STUDY ON CIRCUMFERENTIAL PROCESSING ON MILLING MACHINES IN 5 AXIS CNC

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Abstract

The front milling is applied to large surfaces with complicated shape.

Side (circumferential) milling is applied to long, narrow and twisted shapes. In the 2 cases, the shape of the processed region differs and will be analyzed separately. The estimation of the positioning error of the tool is necessary when determining the accuracy of the calculations and the approximation of the trajectory. In the case of 3-axis milling, the errors are measured in the normal direction of the surface. These situations rarely occur, but the NC system must have an option for the exact calculation of the diameter of the processed region.

Key words: milling machine, 5 axis CNC,.vectors

INTRODUCTION

To represent a solid we use points and vectors. The difference between them is that the vectors are the difference between 2 points and they are not related to a certain point in space; they only have direction and mode. The sum and difference of 2 vectors is a vector, the difference of 2 points is also a vector, but the sum of 2 points does not make sense.

We will note the lower case vectors, and the capital letters.

Transforming objects involves changing position, orientation and shape. The set of transformations, essential in geometric modelling, includes the movements of the rigid solid (translation and rotation), symmetry, scaling and their overlays.

All these are particular cases of general blueberry Euclidean transformation. A related transformation is the overlap between a translation and a linear transformation.

In a cartesian coordinate system, a linear transformation of a vector can be described as follows:

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \begin{bmatrix} L_1^1 & L_1^2 & L_1^3 \\ L_2^1 & L_2^2 & L_2^3 \\ L_3^1 & L_3^2 & L_3^3 \end{bmatrix} \cdot \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix}$$

or $v=L\cdot u$. Here u is the vector before, and v is the vector after transformation. The matrix L is called the transformation matrix. (Derecichei et al., 2015)

The fact that a vector is invariant in space implies the idea that the transformation to be refined is reduced to a linear transformation. The affine transformation of a point is described by the formula:

$$W=L\cdot U+t.$$

MATERIAL AND METHOD

Circumferential processing on 5-axis milling machines

This procedure is especially applicable to long and twisted surfaces (fig.1)

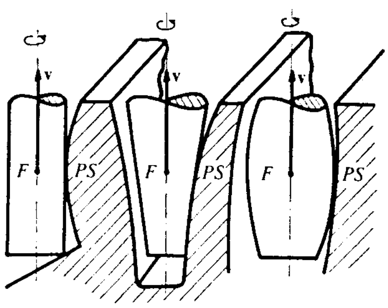

Fig. 1 The processing of a long and twisted surface

Processing of the surfaces covered with cylindrical tools (Derecichei et al., 2013, 2014)

There is a surface defined by 2 curves Q (u) and R (u) and mapping P (u, v) of the form:

$$P(u, v)=v\cdot Q(u)+(1-v)\cdot R(u)$$

We can look at this definition as a family of straight lines W (u) defined as:

$$W(u)= v\cdot Q(u)+(1-v)\cdot R(u)$$

Let a cylindrical tool positioned so as to form a common line W (u), as in fig.2. It can be seen that the tool causes underfeeding. We can minimize the depth e (u) of the undercut by aligning the axis of the symmetrical cylindrical tool, where only the surface between the curves Q (u) and R (u), as seen in fig. 2, is taken into account. https://www.haascnc.com/productivity/5-Axis-Simplified.html

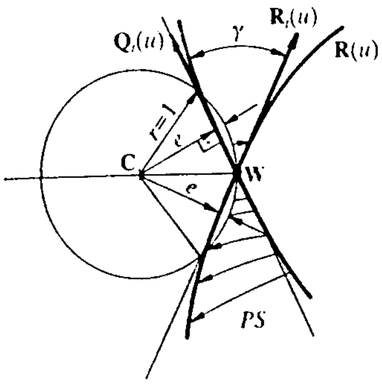

Fig. 2 Positioning of a cylindrical tool

If γ (u) is the angle between the projections of Qu (u) and Ru (u) on a plane perpendicular to W (u), then for small curves of the surface bounded in comparison with the curvature of the tool we obtain:

$$e(u) = 1 - \cos(\gamma/2) = \gamma^2/8$$

For example, if γ = 7 ° and the radius of the tool is 10 mm, we obtain e (u) = 0.0125 mm. (Derecichei, et al., 2013)

It can be observed that the error disappears if γ = 0, namely the vectors Qu (u) and Ru (u) have the same direction. This can only occur if the surface is a curvilinear cone. (Derecichei et al., 2016)

It can be seen that a cylindrical tool can be translated along without changing the distance between the tool and the part. This additional degree of freedom can be eliminated by positioning the tangent tool to an additional guiding surface as in fig. 3. (Derecichei et al., 2015)

If the error e (u) is too large, the tool position must be corrected, but in this case more complicated programming methods, described in the following sections, must be applied.

