Before you begin: Turn on the sound on your computer. There is audio to accompany this presentation.

Milling

Milling is a complex process:
- Surface generated by progressive chip removal.
- Workpiece fed into a rotating cutting tool.
- Typically uses a multiple tooth cutter = interrupted cutting.
- High material removal rate.
Basic Milling Operations

Peripheral (Slab) Milling

- Surface generated by teeth located on periphery of cutter.
- Surface is parallel with axis of rotation of cutter.
- Flat and contour surfaces produced.
- Slab milling usually on horizontal spindle machines.

Face (End) Milling

Chapter 24 - 4

Chapter 24 - 5

Chapter 24 - 6
Face (End) Milling

- Most of the cutting done by teeth located on periphery of cutter with face (end) providing some finishing action.
- Surface is at right angle to axis of rotation of cutter.
- Both horizontal and vertical-spindle machines.

Milling Cutting Parameters

* $N_s = \text{Spindle Speed (rpm)}$

$$N_s = \frac{12V}{\pi D}$$

$D = \text{Cutter diameter (inch)}$

$V = \text{cutting speed (fpm)}$

*applicable to both face and peripheral milling types

Milling Cutting Parameters

* $f_m = \text{Feedrate (ipm)}$

$$f_m = f_t \times N_s \times n$$

$f_t = \text{feed/tooth (ipr)}$

$n = \text{number of teeth}$

*applicable to both face and peripheral milling types
Cutting Parameters Slab Milling

Cutting time formula:

\[ T_m = \frac{L + L_A}{f_m} \]

where:
- \( T_m \) = cutting time (min)
- \( L \) = total length of cut (in)
- \( L_A \) = approach length
- \( f_m \) = feedrate (ipm)
- \( t \) = depth of cut
- \( D \) = cutter diameter

Material Removal Rate formula:

\[ MRR = W \times f_m \times t \]

where:
- \( MRR \) = Material Removal Rate (in³/min)
- \( W \) = cut width (inch)
- \( t \) = depth of cut (inch)
- \( f_m \) = feedrate (ipm)

*note that \( W \) is cut width, not cutter width.
Example Problem

- Process: Slab Milling
- Cutter: 3.0 dia x 4.0 wide, HSS, 6 teeth
- Material: 3.0 wide x 10 length, 6064-T6 Aluminum Alloy
- Operation: remove 0.250" (1) pass

Determine the Machining Parameters
### Example Problem

1. Material: 3 in dia x 1/8 in wall 6061 T6 Aluminum Alloys (data in Table 24.1)
2. Process: Machined to wall of 0.250 in at 12 in/min
3. Tool: HSS Std Dia B 5.00 in diameter x 0.25 in rake x 0.040 in clearance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rake Angle, δ</td>
<td>3.0</td>
</tr>
<tr>
<td>Feed Rate, f</td>
<td>0.250</td>
</tr>
<tr>
<td>Speed, N</td>
<td>2000 rpm</td>
</tr>
<tr>
<td>Cutting Force, Fc</td>
<td>27 N</td>
</tr>
<tr>
<td>Tool Life, T</td>
<td>10 min</td>
</tr>
<tr>
<td>Tool Material</td>
<td>HSS Std Dia B 5.00 in diameter x 0.25 in rake x 0.040 in clearance</td>
</tr>
</tbody>
</table>

**Equation:**

\[ T = \frac{k}{f} \]
Cutting Parameters Face Milling

- $T_m = \text{cutting time (min)}$
- $T_m = \frac{L + L_A + L_O}{f_m}$
  - $L = \text{length of cut}$
  - $L_A = \text{approach length}$
  - $L_O = \text{over travel length}$
  - $f_m = \text{feedrate (ipm)}$

Cutting Parameters Face Milling

- $L_A = \begin{cases} \frac{\sqrt{W(D-W)}}{W} & \text{for } W < \frac{D}{2} \\ \frac{D}{2} & \text{for } W \geq \frac{D}{2} \end{cases}$
  - $L_A = \text{approach distance}$
  - $L_O = \text{over travel distance}$
  - *W = cut width*
  - *D = cutter diameter*
  - *note that W is cut width, not cutter width*

Cutting Parameters Face Milling

- $\text{MRR} = \text{Material Removal Rate (in}^3\text{/min)}$
- $\text{MRR} = W \times t \times f_m$
  - *W = cut width (inch)*
  - *t = depth of cut (inch)*
  - *f_m = feedrate (ipm)*
  - *note that W is cut width, not cutter width*
Example Problem #2

