ISSN 0976-559X

वागीश्वरी

संस्कृतविभागीया विज्ञ-वीक्षिता बहुभाषिकी वार्षिकी शोधपत्री

संख्या -१८

VĀGĪŚVARĪ

Peer Reviewed Multilingual Annual Research Journal

Volume : XVIII

DEPARTMENT OF SANSKRIT
ASSAM UNIVERSITY, SILCHAR
2024

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Department of Sanskrit
Assam University
Silchar-788011

Publisher
Department of Sanskrit
Assam University, Silchar

Published
June, 2024

Printed at
Avishek Printers & Publishers
Ambicapatty, Silchar-788004

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Converting a Square into a Circle of Equal Area According to the Baudhāyana Śulvasūtras

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Abstract:

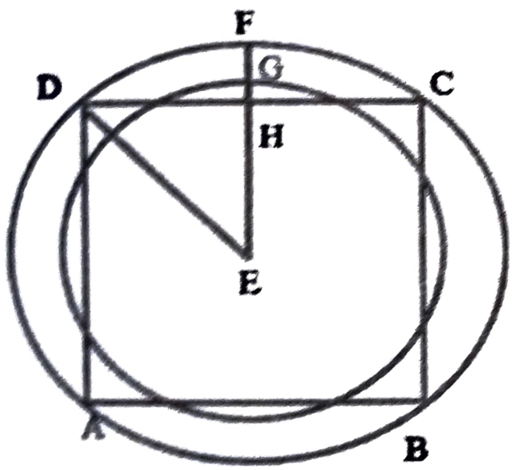
The Śulvasūtras are an important part of the Kalpa Vedāṅga, which are the storehouse of information on the construction and measurements of various sacrificial fire altars, maṇḍapas and citis. The sacrificial fire altars are of different shapes and sizes but have the same area. The authors of the Śulvasūtras had to take utmost care for the correct size and shape of the fire altars because even the slightest irregularity and inconsistency in the shape and size of the fire altars would destroy the purpose of the entire ritual and could have adverse effects. Consequently, they got involved in mathematics and Architectural design. For the construction of fire altars they provided an innovative method of converting a square into a circle, which is approximately accurate, the area of the transformed circle is less by 0.00001. Even modern mathematicians have not been able to solve this problem or calculate it with absolute accuracy, the area of the transformed circle exceeds by 0.06898. It is a remarkable achievement that the people of the Vedic age knew this method with great precision.

Introduction:

The Śulvasūtras are the repository of information on the construction and measurements of various sacrificial fire altars, maṇḍapas and citis. These sacrificial fire altars are required as per the requirements of the sacrifices. It is said that even the slightest irregularity and inconsistency in the size and shape of the fire altars will destroy the purpose of the whole ritual and may have an adverse effect. Therefore utmost care was to be taken for the correct size and shape of the fire altars. Consequently, the Śulvasūtras got involved in Mathematical calculations, Geometric speculations, and Architectural designs. Therefore, the authors of Śulvasūtras have developed and gifted the world with some innovative formulas and methods of Mathematics, especially in geometry. This paper analytically discusses the method of transforming a square into a circle of equal area.

The early history of converting a square into a circle or vice versa dates back to the time of Saṁhitā and Brāhmaṇ period. That was in connection with the construction of three primary essential sacrificial altars namely, Gārhapatya, Āhavaniya, and Dakṣhināgni altars. These three altars have the same areas but different shapes, the first altar is circular, the second altar is square and the last altar is semicircular. However, it is not clear how to convert one square into a circle in the Saṁhitā and Brāhmaṇ texts.

In the Śulvasūtra period all the authors of Śulvasūtras have discussed this transformation method almost in similar terms. For this transformation Kātyāyana Śulvasūtra gives the following method- "चतुरस्रं मण्डलं चिकीर्षन्मध्यादंसे निपात्य पार्श्वतः परिलिख्य तत्र यदतिरिक्तं भवति तस्य तृतीयेन सह मण्डलं परिलिखेत् स समाधिः।"[1] Similarly, Āpastamba Śulvasūtra describes method stated as-"चतुरश्रं मण्डलं चिकीर्षन् मध्यात्कोट्यां निपातयेत् । पार्श्वतः परिकृष्यातिशयतृतीयेन सह मण्डलं परिलिखेत्। सा नित्या मण्डलम्। यावद् धीयते तावदागन्तु॥"[2] Baudhāyana Śulvasūtra describes methods of Converting a Square into a Circle of Equal Area as – "चतुरस्रं मण्डलं चिकीर्षन्नक्ष्णयार्धं मध्यात्प्राचीमभ्यापातयेद्यदतिशिष्यते तस्य सहतृतीयेन मण्डलं परिलिखेत्".[3] In this method Baudhāyana suggests that to transform a square into a circle draw half of the cord stretched in the diagonal from the centre towards the east (prācī-line). Describe the circle together with the third part of that piece of the cord which stands over (take for radius of the circle the whole piece of the cord which lies inside the square plus the third part of the piece which lies outside). Mānava Śulvasūtra[4] also defined the same propositions almost in similar words.



