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MATHEMATICS

SETTING CONDITIONS FOR AN EFFECTIVE COVERING OF A CIRCLE AREA BY THE EQUILATERAL TRIANGLE AREA WITH A COMMON CENTER

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Abstract

The question of an optimal and extreme (minimum) covering of one plane figure area, namely, an equilateral triangle by the area of the other plane figure, precisely, a circle with a common center of the indicated figures is investigated in the article. The value of some function, which determines the difference of the areas in which the figures do not coincide is obtained. The extremum of the function is investigated, two extrema of this function are determined in the area of its definition. It is shown that at one of these points the function acquires the minimum and at the other maximum values. The conditions of such extreme covering of one area by the other one have been established, the drawings for the statement and the solution of the task have been given and conclusions have been drawn.

Keywords: the area of a circle and its parts, the area of an equilateral triangle and its parts, extremity (minimum and maximum) of function with variable one.

Introduction. The problem of an effective extreme (minimum and maximum) covering of one plane geometric figure by another one [1-9], in particular, covering the area of another geometry such as an equilateral triangle by the area of a circle (Fig.1).

As the main criterion for such an effective covering, it is logically proposed to choose such an indicator as the value of the extreme area, in which the geometric figures do not coincide [1,2,6]. The study of this article is devoted to the setting of such extreme values of a particular argument within the scope of defining a function corresponding to the outlined area, in which these figures do not coincide.

Analysis of literary sources. The research and studies of extreme values of certain mathematical functions of one or more variables, determined by the conditions of specific practical problems are devoted to scientific works [2-6], these researches are offered in engineering, in energy [7] and research works in economics [8]. The results of this work are a logical continuation of the research conducted by the author [1], in which the optimal relative position of given geometric figures is considered. The overall area, over which these figures do not coincide, is optimized.

The purpose of research. The main purpose of the studies carried out with the help of the differential calculus apparatus is to establish certain geometric conditions under which the total area over which the area of a circle does not coincide with the area of an equilateral triangle with a common center.

Research results. Suppose that we have an equilateral triangle ABC with side a whose area is covered by another area, namely, the area of the circle of radius r with the common center of these two figures (Fig. 1).

Suppose that we have an equilateral triangle ABC with side a , whose area is covered by another area, namely, the area of the circle of radius r with the common center of these two figures (Fig. 1).

We have $OH = OT = OP = r$, $AB = AC = BC = a$. The points H, T, P can vary depending on the change in the radius of the circle itself or on the change of the length of the side of an equilateral triangle. Therefore, the angle β , which is the angle between the OR catheter and the hypotenuse OH of the right-angled triangle ORN, will also be a variable. The limits from which the specified angle β can be changed, namely: $0 < \beta < 60^\circ$, are obvious from (Fig.1), since the angle $\angle ROH = 60^\circ$.

In the entered notation there are obvious trigonometric ratios:

$$\cos \beta = \frac{a\sqrt{3}}{6r} \Rightarrow \frac{a}{r} = \frac{6}{\sqrt{3}} \cos \beta = 2\sqrt{3} \cos \beta. \quad (1)$$

