A STUDY OF POLYGONAL TURNING USING ATTACHMENT

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SUMMARY

This paper presents a proposed method to produce parts with polygonal cross-section by turning. Based on hypotrochoid curve construction, a mechanism which combines motions of workpieces and cutting tool to machines polygons'sides is proposed. A numerical program has been established to find the optimized parameters for polygon's properties. The results showed that the geometry character of parts which are manufactured from this method can enhanced machining efficiency, compared to conventional machine.

Key word: *Hypotrochoid curve, polygon, turning, machining efficiency*

INTRODUCTION

Polygonal surfaces are produced usually by milling or grinding on conventional or CNC multifunctional specialized machine tools[1]. Surfaces of such polygonal structures are required to meet the dimensional accuracy, shape and quality conditions in assembly[1,2]. When milling or grinding these structures, if the process area is small, there will be problem of low efficient. Polygonal turning is a new developed process which allows non-circular forms to be machined without interrupting the rotation of workpiece (During the operation, workpiece and cutters rotate withthe certain conditions) [3]. Some investigations have been done with tool-holder's structure and the methods to machine faces[1,3,4,5]. However, these methods only produce polygons with even edges – holder mount multiple cutters, each cutter form two oppositely sides. The paper presents a method to machine parts with polygonal cross-section by turning using single cutter in holder based on hypotrochoid curve construction.

THEORETICAL METHOD

In geometry, a hypotrochoidis a roulette traced by point $\boldsymbol{M}$ attached to a circle $\boldsymbol{c_2}$of radius $\boldsymbol{R_{02}}$ rolling around the inside of a fixed circle $\boldsymbol{c_1}$ of radius $\boldsymbol{R_{01}}$, where the point is a distance $\boldsymbol{d}$ from the center of the interior circle $\boldsymbol{c_2}$. Assign R_{01}/R_{02} =n; the parametric equationsfor the curve can be given by:

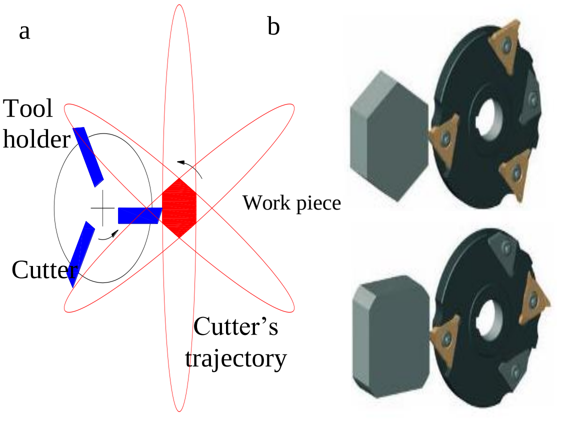

Figure 1. *A method to machine 6-side polygon (a) and Tool-holder's construction(b);*

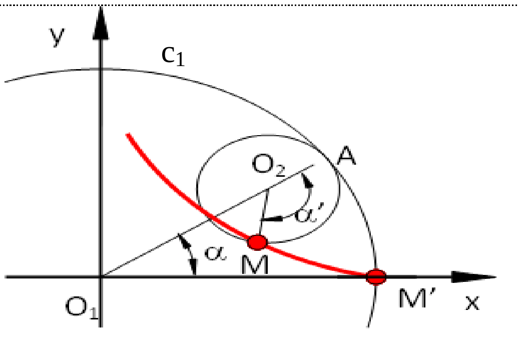

Figure 2. *Hypotrochoid curve*

$$\begin{cases} x = (R_{01} - R_{02}).\cos\alpha \ + \ d.\cos(\alpha - n\alpha) \\ y = (R_{01} - R_{02})\sin\alpha \ + \ d.\sin(\alpha - n\alpha) \end{cases} \quad (1.1)$$

Where α is the angle formed by the horizontal

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and the center of the rolling circle.

With n integer, the shape of the region formed inside the curve has is similar polygon. When the distance between O_2 and M changes, two possible cases might be happened to the region:

*** Case 1 - WhenOM<R_{O2} (Fig. 3a)**: Trajectory of O_2 incline the region, according to the construction method and the theory of machining, this case is not suitable to be used.

