Machining Equations (Turning)

Example from Book (p685)

- A 6-in long, 0.5 in diameter 304 stainless-steel rod is being reduced in diameter to 0.48 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, and power.

Revisit Terminology

- **Independent Variables**
  - **Material (machinability)**
  - **Cutting tool**
  - **Speed (sfpm)**
  - **Depth of cut (in)**
  - **Feed (ipr or ips)**
  - **Cutting environment**
- **Dependant Variables**
  - **Metal removal rate**
  - **Cut time**
  - **Horsepower**
  - **Temperature**
  - **Surface finish**

Turning Formulas

TABLE 23.3

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/fN
MRR	=	mm^3/min or in ^{3}/min
	=	$\pi D_{avg} d f N$
Torque	=	N•m or lb•ft
	=	$F_c D_{avg}/2$
Power	=	kW or hp
	=	(Torque)(ω), where $\omega = 2\pi N$ rad/min

Note: The units given are those that are used commonly; however, appropriate units must be used and checked in the formulas.

Turning Operation

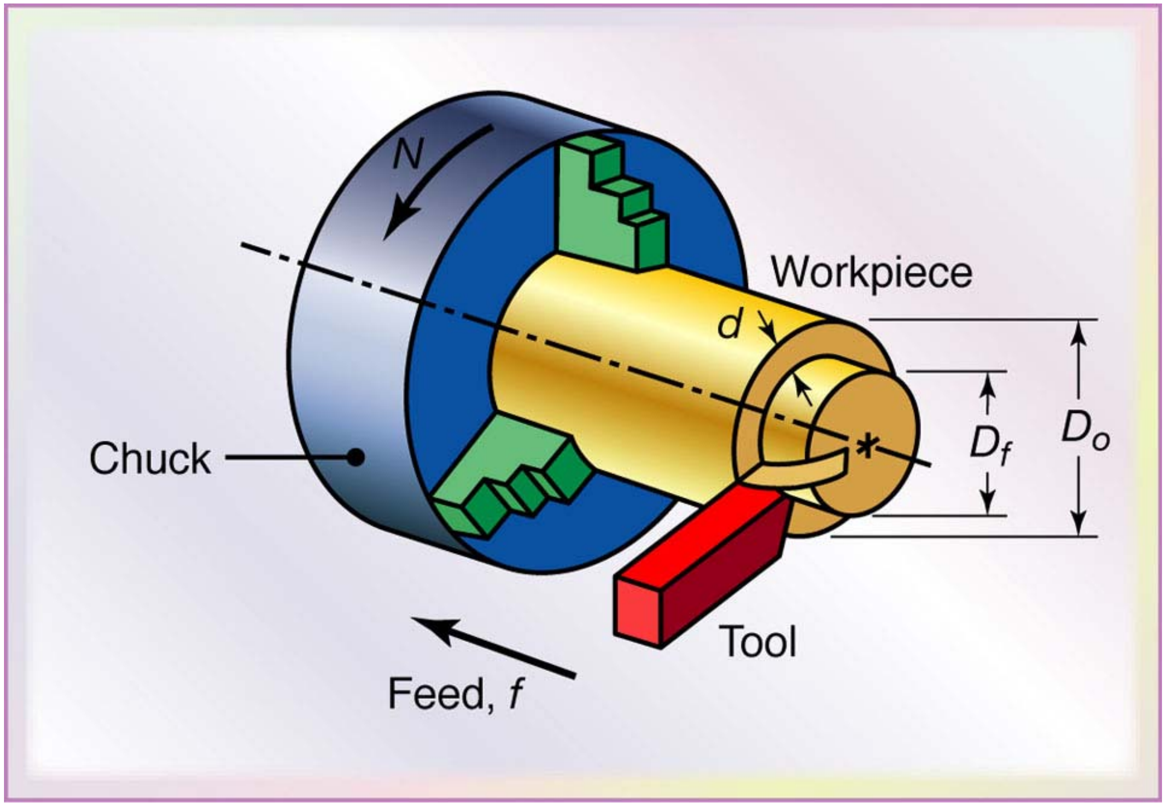
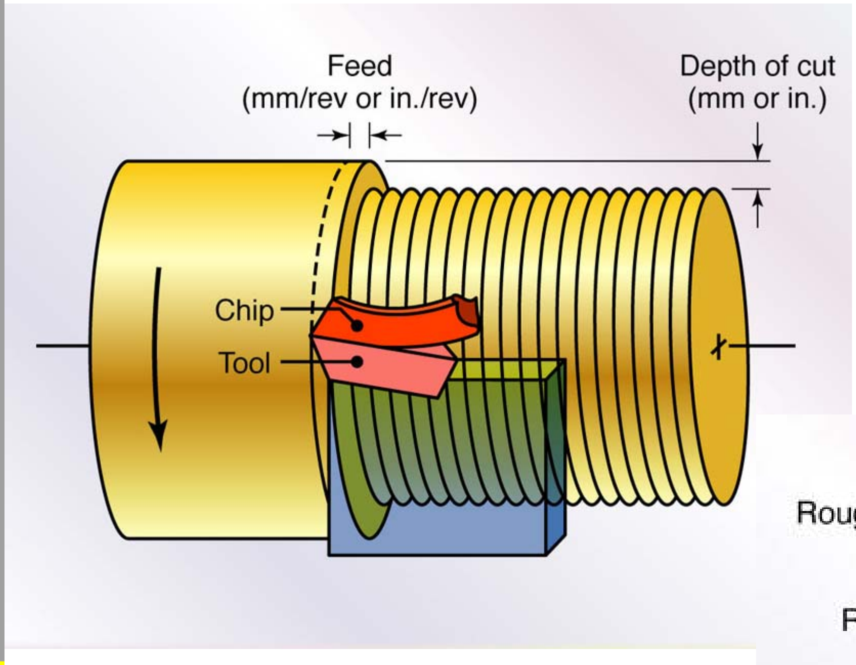
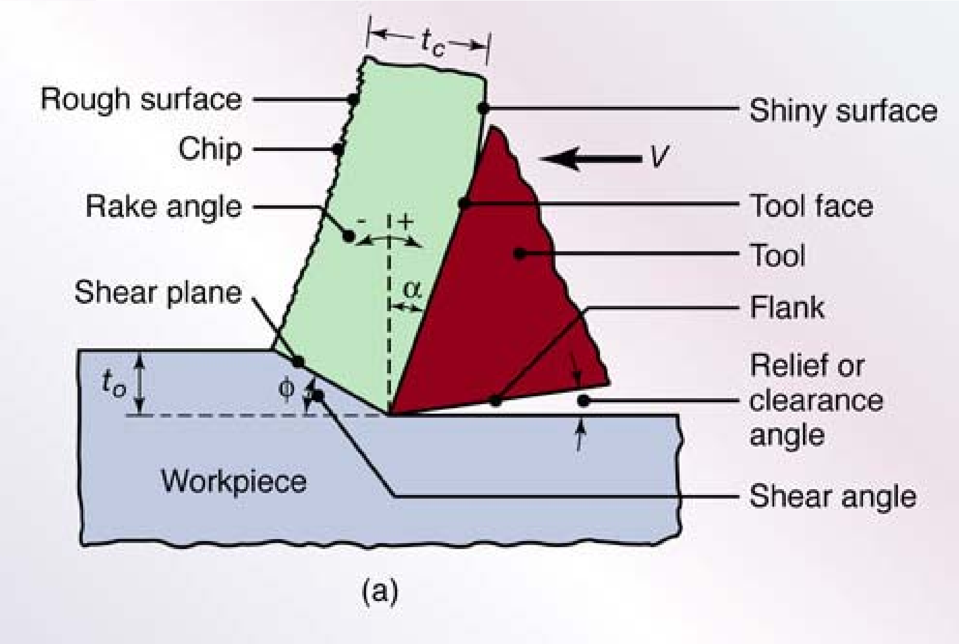


Figure 23.3 Schematic illustration of the basic turning operation, showing depth-of-cut, *d*; feed, *f*; and spindle rotational speed, *N* in rev/min. Cutting speed is the surface speed of the workpiece at the tool tip.

