((Manufacturing))

Cutting Conditions :

Relative motion is required between the tool and work to perform a machining operation.

- **The primary motion is accomplished at a certain cutting speed (V_c).**
- **In addition, the tool must be moved laterally across the work. This is a much slower motion, called the feed (*f*).**
- **The remaining dimension of the cut is the penetration of the cutting tool below the original work surface, called the depth of cut (b) .**
- **Collectively, speed, feed, and depth of cut are called the *cutting conditions*. The cutting conditions for a turning operation are depicted in [figure (1)].**
- **They form the three dimensions of the machining process, and for certain operations (e.g., most single-point tool operations) they can be used to calculate the material removal rate for the process:**

$$V_{removal} = V_c \cdot f \cdot b$$

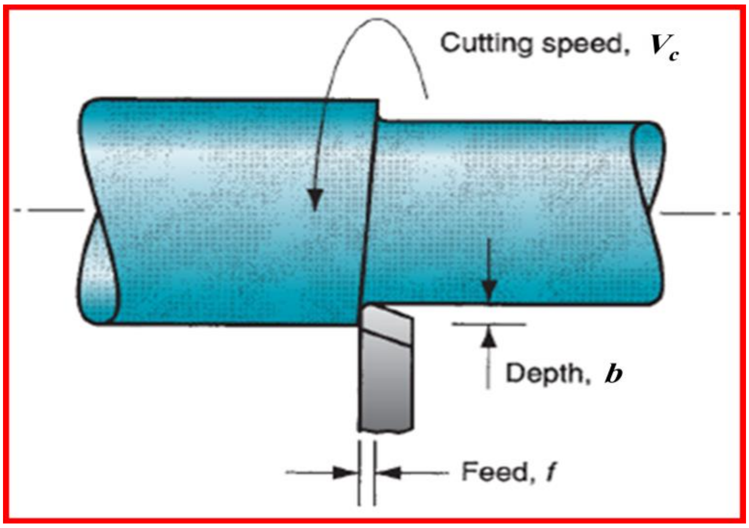

Figure 1: Cutting speed, feed, and depth of cut for a turning operation.

Where:

$V_{removal}$ = material removal rate (mm^3/s)

V_c = cutting speed (m/s), which must be converted to (mm/s)

***f* = feed (mm); Feed in turning is expressed in (mm/rev)**

b = depth of cut, (mm).

***The Feed in Turning* : is generally expressed in (mm/rev). This feed can be converted to a linear travel rate in (mm/min) by the formula [Figure (2)]:**

$$f_r = Nf$$

The time to machine from one end of a cylindrical workpart to the other is given by:

$$T_m = \frac{L}{f_r}$$

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<u>Where</u>:

T_m = machining time (min); and

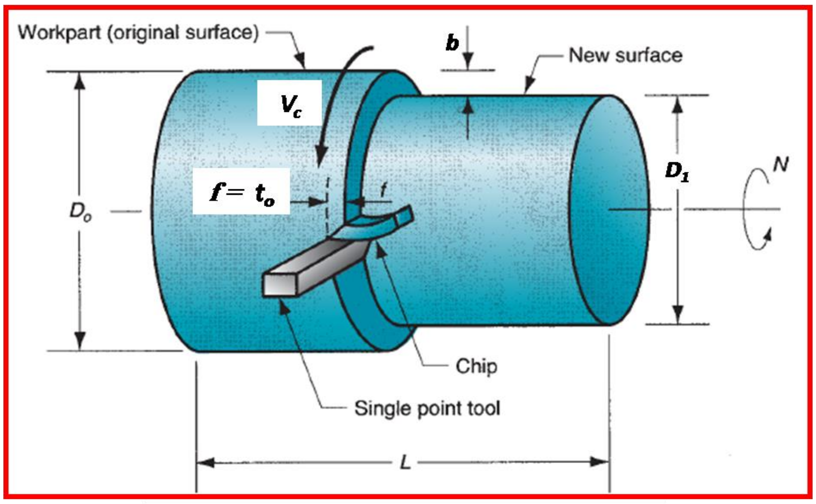
L = length of the cylindrical workpart (mm).

