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Theoretical Basis of the Principle of Roundness Ensuring Under Centreless Machining of Large Capacity Parts.

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ABSTRACT

This paper deals with a theoretical basis of a possible principle of the roundness of a large capacity part, such as a bandage of the rotary kiln without its centerless handling using an attached machine with the floating caliper with the cutting tool . Moreover, one can use an edge or abrasive tool as a cutting tool. The principle described in this article enables to handle the roll surface of large capacity parts without dismantling and stoppage of the device , which allows to have a considerable saving of means and strength and reduce downtime of machienery because of their repair. In the process of theoretical calculations it was formulated a theorem of sliding of conjugate tangents in a closed loop , constantly changing the shape , as well as it is shown the version of its decision in the form of block diagrams of PC programs . In conclusion, it is given the advantages of algorithms presented and described a potential applicability for analysis capabilities in order to ensure the accurate shapes of the various parts.

Keywords: large capacity rotating parts, machining, precision-shaped, cross-grinding, turning operation, the theory of cutting, bandage, rotary cement kiln, belt grinding, restoration, surface renovation , basis, processing errors, deviation from roundness, controlled cutting, the algorithm ,program block- diagram.

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INTRODUCTION

The peculiarity of handling of large capacity parts with an uncertain rotation axis: bandages rotating cement kilns (BRCK), dryers, drums, mills pins, shafts when being mounted on the rollers and others is the absence of the basis of the axial rotation of components [1, 2, 3]. In this context, engineers and scientists prefer the principle of the controlled cutting [4-7] , which is based on the continuous change of the position of the cutting edge of the cutting tool relative to the workpiece to ensure its relative motion on the path which resembles a perfect circle. This approach can be implemented either by using more expensive CNC with the preliminary surface measurement [8, 9] or by using adaptive mechanical or hydraulic devices [10]. On the contrary in the paper [11] it is offered the creation of some "virtual" technological base in the form of a special base in the form of a strictly concentric cylindrical groove. Basing of a movable working machine body along such a groove allows to handle the surface with sufficient accuracy, despite the uncertainty of the rotation axis of the part itself. The main part. Let's consider the possibility of providing a circularity of the surfaceof the bandage rolling without dismantling. The trajectory of the cutter when doing the basic groove will be a helix (Fig. 1) with a constant or variable pitch depending on the specific processing conditions. The position of the floating caliper 2 can be represented in a formalized manner based on the obvious geometric fact: through three points on a plane lying on one plane one can draw a single circle of a definite radius. However, if the contour of the workpiece 1 is defined by a set of points, then bringing it to a strictly predetermined diameter with high requirements to its roundness requires a special proving.

