Summary Of Turning Parameters and Formulas

N = Rotational speed of the workpiece, rpm

f = Feed, mm/rev or in./rev

v = Feed rate, or linear speed of the tool along workpiece length, mm/min or in./min

$= fN$

V = Surface speed of workpiece, m/min or ft/min

$= \pi D_o N$ (for maximum speed)

$= \pi D_{avg} N$ (for average speed)

l = Length of cut, mm or in.

D_o = Original diameter of workpiece, mm or in.

D_f = Final diameter of workpiece, mm or in.

D_{avg} = Average diameter of workpiece, mm or in.

$= (D_o + D_f)/2$

d = Depth of cut, mm or in.

$= (D_o + D_f)/2$

t = Cutting time, s or min

$= l/f\,N$

MRR = mm^3/min or $in.^3$/min

$= \pi D_{avg} d\, fN$

Torque = N·m or lb·ft

$= (F_c)(D_{avg}/2)$

Power = kW or hp

= (Torque) (ω), where $\omega = 2\pi N$ radians/min

In Turning

$$DOC = \frac{D_1 - D_2}{2} = d$$

The rpm of the rotating workpiece is N_s. It establishes the cutting speed V, at the tool, according to $N_s = 12V/\pi D$.

The depth of cut, d, is equal to $(D_1 - D_2)/2$.
The length of cut is the distance the tool travels parallel to the axis, L.

The selection of the cutting speed V determines the surface speed of the rotating part that is related to the outer diameter of the workpiece.

$$V = \frac{\pi D_1 N_s}{12} \tag{20-2}$$

where D_1 is in inches, V is speed in surface feet per minute, and N_s is the revolutions per minute (rpm) of the workpiece. The input to the lathe will be in revolutions per minute of the spindle.

Once cutting speed V has been selected, equation 20-3 is used to determine the spindle rpm, N_s. The speed and feed can be used with the DOC to estimate the metal removal rate for the process, or MRR. For turning, the MRR is

$$\text{MRR} \cong 12 V f_r d \tag{20-4}$$

This is an approximate equation for MRR. For turning, MRR values can range from 0.1 to 600 in.^{3}/min. The MRR can be used to estimate the horsepower needed to perform a cut, as will be shown later. For most processes, the MRR equation can be viewed as the

L = length of cut

$$T_m = \frac{L + A}{f_r N_s}$$

$$\text{MRR} = \frac{\text{volume of cut}}{T_m}$$

$$T_m = \frac{L + \text{allowance}}{f_r N_s}$$

Power and Energy

3 Force

F_C = Cutting force (vertical)

F_R = Radial force (thrust)

F_F = Feed force

The power required for cutting is

$$P = F_c V \text{ (ft-lb/min)}$$

The horsepower at the spindle of the machine is therefore

$$\text{hp} = \frac{F_c V}{33{,}000}$$

In metal cutting a very useful parameter is called the unit, or specific, horsepower HP_s, which is defined as

$$\text{HP}_s = \frac{\text{hp}}{\text{MRR}} (\text{hp/in.}^3\text{/min})$$

In turning, for example, where $\text{MRR} \cong 12 V f_r d$, then

$$\text{HP}_s = \frac{F_c}{396{,}000 f_r d}$$

$\text{HP} = F_c V/33000$

$\text{HP}_s = \text{HP/MRR}$ Where

$\text{MRR} = 12 V tw$ for tube turning

$\text{HP}_s = F_c V / 12 V tw \times 33000 = F_c / tw \times 396000$

Calculation of specific energy (U)

$U = F_c V / V tw = F_c / tw$ for tube turning

Specific power can be used in a number of ways. First, it can be used to estimate the motor horsepower required to perform a machining operation for a given material. HP_s values from the table are multiplied by the approximate MRR for the process. The motor horsepower HP_m, is then

$$HP_m = \frac{HP_s \times MRR \times CF}{E}$$

where E is the efficiency of the machine. The E factor accounts for the power needed to overcome friction and inertia in the machine and drive moving parts. Usually, 80% is used. Usually the maximum MRR is used in this calculation. Correction factors (CFs) may also be used to account for variations in cutting speed, feed, and rake angle. There is usually a tool wear correction factor of 1.25, used to account for the fact that dull tools use more power than sharp tools.

