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Review of existing methods and tools for part processing limited to polyhedral surfaces

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Abstract. Looking retrospectively at the many years of efforts by a number of researchers to develop a method for machining by cutting of polyhedral parts, it is found that the obtained results were not particularly satisfactory. For this finding, it is not possible to substantiate justify the basis in this paper, but the reason can be briefly indicated. One of the less successful methods has been created, though unintentionally, on the basis of fundamental kinematic cutting schemes (FKCS). The uniform rotary motion B, of the stock is kinematically related to the straight-line reciprocating motion C of the simple lathe cutting tool. Uniform, straight forward motion is also performed from the stock and it is a longitudinal feed movement. This method has some disadvantages: changing the actual angles of the tool during very wide cuts between 0° to 45°; variable size chip which is a source of periodic force loading of the tool and the stock and the correct reciprocating motion is realized by a CNC machine and the deviations from the exact shape being copied relative to the shape of the part surface of the machined area.

1. Introduction
In order to overcome the shortcomings of the method under consideration, another method has been established for a similar purpose but on the basis of fundamental kinematic cutting schemes (FKCS). The uniform rotational motion B of the stock is related to the rotary reciprocating motion C of the tool and the uniform straight and forward motion A is also of the stock and is a longitudinal feeding motion [1]. The choice of rotary reciprocating motion method is dictated by the need not to alter the actual cutting angles within wide limits. However, this method has one major disadvantage: the complex kinematics of the machine tool.
Given the disadvantages of the two methods considered, neither of them can be considered as rational and reasonably recommended as the most suitable for use when needed.

2. Existing methods and tools for part processing limited to polyhedral surfaces
In order to create a more rational alternative to the methods discussed here, it is necessary to focus on the analysis of those kinematic cutting schemes which, at certain values of the relations i between the angular velocities of their motion, have relative trajectories with straight lines sections [2]. These are shown in Figure1(a, b).
In analyzing a fundamental kinematics scheme it is found that when:

$$i = \frac{\omega_A}{\omega_B} \quad (1)$$

within limits: $2 < i < 3$ and $R < a_0$

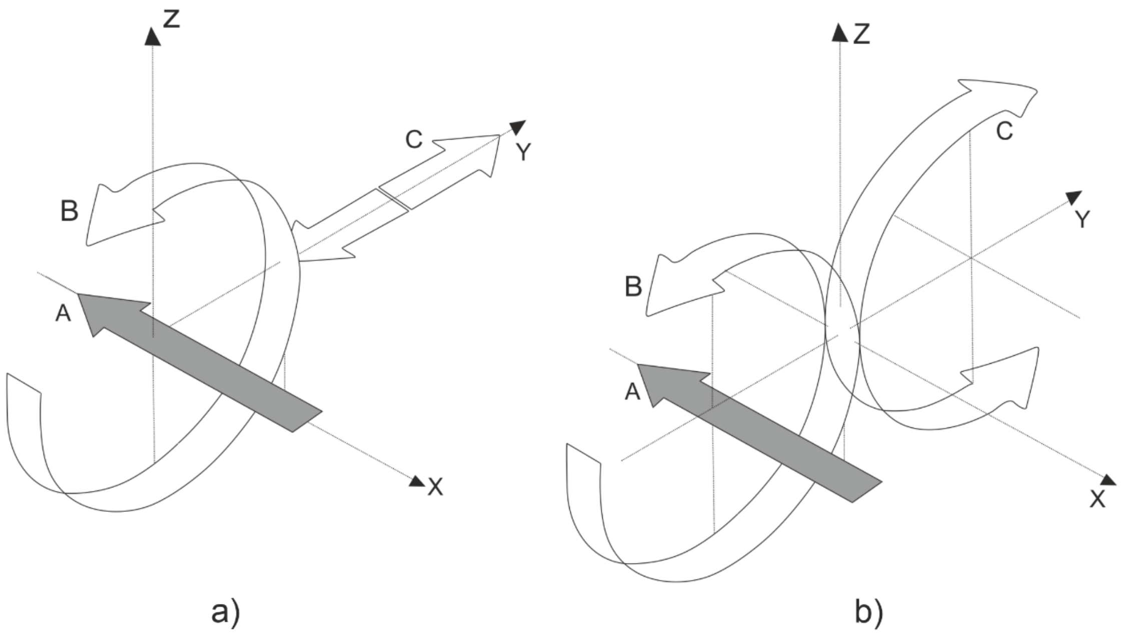

Figure 1. Kinematic cutting schemes used in polyhedral part machining.

