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RESEARCH

# Kinematic of Tools for Polygonal Holes - Production in the Real Condition*

*Polygonal holes can be made in many different ways. Using rotational tool for boring the polygonal holes is a very efficient way of doing it. Since, in this case, the applied tool is of a very complex movement, the variable speed of a blade of the tool must be found for the given constant angle velocity. The aim of this paper is to determine the speed of the tool's blade used for polygonal hole production. The given task will be solved using alternative mechanism and applying centrodes. Euler-Savary equation will be used for defining the path of the tool's blade at the top points, while processing the polygonal holes. After theoretical description of the kinematics problem the cutting speed will be defined too in real conditions. The proposed procedure was applied on a concrete case of polygonal hole processing with the aim of defining the velocity of tool's blade as well as of geometry of polygonal contour. The procedure is a very simple one and a very accurate one giving the precise solutions in an analytical and a graphical presentation.*

**Keywords:** *kinematics, polygonal holes, cutting speed*

## 1. INTRODUCTION

Besides the possible way of polygonal holes production by grating or pulling through they could also be made by boring. During boring of these holes tool geometry and the polygonal hole itself must be synchronized, which means that the hole contour can be wind on several consecutive tool positions. The tool is guided during work according to stereotype with the shape same as the hole to be produced. Besides rotational movement tool has also a vertical movement during work. At one observed moment of time excluding vertical movement tool is moving with angle speed ω guided inside contour stereotype. Because of complex movement of tool it is interesting to analyze the change of speed of cutting blade during working cycle.

## 2. KINEMATICAL DESCRIPTION OF THE POLYGONAL HOLES BORING

Let us take one sector from single most general shape of polygonal hole given in Figure 1.

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It is enough to notice, in the observed time, two points of tool blade whose path corresponds to stereotype contour for tool leading. It is shown in the Fig.1 that the path of point A and B are overlapped with contour and II. In that case the direction of speed $V_A$ and $V_B$ are overlapped with contours and II. Now the direction of speed for point C is determined in the relation to existing pole P determined via turnover speed direction of $V_A$ and $V_B$. The same solution can be achieved by using alternative (changeable) mechanism shown in Fig.2. Being acquainted now with mechanism shown in Fig.2 the movement can be brought to rolling of moveable centrode over fixed one (fig.3.) by using construction of fixed centrode presented by construction of moveable centrode.

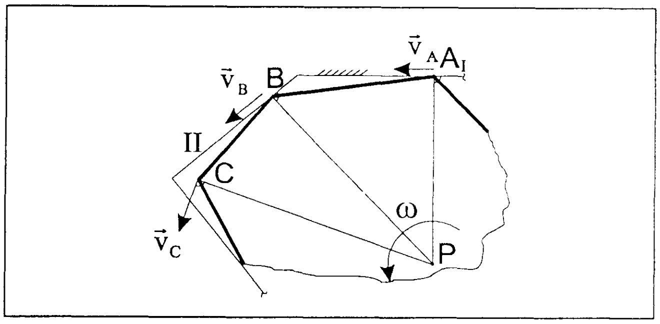


*Fig.1. Contour of polygonal hole*

* *The paper was published at The First Mediterranean Conference on Tribology in Israel.*