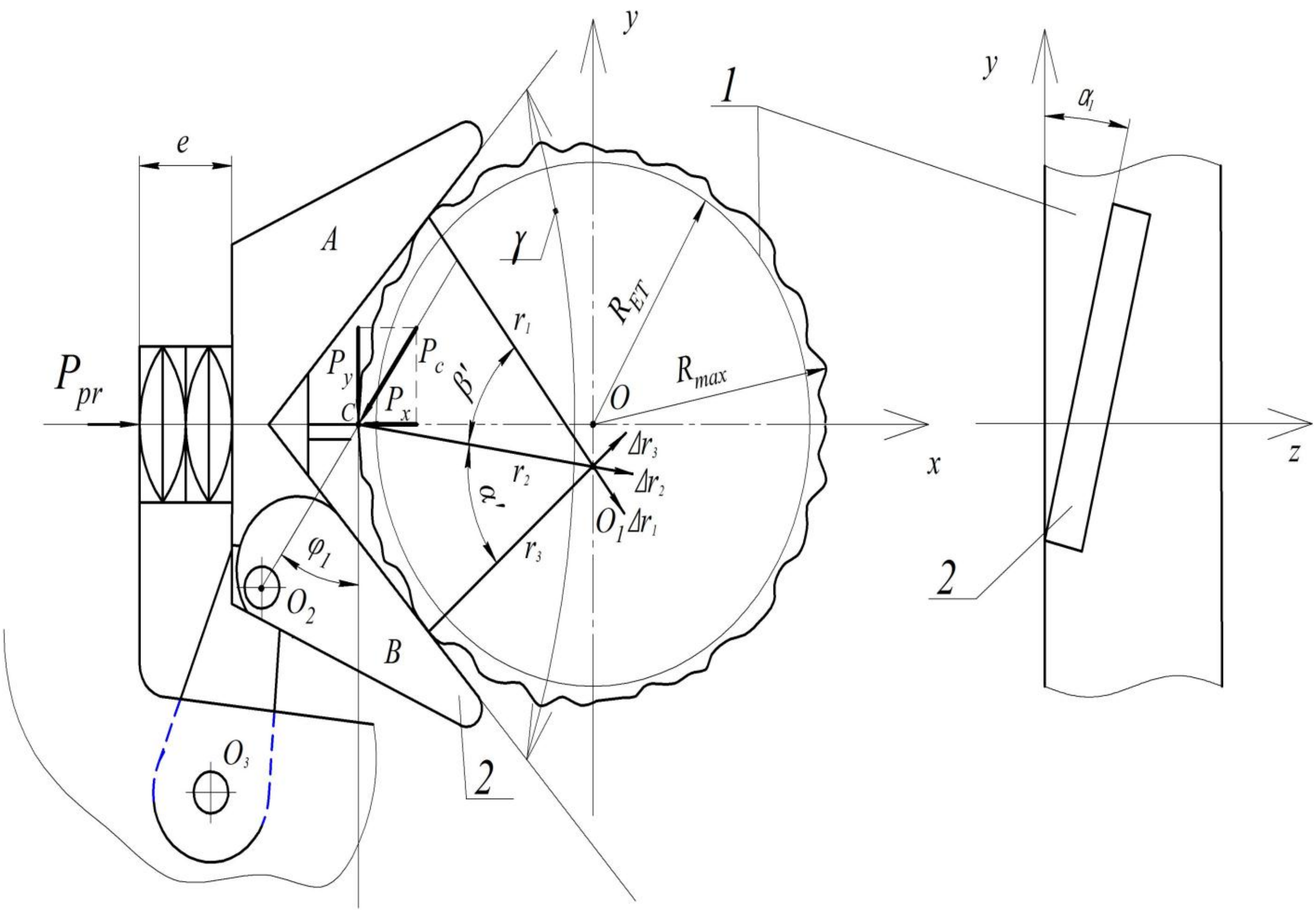

Figure 1. Schematic diagram of the floating caliper

It is obviously, that the instantaneous trajectory of the top of the cutter is a circle with a radius and the coordinates of the rotation center corresponding to a given time. In this case, the entire process of the handling, as the elimination of deviations from the circularity, one can imagine by a variety of instant random

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floating circles so that adjacent and inscribed circles will be the two extreme diameters of the handling. The centers of the extreme circles will not match in most cases, as shown in Fig. 2.

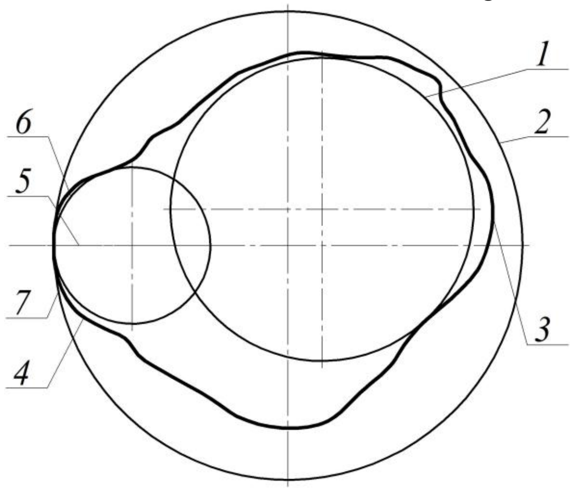

Figure 2: The position of the initial contour between the two extreme diameters of the handling: 1 – the inscribed adjacent circle; 2 – the described adjacent circle; 3 - the original contour; 4 - one of the instant circles under processing of the contour at 5; 6 and 7 - the points of contact of the floating caliper.