*** Case 2 - When OM>R_{O2} (Fig. 3b)**:the shape of bounded region is similar as polygon. However, at several moments, the cutter may not involvein cutting process (the cutting point is out of workpiece boundary). When raising the distance ***d*** between O_2 and M, polygon's faces will be flatter butthe time consumed in non-cutting stage is increases (the region outside polygons will be bigger). The percentage ratio of cutting time and total time can be calculated as:

$$\Delta t = \frac{100.n.\Delta\alpha}{\pi}\% \tag{1.2}$$

($\Delta\alpha$: the rotates angle in which the cutter move half length of each face)

The convexity of faces can be determined as:

$$e = \frac{l_n}{l_0} = \frac{(R_{01} - R_{02}) - d}{\max(O_1M).\cos\left(\frac{\pi}{n}\right)} \tag{1.3}$$

BUILDING THE MECHANISM

Figure 4 illustrates the mechanism with holder driven by four-gear train connected to the spindle. In this setup, only onecutter is mounted in holder. Distance R_1 between center of workpieces and holder can be adjusted while the speed of cutter is unchanged because of the fixed gearratio. Distance R_2 between cutter and center of holder can also be changed. When workpiece rotate and angle α, cutter rotate an angle $n\alpha$ respectively.

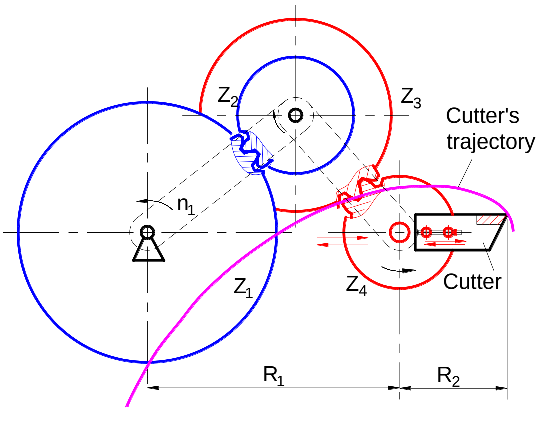

Figure 4. *Schematic diagram*

The velocity of cutter also changes corresponding to its position. When workpiece is rotated at an angular speed of ω rad/s (the same speed as spindle), velocity of point cutter at point A in the trajectory (Fig.5) can be determined as:

$$\vec{V}_A = \vec{V}_{A1} + \vec{V}_{A2} \tag{1.4}$$

Where:

V_{A1} : Velocity of point A on workpiece;

$V_{A1}=\omega.O_1A$

V_{A2} : Velocity of cutter;$V_{A2}=\omega.n.R_2$

φ_x: Angle between velocity vectors:

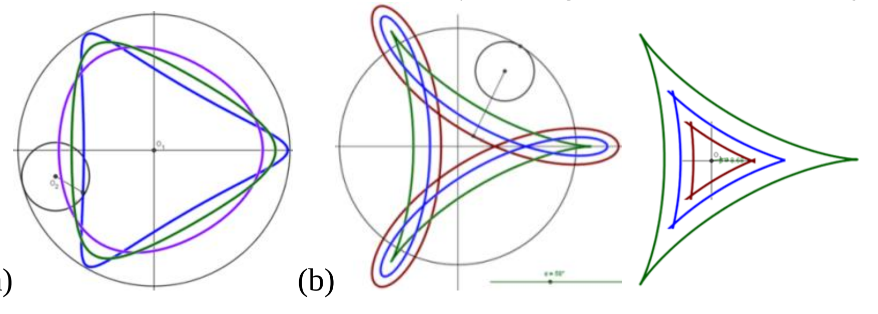

Figure 3. *Hypotrochoid curve (n=3) when OM<R_{O2}(a); OM>R_{O2} and the bounded regions (b)*

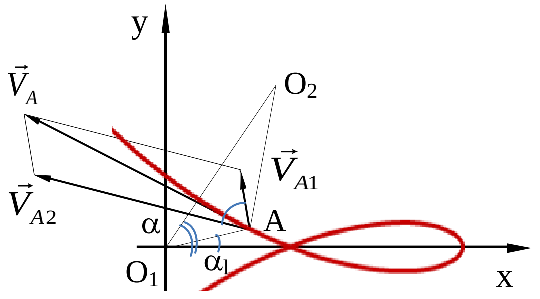

Figure 5. *Velocity diagram at an abitrary point*

$$\varphi_x = \left(\varphi_l - \varphi(\mathrm{n}-1)\right) \qquad (1.5)$$

From (1.4) and (1.5):

$$V_A = \sqrt{V_{A1}^2 + V_{A2}^2 + 2.V_{A1}.V_{A2}.\cos(\varphi_x)} \qquad (1.6)$$

$$= \omega.\sqrt{O_1A^2 + n^2.R_2^2 - 2.\mathrm{n}.O_1A.R_2.\cos\left(\varphi_l - \varphi(\mathrm{n}-1)\right)}$$

This velocity reaches the maximum value at the middle points of sides and minimum at edges of polygons (Fig.6c).

With *n* is integer, polygon can be formed in one rotation of spindle. However, through the simulations, it was found that when *n* is fraction, polygons formed by the mechanism could be more precisely (Fig.6).