A more direct computation of the machining time (T_m) is provided by the following equation:

$$T_m = \frac{\pi \,.\, D_o \,.\, L}{f \,.\, V_c}$$

<u>Where</u>:

$$f_r = N \,.\, f \,, \qquad and \qquad N = \frac{V_c}{\pi \,.\, D_o}$$



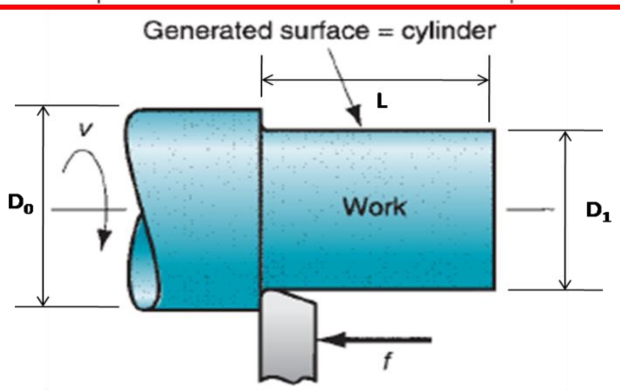


Figure 2: Turning operation.

<u>Machining operation:</u>

Machining operations usually divide into two categories, distinguished by purpose and cutting conditions: <u>roughing cuts and finishing cuts</u>.

<u>Roughing cuts</u> **: are used to remove large amounts of material from the starting workpart as rapidly as possible, in order to produce a shape close to the desired form, but leaving some material on the piece for a subsequent finishing operation.**

- **Roughing operations are performed at high feeds and depths, feeds of (0.4 to 1.25 mm/rev) and depths of (2.5 to 20 mm) are typical.**

<u>Finishing cuts</u> **: are used to complete the part and achieve the final dimensions, tolerances, and surface finish.**

- **Finishing operations are carried out at low feeds and depths, feeds of (0.125 to 0.4 mm) and depths of (0.75 to 2.0mm) are typical.**
- **Cutting speeds are lower in roughing than in finishing.**

Cutting Energy & Specific Energy:

- **The total Power input in cutting process is [Figure (3)]:**

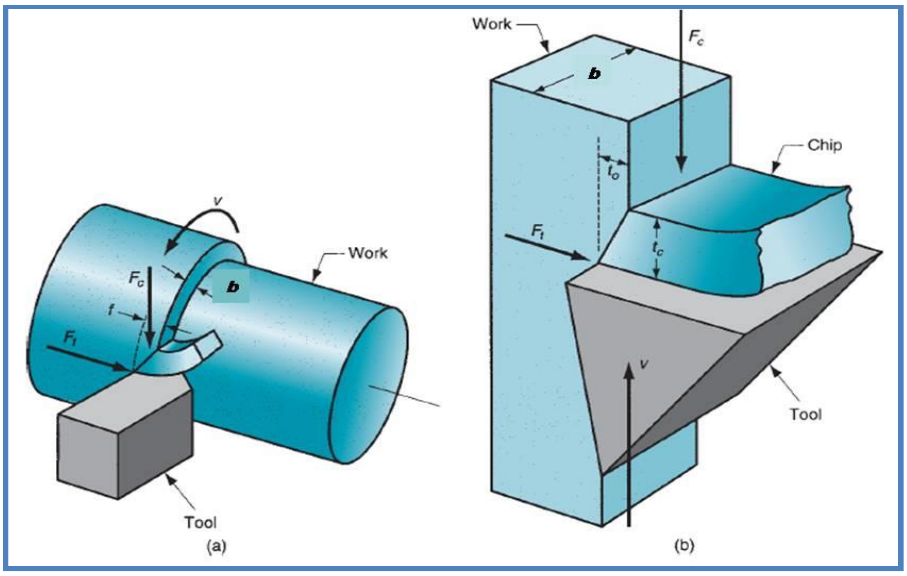
$$Power = \ P \ = \ F_c \ . \ V_c$$

Where: P = the power input in Watt (W) or (KW)

