OPTIMIZING THE CUTTER FOR SLANTING KNIFE CUTTING OPERATION AND ITS BLANKING FORCE①

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ABSTRACT

The cutting force under a slanting cutter is discussed. It is not only related to the sheet to be cut and the slanting cutter height, but also to the shape of the cutter. It is from this point of view that the question of optimizing the cutter for slanting knife cutting operation is addressed. Then the general differential equations for the optimum cutter are obtained, and analytic solutions for the workpiece, the contour of which consists of straight lines and arcs, are obtained. A method for solving the general equations is also presented.The cutting force and breaking noise will be minimized for a given slanting cutter height and workpiece if the optimum cutter is employed.

Key words: slanting knife cutting operation; blanking force optimum cutter

1 INTRODUCTION

Because the seperation of material is continuous in the slanting knife cutting operations, the cutting force and the breaking noise can be effectively reduced. The operation is especially suited for blanking and trimming for large size or thick sheet. At present the force of slanting knife cutting operations is considered to be 0.15–0.6 times the force coresponding to a flat cutter in the general literature papers. Analysis shows that different cutter shapes produce greatly different cutting forces even under the same slanting cutter height. Then what kind of cutter shape makes the force and the noise smallest? It's just a question of optimizing the cutter shape for slanting knife cutting operations[1–4].

The optimum single peak cutter for axially symmetric parts and the cutting force under a slanting cutter will be discussed first. Then, the results will be extended to the multiple peak cut and the general sheet. Regardless of whether the slanting cutter is put on a punch or die, the analysis and conclusions do not change. Therefore, only a slanting cutter on punch is discussed.

2 THE CUTTING FORCE ON AXIALLY SYMMETRIC PARTS WITH A SINGLE PEAK CUTTER

2.1 *Cutting Force of General Axially Symmetric Part*

Assuming an axially symmetric piece, as shown in Fig. 1a , take curve $\widehat{CD}$, 1 / 4 of the contour, to be analysized. $\widehat{AB}$ is the curve segment i in $\widehat{CD}$, expressed as $r = r(\varphi)$ or $y = y(x)$ in a coordinate system with a y axis parallel to the generatrix of the cutter $f = f(u)$ cylinder. Supposing that the cutting stroke u is getting into curve segment i, and cutter $\widehat{ab}$ is acting with the material to be cut, then the local cuting force on $\widehat{ab}$ shall be the product of

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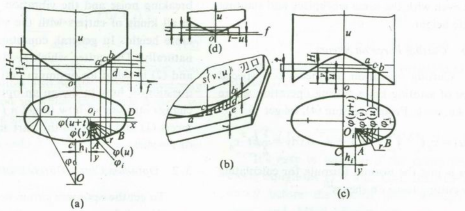

Fig. 1 Slanting knife cutting operation analysis for an axially symmetric workpiece

the material cross area under ab times τ_o, the shearing stress limit of the material. Take $u < v < u+t$, and the arc length cd $= s(v, u)$ (hereafter called effective arc length)corresponding to v is:

$$s(v,u) = \int_{\varphi(v)}^{\varphi(u+t)} \sqrt{r^2 + r'^2}\, d\varphi \quad (1)$$

effectrive area

$$F(u) = \int_u^{u+t} s(v,u) dv \quad (2)$$

The parameters in fomulas (1) and (2) are shown in Fig. 1a. Of these parameters, $\varphi(u)$ can be calculated by

$$f(u) = r\sin\varphi(u) + h_i \quad (3)$$

Then the cutting force corresponding to u is

$$P(u) = 4\tau_0 \int_u^{u+t} \int_{\varphi(v)}^{\varphi(u+t)} \sqrt{r^2 + r'^2}\, d\varphi dv \quad (4)$$

With cartesian coordinates similar analysis can be made:

$$P(u) = 4\tau_0 \int_u^{u+t} \int_{f(v)}^{f(u+t)} \sqrt{1 + y'^2}\, dx dv \quad (4)'$$

