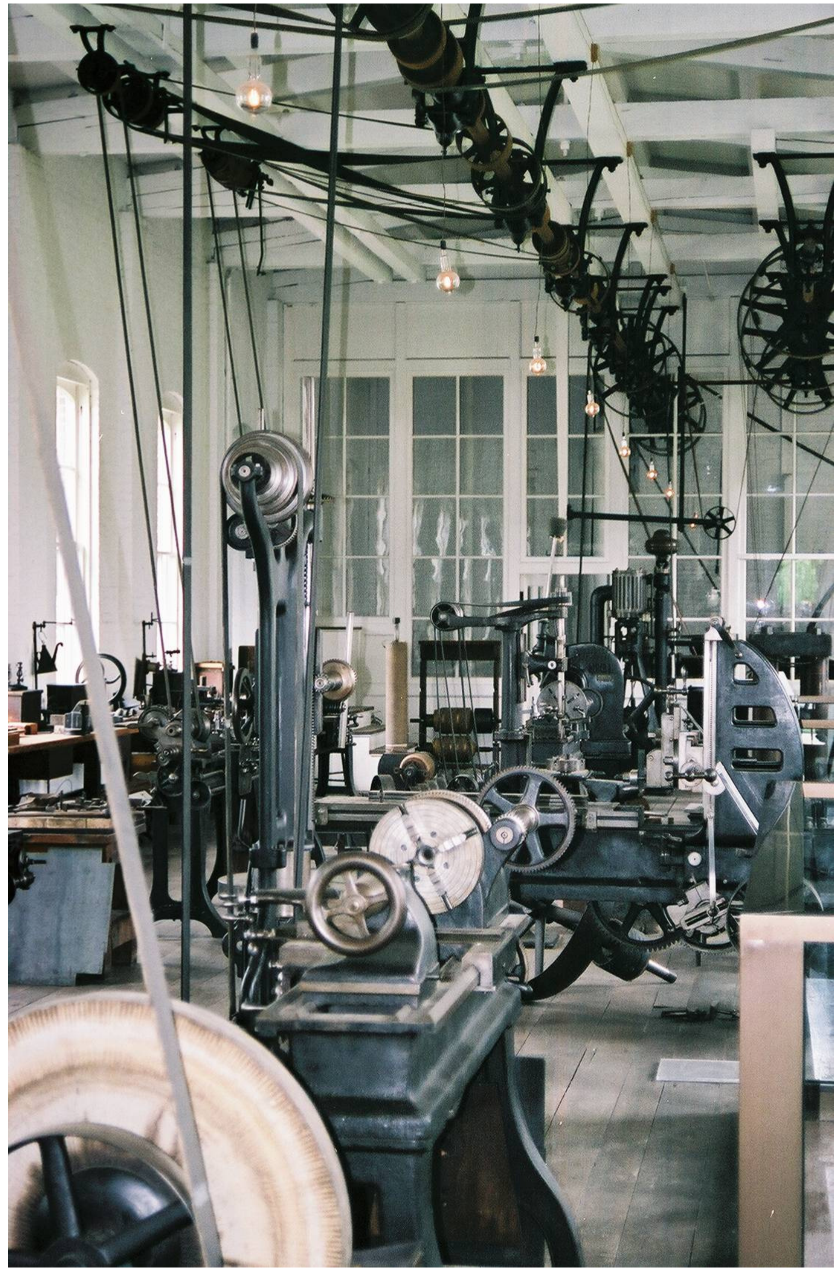
# Machining

ver. 1

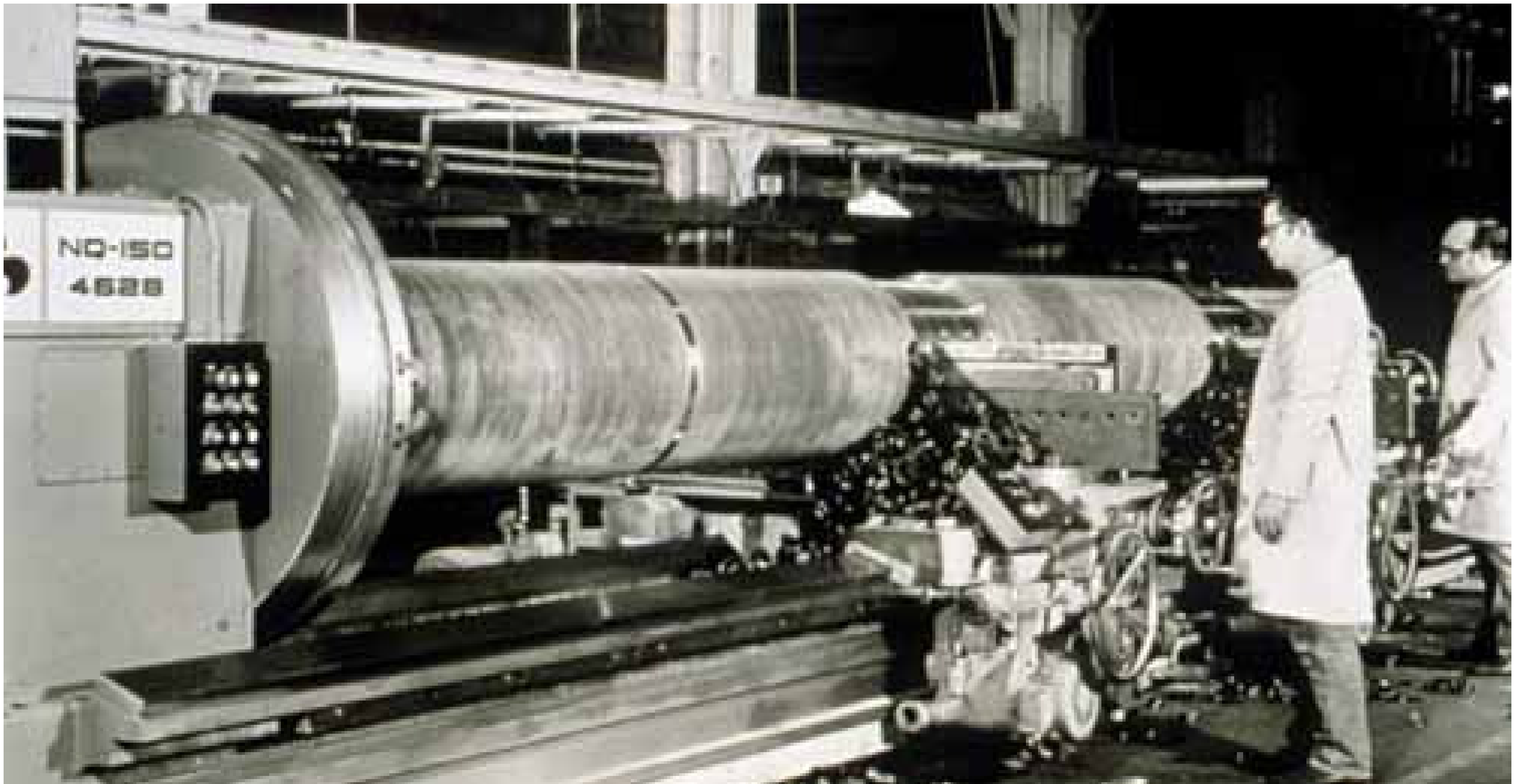
ME 338: Manufacturing Processes II
Instructor: Ramesh Singh; Notes: Profs. Singh/Melkote/Colton

Old Machine Shop – Edison's lab



# Machining = Chip formation by a tool

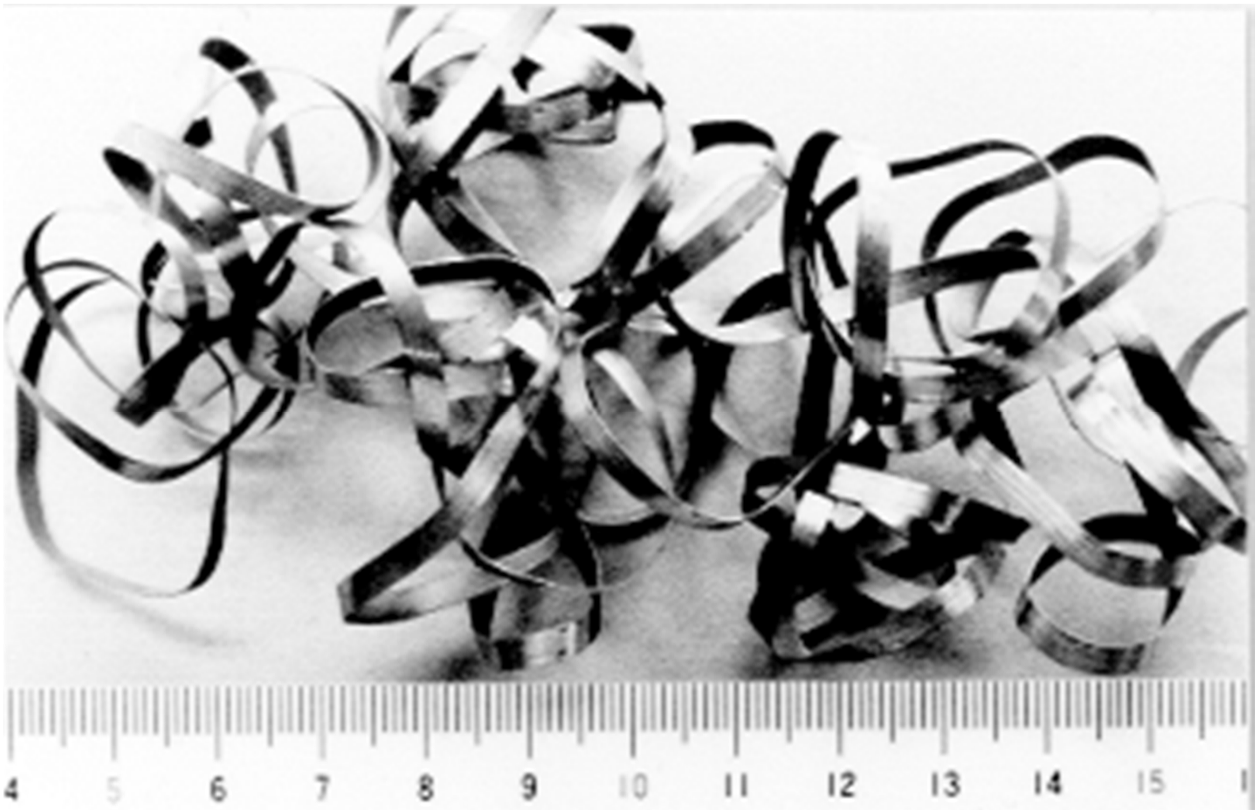
# Big lathe with big chips



# Giant Lathe

# Discontinuous chips

# Continuous chips

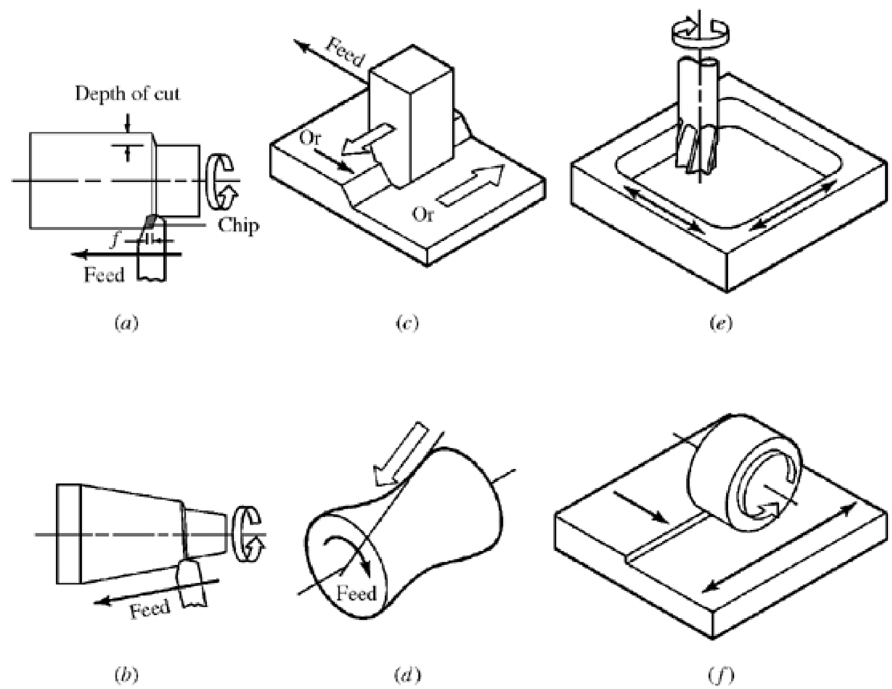


# Machine Tools and Processes

- Turning
- Boring
- Milling
- Planing
- Shaping
- Broaching
- Drilling
- Filing
- Sawing
- Grinding
- Reaming
- Honing
- Tapping