In fact, the trajectory of the cutter movement can be considered as an oscillatory damped motion, see Fig. 3. The cutter feed motion in a floating caliper leads to the fact that processing is carried out, starting with the points having the maximum curvature, which corresponds to the instantaneous circles certain minimum radius which is set by the cutter inlet to the initial contour of the workpiece.

The basis of the scheme (see Fig. 1) is the property of conjugated tangents. The tool is mounted on two fixed interconnected stripes which form the prism sliding along the surface being treated. According to this scheme, the surface being treated is also the base that corresponds to centerless treatment. Functional rotation of the machine or a standard drive is commonly used as the main motion. During rotation allowance for the most projecting portion of the workpiece is removed for one turn. During the next turn support rails slide along a new, more smooth contour. Therefore, from turn to turn circular accuracy of the workpiece will improve. If the processing is performed with a continuous cross- feed motion, for example, during the treatment of narrow ledges or corbels , the support bar sliding occurs along continuously changing contour and the improvement of roundness is also going on. The correct circumference equal to of the circle inscribed into the original contour results from the properly chosen cross-feed motion.

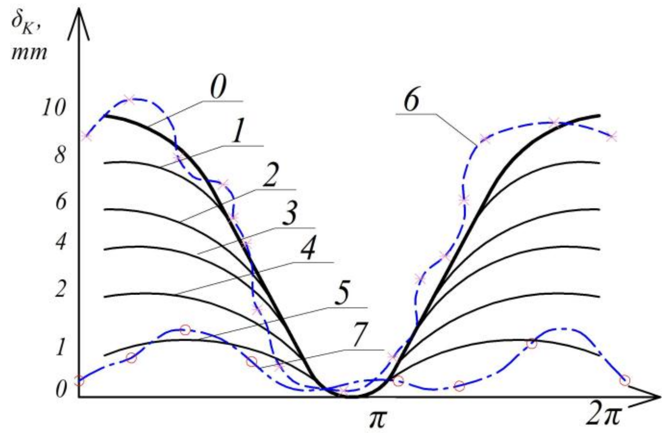

Figure 3: Diagram of improvement of circumference when processed part has no center: 0 - original contour; 1 ... 5 - circuit after each passage; 6 - the actual original circuit; 7 - the actual contour of the bandage after treatment.

In order to sum up the above method, you must submit it in the formal - logical terms to pose and solve the fundamental problem. Therefore, it is necessary to prove that the method of conjugate tangents has peculiar characteristic namely provides any desired roundness of cylindrical surfaces. The proposed method can be used in practice without additional research in each particular case. Therefore, this problem is studied as a purely engineering task so it will be presented as an assumption. In order to avoid further considerations and taking into account the novelty and importance of the solved problem for the practice we shall use only mathematical categories. According to the above considerations, we have formulated a hypothesis. It is a theorem. To be more exact we name it as "The theorem of conjugate sliding tangent in a closed loop with constantly changing shape.'' For simplicity let's assume that the original contour is convex having a positive curvature everywhere.

Suppose that from the point P (Fig. 4) which is the intersection of conjugate tangents crossing at smoothly changing angle 2α = λ, and sliding on a rotating convex closed loop bisector is drown along which the material point C (vertex cuts) moves evenly and slowly towards the contour . Point C is close to the contour due to its own motion as well as a result of changes in the angle 2α = λ between the tangents .