When the punch dosen't go through the sheet (see Fig. 1d), the effective arc length can be written as

$$\left. \begin{aligned} & s(v,u) = \int_{\varphi(v)}^{\varphi(u)} \sqrt{r^2 + r'^2}\, d\varphi \\ & (0 \leqslant u < t) \end{aligned} \right\} \quad (5)$$

or

$$\left. \begin{aligned} & s(v,u) = \int_{f(v)}^{f(u)} \sqrt{1 + y'^2}\, dx \\ & (0 \leqslant u < t) \end{aligned} \right\} \quad (5)'$$

and the effective area $F(u)$ can be written as

$$\left. \begin{aligned} & F(u) = \int_0^u s(v,u) dv + s(o,u)(t-u) \\ & (0 \leqslant u < t) \end{aligned} \right\} \quad (6)$$

the cutting force becomes

$$P(u) = 4\tau_o F(u) \quad (0 \leqslant u < t) \quad (7)$$

For a concave cutter in a coordinate system as shown in Fig. 1c, $\varphi(u)$ is calculated by

$$f(u) = r\cos\varphi(u) + h_i \quad (8)$$

All the formulas above are suited for the corresponding cutting force calculations.

2.2 *Cutting Force of a Circular Part Under Slanting a Flat Cutter*

The shape of a convex flat cutter is given by $f = (au / H)$, where H is the slanting knife height, and the radius of the circular part is $r = a$. Thus from equations (1)~(4), we get:

$$\begin{aligned} P_{max} &= P|_{u=H-t} \\ &= 4a\tau_0 \{\sqrt{H^2 - (H-t)^2} - \\ & (H-t)\cos^{-1}[(H-t)/H]\} \end{aligned} \quad (9)$$

If the cutter is concave, $f = a(H-u) / H$, the maximum force is given by

$$P_{max} = 4a\tau_0 [\alpha(H\cos\alpha + t) - H\sin\alpha] \quad (10)$$

where α is the root of equation $\alpha\sin\alpha - t / H = 0$. It's easy to work out that when $t / H = 0.1 \sim 1.0$, the ratio of equations (9) to (10) is about 2. This means that the cutting forces under different shape cutters are greatly different even with the same workpiece and slanting knife height.

2. 3 *Cutting Force on Shears*

Cutting operation on shears is a special type of slanting knife cutting operation where $f=ku, y=b$. From equation (4), we get

$$P(u)=\tau_0\int_u^{u+t}\int_{kv}^{k(u+t)}\sqrt{1+y'^2}\,\mathrm{d}x\mathrm{d}v=\frac{1}{2}kt^2\tau_0$$

this is just the normal formula for calculating the cutting force on shears[2].

3 OPTIMUM CUTTER DIFFERENTIAL EQUATIONS AND OPTIMUM CUTTER FOR AXIALLY SYMMETRIC PARTS

3. 1 *Target Analysis*

The tool designer always hopes that the cutting force first increases slowly with cutting stroke and then reduces slowly, and that the maximum force is small. Thus, he can decrease the tonage of the equipment, the breaking noise and the elastic energy which is stored and released in a working cycle. Of course, the cutting force can be reduced by increasing the slanting knife height, but the approach is limited by the tool life, the workpiece deflection and the equipment stroke. Then, what kind of cutter can make the force and the noise smallest for a given H?

Imagine a cutter $f=f(u)$which meets the following criteria:

(1) The force is an increasing function of the punching stroke when the punch dosen't go through the sheet;

(2) The force remains constant when the punch goes through;

(3) Finally, the force slowly reduces to zero.

when the cutter shape meets these three conditions, the distribution of the force with u is most even, so that the maximum force, the breaking noise and the vibration are smallest in all kinds of cutters with the same slanting kinfe height. In general, condition (3) is met naturally. The cutter which $f=f(u)$ meets (1) and (2) is called an optimum cutter. Now the question of how to design an optimum cutter changs into one of how to get a $f=f(u)$ which meets (1) and (2) from the part shape $r=r(\varphi)$ or $y=y(x)$.