In Figure 2, the trajectory of the relative working movement is of the nature of a shortened hypocycloid with rectilinear sections. All other relationships outside the specified range are concave or convex hypocycloids and they are unsuitable for the case at hand.

Despite their straight sections, the relative paths of Figure 2 described by points A_1, A_2, A_3, …and B_1, B_2, B_3… of the cutting edges of the two tools of the tool head do not correspond to the machined multi-wall surface of the part for the following two reasons:

- The outline of the multi-walled part in cross-section is asymmetrical and with different lengths;
- The relative trajectory is open within a single work cycle.

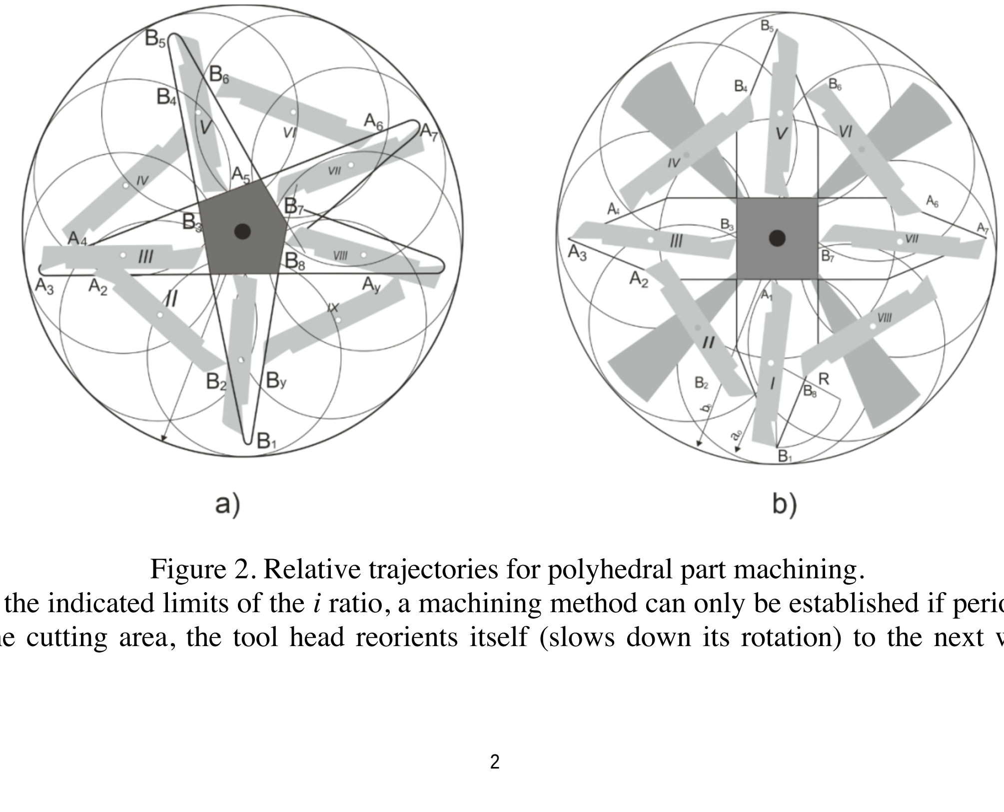

Figure 2. Relative trajectories for polyhedral part machining.

In fact, at the indicated limits of the *i* ratio, a machining method can only be established if periodically outside the cutting area, the tool head reorients itself (slows down its rotation) to the next working process. This means that the kinematic relationship between the rotation of the tool and the stock should be preserved only for the duration of the work process and not beyond. This possibility is illustrated in Figure 2.

As it is mentioned slowing down of the rotational movement of the tool should be performed in the shadow sections shown in the Figure 2. It turns out that such a possibility is only theoretical. So far, it is not known that a mechanism with the indicated kinematic capabilities is practically implemented, due to the significant technical difficulties in its design and manufacture [3].

To determine if it is possible to build a multi-wall machining process with capabilities that FKCS offer, the solution must be sought beyond the limits of the "ï" ratios taken above, despite the fact that relative trajectories would have a curvilinear type [4]. However, the requirement must be respected that the relative trajectories represent closed contours within a single duty cycle.