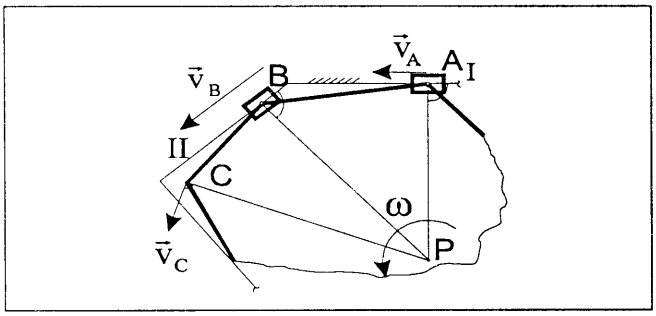


*Fig. 2. Alternative mechanism*

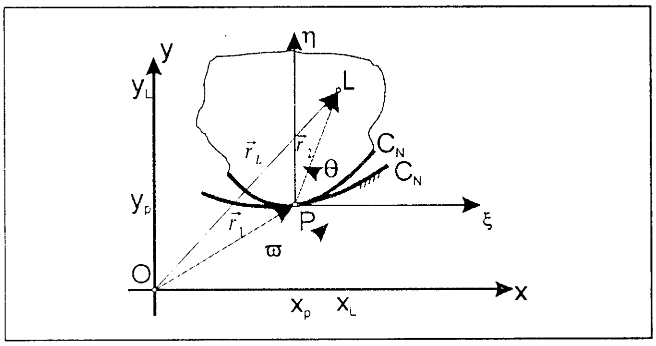


*Fig.3. Construction of centrode*

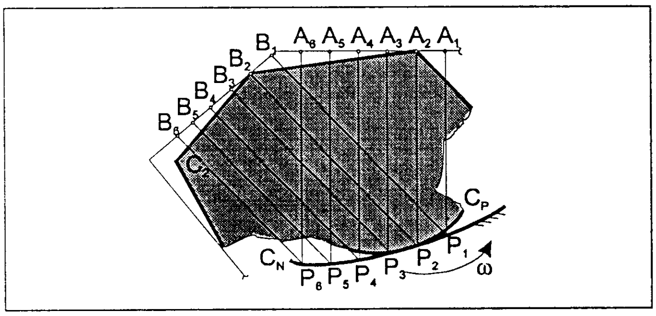


*Fig. 4. Kinematics of centrode*

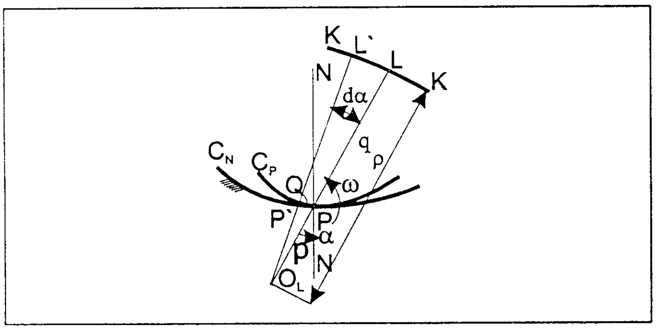


*Fig. 5. Position of centrode*

Fixed centrode is presented with $C_N$ curve, and moveable with $C_P$ curve with current observed conjugation in the current $P_2$ pole. The movement of moveable centrode $C_P$ is done with known angle speed ω. Let us analyze now the movement of movable centrode shown in Fig. 4, with the aim to determine the cutting speed of the points which present the tool blade. Moveable coordinate system $P\xi\eta$ is linked to moveable centrode $C_P$, while fixed coordinate system Oxy is lined to fixed centrode $C_N$.

Position vector of point L is given by the expression $\vec{r}_L = \vec{r}_1 + \vec{r}_2$. First derivation of vector position $\vec{r}_L$ by time gives velocity of point L.

$$\vec{V}_L = \frac{d\vec{r}_L}{dt} = \frac{d\vec{r}_1}{dt} + [\vec{\varpi}, \vec{r}_2] = \\ = \vec{j}\dot{\theta}(x_L - x_p) - \vec{i}\dot{\theta}(y_L - y_p) \qquad (1)$$

Where:

$\vec{r}_1, \vec{r}_2$ – vector position of current pole P and L in coordinate system Oxy and Pξη

$\vec{\varpi} = \dot{\theta}$ -angular velocity of tool,

$\frac{d\vec{r}_1}{dt} = \vec{V}_P = 0$, $\vec{V}_P$ – speed of current speed pole

$\vec{i}, \vec{j}, \vec{k}$ - unit vectors of fixed coordinate system Oxyz.

Using equation (1) the way of determination of speed of one arbitrary tool point for boring is given, while the speed of all of the rest interesting points is determined in the same way.

Beside kinematics it is necessary to analyze the path of tool blade point in one determined period, because the polygonal hole can not be made with sharp but with rounded crowns.

The path of some arbitrary point L and semi diameter of curve at the determined period is achieved by analyzing the movement of the pair of centrodes given in Fig. 5.

From the Euler-Savary equation the radius of curve ρ in the observed point L of the curve k-k can be presented in the form:

$$\rho = \frac{q^2}{q - d \cdot \cos\alpha} \qquad (2)$$

d - diameter of the circle of the tangential acceleration.

