A CALCULATION OF POWER FOR FORMING METAL SHEET BY SPIF PROCESS

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ABSTRACT: *This paper attempts to represent a case of calculating of the energy power that is consumed by CNC milling machine when manufacturing via forming membrane metal sheet by SPIF (Single Point Incremental Forming), the recent manufacturing process of metal sheet forming by drafting a no cutting-edge spheric tip tool on a clamped metal sheet. The calculation is based on the disclocation, the crystal plasticity and the slip of lattices inside the structure of the deformed metal. In the while time there is a series of empirical species of 24 groups batch of workpieces that were also machined by CNC milling machine Bridge Port VMC500, CAD/CAM Lab., FME of HCMUT for checking this calculation on consumed power.*

1. INTRODUCTION

Single Point Incremental Forming (SPIF), the recent manufacturing process of metal sheet forming by drafting a no cutting-edge spherical tip tool on a clamped metal sheet. The process can be performed on the 3 axes CNC milling machine or industrial robot [4], [5]. However, one of the important matters, we need to define consumed power when manufacturing metal sheet base on the maximum tangent stress in crystal micro structure of sheet material. It ensures the manufacturing equipments can satisfy, concurrently, help to choose suitable manufacturing mode. So that, this paper focuses on researching to build a formula that can calculate consumed power when manufacturing metal sheet. It helps to choose the equipments and suitable manufacturing mode with variety of materials and thickness of metal sheet.

2. CALCULATING THE POWER OF SPINDLE

Forming metal sheet by SPIF process can be divided into 3 stages; each stage has its particular specifications and clearly demands it's calculating of power:

2.1. Power of initial deformation by axial feeding z of tool that has translation in the plane xoy

From the figure 1, the contact surface of the spherical tool tip and the clamped membrane is the inside bowl that has D as its diameter of the curvature and t as the initial depth of the tool. Refer to [1], [2], [3] we can apply the stress formula for tangent stress in the face of the crystal of the machined metal sheet:

$$\tau = \tau_{\max} \sin\left(\frac{2\pi x}{d}\right)$$

and (1)

$$\tau_{\max} = \frac{Gd}{2\pi h}$$

Herein: x is small displacement along the surface of the drawn metal
d is the distance between 2 atoms along the surface of the drawn metal
h is the distance between 2 layers of atoms Fig 1[1]
But

$$G = \frac{E}{2(1+\upsilon)}$$

so

$$\tau_{\max} = \frac{Ed}{4\pi h(1+\upsilon)}$$

Hence

$$\tau = \frac{Ed}{4\pi h(1+\upsilon)} \sin\left(\frac{2\pi x}{d}\right)$$

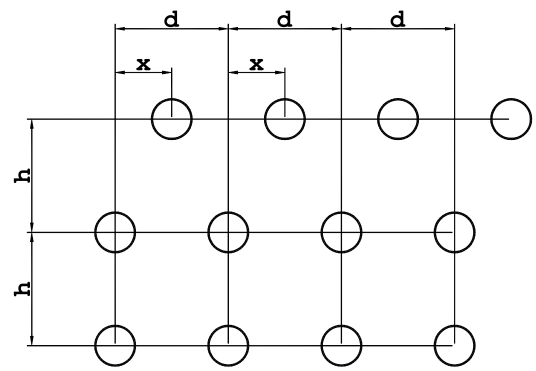

Figure 1. Distances between atoms in lattice of crystals when plastic deforming

τ : Tangent stress
E: Young's modulus
G: Shear modulus
ν : Poisson's coefficient
h: vertical distance between 2 layers of atoms of the surfaces of crystal.
x: displacement of an atom along the direction of slip
According to [1] we will have the equality d=h in ideal structure metal so:

$$\tau = \frac{E}{4\pi(1+\upsilon)} \sin\left(\frac{2\pi x}{d}\right) \quad (2)$$

We consider that the displacement x of an atom in the structure of the workpiece could calculated from the total deformation by a numbers of atoms n that have participated the deformation. Refer to the fig. 2:

t : vertical contact depth of tool tip.
d : distance between 2 atoms in the deforming direction