The primary cutting force F_c can be roughly estimated according to

$$F_c \cong \frac{HP_s \times MRR \times 33{,}000}{V}$$

This type of estimate of the major force F_c is useful in analysis of deflection and vibration problems in machining and in the proper design of workholding devices, because these devices must be able to resist movement and deflection of the part during the process.

Equation 20-12 can be used to estimate the maximum depth of cut, d, for a process as limited by the available power.

$$d_{max} = \frac{HP_m \times E}{12 HP_s V F_r (CF)} \tag{20-13}$$

Another handbook value useful in chatter or vibration calculations is cutting stiffness K_s. In this text, the term *specific energy U* will be used interchangeably with cutting stiffness K_s.

$$U = U_s + U_f$$

where specific energy (also called cutting stiffness) is

$$U = \frac{F_c V}{V f_r d} = \frac{F_c}{f_r d} = K_s \text{ (turning)}$$

The specific shear energy is

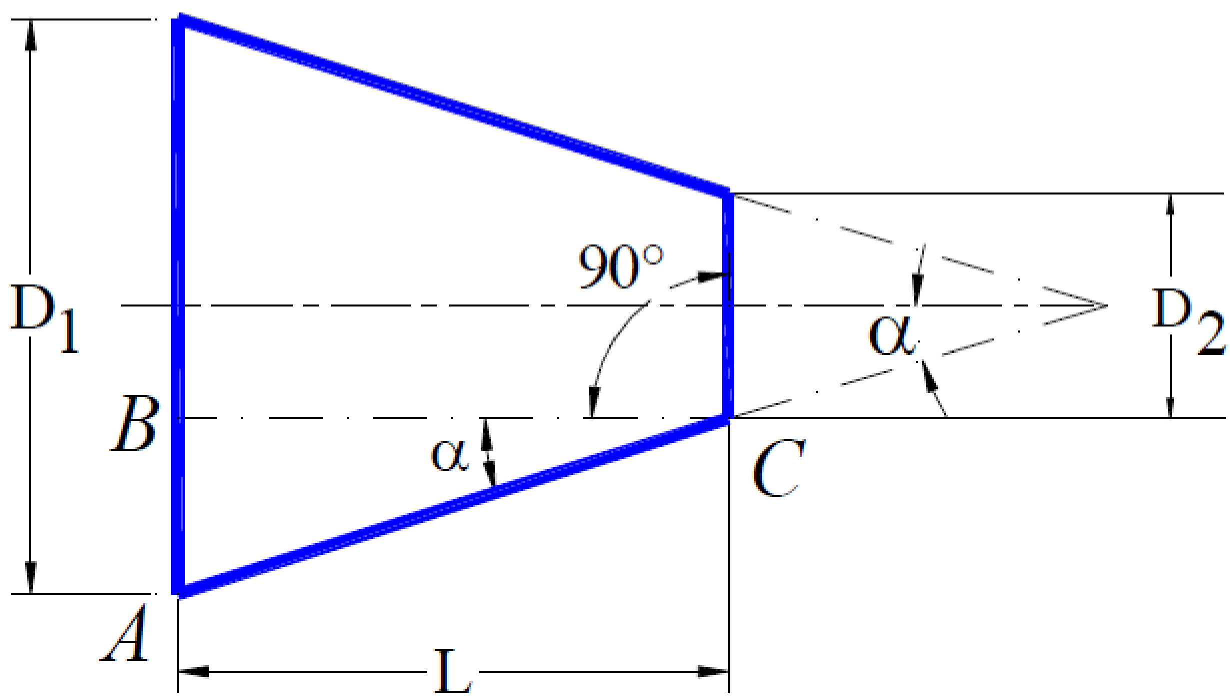
$$U_s = \frac{F_c V_s}{V f_r d}$$

where V_s is the shear velocity and F_s is the shear force.
Specific friction energy is

$$U_f = \frac{F V_c}{V f_r d} = \frac{F r_c}{f_r d}$$

Taper Turning (Compound Rest angle)

$$\tan \alpha = \frac{D_1 - D_2}{2L}$$



Turning Problem

Determine the angle at which the compound rest would be swiveled for cutting a taper on a work piece having a length of 150 mm and outside diameter 80 mm. The smallest diameter on the tapered end of the rod should be 50 mm and the required length of the tapered portion is 80 mm.