Turning

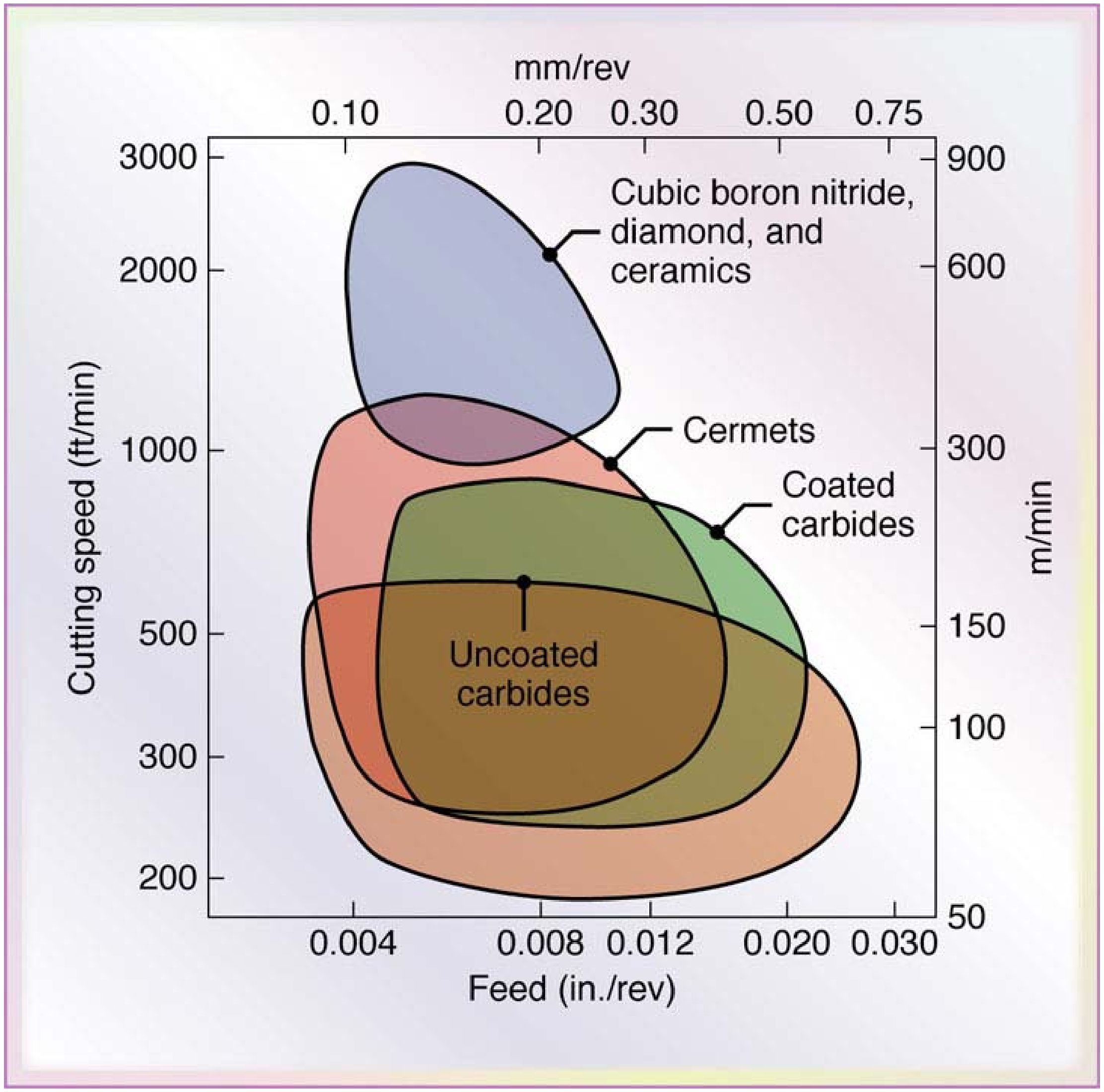

Feed
(mm/rev or in./rev)
Depth of cut
(mm or in.)
Chip
Tool


t_c
Rough surface
Chip
Rake angle
Shear plane
t_o
ϕ
α
Workpiece
Shiny surface
V
Tool face
Tool
Flank
Relief or
clearance
angle
Shear angle
(a)

Understanding Formulas

- (in class)

Feeds & Speeds for Tool Materials



Turning Feeds & Speeds

TABLE 23.4

General Recommendations for Turning Operations

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 (350–1500)
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)
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

(Continued)

Energy Requirements

TABLE 21.2

Approximate Range of Energy Requirements in Cutting Operations at the Drive Motor of the Machine Tool (For Dull Tools, Multiply by 1.25)

Material	Specific energy	
	W-s/mm^3	hp-min/in^3
Aluminum alloys	0.4-1	0.15-0.4
Cast irons	1.1-5.4	0.4-2
Copper alloys	1.4-3.2	0.5-1.2
High-temperature alloys	3.2-8	1.2-3
Magnesium alloys	0.3-0.6	0.1-0.2
Nickel alloys	4.8-6.7	1.8-2.5
Refractory alloys	3-9	1.1-3.5
Stainless steels	2-5	0.8-1.9
Steels	2-9	0.7-3.4
Titanium alloys	2-5	0.7-2