- Process: Face Milling
- Cutter: 6.0 inch dia, 6 carbide inserts
- Material: 3.0 inch wide x 10 inch length, 6064-T6 Aluminum Alloy
- Operation: remove 0.250” (1) pass

*Determine the Machining Parameters*
Example Problem #2

Cutting Parameters End Milling
Cutting Parameters End Milling

Maximum Material Removal

\[ d = \frac{hp_m}{hp_s \times f_m \times DOI} \]

- \( hp_s \): specific horsepower
- \( hp_m \): machine horsepower
- \( f_m \): feed rate
- \( DOI \): depth of immersion

UP and DOWN Milling

Conventional (Up) Milling

- Cutter rotates against direction of work feed.
- Chip thin at beginning of tooth entry and increases in thickness.
- Cutter tends to push work and lift work off table.
- Direction tends to eliminate problems associated with looseness of feed screw.
- Less horsepower required.
- Less accuracy and lower surface finish.
Climb (Down) Milling

- Cutter rotation in same direction as feed rate.
- Maximum chip thickness at beginning of tooth entry and decreases in thickness.
- Cutter tends to pull work into cutter.
- Cutter pushes work into work holding device.
- Climb milling not possible on machine with looseness in feed screw.
- More horsepower required.
- Higher accuracy and better surface finish.
Milling Cutters

1. Shank Mounted Cutters:
   a. End mills - peripheral and end teeth. Straight or helical tooth form.
   b. Face Mills: Most use insert tooth design.
   c. T-slot: teeth on periphery and both sides.
   d. Woodruff key seat: standard sizes for key seat
   e. Fly: single cutting edge.

Shank Mounted Cutters

a. Plain End Mills: HSS, coated, carbide.
Shank Mounted Cutters


Shank Mounted Cutters

a. Shell End Mills: multiple tooth cutters without a shank.

Shank Mounted Cutters

a. Hollow End Mills: tubular cross section. Used on screw machines to size stock.
Shank Mounted Cutters

b. Face Mills: Most use insert tooth design.

c. T-slot - teeth on periphery and both sides.

d. Woodruff key seat - standard sizes for key seat.
Shank Mounted Cutters

e. Fly Cutters - single cutting edge.

Milling Cutters

2. Arbor Mounted Cutters:
   a. Plain - used for slab milling. Straight or helical tooth.
   b. Side - similar to plain mill except tooth extends radially.
   c. Interlocking slotting - similar to side mill except more than one cutter used.
   d. Staggered-tooth - free cutting action for deep slots.
   e. Slitting saw - 1/32 to 3/16 wide with dished sides for slotting and cut-off.
   f. Angle - conical or V-shaped teeth.
   g. Form - teeth ground to special shape.
Arbor Mounted Cutters

a. Plain - used for slab milling. Straight or helical tooth.

b. Side - similar to plain mill except tooth extends radially.

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Arbor Mounted Cutters

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Arbor Mounted Cutters

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Arbor Mounted Cutters

g. Form - teeth ground to special shape.

Milling Machines

Increasing Power and Metal Removing Ability

Milling Machine Types
- Ram type.
- Column and knee type.
- Fixed-bed type.
- Planer-type.

Electronically Controlled Machines
- Manual Data Input Machines
- Programmable CNC Machines
- Machining Centers
- Flexible Manufacturing System
- Transfer Lines
Milling Machines

Column and Knee Type - General purpose machine. Variations:

- Plain horizontal – knee, saddle and table provide motion. Power and or hand table feed.
- Universal – horizontal to vertical spindle adjustments.
- Vertical – spindle may also have motion.
- Turret-type universal – vertical machine with dual heads.
Milling Machines

Bed Type – Production/manufacturing with table mounted directly on bed of machine. Variations:

- Simplex - single vertical or horizontal spindle.
- Duplex - two horizontal spindles.
- Triplex - three spindles.
Milling Machines

Planer Type – Designed for large work. Uses several milling heads.

Special Type – Variations:
- Rotary table - can load and unload with stopping machine (mass production).
- Drum type.
- Profilers (tracers) - duplicates geometry in two dimensions.
- Duplicators (die-sinking machines) - duplicate geometry in three dimensions.
Milling Machines

Machine Selection Criteria:
- Spindle orientation and rpm capability.
- Machine accuracy and precision capability.
- Machine size capacity.
- Horsepower.
- Automatic tool changing capability.

Milling Machine Accessories

- Vertical milling attachment for horizontal machines.
- Universal milling attachment – can swivel about both axes.
- Universal dividing head – holds and indexes workpiece. Can be connected to feed screw on machine for helical motion.
Workholding Methods

- T-slots
- Vises
- Fixtures

The End – See Oncourse for Videos