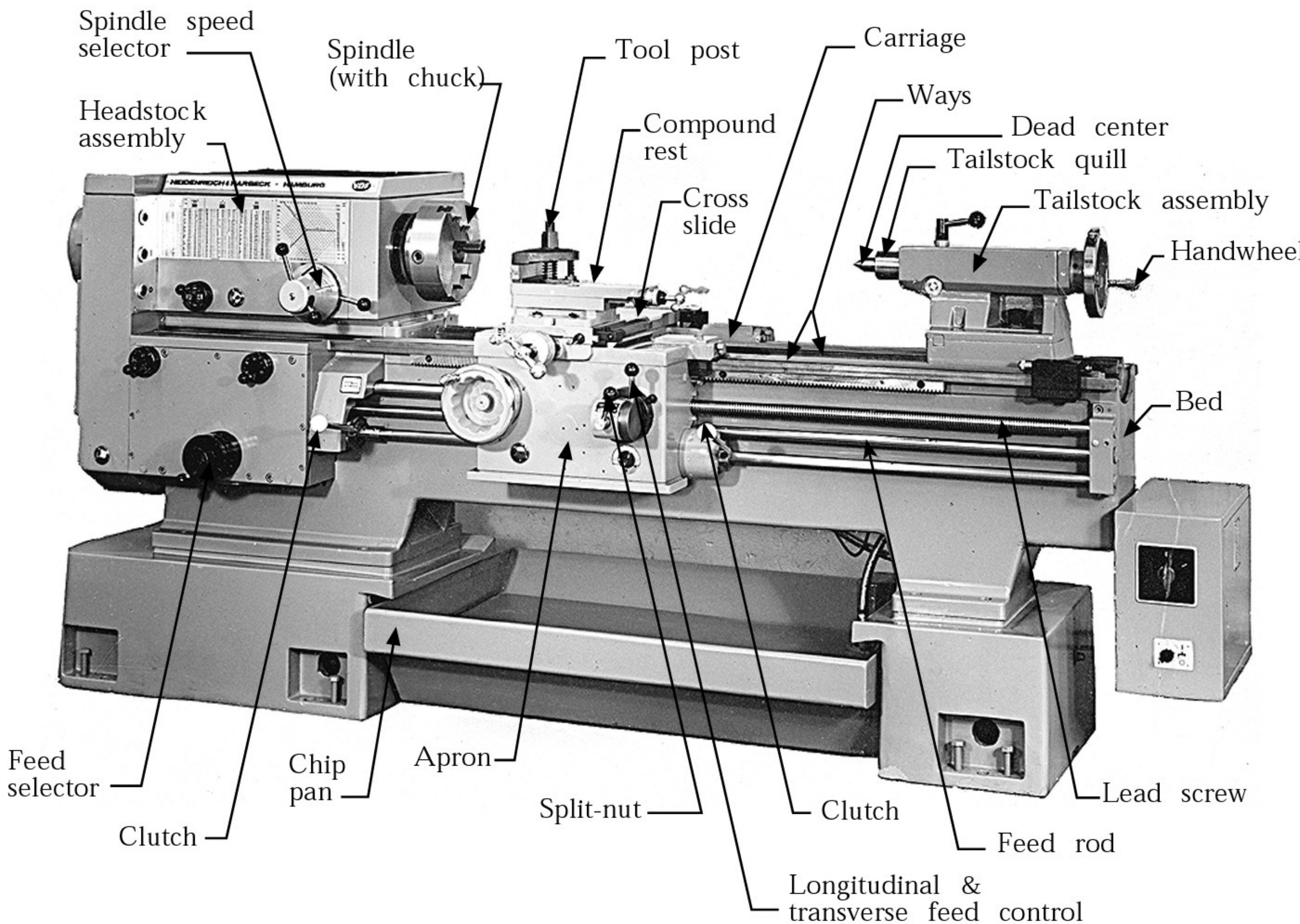
# Classification of Conventional Machining

- Cutting processes
  - Single point: e.g. shaping, planing, turning, boring, etc.
  - Multiple point: e.g. milling, drilling, etc.
- Abrasive processes
  - Grinding, honing, etc.



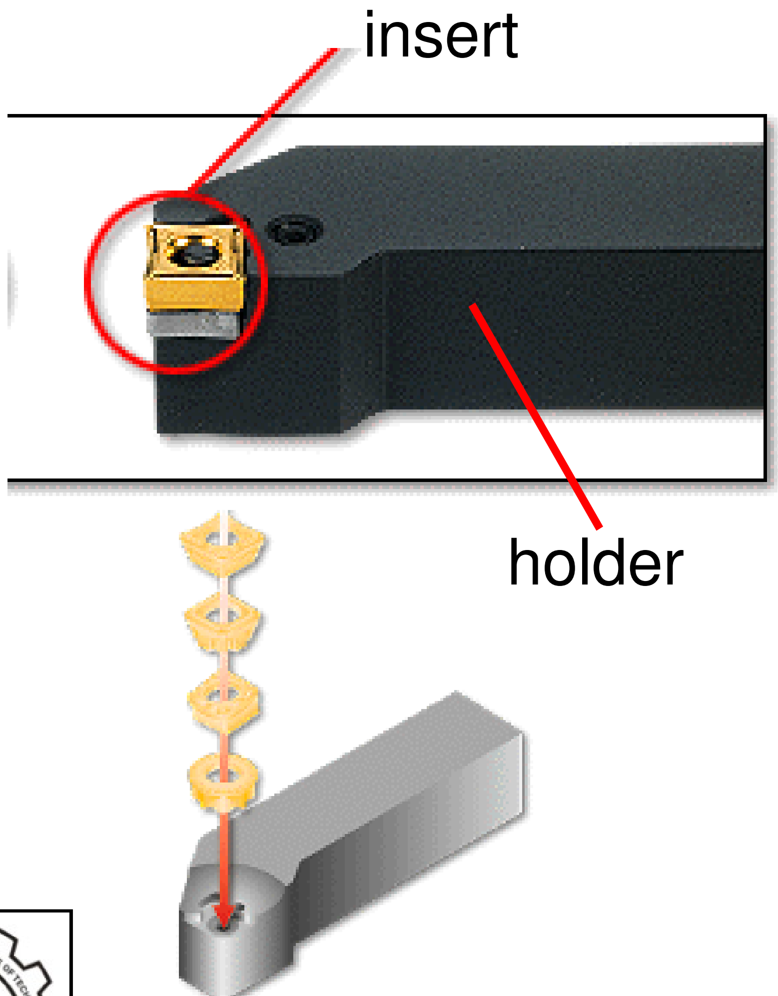
# Lathe (for turning)

# Lathe Parts



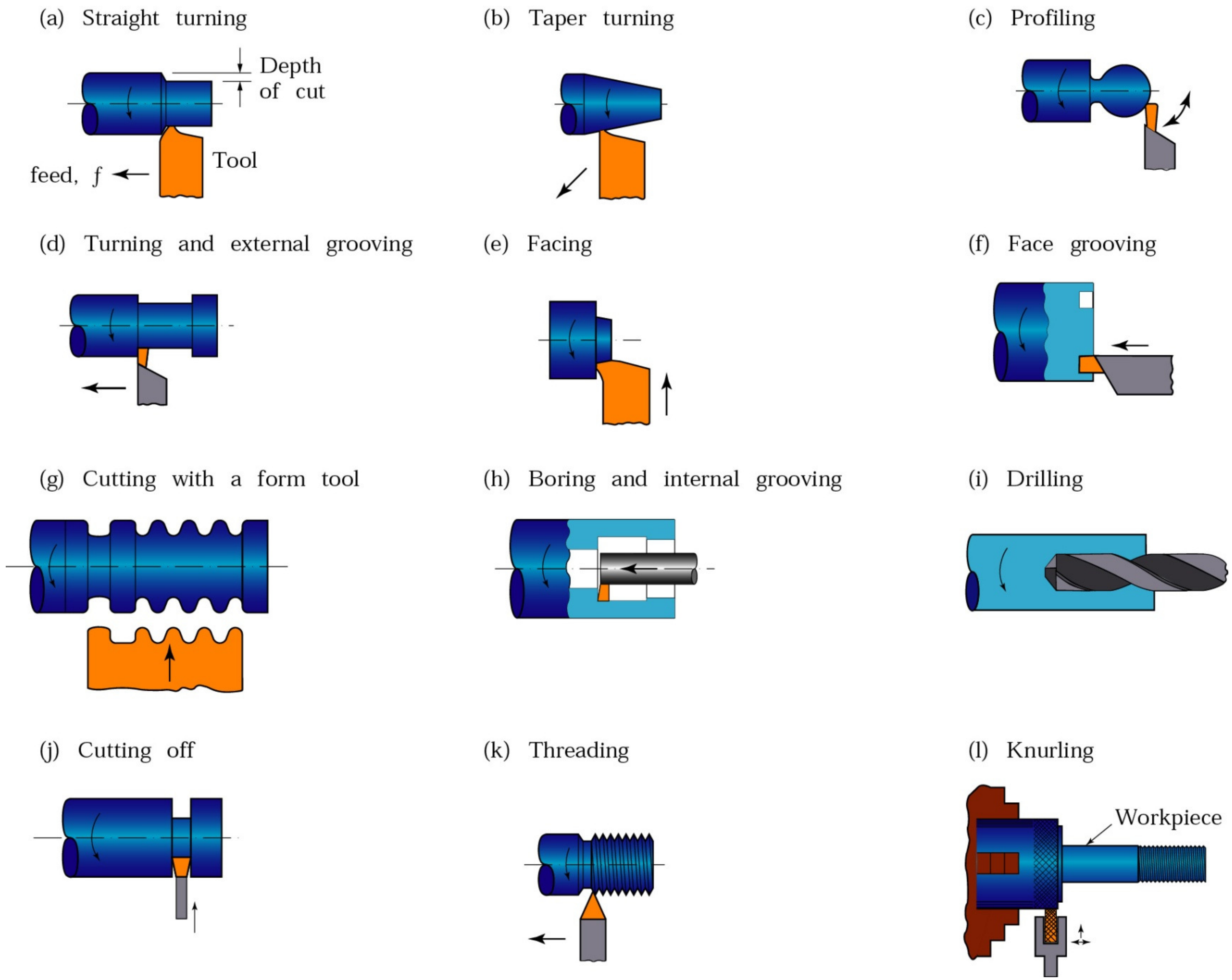
Spindle speed selector
Spindle (with chuck)
Tool post
Carriage
Ways
Headstock assembly
Compound rest
Dead center
Tailstock quill
Cross slide
Tailstock assembly
Handwheel
Bed
Feed selector
Chip pan
Apron
Split-nut
Clutch
Lead screw
Clutch
Feed rod
Longitudinal & transverse feed control