Turning Problem

Calculate the approximate time required to machine a work piece 170 mm long, 60 mm diameter to 165 mm long 50 mm diameter. The work piece rotates at constant speed 440 rpm, feed is 0.3 mm/rev and maximum depth of cut is 2 mm. Assume total approach and over travel distance as 5 mm for turning operation.

Turning Problem

An 8-in-diameter stainless-steel bar is being turned on a lathe at 600 rpm and at a depth of cut, $d = 0.1$ in. If the power of the motor is 5 hp and has a mechanical efficiency of 80%, what is the maximum feed that you can have at a spindle speed of 500 rpm before the motor stalls?

Material Removal Rate and Cutting Force in Turning

A 6-in.-long, $\frac{1}{2}$-in.-diameter 304 stainless steel rod is being reduced in diameter to 0.480 in. by turning on a lathe. The spindle rotates at $N = 400$ rpm, and the tool is traveling at an axial speed of 8 in./min. Calculate the cutting speed, material removal rate, cutting time, power dissipated, and cutting force.

Turning Problem

A 3-in. diameter low-strength, stainless-steel cylindrical part is to be turned on a lathe at 600 rpm, with a depth-of-cut of 0.2 in. and a feed of 0.025 in./rev. What should be the minimum horsepower of the lathe?

Turning Problem

A 6-in. diameter aluminum cylinder 10 in. in length is to have its diameter reduced to 4.5 in.
estimate the machining time if a TiN-coated carbide tool is used.

Also find the Power

Turning Problem

Estimate the machining time required to rough turn a 0.4-m long, annealed copper-alloy round bar from 60-mm diameter to 55-mm diameter using a high-speed-steel tool.

Estimate the time required for a carbide tool.

Turning Problem

A 6-in.-diameter aluminum bar with a length of 12 in. is to have its diameter reduced to 5 in. by turning. Estimate the machining time if an uncoated carbide tool is used.

Turning Problem

A 150-mm-long, 75-mm-diameter titanium-alloy rod is being reduced in diameter to 65 mm by turning on a lathe in one pass. The spindle rotates at 400 rpm and the tool is traveling at an axial velocity of 200 mm/min Calculate the cutting speed, material removal rate, time of cut, power required, and the cutting force.

Turning Problem

- A 4.00-in-diameter work piece that is 25 in long is to be turned down to a diameter of 3.50 in, using two passes on an engine lathe using a cutting speed = 300 ft/min, feed = 0.015 in/rev, and depth of cut = 0.125 in. The bar will be held in a chuck and supported on the opposite end in a live center. With this work holding setup, one end must be turned to diameter for 15 in length; then the bar must be reversed to turn the other end. Using an overhead crane available at the lathe, the time required to load and unload the bar is 5.0 minutes, and the time to reverse the bar is 3.0 minutes. For each turning cut an allowance must be added to the cut length for approach and overtravel. The total allowance (approach plus overtravel) = 0.50 in. Determine the total cycle time to complete this turning operation.

Turning Problem

- A tapered surface is to be turned on an automatic lathe. The work piece is 750 mm long with minimum and maximum diameters of 100 mm and 200 mm at opposite ends. The automatic controls on the lathe permit the surface speed to be maintained at a constant value of 200 m/min by adjusting the rotational speed as a function of work piece diameter. Feed = 0.25 mm/rev and depth of cut = 3.0 mm. The rough geometry of the piece has already been formed, and this operation will be the final cut. Determine (a) the time required to turn the taper and (b) the rotational speeds at the beginning and end of the cut.

Approximate Energy Requirements in Cutting Operations

TABLE 20.2 Approximate Energy Requirements in Cutting Operations (at drive motor, corrected for 80% efficiency; multiply by 1.25 for dull tools).

