Bhāsvatī. of Śatānanda: In the Pages of Mystery

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Abstract:

Śatānanda, the astronomer and mathematician of 11th century, was born in 1068 C.E. at Purusottamdharn Puri (Jagannath Puri) of Odisha wrote the scripture Bhāsvatī in 1099 C.E.[1]. This scripture has significant contribution to world of astronomy and mathematics. Śatānanda has adopted Centesimal System for the calculation of position and motion of heavenly bodies, which is similar to the present day Decimal System[2]. The treaties got the recognition of a scripture of Karana grantha[3]. Commentary of this work has been made by different persons during different times of history[4]. Though it is found to be remade in almost once in each century and was well known all over India and abroad. Presently it is completely lost and no reference is available in ongoing works. The main aim of this paper is to outline and bring to the notice of a wider audience- the genius of Śatānanda and his contribution to the world of astronomy and mathematics.

Key Words: Decimal System, Centesimal System, Bhāsvatī, Ṭīkās (Commentaries), Śatāṁśa, Dhruvāṅka (longitude), Ayanāṅśa

Introduction:

The history of development of mathematics in India is as old as Vedas. From the prehistoric days mathematics began with rudiments of metrology and computation, of which some fragmentary evidence has survived till date. The sacred literature of the Vedic Hindus- the Samhītās, the Kalpas and the Vedāṅgas contain enough materials, which prove the mathematical ability of those pioneers who developed this class of literature. Those pioneers, mostly astronomers, were using mathematics as an instrument for calculation of position of stars and planets. Rather one can say that such calculation of heavenly bodies, their positions and movements (Astronomy) urged for the origin of mathematics i.e. addition, subtraction, multiplication and division, so also fractions. The division of the days, the months, the seasons contemplated an idea of fractions.

In all ancient calculations the astronomers assigned 360 aṅśa for one cycle, since 360 is the smallest number divisible by the integers 1 to 10 excluding 7. The trend is still implemented in the present day calculations. However in late 11th century an astronomer Śatānanda born in Odisha tried to make a deviation from the ongoing mathematical research and was successful in his attempt. He had converted all cyclic calculations into multiples of hundred for convenience. He had used 1200 aṅśa while calculating the positions and motions of planets with respect to 12 constellations and used 2700 aṅśa while calculating the positions and motions of the Sun and Moon with respect to 27 Nakṣatras.

The scripture Bhāsvatī of Śatānanda has introduced very simple methods to calculate celestial parameters without using trigonometric functions. Therefore it was appreciated by the society and it spread all over north India, though many astronomers like Samanta Chandra Sekhar considered it as an
approximate calculation. Transformation of anśa (degrees) into śatāṁśa (multiple of hundred) was the greatest achievement of Śatānanda of 11th century recorded in Bhāsvatī. There is a claim exists that this mathematical calculation was the initial form of the modern day decimal system calculation[2]. The commentary of this work was made almost in each century in history of India and abroad. In the present day research, this reference is completely ignored by the mathematicians and astronomers of our country. This pioneering piece of work of Śatānanda has been very little known even in the learned society of his native place Odisha.

In this paper the mathematical calculations where Śatānanda had introduced (i) Centesimal fractions and (ii) converted the anśa (degrees) into śatāṁśa (multiple of hundred) have been explained. Section I deals in introduction about the history of mathematical Science before Śatānanda wrote Bhāsvatī, Section II, deals in the historical details regarding Śatānanda and Comments and Commentaries on Bhāsvatī, Section III, explained the mathematics, Śatānanda had introduced in his text Bhāsvatī and the explanations to it. Section-IV the conclusion and the future plan.

Section I: Śatānanda: From the history of Odisha it is known that Śatānanda might have been a courtier in the period of Keśāri Dynasty (474 C.E.-1132 C.E.). In that period, many constructive works were done. The kingdom was peaceful and patronage was given to scientists and architects. Establishment of Cuttack city, the then state capital had been made in that period. Besides this the stone embankment on the river Kāṭhajodi and Aṭharanalā bridge of Śrikhetra Purī were the significant achievements of that time. Bhāsvatī of Śatānanda was the greatest achievement of Keśāri dynasty.

Śatānanda wrote this scripture, which was a guideline to make Pañcāṅga (calendar) for the benefit of performing rituals in Jagannātha temple, Puri. Since Pañcāṅga (calendar) has an important role in Hindu society. Śatānanda made the calculation of heavenly events of heavenly bodies accurately. Hence there was a saying in Varanasi (the then knowledge center of India) -- ग्रहणे भास्वती धन्या (Bhāsvatī is the best book to predetermine eclipses.). It is also enlightening to know that the great Hindi poet Mallik Muhammad Jayagi praised Bhāsvatī in his book as[1]

भास्वती औद्याकरनपिड़गलपाठपुराण।
वेदनेद सो वात कहि जनुलागहिम वान ||

This shows the popularity of Bhāsvatī in the society.