# Typical Insert Cutting Tool

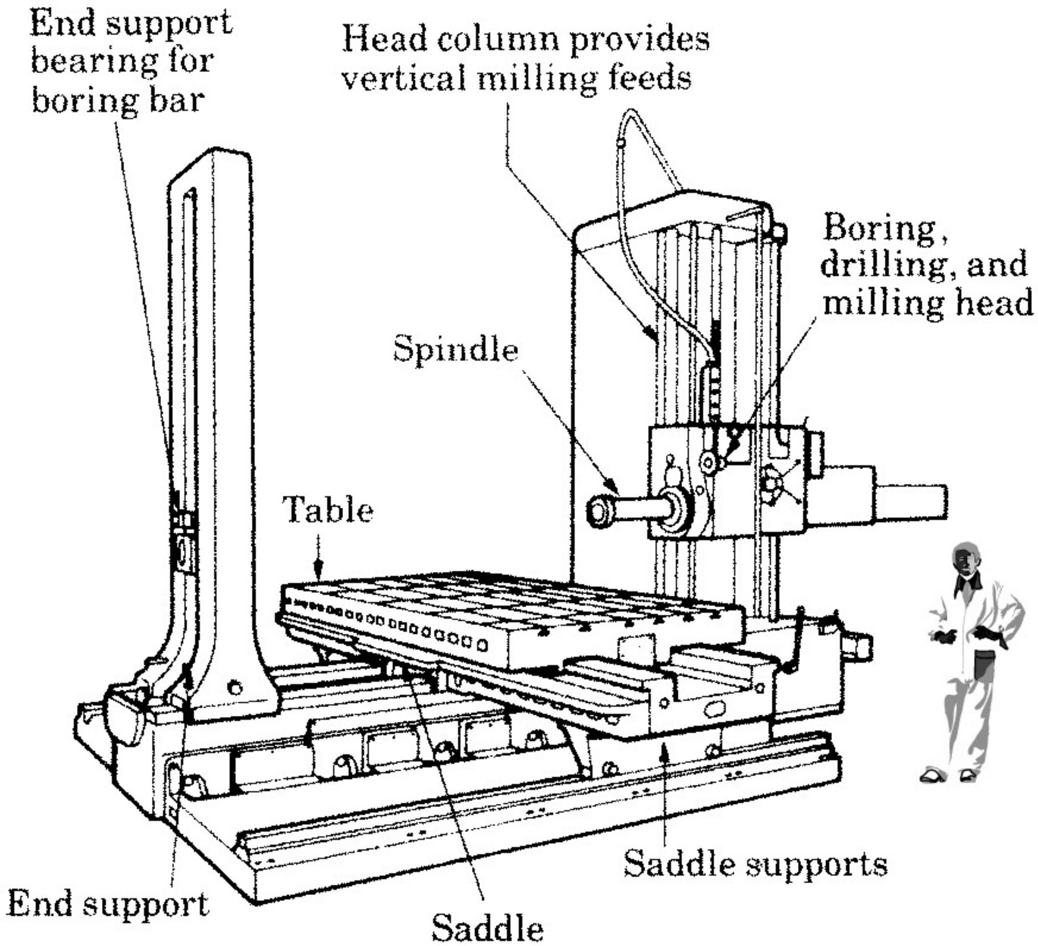


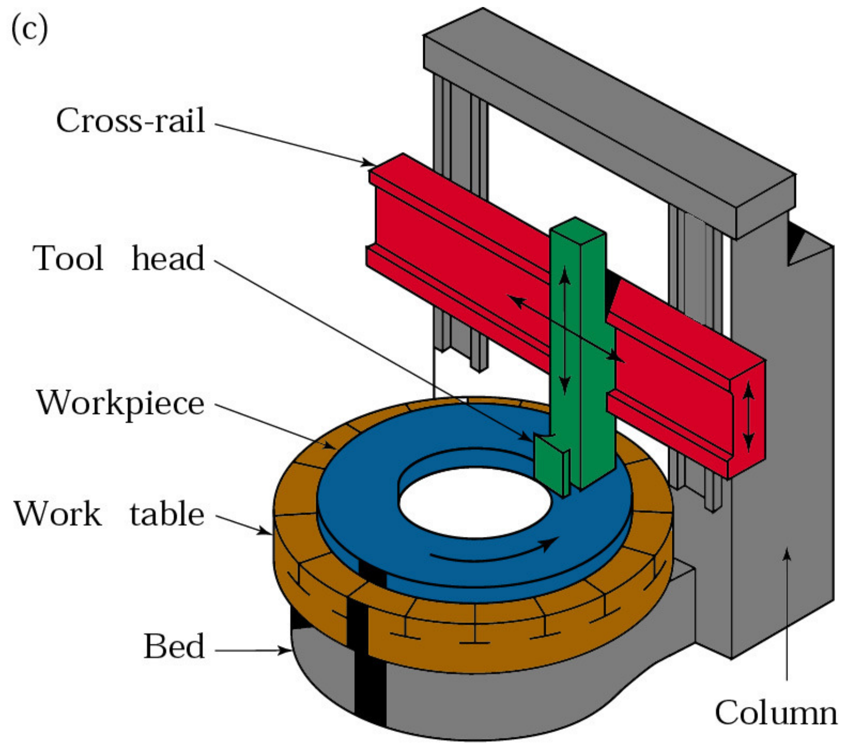

# Pillars made on Lathe

# Old Lathe

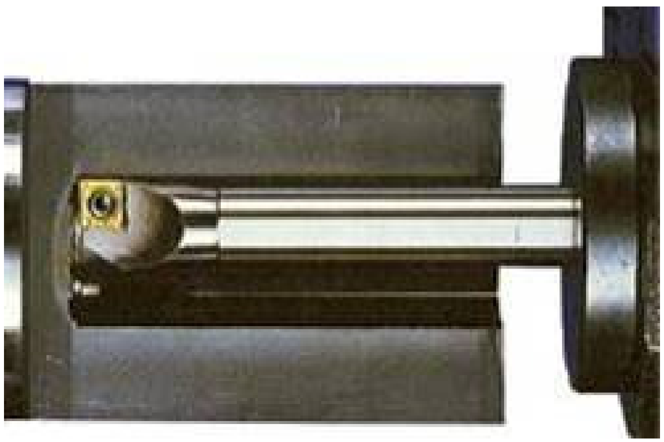

(a) Straight turning
Depth of cut
Tool
feed, f
(b) Taper turning
(c) Profiling
(d) Turning and external grooving
(e) Facing
(f) Face grooving
(g) Cutting with a form tool
(h) Boring and internal grooving
(i) Drilling
(j) Cutting off
(k) Threading
(l) Knurling
Workpiece

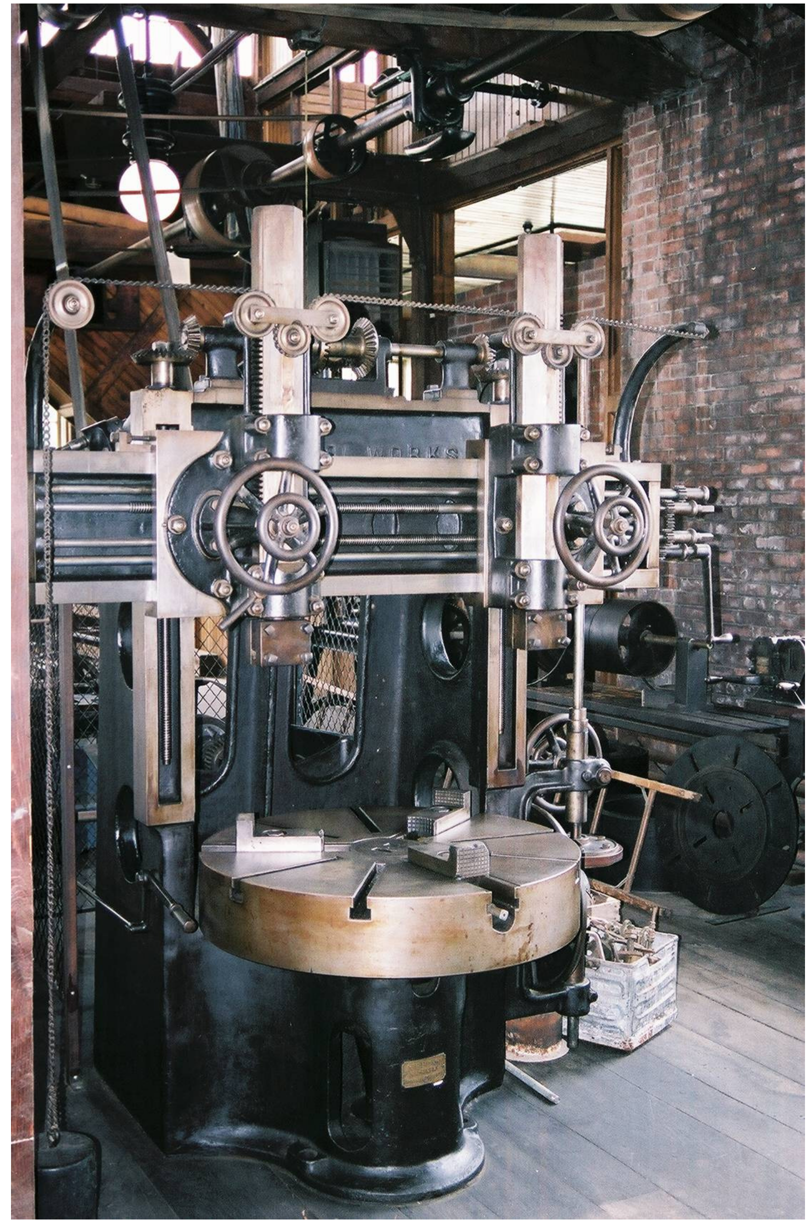
# Boring


End support bearing for boring bar
Head column provides vertical milling feeds
Boring, drilling, and milling head
Spindle
Table
End support
Saddle
Saddle supports


(c)
Cross-rail
Tool head
Workpiece
Work table
Bed
Column

# Old Boring Machine



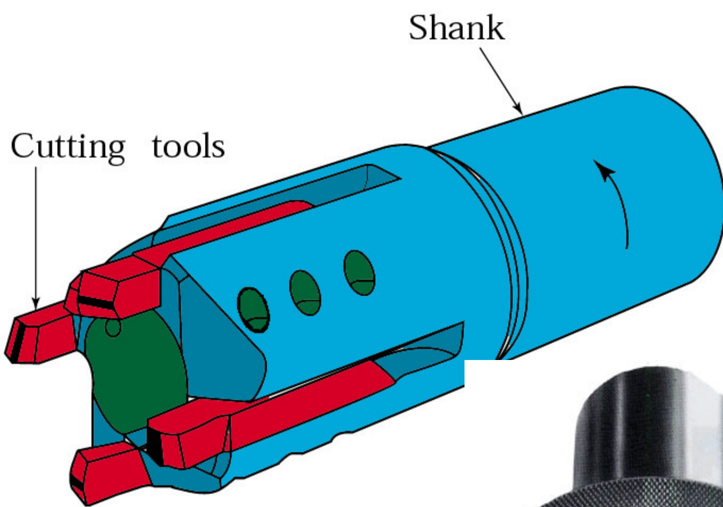


# Old Planer

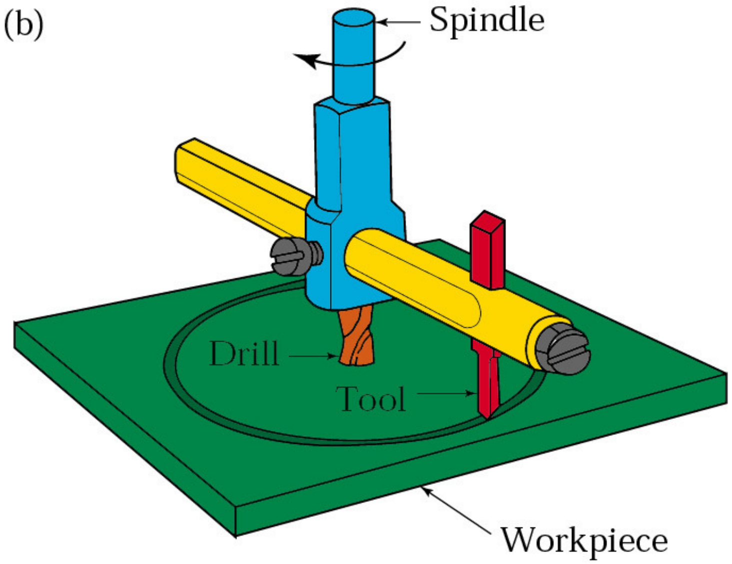
# Shaper

# Trepanning

(a)

