bhagana Yantra. The unidentified instrument may be a remnant of Dhruvabhramaka Yantra, meant to mark the time in the night.

Appendix 1. The first equatorial mount

The equatorial mount which was perfected by the Jesuit Christopher Grienberger was described by Scheiner in his *Rosa Ursina sive Sol* (Bracciano, 1630), although he had used it as early as 1620. In 1613, Scheiner in turn contributed to the perfection of the refracting telescope with which we are familiar today. He constructed a number of different kinds of telescopes, and in particular (perhaps at the suggestion of Kepler), he made one with two convex lenses instead of Galileo's scheme which included one concave and the other convex. This greatly improved the sightings. Scheiner gave one of his telescopes to the Archduke of Tyrol, who was more interested in the scenery from his Innsbruck castle than he was in the stars. When he complained that the image was upside down, Scheiner inserted another lens to invert the image and so created one of the first terrestrial telescopes (http://www.faculty.fairfield.edu/jmac/sj/scientists/scheiner.htm).

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Edited and published by P. Balaram, Current Science Association, Bangalore 560 080.
Typeset by WINTECS Typesetters (Ph: 2332 7311), Bangalore 560 021 and Printed at Printek Printers, Bangalore (Ph: 2328 7763)