Section II: Commentaries:

There is a commentary on Bhāsvatī written in Śaka 1417 by Aniruddha of Varanasi from which it appears that there were many other commentaries on it written before¹.

Mādhava a resident of Kanauja (Kānyakubja) wrote the commentary of Bhāsvatī in Śaka 1442. Another commentary of this scripture was written in Śaka 1607 by Gaṅgādhara. The author of the commentary written in Śaka 1577 is not known. According to the Colebrooke, the commentary of Balabhadrā born in Jumula region of Nepal was written in Śaka 1330[2]. From the catalogue of Sanskrit books prepared by Aufrecht, the title of this commentary appears to be Bālabodhini. This book was the
first mathematics text book in Nepal[6], since the mathematical operations like Additions, Subtractions, Multiplications and Divisions are explained explicitly in Bhāsvatī. According to Aufrecht’s Catalogue there are following additional commentaries on Bhāsvatī karana: Bhāsvatī karanapaddhati; Tatvaprabhāśīkā by Rāmakṛṣṇa, Bhāsvatīcakaraśmyudaharana by Rāmakṛṣṇa, Udāharaṇa by Śatānanda, Udāharaṇa by Vṛundāvāna. Similarly, there are commentaries by Achutabhaṭṭa, Gopāla, Cakraviprāśa, Rāmeśvara, Sadānanda and a “Prakrit” commentary by Vanamāli. Very recently it is found that there was commentary of this scripture with examples in Odia by Devīdāsa in Śaka 1372 from the State Museum, Odisha. This is a well explained book on mathematics and heavenly phenomena calculated in Bhāsvatī.

Most of these commentators hail from Northern India. The author of History of Indian Astronomy Sankar Balakrishna Dixit regrets that this great work is not known and there is no reference of this work has been uttered in any research presently.

The copy of these commentaries are presently available in the library of (i) Alwar (Rajasthan), (ii) Asiatic Society, Bengal (Kolkata), (iii) India Office Library (London), (iv) Rajasthan Oriental Research Institute (Jodhpur), (v) Saraswati bhavan Library (Banaras), (vi) Visveswarananda Institute (Hoshiarpur), (vii) Bhandarkar Oriental Research Institute (Pune)[5].

Section III: Contents of Bhāsvatī:

Bhāsvatī contains 128 verses in eight Adhikāras (chapters). Those are (i) Tīthyādi dhruvādhikāra (Tithi Dhruva), (ii) Grāhadhruvādhikāra (Graha Dhruva), (iii) Paṅcāṅga spaṣṭādhikāra (Calculation of Calendar), (iv) Graha spaṣṭādhikāra (True place of Planets), (v) Triprāśnādhikāra (Three problems: Time, Place and Direction), (vi) Chandragrahanādhikāra (Lunar Eclipse), (vii) Sūryagrahanādhikāra (Solar Eclipse), (viii) Parilekhādhikāra (Sketch or graphical presentations of eclipses)[1].

The first sloka of his scripture Śatānanda acknowledged the observational work of Varāhamihira which he has used in his calculation. He also claims that his calculations are as accurate as Śūrya Siddhānta though the methods of calculation are completely different. The Śloka is as follows:

अथ प्रवक्ष्ये मिहरोऩदेशाच्छ्रीसूर्यययमसद्धान्तसिंसात्

Indian astronomers have differed on the rate of precession during different periods with respect to the ‘zero year’. The accumulated amount of precession starting from ‘zero year’ is called ayanaṁśa.

There are different methods to calculate the exact amount of ayanaṁśa. (i) The Siddhāntas furnish rate for computing it, which is in principle the same as the method of finding the longitude of a star at any given date by applying the amount of precession to its longitude, at some other day. (ii) Defining the initial point with the help of other data such as the recorded longitudes of the stars, its present longitudes from the equinocial point may be ascertained. (iii) Knowing the exact year when the initial point was fixed, its present longitude ayanaṁśa may be calculated from the known rate of precession. However it is so happen that the result obtained by these three methods do not agree. Śatānanda has his own method of calculation which is very simple but considered to be approximate.
Bhāsvatī, has assumed śaka 450 (528 C.E.) as the Zero precession year and 1 minute as the rate of precession per year. However Jogesh Chandra Roy in his 61 page introduction to Siddhānta Darpaṇa claims that the zero precession years adopted in Bhasvati is Saka 427(505 C.E.). He got this number by making the reverse calculation. The calculation of ayanāṁśa has been explained in first sloka of 5th chapter Tripraśnādhikāra. The meaning of this sloka is:

Subtract 450 from the past years of Śālivāhana (Śaka) and then divide it with 60. The quotient is the ayanāṁśa (precession). Add ayanāṁśa with ahargaṇa to bring the proof of day night duration.