Cut Environment

TABLE 22.5 General Recommendations for Cutting Fluids for Machining

Material	Type of fluid
Aluminum	D, MO, E, MO + FO, CSN
Beryllium	MC, E, CSN
Copper	D, E, CSN, MO + FO
Magnesium	D, MO, MO + FO
Nickel	MC, E, CSN
Refractory	MC, E, EP
Steels (carbon and low alloy)	D, MO, E, CSN, EP
Steels (stainless)	D, MO, E, CSN
Titanium	CSN, EP, MO
Zinc	C, MC, E, CSN
Zirconium	D, E, CSN

Note: CSN, chemicals and synthetics; D, dry; E, emulsion; EP, extreme pressure; FO, fatty oil; and MO, mineral oil.

Solution

Solution: The cutting speed is the tangential speed of the workpiece. The maximum cutting speed is at the outer diameter, D_o, and is obtained from the expression

$$V = \pi D_o N.$$

Thus,

$$V = (\pi)(0.500)(400) = 628 \text{ in./min} = 52 \text{ ft/min}.$$

The cutting speed at the machined diameter is

$$V = (\pi)(0.480)(400) = 603 \text{ in./min} = 50 \text{ ft/min}.$$

From the information given, we note that the depth of cut is

$$d = \frac{(0.500 - 0.480)}{2} = 0.010 \text{ in.}$$

and the feed is

$$f = \frac{8}{400} = 0.02 \text{ in./rev.}$$

According to Eq. (22.1), the material removal rate is then

$$\text{MRR} = (\pi)(0.490)(0.010)(0.02)(400) = 0.123 \text{ in.}^3\text{/min.}$$

The actual time to cut, according to Eq. (22.2), is

$$t = \frac{6}{(0.02)(400)} = 0.75 \text{ min.}$$

(continued)

Solution

We can calculate the power required by referring to Table 20.1 and taking an average value for stainless steel as $4 \text{ w} \cdot \text{s/mm}^3 = 4/2.73 = 1.47 \text{ hp} \cdot \text{min/in.}^3$. Therefore, the power dissipated is

$$\text{Power} = (1.47)(0.123) = 0.181 \text{ hp},$$

and since 1 hp = 396,000 in.-lb/min, the power dissipated is 71,700 in.-lb/min.