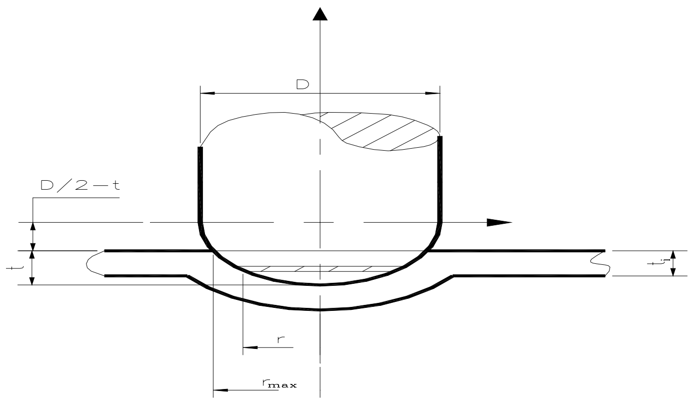

Figure 2. Tool is applied initially on membrane workpiece in SPIF

Number of atoms that participated to the deformed slip: $n = \frac{t}{d}$ (3)

With the selected coordinate such as in the fig 1 we have plane equation of the profile of sphere tip of the tool:

$$x^2 + y^2 = \left(\frac{D}{2}\right)^2 \Rightarrow y = \sqrt{\frac{D^2}{4} - x^2}$$

We call that r is radius of differential donut contact of the bowl surface area. Approximately we consider it as a plane donut because the contact area is so small, so:

$ds = 2\pi r dr$ and $r \in [0, r_{\max}]$

With $r_{\max} = \sqrt{Dt - t^2}$ (4)

t_r is the deformation depth at radius r: $t_r = y_r - \left(\frac{D}{2} - t\right) = \sqrt{\frac{D^2}{4} - r^2} - \frac{D}{2} + t$

x_r is the deformation displacement of each atom at radius r in the deformed area:

$$x_r = \frac{t_r}{n} = \frac{\sqrt{\frac{D^2}{4} - r^2} - \frac{D}{2} + t}{n} = \frac{d\left(\sqrt{\frac{D^2}{4} - r^2} - \frac{D}{2} + t\right)}{t} \quad (5)$$

Replace (5) into (2) we have the tangent stress at the radius r:

$$\tau_r = \frac{E}{4\pi(1+\upsilon)} \sin\frac{2\pi x_r}{d} = \frac{E}{4\pi(1+\upsilon)} \sin\frac{2\pi d}{dt}\left(\sqrt{\frac{D^2}{4} - r^2} - \frac{D}{2} + t\right) \quad (6)$$

Realized that the deformation when manufacturing is elasto-plastic, so the normal stress σ_r at radius r still conforms the Schmid's law (1924) [1]:

$\tau_r = \sigma_r \cos\phi \cos\lambda$

ϕ: Angle between direction of force and the one of crystal

λ: Angle between direction of force and face of crystal

Tangent stress could reach the maximum value when these angles are 0 so we can judge that in case of great deformation in manufacturing

$\tau_r = \sigma_r$, hence

$$\sigma_r = \frac{E}{4\pi(1+\upsilon)}\sin\frac{2\pi}{t}\left(\sqrt{\frac{D^2}{4}-r^2}-\frac{D}{2}+t\right) \quad (7)$$

Refer to the fig.1, we can see the axial force that stand for vertical pressure is calculated as:

$$N = \int_0^{r_{\max}} \sigma_r \cos\alpha.ds = \int_0^{r_{\max}} \frac{E}{4\pi(1+\upsilon)}\sin\frac{2\pi}{t}\left(\sqrt{\frac{D^2}{4}-r^2}-\frac{D}{2}+t\right).\cos\alpha.ds \quad (8)$$

α is angle that forms of σ_r and vertical direction.

