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MIŚRA YANTRA OF THE DELHI OBSERVATORY

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In this paper the author critically examines the Miśra Yantra of Sawai Jai Singh's Delhi observatory. The author believes that it is not Jai Singh but his second son, Madho Singh, who added the instrument to the observatory. Further, the author believes that Madho Singh did this sometime between 1750 and 1754. It is pointed out that, contrary to popular belief, the Niyata Cakras of the Miśra yantra do not represent meridian arcs of the observatories Greenwich, England; Zurich, Switzerland; Serichew, Russia; and Notkey, Japan, Finally, the author makes suggestions for the instrument's restoration.

INTRODUCTION

In order to update the existing astronomical tables, Sawai Jai Singh (1688-1743) built observatories in five different cities of north India-Mathurā, Ujjain, Vārāṇasī, Jaipur and Delhi. His observatories, except that of Mathurā, still exist. His Delhi observatory, popularly known as the Jantar Mantar of Delhi, is located on Parliament Street, near Connaught Place, in the business district of New Delhi. The observatory today has four surviving instruments: the Samrāṭ yantra, Jaya Prakāśa, Rāma yantra, and Miśra yantra. The object of this paper is to critically examine the Miśra yantra, investigate certain myths surrounding it, and to make suggestions for its future restoration.

Jagannātha, the principal astronomer of Jai Singh, does not mention the Miśra yantra in his *Samrāṭ Siddhānta,* nor does the *Yantraprakāra* include it in the list of instruments built by Jai Singh.[2] Tieffenthaler, who visited Delhi in 1747, just four years after Jai SIngh's death, also does not mention it in his memoirs.[3] The author believes, therefore, that the instrument was not built by Jai Singh but by his second son Madho Singh, who ascended the Jaipur throne in 1750. Madho Singh also had interest in astronomy. Madho Singh must have built the Miśra yantra between 1750 and 1754, when he was in the good graces of the emperor Aḥmad Shāh. Strong political motives, most probably, led Madho Singh to construct the yantra at Delhi instead of Jaipur. The emperor, however, was deposed in 1754, after which the political situation in Delhi rapidly detcriorated. Madho Singh himself got entangled in numerous conflicts of his own, with the result that the Delhi observatory was completely neglected.[4] Just about this time anarchy swept the countryside surrounding Delhi and the observatory ceased to function as a place of astronomical activity.

In 1764 a Jat army led by Jawāhara Singh bombarded Delhi.[5] As pointed out by

Franklin,[6] and later cofirmed by Thorn,[7] the observatory was looted by Jawāhara Singh's troops, and its instruments vandalized for their material.

In 1909-1910, Gokul Chand Bhavan restored the Miśra yantra along with the other instruments of the observatory.[8] The most recent restoration of the Niyata Cakras of the Miśra yantra was undertaken in 1951.[9] Pundit Kedar Nath, the *Rāja Jyotiṣī* of Jaipur, was in charge. Since then some half-hearted efforts have been made by the Archaeological Survey personel to repair the instruments, but these may only be classified as patchwork at best, and their effects on some of the instruments have been more of a detrimental nature than beneficial.

THE INSTRUMENTS

The yantra, as its name indicates, consists of several instruments within a single structure. The instruments included in the structure are as follows:

1. Dakṣiṇottara Bhitti
2. Karkarāśi Valaya
3. Samrāṭ yantra in two halves
4. Niyata Cakras (4)
5. Quadrant arc of unknown function

The Miśra yantra building has a hollow space under the structure which has been turned into the office of the local respresentative of the Archaeological Survey of India.

DAKṢIṆOTTARA BHITTI

The Dakṣiṇottara Bhitti of the Miśra yantra is the smallest instrument of the Delhi observatory complex. It is located on the east-facing wall of the Miśra yantra complex. The instrument recently was replastered in cement, and its scales were redrawn. However, the work was poorly done. The instrument, as it stands today, is a semicircular arch or, more appropriately, a double-arc jointed at the top. The arcs have a radius of 1.6 m and 1.66 m respectively. The two arcs of the semicircle thus have slightly different radii and do not meet properly at the top, as they should. They miss each other by almost a centimeter. Close to the center of the arcs, there is a pin or style.