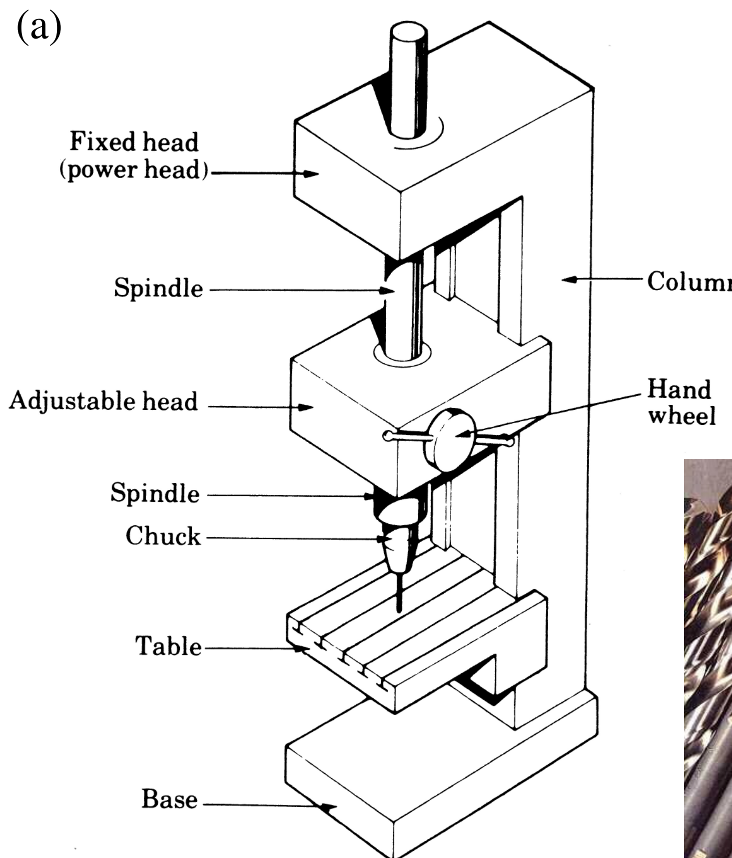



(b)




# Drilling

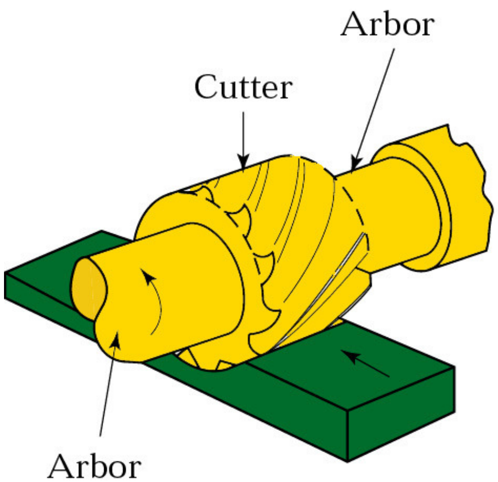

Clarke
METALWORKER


(a)
Fixed head
(power head)
Spindle
Adjustable head
Spindle
Chuck
Table
Base
Column
Hand
wheel