Material	Specific energy W-s/mm^3	Specific energy hp-min/in.^{3}
Aluminum alloys	0.4–1.1	0.15–0.4
Cast irons	1.6–5.5	0.6–2.0
Copper alloys	1.4–3.3	0.5–1.2
High-temperature alloys	3.3–8.5	1.2–3.1
Magnesium alloys	0.4–0.6	0.15–0.2
Nickel alloys	4.9–6.8	1.8–2.5
Refractory alloys	3.8–9.6	1.1–3.5
Stainless steels	3.0–5.2	1.1–1.9
Steels	2.7–9.3	1.0–3.4
Titanium alloys	3.0–4.1	1.1–1.5

General Recommendations for Turning Operations

TABLE 22.4

Workpiece material	Cutting tool	General-purpose starting conditions: Depth of cut mm (in.)	Feed mm/rev (in./rev)	Cutting speed m/min (ft/min)	Range for roughing and finishing: Depth of cut mm (in.)	Feed mm/rev (in./rev)	Cutting speed m/min (ft/min)
Low-C and free-machining steels	Uncoated carbide	1.5-6.3 (0.06-0.25)	0.35 (0.014)	90 (300)	0.5-7.6 (0.02-0.30)	0.15-1.1 (0.006-0.045)	60-135 (200-450)
	Ceramic-coated carbide	"	"	245-275 (800-900)	"	"	120-425 (400-1400)
	Triple coated carbide	"	"	185-200 (600-650)	"	"	90-245 (300-800)
	TiN-coated carbide	"	"	105-150 (350-500)	"	"	60-230 (200-750)
	Al_2O_3 ceramic	"	0.25 (0.010)	395-440 (1300-1450)	"	"	365-550 (1200-1800)
	Cermet	"	0.30 (0.012)	215-290 (700-950)	"	"	105-455 (350-1800)
Medium and high-C steels	Uncoated carbide	1.2-4.0 (0.05-0.20)	0.30 (0.012)	75 (250)	2.5-7.6 (0.10-0.30)	0.15-0.75 (0.006-0.03)	45-120 (150-400)
	Ceramic-coated carbide	"	"	185-230 (600-750)	"	"	120-410 (400-1350)
	Triple coated carbide	"	"	120-150 (400-500)	"	"	75-215 (250-700)
	TiN-coated carbide	"	"	90-200 (300-650)	"	"	45-215 (150-700)
	Al_2O_3 ceramic	"	0.25 (0.010)	335 (1100)	"	"	245-455 (800-1500)
	Cermet	"	0.25 (0.010)	170-245 (550-800)	"	"	105-305 (350-1000)

General Recommendations for Turning Operations (cont.)

TABLE 22.4 (continued)

		General-purpose starting conditions			Range for roughing and finishing		
Workpiece material	Cutting tool	Depth of cut mm (in.)	Feed mm/rev (in./rev)	Cutting speed m/min (ft/min)	Depth of cut mm (in.)	Feed mm/rev (in./rev)	Cutting speed m/min (ft/min)
Cast iron, gray	Uncoated carbide	1.25-6.3 (0.05-0.25)	0.32 (0.013)	90 (300)	0.4-12.7 (0.015-0.5)	0.1-0.75 (0.004-0.03)	75-185 (250-600)
	Ceramic-coated carbide	"	"	200 (650)	"	"	120-365 (400-1200)
	TiN-coated carbide	"	"	90-135 (300-450)	"	"	60-215 (200-700)
	Al_2O_3 ceramic	"	0.25 (0.010)	455-490 (1500-1600)	"	"	365-855 (1200-2800)
	SiN ceramic	"	0.32 (0.013)	730 (2400)	"	"	200-990 (650-3250)
Stainless steel, austenitic	Triple coated carbide	1.5-4.4 (0.06-0.175)	0.35 (0.014)	150 (500)	0.5-12.7 (0.02-0.5)	0.08-0.75 (0.003-0.03)	75-230 (250-750)
	TiN-coated carbide	"	"	85-160 (275-525)	"	"	55-200 (175-650)
	Cermet	"	0.30 (0.012)	185-215 (600-700)	"	"	105-290 (350-950)
High-temperature alloys, nickel base	Uncoated carbide	2.5 (0.10)	0.15 (0.006)	25-45 (75-150)	0.25-6.3 (0.01-0.25)	0.1-0.3 (0.004-0.012)	15-30 (50-100)
	Ceramic-coated carbide	"	"	45 (150)	"	"	20-60 (65-200)
	TiN-coated carbide	"	"	30-55 (95-175)	"	"	20-85 (60-275)
	Al_2O_3 ceramic	"	"	260 (850)	"	"	185-395 (600-1300)
	SiN ceramic	"	"	215 (700)	"	"	90-215 (300-700)
	Polycrystalline CBN	"	"	150 (500)	"	"	120-185 (400-600)

General Recommendations for Turning Operations (cont.)