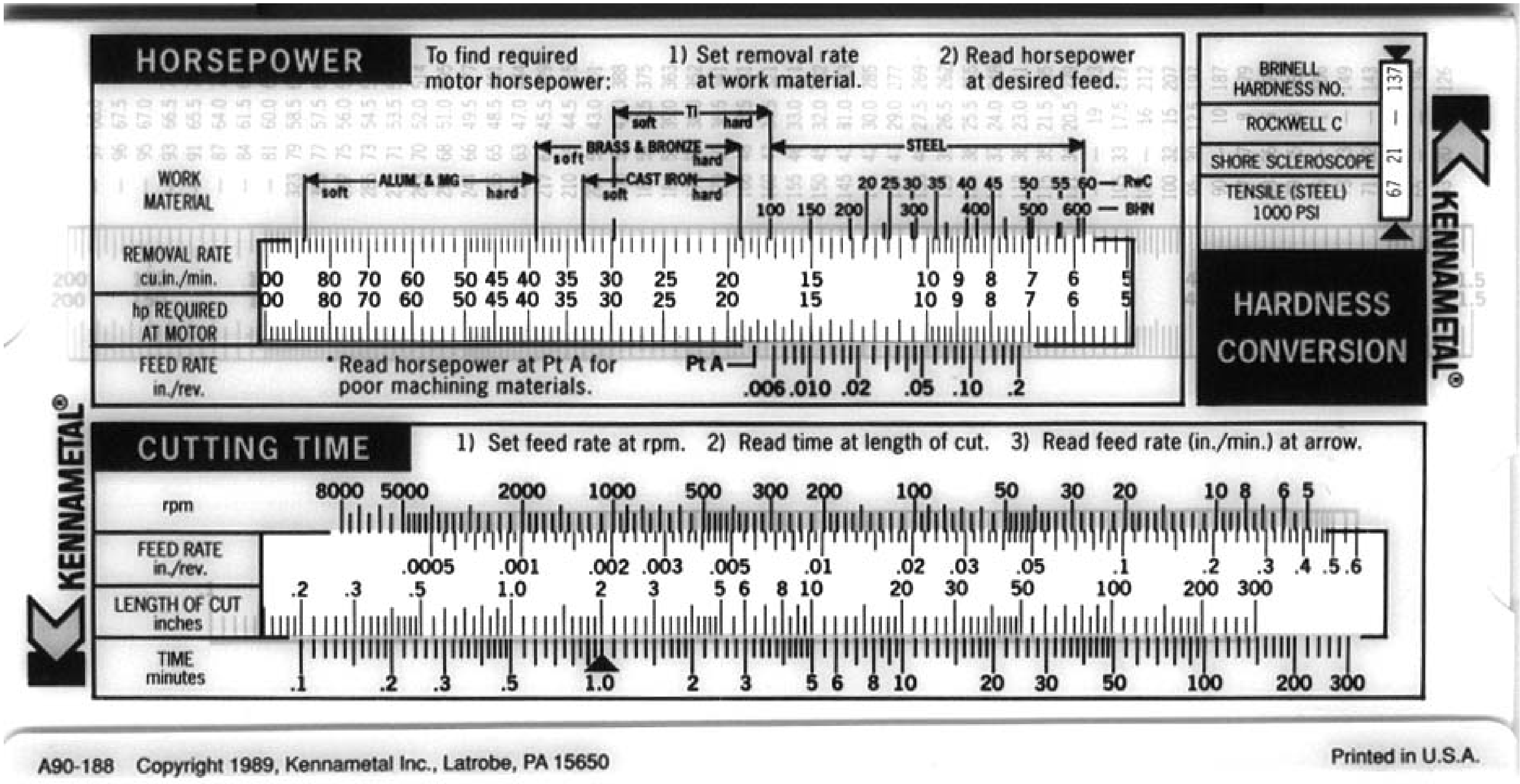
The cutting force, F_c, is the tangential force exerted by the tool. Power is the product of torque, T, and rotational speed in radians per unit time; hence,

$$T = \frac{(71{,}700)}{(400)(2\pi)} = 29 \text{ lb} - \text{in.}$$

Since $T = (F_c)(D_{avg}/2)$, we have

$$F_c = \frac{29}{(0.490/2)} = 118 \text{ lb.}$$

Kennametal Calculator



Kennametal Calculator

Kennametal Turning Calculator

How to use your new Kennametal calculator

SETUP DATA

workpiece material:	AISI 4140 steel, 230 BHN
workpiece diameter:	5 inches
workpiece length:	4 inches
depth of cut:	.150
insert:	CNMG 432
machine:	40 horsepower, good condition
speed:	500 sfm
feed:	.015

1) DETERMINE FEED AND SPEED
To determine suggested speed and feed, consult the technical information section of the most recent Kennametal catalog.