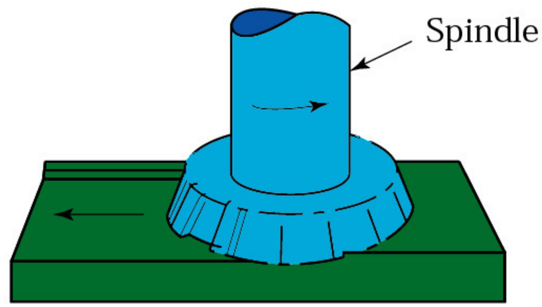

DRILL BITS

# Milling

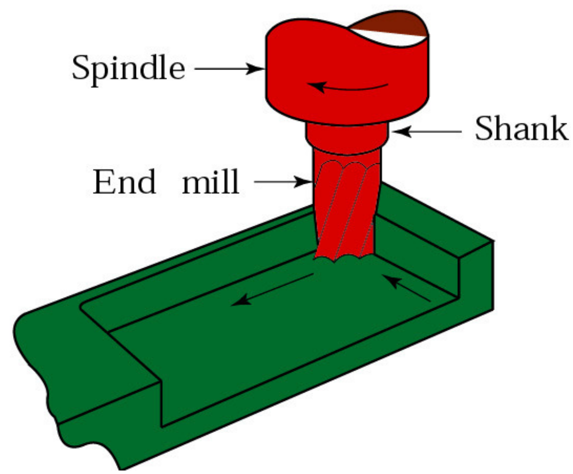
(a) Slab milling

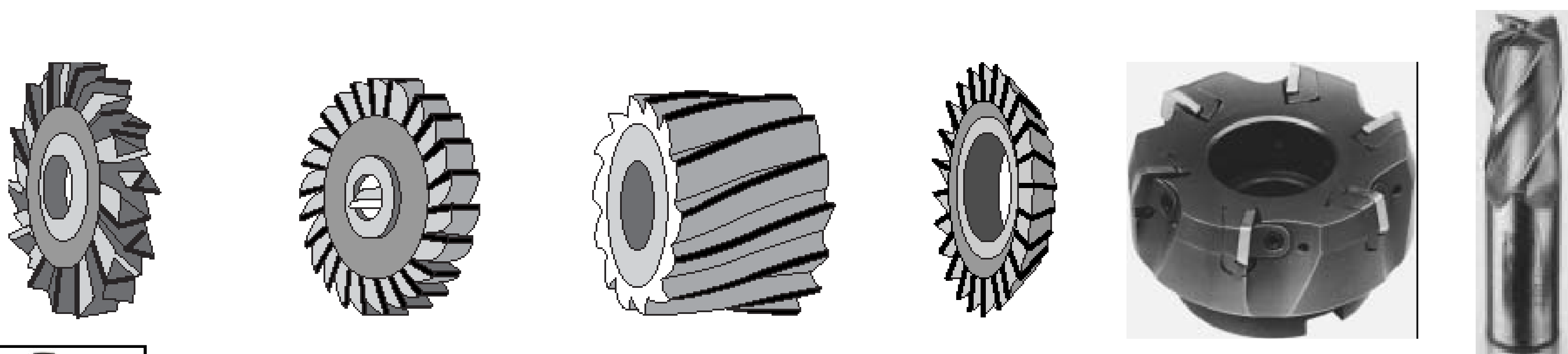



(b) Face milling




(c) End milling

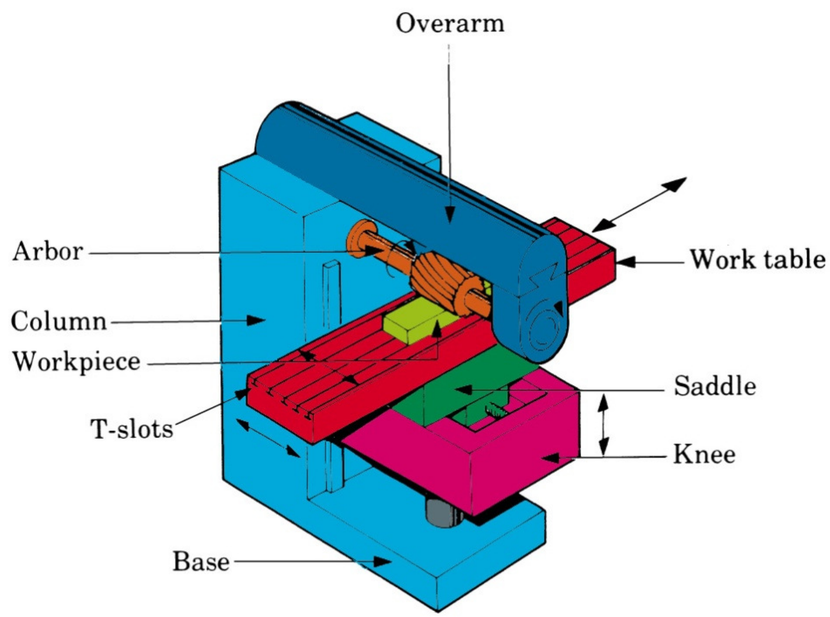


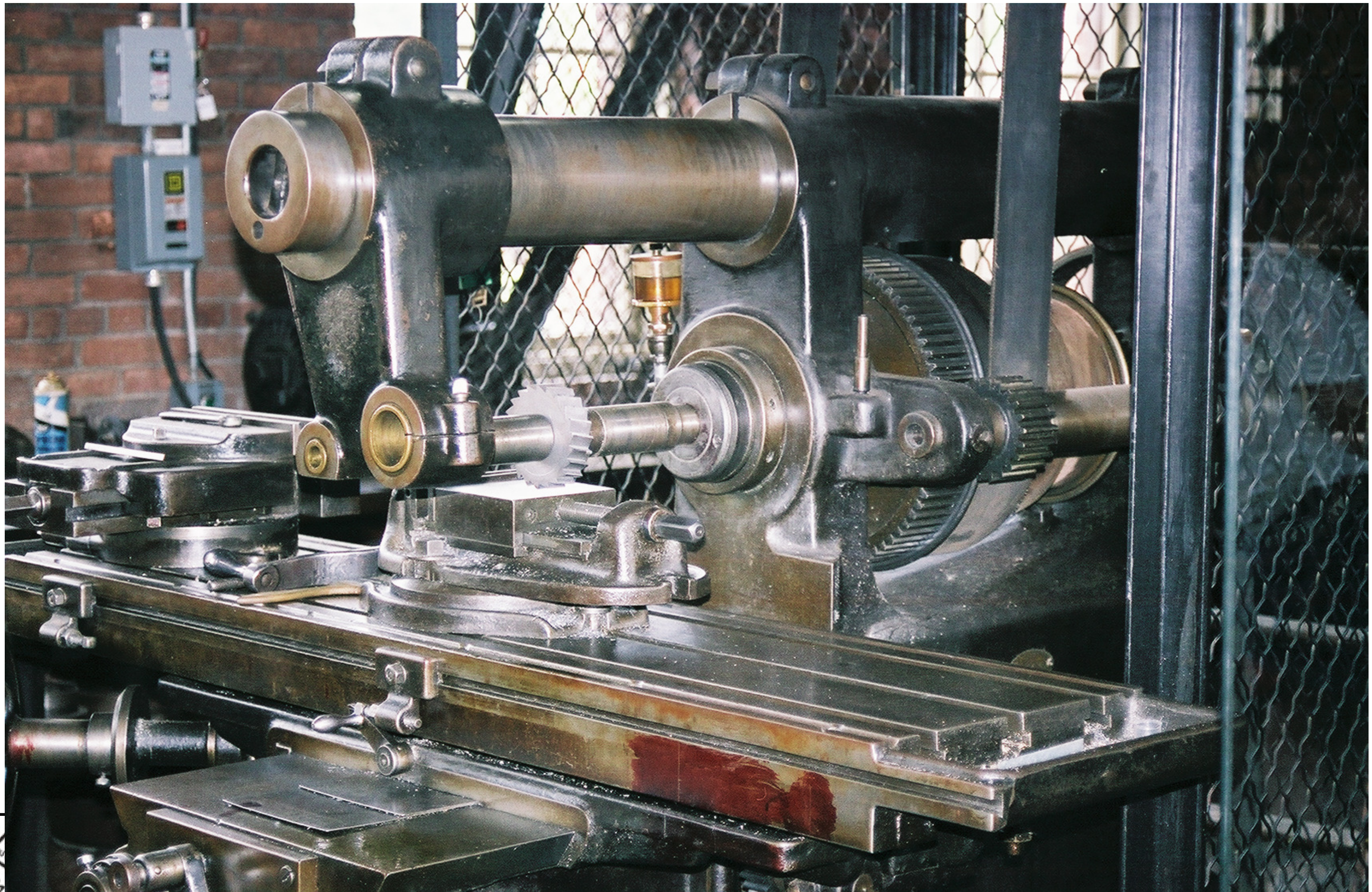
*Common HSS milling cutters.*

# Face Milling

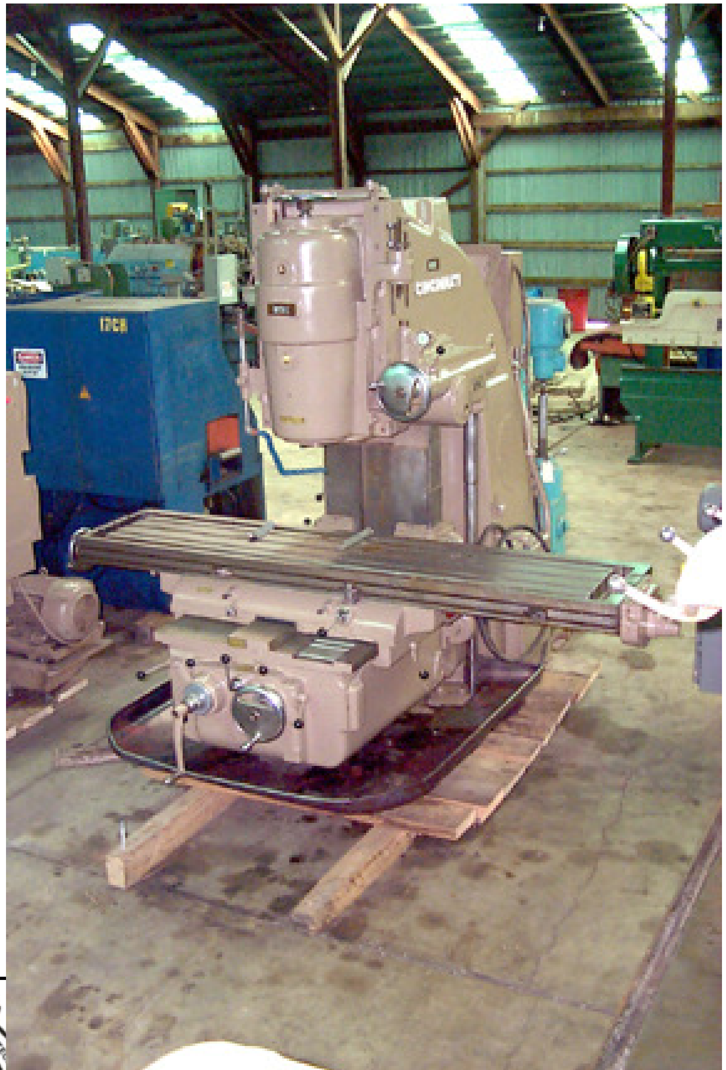
# Horizontal Mill

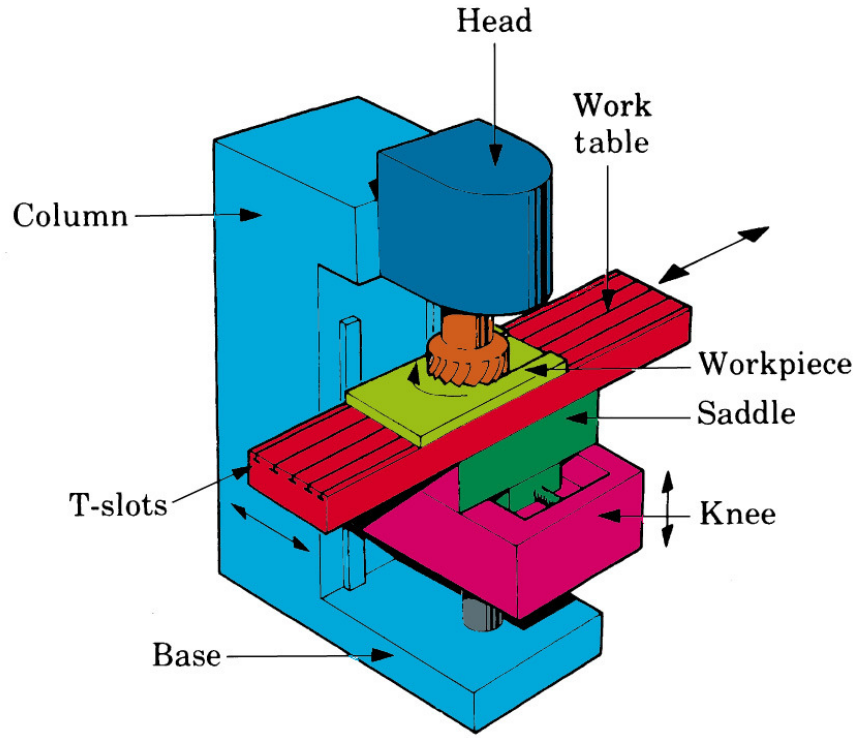


# Old Horizontal Mill

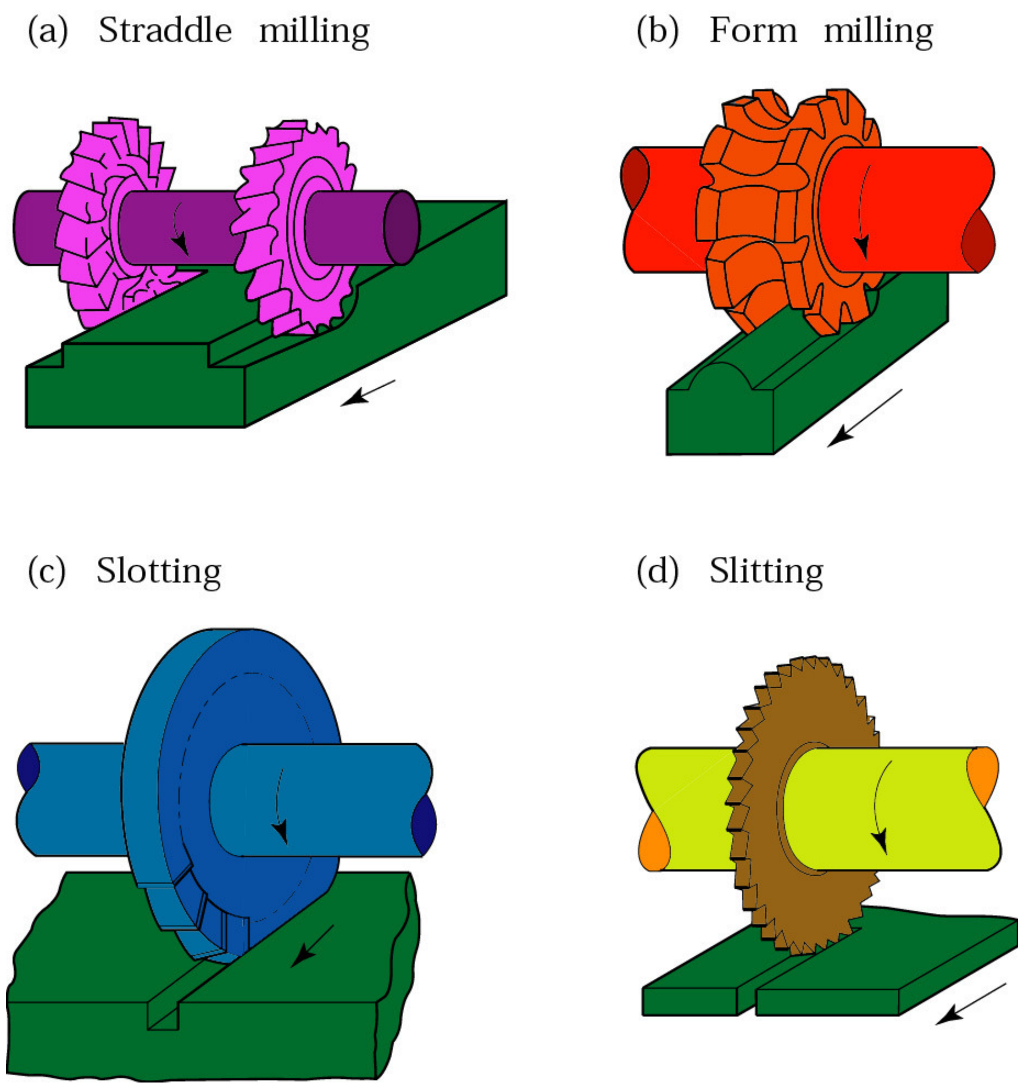


# Vertical Mill

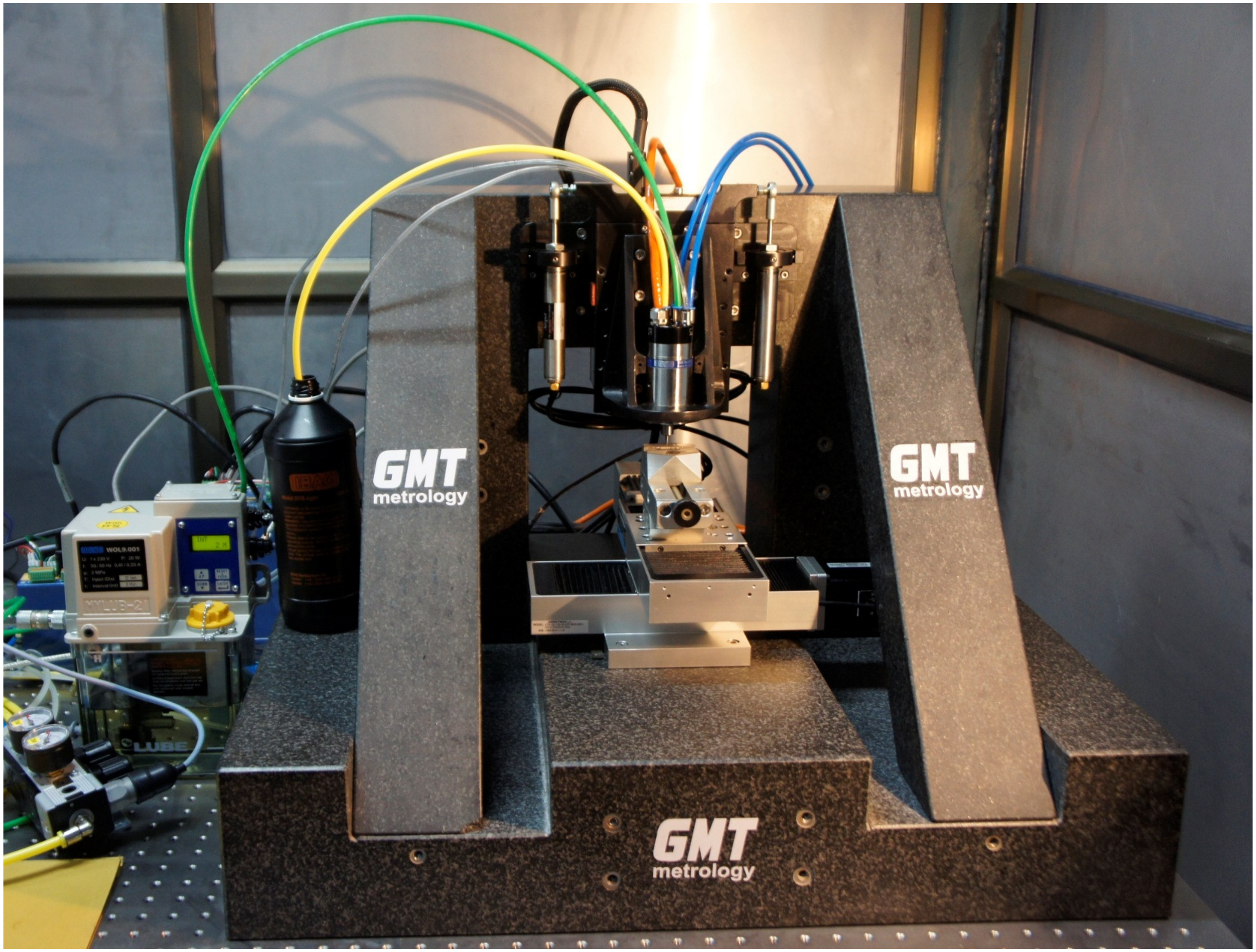