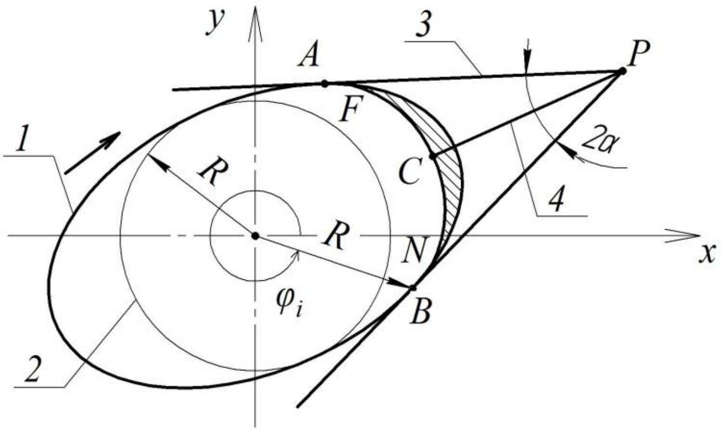

Figure 4:The theorem of conjugate tangents sliding in closed constantly changing contour: 1 - original contour; 2 - inscribed circle; 3 - rigidly coupled tangents at an angle 2α; 4 - bisector; N and F - entry and exit points of the contour of the material point C.

Passing a number of turns the point C will be inside the closed loop and inscribe curve NCF in a limited surface.

If shaded area bounded by the curve and the NCF is removed one at a time a new contour will be formed after each turn. Therefore, by rotating a closed loop so that the conjugate tangents slide without interruption on constantly changing contour point C (top of the cutter) will describe a perfect circle, equal to the maximum circle inscribed in the original contour. Taking into account that the proof of this assumption with regard to the general theoretical position is a difficult task we use a universal numerical method. Such evidence is quite clear and allows to use its algorithm for practical calculations for designing portable machines and technological methods of processing of various parts and objects.

The developed algorithm was used to create the modeling program for the PC. An ellipse and various curves are the original contours described by the splines of the second order. Proper circular accuracy was achieved during 8 ... 10passings (revolutions) .

Proof: Suppose $R_i = f(\varphi_i);\alpha$ and $R_i = f(\varphi_i)$ is given. Then the tangent angle can be determined

$$tgK_1 = \frac{Dy}{Dx}\bigg|b\,.$$

(1)

As we know let's define by the equation

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$$K_1 + K_2 + 2\alpha = \pi$$

(2)

And then by the equation

$$tgK_2 = \frac{Dy}{Dx}\bigg|a$$

(3)

We define - Coordinates of the point of tangency to the second support bar. To find the coordinates of the point we solve the system of equations:

$$\begin{cases} x_B - BP\cos K_1 = x_A + AP\cos K_2, \\ y_B - PB\cos K_1 = y_A + AP\cos K_2; \end{cases}$$

(4)

And we find

$$BP = \frac{(y_A - y_B)\cos K_2 - (x_A - x_B)\sin K_2}{\sin(K_1 + K_2)}$$

(5)

And then

$$\begin{aligned} y_C &= y_B + BP\sin K_1 - PC\sin(K_1 + \alpha), \\ x_C &= x_B + BP\cos K_1 + PC\cos(K_1 + \alpha). \end{aligned}$$

(6)

With the following test.

Due to the fact that the real contour is usually set discretely for solving this problem two schemes of determining position of the top of tool were developed - interpolation of straight lines and circles.

Polyhedron is inscribed into the contour so that the angle of tangent inclination at each point can be determined by the following equation (Fig. 5):

$$tgK_1 = \frac{y_{i+1} - y_{i-1}}{x_{i+1} - x_{i-1}}$$

(7)

Ellipse $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$ is a block-diagram and proof algorithm (Figs. 5 and 6) for the original contour.