Example: If we will subtract 450 from Śaka 1374, it will be 924. Dividing 924 with 60 becomes 15| 24. By adding this value with ahargaṇa 27 the result becomes sayana dinagana as 42|24.

The table for ‘zero ayanāṁśa’ year and annual rate of precession adopted in different scriptures is given below.

| Siddhānta          | Annual rate of precession | Zero year of equinox in C.E. |
|--------------------|---------------------------|-------------------------------|
| Śūrya Siddhānta    | 54”                       | 499                           |
| Soma Siddhānta     | 54”                       | 499                           |
| Laghu-Vasiṣṭha Siddhānta | 54”                     | 499                           |
| Grahalāghava       | 60”                       | 522                           |
| Bhāsvatī           | 60”                       | 528                           |
| Brhatamihitas, Manjala(Quoted by Bhāskara-II) | 59.9” | 505               |
| Modern data        | 50.27                     |                               |

TABLE-2: SIDEREAL PERIODS IN MEAN SOLAR DAYS

| Planets | European Astronomy | Śūrya Siddhānta | Siddhānta Siromaṇi | Siddhānta Darpaṇa | Bhāsvatī |
|---------|--------------------|-----------------|-------------------|-------------------|----------|
| Sun     | 365.25637          | 365.25875+00238 | 365.25843+00206   | 365.25875+00238   | 365.25865+00228 |
| Moon    | 27.32166           | 27.32167+00001  | 27.32114-00052    | 27.32167+00001    | 27.32160+00006 |
| Mars    | 686.9794           | 686.9975+0181   | 686.9979+0185     | 686.9857+0063     | 686.9692-0102  |
| Mercury | 87.9692            | 87.9585+0107    | 87.9699+0007      | 87.9701+0009      | 87.9672-0020   |
| Jupiter | 4332.5848          | 4332.3206-2642  | 4332.2408-3440    | 4332.6278+0430    | 4332.3066-2782 |
| Venus   | 224.7007           | 224.6985-0022   | 224.9679-0028     | 224.7023+0016     | 224.7025+0018  |
| Saturn  | 10759.2197         | 10765.7730+6.553 | 10765.8152+6.5955 | 10759.7605+5408   | 10759.7006+0599 |

It is seen from the above table-2 that the sidereal periods of the Sun and moon calculated in Bhāsvatī is almost same as in Śūrya Siddhānta and has materially advanced upon it as regards the periods of the other planets[8]. Having regard to the comparatively slow motion of Jupiter and Saturn.
Śatānanda might be very clever to introduce a new calendar from the date he dedicated his work Bhāsvatī for the benefit of the Society. Many calendars were introduced by that time. Those were Śakābda, Gatakali, Hījirābda, Khriṣṭābda (C.E.) and so on. But Śatānanda took Śakābda and Gatakali as his reference calendar and initialized Śāstrābda. He explained the method to convert Śakābda and Gatakali into Śāstrābda in the 1st chapter i.e.tīthādi-dhrūvādhikāra. The śloka and its exact translation are given below.

=Gutakṣaiff प्रकारान्तरेण शास्त्राब्दविधिपिभ्यः-

शाको नवाद्रीन्दुक्षानुयुक्तः कलेभेवत्यव्यवहारणज्ञानस्तुवृक्तः।

वियन्न्भोलोचनबेदह्वीः शास्त्राब्दपिण्डः कथितं स एव॥१.२॥

Gatakali can be ascertained by adding 3179 to Śakābda. Subtract 4200 from Gatakali, the result is known as Śāstrābāda.)

Example: The above method has been implemented to convert the present year 2017 C.E. to Śāstrābda.

The present year 2017 C.E.-78= 1939 Śakābda.

Śakābda 1939+ 3179=5118 Gatakali

Gatakali 5118 – 4200= 918 Śāstrābda.

Hence as per the record, Bhāsvatī has been written in 1099 C.E. and 918 years have been passed.

However, in this article I have referred the āṭkās made in Śaka 1374(1452 C.E.) i.e. Śāstrābda 353. Therefore all the examples mentioned here are in Sastrābda 353.

In this chapter tīthādi-dhrūvādhikāra Śatānanda had given the method to determine solar days (tithi) and longitude (dhrūva) of nine planets Sun (Ravi), Moon (soma), Mars (Maṅgala), Mercury (Budha), Venus (Śukra), Jupiter (Brhaspati), Saturn (Śanī), and Rāhu, Ketu (the shadow planets). He started his calculation from Sun (Ravi).

In the same chapter-1 śloka 4 and 5 he had given an empirical method for determining the longitude (dhrūvāṅka) of Sun. The ślokas are mentioned below.