Since $\cos\alpha = \frac{2\sqrt{\frac{D^2}{4}-r^2}}{D}$ and ds is given by (4), we can calculate the axial force at the depth t:

$$N = \frac{E}{4\pi(1+\upsilon)}.\int_0^{r_{\max}} \sin\left[\frac{2\pi}{t}\left(\sqrt{\frac{D^2}{4}-r^2}-\frac{D}{2}+t\right)\right].\frac{2\sqrt{\frac{D^2}{4}-r^2}}{D}.2\pi r dr$$

$$N = \frac{E}{D(1+\upsilon)}\int_0^{r_{\max}} \sqrt{\frac{D^2}{4}-r^2}.\sin\left[\frac{2\pi}{t}\left(\sqrt{\frac{D^2}{4}-r^2}-\frac{D}{2}+t\right)\right].rdr$$

$$N = \frac{-E}{2D(1+\upsilon)}\int_0^{r_{\max}} \sqrt{\frac{D^2}{4}-r^2}.\sin\left[\frac{2\pi}{t}\left(\sqrt{\frac{D^2}{4}-r^2}-\frac{D}{2}+t\right)\right].d\left(\frac{D^2}{4}-r^2\right) \quad (9)$$

N has form of $N = A\int_0^{r_{\max}} \sqrt{w}.\sin(B\sqrt{w}+C)dw$

with

$$w = \frac{D^2}{4}-r^2$$
$$A = \frac{-E}{2D(1+\upsilon)} \quad (10)$$
$$B = \frac{2\pi}{t}$$
$$C = \frac{\pi}{t}(2t-D)$$

Hence, we have easily the result by solving the integral (9):

Since:

$$u = \sqrt{w} \Rightarrow du = \frac{dw}{2\sqrt{w}}$$

$$dv = \sin(B\sqrt{w} + C) \Rightarrow v = -\frac{\cos(B\sqrt{w} + C)}{\frac{B}{2\sqrt{w}}} = -\frac{2\sqrt{w}.\cos(B\sqrt{w} + C)}{B}$$

$$\Rightarrow N = A\int_0^{r_{max}} \sqrt{w}.\sin(B\sqrt{w} + C)dw$$

$$N = A\left[-\frac{2\sqrt{w}.\cos(B\sqrt{w} + C)}{B} + \frac{1}{B}\int_0^{r_{max}} \cos(B\sqrt{w} + C)dw\right]$$

$$u' = \cos(B\sqrt{w} + C) \Rightarrow du' = -\frac{B}{2\sqrt{w}}\sin(B\sqrt{w} + C)dw$$

$$dv' = dw \Rightarrow v' = w$$

$$N = A\left[-\frac{2w.\cos(B\sqrt{w} + C)}{B} + \frac{1}{B}\left(w.\cos(B\sqrt{w} + C) + \frac{1}{2}\int_0^{r_{max}} \sqrt{w}.\sin(B\sqrt{w} + C)dw\right)\right]$$

$$N = -\frac{wA.\cos(B\sqrt{w} + C)}{B} + \frac{A}{2}\int_0^{r_{max}} \sqrt{w}.\sin(B\sqrt{w} + C)dw$$

$$N = -\frac{wA.\cos(B\sqrt{w} + C)}{B} + \frac{N}{2}$$

$$\Rightarrow N = \left[-\frac{2wA.\cos(B\sqrt{w} + C)}{B}\right]_0^{r_{max}} \qquad (11)$$

Replace (4), (10) into (11) we will have the result:

$$N = \left[\frac{Et(\frac{D^2}{4} - r^2)\cos\left(\frac{2\pi}{t}\sqrt{\frac{D^2}{4} - r^2} + \frac{\pi}{t}(2t - D)\right)}{2\pi D(1 + \upsilon)}\right]_0^{r_{max}}$$

$$N = \left[\frac{Et(\frac{D^2}{4} - r^2)\cos\left(\frac{2\pi}{t}\sqrt{\frac{D^2}{4} - r^2} + \frac{\pi}{t}(2t - D) \right)}{2\pi D(1+\upsilon)} \right]_0^{\sqrt{Dt-t^2}}$$

$$N = \left[\frac{Et(\frac{D^2}{4} - Dt + t^2)\cos\left(\frac{2\pi}{t}\sqrt{\frac{D^2}{4} - Dt + t^2} + \frac{\pi}{t}(2t - D) \right)}{2\pi D(1+\upsilon)} \right] - \left[\frac{Et\frac{D^2}{4}\cos\left(\frac{2\pi}{t}\sqrt{\frac{D^2}{4}} + \frac{\pi}{t}(2t - D) \right)}{2\pi D(1+\upsilon)} \right]$$