Every three points of the contour circle is drawn, whose parameters are determined by the system (Fig. 6)

$$D_0 = \begin{vmatrix} X_{i-1} & Y_{i-1} & 1 \\ X_i & Y_i & 1 \\ X_{i+1} & Y_{i+1} & 1 \end{vmatrix}; \; D_1 = \begin{vmatrix} -(X_{i-1}^2 + Y_{i-1}^2) & Y_{i-1} & 1 \\ -(X_i^2 + Y_i^2) & Y_i & 1 \\ -(X_{i+1}^2 + Y_{i+1}^2) & Y_{i+1} & 1 \end{vmatrix};$$

$$D_2 = \begin{vmatrix} X_{i-1} & -(X_{i-1}^2 + Y_{i-1}^2) & 1 \\ X_i & -(X_i^2 + Y_i^2) & 1 \\ X_{i+1} & -(X_{i+1}^2 + Y_{i+1}^2) & 1 \end{vmatrix}; \; D_3 = \begin{vmatrix} X_{i-1} & Y_{i-1} & -(X_{i-1}^2 + Y_{i-1}^2) \\ X_i & Y_i & -(X_i^2 + Y_i^2) \\ X_{i+1} & Y_{i+1} & -(X_{i+1}^2 + Y_{i+1}^2) \end{vmatrix};$$

$$A_0 = \frac{D_1}{D_0}; \; B_0 = \frac{D_2}{D_0}; \; C_0 = \frac{D_3}{D_0}.$$

Coordinates of the center of each circle:

$$x_0 = \frac{A_0}{2}; \; y_0 = \frac{B_0}{2}.$$

(8)

Its radius:

$$R_0 = \frac{\sqrt{A_0^2 + B_0^2 - 4C_0}}{2}$$

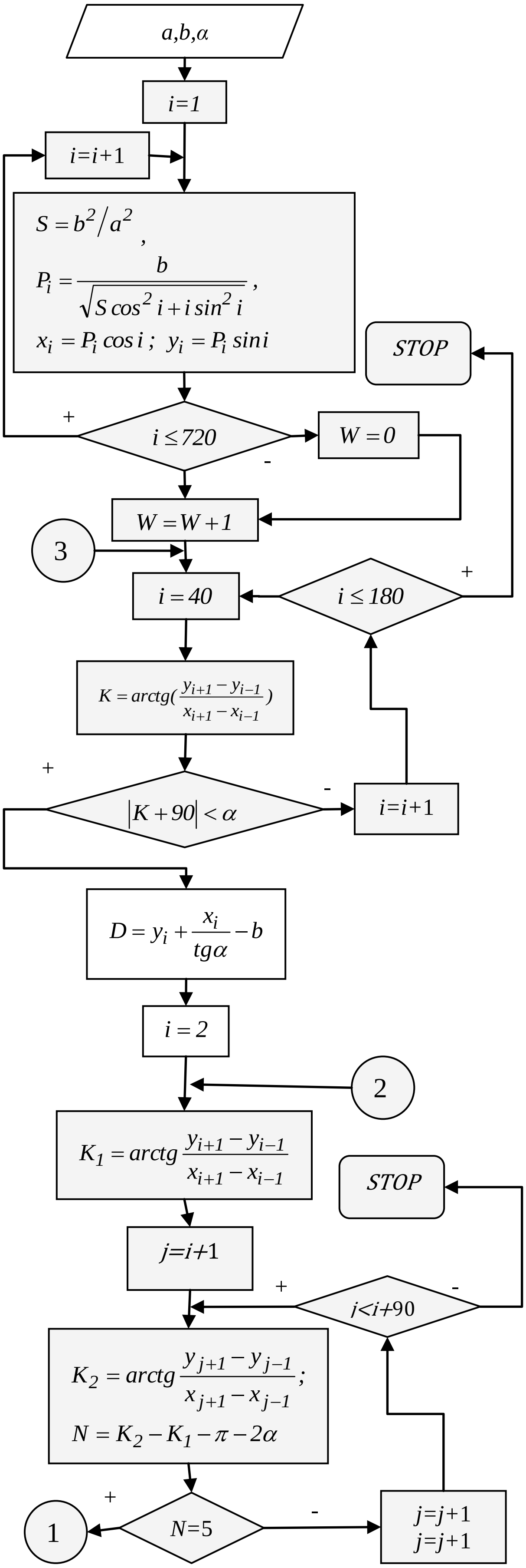
(9)

