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APPROPRIATE METHODOLOGY ADOPTED FOR THE DESIGN OF SINGLE POINT CUTTING TOOL

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ABSTRACT

The appropriate methodology adopted for the design of single point cutting tool is an important aspect of tool engineering. It deals with the design of tool shank, design of single point cutting tool, and various forces involved during machining of the workpiece. Selection of the appropriate material for the design of the single point cutting tool is paramount important and consideration must be put emplace. Various aspects of tooling, material cost, fabrication, manufacturing methods and the proper functioning of product should be considered. Strength and rigidity of tool is also taken into account while designing single point cutting tool. The main design criterion for shank size is rigidity. The deflection at the cutting edge is limited to a certain value depending on the size of machine, cutting conditions and tool overhung.

Keywords: *Back Rake Angle, Cutting Force, Merchants Circle, Tool shank, Geometry, Material*

INTRODUCTION

Design of single point cutting tools objective is to remove greatest amount of material in the shortest length of time consistent with finish requirements, work and tool rigidity, available power of the machine, and relative cost of labor and cutting tools.(1) In design of a single point cutting tool the following factors are to be considered, for example the type of work piece material and tool material, type of operation and surface finish required, Optimum tool angles, Permissible cutting speed, feed and depth of cut, Cutting forces, Condition of work holding, Work held as a cantilever, Work held in between two centres and both of which can be live or one live and the other dead. Work held in chuck and tailstock centre. Overhung of the tool from the tool post, accuracy of the work in terms of permissible deflection (maximum) of job with respect to the tool. Strength and rigidity are the important parameters while designing the shank of the cutting tool. Forces and power consumption decreases with increase in positive back rake angle. A positive back rake angle is responsible to move the chip away from the machined work piece surface. The tool material should have high wear resistance, hot hardness, hardness, toughness, thermal conductivity, and low coefficient of thermal expansion. Cutting force, feed force and shear force acts on the work piece and cutting force is the largest of these three forces. Dynamometers are used for measuring tool forces with great accuracy.

DESIGN OF TOOL SHANK

The shank of a cutting tool is generally analyzed for strength and rigidity. Tool is assumed to be loaded as a cantilever by tool forces at the cutting edge as shown in Figure 1.

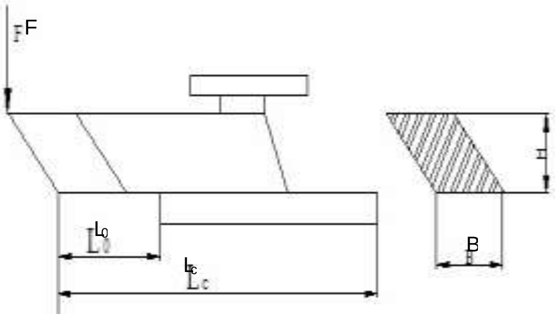

Figure 1 : Forces Acting on Tool Shank

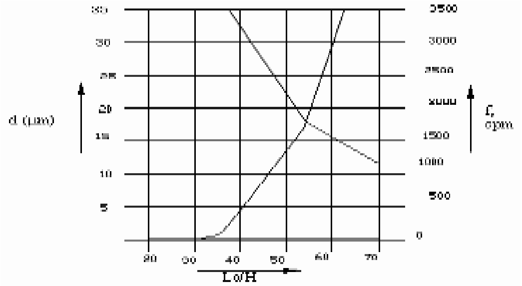

Figure 2: Deflections and Frequency of Chatter for Several Overhung Values

The notations used in design of shank is given below:

F = Permissible tangential force during machining, N
f = Chatter frequency, cycle per second (c.p.s)
H = Depth of shank, mm
B = Width of shank, mm
L_0 = Length of overhung, mm
d = Deflection of shank, mm
E = Young's modulus of material, N/mm^2
I = Moment of inertia, mm^4
h_c = Height of centres, mm
σ_{ut} = Ultimate tensile strength, N/mm^2
σ_{per} = Permissible stress of shank material, N/mm^2
L_c = Length of centers, mm

The tool overhung (L_0) is related also to the shank size as well as to the end support conditions. Figure 2 shows graph of the amplitude and frequency of chatter for several overhung values. It is seen from Figure 2 that only below $L_0/H = 2$, the amplitude is practically zero. The recommended value of (L_0/H) lies between 1.2 and 2. For the given value of chatter frequency f, the shank deflection can be calculated from the (Eq. 1) given as follows.

$$f = \frac{(15.76)}{\sqrt{d}} c.p.s \qquad \text{. . . (1)}$$

Where, d is deflection in mm.