$$N = \left[\frac{Et(\frac{D}{2} - t)^2}{2\pi D(1+\upsilon)} \right] - \left[\frac{EtD\cos 2\pi}{8\pi(1+\upsilon)} \right]$$

$$N = \left[\frac{Et(D-2t)^2}{8\pi D(1+\upsilon)} \right] - \left[\frac{EtD^2}{8\pi D(1+\upsilon)} \right]$$

$$N = \frac{Et^2|D-t|}{2\pi D(1+\upsilon)}$$

N is total normal axial force that applies on the membrane of workpiece, if S is vertical feeding velocity of the spindle, we could calculate the initial applied power P_i:

$$P_i = N.s \Rightarrow P_i = \frac{E.s.t^2|D-t|}{2\pi D(1+\upsilon)} \quad (12)$$

Calculating for experiment case with these following parameters:

E= 70 Gpa= 70.10^9 N/m^2 (Workpiece material: Alunium A1050-H14)

s=5m/minute=0.083 m/s downward axial feeding of tool

t=3mm initial depth of tool

D=10mm Diameter of sphere tip tool.

ν=0.33 Poisson's Coefficient

$$P_i = \frac{E.s.t^2|D-t|}{2\pi D(1+\upsilon)} = \frac{70.10^9.5.3^2.10^{-6}(10-3)}{2\pi.10.(1+0,33).60} = 4,39kW$$

This value is fit to the power gauge that indicated in the CNC milling machine Port Bridge 500 at the workshop (7.5 Kw for spindle).

According to Fig. 3 we can calculate the normal tensor stress on the transitory surface S that is represented by line AB in the frontal cut view (fig 4): with the coordinate system at O, the center of tool tip, t_i is the initial thickness of the workpiece membrane we realize that A is one intersection point of the profile of tool tip (C_1) and the horizontal line (D_1) that stands for the front top of the workpiece and B is the intersection point of the back plane surface (C_2) and the back curve (C_2).

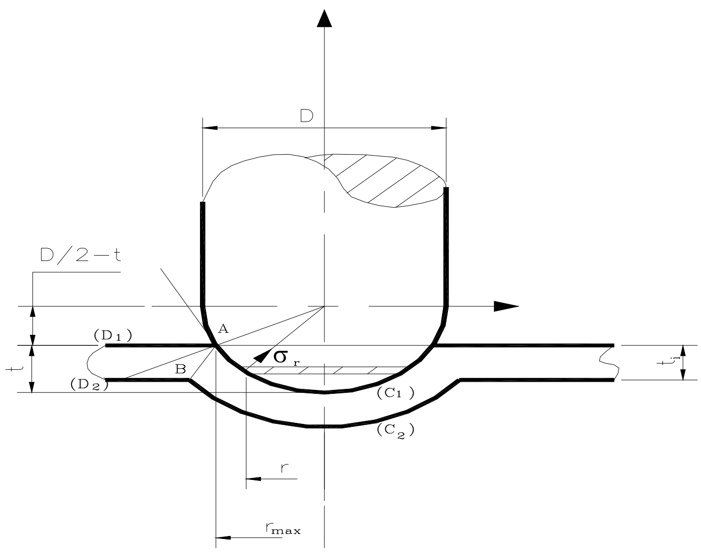

Figure 3. Calculating the normal tensor stress on the transitory surface

Equations :

$$(C_1) = x^2 + y^2 = \frac{D^2}{4}$$

$$(C_2) = x^2 + y^2 = (\frac{D}{2} + t_i)^2$$

$$(D_1): y = -(\frac{D}{2} - t) = t - \frac{D}{2}$$

$$(D_2): y = -(\frac{D}{2} - t) - t_i = t - t_i - \frac{D}{2}$$

$$A = (C_1) \cap (D_1) \Rightarrow x^2 + \left(t - \frac{D}{2}\right)^2 = \frac{D^2}{4}$$

$$\Rightarrow A = \begin{pmatrix} -\sqrt{Dt - t^2} \\ t - \frac{D}{2} \end{pmatrix}$$