3. 2 *Optimum Cutter Differential Equations*

To get the optimum cutter, consider equation (1) and change equation (4) into:

$$P(u)=4\tau_0\int_u^{u+t}s(v,u)\mathrm{d}v$$

According to the law of differentiation of integrals with varying parameters, we get

$$\frac{\mathrm{d}P(u)}{\mathrm{d}u}=4\tau_0[\int_u^{u+t}\frac{\partial s(v,u)}{\partial u}\mathrm{d}v+s(u+t,u)-s(u,u)]$$

To make cutter $f=f(u)$ meet condition(2), put $\mathrm{d}P(u)/\mathrm{d}u=0$, i. e.

$$\int_u^{u+t}\frac{\partial s(v,u)}{\partial u}\mathrm{d}v+s(u+t,u)-s(u,u)=0 \quad (11)$$

Obviously, condition (1) is also an integral with varying parameters. This results in the following equation

$$\frac{\partial s(v,u)}{\partial u}=\sqrt{r^2+r'^2}\mid_{\varphi=\varphi(u+t)}\cdot\varphi(u+t)$$

Thus,

$$\int_u^{u+t}\frac{\partial s(v,u)}{\partial u}dv=t\sqrt{r^2+r'^2}\mid_{\varphi=\varphi(u+t)}\times\varphi'(u+t) \quad (12)$$

Again it's easy to get from equation (1)

$$s(u+t,u)=\int_{\varphi(u+t)}^{\varphi(u+t)}\sqrt{r^2+r'^2}\,\mathrm{d}\varphi\equiv 0 \quad (13)$$

$$s(u,u)=\int_{\varphi u}^{\varphi(u+t)}\sqrt{r^2+r'^2}\,\mathrm{d}\varphi \quad (14)$$

Putting equation (12), (13) and (14) into equation (11) yields

$$t\cdot\sqrt{r^2+r'^2}\mid_{\varphi=\varphi(u+t)}\cdot\varphi'(u+t)-\int_{\varphi(u)}^{\varphi(u+t)}\sqrt{r^2+r'^2}\,\mathrm{d}\varphi=0 \quad (15)$$

Similarly Cartesian coordinates

$$t \cdot \sqrt{1+y'^2}\,|_{x=f(u+t)} \cdot f'(u+t) -$$

$$\int_{f(u)}^{(u+t)} \sqrt{1+y'^2}\, dx = 0 \qquad (15)'$$

In order to make the cutter optimum, condition (1) must also be met. Thus, considering the situation in which the punch dosen't go through the sheet, from equation (7),

$$\frac{dP(u)}{du} = 4\tau_0 \frac{dF(u)}{du}, \quad (0 \leqslant u < t) \qquad (16)$$

From equation (6)

$$\left.\begin{aligned} &\frac{dF(u)}{du} = \int_o^u \frac{\partial s(v,u)}{\partial u} dv + s(u,u) + \\ &\frac{ds(0,u)}{du}(t-u) - s(0,u) \\ &(0 \leqslant u < t) \end{aligned}\right\} (17)$$

From equation (5),

$$\frac{\partial s(v,u)}{\partial u} = \sqrt{r^2 + r'^2}\,|_{\varphi=\varphi(u)} \cdot \varphi'(u)$$

$$(0 \leqslant u < t)$$

$$\int_o^u \frac{\partial s(v,u)}{\partial u} dv = |u \cdot \sqrt{r^2 + r'^2}\,|_{\varphi=\varphi(u)} \varphi'(u)$$

$$(0 \leqslant u < t) \qquad (18)$$

$$s(0,u) = \int_{\varphi(0)}^{\varphi(u)} \sqrt{r^2 + r'^2}\, d\varphi, \quad (0 \leqslant u < t) \qquad (19)$$

Thus,

$$\left.\begin{aligned} &\frac{ds(0,u)}{du} dv = \sqrt{r^2 + r'^2}\,|_{\varphi=\varphi(u)} \varphi'(u) \\ &(0 \leqslant u < t) \end{aligned}\right\} (20)$$