TABLE 22.4 (continued)

Workpiece material	Cutting tool	General-purpose starting conditions: Depth of cut mm (in.)	Feed mm/rev (in./rev)	Cutting speed m/min (ft/min)	Range for roughing and finishing: Depth of cut mm (in.)	Feed mm/rev (in./rev)	Cutting speed m/min (ft/min)
Titanium alloys	Uncoated carbide	1.0-3.8 (0.04-0.15)	0.15 (0.006)	35-60 (120-200)	0.25-6.3 (0.01-0.25)	0.1-0.4 (0.004-0.015)	10-75 (30-250)
	TiN-coated carbide	"	"	30-60 (100-200)	"	"	10-100 (30-325)
Aluminum alloys, free machining	Uncoated carbide	1.5-5.0 (0.06-0.20)	0.45 (0.018)	490 (1600)	0.25-8.8 (0.01-0.35)	0.08-0.62 (0.003-0.025)	200-670 (650-2000)
	TiN-coated carbide	"	"	550 (1800)	"	"	60-915 (200-3000)
	Cermet	"	"	490 (1600)	"	"	215-795 (700-2600)
	Polycrystalline diamond	"	"	760 (2500)	"	"	305-3050 (1000-10,000)
High silicon	Polycrystalline diamond	"	"	530 (1700)	"	"	365-915 (1200-3000)
Copper alloys	Uncoated carbide	1.5-5.0 (0.06-0.20)	0.25 (0.010)	260 (850)	0.4-7.51 (0.015-0.3)	0.15-0.75 (0.006-0.03)	105-535 (350-1750)
	Ceramic-coated carbide	"	"	365 (1200)	"	"	215-670 (700-2200)
	Triple-coated carbide	"	"	215 (700)	"	"	90-305 (300-1000)
	TiN-coated carbide	"	"	90-275 (300-900)	"	"	45-455 (150-1500)
	Cermet	"	"	245-425 (800-1400)	"	"	200-610 (650-2000)
	Polycrystalline diamond	"	"	520 (1700)	"	"	275-915 (900-3000)

General Recommendations for Turning Operations (cont.)

Workpiece material	Cutting tool	General-purpose starting conditions: Depth of cut mm (in.)	Feed mm/rev (in./rev)	Cutting speed m/min (ft/min)	Range for roughing and finishing: Depth of cut mm (in.)	Feed mm/rev (in./rev)	Cutting speed m/min (ft/min)
Tungsten alloys	Uncoated carbide	2.5 (0.10)	0.2 (0.008)	75 (250)	0.25-5.0 (0.01-0.2)	0.12-0.45 (0.005-0.018)	55-120 (175-400)
	TiN-coated carbide	*	*	85 (275)	*	*	60-150 (200-500)
Thermoplastics and thermosets	TiN-coated carbide	1.2 (0.05)	0.12 (0.005)	170 (550)	0.12-5.0 (0.005-0.20)	0.08-0.35 (0.003-0.015)	90-230 (300-750)
	Polycrystalline diamond	*	*	395 (1300)	*	*	150-730 (500-2400)
Composites, graphite reinforced	TiN-coated carbide	1.9 (0.075)	0.2 (0.008)	200 (650)	0.12-6.3 (0.005-0.25)	0.12-1.5 (0.005-0.06)	105-290 (350-950)
	Polycrystalline diamond	*	*	760 (2500)	*	*	550-1310 (1800-4300)

Source: Based on data from Kennametal, Inc.
Note: Cutting speeds for high-speed steel tools are about one-half those for uncoated carbides.