$$B = (C_2) \cap (D_2) \Rightarrow x^2 + \left(t - t_i - \frac{D}{2}\right)^2 = \left(\frac{D}{2} + t_i\right)^2$$

$$\Rightarrow B = \begin{pmatrix} -\sqrt{Dt + 2tt_i - t^2} \\ t - t_i - \frac{D}{2} \end{pmatrix}$$

$$AB = \sqrt{\left(-\sqrt{Dt + 2tt_i - t^2} - (-\sqrt{Dt - t^2})\right)^2 + \left(t - t_i - \frac{D}{2} - (t - \frac{D}{2})\right)^2}$$

$$AB = \sqrt{\left(\sqrt{Dt - t^2} - \sqrt{Dt + 2tt_i - t^2}\right)^2 + t_i^2}$$

$$AB = \sqrt{t_i^2 - 2tt_i - 2\sqrt{(Dt - t^2).(Dt + 2tt_i - t^2)}}$$

Area S of tensor section have a form of a cone and is calculated via formula 6 page 246 of [3]:

$$S = \pi RL$$

$$Since:$$

$$R = HB = |x_B| = \sqrt{Dt + 2tt_i - t^2}$$

$$L = AB = \sqrt{t_i^2 - 2tt_i - 2\sqrt{(Dt - t^2)(Dt + 2tt_i - t^2)}}$$

$$Hence$$

$$S = \pi\sqrt{Dt + 2tt_i - t^2}.\sqrt{t_i^2 - 2tt_i - 2\sqrt{(Dt - t^2)(Dt + 2tt_i - t^2)}}$$

So the average normal tensor stress on the transition area is:

$$\sigma = \frac{N}{S}$$

$$\sigma = \frac{4Et(Dt - t^2)}{8\pi^2 D(1+\upsilon)\sqrt{Dt + 2tt_i - t^2}.\sqrt{t_i^2 - 2tt_i - 2\sqrt{(Dt - t^2)(Dt + 2tt_i - t^2)}}} \quad (13)$$

2.2. Power of friction between sphere tip tool and workpiece in initial downward feeding at revolution n of the spindle

Since S is the RPM and ω is the angular velocity of the spindle of CNC milling machine we have the relation:

$$\omega = \frac{\pi S}{30} \quad (14)$$

Referring to Fig 2 and considering that the normal stress σ_r that is given in eq. (7) is always concentric and perpendicular to tangent spherical plane. When f is the friction coefficient of the 2 tangent spherical faces (workpiece and tool) we can calculate the friction surface pressure at radius r:

$$\tau_r = f.\sigma_r$$

Differential friction force at radius r: $dF_r = t_r ds = 2pf .s_r .rdr$

Differential friction power at radius r:

$$dP_r = v_r.dF_r = \omega.r.dF_r = 2\pi\omega f.\sigma_r.r^2dr = \frac{2\pi^2 S.f.\sigma_r.r^2dr}{30} = \frac{\pi^2 S.f.\sigma_r.r^2dr}{15}$$

$$dP_r = \pi S.f.\frac{E}{60(1+\upsilon)}\sin\frac{2\pi}{t}\left(\sqrt{\frac{D^2}{4} - r^2} - \frac{D}{2} + t\right).r^2dr$$

With the limitation of tangent radius r_{max} that is given in (4) we can calculate the total friction power as:

$$P_f = \int_0^{r_{\max}} dP_r = \pi S.f.\frac{E}{60(1+\upsilon)} \int_0^{r_{\max}} \sin\frac{2\pi}{t}\left(\sqrt{\frac{D^2}{4} - r^2} - \frac{D}{2} + t\right).r^2 dr$$

Setting :

$$K = \pi S.f.\frac{E}{60(1+\upsilon)}$$

$$L = \frac{2\pi}{t}$$

$$M = \frac{D^2}{4}$$

$$N = -\frac{D}{2} + t$$

$$x = r$$

Hence

$$P_f = K\int_0^{r_{\max}} x^2.\sin L\left(\sqrt{M - x^2} + N\right)dx$$

Setting:

$$u = x^2 \Rightarrow du = 2xdx$$

$$dv = \sin L\left(\sqrt{M - x^2} + N\right) \Rightarrow v = \frac{-\cos L\left(\sqrt{M - x^2} + N\right)}{\dfrac{-2xL}{2L\sqrt{M - x^2}}} = \frac{\sqrt{M - x^2}}{x}.\cos L\left(\sqrt{M - x^2} + N\right)$$