The angle of tangent inclination in each point of the contour

$$tgK_1 = \frac{x_{0i} - x_i}{\sqrt{R_{0i}^2 - (x_i + x_{0i})^2}}$$

(10)

Analysis of the calculation results shows that the transition of the tangents (after each turn) to a new contour formed by the trajectory of the point C, Ri is constantly decreasing, tending to R_i. That is, the trajectory of the point C is approaching to the circle inscribed in a given contour.


a,b,α
i=1
i=i+1
S = b²/a²,
Pᵢ = b / √(S cos² i + i sin² i),
xᵢ = Pᵢ cos i ; yᵢ = Pᵢ sin i
STOP
i ≤ 720
+
-
W = 0
W = W + 1
3
i = 40
i ≤ 180
+
K = arctg((yᵢ₊₁ − yᵢ₋₁)/(xᵢ₊₁ − xᵢ₋₁))
+
|K + 90| < α
-
i=i+1
D = yᵢ + xᵢ/tgα − b
i = 2
2
K₁ = arctg (yᵢ₊₁ − yᵢ₋₁)/(xᵢ₊₁ − xᵢ₋₁)
STOP
j=i+1
+
j<i+90
-
K₂ = arctg (yⱼ₊₁ − yⱼ₋₁)/(xⱼ₊₁ − xⱼ₋₁);
N = K₂ − K₁ − π − 2α
+
1
N=5
-
j=j+1
j=j+1