α - angle between direction of normal on the centrode $C_P$ and $C_N$ in the conjunction point P and line $\overline{PL}$.

In this way radius of the path of any point of tool blade can be determined.

If we know the trajectory of a single point r(s) at the top point holes then the radius of a curve can be obtained on the basis of the expression (3):

$$\rho(s) = \frac{\left|\dot{\vec{r}}(s)\right|^3}{\left|\dot{\vec{r}}(s) \times \ddot{\vec{r}}(s)\right|} \qquad (3)$$

Where s is a parameter of the trajectory point of the tool.

In our case top point of a tool has the following coordinates $X_m(\theta,n,m), Y_m(\theta,n,m)$. On the basis of that we have the vector position $\vec{r}_m(\theta,n,m) = X_m(\theta,n,m)\cdot\vec{i} + Y_m(\theta,n,m)\cdot\vec{j}$ .... in a fixed system (xOy). Radius of a path curve in the function of parameter *(θ)* is given by the expression (4):

$$\rho(\theta,n,m) = \frac{\left|\dot{\vec{r}}_m(\theta,n,m)\right|^3}{\left|\dot{\vec{r}}_m(\theta,n,m)\times\ddot{\vec{r}}_m(\theta,n,m)\right|} = \frac{\left|\sqrt{\dot{X}_m(\theta,n,m)^2+\dot{Y}_m(\theta,n,m)^2}\right|^3}{\left|\dot{X}_m(\theta,n,m)\cdot\ddot{Y}_m(\theta,n,m)-\ddot{X}_m(\theta,n,m)\cdot\dot{Y}_m(\theta,n,m)\right|} \quad (4)$$

If the top of the tool enters the hole then the radius of the curve decreases, and the radius of the curve on the exit path increases. On the basis of that minimum radius appears at the positions ($\theta_{p\min} = 0, 2\cdot\theta g, 4\cdot\theta g \ldots 2\cdot n\cdot\theta g$).

The obtained radius represents non-dimensional value. The real radius is obtained via formula $\rho(\theta,n,m)_{real} = a\cdot\rho(\theta,n,m)$.

Knowing the position of any of the top points in the function of rotating angle of the tool, the velocity of the top points can be easily obtained through general kinematic relation:

$$\vec{v}_m(\theta,n,m) = \dot{\vec{r}}_m(\theta,n,m) = \dot{X}_m(\theta,n,m)\cdot\vec{i} + \dot{Y}_m(\theta,n,m)\cdot\vec{j} \quad (5)$$

When defining the regime of the processing we have to know the intensity of vector velocity as:

$$v_m(\theta,n,m) = \sqrt{\dot{X}_m(\theta,n,m)^2+\dot{Y}_m(\theta,n,m)^2} \text{ (m/rad)} \quad (6)$$

In that way we obtain the velocity of the top points of the tool depending on rotating angle of the tool. Since all length measures are non-dimensional comparing to the size of the hole contour (a), the real blade speed is obtained as: $v(\theta,n,m)_{real} = a\cdot v(\theta,n,m)$. During boring the tool is rotating with a constant angle velocity $(\dot{\theta})$, so we can introduce the shift $\theta(t) = \dot{\theta}\cdot t$. On the basis of that we can obtain the velocity depending on the time as:

$$v_m(t,n,m) = \dot{\theta}\cdot\sqrt{\dot{X}_m(\theta,n,m)^2+\dot{Y}_m(\theta,n,m)^2} = \dot{\theta}\cdot v_m(\theta,n,m) \text{ (m/s)} \quad (7)$$

## 3. EXAMPLE

Using the centrodes we can find the velocity of points and after that by using Euler-Savary equation can be found as well as the radius of part curve of tool blade point. The presentation of the solving of this problem with the help of centrode will be given by the example of square hole. The shape of tool for boring of square hole is given in Fig. 6d.