The scale of the instrument is about 2.5 cm wide with its zero marking at the top. The two quadrants on either side of the zero are divided into 15 main divisions. The left quadrant is further graduated with its main division subdivided into six parts; thus, the small division of the instrument measures an *aṃśa*, or degree. The divisions have been very poorly marked, however. Although most divisions are 2.8 cm wide, the variations between division could be as much as 2.5 mm. The script used for labeling the divisions is Devanāgarī. In addition to the recent scale markings, faint traces of the 1910 restoration may also be seen on the instrument.

For measuring the zenith distance or altitude of the midday sun with this instrument, one has to hold a pin or a rod vertically above the scale, such that the shadow of the pin falls over the fixed style at the center. The part of the shadow falling on the scale then indicates the zenith distance of the sun. The zenith distance of the meridian moon at night, if bright enough, may also be similarly determined.

With this Dakṣiṇottara Bhitti, the procedure for measuring the altitude of a planet or star that does not cast any discernible shadow is cumbersome at best, because the instrument is too close to the ground to facilitate an easy reading. It is debatable, therefore, that this instrument was ever used for any serious work, particularly when another and more accurate Dakṣiṇottara Bhitti as described by Hunter was available to the observer.[10]

KARKARĀŚI VALAYA

On the back wall of the Miśra yantra complex, facing north, is the semicircular scale of Karkarāśi Valaya, with its two ends facing upward. The wall on which the instrument is engraved is tilted approximately 5 degrees towards the south and, therefore, is parallel to the plane of the Tropic of Cancer. On June 21, when the sun is at the Tropic of Cancer, its rays at noon fall at grazing incidence on the instrument. It is not known what application the designers had in mind when they built the Karkarāśi Valaya. The instrument is now in ruins.

Most of its markings are gone, and deep gouges may be seen in places. According to a photograph in Kaye's *The Astronomical Observatories of Jai Singh*,[11] there used to be a door on the west side of the Karkarāśi Valaya. The door is now closed with bricks and mortar, and two windows have been added to the wall in its place.

According to Bhavan, the Karkarāśi Valaya scale had two "zero" markings at the two top ends of the scale and had two 90-degree markings at the bottom.[12] From what little is left of the instrument the author concludes that the diameter of its scale had been 11.81 ±3 cm and that it was marked according to the Hindu scheme of dividing a circle into quadrants of 15 large divisions and then subdiving them into *aṃśa* or degrees. Next, each degree was divided into 10 parts which were once again parted into six subdivisions of one minute, thus giving the instrument a least count of 1' of arc. From the markings still visible at a few places, it is noted that the small divisions indicating minutes were on the average 1.7 mm wide. The markings are done rather poorly, however. For example, a number of divisions of width as small as one millimeter may be noted on the scale. Because the instrument has been designed to measure to the nearest minute of arc, it is the most sensitive device at present in the Delhi observatory.

In theory, the Karkarāśi Valaya may be used once every 24 hours to directly measure the longitude of a celestial object, such as the moon, at the moment when the first point of the sign of Cancer, or the summer solstitial point of the ecliptic, is on the meridian. The time when the solstitial point reaches the meridian may be determined from tables or with an astrolabe. For objects such as the planets, which are visible only after dark, observations are possible only after September 22 and before March 21, when the sun is below the horizen at the time the solstitial point approaches the meridian.

SAMRĀṬ YANTRA

The Samrāṭ of the Miśra yantra is constructed in two halves, to be used before and after the noon hour to determine the local time. These two halves flank the Niyata Cakras of the Miśra and are identical to a large extent. The gnomon of the east half is 10.97 m long, whereas the gnomon of the west half is 11.00, meters or about 2.5 cm longer, They both are about 46 cm wide, and each has a quadrant attached to its outer flank. The radius of the east quadrant is 2.63 m. and that of the west, 2.87 m ±4 cm. The west gnomon in addition has a second quadrant attached to it.