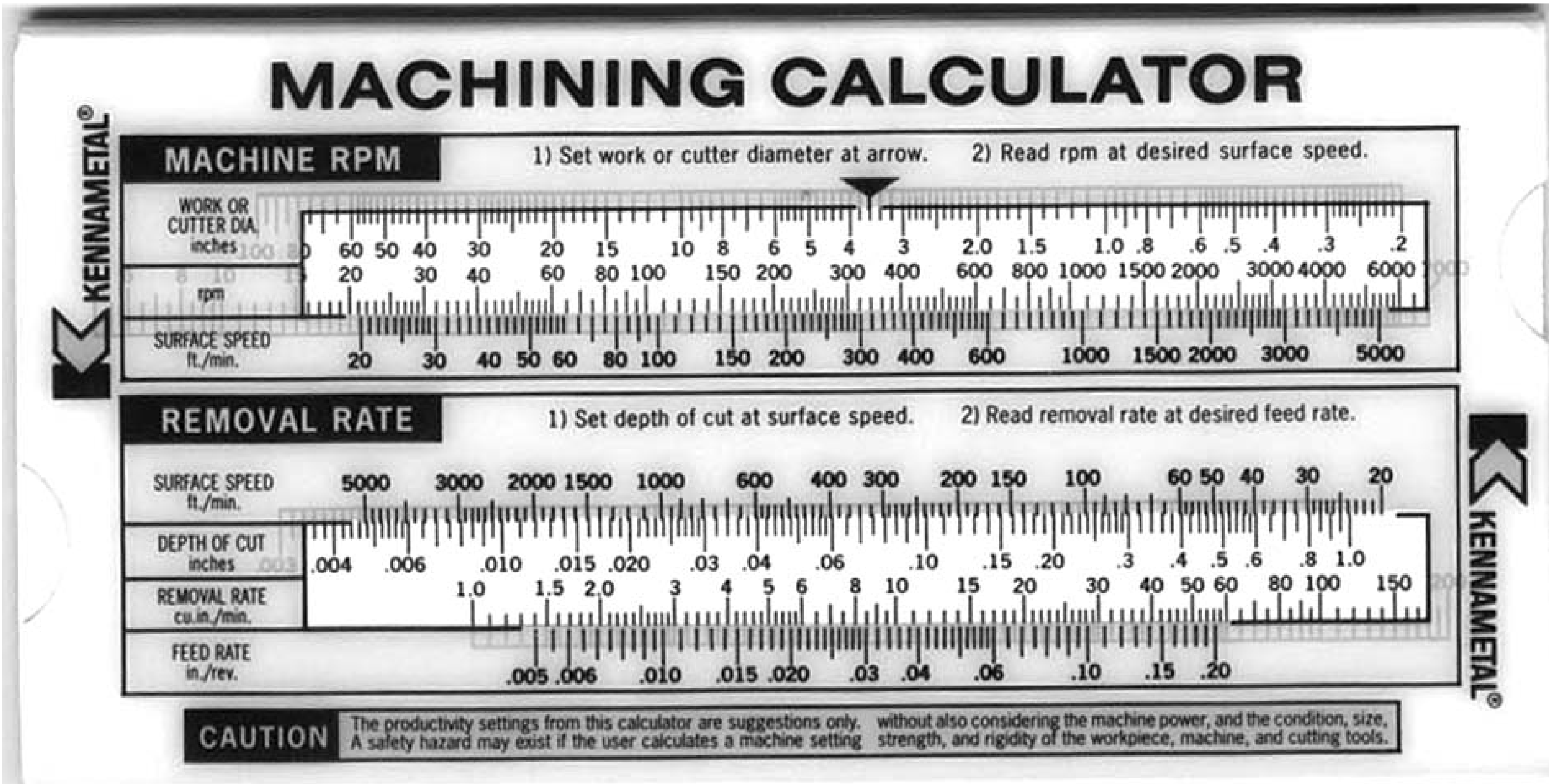
2) DETERMINE THE RPM
On the front side, MACHINE RPM, find 5 on the WORK DIAMETER scale and set this mark under the arrow. Opposite 500 on the SURFACE SPEED scale, read 380 on the RPM scale. The RPM is 380.

3) DETERMINE THE METAL REMOVAL RATE
On the front side, REMOVAL RATE, locate 500 on the SURFACE SPEED scale. Under this mark, set .150 on the DEPTH OF CUT scale. Without moving the slide, locate .015 on the FEED RATE scale and read 13.5 opposite it on the REMOVAL RATE scale. Metal removal rate is 13.5 cubic inches per minute.

4) DETERMINE THE HORSEPOWER
On the flipside, HORSEPOWER, locate 230 BHN on the WORK MATERIAL scale. Under it set 13.5 on the REMOVAL RATE scale. Without moving the slide, find .015 on the FEED RATE scale, and above it read 15 on the HORSEPOWER REQUIRED scale. The horsepower required is 15.

5) DETERMINE CUTTING TIME
Also on the flipside, CUTTING TIME, locate 380 on the RPM scale. Under it, set .015 on the FEED RATE scale. Without moving the slide, find 4 on the LENGTH OF CUT scale, and read .7 under it on the TIME scale. The proposed cut will require .7 minutes.

Kennametal Calculator



Equations, 1

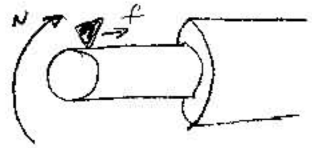
Let's understand Table 23.3

10/2003

revised 3/2006

N

f



$N = \frac{Rev}{min}$ or RPM of the spindle

f = feed or tool movement across part

$= \frac{in.}{rev}$

We can also express feed as a "rate".

what is the tool advancement per "time"?

v = feed rate $= fN = \left(\frac{in}{\cancel{rev}}\right)\left(\frac{\cancel{rev}}{min}\right)$

$= \frac{in}{min}$

Always check units!!