संवत्सरपालक: शुद्धि सूर्यधुवविधियः:

अथ प्रवक्ष्ये मिहिरोपदेशाच्चैसूर्यसिद्धान्तसमं समासात।
शास्त्राब्दपिण्डे: स्वरवृन्दवद्धस्तानाग्नियुक्तोऽष्टादितिविभक्त:॥१.४॥

लब्धन्नग: शेषतममढङ् युक्तः सूयादिसंवत्सरपालकः स्वातः॥
Multiply 1007 to Śāstrābda and add 349 and divide by 800 add 6 to the quotient and divide the quotient by 7. The reminder is the saṁvatsarapālaka of Śūrya. By subtracting it from the divisor Sudhi comes.

Keep this value in two places. Divide by 108 to the digit of one place. That is the dhrūva (longitude) of madhyama Śūrya. Quotient should be taken up to three places.

Mathematically:
Śāstrābda 919X 1007 = 925433 + 349 = 925782

925782 ÷ 800 = 1157, with reminder 182

1157 + 6 = 1159 ÷ 7 = 166, with reminder 1 -> the fourth graha (planet) from Sun, i.e. Soma (Moon) is the Saṁvatsara pālaka

From (1) 800 – reminder 182 = 618 Śuddhi

Śuddhi 618 ÷ 108 = 5 aṁśa, with reminder 78

78X60 = 4680 ÷ 108 = 43 kalā, with reminder 36

36 X 60 = 2160 ÷ 108 = 20 vikalā

So the dhrūvāṅka (longitude) of morning Sun on Caitra Śukla Pūrṇimā (Full moon day of the month of Caitra) is 5[43][20 aṁśa or 5 aṁśa 43 kāla 20 vikāla. In Bhāsvatī, Śatānanda first initialized the position of planets on Caitra Śukla Pūrṇimā and then calculated the rate of motion, position and time taken by the planets to complete one rotation in its orbit from the ahargana (the day count), unlike other siddhāntas including Śūryasiddhānta which has taken the starting point approximately from the date of the beginning of the civilization (i.e. 6 manu+7 Sandhi+27 mahāyuga+3 yuga+present years elapsed from kaliyuga) for this purpose. Therefore the number is huge so there is every possibility to make mistake. With all these simplifications Bhāsvatī still regarded has an authority for the calculation of eclipse.

Implementation of Śatāṁśa:

Ancient Indian astronomy believes the effect of 12 constellations and 27 Nakṣatras on the human life. They took 360 aṁśa approximately for one rotation, in 365 days, approximately 1° for one day and specified 30 aṁśa to each constellation and 40/3 aṁśa to each star out of 12 constellations and 27 Nakṣatras respectively.

Śatānanda very cleverly multiplied 30/4 to 360 aṁśa to make it a multiple of hundred without losing the generality.

360X 30/4= 2700 aṁśa

Hence each constellation has 225 aṁśa and each nakṣatra has 100 aṁśa.
He adopted 2700 amśa for the calculation of motion (Sphuṭa gati) of Sun, Moon and Rāhu and Ketu the shadow planets. However he adopted 1200 amśa for the calculation of motion of other planets like Mars (Maṅgala), Mercury (Budha), Venus (Śukra), Jupiter (Bṛhaspati) and Saturn (Śani) by taking each constellation as 100 amśa and 400/9 to each nakshatra to avoid dealing with huge number.

In Chapter –IV (Graha spaṣṭādhiṅkāra), Śatānanda introduced satāṁśa while determining the positions of planets.

Example: In śloka 4.10 he explained the position of the shadow planets Rāhu and Ketu as follows.

रािुकेतु स्िष्ट पळधि:
अहगयणं वेदहतं दशाप्तं ध्रुवाद्धययुक्तं भवतीह |
खखागनेरान्तररतो िुखं स्याच्छ्चक्राद्धययुक्तं स्पुट राहुऩुच्छ् ||४.१०||

(Multiply dinagaṇa with 4 and then divide by 10. Add the quotient with last given dhruva (longitude). Subtract it from 2700. That is Rāhu. Again by dividing the given number by 225 rāśi (constellation) of Rāhu will come.

Then by adding cakrārdha 1350 to Rāhu, ketu comes. And by dividing the position number of Ketu by 225, rāśi (constellation) of ketu can be determined.)

[ Fig-1: The position of Sun, Earth and Moon for the calculation of eclipse time.]