The instrument has suffered from improperly done repairs. Numerous repairs of the surface have all but obliterated the scale markings on the two gnomons. A faint line running parallel to the surface edge near the top of the east gnomon and a few traces here and there on the west gnomon suggest that the instrument was designed

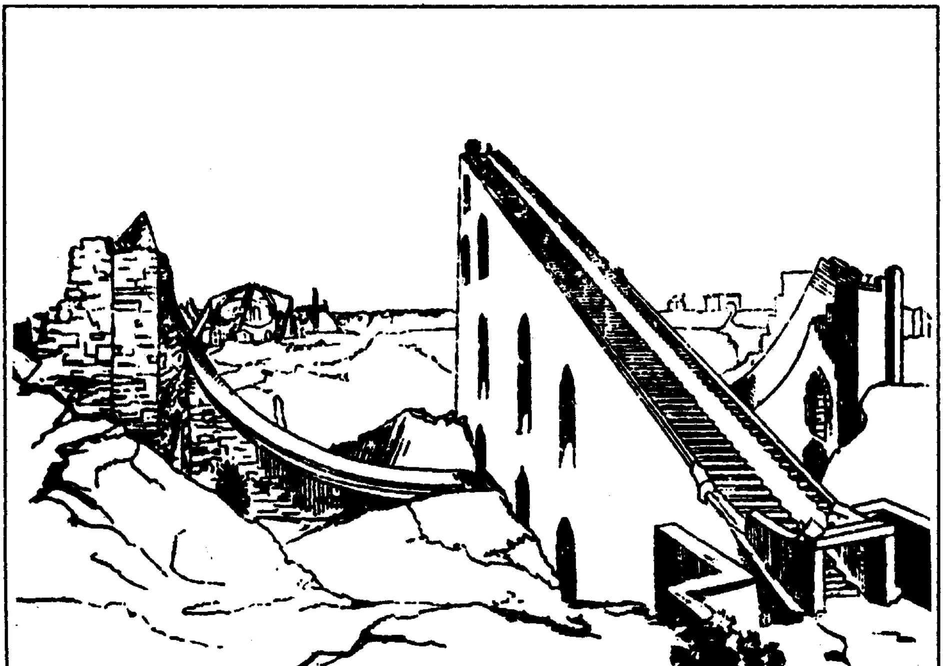

Fig. 1. An engraving of the Delhi observatory published in 1816. The Miśra yantra can be seen near the top left part of the drawing. (Ref. 26).

to measure declination as well.

The markings from the upper surface of the quadrants are mostly gone; however, approximately 2/3 of the original markings on the side may still be seen. One can see the Hindu scheme of dividing a quadrant into 15 parts, as well as dividing a quadrant into 90 deg. These markings show that a degree was divided into 20 parts, and that the instrument had a least count of 3 minutes. The width of a small division was approximately 1.5 to 2 mm, and the script used in labeling was Devanāgarī.

Niyata Cakra

The Niyata Cakra, or "fixed arc", is the best preserved instrument in the Delhi observatory. The instrument consists of four semicircular scales of marble on either side of a gnomon. The instrument was originally built in lime plaster,[13] but in 1951 it was surfaced with marble.[14] Stairs are provided between the scales and around the outer scales to approach the top of the structure. Another set of steps is provided in the middle of the gnomon to reach to its very top. The gnomon, with which the ends of the scales meet, is also the diameter of the semicircular scales. Further, the scales are inclined with the plane of the meridian, or with the vertical surface of the gnomon as Fig. 2 indicates.

According to Kaye, who had the angles measured by engineers, the Niyata semicircles lie in the planes inclined with the meridian plane by 77;18W, 69;50 W,