From equation (5) again

$$\left.\begin{aligned} &s(u,u) = \int_{\varphi(u)}^{\varphi(u)} \sqrt{r^2 + r'^2}\, d\varphi \equiv 0 \\ &(0 \leqslant u < t) \end{aligned}\right\} (21)$$

Putting equations (18)~ (21) into equation (17) yields

$$\frac{dF(u)}{dt} = t \cdot \sqrt{r^2 + r'^2}\,|_{\varphi=\varphi(u)} \cdot \varphi'(u) -$$

$$\int_{\varphi(o)}^{\varphi(u)} \sqrt{r^2 + r'^2} d\varphi, \quad (0 \leqslant u < t) \qquad (22)$$

Putting equation (22) into equation(16)

$$\frac{dP(u)}{du} = 4\tau_0 \, [t \cdot \sqrt{r^2 + r'^2}\,|_{\varphi=\varphi(u)} \times$$

$$\int_{\varphi(o)}^{\varphi(u)} \sqrt{r^2 + r'^2}\, d\varphi] \; (0 \leqslant u < t) \qquad (23)$$

In order to make $f=f(u)$ meet (1), put $dP(u)/du > 0 (0 \leqslant u < t)$, i. e.

$$t \cdot \sqrt{r^2 + r'^2}\,|_{\varphi=\varphi(u)} \cdot \varphi'(u) -$$

$$\int_{\varphi(o)}^{\varphi(u)} \sqrt{r^2 + r'^2}\, d\varphi > 0, \quad (0 \leqslant u < t) \qquad (24)$$

In Cartesian coordinates equation (24) is expressed as

$$t \cdot \sqrt{1+y'^2}\,|_{x=f(u)} \cdot f'(u) -$$

$$\int_{f(o)}^{f(u)} \sqrt{1+y'^2}\, dx > 0, \quad (0 \leqslant u < t) \qquad (24)'$$

It's easy to see that if the cutter $f=f(u)$ meets equations (15) and (24), then $dP(u)/du>0$ before the punch goes through the sheet, and $dP(u)/du=0$ after. The cutting force and breaking noise certainly are smallest with this kind of cutter. It's necessary to point out that equation (24) must be met by $f=f(u)$ or a greater cutting force will develop probably before the punch goes through the sheet. Equations (15) and (24) are called optimum cutter differential equations. Obtained by assuming an axially symmetric sheet, they can be applied to general blankings too. Now the question of how to get all optimum cutters is just a question of how to further get a solution from differential equations equations (15) and (24).

3.3 *Optimum Cutter for Circular Blanking*

For circular blanking, $r=a$, $\varphi=\sin^{-1}[f(u)/a]$. From equation (15), the differential equation corresponding to the optimum cutter is

$$t \cdot [\sin^{-1}\frac{f(u+t)}{a}]'_u - \sin^{-1}\frac{f(u+t)}{a} +$$

$$\sin^{-1}\frac{f(u)}{a} = 0$$

and the solution is

$$f(u) = a\sin(Au+B) \qquad (25)$$

According to the boundary conditions, i. e. $f|_{u=0}=0$, and $f|_{u=H}=a$, we have

$$f(u) = a\sin[\pi u/(2H)] \qquad (26)$$

where H is the slanting cutter height. It's easy to see that equation (25) meets equation

(24), and the cutting force under optimum cutter (26) is

$$P = rat^2\tau_0 / H = P_0(t/2H) \qquad (27)$$

where P_0 is the force corresponding to the normal flat cutter.

3.4 *Optimum Cutter for Rhomboidal Blanking*

As shown in Fig. 2a, in Cartesian coordinates, the shape of the blanking is $y = a(1-x/b)$. From equation (15), one finds

$$f'(u+t) = [f(u+t) - f(u)] / t$$

the solution is

$$f(u) = Au + B \qquad (28)$$

Considering that $f|_{u=0} = 0$, $f|_{u=H} = b$, then we have

$$f = bu / H \qquad (29)$$

Equation (27)meets equation (24)′, and the corresponding cutting force is

$$P = 2\sqrt{a^2 + b^2}\, t^2\tau_0 / H = P_0 t / (2H)$$

3.5 *Optimum Cutter for Axially Symmetric Blankings with Contours Which Consist of Straight Lines and Arcs*

Examples are shown in Fig. 2. The optimum cutter corresponding to straight lines on contour can be determined by equation (28), and that corresponding to arcs by equation (26). The continuous, optimum cutter is formed by equations (26) and (28). Limited by length, the analysis is left out and the results are shown below.

