MILLING

Lecture 5
MILLING

• Surface generation by progressive chip removal

• Very efficient process → used very effectively in present manufacturing.

• The tool with multiple cutting edges tools (cutters) machines the surface. Many teeth, Intermittent engagement of teeth → Interrupted cutting

• Either work piece and / or cutter is fed. usually the work piece is fed.

• Two Types of Milling:

  Peripheral Milling or Slab Milling and
  Face Milling or End milling
1) Peripheral milling (slab milling):

- Machined surface is parallel to the axis of rotation of the cutter
- Any contour or flat surface can be created.
- Horizontal spindle machine

FIGURE 25-1 Basics of peripheral or slab milling process (see also Figure 25-8).
Milling (slab milling or end milling)

The tool rotates at rpm Ns. The work-piece translates past the cutter at feed rate $f_m$, the table feed.

The length of cut, $L$, is the length of work-piece plus allowance, $L_a$,

$$v = \pi D_1 N, \text{m/min, } D_1 \text{in/m}$$

$$L_A = \sqrt{\frac{D^2}{H} - \left(\frac{D}{2} - d\right)^2} = \sqrt{d(D-d)} \text{...inches}$$

$$CT = \frac{(L + L_A)}{f_m}$$

If $L_a = 0$

$$MRR = Wdf_m, \text{m}^3/\text{min} \quad \text{where}$$

$W = \text{width of the cut, } d = \text{depth of cut.}$

$f_m = f_t n \text{ Ns, m/min}$

If $L_a$ is considered,

$$MRR = \frac{Vol}{CT} = LWd/CT$$
2) Face milling (end milling):

- machined surface is perpendicular to the axis of rotation of the cutter.

- Vertical spindle machine

![Diagram of Face milling Multiple tooth cutting](image)

**The majority of the cutting is being done by the peripheral portion of the tooth**

\[
L_o = L_A = \sqrt{W(D-W)} \quad \text{for} \quad W < D/2
\]

\[
L_o = L_A = \frac{D}{2} \quad \text{for} \quad W \geq D/2
\]
Face Milling

\[ f_m = f_t \times n \times \text{RPM} \]

Given a selected cutting speed \( V \) and a feed per tooth \( f_t \), the rpm of the cutter is \( N_s = \frac{12V}{\pi D} \) for a cutting of diameter \( D \). The table feed rate is \( f_m = f_t \times n \times N_s \) for a cutter with \( n \) teeth. The cutting time, \( CT = (L + L_A + L_o)/f_m \), where \( L_o = L_A = \sqrt{W(D - W)} \) for \( W < D/2 \) or \( L_o = L_A = D/2 \) for \( W \geq D/2 \). The MRR = \( Wdf_m \) where \( d = \) depth of cut.

\[ v = \pi D_1 N, \text{ } m/\text{min}, \text{ } D_1 \text{ in } m \]

\[ \text{MRR} = Wdf_m, \text{ } m^3/\text{min}, \text{ when allowance is neglected} = \frac{\text{Vol}}{\text{CT}} \]

Basics of the milling process (face and end milling) as performed on a vertical spindle machine, including equations for cutting time and metal-removal rate.

Need Multiple Passes for wider jobs...
<table>
<thead>
<tr>
<th>Material</th>
<th>Carbide Cutters</th>
<th>High-speed Steel Cutters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feed</td>
<td>Face</td>
</tr>
<tr>
<td>Malleable iron, soft/hard</td>
<td>.005-.015</td>
<td>.005-.015</td>
</tr>
<tr>
<td>Cast steel, soft/hard</td>
<td>.008-.015</td>
<td>.005-.015</td>
</tr>
<tr>
<td>BHN 100-150</td>
<td>.010-.015</td>
<td>.008-.015</td>
</tr>
<tr>
<td>150-250</td>
<td>.010-.015</td>
<td>.008-.015</td>
</tr>
<tr>
<td>250-350</td>
<td>.008-.015</td>
<td>.007-.012</td>
</tr>
<tr>
<td>350-450</td>
<td>.008-.015</td>
<td>.007-.012</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>.005-.010</td>
<td>.005-.010</td>
</tr>
<tr>
<td>Hard, BHN 180-225</td>
<td>.125-.200</td>
<td>.100-.175</td>
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<tr>
<td>Medium, BHN 180-225</td>
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<td>.008-.015</td>
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<tr>
<td>Soft, BHN 150-180</td>
<td>.015-.025</td>
<td>.010-.020</td>
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<tr>
<td>Bronze, soft/hard</td>
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<td>.010-.020</td>
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<td>Brass, soft/hard</td>
<td>.010-.020</td>
<td>.010-.020</td>
</tr>
<tr>
<td>Aluminum alloy, soft/hard</td>
<td>.010-.040</td>
<td>.010-.030</td>
</tr>
</tbody>
</table>