Fig. 2. Miśra yantra of Delhi

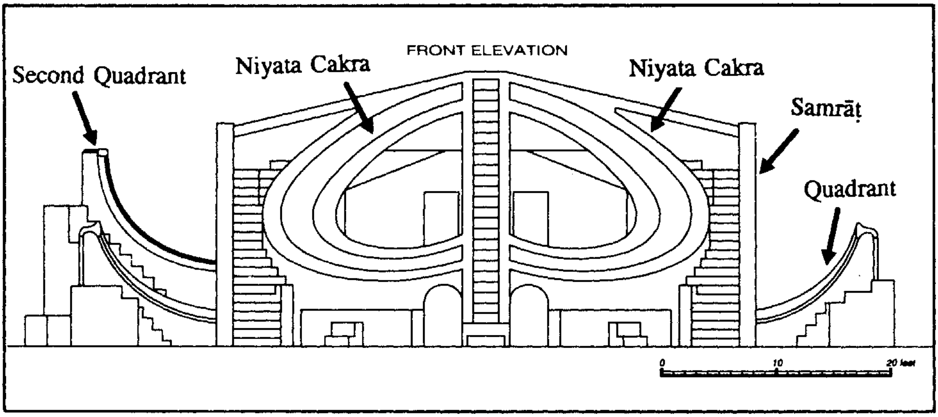

Fig. 3. Miśra Yantra, front elevation

69;42E, 77;22 E, respectively.[15,16] The angles are difficult to measure, as Kaye points out. The pundits he consulted gave him different answers, however. According to the pundits, "the semicircles are inclined to the plane of the Delhi meridian at angles of 77;16 W., 68;34 W., 68;1 E. and 75;54 E."[17]

The Niyata Cakras scales are 53 cm wide. The Cakras on the outside, inclined at about 77 degrees, have a radius of 4.83 m. The radius of the Cakras on the inside, on the other hand, is 4.01 m. At the center of the Cakras on the gnomon, holes are provided for fixing a pin. The holes, however, have been incorrectly located as they are off from the true center by about 4 cm.

The Niyata Cakras are provided with two scales, each running side by side along their inner and outer edges, respectively. These scales are not identical, however. The scale on the outer side of a Niyata semicircle measures declination in degree and minutes. Each degree on this scale is divided into 10 parts, and the parts are once again divided into 3 subparts each. The zero point on this scale is along the east-west line in the middle.

The inner scale, on the other hand, is divided into two quadrants of 15 main divisions each. For this scale the zero marks are on the north-south points. The main divisions here are subdivided into degrees or *aṃśa*, which are once again divided into small divisions of 2' of arc each. Originally the least count of the instrument was 1' of arc, as Hunter reports,[18] but that is changed now. The width of the 2' divisions, at present, however, is large enough to divide them further into 1' divisions.

For the Niyata Cakras of larger diameter, the small divisions on their outer scale measure 3.20 ± .05 mm. Similarly the width of the small divisions on their inner scale is 3 mm. The divisions on the two scales of the inner Niyata Cakras (dia. 4.01 m), on the other hand, have widths of the about 2.5 mm and 2.35 mm respectively. The divisions of the Niyata scales have been fairly well laid out.

THE PURPOSE OF THE INSTRUMENT

The Niyata Cakras have been constructed for measuring the declination of an object at intervals of a few hours as the object travels from east to west in the sky in the course of a day. According to Bhavan, the Niyata Cakras on the west side of the central gnomon are meant for observing the declination of the sun at 52 minutes and at 1 hour 24 minutes after sunrise.[19] The procedure, as he illustrates, is to fix a rod into the hole at the center and observe its shadow on the scale at the times just indicated. Similarly, the Niyatas on the eastern side of the gnomon are meant to observe the declination of the sun at 4 hr 36 min., and at 5 hr 8 min after the noon hour.[20] At night, the readings are taken at the moment when the object is at the grazing incidence witht the surface of a Niyata scale. For this, the "eye" is placed at the edge of the scale such that the object and the central pin appear in one line. The vantage point on the scale then indicates the declination of the object.

Following the procedure elaborated by Bhavan, we measured the declination of the sun on November 11, 1981, with the Niyata Cakras on the west. We observed that on that day the rays of the sun became tangential to the outer Niyata at 6:57:12 A.M., Indian Standard Time. The sun was extremely weak, casting no appreciable shadows and, therefore, it became necessary to look at it directly. This way the declination was found to be approximately 17 degrees. Next, less than an hour later, at 7:29:26 A.M., the rays of the sun became parallel again to the inner Cakra on the west, and from its scale the declination of the sun was measured to be 16;20. The ephemeris value of the declination for that day was 17;20,10, and thus there was a discrepancy of about 40' between the two readings. Part of the reason for this discrepancy could have been that the hole for inserting the pin was off-center by about 4 cm., as pointed out earlier. The Niyata Cakras on the east could not be checked due to the high-rise buildings to the west of the observatory.