Mathematically: Ahargaṇa 27 X 4 =108 ÷ 10 = 10|48 |0
Longitude of rāhu 5130|25| 39 ÷ 2= 2565|12|49 + 10|48 |0 = 2576|0|49
2700 - 2576|0|49 = Rāhu 123|59 |11
\[ Rāhu \ 123|59|11 \div 225 = 0|16|39|47 \text{ is the rāśi of Rāhu} \]

Again \( cakrārdha \ 1350 + Rāhu \ 123|59|11 = \text{ketu} \ 1473|59|11 \)

Here Śatānanda took \( cakrārdha \) (half rotation) as 1350, as one \( cakra \) (rotation) is 2700 \( aṁśa \).

It was known that Rāhu and Ketu points are opposite to each other (180° apart) in a circle and when Moon is near Rāhu point then there is a chance of getting Lunar eclipse and when is on Ketu point Solar eclipse occurs.

\[ \text{Ketu} \ 1476|59|11 \div 225 = 6|16|39|47 \text{ is the rāśi of Ketu} \]

This is an example of implementation of Śatāṁśa in Bhāsvatī.

Implementation of Śatāṁśa had a significant role in predetermining solar and lunar eclipses. It is because (i) 2700 \( aṁśa \) is a very big number in comparison to 360 \( aṁśa \), (ii) assigning 100 \( aṁśa \) to each \( naksattra \) or constellation could avoid many error while taking fractions.

**Section-IV**

In this section we want to show the simplified method to calculate time from gnomonic shadow introduced in Bhāsvatī. Calculation of time from the Gnomonic (Śaṅku) Shadow explained in Bhāsvatī:

Example: Calculation of time on 15th June of this year, when the shadow of the 12 unit gnomon becomes 15 units.

Ans: Here the equinoxial day is 23rd March.

So number of days elapsed = 8 days of March + 30 days of April + 31 days of May + 15 days of June = 84 days

or 30 days Aries + 30 days Taurus + 24 days Gemini = 84 days

Now to calculate \( carārdha \ \text{litā} \)

for the month of Aries = 30+30/2 = 45

for the month of Taurus = 30+30/6 = 35

for the month of Gemini = 24/2 = 12

So \( carārdha \ \text{litā} = 45 + 35 + 12 = 92 = \text{Danda 1|32 linta on the day required} \)

\[ \text{Dinārdha} = 15 +1|32 = 16|32 \text{ đaṇḍa} \]

To calculate Madhya Prabhā

\[ Carārdha \ \text{litā} 92 \times 6 = 552/10 = 55|12 \]

552 - 55|12 = (496|48)/10 = 49|41
On 15th June Sun is in northern hemisphere. So the above number should be kept as it is.

Now 49|41 – Akṣa 44|43 =4|58 ----> Madhya prabhā

Here the gnomonic shadow or Iṣṭa chāyā =15|0 aṅgula X 10 =150 +100 = 250

250 – Madhya prabhā 4|58= 245|02 = 245 X 60 +2 = 14702 ----> Śaṅku

now Dinārdha 16|32 = 16 X60 +32 =992

992 X 100 =99200

99200/14702 = danda 6|45 litā

Now we have to convert it modern time.

danda 6|45 litā ~ 2 hours and 42 minutes

As we know in Indian astronomy day starts from the sunrise.

Dinārdha on 15th June is 16|32 ~ 6 hours and 22 minutes= 6\text{h} 22\text{m}

Midday at 87° longitude = 12\text{h} – 14\text{m} =11\text{h} 46\text{m}

11\text{h} 46\text{m} - 6\text{h} 22\text{m} =5\text{h} 24\text{m} ----> time of Sunrise

5\text{h} 24\text{m} + 2\text{h} 42\text{m} = 8\text{h} 06\text{m} ----> is the required time when the shadow of 12 aṅgula Śaṅku becomes 15 aṅgula.

Physical explanation to all terms and the method adopted:

To know time from the Gnomonic shadow there are to terms involved for the calculation.

(i) Madhya prabhā
(ii) Dinārdha danda

Again for the calculation of Madya prabhā and dinārdha danda we need to calculate Carārdha, Nadi and Nata. Nata has two parts, saumya nata and yamya nata.

The first step of this method is to decide whether the Sun is in northern or southern hemisphere. If Sun is in northern hemisphere then akhya has to be subtracted and will be added otherwise. It is because the author of Bhasvati acharya Satananda had made all calculations with reference to Puri, Odisha in northern hemisphere. Therefore when the Sun travels from northern to southern hemisphere it has to pass the equator the zero equinoxial gnomonic shadow line. Hence to consider the gnomonic shadow when Sun is in southern hemisphere a term akhya has to be added.

According to Bhasvati Sun lies in northern hemisphere i.e. the days elapsed from vernal equinox to autumnal equinox is 187 days (modern data 186 days) and from autumnal equinox to vernal equinox is 178 days (modern data 179 days).
In second step we have to calculate Carārdha (spreading). As we know day and night duration changes every day and it is not completely uniform. Therefore to take care of the changes in a day duration Carārdha has to be calculated. This method is an imperial method and Acharya Satananda claims that the method is completely of his own and he had not followed the advice from any previous scriptures. From madhya prabhā the midday gnomonic shadow for the day concerned can be derived. From the proportion of Madhya prabhā and Iṣṭa chāyā the time can be calculated.