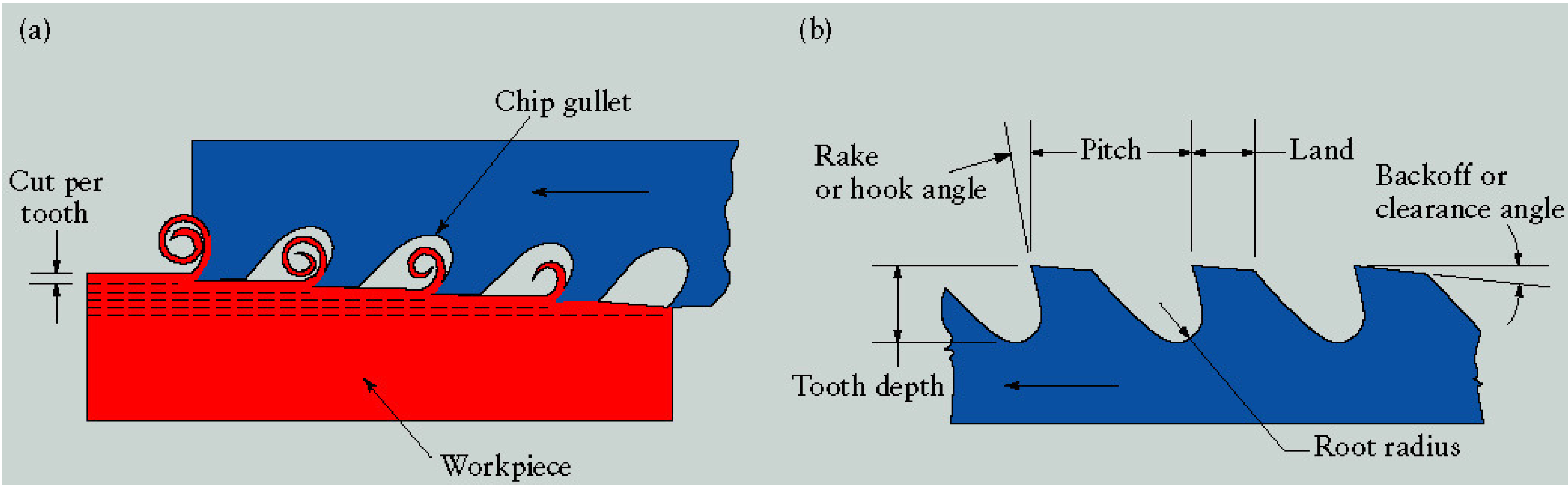
# Milling Types



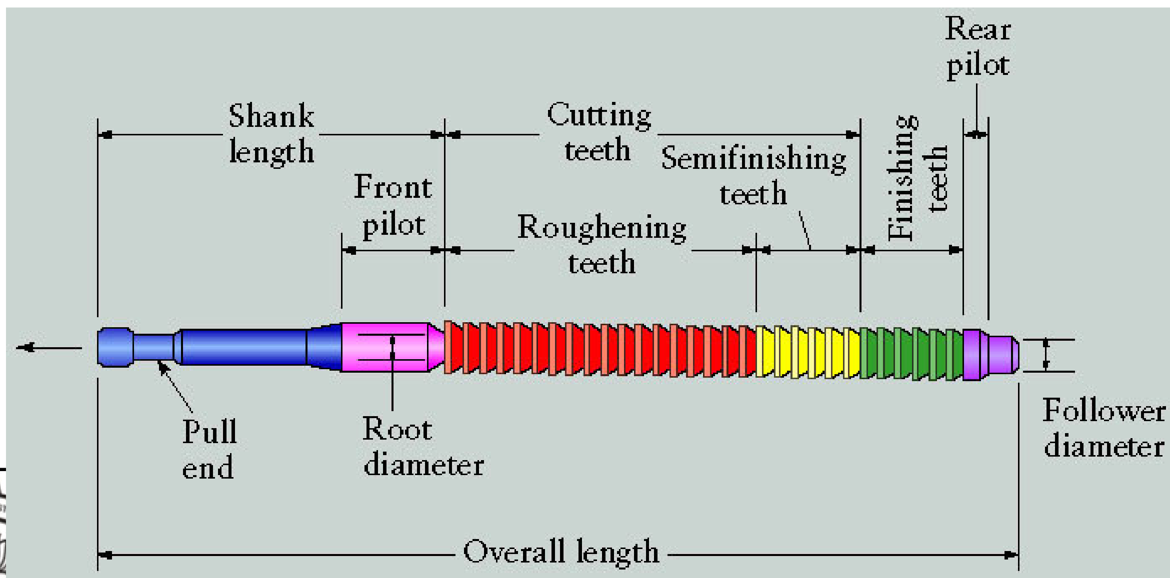
# Ultra-High Speed Micromilling Machine in the Machine Tools Lab at IITB



# Broach

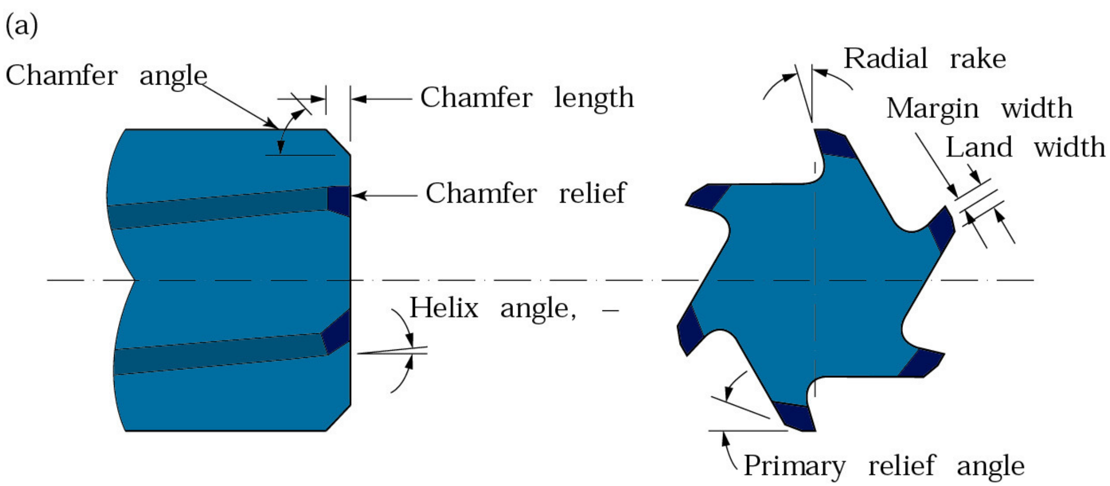


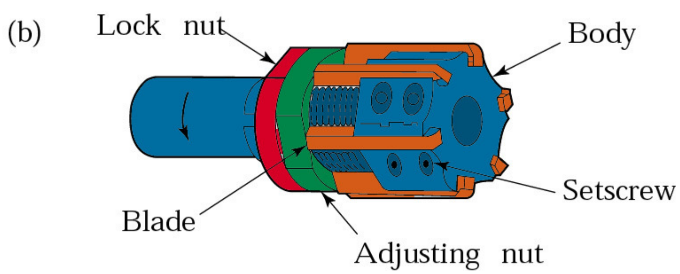
(a)
(b)
Chip gullet
Cut per tooth
Workpiece
Rake or hook angle
Pitch
Land
Backoff or clearance angle
Tooth depth
Root radius

Rear pilot
Shank length
Cutting teeth
Semifinishing teeth
Finishing teeth
Front pilot
Roughening teeth
Pull end
Root diameter
Follower diameter
Overall length