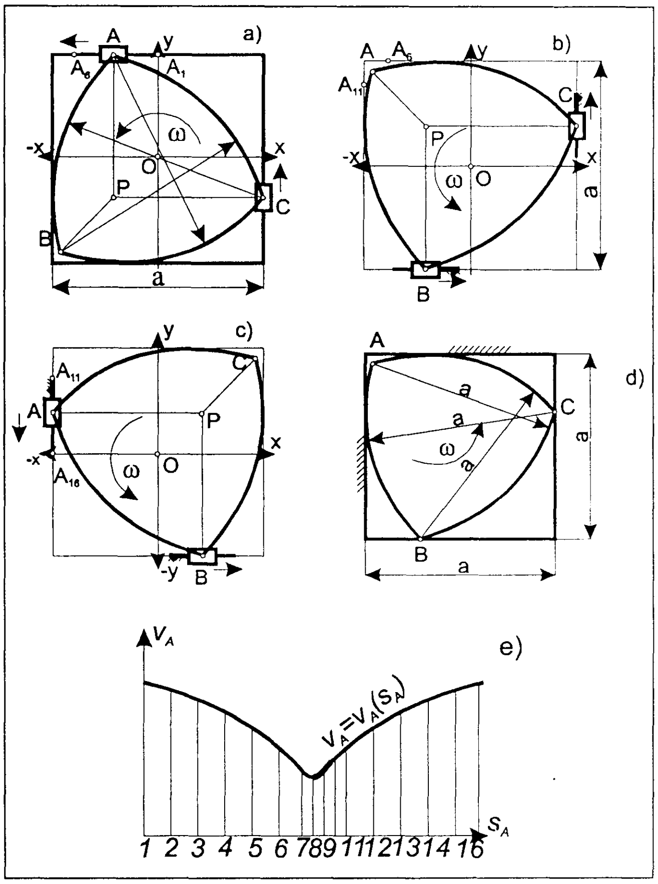


*Fig. 6 Kinematics scheme of alternative mechanisms Fig. 6a,b,c and squares hole with tool, Fig.6d., and velocity of blade of tool $V_A = V_A(S_A)$ Fig.6e.*

Dimensions of tool are synchronized with the dimensions of the square holes as shown in Fig. 6a,b,c. The tool during boring is led over the square hole of dimension (a), and is turned by angle speed $\dot{\theta} = \omega$.

The speed of blade cutting of the tool A, B and C will be determined using already determined way, given in the introduction. Alternative mechanisms for one fourth of tool turn are given in Fig. 6a,b,c. On the basis of the general expression (4) the speed for points A,B and C are:

$$\vec{V}_A = [\dot{\vec{\theta}},(\vec{r}_A-\vec{r}_P)]; \quad \vec{V}_B = [\dot{\vec{\theta}},(\vec{r}_B-\vec{r}_P)]; \quad \vec{V}_C = [\dot{\vec{\theta}},(\vec{r}_C-\vec{r}_P)] \quad (8)$$

$\vec{r}_A, \vec{r}_B, \vec{r}_C, \vec{r}_P$ – vectors position of points A, B , C and P

Using expression (4), Fig. 4 the survey of speed change for point A from $A_1$-$A_{16}$ can be given in Fig. 6e. The survey of the current position of centrode of curve k-k and position of point $A_8$ in which radius $\rho_8$ of the curve k-k is searched for is given in the Fig.5 and equation (2).

$$\rho_8 = \frac{q^2}{q + d \cdot \cos\alpha} \qquad (9)$$

According to that the current pole of acceleration $Pa_8$ is achieved in the cross section of direction of acceleration for point $B_8$ and $C_8$. We can say that the diameter of circle of tangential acceleration is d = $\overline{P_8 P_{a8}}$ .

On basis of the expression (7) the velocity of tool blades during single moving period is calculated and is shown in Fig 7. for each top-head of a triangle shaped tool (m = 1,2,3).

Maximal and minimal (non-dimensional) blade velocity during drilling of a square hole is $v_{max} = 0.861 \cdot a$ ; $v_{min} = 0.366 \cdot a$ . Velocity obtained in this way has dimension $(\frac{m}{rad})$,

where A is the edge of the square hole. On basis of the expression (4) the radius of curve path of the tool blade at the top points of the square hole (n=4), as well as of the triangle shaped tool (m was calculated m = 3) were calculated, and its change was shown in the Fig. 8. Minimal radius of the curve hole contour is obtained at the top points of the hole (Fig. 8). Minimal radius of square holes is $\rho_{min}(\theta = 0,4,3) = 0.098 \cdot a$ for a = 50 mm, we have $\rho_{min} = 0,098 \cdot 50 = 4,5mm$ . In Fig.9 we have real shape of the squares hole.