Dinārdha danda can be calculated by adding or subtracting Carārdha lītā from the dinārdha danda on Mahāviṣuva saṅkrānti i.e. 15 danda depending upon when Sun is in northern or southern hemisphere respectively. Comparision table for Midday gnomonic shadow on all 12 sangkrantis are with modern data has been given below.

The length of the shadow of the gnomon should be recorded of the moment of which the time has to be calculated. This is known as iṣṭa chāyā.

\[
iṣṭa \text{ chāyā} \times 10 + 100 - \text{Madhya prabhā} = \text{Śaṅku} \quad \text{-------------(1)}
\]
(This Śaṅku is different from the gnomon itself)

Keep dinārdha (half day duration) of that day. Convert daṇḍa and litā into litā by multiplying 60 with danda and then adding litā. Now multiply litā pind with 100 and then divide it with the value of Śaṅku in equation (1). The result is the iṣṭa chāyā kāla (Time).

This time is of two types, Gata kāla: from morning upto noon and Eṣva kāla: from noon up to evening.

Madhya prabhā: To know Madhya prabhā the carārdha litā is necessary to be calculated.

Then multiply 6 with carārdha litā. Keep the result in two places. Subtract one tenth of it from the number in second places. If the Sun is in northern hemisphere then keep the number as it is, else add one third of the number with it. Again divide the number with 10. If the Sun is in southern hemisphere then akhya has to be added.

Carārdha: Śatānanda claimed in his scripture that this method of calculation of Carārdha is completely of his own.

According to him if Sun is in Aries (Meṣa), then the day count + the half of the day count is the carārdha lītā. If Sun is in Tarus (Vṛṣa) then Carārdha will be the carārdha lītā of Meṣa + number of days elapsed from Vṛṣa + one sixth of number of days elapsed from Vṛṣa.

Again if Sun is on Gemini (Mithuna), the half of the days elapsed from the month of Mithuna has to be added with the carārdha of the month Vṛṣa. The result is the carārdha lītā for the month of Gemini (Mithuna). The carārdha lītā for the month of Karkaṭa to Kanyā will decrease in the similar manner and on Kanyā Saṅkrānti it will be zero. Similar calculation has to be followed if the Sun is in southern hemisphere.

Dinārdha (Half day duration): The half day duration on Mahāviṣuva saṅkrānti is 15 daṇḍa. Calculate the carārdha lītā for the day concerned. add the carārdha lītā with 15 if Sun is in northern hemisphere.
and subtract if Sun is in southern hemisphere. The result is the required dinardha (half day duration) for the day concerned.

Table-3 Midday Gnomonic shadow on all 12 Sangkranti

| Sl No. | Declination of Sun (δ) in degrees | Right ascension of Sun (λ) in degrees | Midday gnomonic shadow from modern method | Midday gnomonic shadow from method in Bhāsvāti | Difference= Error in % |
|--------|----------------------------------|--------------------------------------|------------------------------------------|-----------------------------------------------|------------------------|
| 1      | 0.0                              | 0.0                                  | 4.3676                                   | 4.45                                          | 0.0824=0.69%           |
| 2      | 11.5008                          | 30.0                                 | 1.7933                                   | 1.9788                                        | 0.1855=1.55%           |
| 3      | 20.2017                          | 60.0                                 | 0.04225                                  | 0.098                                         | 0.0557=0.46%           |
| 4      | 23.5                             | 90.0                                 | -0.7339                                  | -0.658                                         | 0.0759=0.63%           |
| 5      | 20.2017                          | 120.0                                | -0.04225                                 | -0.037                                         | 0.0795=0.66%           |
| 6      | 11.5003                          | 150.0                                | 1.7933                                   | 1.739                                          | -0.543=0.45%           |
| 7      | 0.0                              | 180.0                                | 4.3676                                   | 4.45                                          | 0.082=0.69%            |
| 8      | -11.5004                         | 210.0                                | 7.3537                                   | 7.496                                          | 0.1423=1.19%           |
| 9      | -20.2017                         | 240.0                                | 10.1414                                  | 10.232                                         | 0.0906=0.75%           |
| 10     | -23.5                            | 270.0                                | 11.3875                                  | 11.24                                          | -0.1475=1.23%          |
| 11     | -20.2017                         | 300.0                                | 10.1414                                  | 10.148                                         | 0.0066=0.05%           |
| 12     | -11.5008                         | 330.0                                | 7.3537                                   | 7.595                                          | 0.2413=2.025%          |