F_c = the cutting force in Newton (N) or (kN)

V_c = the cutting velocity in (meter / second) (m/s)

Figure 3: Approximation of turning by the orthogonal model: (a) turning; and (b) the corresponding orthogonal cutting.



$$Power = \ P \ = \frac{F_c \ . \ V_c}{60}$$

Where: V_c = cutting velocity in meter/min (m/min), but we know that the cutting velocity (V_c) which is also the surface velocity and is equal to:

$$V_c \ = \ r\,.\,\omega \ = \ r.\ (2\,\pi\,.\ N) \ = \ \pi\,.\,D_o\,.\,N$$

Where: ω = the angular velocity (rad/min) = 2 π . N
N = the rotational velocity in revolution per minute (rpm)
D_o = the workpiece diameter in meter (m)
r = the workpiece radius in meter (m)

Thus,

$$N \ = \ \frac{V_c}{\pi\ .\ D_o}\ , \qquad or, \qquad N \ = \ \frac{1000 * V_c}{\pi\ .\ D_o}$$

Where: D_o = the workpiece diameter in (mm)

Specific Energy (u_c):

It is defined as the total power energy per unit volume of material removed (m^3/min or cm^3/min), thus (u_c) is equal to:

$$u_c \ = \ \frac{P}{V_{removal}} \ = \ \frac{F_c\ .\ V_c}{V_c\ .\ f\ .\ b} \ = \ \frac{F_c}{t_o\ .\ b}$$

It is simply (u_c) is the ratio of the cutting force (N) to projected area of the cut (mm^2).
Where: $V_{removal}$ = the volume of the material removed (m^3/min or cm^3/min)
f = the uncut chip thickness (t_o) or the feed per revolution (mm / rev.)
b = the width of chip (mm)

In the same way, it can also be seen that the power required to overcome friction at the tool chip interface is the product of (F_f) and (V_c), or in terms of frictional specific energy (u_f) is equal to:

$$u_f = \frac{F_f \cdot V_f}{V_c \cdot f \cdot b} = \frac{F_f \cdot r}{t_o \cdot b}$$

Likewise, the power required for shearing along the shear plane is the product of (F_s) and (V_s), hence the specific energy for shear (u_s) is given by:

$$u_s = \frac{F_s \cdot V_s}{V_c \cdot f \cdot b} = \frac{F_s \cdot V_s}{t_o \cdot b \cdot V_c}$$

The total specific energy (u_c) is the sum of the above two specific energies:

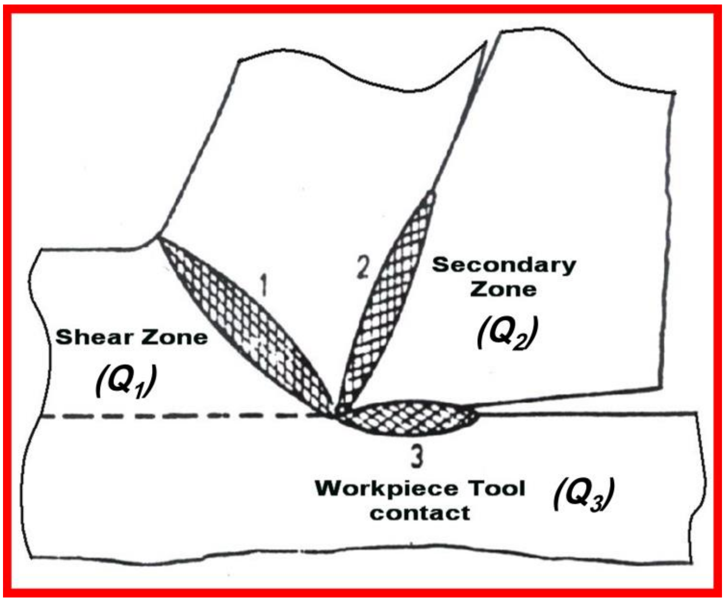
$$u_c = u_f + u_s$$

Cutting Temperature:

Almost all the work done in deformation the material to form the chip and move the chip and the freshly cut work surface over the tool is converted into heat.

