The design of the wings tapered plug cutter

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Abstract. The existing processing methods of machining parts with an array of micro-cylinders (The small mold punch and spinneret micro-porous electrode) is circumferential milling which has the following three major problems (1) longer cutting tool path, (2)difficulty of accuracy guarantee, (3) complex processing. For this reason, this paper proposes a new way of processing - plunging, it has high efficiency, simple process, small cutting force, etc. For plunge milling process, the wings tapered plug cutter is designed.

Introduction

Spinneret plate is an important part in textile machinery, the microspore on the spinneret plate has a great impact on fiber forming process and quality because of the dimensional tolerances and finish effect. There are thousands of guiding holes on each nozzle spinneret plate, as can be seen from the Figure1, Figure 2. We usually use EDM to process the cone-shaped guide hole, and the electrodes' precision has a great impact on the accuracy of the tapered guide hole. The parts diagram of Figure 2 is shown in Figure 3. Usually we use peripheral milling to machine the parts which have micro-arrays containing the work piece cone, like Figure 4, and it's not only inefficient but also difficult to guarantee the accuracy. This paper proposes a new process for this type of work piece, like Figure 5, and this way is not only efficient, but also easy to ensure accuracy. To achieve this processing method, a special cutter - wings tapered plug cutter was designed.

Figure 1 Plate-shaped spinneret

Figure 2 Rectangular spinnerets

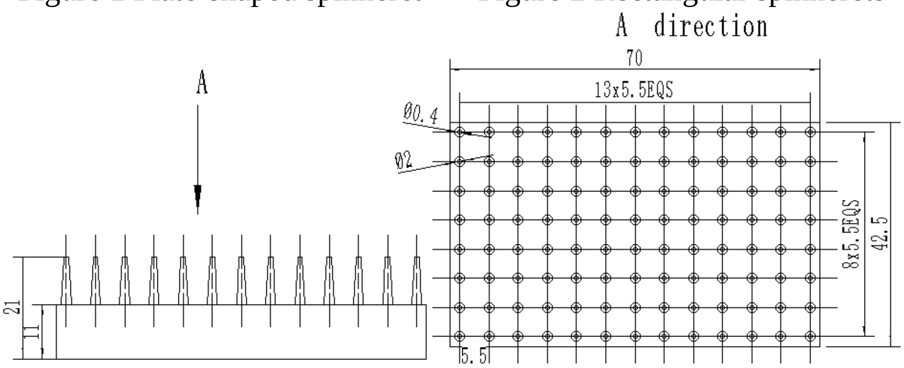


Figure 3 Tapered guide hole electrode in spinneret plate

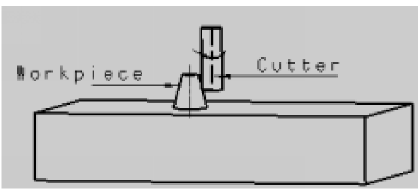


Figure 4 Peripheral milling

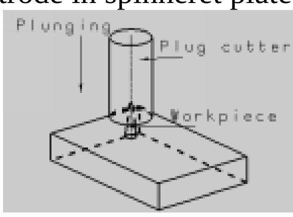


Figure 5 Plunge milling

Plunge milling for cylindrical array

The electrode in Figure 3 needs rough milling and finish milling processes. To obtain a large enough power, lower spindle speed was adopted in rough milling, while finish milling needs a high spindle speed, which can be seen in Table 2 below.

Plunge Milling also known as the Z-axis milling method, the cutting tool feed along with the tool axis direction, using the cutting edge, located in bottom of cutting tool, to drilling and milling[1-2]. Compared with the side milling, plunge milling has less radial cutting force, but more axial cutting force, which benefit more stable and less vibration [3], especially suite for large allowance removal process or long cutting tool condition. Plunge milling is an axial linear feed movement from the processing craft.