Hence:

$$P_f = Kx.\sqrt{M - x^2}.\cos L\left(\sqrt{M - x^2} + N\right) - 2K\int_0^{r_{\max}} \sqrt{M - x^2}.\cos L\left(\sqrt{M - x^2} + N\right)dx$$

Setting :

$$w = \sqrt{M - x^2} \Rightarrow dw = -\frac{x}{\sqrt{M - x^2}}dx$$

$$dt = \cos L\left(\sqrt{M - x^2} + N\right) \Rightarrow t = \frac{\sin L\left(\sqrt{M - x^2} + N\right)}{\dfrac{-2xL}{2L\sqrt{M - x^2}}} = \frac{-\sqrt{M - x^2}}{xL}.\sin L\left(\sqrt{M - x^2} + N\right)$$

Hence:

$$P_f = Kx.\sqrt{M - x^2}.\cos L\left(\sqrt{M - x^2} + N\right) -$$

$$\frac{2K}{L}\left(-\frac{M - x^2}{x}\sin L\left(\sqrt{M - x^2} + N\right) + \int_0^{r_{\max}} \sin L\left(\sqrt{M - x^2} + N\right)dx\right)$$

So :

$$P_f = Kx.\sqrt{M-x^2}.\cos L\left(\sqrt{M-x^2}+N\right)+\frac{2K(M-x^2)}{Lx}\sin L\left(\sqrt{M-x^2}+N\right)-$$

$$\frac{2K}{L}\int_0^{r_{max}}\sin L\left(\sqrt{M-x^2}+N\right)dx$$

$$P_f = \left[\begin{array}{l} Kx.\sqrt{M-x^2}.\cos L\left(\sqrt{M-x^2}+N\right)+\frac{2K(M-x^2)}{Lx}\sin L\left(\sqrt{M-x^2}+N\right)- \\ \frac{2K}{L}\left(\frac{-\cos L\left(\sqrt{M-x^2}+N\right)}{\frac{-xL}{\sqrt{M-x^2}}}\right) \end{array}\right]_0^{r_{max}}$$

.

So:

$$P_f = \left[\begin{array}{l} Kx\sqrt{M-x^2}.\cos L\left(\sqrt{M-x^2}+N\right)+\frac{2K(M-x^2)}{Lx}\sin L\left(\sqrt{M-x^2}+N\right)- \\ \frac{2K\sqrt{M-x^2}}{xL^2}\cos L\left(\sqrt{M-x^2}+N\right) \end{array}\right]_0^{r_{max}}$$

$$P_f = \pi S.f.\frac{E}{60(1+\upsilon)}\left[\begin{array}{l} x.\sqrt{M-x^2}.\cos\frac{2\pi a}{bt}\left(\sqrt{M-x^2}+N\right)+\frac{2(M-x^2)}{\frac{2\pi a}{bt}x}\sin L\left(\sqrt{M-x^2}+N\right)- \\ \frac{2\sqrt{M-x^2}}{x\left(\frac{2\pi a}{bt}\right)^2}\cos\frac{2\pi a}{bt}\left(\sqrt{M-x^2}+N\right) \end{array}\right]_0^{\sqrt{Dt-t^2}}$$

.

$$P_f = \pi S.f.\frac{E}{60(1+\upsilon)}\left[\begin{array}{l} x.\sqrt{\frac{D^2}{4}-x^2}.\cos\frac{2\pi}{t}\left(\sqrt{\frac{D^2}{4}-x^2}-\frac{D}{2}+t\right)+\frac{2(\frac{D^2}{4}-x^2)}{\frac{2\pi}{t}x}\sin L\left(\sqrt{\frac{D^2}{4}-x^2}-\frac{D}{2}+t\right)- \\ \frac{2\sqrt{\frac{D^2}{4}-x^2}}{x\left(\frac{2\pi}{t}\right)^2}\cos\frac{2\pi}{t}\left(\sqrt{\frac{D^2}{4}-x^2}-\frac{D}{2}+t\right) \end{array}\right]_0^{\sqrt{Dt-t^2}}$$