Now as chatter frequency ranges from 80 to 160 c.p.s.

Let, f = 100 c.p.s

$$d = (15.76/100)^2 \cong 0.025 \text{ mm} \qquad . \quad (2)$$

The permissible deflection of shanks ranges from 0.025 mm for finish cuts to 0.9 mm for rough cuts. Considering shank as a cantilever,

$$d = \frac{FL^3{}_o}{3EI}$$

$$d = \frac{FL^3{}_o}{3E}\left(\frac{12}{BH^3}\right) = \frac{4FL^3{}_o}{EBH^3} = 0.025 \qquad \text{. . . (3)}$$

$$d = 0.025mm$$

This can be noted that the same value of d has been obtained from Eq. (2) also. The shank size can be estimated with respect to machine tool size by the following method:

The force F for given size of lathe is given by
$F = f \times t \times C$
Where, f is the feed in mm,
t is the depth of cut in mm, and
C is cutting force constant.
Nicolson's Manchester experiments have set a standard area of cut for lathe design given by
$A_c = f \times t$
Let, $f = h_c/180$ mm and
$t = h_c/25$ mm
$Ac = 180\underline{c} \times h25\underline{c}$

$$A_c = \frac{h_c}{180} x \frac{h_c}{25} = \frac{h^2{}_c}{4500} mm^2$$

Where, h_c is height of centre in mm,
Let, $\sigma_{ut} = 440$ N/mm^2
$C = 4\sigma_{ut}$
$= 4 \times 400 = 1760$ N/mm^2
$^{C} = 1760$ N/mm^2

When, $$F = \frac{h^2{}_c}{4500} mm^2 x 1760 mm^2$$

$$F = 0.4h^2{}_c$$

Substituting the value of $F = 0.4^{h}{}_{c}^{2}$ in Eq. (3), we will arrive at

$$d = \frac{4\left(0.4h^2{}_c\right)L^3{}_o}{EBH^3}$$

$$0.025 = \frac{4\left(0.4h^2{}_c\right)L^3{}_o}{EBH^3}$$

Since d = 0.025mm from equ. (2), thus

$$0.025 = \frac{\left(1.6h_c{}^2\right)L^3{}_o}{EBH^3}$$

B = 0.6 H for rectangular shanks

Therefore, $$\frac{h^2{}_c}{H^4} = 0.6\frac{ED}{L^3{}_o}$$

Let, $L_o = 3mm$
$E = 200$ kN/mm^2 and
$d = 0.025$ mm,
From Eq. (2)
Substituting these values in above equation, i.e.

$$\frac{h^2{}_c}{H^4} = 0.6\frac{ED}{L^3{}_o}$$

$$\frac{h^2{}_c}{H^4} = 1000mm^{-2}$$

Table 1 shows the standard shank size according to this rule.

1.2 Table 1

Height of Centres h_c (mm)	Shank Size	
	***H* (mm)**	***B* (mm)**
250	20	12
300	30	20
350	40	25

The shank size is also checked for strength.

$$Nothing, FL_o = \frac{1}{6}BH^2\sigma_1$$

$$\sigma_1 = \frac{6FL_o}{BH^2}$$

When the effect of F_x is included,

$$\sigma = \sigma_1 + \sigma_2 = \frac{6FL_o}{BH^2} + F_x\frac{L_o}{HB^2} \quad ... \quad (4)$$

F_x = Component of force F acting in x direction (in Newton)
F_x = 0.3 to 0.40 F

Hence, $\sigma = \frac{6FL_o}{BH}\left(\frac{0.4}{B}\right) + \left(\frac{1}{H}\right)\angle\sigma_{per}$ (5)

We can express this as $F = \left\{\frac{BH}{\left(\frac{0.4}{B}\right)} + \left(\frac{1}{H}\right)\right\}\frac{\sigma_{per}}{6L_o}$ (6)

Where, F is permissible tangential force during machining.
The maximum depth of shank ($H_{\max}$) must be less than the value h_k as shown in Table 2.

Table 2

hk (mm)	**11**	**14**	**22**	**28**	**45**	**56**
*H*max(mm)	10	12	20	25	40	50

DESIGN OF TOOL GEOMETRY

Basic Elements

The basic elements of tool are shown in Figure 3.