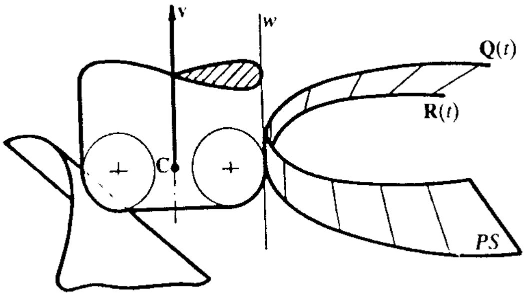

Fig. 3 The tangential position with respect to the guiding surface

RESULTS AND DISCUSSION

Acceptable tool positions

If the tool is positioned as in fig. 4 and x, y, kx, ky are the main directions and curves of the piece, then u, w, ku, kw are the main directions and curves of the tool (Marciniak, 1991; Yoshimi, 2008). We assume ky <kx and ku <kx in the circumferential milling and in addition, we assume that the parallel curvature of the tool is large, that is:

$$k_u<k_w$$

It has been shown before that if φ is the angle between the x and u axes, then the distance between surfaces measured in the direction of the normal verse n can be approximated in the system (P, x, y, n) with:

$$\Delta n=\tfrac{1}{2}\cdot(ax^2+2bxy+cy^2),$$

where:

$$a=k_u\cdot\cos^2\varphi+k_w\cdot\sin^2\varphi-k_x$$
$$b=(k_u-k_w)\cdot\sin\varphi\cdot\cos\varphi$$
$$c=k_u\cdot\sin^2\varphi+k_w\cdot\cos^2\varphi-k_y$$

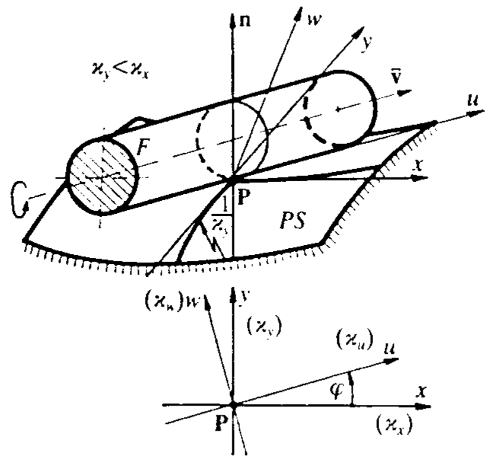

Fig. 4 An acceptable tool position

We distinguish 2 cases:

1. Unrestricted φ angle. If ky≤kx≤ku≤kw then no sub-region appears and all values of φ are admissible. For example, milling a convex surface with a cylindrical tool (Derecichei et al., 2017, 2018).

2. Angle φ restricted. If ky≤ku≤kx≤kw then the potential sub-region

appears and the allowable values of φ are limited by the sub-condition:

$$\frac{(k_u - k_x)(k_w - k_y)}{(k_u - k_w)(k_x - k_y)} = s \le \sin^2 \varphi$$

which can be expressed as: φm≤φ, where φm = arcsin($\pm\sqrt{s}$). Such a situation occurs when milling concave-convex surfaces (kx · ky <0) with a cylindrical milling cutter. https://northwoodmachine.com/products/5-axis-moving-table/

Unrestricted φ angle

In this case ky≤kx≤ku≤kw, no undercutting occurs, and the processed region defined by the condition Δn≤h, where h is processing tolerance, is bounded by the ellipse of fig. 5.

The large semiaxis is inclined to the x-axis with the angle Ψ defined as:

$$\tan 2\Psi = \frac{\sin 2\varphi}{\cos 2\varphi - k}$$, where: $$k = \frac{k_x - k_y}{k_u - k_w}$$.

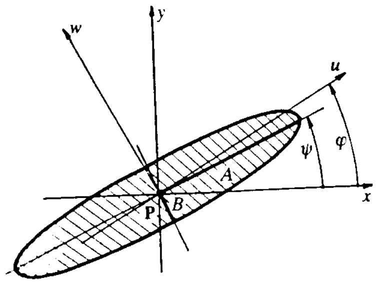

Fig. 5 The elliptical margin of a processed region

The maximum bandwidth is obtained for φ = 0 and γ = 0.

The projection of the tool axis on a tangent plane T is parallel to x, and the speed of the contact point is parallel to the y axis.

We find Ψ = 0 and the maximum width is dm = 2Amax.

In fig. 6 shows a typical example of the effect of the difference of curvature kx-ky on the maximum width of the processed strip.

If long and twisted surfaces are processed, we can further assume that the main curvature of the tool parallel is much larger than other curves.

In this case we can assume that ku – kw = kw.