Since Satananda has made calculation with respect to ahargana, so to have all calculation in same frame of reference I have adopted the data provided by NASA for my calculation. The old data table by NASA is given below, where March 21 has been taken as Mahabisuba Sangkranti or Mesha Sangkranti. In Bhāsvāti it is also mentioned that Sun lies in northern hemisphere for 187 days and 178 days in southern hemisphere, which is same as the NASA table.
Conclusion:

In this paper, the contribution of Śatānanda to the world of mathematics and astronomy has been discussed. Some of the Ślokas from his scripture Bhāsvatī has been translated to explain his achievements. It was necessary to prepare an accurate almanac for the Hindu society, mostly for the benefit of Jagannātha temple at Puruṣottama dhāma Puri. For this purpose he applied the observational data of Varāhamihira and took 450 C.E. the year when the scripture Pañcasiddhāntikā of Varāhamihira was written, as zero ayanāmaś year. Śatānanda started Śastrābda from the year he dedicated Bhāsvatī to the Society. All calculations in Bhāsvatī were in Śastrābda and he had given rules to convert Śastrābda to Śakābda and vice versa. Śatānanda has taken the latitude and longitude of Puri, Odisha as his reference point. May be it was easy for him to recheck his methods from the observation at his native place.

The most interesting thing found in Bhāsvatī is that Śatānanda could calculate the position and rate of motion of heavenly bodies quite accurately without using trigonometric functions. Though some ancient astronomer had rejected the methodology by saying the method to be an approximate method, it is interesting to see that an approximate method could conclude with an exact solution of predetermining the eclipse. Use of Śatāmāśa (Centesimal system) in the procedure and making a back transform is quite modern idea adopted by Śatānanda. A strong claim exists that the conversion of the sexagecimal system to the centesimal system is the first step that led mathematicians towards the introduction of decimal system in mathematical calculations[1]. It is necessary to study the physical and mathematical interpretation of all 128 ślokas in Bhāsvatī.

A detail study is in progress to establish the relation among the method in Bhāsvatī and modern European method to predetermine eclipse.

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Appendix A: Method of calculation of sidereal period of Moon

Step-1. Multiply 90 with ahargana and add Chandra Dhruba with it. Divide the result with 2457.

Step-2. Multiply 100 with ahargana and add Kendra dhruba with it. Divide the result with 2756.

Step-3. Divide ahargana with 120 and add the remainder of step 1. The carardha of the respective month has to be subtracted from the result. (carardha for different months are given below.)

Step-4. Divide ahargana with 50 and add the reminder of step-2. Then divide the result with 100.

Step-5. From the quotient the corresponding Khanda and Anukhanda (khanda +1) has to get from khanda table given below. Subtract Khanda from Anukhanda, the result is Chandra bhoga. Reminder from step-4 has to be multiplied by Chandra bhoga. Divide the result with 100. The result has to be added with khanda and the result of Step-3. The result is Chandra Sphuta.

In the similar manner Chandra sphuta for the next day (ahargan) has to be calculated. The positional difference of the day is called Chandra bhukti (moon’s durinal motion). This motion is not uniform. Therefore for the sidereal calculation I have kept on increasing the ahargana until moon’s comes to the same position (Chandra Sphuta)

Table for Carardha has to be subtracted in different months

| Name of Sidereal Month | Carardha | Name of Sidereal Month |
|------------------------|----------|------------------------|
| Aries                  | 0        | Pisces                 |
| Taurus                 | 1        | Aquarius               |
| Gemini                 | 2        | Capricorn              |
| Cancer                 | 2        | Sagittarius            |
| Leo                    | 1        | Scorpio                |
| Virgo                  | 0        | Libra                  |

Table: Chandra Khanda-difference (antara) – Bhukti bodhaka Chakra

| 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | Number |
|----|----|----|----|----|----|----|----|----|--------|
| 0  | 0  | 1  | 3  | 6  | 10 | 16 | 24 | 35 | Khanda |
| 0  | 1  | 2  | 3  | 4  | 6  | 8  | 11 | 11 | difference |
| 9  | 10 | 11 | 12 | 13 | 14 | 15 | 15 | 17 | Number |
| 46 | 60 | 75 | 91 | 108| 126| 143| 159| 175| Khanda |
| 14 | 15 | 16 | 17 | 18 | 17 | 16 | 16 | 15 | Difference |

| 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | Number |
|----|----|----|----|----|----|----|----|----|--------|
Appendix B: Method of calculation for midday gnomonic shadow in different Sangkrantis

NASA table for different Sangranti

1. On March 21, Sun lies on the equator. So we take Sun’s position in $0^\circ$. Aries
   So the gnomonic shadow will be 4.45.