Let ABCD be the given square that has to be transformed into a circle, whose area will be equal to the given square. Let E be the centre point of the square. Join DE. The half diagonal DE is drawn over the east-west line EF, such that DE = EF. Now H is the midpoint of DC, divide HF at G such that GH = $\frac{1}{3}$ of HF. Then with centre E and radius EG describe a circle. This is the required transformed circle, whose area will be approximately equal to that of the given square ABCD.

Proof

Let x be the length of each side of the square ABCD and r is the radius of the required circle.

i.e, DC = x, DH = EH = $\frac{x}{2}$, and EG = r.

Then, $(ED)^2 = (EH)^2 + (DH)^2$

$$ED = \sqrt{(EH)^2 + (DH)^2}$$
$$= \sqrt{(\frac{x}{2})^2 + (\frac{x}{2})^2}$$
$$= \frac{1}{2}x\sqrt{2}$$

Now, $$EG = EH + HG$$
$$r = EH + \frac{1}{3}\ HF$$
$$= EH + \frac{1}{3}\ (EF - EH)$$
$$= \frac{x}{2} + \frac{1}{3}\left(ED - \frac{x}{2}\right)$$
$$= \frac{x}{2} + \frac{1}{3}\left(\frac{1}{2}x\sqrt{2} - \frac{x}{2}\right)$$
$$= \frac{x}{2} + \frac{1}{6}x\left(\sqrt{2} - 1\right)$$
$$= x + \frac{1}{3}\ x\left(\sqrt{2} - 1\right)$$
$$= \frac{x[3 + \sqrt{2} - 1]}{3}$$
$$= \frac{x}{3}\ (2 + \sqrt{2})$$

According to Baudhāyana Śulvasūtra[5] the value of $\sqrt{2}$ is –

$$\sqrt{2} = 1 + \frac{1}{3} + \frac{1}{3 \times 4} - \frac{1}{3 \times 4 \times 34}$$
$$= \frac{577}{408}$$
$$= 1.41421.....$$

Therefore,

$$r = \frac{x}{3}\ (2 + 1.41421\ )$$
$$= x\,\frac{3.41421}{3}$$
$$= x \times 1.13807$$

If we suppose,

The area of the transformed circle = area of the square

$$\pi r^2 = 4x^2$$

$$\pi x^2(1.13807)^2 = 4x^2$$

$$\pi = \frac{4x^2}{x^2(1.13807)^2}$$

$$\pi = \frac{4}{1.29520}$$

$$\pi = 3.08832$$

Now, the area of the transformed circle $= \pi r^2$

$$= 3.08832 \times x^2 \times (1.13807)^2$$

$$= 3.08832 \times x^2 \times 1.29520$$

$$= 3.99999x^2$$

The area of the square $= 4x^2$

So, the area of the transformed circle is less by $0.00001x^2$.

If we take the modern value of π, i.e., $\pi = 3.14159$.

Then,

The area of the transformed circle $= \pi r^2$

$$= 3.14159 \times x^2 \times (1.13807)^2$$

$$= 3.14159 \times x^2 \times 1.29520$$

$$= 4.06898x^2$$

So, the area of the transformed circle exceeds by $0.06898x^2$

Hence, from the above calculations, it is clear that the method prepared by Baudhāyana is almost accurate. Even modern mathematicians could not solve this problem. Recently it has been proven that transforming a square into a circle of equal area is a problem that has not yet been solved. It is a remarkable achievement that the people of India knew this method with great accuracy thousands of years ago.

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1 KŚS- 3.13

2 ĀŚS- 3.2-5

3 BŚS- I.58

4 मण्डलविष्कम्भसमस्त्रिभुजादवलम्बकश्चतुःस्रक्तिः प्रागायतात् त्रिभागात् कर्णात् स मण्डलं भवति।, MŚS- 10.3.2.10;
चतुरस्रं नवधा कुर्याद् धनुः कोट्यास्त्रिधात्रिधा ।
उत्सेधात्पञ्चमं लुम्पेत्पुरीषेणेह तावत्समम् ॥ MŚS- 10.3.2.15

5 प्रमाणं तृतीयेन वर्धयेत्तच्च चतुर्थेनात्मचतुस्त्रिंशोनेन, सविशेषः ।, BŚS- I.61-62

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