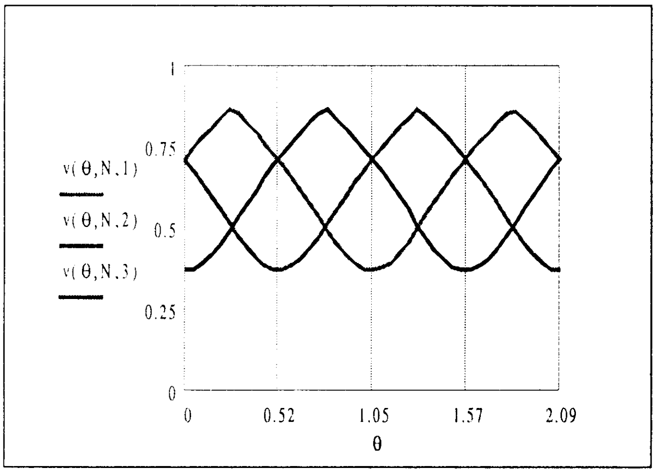


*Fig. 7. Change of tool cutting velocity*

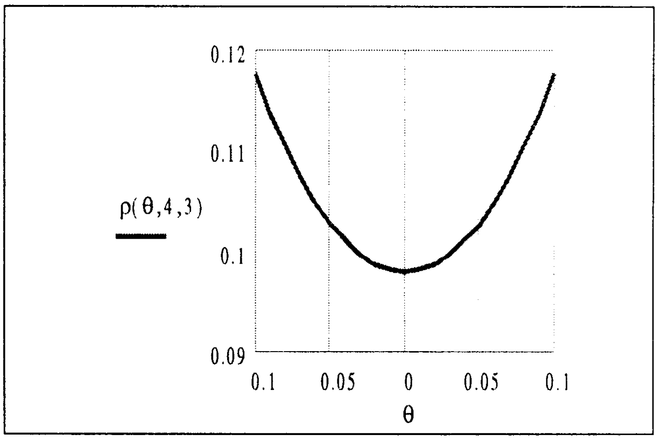


*Fig. 8. Radius of curve at top point of the hole*

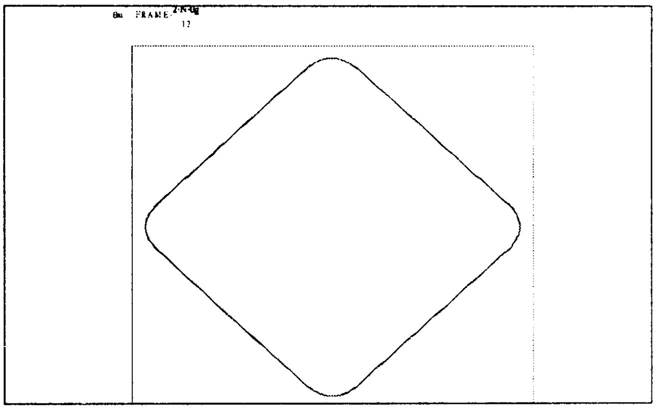

*Fig. 9. Real shape of the squares hole*

## 4. CONCLUSION

Proposed way of solving the problem is very quick and simple. Besides analytical and graphical solution it gives quick and accurate results concerning the velocity, and also concerning the geometry of the hole.

### *REFERENCES*


[1.] *Suh C. H. & Radcliffe C. W.*, **Kinematics & Mechanisms Design**, John Wiley & Sons, Inc., New York, 1978.

[2.] *Zlokolica, M.*, **Kinematics of Tools for Polygonal Drilling**, Journal Tehnika – Masinstvo, Beograd, year XXIV-1975, No. 6, p.p. 15-18.

[3.] *Zlokolica, M.*, **About the blade cutting speed of the tools for polygonal hole processing**, V International Conference- Flexible Technologies, Proceeding II, Novi Sad,1994, pp. 763-769.