.

$$P_f = \pi S.f.\frac{E}{60(1+\upsilon)}\left[\begin{array}{l} [\sqrt{Dt-t^2}.\sqrt{t^2-Dt+\frac{D^2}{4}}.\cos\frac{2\pi}{t}\left(\sqrt{t^2-Dt+\frac{D^2}{4}}-\frac{D}{2}+t\right)+ \\ \frac{2(\frac{D^2}{4}-x^2)}{\frac{2\pi}{t}\sqrt{Dt-t^2}}\sin\frac{2\pi}{t}\left(\sqrt{t^2-Dt+\frac{D^2}{4}}-\frac{D}{2}+t\right)- \\ \frac{2\sqrt{t^2-Dt+\frac{D^2}{4}}}{\sqrt{Dt-t^2}.\left(\frac{2\pi}{t}\right)^2}\cos\frac{2\pi}{t}\left(\sqrt{t^2-Dt+\frac{D^2}{4}}-\frac{D}{2}+t\right)]-[\frac{tD^2}{4\pi x}\sin 2\pi-\frac{Dt^2}{x(2\pi)^2}\cos 2\pi] \end{array}\right]$$

.

$$P_f = \pi S.f.\frac{E}{60(1+\upsilon)}\left[\begin{array}{l} [\sqrt{Dt-t^2}.\sqrt{t^2-Dt+\frac{D^2}{4}}.\cos\frac{2\pi}{t}\left(\sqrt{t^2-Dt+\frac{D^2}{4}}-\frac{D}{2}+t\right)+ \\ \frac{2(\frac{D^2}{4}-x^2)}{\frac{2\pi}{t}\sqrt{Dt-t^2}}\sin\frac{2\pi}{t}\left(\sqrt{t^2-Dt+\frac{D^2}{4}}-\frac{D}{2}+t\right)- \\ \frac{2\sqrt{t^2-Dt+\frac{D^2}{4}}}{\sqrt{Dt-t^2}.\left(\frac{2\pi}{t}\right)^2}\cos\frac{2\pi}{t}\left(\sqrt{t^2-Dt+\frac{D^2}{4}}-\frac{D}{2}+t\right)]-[\frac{tD^2}{4\pi x}\sin 2\pi-\frac{Dt^2}{x(2\pi)^2}\cos 2\pi] \end{array}\right]$$

.

$$P_f = \pi S.f.\frac{E}{60(1+\upsilon)}\left[\sqrt{Dt-t^2}.(\frac{D}{2}-t)-\frac{2(\frac{D}{2}-t)}{\sqrt{Dt-t^2}.\left(\frac{2\pi}{t}\right)^2}-[\frac{btD^2}{4\pi ax}\sin\frac{2\pi}{t}.t-\frac{Dt^2}{4x\pi^2}\cos 2\pi]\right]$$

.

$$P_f = \pi S.f.\frac{E(D-2t)}{120(1+\upsilon)}\left[\sqrt{Dt-t^2}-\frac{2}{\sqrt{Dt-t^2}.\left(\frac{2\pi}{t}\right)^2}\right]$$

$$P_f = \pi S.f.\frac{E(D-2t)}{120(1+\upsilon)\sqrt{Dt-t^2}}\left[Dt-t^2-\frac{t^2}{2\pi^2}\right] \quad (15)$$

.

2.3. Consummed power when drafting at the depth *h* from initial surface with deformed angle α

Referring to the figure 4 we can realize that the contacted surface between tool tip and the membrane is decreased to one fourth of the bow:

Call F is the feeding rate, the consumed power when drafting can be calculated as:

$$P = \frac{P_f}{4} + F.f.N = \pi.S.f.\frac{E(D-2t)}{480(1+\upsilon)\sqrt{Dt-t^2}}(Dt - t^2 - \frac{t^2}{2\pi^2}) + F.f.\frac{Et^2|D-t|}{2\pi D(1+\upsilon)} \quad (16)$$

Calculating for the same experiment case with these following parameters as in the advanced example:

E= 70 Gpa= 70.10^9 N/m^2 (Workpiece material: Alunium A1050-H14)

s=5m/minute=0.083 m/s downward axial feeding of tool

t=3mm initial depth of tool

D=10mm Diameter of sphere tip tool.