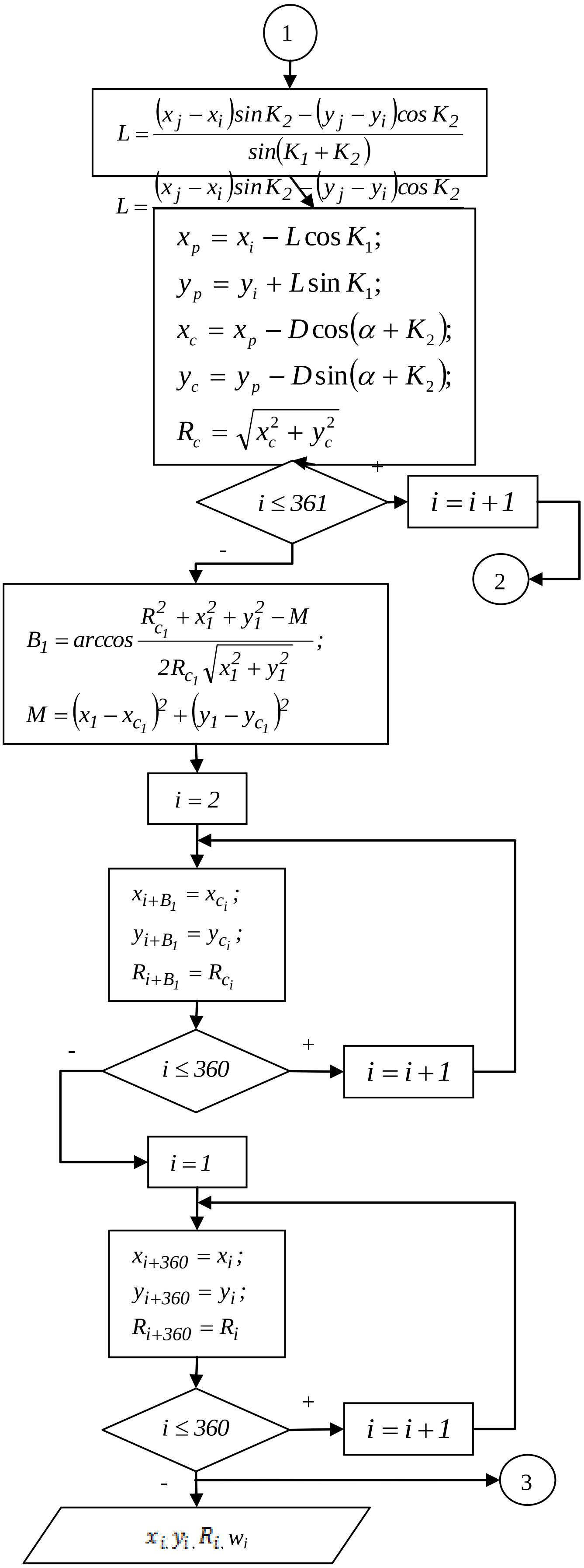

1
$L=\frac{(x_j-x_i)\sin K_2-(y_j-y_i)\cos K_2}{\sin(K_1+K_2)}$
$x_p=x_i-L\cos K_1;$
$y_p=y_i+L\sin K_1;$
$x_c=x_p-D\cos(\alpha+K_2);$
$y_c=y_p-D\sin(\alpha+K_2);$
$R_c=\sqrt{x_c^2+y_c^2}$
$i\le 361$
+
$i=i+1$
-
2
$B_1=\arccos\frac{R_{c_1}^2+x_1^2+y_1^2-M}{2R_{c_1}\sqrt{x_1^2+y_1^2}};$
$M=(x_1-x_{c_1})^2+(y_1-y_{c_1})^2$
$i=2$
$x_{i+B_1}=x_{c_i};$
$y_{i+B_1}=y_{c_i};$
$R_{i+B_1}=R_{c_i}$
$i\le 360$
+
-
$i=i+1$
$i=1$
$x_{i+360}=x_i;$
$y_{i+360}=y_i;$
$R_{i+360}=R_i$
$i\le 360$
+
$i=i+1$
-
3
x_i,y_i,R_i,w_i

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Fig. 5. Block – diagram of the proof algorithm (interpolation by lines)