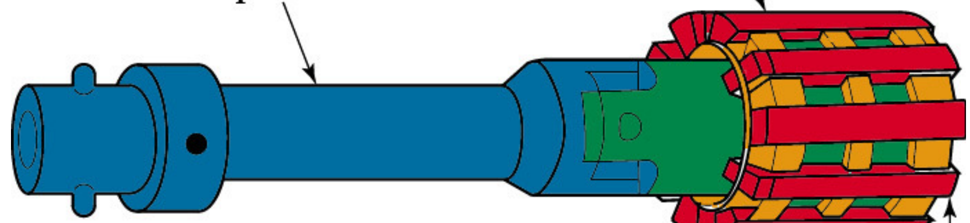

# Reamers



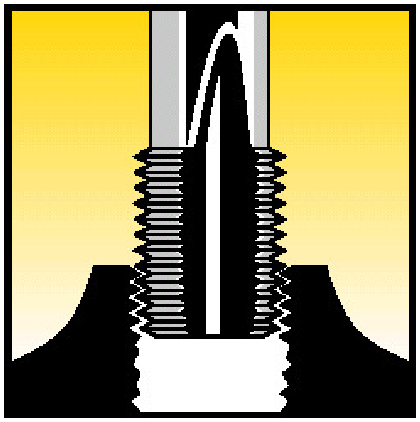




bridge reamer

# Honing



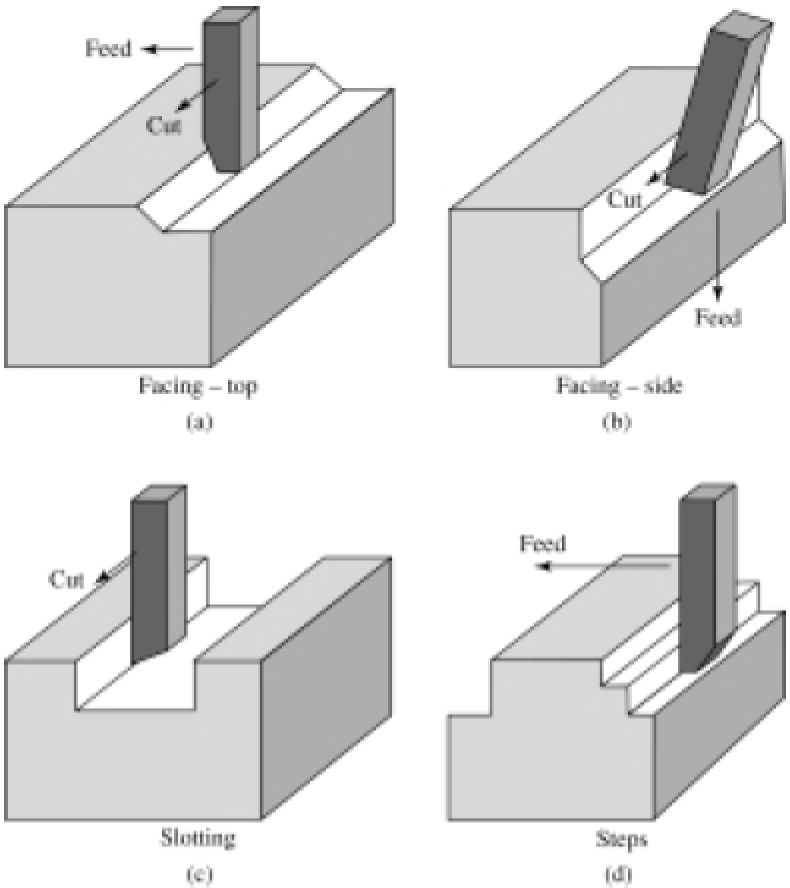

# Thread Tap and Die



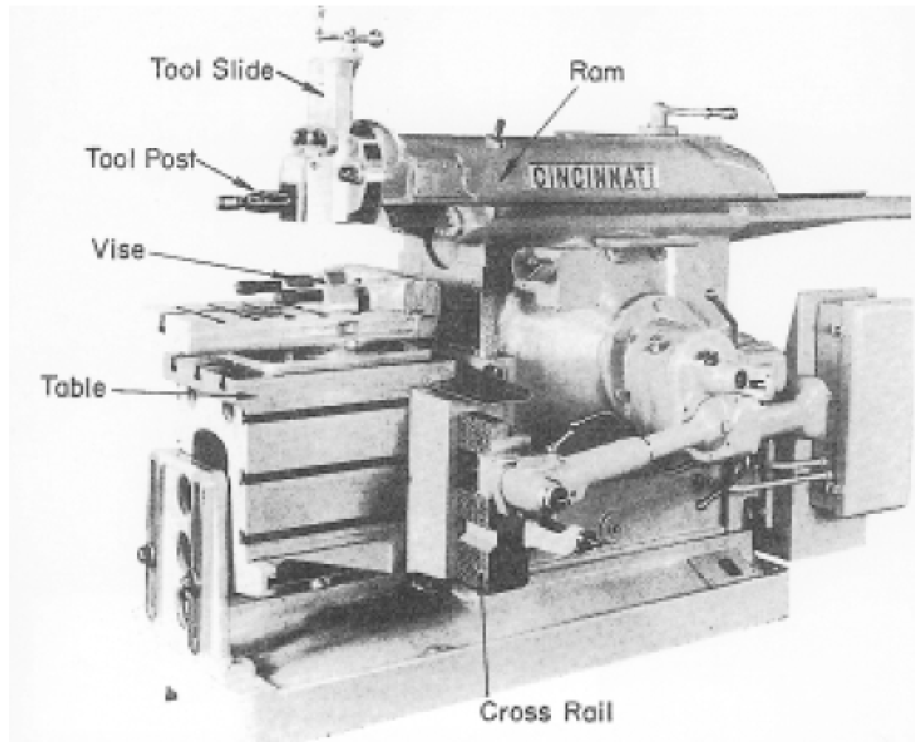
internal


external

# Shaping

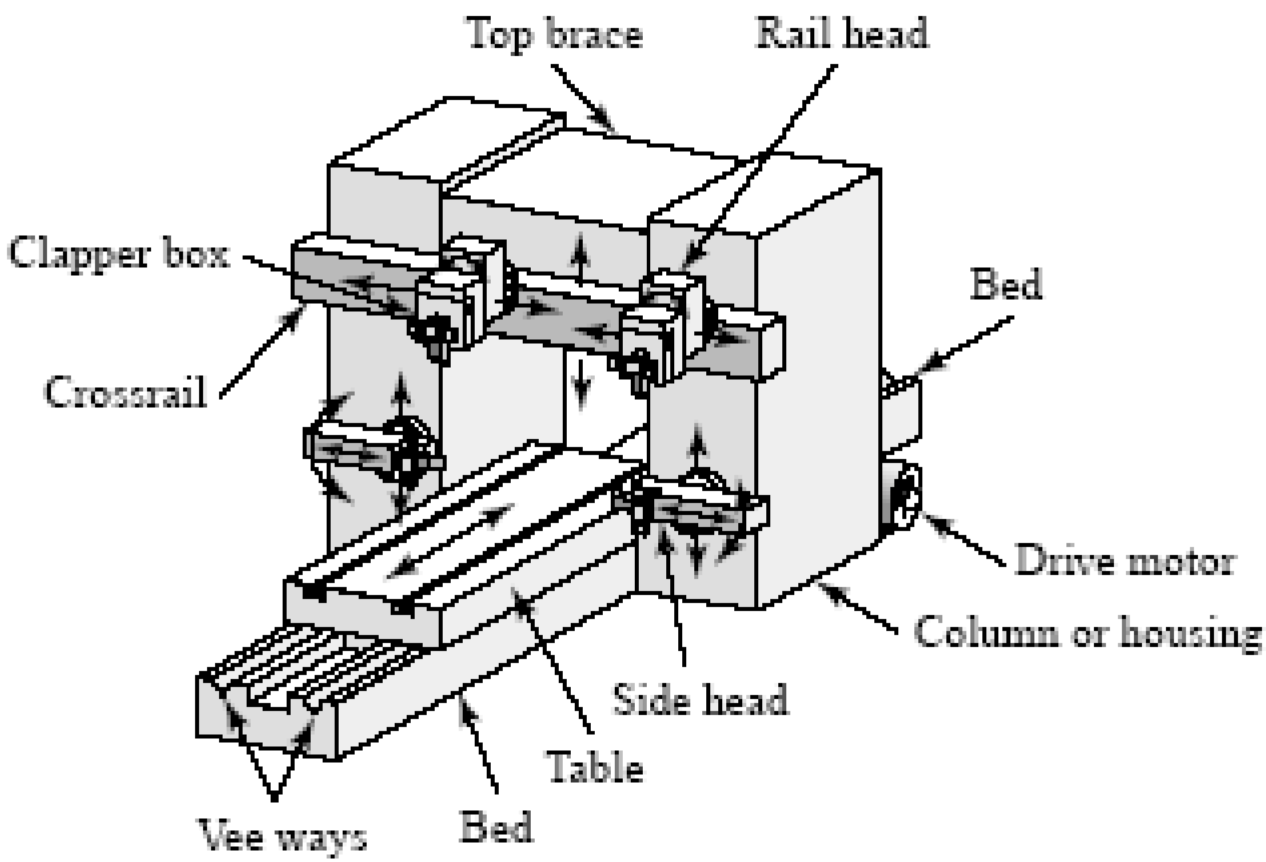


Feed
Cut
Facing – top
(a)
Cut
Feed
Facing – side
(b)
Cut
Slotting
(c)
Feed
Steps
(d)

Tool Slide
Ram
Tool Post
CINCINNATI
Vise
Table
Cross Rail

# Planing



Top brace
Rail head
Clapper box
Bed
Crossrail
Drive motor
Column or housing
Side head
Table
Vee ways
Bed

# Shaping & Planing

- Material removal rate, $MRR = Vwt_0$
- Cutting power, $P_c = u_c MRR$
- Machining time, $t_m = L/V$
  - $L$ is the length of cut

# u is composed of:

- $u_s$, the shear energy per unit volume
- $u_f$, frictional energy per unit volume
- chip curl energy
- chip acceleration kinetic energy
- surface energy of new surfaces

# Where does cutting energy go?

- 90% to chip
- 5% to tool
- 5% to workpiece

# u can be obtained in two ways

- Tabulated
- Estimated
  - u ~ HB

# Cutting Energy (u)

As a first approximation:

$$u \approx u_s + u_f$$

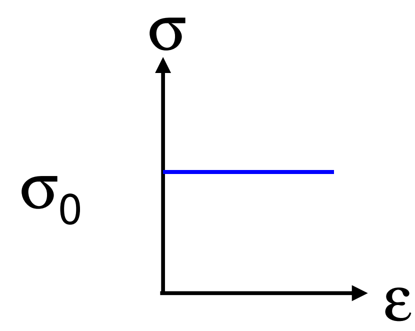
$$u_s \approx 0.75 - 0.8\ u$$

hence

$$u \approx 1.5\ u_s$$

# Estimation of u

- Assume a simple, rigid-perfectly plastic material:




$$u_s = \int \sigma \cdot d\varepsilon = \sigma_o \cdot \varepsilon = \tau_{fm} \cdot \gamma$$

$$\sigma_o \approx \frac{HB}{3}$$ for heavily cold-worked metals

$$\varepsilon \approx 1 - 2 \Rightarrow \gamma \approx 2 - 4$$

# Estimation of u

$$\tau_{fm} \approx \frac{\sigma_o}{2} \approx \frac{1}{6} HB$$

$$u_s \approx \frac{1}{3} HB \rightarrow \frac{2}{3} HB$$

# What number to use?

From above

$u \approx 1.5\ u_s$

$u_s \approx (1/3 \text{ to } 2/3)\ HB$

$u \approx (1/2 \text{ to } 1)\ HB$

so, if no data, $u \approx HB$

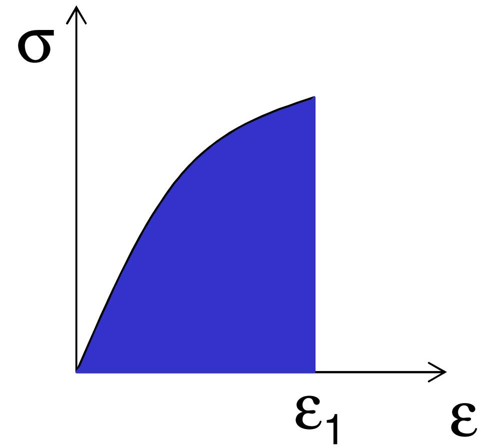
# Comparison of Tensile and Cutting (Ex. 1-1)

- 304 stainless steel rod
- $d_o$ = 0.5 in, $d_f$ = 0.48 in, $l_o$ = 6 in

- What is the energy required using tension?
- What is the energy required using cutting?

# Tension: Ex. 1-2

$$\int \sigma \cdot d\varepsilon_1 = u = \frac{K \cdot \varepsilon_1^{n+1}}{n+1}$$




$$u \times volume = Energy$$

K = 185,000 psi; n = 0.45

# Tension - Ex. 1-3

$$\varepsilon_1 = 2\ln\left(\frac{0.5}{0.48}\right) = 0.0816$$

$$Energy = \frac{K \cdot \varepsilon_1^{n+1}}{n+1} A_o l_o$$

$$= \frac{(185{,}000) \cdot (0.0816)^{1.45}}{1.45} \pi (0.25)^2 (6)$$

$$= 3{,}970 \; in - lbf \; = 449 \; J$$

# Cutting - Ex. 1-4

Energy = (specific cutting energy) *
(volume removed)

$$E = u \times \frac{\pi}{4}\left(D_i^2 - D_f^2\right)\cdot l$$

$u_{ss} \approx$ 1.5 hp min/in$^3$ x 550 x 60 x 12
= 594,000 in-lbf/in$^3$

$$E = 594{,}000 \times \frac{\pi}{4}\left(0.5^2 - 0.48^2\right)\cdot 6$$

= 54,650 in-lbf (6,176 J)

# Relation between u and $t_0$

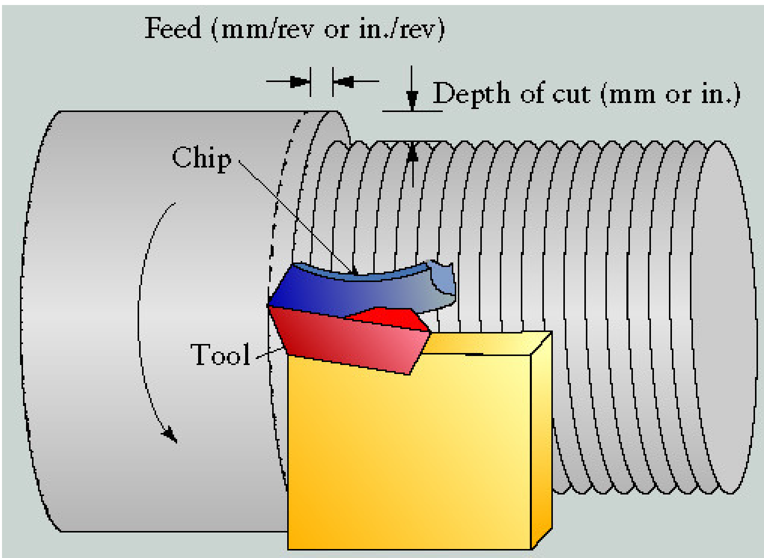
- As the depth of cut decreases, the surface area to volume ratio increases, hence friction (energy) increases
- Since