After FKCS (Figure 1a) analyze, it is found that such trajectories (Figure 3) are possible when:

$$i = \frac{\omega_A}{\omega_B} = \frac{b_0}{a_0} = 2 \tag{2}$$

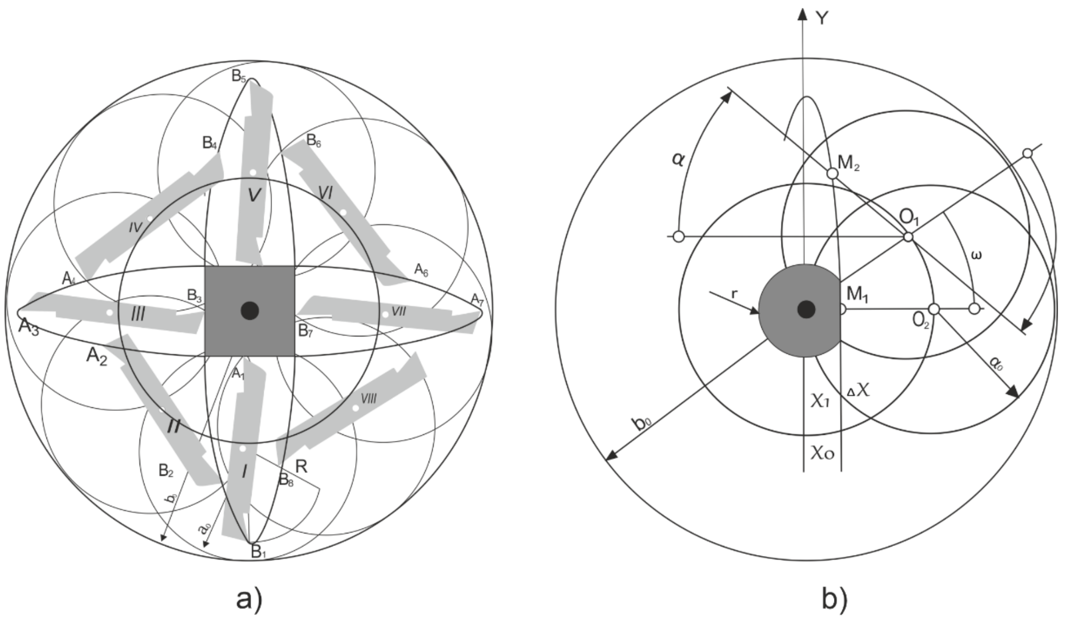

Figure 3. Variant of relative trajectory in polyhedral part machining.

The two closed relative trajectories with the character of shortened hypocycloids and the appearance of elliptic curves with mutually perpendicular axes, described by cutting edges of the two knives of the tool head, form on two opposite sides of the multifaceted stock, in the accomplished of kinematic relationship between the rotational movement of the tool and detail. In order to determine the appropriateness of using the obtained relative trajectory, should be determined the maximum deviation p from the rectilinear shape of the stock, upon receipt of a curvilinear outline of each side of the multi-walled part in cross-section [5, 6]. This can be achieved by using the scheme of Figure 3b.

The stock with radius r is connected to a circle with radius b_0, and the tool with a second circle with radius a_0 which rolls without sliding along the first, which providing internal contact. When the tool is rotated and the circle associated with it around the angle α, its center from position O_1 moves to position O'_1, on angle ω from his original position.

If:

$$O_1M_1 = O_1'M_2 = e \tag{3}$$

Coordinates for position M_2 can be determinate with the following mathematical equations:

$$x = (b_0 - a_0)cos\omega - e\ cos\alpha \tag{4}$$

$$y = (b_0 - a_0)sin\omega + e\ sin\alpha \tag{5}$$

Figure 3, b shows that:

$$\alpha=\phi-\omega \tag{6}$$

and from the condition that the two circles roll against each other without slipping the following:

$$b_0\omega = a_0\varphi \quad or \tag{7}$$

$$\varphi = \left(\frac{b_0}{a_0}\right)\omega \tag{8}$$

So in that case:

$$\alpha = \left[\frac{b_0 - a_0}{a_0}\right]\omega \tag{9}$$

In substitution of (5) and (9), the coordinates of point M_2 of the relative trajectory are determined by the equations:

$$x = (b_0 - a_0)cos\omega + e\cos\left[\frac{b_0 - a_0}{a_0}\right]\omega \tag{10}$$

$$y = (b_0 - a_0)sin\omega + e\sin\left[\frac{b_0 - a_0}{a_0}\right]\omega \tag{11}$$