Figure (4) below shows the regions where the heat is primarily developed at the shear zone (Q_1), at the face tool [secondary zone (Q_2)] and at tool workpiece interface (Q_3).

Figure 4: **Source of heat generation in metal cutting.**



Under normal conditions, the largest portion of the work is done in forming the chip at the shear plane (Q_1), most the heat resulting from this work remains in the chip is carried away by it, while only a small percentage is conducted into the workpiece.

(Q_2) is the heat generated in the tool – chip interface; it is due to friction between the chip and the tool face.

(Q_3) is the heat generated in tool – workpiece interface, only a small percentage of the total work done is converted into this heat.

That means:

$$Power = P = F_c \cdot V_c = Q = Q_1 + Q_2,$$

$$where, \quad Q_3 \cong 0 \text{ which ignored since it is little}$$

It is found that approximately (80%) of the generated heat is dissipated by the chip, (18%) by the tool and the rest by the work surface. From this it clear that most of the heat in the metal cutting is dissipated by the moving chip:

$$Q = Q_C + Q_T + Q_W$$

<u>Where:</u> **Q_C = heat dissipated with chip.**

Q_T = heat dissipated with tool.

Q_W = heat dissipated with workpiece.

The Temperature Rise:

So, the maximum temperature rise in the chip occurs where the material leaves the secondary deformation zone and is given by:

$$T_{max} = T_o + \Delta T_1 + \Delta T_2$$

Where: T_o = the initial workpiece temperature (℃)

ΔT_1 = temperature rise of the material passing through the primary zone (℃)

ΔT_2 = temperature rise of the material passing through the secondary zone (℃)

Cutting temperatures are important because high temperatures will causes:

- **Reduce tool life.**
- **Produce hot chips that pose safety hazards to the machine operator, and,**
- **It can cause inaccuracies in workpart dimensions due to thermal expansion of the work material.**

This section will discuss the methods of calculating and measuring temperatures in machining operations.

- **There are several analytical methods to calculate estimates of cutting temperature.**
- **The most method, which was derived using experimental data for a variety of work materials to establish parameter values for the resulting equation.**
- **The equation can be used to predict the increase in temperature at the tool–chip interface during machining:**

$$\Delta T = \frac{0.4\, u_c}{\rho C}\left(\frac{V_c \cdot t_o}{K}\right)^{0.333}$$

Where:

ΔT = mean temperature rise at the tool–chip interface, (^{o}C).

u_c = specific energyin the operation, (N . m/mm^3 or J/mm^3) .

V_c = cutting speed, (m/s);

t_o = chip thickness before the cut, (m); ρ C = volumetric specific heat of the work

K = thermal diffusivity of the work material, (^{m2}/sec).

Example : Calculate the increase in temperature above ambient temperature of (20 ^{o}C). Use the given data:

V_c = 100 m/min, t_o = 0.50 mm.

In addition, the volumetric specific heat for the work material (ρC = 3.0 (10 $^{-3}$) J/mm^3 .C, and, Thermal diffusivity (K) = 50 (10 $^{-6}$) m^2/s (or 50 mm^2/sec).

Solution:

Cutting speed must be converted to mm/s:

$$V_c = (100 \text{ m/min}) * (10^3 \text{ mm/m}) / (60 \text{ s/min}) = 1667 \text{ mm/s}.$$

To compute the mean temperature rise:

$$\Delta T = \frac{0.4\, u_c}{\rho C}\left(\frac{V_c \cdot t_o}{K}\right)^{0.333}$$

$$\Delta T = \frac{0.4(1.038)}{3.0(10^3)}{}^{\circ}\text{C}\left(\frac{1667(0.5)}{50}\right)^{0.333} = (138.4)(2.552) = 353^{\circ}\text{C}$$