The optimum cutter for the piece in Fig. 2c is

$$f(u) = \begin{cases} bu / H_1 \quad (0 \leqslant u < H_x) \\ b - r\sin\varphi_o + r\sin[\pi(u - H_x)/2H_2 + \\ \varphi_o], \quad (H_x \leqslant u \leqslant H_x + H_y = H) \end{cases}$$

where $H_1 = H_x = 4bH / l$;

$H_2 = 2Hr\pi / l$;

$H_y = 4(\pi/2 - \varphi_0) rH / l$;

l—Perimeter of the blanking.

For that in Fig. 2b are given by the following equations

$$f(u) = \begin{cases} r_1\sin[\pi u/(2H_1)], \quad (0 \leqslant u < H_x) \\ r_1\sin\varphi_o + b(u - H_x)/H_2, \\ \qquad (H_x \leqslant u < H_x + H_y) \\ r_1\sin\varphi_o + b - r_2\sin\varphi_o + r_2\sin \\ [\pi(u - H_x - H_y)/(2H_3) + \varphi_o], \\ \qquad (H_x + H_y \leqslant u \leqslant H) \end{cases}$$

where $H_1 = 2r_1\pi H / l$;

$H_2 = 4bH / (l \cdot \cos\varphi_0)$;

$H_3 = 2r_2\pi H / l$;

$H_x = 4r_1 H\varphi_0 / l$; $H_y = H_2$

And for that in Fig. 1a are given by

$$f(u) = \begin{cases} R\sin[\pi u/(2H_1)], \quad (0 \leqslant u < H_x) \\ R\sin\varphi_0 - r\sin\varphi_0 + r\sin \cdot \\ [\pi(u - H_x)/(2H_2) + \varphi_0], \\ (H_x \leqslant u \leqslant H) \end{cases}$$

where $H_1 = 2R\pi H / l$;

$H_2 = 2r\pi H / l$;

$H_x = 4\varphi_0 RH / l$

It can be shown that all the cutters above fulfill equations (15) and (24). And it is necessary to point out that the optimum cutters for these kinds of sheets can be directly written out with no need for obtaining solution from differential equations equations (15) and (24) every time. The corresponding cutting forces can be expressed uniformly as

$$P = P(t/2H)$$

3.6 *An Optimum Cutter for General, Axially Symmetric Pieces*

The general form of equation (15) is

$$G[f'(u+t), f(u+t), f(u), u] = 0,$$

this is a kind of differential equations which has been studied by few people. It's a mathematical theory problem presenting difficulties in finding its general solution. In engineering its solution for blanking can be found with a computer by numerical methods. The method is as follows.

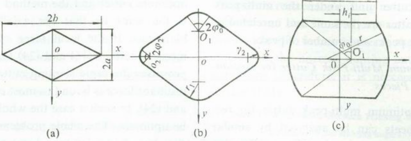

Fig. 2 The axial symmetric blankings the contours of which consist of straight liness and arcs

A function $f=f(u)(0\leqslant u<t)$, for example,

$$f=ku^n \qquad (k>0, 0\leqslant u<t) \qquad (30)$$

can be first given by designer. Then, the values of f corresponding to $u>t$ can be determined from equation (15). A numerical solution of the optimum cutter for an elliptic sheet with different $f=f(u)(0\leqslant u<t)$ is shown in Fig. 3.