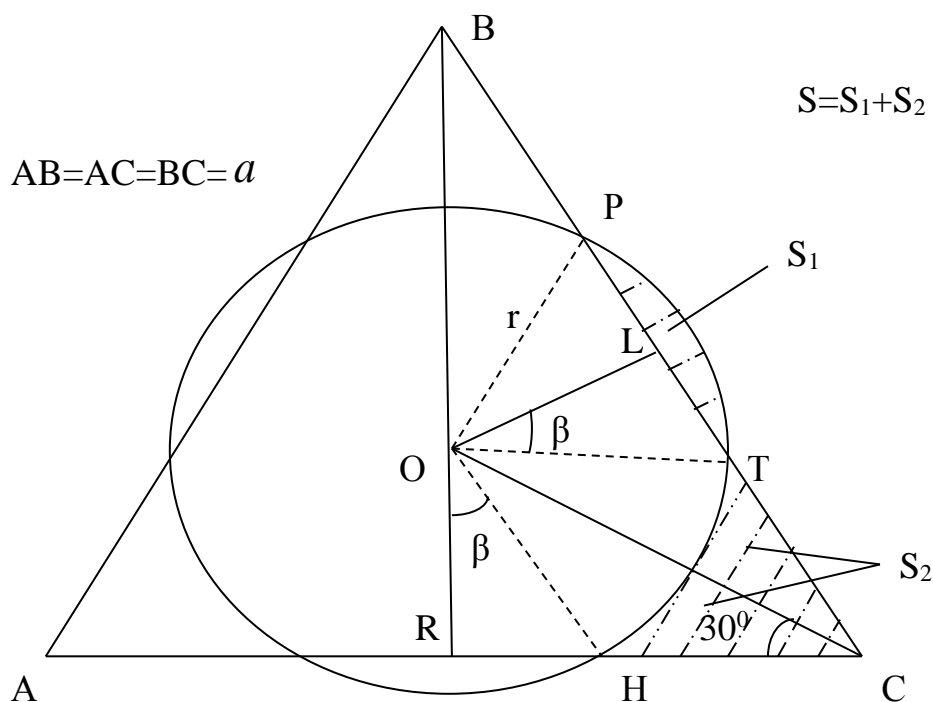


Fig. 1. Equilateral triangle ABC with side a , whose area is covered by the area of the circle of radius r with common center.

As part of the area on which the geometric figures do not coincide, as shown in (Fig.1), we take the area $S = S_1 + S_2$. Then, obviously, the total area over which the figures do not coincide will be $3S$. For the components of the additions of the required area using the appropriate geometric formulas we have the following equations:

$$S_1 = \frac{1}{2} r^2 (2\beta) - \frac{1}{2} OL \cdot TP = r^2 \beta - \frac{a\sqrt{3}}{12} (a - 4r \sin(60^\circ - \beta)). \quad (2)$$

$$S_2 = 2\left(\frac{1}{2} OC \cdot HC \sin 30^\circ - \frac{1}{2} r^2 \left(\frac{\pi}{3} - \beta\right)\right) = \frac{2\sqrt{3}}{3} ar \sin(60^\circ - \beta) - r^2 \frac{\pi}{3} + r^2 \beta. \quad (3)$$

Thus, the total area becomes significant

$$S = S_1 + S_2 = r^2 \beta - \frac{a\sqrt{3}}{12} (a - 4r \sin(60^\circ - \beta)) + \frac{2\sqrt{3}}{3} ar \sin(60^\circ - \beta) - r^2 \frac{\pi}{3} + r^2 \beta =$$

$$2r^2 \beta - \frac{a^2 \sqrt{3}}{12} + \sqrt{3} ar \sin(60^\circ - \beta) - r^2 \frac{\pi}{3}. \quad (4)$$

Conducting in the last equality identical algebraic transformations using relation (1), we obtain the final form of the function of the variable area S using the formula (5), which is definitive for further study:

$$S = r^2 \left(2\beta - \frac{\sqrt{3}}{12} \left(\frac{a}{r}\right)^2 + \sqrt{3} \frac{a}{r} \sin(60^\circ - \beta) - \frac{\pi}{3}\right) = r^2 \left(2\beta - \frac{\sqrt{3}}{12} (2\sqrt{3} \cos \beta)^2 + \right.$$

$$\left. \sqrt{3} \cdot (2\sqrt{3} \cos \beta) \sin(60^\circ - \beta) - \frac{\pi}{3}\right) = r^2 \left(2\beta + \sqrt{3} - \frac{\pi}{3} + \sqrt{3} \cos 2\beta - \frac{3}{2} \sin 2\beta\right). \quad (5)$$

In this last relation (5) we have a record of a function S dependent on the variable argument β . Thus, it remains to investigate for the existence of extreme values the obtained function.