ν=0.33 Poisson's Coefficient

With included coefficient of friction f=0.05 in case of oil lubricating of the punch and the feeding rate F=1mm/s =10^{-3} m/s. The value of power P in (16) is calculated in this case is P=2826.497869 W~2.82 KW that is similar to the indicated power gauge of the panel of the machine.

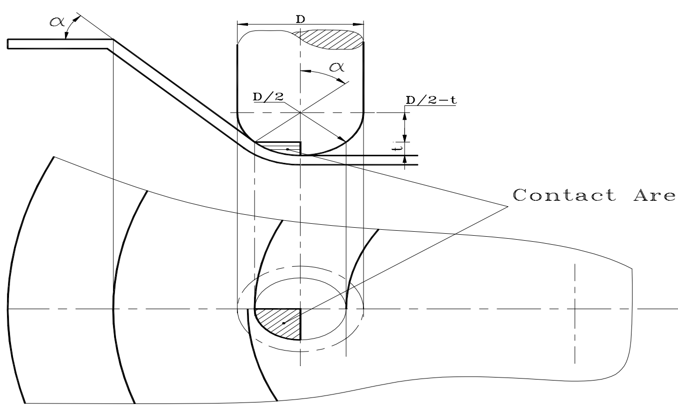

Figure 4. Contact area when feed rate machining

3. CONCLUSIONS

Two cases are calculated the consumed power base on the maximum tangent stress in crystal micro structure of sheet material: the first stage when the punch presses on the sheet and the second stage when the punch translates in the XOY plane. The specified value consumed power in manufacturing sheet A1050-H14 with 10mm diameters high speed steel spherical tip punch is applied by (12) & (16) formulas, that is suitable between the theory formula with the indicated consumed power gauge of the panel when testing manufacturing 24 groups batch of 1mm thickness A1050-H14 workpieces on Bridge Port VMC500 CNC milling machine in CAD/CAM Lab., FME, Ho Chi Minh city University of Technology. Accordingly, using the consumed power formulas above, we can calculate to choose the equipments and suitable manufacturing mode corresponding to the variety of materials and thickness of metal sheet.

NGHIÊN CỨU TÍNH TOÁN CÔNG SUẤT TIÊU THỤ TRONG TẠO HÌNH KIM LOẠI TẤM BẰNG PHƯƠNG PHÁP SPIF

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TÓM TẮT: *Bài viết này trình bày một trường hợp tính công suất tiêu thụ của trục chính máy phay CNC khi tạo hình tấm kim loại dạng màng bằng phương pháp SPIF (Single Point Incremental Forming), là phương pháp tạo hình tấm mới nghiên cứu trên thế giới trong những năm gần đây bằng cách điều khiển miết một đầu chày hình cầu không lưỡi cắt lên tấm kim loại được kẹp trên đồ gá. Hai trường hợp được tính toán công suất dựa trên ứng suất tiếp cực đại trong cấu trúc vi mô tinh thể của vật liệu tấm: đó là giai đoạn đầu tiên khi chày nén thẳng xuống bề mặt tấm và giai đoạn đang gia công khi chạy dao vòng. Giá trị cụ thể của công suất tiêu thụ cho gia công tấm nhôm A1050-H14 với đầu chày thép gió có đường kính 10mm được áp dụng từ công thức kết luận trong bài viết cho thấy sự phù hợp của công thức lý thuyết với công suất tiêu thụ chỉ thị trên máy khi gia công thử nghiệm 24 nhóm mẫu nhôm A1050-H14 dày 1mm trên máy phay CNC Bridge Port VMC500 của phòng thí nghiệm CAD&CAM, khoa Cơ khí, trường Đại học Bách khoa Tp HCM.*

Từ khóa: *SPIF, tạo hình tấm kim loại, phay CNC, công suất tiêu thụ trong tạo hình.*

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