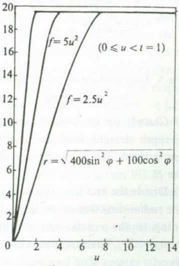

Fig. 3 Numerical value optimum cutter for elliptic sheets

One must pay attention to the following points when seeking a numerical solution: (1) Equation (24) must be met by $f(u)(0\leqslant u<t)$; (2) The numerical solution is probably related to the thickness of sheet t; (3) Giving different $f=f(u)$ $(0\leqslant u<t)$ is tantamount to giving different values of of H; (4) The cutting force is

$$P=4\tau_0\int_0^t\int_{\varphi(v)}^{\varphi(t)}\sqrt{r^2+r'^2}\,\mathrm{d}\varphi\mathrm{d}v$$

or $P=4\tau_0\int_0^t\int_{f(v)}^{f(t)}\sqrt{1+y'^2}\,\mathrm{d}x\mathrm{d}v$

4 OPTIMUM (OR MULTI-PEAK) CUTTER

The multi-peak cutter shall be employed for large sheet owing to the equipment stroke and the sheet deflection. It's considered that the lateral forces of every peak are balanced by another when there are more peaks on the multi-peak cutter. Therefore, the optimum multi-peak cutter can be applied to general blanking pieces.

4.1 *Optimum Multi-peak Cutter for Circular Pieces*

Assuming that there are n peaks on the cutter for circular blanking shown in Fig. 4a, and that the central angle coresponding to peak i is $2\varphi_i$ and defining the radial direction of the peak as the y axis, then it can be found that the optimum cutter for peak i is

$$f_i(u)=r\sin(\pi u/2H_i), \quad (0\leqslant u\leqslant H) \quad (31)$$

where $H_i=\pi H_0/(2\varphi_i)$. The cutting force is

$$P=\sum_{i=1}^{n}P_i=\frac{r}{H}t^2\tau_o\sum_{i=1}^{n}\varphi_i=\frac{r\pi}{H}t^2\tau_o=P_0\left(\frac{t}{2H}\right),$$

where P_i is the local cutting force on peak i. Comparing with equation (27), it's obvious that the cutting forces under the single peak optimum cutter and under the multi-peak optimum cutter are the same and unrelated to the dividing peaks and number of peaks.

4. 2 *Optimum Multi-Peak Cutter for Rectangular Pieces*

The optimum multi-peak cutter for rectangular sheets can be analyzed by similar manner. Select the normal of the straight edge of the cutter as y axis, as shown in Fig. 4b. The width f of peak i is 2b. The optimum cutter for the peak is

$$f_i(u) = ub'_i / H, \quad (0 \leqslant u \leqslant H) \quad (32)$$

and the cutting force is

$$P = (lt\tau_o(t / 2H) = P_o(t / 2H)$$

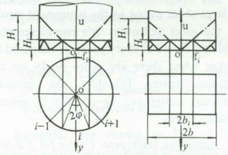

Fig. 4 The multi-peak optimum cutter for axially symmetric sheets

5 OPTIMUM CUTTER FOR GENERAL PIECES

Only the multi-peak cutter can be employed for general blankings considering lateral forces, and there is no need for every peak to be symmetric with respect to its y axis. Assuming that there is a peak at point A on the curve edge (Fig. 5), select a y axis on the basis of ease of calculation. The shapes of the cutter of the peak are $f_1=f_1(u)$ and $f_2=f_2(u)$ respectively. It can be shown by an analysis similar to that in section 2 that if f_1 and f_2 both meet equations (15) and (24), the peak is a local optimum cutter and the method for finding it is the same as that for axially symmetric blankings. If the local force of every peak meets equations (15) and (24) and every peak possesses the same slanting cutter height, the resultant force is bound to meet equations (15) and (24). In such a case the whole cutter shall be optimum. The whole problem of optimization has changed into a local optimiza- tion problem, and the optimum cutter for general sheet can be obtained as follow.

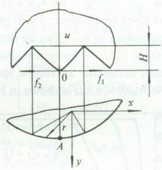

Fig. 5 Local optimizing of the multi-peak cutter for general blanking

(1) Classify the contour of the sheet, arcs as one type, straight lines as another, and others as a third. The slantng cutter height is the same H.