It follows that k = 0, φ = Ψ and semiaxele ellipse region to be processed:

$$A = \sqrt{\frac{2h}{k_u + (k_x \cos^2 \varphi + k_y \sin^2 \Psi)}}$$ și B=0

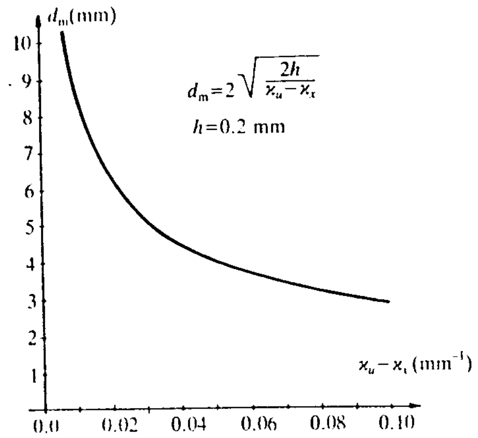

Fig. 6 The maximum width of the processed strip as a function of curvature difference

Substituting in the definition of the width of the processed strip we obtain:

$$d(\varphi, \gamma)=2A\cdot\cos(\gamma-\varphi)$$

In circumferential milling we are usually forced to move the tool along a predefined contact point trajectory and thus the maximum bandwidth is rarely obtained. www.gefanuc.com

This function is illustrated in fig. 7.

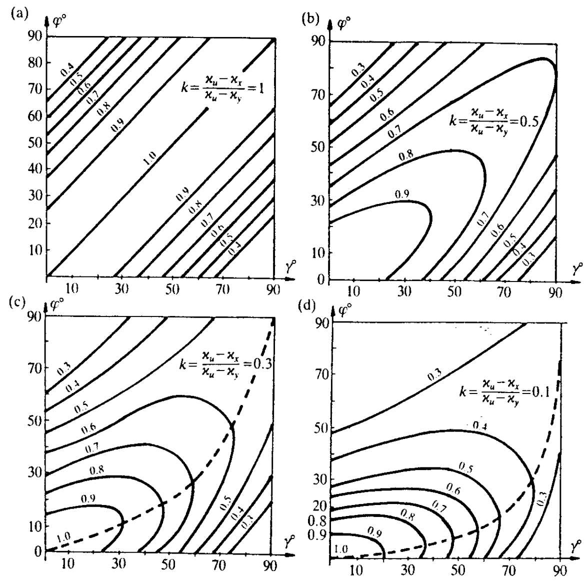

Fig. 7 Function ε(φ, Ψ)

In the case of almost spherical surfaces (fig. 7a), the optimal positions of the tool are defined by the condition φ = Ψ. https://northwoodmachine.com/materials/wood-cnc-routers/

When the difference of the curves of the surface is much greater than the difference between the smallest curvature of the tool and the largest curvature of the surface, that is kx – ky >> ku – ky (for example k = 0.1 << 1) as in fig. 7d, the tool position with cu = 0 must be chosen.

The intermediate effects of φ on the width of the processed strip are shown in fig. 7b and 7c

Angle φ restricted

In this case ky≤ku≤kx≤kw, the potential sub-region appears and the permissible values of φ are limited by the sub-condition:

$$\frac{(k_u - k_x)(k_w - k_y)}{(k_u - k_w)(k_x - k_y)} = s \leq \sin^2 \varphi$$

The maximum bandwidth is obtained if the tool position is defined by the angle $\varphi=\varphi_m=\arcsin(\pm\sqrt{s})$. In this position both paraboloids representing the tool and the surface are tangent along a common parabola. The machined strips are large except for the movement of the contact point P defined by the angle φ_m.

The particular case of a convex-concave surface processed by a cylindrical tool is characterized by the conditions $k_u=0$, $k_w=1/R$, și $k_y<0<k_x$. By replacing these values in the previous relation, we obtain:

$$\varphi_m(R) = \arcsin\sqrt{\frac{k_x \cdot (1 - Rk_y)}{k_x - k_y}}$$

In practical cases we can approximate this function with its Taylor series development at R = 0:

$$\varphi_m(0) \cong \varphi_a(R) = \varphi_m(0) + \frac{d\varphi_m}{dR}(0) \cdot R \ ,$$

where:

$$\varphi_m(0) = \arcsin\sqrt{\frac{k_x}{k_x - k_y}} \qquad \text{and} \qquad \frac{d\varphi_m}{dR}(0) = \sqrt{\frac{-k_x k_y}{2}}$$

The error in this approximation can be estimated by analyzing the following parameters:

1) for k_x=–k_y=0.1, get:
$\Phi_m(0)=45°$, $\varphi_m(1)=47.87°$, and $\varphi_a(1)=47.86°$
2) for k_x=–k_y=0.2, get:
$\varphi_m(0)=45°$, $\varphi_m(1)=50.77°$, and $\varphi_a(1)=50.73°$

CONCLUSIONS

Finally, it should be specified that at the circumferential milling the processed region can be so large that the paraboidal approximation can be satisfactory only as a model for a first estimation of the tool position. For example, using angles φ slightly larger than φm to avoid undercutting is a good practice. In the case of spherical surfaces the extreme is flat and even large deviations from the optimum values do not cause a substantial decrease in the width of the processed strip, and when the difference of the curvature of the surface is much greater than the difference between the smallest curvature of the tool and the greatest curvature of the surface the extreme is flat and even large deviations from the optimal values can be acceptable.

It is also recommended that the visual inspection of the underfloor condition on a graphical screen as a final verification of the programmed trajectory of the tool.

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