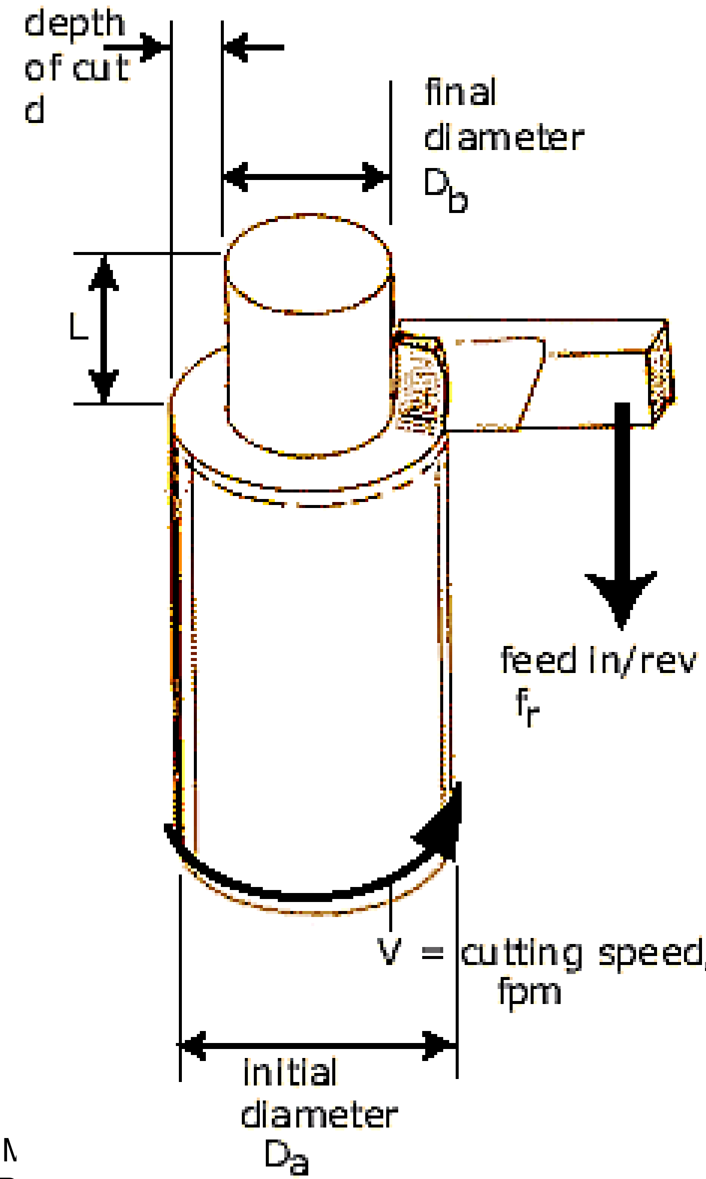
$$u \approx u_s + u_f$$

- Hence

$$u \propto \frac{1}{t_0}$$

# Turning -MRR


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


depth
of cut
d
final
diameter
$D_b$
L
feed in/rev
$f_r$
V = cutting speed,
fpm
initial
diameter
$D_a$

# Turning

- Average cutting speed, $V_{avg} = \pi D_{avg} N$
  - $D_{avg}$ is the average diameter of workpiece
  - $N$ is the spindle speed in rpm
- Material removal rate, $MRR = V_{avg} d f$
  - $d$ is the depth of cut
  - $f$ is the feed (units: mm/rev or in/rev)
- Cutting power, $P_c = u_c MRR = F_c V$
  - $F_c$=Cutting force
  - V = Cutting speed
- Machining time, $t_m = L/(fN) = L/F$
  - $F$ is the feed rate (units: mm/min or in/min)

# Turning Power and Force- Ex. 2-1

Turning Titanium:

- speed = 1 m/s = 200 sfpm
- feed rate = 0.1 mm/rev = 0.0004” / rev
- depth of cut = 3 mm = 0.1”

What is cutting power and cutting force?

# Power - Ex. 2-2

$u \approx 0.06\ kW/cm^3/min = 3.6\ W/mm^3/sec$

$MRR = Q = Vfd = 1{,}000 \times 0.1 \times 3$

$= 300\ mm^3/sec$

$P = u \times MRR = 3.6 \times 300 = 1{,}080\ W$

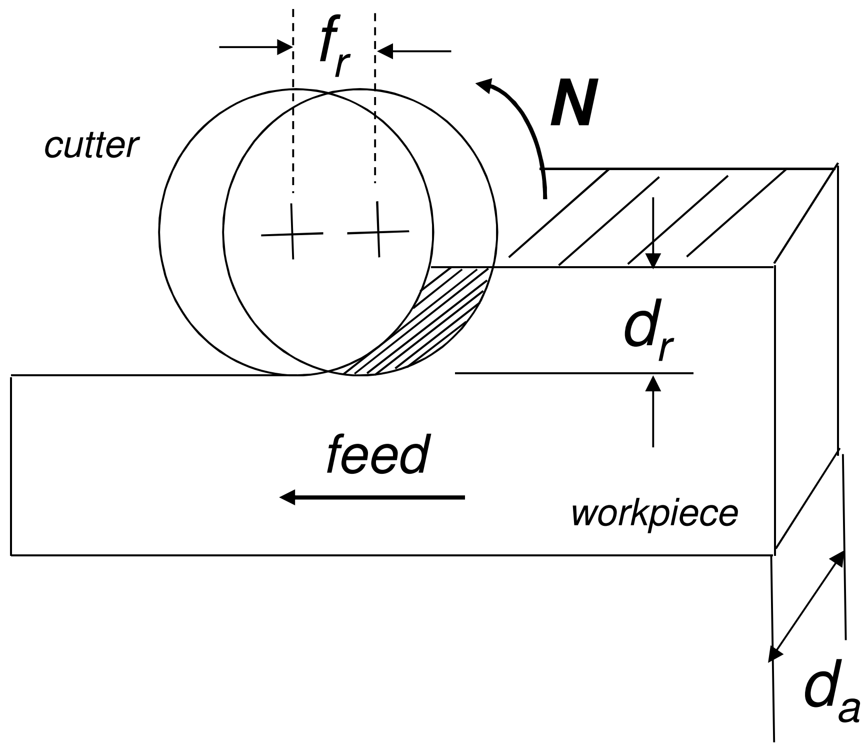
$= 1.45\ hp$

# Force - Ex. 2-3

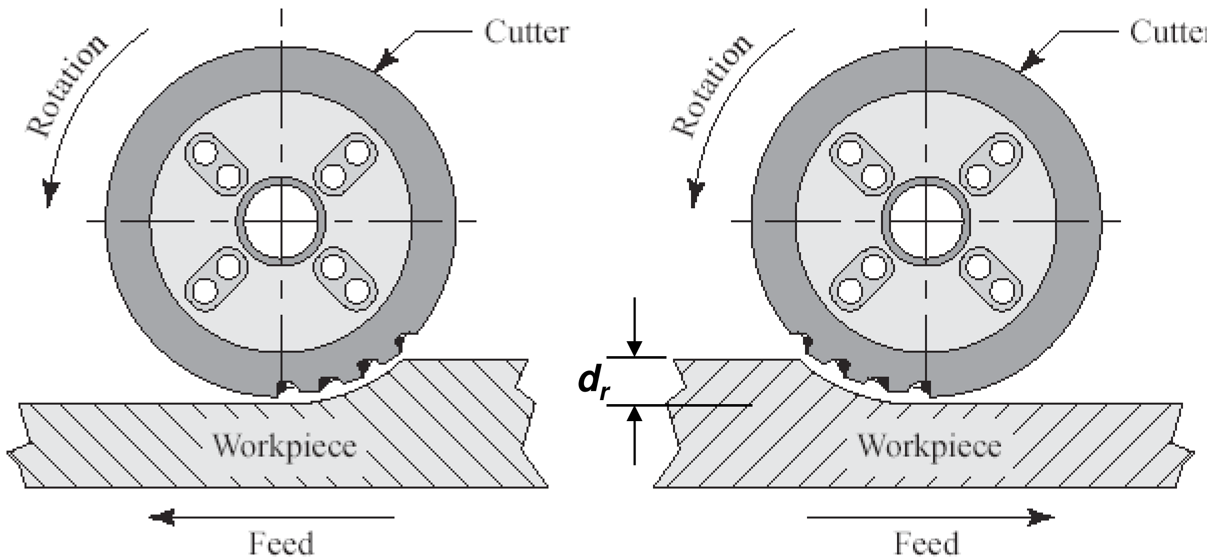
F = P/V = 1,080 W ÷ 1 m/s

= 1,080 N (243 lbf)

# Milling



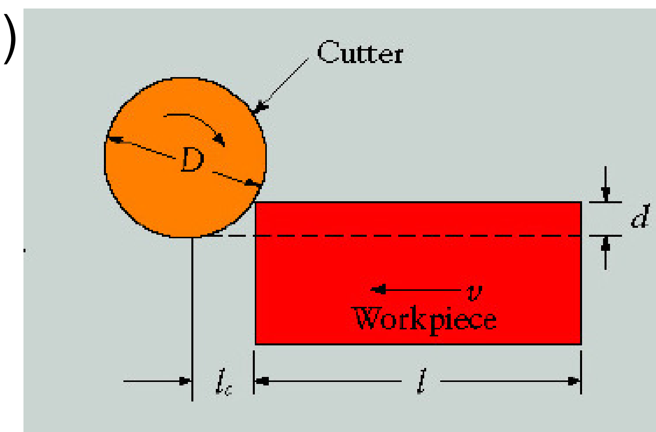
# Milling Modes




***Up Milling*** ***Down Milling***

# Milling

- Cutting speed, $V = \pi DN$
  - $D$ is the cutter diameter
- Material removal rate, $MRR = fNd_a d_r = Fd_a d_r$
  - $d_a$ is the axial depth of cut
  - $d_r$ is the radial depth of cut
  - $f$ is the feed per revolution (= $f_t N_t$ ; $f_t$ is the feed per cutting edge/tooth and $N_t$ is the number of teeth)
  - F is the feed rate (in/min or mm/min)




- Cutting power, $P_c = u_c MRR$
- Machining time, $t_m = (L + l_c)/F$
  - $l_c$ is the length of the cutter's first contact with the workpiece

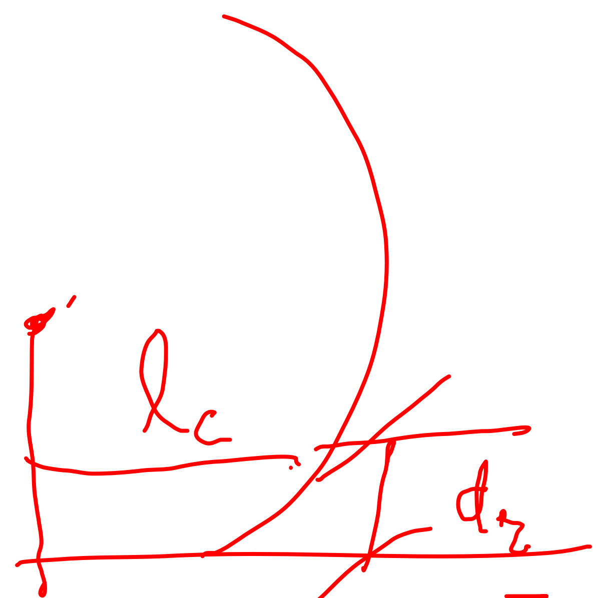
# Example

- A slab-milling operation is being carried out on a 25-in. long, 4-in. wide metal block (u = 4.3 hp-min/in$^3$) at a feed of 0.02 in./tooth and a depth of cut of 0.125 in. The cutter has a diameter of 4 in., has eight straight cutting teeth, is 2 inches wide and rotates at 200 rpm. Calculate the material removal rate, the cutting time, and the power required.

- $d_a$ = 2"
- $d_r$ = 0.125"
- u = 4.7 hp min/in$^3$
- $l_c$ =
- $F = f \cdot N \cdot n_t$

$$F = 0.02 \times 8 \times 200$$

$$l_c^2 = (D - d_r) \cdot d_r$$




$$l_c = \sqrt{(D - d_r) d_r}$$

# Summary

- General Machining Process
- Shaping & planing
- Turning
- Milling