(2) Divide the arcs into appropriate peaks Take the radial direction of every peak as corresponding to the y axis, and determine the central angle, $2\varphi_i$. Then the optimum cutter of peak i is

$$f_i = R_i \sin\frac{\pi}{2H} u,$$

where R_i is the corresponding radius, and $H_i = \pi / 2\varphi_i H;$

(3) Select the normal of the straight line as the y axis. If the width of peak i is $2b_j$, its optimum cutter is

$$f_j = b_j / H \cdot u;$$

(4) Select a y axis according to calcula-

tion convenience for other curves. Get the analytic solution or numerical solution from equations (15) and (24);

(5) By the method explained in seetion 2.5 one can find the analytic solution for arc or straight lines which aren't long enough for one peak if the curves next to it are still arcs or straightlines.

(6) The resultant cutting force is the sum of the cutting forces under every peak.

6 EXPERIMENTAL TEST

The analysis in this paper is based on that the cutting force being the product of the effective area times the shearing stress limit of the material. The goal of the experiment is to verify whether this approach is justified. The experimental results from reference [3] will be compared with the analytic results of this paper. The experimental conditions are: dia 35 mm punches with slanting convex flat cutter and the slanting angles 2, 4, 8, 11 and 15 (°) respectively, and steel sheet with thicknesses of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 mm respectively, $\tau_o = 304 \sim 441$ MPa from referen- ce [2]. Take $\tau_o = 400$ MPa in the theory cal- culation. Table 1 is the comparision bet- ween the results of the experiment and those of the analysis, P_1 was calculated by equation (9) P_2 was calculated by equation (27). P' refers to the experimented results. The table shows that P_1 coincides with P' quite well in a range of thickness $t = 1.0 \sim 2.5$ mm and that P_1 is a little smaller when $t = 0.5$mm and little greater when $t = 3.0$ mm. The error is probably related to the real value of τ_o. The size of the grains of the rolling sheet is related to the thickness of the sheet. τ_o is greater when the thickness is small because of the small grains, and vice versa. P_1 would coincide with P' well if calculated according to $\tau_o = 304–441$ MPa. This shows that the method employed in the paper conforms to reality. The comparison between P' and P_2 shows the optimum cutter can effecctively reduce the cutting force. It must be pointed out that in the experiment directly comparing the forces between the optimum cutter and the normal slanting cutter is very significant. Therefore, it is neccessary to do further study.

Table 1 Relationship Between blanking force (P), plate thickness (t) and slanting angle (β)

β/ (°)	P/ kN	t/mm 0.5	1.0	1.5	2.0	2.5	3.0
2	P'	15.3					
	P_1	12.51					
	P_2	9.0					
4	P'	12.1	23.3				
	P_1	8.62	25.50				
	P_2	4.49	17.97				
6	P'	9.3	19.6	36.9			
	P_1	7.31	20.1	37.46			
	P_2	2.99	11.96	26.90			
8	P'	8.7	17.6	33.0	48.1		
	P_1	6.03	17.2	32.00	49.90		
	P_2	2.24	8.94	20.12	35.77		
11	P'		13.9	27.6	41.6	53.0	65.0
	P_1		14.5	26.90	41.8	58.90	78.20
	P_2		6.47	14.55	25.86	40.41	58.18
15	P'		11	24.0	36.0	45.1	55.6
	P_1		12.3	22.80	35.30	49.60	65.60
	P_2		4.69	10.55	18.76	29.31	42.21

7 CONCLUSIONS

The cutting force under multi-peak cutter can be calculated by one peak after another, and the sum is the resultant force. In cutting operations for general blankings with slanting cutters, the optimum cutter will make the cutting force and the breaking noise smallest. When the contour consists of arcs and straight lines, the optimum cutter satisfies equations (31) and (32). The axially symmetric blanking can be blanked by an optimum single peak cutter or a multi-peak optimum cutter, but only optimum multi-peak cutters can be employed for general sheet. The optimum cutter

(*To be continued on page* 87)