Adaptability analysis for machining micro array cylindrical

Efficiency analysis for processing array micro-cylinder. The existing milling method for Figure 3 is peripheral milling; the diameter of cutter is 2mm, and the processing parameters in Table 1. The milling tool path can be designed from UG's CAM module, like Figure6, and the process takes for 24,006 seconds, as shown in Figure 7. While the plunge milling uses the tool having a diameter of 8 mm, and rough milling is to clear residual material between cylinders, the shaded parts in Figure 8 is the intersection of milling cutter, and the processing parameters in Table 2, with the tool path from UG's CAM module, it takes for 2418 seconds, shown in Figure 10.

Table 1 Parameters of peripheral milling

	Spindle speed(r/min)	Cutting depth(mm)	Feed rate(mm/min)
Rough milling	2000	1	1000
finish milling	3000	0.1	1400

Table2 Parameters of plunge milling

	Spindle speed(r/min)	Cuttingdepth(mm)	Feed rate(mm/min)
Rough milling	3500	10	600
Finish milling	8000	10	1000

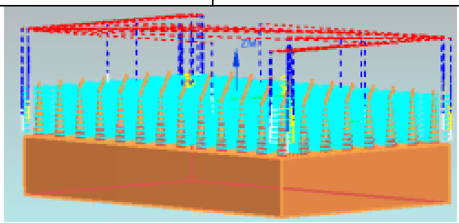


Figure 6 Tool paths for peripheral milling

名称	刀轨	刀具	时间	长度	几何体	方法	进给
GEOMETRY			00:40:06	56803.4			
未用项			00:00:00	0.0			
MCS_MILL			00:40:06	56803.4			
WORKPIECE			00:40:06	56803.4			
CAVITY_MILL	✔	D2	00:28:58	31339.1	WORKPIECE	MILL_ROUGH	1000 mmpm
ZLEVEL_PROFILE	✔	D2R1	00:10:44	25464.3	WORKPIECE	MILL_FINISH	1400 mmpm

Figure 7 Circumferential milling time spinneret electrode

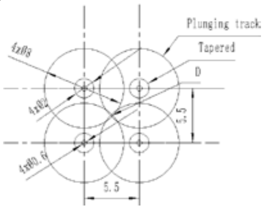


Figure 8 Schematic diagram of plunge milling

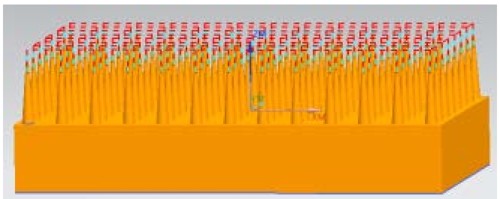
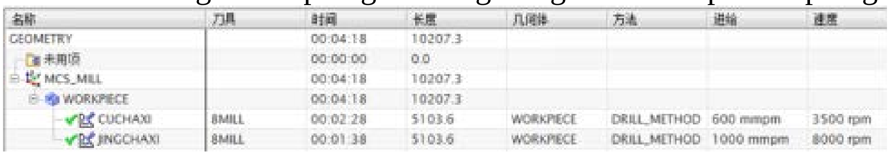


Figure 9 Tool path of plunge milling



名称	刀具	时间	长度	几何体	方法	进给	速度
GEOMETRY		00:04:18	10207.3				
未用项		00:00:00	0.0				
MCS_MILL		00:04:18	10207.3				
WORKPIECE		00:04:18	10207.3				
CUCHAXI	8MILL	00:02:28	5103.6	WORKPIECE	DRILL_METHOD	600 mmpm	3500 rpm
JINGCHAXI	8MILL	00:01:38	5103.6	WORKPIECE	DRILL_METHOD	1000 mmpm	8000 rpm

Figure 10 Processing time of plunge milling

Accuracy analysis for machining an array of micro-cylinders. Currently we use peripheral milling to machine a work piece with an array of micro-cylinders, like Figure 11. Because of the stiffness of work piece, causing a shape error of the work piece. However, the design of wings tapered plug cutter has solved these problems, the inside pair of symmetrical cutter cutting edges guaranteed the cone shape with the balanced force, improving the machining accuracy of the work piece.