A popular belief is that the Niyatas are meant to duplicate the declination readings for the meridian arcs of four different locations on the globe. In the words of Bhavan, the Niyatas are similar to the meridian arcs at Notkey, a small town in Japan; Serychevo, a town on the Kuril island in the Pacific; Zurich, Switzerland; and Greenwich, England.[21] All these places except Serychevo supposedly have observatories.[22] A check carried out on behalf of the author revealed that there had never been any observatory at Notkey in Japan.[23] Further, the Zurich observatory was built in 1759, a few years after Madho Singh built the Miśra yantra, as this author believes. The observatory of Greenwich was built earlier, in 1675, about 13 years before Jai Singh's birth.

DIFFICULTIES WITH NIYATA CAKRAS

Because the Niyata Cakras are built in planes too close to the horizon, they are cumbersome to use. In the morning, particularly during the winter months when the sun is weak and there is a haze over the horizon, the shadow of the the pin cannot be easily discerned. And it becomes difficult to ascertain the location of the shadow on the scales without looking directly at the sun. Besides, for readings close to the horizon, the refraction correction becomes important and may not be neglected. Neither Hindu nor Muslim astronomers applied refraction corrections to their works. Jai Singh, however, did realize its importance and included a refraction correction table in his *Zīj-i-Muḥammad Shāhī.*

Although the Niyata Cakras are impressive in appearance, they may not be clasified as well-designed instruments. A considerable part of their scales, particularly the section above the horizontal line passing through the center of the arcs, is useless and can never be used. If Bhavan's procedure is followed, the scales above the horizontal line can only be used for measuring the declination of the objects that lie below the horizon. And that can never be possible. It may be suggested that by altering the vantage point and viewing the objects from the location of the pin at the center, the instrument could be useful.[24] But this procedure also has difficulties, because the two gnomons of the Samrāṭ get in the way for part of the observation. The two inner Niyata Cakras, on the other hand, cannot be worked with this procedure either. The scales of the outer Cakras obstruct the field of view if this procedure is attempted. The real worth of the Niyata Cakras, or the Misra yantra as a whole for that matter, lies in its being a good teaching tool.

THE SECOND QUADRANT ON THE WEST

Attached to the Miśra Samrāṭ's west gnomon is a second quadrant. Kaye erroneously calls it Agrā yantra, or amplitude instrument,[25] Hunter does not mention it all in his paper published in 1799. However, the quadrant can be discerned in Daniell's engravings which were made only a few years after as Hunter and were printed in 1816.[26] Bhavan says that he repaired the quadrant in 1910 without altering its shape and that he did not find any special gnomon just for this quadrant.[27] Further, Bhavan is silent about its application. Apparently, there was little left of its gnomon and its markings to give him any clues.

The second quadrant has a length of 5.0 m, width 74 cm. radius 3.18 m. Its radius is thus about 31 cm larger than that of the Samrāṭ quadrant next to it. The plane of the quadrant, as the author judged, is tilted by about 5 degrees toward the south, i.e., by about the same angle as the Karkarāśi Valaya. The scale markings etched on its surface in 1910 have more or less disappeared, except for a few traces left here and there. The scale markings on either side of the surface, however, may still be seen intact at places.

From what little is left of the scales, one can see that Bhavan in 1910 divided the scales into 90 degrees with the zero mark at the bottom. The degree divisions were further subdivided into 10 parts each. Thus the least count of the instrument was 6' of arc. The Hindu system of marking a circular scale had also been used, and the quadrant was divided into 15 major parts. The least count of this division scheme was also 6' of arc. The average length of the small divisions was 6 ± 2 mm.

From the five-degree tilt of the quadrant, it appears that the instrument was meant to directly measure the latitude and longitude of a celestial body once every 24 hours when the summer solstitial point on the ecliptic, or the first point of the sign of Cancer, is at the meridian.