The maximum deviation Δx from the exact rectilinear shape of the multi-walled part is at a point of relative trajectory with the coordinate $x=x_0$, obtained at $\omega=0^0$. Then:

$$\Delta x=x_0-x_1 \tag{12}$$

The second term $x_1=x$ on the right side of the equation (12), his coordinate $y_1=y$ determine the position of the outline point from origin line area of part, for angle $\omega_1=\omega$.
Substitution of the last three equations in (10) and (11) and after minor processing results we get:

$$x_1 = (a_0 - e)cos\omega_1 \tag{13}$$

$$y_1 = (a_0 + e)sin\omega_1 \tag{14}$$

Considering that: $b_0=2a_0$,

$$x_0 = (a_0 - e) \tag{15}$$

Substitution of (13), (14) and (15) in (12), the magnitude of the maximum deviation of the part from its theoretical rectilinear shape is determined by the equation:

$$\Delta_x = (a_0 - e)(1 - cos\omega_1) \tag{16}$$

With the number of sides of the multi-walled part n=2,4,6,8… the ordinate y_1, are determined by the equation:

$$y_1 = r.\sin\left(\frac{\pi}{n}\right) \tag{17}$$

After replacing the right side (17) in the equation (14), we get equation for determinate the value for angle ω_1:

$$\frac{\omega_1 = arc\sin\left[r.\sin\left(\frac{\pi}{n}\right)\right]}{a_0 + e} \tag{18}$$

It is know that the radius of curvature ϱ at a point of any non-linear trajectory represented by its Cartesian coordinates is determined by the equation:

$$\rho = \frac{\left[1+\left(\frac{dy}{dx}\right)\right]^{\frac{3}{2}}}{\frac{d^2y}{dx^2}} \tag{19}$$

So the last equation will be:

$$\frac{dy}{dx} = \frac{cos\omega+\frac{e}{a_0}cos\left(\frac{b_0-a_0}{a_0}\omega\right)}{-sin\omega+\frac{e}{a_0}sin\left(\frac{b_0-a_0}{a_0}\omega\right)} \tag{20}$$

In the perceived relationship between the rotational motions of the tool and the stock, the relationship between the circles connected to the two elements of the kinematic pair is represented as follows: $b_0=2a_0$. In that case the equation for dy/dx, gets his final appearance:

$$\frac{dy}{dx} = \frac{(e+a_0)cos\omega}{(e-a_0)sin\omega} \tag{21}$$

It is know that:

$$\frac{d^2y}{dx^2} = \frac{\frac{d^2y}{d\omega^2}\cdot\frac{dx}{d\omega}-\frac{d^2x}{d\omega^2}\cdot\frac{dy}{d\omega}}{\left(\frac{dx}{d\omega}\right)^3} \tag{22}$$

then:

$$\frac{d^2y}{dx^2} = \frac{-(e+a_0)}{(e-a_0)sin^3\omega} \tag{23}$$

Substitution of dy/dx and $d^2 y/dx^2$ in equation for determined the radius *r* of the curvature of the multi-walled part is obtained:

$$r = \frac{[-(e+a_0)^2]}{e} - a_0 \tag{24}$$

3. Conclusions

Determining the deviation *Dx*, according to an algorithm developed in accordance with the described study, allows to estimate the magnitude of the deviation when machining multi-walled parts with different number of sides (Table 1.)

Table 1. Machining multi-walled parts with different number of sides.

	Number of sides	**Deviation**
For parts with	n=4	$\Delta_x = 0.09 - 0.17$ mm
For parts with	n=6	$\Delta_x = 0.05 - 0.11$ mm
For parts with	n=8	$\Delta_x = 0.02 - 0.007$ mm

This method of machining allows receipt multi-walled parts with 3-4 degrees of accuracy, they meet the engineering products to which medium technical requirements are imposed. The proposed method is the most rational in comparison to the other two designed for a similar purpose, one of them practically

unrealized. Its application has been appropriate for both technical and economic reasons where such production is required.
This method can be implemented on existing equipment for example Lathe CNC machine, such as the type of lathe 401 FKCS, in accordance with which this machine tool operates, get upgrade with another rotary motion, kinematically related to the available. The transition between 401 to 701 FKCS would ensure the appropriate nature of the relative trajectory. For this purpose it is necessary to design and construct a relatively simple device, which should be integrated into the basic structure of the lathe.
Another approach is selected by the German company HAHN& KOLB - Stuttgart. According to the proposed by Academician “Granovsky G.I.” [7] kinematics, the same company produces automatic machines for the production of multi-walled parts with maximum profile sizes in the range of 3 to 40mm. The machines manufactured by this company find a market not only in the Federal Republic, but also in Italy, Austria, Australia and the countries of South and North America.
This method allows standard equipment with tools such as multi-wall heads or milling cutters to produce outer or inner multi-wall surfaces, with the minimum radius of the shaping tool being determined by internal machining.
The transition from kinemtic scheme (Figure 1a) requires using different construction tools, and in the design of the manufacturing process it is necessary to look for a combination between the speeds of elementary movements and the scheme of use of the additive.

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