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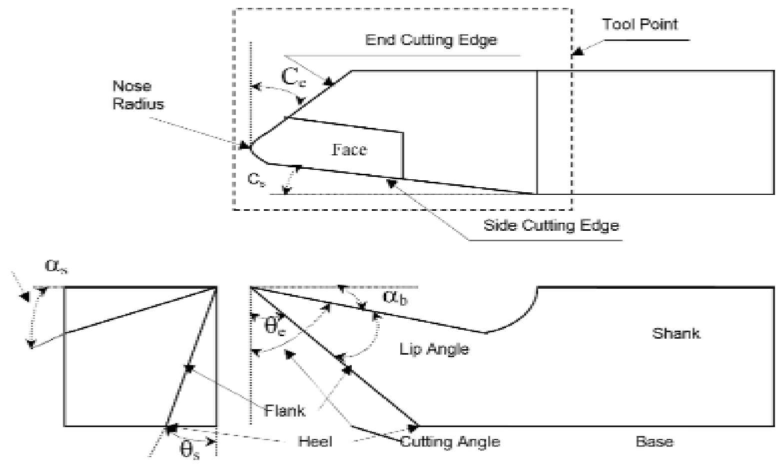

Figure 2.3 : Single Point Cutting Tool

Symbol used in figure are:
α_b – Back rake angle
α_s – Side rake angle
θ_e – End relief angle
θ_s – Side relief angle
C_e – End cutting edge angle
C_s – Side cutting edge angle

SELECTION OF TOOL MATERIAL

The tool engineer is required to select material for variety of products such as cutting tools, jigs, punches, dies, special machine etc. A tool engineer must possess the knowledge of these materials and understand their properties. In addition, the various aspects of tooling, material cost, fabrication, manufacturing methods and the proper functioning of product should be considered. In considering the desirable properties of tool materials, the following must be put emplace for example, Wear Resistance, Design of Single, Point Cutting Tools, Hot Hardness, Toughness, Coefficient of Thermal Expansion, Hardness, Thermal Conductivity, High Carbon Steel, High Speed Steel and Stellite

CALCULATION OF FORCES AND DESIGN FOR CUTTING FORCES

The forces acting on the tool are an important aspect of machining. The knowledge of force is required for determination of power and also to design the various elements of machine tool, tool holders and fixtures.

The cutting forces vary with the tool angle and accurate measurement of forces is useful in optimizing tool design. Dynamometers are capable of measuring tool forces with increasing accuracy. The component of forces acting on the rake face of tool, normal to the cutting edge is called cutting force, i.e. in the direction of line *YO* in Figure 2.4.

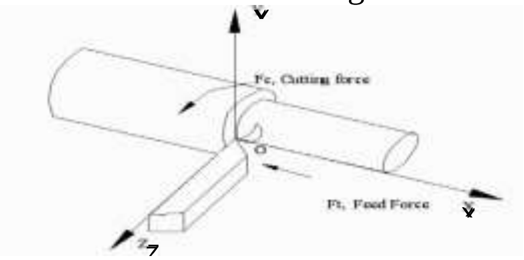

Figure 2.4: Forces Acting on the Workpiece

Cutting force *Fc*, is largest of three forces acting on workpiece and its direction is in the direction of cutting velocity.

The force component acting on tool in direction of *OX*, parallel to the direction of feed, is feed force, *Ft*. It acts tangential to main cutting force, *Fc*.

The forces involved in machining are relatively low as compared to those in other metal working operations such as forging. This is because the layer of metal being removed (i.e. the chip) is thin, so forces to be measured are less in case of machining.

Here, *Fc* is cutting force,
Fs is shear force,
φ is shear angle,
β is frictional angle and
α is rake angle,
t_1 is uncut chip thickness, and
t_2 is chip thickness.

Figure 5 shows Merchants Circle for calculation of forces. Merchants force circle is used to determine various forces.