Figure 11 Peripheral milling micro-cylinders

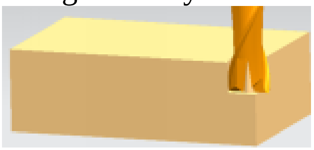


Figure 12 Plunge milling micro-cylinder

General analysis for wings tapered plug cutter. The shape and precision of micro-cylinder on work piece are guaranteed by a pair of internal cutting edges. The size and shape of the cutting tool have to change with the micro-cylinder. The diameter of cutting tool is limited when the space is not big enough. But the high-efficiency and good accuracy of the wings tapered plug cutter cannot be ignored.

Modeling of the wings tapered plug cutter

The main structure size are: the main relief angle α=15°, rake angle γ=10°, entering angle kr=90°, Helical angle $\omega = 30°$, auxiliary angle $\varphi = 3°$, relief and rake angle of internal cutting edge are 15°.The model designed by UG is shown in Figure 13.

Figure 13 The wings tapered plug cutter

Plunge milling force

There are 6 cutting edges, two main edges, two outside edges and two inside edges. The cutting force F_{x1} and F_{x2}, the radial force F_y and F_{y1}, the axial force F_{z1} and F_{z2} of each edge are shown in Figure 14. From the Figure 14, the radial force are two pairs of balance force, the total axial force F_z, and the total tangential force F_x are:

$$F_z = 2F_{z1} + 2F_{z2} \quad (1)$$

$$F_x = F_{x1} + F_{x2} \quad (2)$$

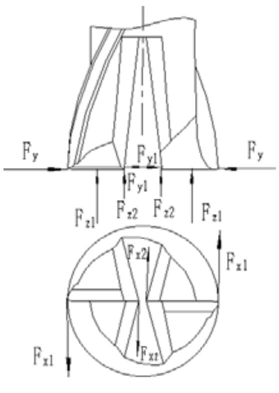


Figure 14 Plunge milling force

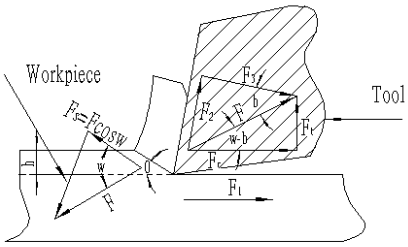


Figure 15 Binary orthogonal cutting model

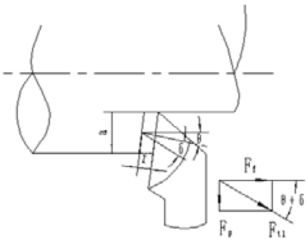


Figure 16 Inclined cutting

Cutting force on the end of main edge. Simplifying the wings tapered plug cutter to Binary orthogonal cutting model, shown in Figure 15, the forces on the main edge are:

Plowing force F.

$$F = bh\tau_s / \sin\Phi \cos\omega \quad (3)$$ [4]

Where: b is the width of cut, h is the thickness of the cutting, Φ is the shear angle, ω is the angle F with a shear plane, τ_s is the shear deformation stress.

4.1.2 The cutting force and friction force of rake face are:

$$F_c = F\cos(\omega - \Phi) = bh\tau_s(ctg\Phi - tg\omega) \quad (4)$$

From the Formula 11, we can know that friction force F_2 is the product of the average friction stress and contact area [4]:

$$F_2 = bl_c\overline{\tau_s} = k_c k_m h\tau_s \sin(\Phi + \beta - \gamma) / \sin\Phi\cos\beta \quad (5)$$

Where: $\overline{\tau_s}$ is the average frictional stress on the rake face, τ_s is the processing shear stress, which equals to τ_s, k_c is the ratio of real contact area and appearance of the contact area, which is a constant of about 0.8, k_m is the ratio of the appearance of the contact length and the theory contact length, which is a constant of about 2.0.