However, for these measurements, the section of the gnomon adjacent to the quadrant should also be tilted by an additional five degrees to the south. The instrument will then work just like the Karkarāśi Valaya of Jaipur.[28] It is not known if the builders had such an application in mind and if they provided the gnomon with an additional tilt of five degrees to the south as required. By 1910, the gnomon had become so dilapidated that Bhavan, with no clues to its original tilt, simply extended the lower section of the gnomon meant for the west Samrāṭ, as we find it today.

How the Instrument Should be Restored

Some scholars have advocated the restoration of the instruments of the Delhi observatory including the Miśra yantra. The restoration of the Miśra yantra would be longer lasting and worthwhile if consideration is given to the following suggestions :

1. Restore the instrument scales in marble so that they will not deface easily.

2. On the Ṣamrāṭ quadrants, give prominence to the *ghaṭikā* and *pala* units of time-measurement. Jai Singh's astronomers as well as those of Madho Singh used *ghaṭikās* and *palas,* and not hours and minutes.

3. Keep the hour and minute graduations however, but on the side of the scales only. These hour and minute graduations should be retained for the benefit of a modern visitor who is unfamiliar with *ghatikās* and palas.

4. Lower the plane of the Samrāṭ gnomons by a few centimeters so that the outer Niyata cakra scale could be used. The author believes that this is how the gnomon-planes had been originally built before their restoration by Bhavan.

5. Keep the inclination of the gnomon of the west Samrāt up to about 35° N as it is today and tilt the rest so that the tilted part becomes perpendicular to the plane of the second gnomon attached to this gnomon. The author believes that this is how the original builders must have constructed the instrument.

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12. Bhavan, Ref. 8, p. 70.

13. Hunter, Ref. 10.

14. The repair work was done under the supervision of Kedar Nath Sharma (no relation of the author), the *Rāja Jyotiṣī* of Jaipur at the time.

15. Kaye, Ref. 11, p. 45

16. The author attempted to measure the inclination of the outer Niyata Cakra on the western side by observing the timings when the stars Castor and Pollux in the constellation of Gemini came into the plane of the instrument. His average value of two readings was 77;12, On the night of observations, the visibility was poor, and therefore, his readings could be off by as much as 0;45. The observations were conducted on the evening of January 6, 1990.

17. According to Bhavan, the inclination of the Cakra Planes is 77°E, 69°E, 69°W, and 77°W of the Delhi meridian respectively. Bhavan, Ref. 8, pp. 68-69.

18. Hunter, Ref. 10.

19. Bhavan, Ref. 8, pp. 67-69. Bhavan's comments regarding the time of observation after sunrise is true only at an equinox and not at any other time.

20. Bhavan's observation is true at equinox only.

21. Bhavan, Ref. 8, p. 69. The Hindi incription on the plaque in front of the instrument also states this.

22. The coordinates of these places are reported to be as follows:

Notkey	43;33,O N.	145;17 E.
Serichew	48;6 N.	153;12 E

Zurich 47;23 N. 8;33 E

See Kaye, Ref. 11.p. 45.

23. Profs. Yoshihide Kozai of the Tokyo Astronomical Observatory, Michio Yano and K. Yabuuti of Kyoto Sangyo Univ., and Shigeru Nakayama of Kanagawa University have all identified Notkey with Notsue, a very remote area of the Hokkaido island of Japan. (Private communication). The place is very desolate, inhospitable, and cold, even in summer. An observatory at such a location is highly unlikely. Besides, the author has not seen any mention of an observatory at Notsue in literature related to the history of astronomy in Japan.

24. This procedure would require two observers-one viewing from the site of the pin and directing the other with a pin or slit at the scale.

25. Kaye, Ref. 11, p. 45.

26. Daniell, Thomas and William, *Oriental Scenery,* fifth series, plate No. 19, London, 1816.

27. Bhavan, Ref. 8, p. 66.

28. See Ch.VII, of the author's forthcoming book, *Sawai Jai Singh and His Astronomy.* Or see Kaye, Ref. 11, p.52.

29. NSF Grant No. INT-8016996.