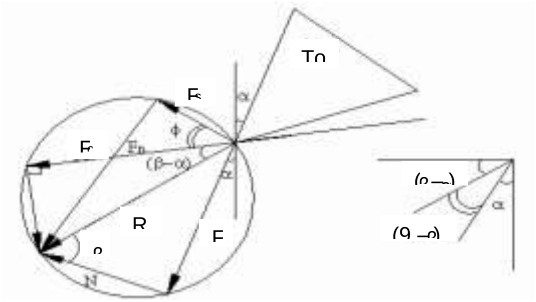

Figure 2.5: Merchant's Force Circle

Coefficient of friction between chip-tool interfaces is given by

$$\mu = \tan \beta$$

Now from merchants circle, $R = \frac{F}{Sin\beta} = \frac{N}{Cos\beta}$ (7)

Also, $R = \frac{F_c}{Cos(\beta - \alpha)} = \frac{F_t}{Sin(\beta - \alpha)}$ (8)

$$R = \frac{F_s}{Cos(\varphi + \beta - \alpha)} = \frac{F_N}{Sin(\phi + \beta - \alpha)} \quad (9)$$

$$\frac{F_c}{Cos(\beta - \alpha)} = \frac{F_s}{Cos(\phi + \beta - \alpha)}$$

$$F_c = \frac{F_s Cos(\beta - \alpha)}{Cos(\phi + \beta - \alpha)} \quad (10)$$

$$\tan(\beta - \alpha) = \frac{F_t}{F_c}$$

$$(\beta - \alpha) = \tan^{1} \frac{F_t}{F_c}$$

$$\beta = \alpha + \tan^{1} \frac{F_t}{F_c} \quad (11)$$

Now, Shear stress = $\frac{F_s}{A_s}$

From figure 6, shear area, $A_s = b \times (AB)$

$$AB = \frac{t_1}{Sin\phi}, A_s = \frac{t_1 b}{Sin\phi}$$

Shear stress, $\tau = \frac{F_s Sin\phi}{t_1 b}$ (12)

If shear stress is greater than ultimate shear stress then only cutting takes place.

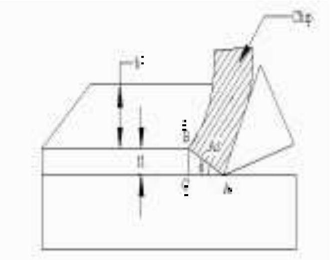

Figure 2.6(a): Force Analysis

Total work done is given by,

$$W = F_c V_c + F_t V_{feed}$$

But, $V_{feed} = FN =$ very loss (since linear velocity is low)

Thus, $W = F_c V_c$

But, work done is equal to power,

So, Power = $F_c V_c$

Now, from equ. (10), $F_c = F_s \dfrac{Cos(\beta - \alpha)}{Cos(\phi + \beta - \alpha)}$

Power = $F_s \times V_c \dfrac{Cos(\beta - \alpha)}{Cos(\phi + \beta - \alpha)}$

Various forces acting on orthogonal cutting when producing continuous chip is shown in Figure 6(b).

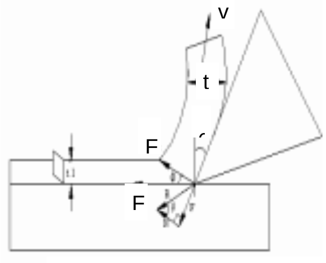

Figure 2.6 (b)

But from Eq. (12),

$$F_s = \frac{\tau l_1 b}{Sin\phi}$$

Power = $\left[\dfrac{\tau l_1 b}{Sin\varphi}\right] + \left[\dfrac{Cos(\beta - \alpha)}{Cos(\phi + \beta - \alpha)}\right]$

For minimum energy,

$$\frac{dp}{d\phi} = 0$$

On solving this, we get

$2\varphi + \beta - \alpha = 90$

$$\phi = 45 - \frac{(\beta - \alpha)}{2} \qquad \text{(Theoretical)}$$

If friction between chip-tool interfaces is 0, we get

$$\phi = 45 + \frac{\alpha}{2}$$

Normal stress =

$$\frac{F_N}{A_s} = \frac{F_N Sin\phi}{t_1 b}$$

SUMMARY

Strength and rigidity are the important parameters while designing the shank of the cutting tool. Forces and power consumption decreases with increase in positive back rake angle. A positive back rake angle is responsible to move the chip away from the machined workpiece surface. The tool material should have high wear resistance, hot hardness, hardness, toughness, thermal conductivity, and low coefficient of thermal expansion. Cutting force, feed force and shear force acts on the workpiece and cutting force is the largest of these three forces. Dynamometers are used for measuring tool forces with great accuracy.

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