Therefore, we first find the value of the first derivative of the function obtained by its argument β and equate the value of this derivative to zero:

$$S'_\beta = r^2 (2 - 2\sqrt{3} \sin 2\beta - 3 \cos 2\beta) = 0. \quad (6)$$

From the obtained equation (6) we have the following equality with respect to the unknown argument β :

$$4\sqrt{3} \sin \beta \cos \beta + 3 \cos^2 \beta - 3 \sin^2 \beta - 2 \sin^2 \beta - 2 \cos^2 \beta = 0. \quad (7)$$

Using known trigonometric transformations, equality (7) is transformed into the following:

$$5 \operatorname{tg}^2 \beta - 4\sqrt{3} \operatorname{tg} \beta - 1 = 0 \quad (8)$$

Solve the obtained quadratic equation with respect to:

Then we have unknown solutions of equation (8) are as follows:

$$(\operatorname{tg} \beta)_1 = \frac{\sqrt{17} - 2\sqrt{3}}{5},$$

$$(\operatorname{tg} \beta)_2 = \frac{\sqrt{17} + 2\sqrt{3}}{5}.$$

Since $\operatorname{tg} 60^\circ = \sqrt{3} \approx 1,73$, therefore, both values will be within the range of possible values of β .

The nature of the possible extreme values of the angle β is found by finding and investigating the second derivative of S . We have:

$$S''_{\beta\beta} = r^2 (-4\sqrt{3} \cos 2\beta + 6 \sin 2\beta) = r^2 (12 \sin \beta \cos \beta - 4\sqrt{3} \cos^2 \beta + 4\sqrt{3} \sin^2 \beta) =$$

$$= \frac{r^2}{\cos^2 \beta} (\sqrt{3} \operatorname{tg}^2 \beta + 3 \operatorname{tg} \beta - \sqrt{3}). \quad (9)$$

Find the signs of the second-order derivative at both points $\beta_{1,2}$ of the possible extremum of the function under study:

$$S''_{\beta\beta}((\operatorname{tg} \beta)_1) = \frac{4r^2}{\cos^2 \beta} \left(\sqrt{3} \left(\frac{\sqrt{17} - 2\sqrt{3}}{5} \right)^2 + 3 \left(\frac{\sqrt{17} - 2\sqrt{3}}{5} \right) - \sqrt{3} \right) < 0, \quad (10.1)$$

$$S''_{\beta\beta}((\operatorname{tg} \beta)_2) = \frac{4r^2}{\cos^2 \beta} \left(\sqrt{3} \left(\frac{\sqrt{17} + 2\sqrt{3}}{5} \right)^2 + 3 \left(\frac{\sqrt{17} + 2\sqrt{3}}{5} \right) - \sqrt{3} \right) > 0. \quad (10.2)$$

Since the value of the second derivative of function S at point β_1 becomes negative, therefore, at this point, the function S takes the smallest of its possible values, at the point β_2 , the second derivative is positive, so at this point the function S takes the largest of its possible values (Fig. 2). Note that $0 < \beta_{1,2} < 60^\circ$.

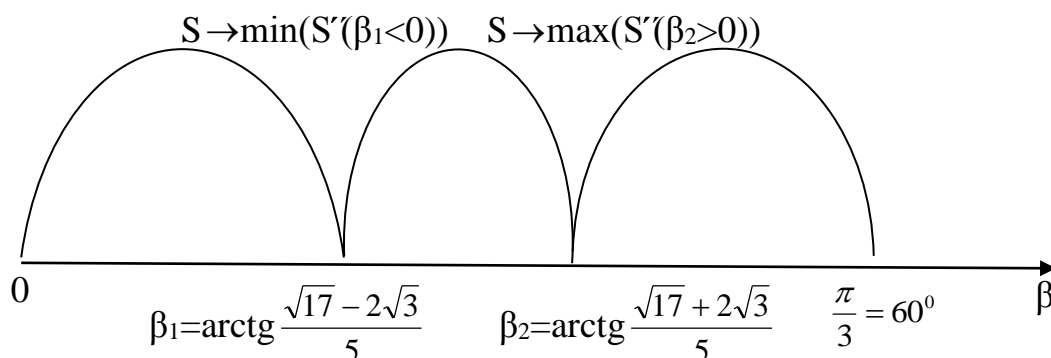


Fig.2. Investigation of the extreme values character of the angle β by the results of the second derivative of S .