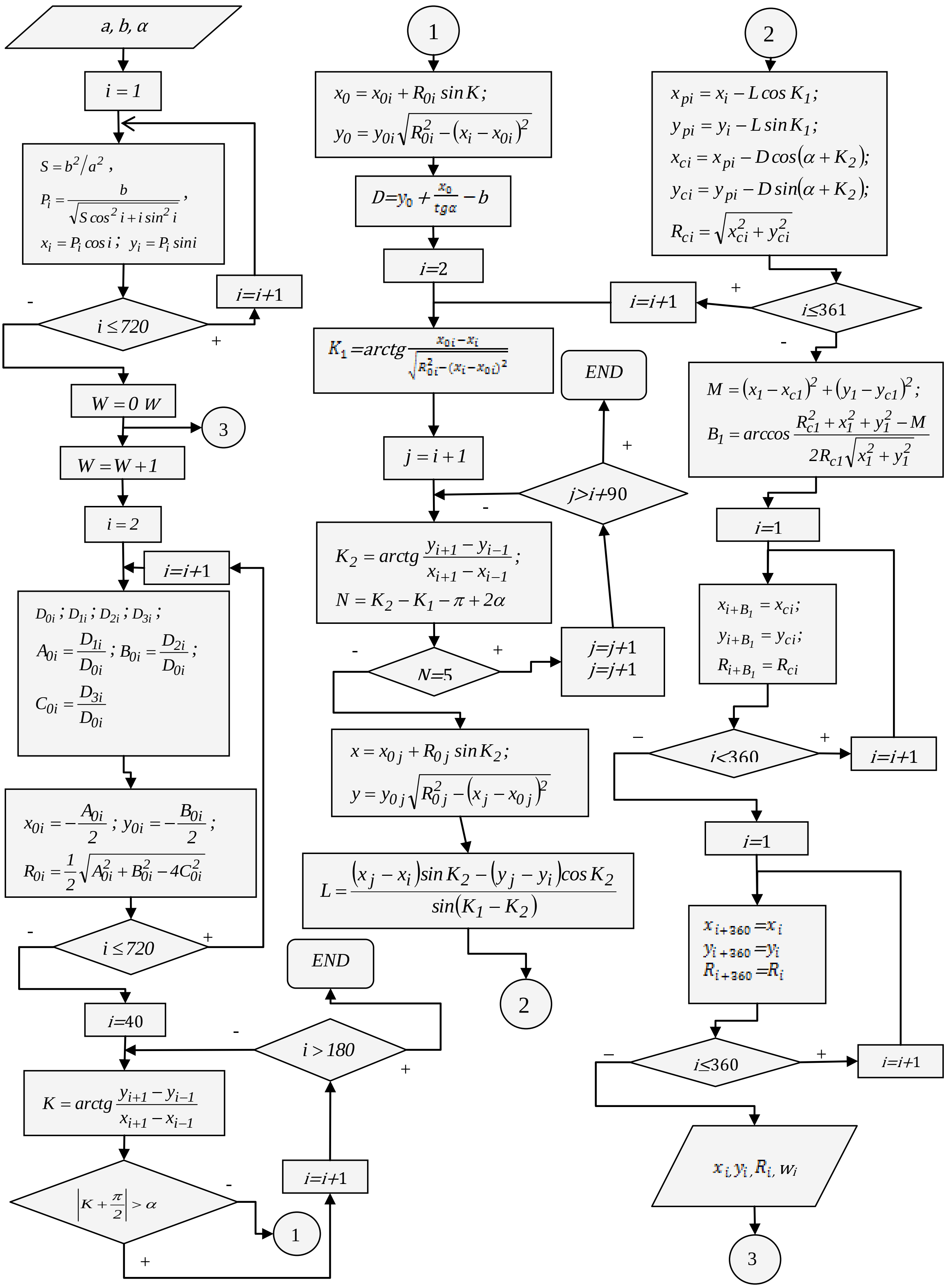

Fig. 6. Block – diagram of the proof algorithm (interpolation by circles)

When using algorithms the distance value from the point of intersection of the tangents to the top of the cutter PC is determined provided that point C is not in a circle inscribed in the original contour.

$$PC = \frac{R_{i\,max} - R_{вн}}{2} \tag{11}$$

where Rimax - the maximum value of the obtained radius after each turn. Process of approaching to the point C in the inscribed circle is finished if

$$[E] \geq R_{i\,max} - R_{вн}, \tag{12}$$

where [E] - possible deviation value from circularity .

Approximation process can be carried out with any degree of accuracy, for any of a convex contour, that is, the assumption is proved numerically. In block – diagrams (see Fig. 5 and 6) the elliptical bandage is considered as the initial contour.

CONCLUSION

The above given proof allows you to use the method of two conjugate tangents to solve various practical problems dealing with centerless processing of large parts. In addition, the studied proof algorithm may have other practical applications in various industries. The proposed algorithms have high stability. Specially made calculations have shown that they can be used not only for convex, but also for the wavy contours replacing the true contour for closed enveloping curve.

Further proof of the correctness of numerical proof of Theorem is the fact that the radii and center coordinates of parectropia-controlling circles and radius and the center coordinates of the inscribed circle are the same.

Practical effectiveness of the evidence can be tested on the contours having small deviations from circularity and containing both positive and negative curvature. Most suitable mathematical model is rotation of the ellipse modulated by sinusoid

$$x = (a + A\sin(n\varphi))\cos t,$$
$$y = (b + A\sin(n\varphi))\sin t.$$

Taken into account the diagram given in Figure 4, the mathematical model will contain varying parameters: alpha - angle between the tangents; a, b - axis of the ellipse A, n - number and amplitude of sine wave modulations. The combination of variable parameters allows to obtain the mathematical model which is actually adequate to the real bandage.

CONCLUSION

The proposed problem solution of processing of large parts with indefinite rotation axis (see Fig. 1) is an alternative controlled processing. Compared with common controlled processing the development of the equipment is greatly simplified and the accuracy of machined parts increases.

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