2. On April 21, Taurus = $30^\circ$ = ahargana = 31 = 30 +1

According to Bhāsvatī the pala prabha (equinoxial midday gnomonic shadow) is 4|27 =4.45
This is little higher than that of modern data. i.e. 4.37 +0.08
\[ \text{carārdha litā} = 45 + 1 + 1/6 = 46.17 \]

\[ 46.17 \times 6 = 277.02 - 27.70 = 249.32 / 10 = 24.932 \]

\text{madhy prabhā} = 44.72 - 24.932 = 19.788

\text{ista chaya} = 19.788 / 10 = 1.9788

3. May 22, Gemini : \(60^\circ\) = ahargana 62 = 30 + 30 + 2

\[ \text{carārdha litā} = 45 + 35 + 1 = 81 \]

\[ 81 \times 6 = 486 - 486 / 10 = 437.4 / 10 = 43.74 \]

\text{madhy prabhā} = 44.72 - 43.74 = 0.98

\text{ista chaya} = 0.98 / 10 = 0.098

4. June 22, Cancer : \(90^\circ\) = ahargana 93 = 30 + 30 + 33

\[ \text{carārdha litā} = 45 + 35 + 33 / 2 = 96.5 \]

\[ 96.5 \times 6 = 579 - 57.9 = 521.1 / 10 = 52.11 \]

\text{madhy prabhā} = 44.72 - 52.11 = - 7.39

\text{ista chaya} = - 7.39 / 10 = 0.739

5. July 23, Leo : \(120^\circ\) = ahargana 124

(In this case there is little change in procedure. It has been mentioned that sun lies 187 days in northern hemisphere and 178 days in southern hemisphere. So when ahargana exceeds half of the days in a hemisphere then we have to take the smaller part for \text{carārdha litā} calculation. i.e.

\[ 187 - 124 = 63. \]

So we have to calculate the \text{carārdha litā} of 63 ahargana.)

\[ 63 = 30 + 30 + 3 \]

\[ \text{carārdha litā} = 45 + 35 + 3 / 2 = 81.5 \]

\[ 81.5 \times 6 = 501 - 50.1 = 450.9 / 10 = 45.09 \]
madhy $prabhā = 44.72 - 45.09 = -0.37$

ista chaya = -0.37/10 = -0.037

6. Aug 22, Virgo: $150° = ahargana 154 = 187 - 154 = 33 = 30 + 3$

   $carārdha litā = 45 + 3 + 3/6 = 48.5$

   $48.5 \times 6 = 291 - 29.1 = 261.9/10 = 26.19$

madhy $prabhā = 44.72 - 26.19 = 18.53$

ista chaya = 18.53/10 = 1.853

7. Sept 24, Libra: $180° = ahargana 187$

Shadow length = 4.45

8. Oct 22, Scorpio: $210° = ahargana 215$

   $215 - 187 = (southern hemisphere) = 28$

   $carārdha litā = 28 + 14 = 42$

   (there is little change in procedure for southern hemisphere)

   $42 \times 6 = 252 - 25.2 = 226.8 + 226.8/3 = 302.4/10 = 30.24$

madhy $prabhā = 44.72 + 30.24 = 74.96$

ista chaya = 74.96/10 = 7.496

9. Nov 23, Sagittarius: $240° = ahargana 247$

   $247 - 187 = 60$

   $carārdha litā = 45 + 35 = 80$

   $80 \times 6 = 480 - 48 = 432 + 432/3 = 576/10 = 57.6$

madhy $prabhā = 44.72 + 57.6 = 102.32$

ista chaya = 102.32/10 = 10.232

10. Dec. 23, Capricorn: $270° = ahargana 277$
277-187 = 90

southern hemisphere 178 -90 = 88

We have to calculate carārdha litā of the smaller part.

So carārdha litā of 88 = 45 + 35 + 14 = 94

94 X 6 = 564 - 56.4 = 507.6 + 507.6/3 = 676.8/10 = 67.68

madhy prabhā= 44.72 + 67.68 = 112.4

ista chaya = 112.4/10 = 11.24

11. Jan 21, Aquarius : 300° = ahargana 306

306 – 187 = 119

178 – 119 = 59

59 = 45 + 29 + 29/6 = 78.83

78.83 x 6 = 473 - 47.3 = 425.7 + 425.7/3 = 567.6/10 = 56.76

madhy prabhā= 44.72 + 56.76 = 101.48

ista chaya = 101.48/10 = 10.148

12. Feb 20, Pisces : 330° = ahargana 336

336 - 187 = 149

178 – 149 = 29

29 + 29/2 = 43.5

43.5 x 6 = 261 - 26.1 = 234.9 + 234.9/3 = 312.3/10 = 31.23

madhy prabhā= 44.72 + 31.23 = 75.95

Ista chaya = 75.95/10 = 7.595