Setting the ratio of the parameters of the geometric characteristics of the side of an equilateral triangle a and the radius of the circle r , this ratio at each of the extremal points will be as follows:

$$\frac{a}{r} = 2\sqrt{3} \cos \beta \Big|_{\beta=\beta_1} = \frac{2\sqrt{3}}{\cos \beta_1} = \frac{2\sqrt{3}}{\sqrt{1 + \left(\frac{\sqrt{17} - 2\sqrt{3}}{5}\right)^2}} \quad (11.1)$$

with $S \rightarrow \min$, and the ratio

$$\frac{a}{r} = 2\sqrt{3} \cos \beta \Big|_{\beta=\beta_2} = \frac{2\sqrt{3}}{\cos \beta_2} = \frac{2\sqrt{3}}{\sqrt{1 + \left(\frac{\sqrt{17} + 2\sqrt{3}}{5}\right)^2}} \quad (11.2)$$

with $S \rightarrow \max$.

The total cumulative area over which the figures discussed in this paper will not be three times larger. To set the numerical values of the smallest and largest such areas, respectively, in each of the extreme values of the angle β for simplifications, we introduce the following notation:

$$N_1 = \frac{\sqrt{17} - 2\sqrt{3}}{5}, \quad N_2 = \frac{\sqrt{17} + 2\sqrt{3}}{5}.$$

Then according to the angle $\beta = \beta_1$ using equality (11.1) we have:

$$\cos \beta_1 = \frac{1}{\sqrt{1 + N_1^2}}, \quad \sin \beta_1 = \frac{N_1}{\sqrt{1 + N_1^2}},$$

and then the total smallest area with the result (5) takes the form:

$$\begin{aligned} S_{\min} = 3S(\beta_1) &= 3r^2 \left(2\arctg N_1 + \sqrt{3} - \frac{\pi}{3} + \sqrt{3} \left(\frac{1}{1 + N_1^2} - \frac{2N_1}{1 + N_1^2} \right) - \frac{3}{2} \cdot 2 \frac{N_1}{\sqrt{1 + N_1^2}} \cdot \right. \\ &\left. \cdot \frac{1}{\sqrt{1 + N_1^2}} \right) = 3r^2 \left(2\arctg N_1 + \sqrt{3} - \frac{\pi}{3} + \frac{\sqrt{3}}{1 + N_1^2} - (3 + 2\sqrt{3}) \frac{N_1}{1 + N_1^2} \right). \end{aligned} \quad (12)$$

Similarly, when $\beta = \beta_2$ and

$$\cos \beta_2 = \frac{1}{\sqrt{1 + N_2^2}}, \quad \sin \beta_2 = \frac{N_2}{\sqrt{1 + N_2^2}},$$

then we have the total, taking into account the result (5), the largest area:

$$\begin{aligned} S_{\max} = 3S(\beta_2) &= 3r^2 \left(2\arctg N_2 + \sqrt{3} - \frac{\pi}{3} + \sqrt{3} \left(\frac{1}{1 + N_2^2} - \frac{2N_2}{1 + N_2^2} \right) - \frac{3}{2} \cdot 2 \frac{N_2}{\sqrt{1 + N_2^2}} \cdot \right. \\ &\left. \cdot \frac{1}{\sqrt{1 + N_2^2}} \right) = 3r^2 \left(2\arctg N_2 + \sqrt{3} - \frac{\pi}{3} + \frac{\sqrt{3}}{1 + N_2^2} - (3 + 2\sqrt{3}) \frac{N_2}{1 + N_2^2} \right). \end{aligned} \quad (13)$$

Using equality (1), we can write equality (12) and (13) in equivalent form by applying the length of side a of an equilateral triangle (these relations are not given).

Conclusions. The article deals with the question of setting conditions of the formation of extreme values of the area, in which geometrical figures such as a circle and an equilateral triangle with the center common to these figures do not coincide. The values of the ratio of

the side length of an equilateral triangle to the magnitude of the radius of the circle (formulas 11.1 and 11.2) have been obtained as the main result of the studies, which respectively formed the minimum or maximum value of the specified area.

The results of the researches on finding the conditions of extreme difference of the covering area of one plane geometric figure, such as the area of an equilat-

eral triangle by the circle area, can be reflected and applied in various systems of technical vision, navigation and correlation systems, problems of extreme effective use of agricultural areas, etc.

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