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
Typical Insert Cutting Tool

- insert
- holder
Pillars made on Lathe
(a) Straight turning

(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
Boring

End support bearing for boring bar

Head column provides vertical milling feeds

Boring, drilling, and milling head

Spindle

Table

Saddle supports

Saddle

(c)

Cross-rail

Tool head

Workpiece

Work table

Bed

Column
Old Boring Machine
Old Planer
Shaper
Trepanning

(a) Shank
Cutting tools

(b) Spindle
Drill
Tool
Workpiece
Drilling

(a)

Fixed head (power head)

Spindle

Adjustable head

Spindle

Chuck

Table

Base

Column

Hand wheel

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

(a) Slab milling
(b) Face milling
(c) End milling

Common HSS milling cutters.

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Face Milling
Horizontal Mill
Old Horizontal Mill
Vertical Mill
Milling Types

(a) Straddle milling

(b) Form milling

(c) Slotting

(d) Slitting
Ultra-High Speed Micromilling Machine in the Machine Tools Lab at IITB
Broach

(a) Chip gullet
Cut per tooth
Workpiece

(b) Rake or hook angle
Pitch
Land
Backoff or clearance angle
Tooth depth
Root radius

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

(a) Chamfer angle, Chamfer length, Chamfer relief, Helix angle.

(b) Lock nut, Body, Blade, Adjusting nut, Setscrew.

Radial rake, Margin width, Land width, Primary relief angle.

bridge reamer
Honing

Stone

Spindle

Nonabrating bronze guide
Thread Tap and Die

internal

external
Shaping
Planing

[Diagram of a planing machine with labeled parts: Top brace, Rail head, Clapper box, Crossrail, Bed, Drive motor, Column or housing, Side head, Table, Vee ways, Bed]
Shaping & Planing

- Material removal rate, $MRR = Vw t_0$

- 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
  - $u \sim HB$
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:

$$u_s = \int \sigma \cdot d\varepsilon = \sigma_0 \cdot \varepsilon = \tau_{fm} \cdot \gamma$$

$$\sigma_0 \approx \frac{HB}{3}$$

for heavily cold-worked metals

$$\varepsilon \approx 1 - 2 \Rightarrow \gamma \approx 2 - 4$$
Estimation of $u$

$$\tau_{fm} \approx \frac{\sigma_0}{2} \approx \frac{1}{6} HB$$

$$u_s \approx \frac{1}{3} HB \rightarrow \frac{2}{3} HB$$
What number to use?

From above
\[ u \approx 1.5 \, u_s \]

\[ u_s \approx (1/3 \text{ to } 2/3) \, \text{HB} \]

\[ u \approx (1/2 \text{ to } 1) \, \text{HB} \]

so, if no data, \( u \approx \text{HB} \)
Comparison of Tensile and Cutting (Ex. 1-1)

- 304 stainless steel rod
- \( d_0 = 0.5 \text{ in}, \ d_f = 0.48 \text{ in}, \ l_o = 6 \text{ in} \)

- What is the energy required using tension?
- What is the energy required using cutting?
Tension: Ex. 1-2

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

\[ u \times \text{volume} = \text{Energy} \]

\[ K = 185,000 \text{ psi}; \ n = 0.45 \]
Tension - Ex. 1-3

\[
\text{Energy} = \frac{K \cdot \varepsilon_1^{n+1}}{n+1} A_o l_o
\]

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

\[
= 3,970 \text{ in} - \text{lbf} = 449 \text{ J}
\]

\[
\varepsilon_1 = 2 \ln \left( \frac{0.5}{0.48} \right) = 0.0816
\]
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 \text{ hp min/in}^3 \times 550 \times 60 \times 12 \]
\[ = 594,000 \text{ in-lbf/in}^3 \]

\[ E = 594,000 \times \frac{\pi}{4} \left( 0.5^2 - 0.48^2 \right) \cdot 6 \]
\[ = 54,650 \text{ in-lbf (6,176 J)} \]
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

final diameter $D_f$

feed in/rev $f_r$

$V = \text{cutting speed, fpm}$

initial diameter $D_i$

depth of cut $d$

$L$

Instructor: Ramesh Singh; Notes: Profs. Singh/Melkote/Colton
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, \( MRR = V_{avg} df \)
  - \( d \) 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

\[ u \approx 0.06 \text{ kW/cm}^3/\text{min} = 3.6 \text{ W/mm}^3/\text{sec} \]

\[ \text{MRR} = Q = Vfd = 1,000 \times 0.1 \times 3 \]
\[ = 300 \text{ mm}^3/\text{sec} \]

\[ P = u \times \text{MRR} = 3.6 \times 300 = 1,080 \text{ W} \]
\[ = 1.45 \text{ hp} \]
Force - Ex. 2-3

\[ F = \frac{P}{V} = \frac{1,080 \text{ W}}{1 \text{ m/s}} = 1,080 \text{ N (243 lbf)} \]
Milling

![Diagram of milling process](image)

cutter

feed

workpiece

$N$

$fr$

$dr$

$d_a$
Milling Modes

Up Milling

Down Milling
Milling

- Cutting speed, $V = \pi DN$
  - $D$ is the cutter diameter

- Material removal rate, $MRR = fNd_ad_r = Fd_ad_r$
  - $d_a$ is the axial depth of cut
  - $d_r$ is the radial depth of cut
  - $f$ is the feed per revolution ($= f_tN_t$; $f_t$ 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, $P_c = u_cMRR$

- 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 \( (u = 4.3 \text{ hp-min/in}^3) \) 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.
\( d_a = 2^{11} \)
\( d_r = 0.125^{11} \)
\( u = \frac{1}{0.2} \text{ min/m}^3 \)
\( l_c = \) (equation)
\( F = f \cdot N \cdot t \)
\( F = 0.02 \times 8 \times 200 \)
Summary

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