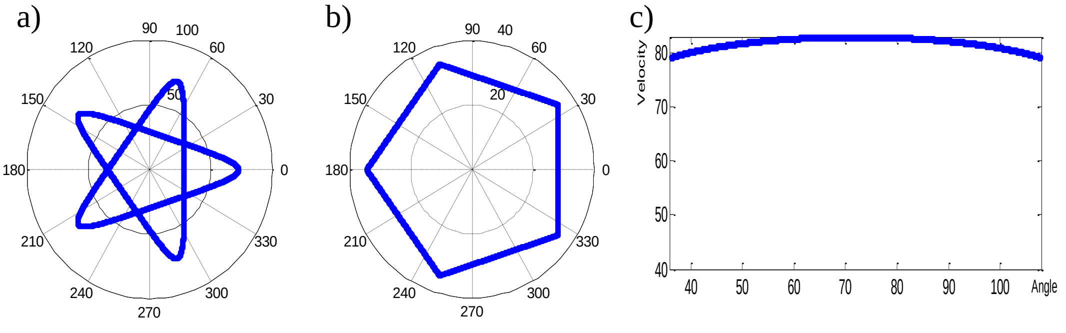

Figure 6. *Illustrations of trajectory where n=5/2, R_1=50, R_2=22(a); Polygon formed from trajectory(b); velocity-position graph on one side (c)*

MATLAB programing is applied to determine the parameters with best properties for polygons. Results from the calculation process showed in Table 1.

Table 1: *Variation input and polygons' properties formed:*

Number of edges	Input variations			Non - cutting time Δt (%)	Radius l_{max}	Convexity e (%)	$\frac{V_{max}}{\omega}$	$\frac{V_{min}}{\omega}$
	n	R_1	R_2					
3	3	50	35	25.97	36.42	-17.65	120.00	110.43
4	4	50	35	13.72	23.35	-9.16	155.00	151.87
5	5	50	35	9.78	19.73	6.00	190.00	188.27
	5/2	50	22	19.78	34.57	0.10	83.00	79.20
6	6	50	35	7.71	18.09	-4.26	225.00	223.86
	6/5	50	35	5.61	16.71	3.63	57.00	56.90
7	7	50	35	6.42	17.20	-3.22	260.00	259.18
	7/3	50	28	9.03	24.41	0.02	87.33	86.47
8	8	50	35	5.47	16.63	-2.38	295.00	294.39
	8/3	50	35	4.90	16.32	-0.52	108.33	108.01
9	9	50	35	13.90	31.47	-5.32	226.00	222.32
	9/4	50	35	4.16	15.96	-0.02	93.75	93.55

SUMMARY AND CONCLUSIONS

The method prove that we can use conventional lathe to machine polygons satisfy the geometry variations and flatness tolerance requirements. In the present work, we can see the effect of input parameters (R_1, R_2, n) to the properties of the polygons (geometry variations, flatness tolerance, convexity):

- Raising $\mathbf{R_2}$ make the polygons more flatter, however the non-cutting time increases, and the holder must have higher stiffness because of cantilever structures.

- Depend on the ratio ***n*** of gear train, the mechanism can make polygons with more than 20 edges.

- Dimensions $\mathbf{R_1}$ and $\mathbf{R_2}$ can exceeded to increase the size of polygon to meet the geometry requirement.

The mechanism machines all faces at the same time, overcome the shortcoming of ordinary machining that need indexing and long working hours. Parts with such polygonal structure as hexagon-bolt heads, nuts, or wooden furniture… can be manufactured by this method instead of milling or planning to improved the time efficiency. To process longer bars with unchanged cross-section, the spline will be mounted in holder's shaft to maintain cutter's speed whilst cutter cuts along z-axis of workpiece. This structure will be described in further study.

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TÓM TẮT

NGHIÊN CỨU PHƯƠNG PHÁP GIA CÔNG ĐA DIỆN ĐỀU TRÊN MÁY TIỆN

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Bài báo nghiên cứu về một phương pháp tiện các chi tiết có tiết diện dạng đa diện đều. Trên cơ sở tạo hình của đường cong hypotrochoid, một bộ cơ cấu được sử dụng cho phép kết hợp các chuyển động giữa phôi và dao trên máy tiện để gia công các mặt đồng thời. Kết quả từ chương trình mô phỏng cho thấy một số ưu điểm của phương pháp gia công này (thông số hình học, hiệu suất gia công) và khả năng mở rộng giới hạn về số cạnh đa diện so với các phương pháp cũ.

Từ khóa: *Đường cong Hypotrochoid, đa diện đều, tiện, hiệu suất gia công*

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