Ex $f = .01$ in/rev

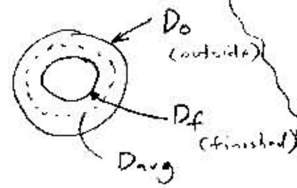
$N = 1$ rev/min

$v = .01 \frac{in}{\cancel{rev}} \cdot 1 \frac{\cancel{rev}}{min}$

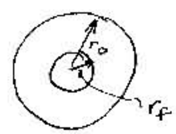
$= .01$ in/min

Depth of cut

Diameters

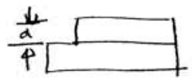


Radii



1

Equations, 2

Depth of cut  flat surface – easy

Here's what I see. ⟹  Curve surface radii, diameters

$$\boxed{d = r_o - r_f}$$

$r_o = \frac{1}{2} D_o$

$r_f = \frac{1}{2} D_f$

another way

same

$$d = \frac{1}{2} D_o - \frac{1}{2} D_f$$

$$\boxed{d = \frac{D_o - D_f}{2}}$$

Surface Speed – V (how fast is the tool tip moving through the material?)

$$V = \frac{\text{distance}}{\text{time}} = \frac{ft}{min}$$

$$= \pi D \left(\frac{in}{rev}\right) * N \frac{rev}{min}$$

Which D? Worst case is D_o (fastest)

When you buy a tool the mfg usually gives you V & d (see Fig 23.6 or Table 23.4)

(2)

Equations, 3

Cut time

How much time does it take to go 60 miles if you are driving 20 miles/hr?

$t = \frac{l}{v}$

same thing for turning

$\boxed{t = \frac{l}{v}} = \frac{in}{in/min} \Rightarrow min$

another way...

$v = fN$

$\boxed{t = \frac{l}{fN}}$ same

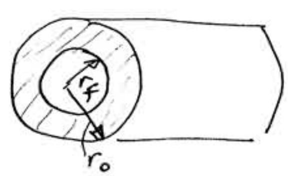
Material Removal Rate (MRR)

$MRR = \frac{Volume}{time}$

Author says $MRR = \pi D_{avg}\, d f N$

Ha??

I prefer looking at the change in volume per time.



$Vol = \pi r^2 l$

$\Delta Vol = \pi r_o^2 l - \pi r_f^2 l$

$t = \frac{l}{fN}$ (from above)

(3)

Equations, 4

MRR (cont)

I see $MRR = \dfrac{\pi \cancel{d}(r_o^2 - r_f^2)}{\cancel{d}/fN}$

or $\pi f N (r_o^2 - r_f^2)$

Let's see if my equation agrees with the author's.

Is $\pi D_{avg}\, d f N \stackrel{?}{=} \pi f N (r_o^2 - r_f^2)$

$$\cancel{\pi} D_{avg}\, d \cancel{f}\cancel{N} = \cancel{\pi}\cancel{f}\cancel{N}(r_o^2 - r_f^2)$$

Is $D_{avg}\, d = r_o^2 - r_f^2$

$$D_{avg} = \frac{D_o + D_f}{2} \qquad d = \frac{D_o - D_f}{2}$$

$$\left(\frac{D_o + D_f}{2}\right)\left(\frac{D_o - D_f}{2}\right) = r_o^2 - r_f^2$$

$$\frac{D_o^2 - D_f^2}{4} = r_o^2 - r_f^2$$

$$D_o = 2r_o \qquad D_f = 2r_f$$

$$\frac{(2r_o)^2 - (2r_f)^2}{4} = r_o^2 - r_f^2$$

$$\frac{\cancel{4}r_o^2 - \cancel{4}r_f^2}{\cancel{4}}$$

$$r_o^2 - r_f^2 = r_o^2 - r_f^2$$ Yes!! the same!!

4

Equations, 5

Power - P

I prefer author's approach:

$$P = \begin{bmatrix} \text{Energy required} \\ \text{to remove a volume} \end{bmatrix} \begin{bmatrix} \text{Rate of removing} \\ \text{a volume} \end{bmatrix}$$

$\Downarrow$ we get from Table 21.2

$\Downarrow$ MRR

$$P = E * MRR$$

Table 21.2 gives high & low. We might use an average.

$$E_{avg} = \frac{E_l + E_h}{2}$$

Now - try some problems by yourself.