According chip hardness and shear stress have the following relationship:

$$\tau_s = H_v / C(C = 5.20 \pm 0.15) \quad (6)$$

Where: H_v is Webster hardness value.

4.1.3 Force in flank surface of cutting tool F_t and friction stress F_1

$$F_t = F\sin(\omega - \Phi)bh\tau_s(ctg\Phi tg\omega - 1) \quad (7)$$

$$F_1 = bl_f\tau_f \quad (8)$$

Where: l_f is the contact length of flank surface of cutting tool and machined surface, τ_f is the average stress in the contact portion.

It can be inferred that the τ_c equals τ_f from Okoshi and Sada's experiment, while the contacting state is not quite like the rake face, may be considered $\tau_c = \tau_f$, and lf usually less than a tenth of l_c. Thus the friction stress is so small that can be neglect.

From the Figure we can know the relation between the front rake angles γ and β, Φ ω is:

$$\omega = \Phi + \beta - \gamma \quad (9)$$

The cutting force can be calculate from Φ and ω. Calculating the front rake angle with M. E. Merchant formula, the result is 34.5̊.

In Figure 14, the horizontal resultant F_{xo} and vertical resultant F_{zo} on the tool are as follows:

$$F_{xo} = F_c + F_1 \quad (10)$$

$$F_{zo} = F_t + F_2\cos\gamma \quad (11)$$

Figure 16 shows the oblique cutting of inner blade, the feeding resistance F_p can be expressed as:

$$F_p = F_{t1}\sin(\theta + \delta)$$

$$= af\tau_s(ctg\Phi tg\omega - 1)\sin(\theta + \delta) \quad (12)$$

Where: F_{t1} for turning resistance, θ for cutting velocity angle, δ for approach angle, a for depth of cut, f for cutting depth.

The known parameters are as follows:

$\gamma = 10°$, $h = 0.1mm$, $b = 3mm$, $\Phi = 34.5°$, $H_v = 205$, $\omega = 45°$, $\theta = 0°$, $\delta = 7°$, $a = 10.03$mm , $f = 0.1mm$, $F_p = F_{z2}$.

The total axial force F_z and total tangential force F_x:

$$F_z = 2F_{z1} + 2F_{z2} = 2F_{zo} + 2F_p = 34.32(N) \quad (13)$$

$$F_x = F_{x1} + F_{x2} = 2F_{xo} = 10.6(N) \quad (14)$$

From the analysis the process of the wings tapered plug cutter, radial forces F_y balance each other, and tangential force F_x is 10.6N, and the biggest force axial force F_z is 34.32N. Thus, the tool is not subject to cutting force, the deformation of cutter tool and work piece can be accepted, improving the durability of the machining accuracy and tool.

Summary

Compare the time consuming of peripheral milling and plunge milling, the plunge milling is more efficiency. The work piece bear the force from one direction when peripheral milling, while a pair of balance forces when plunge milling, which is easier to guarantee the accuracy. The model and analysis of cutting tool provide the basis for deformation and durability of cutter tool. After analysis and verification, the milling cutter has a reliable performance to meet the requirement of the enterprise, not only solved the problem of time-consuming processing spinnerets electrode, but improving the machining accuracy.

References

[1] Altintas Y, Ko J H. Chatter stability of plunge milling [J]. Annals of the CIRP, 2006, 55 (1): p. 361-364.

[2] Ko JH, Altintas Y. Time domain model of plunge mill in go peration [J]. Machine Tools and Manufacture, 2007, 47: p.1351-136

[3] Wakaoka S, Yamane Y, Sekiya K, et al.High-speed and high-accuracy plunge cuttin g for vertical walls [J]. Materials Processing Technology, 2002, 127 (2): p. 246-250.

[4]Zhongshan Kazuo (Japan) with Liyun Fang translation.Metal cutting theory [M].Beijing: Mechanical Industry Press .1985: p. 93-128.