*a Generally, lower end of range used for inserted blade cutters, higher end of range for indexable insert cutters.*
SLAB AND PERIPHERAL MILLING:

Two methods to generate the surface:

UP-MILLING: Traditional

DOWN-MILLING

(Down milling) climb cut

(Up milling) conventional cut

Peripheral or slab milling

Face or end milling
Figure 25-5 Conventional face milling (left) with cutting force diagram for $F_c$, (right) showing the interrupted nature of the process. (From Metal Cutting Principles, 2nd ed., Ingersoll Cutting Tool Company)

- **CHIP** thin at the beginning, thick at the end, the cutting force is increasing

- **FORMATION** thick at the beginning, thin at the end of the cut – creates shocks and the vibration
Up Milling

**Chip:** Thin at the beginning, Thick at the end

**Clamp:** Tendency to push the work along

Tendency to lift the job from table

Down Milling

**Chip:** Thick at the beginning, Thin at the end

**Clamp:** Tendency to pull the work along

Tendency to clamp the job with table
1) **ARBOR CUTTERS**

- Cutters for slab milling – Horizontal spinning spindle
- a hole in the cutter for mounting on a arbor
- Tapered shank is mounted directly
- Straight shank is mounted through keys/Chuck

2) **SHANK CUTTERS**

- Cutters for face milling
  – Vertical spinning spindle
- the shank straight or tapered
  – Mounted together with the cutter directly into the spindle

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**Figure 11.33**

**Figure 25-7** Shank-type milling cutters. Left to right: T-slot, shell end mill, Woodruff key seater, hollow end mill, solid end mill.
HSS Cutter: (+)ve rake angle

Carbide, Ceramic tipped: (-)ve rake angle

Down Milling: Machining of hard materials causes the teeth to dull quickly because fast engaging in the material.

Straight Mills

or Helical Mills:
MATERIALS

High speed Carbon Steel (one piece) shells attached or brazed on the shank
Carbide – bits fixed on a cutter
Inserts threaded on holder → for large size cutters
**Straight**: One tooth engaged at a time → disrupted cutting/cutting force → Higher impact loading → shock and vibrations

**Helical**: Many teeth engaged at a time → Progressive cutting/cutting force → Lower impact loading → reduced shock and vibrations → smoother surface
1. **PLAIN MILLING CUTTERS**

* dish or cylinder shaped cutter – teeth at Circumference only
* for narrow cutters – straight teeth
* for wide cutters – helical (over 5/8 in) → more than one tooth cut at the same time (helical teeth)
2. SIDE MILLING CUTTERS

* Partly plain cutter with the teeth protruding on one side or on both sides
* Side milling cutters have straight, helical or staggered teeth
* Straddle milling – two or more cutters

3. METAL SLITTING - SAW CUTTERS

Cutter resembles a plain or side cutter except it is made very thin (3/16” maximum).

4. ANGLE MILLING CUTTERS

a. Single angle and
b. Double angle
5. FORM MILLING CUTTERS

- special shape is given to the teeth → irregular contour

- convex
- concave

- corner rounding
- tooth cutters (involute)

FIGURE 25-6 Sketch of an arbor (two views) used on a horizontal spindle milling machine and photos of some typical arbor-type milling cutters.
6. END- MILLS CUTTERS
- usually integral with shaft – cylindrical or taper
- Teeth on periphery and on the face
- Straight or helical flutter
- Shell end – mill cutters (large \( \phi \))
  for face milling – bolted or held at the end of a short arbor

7. T-SLOT- CUTTERS
- with teeth on periphery and both sides
- can be used ONLY after a vertical groove is done
- cut simultaneously 5 surfaces

8. WOODRUFFKEY – SEAT CUTTER
- standard sizes
- a slot cutter

9. FLY CUTTERS
- A single point tool cutting
  tool attached to a special shaft
- The tip radius can be changed
- used for face milling and boring
MILLING CUTTER TEETH

Rake angles
- high speed steel 10-15° (positive)
- carbide inserts (negative angles) → (i.e.) lip angle increases → longer life for the tool and better shank resistance (5-10°)

Clearance angle → 7-10°
Relief angle → 25°
For side milling cutters →
Plain cutters
- double negative rake angle
- double positive rake angle
- mixed rake angle (shear angle)
MILLING MACHINES

- milling process is very effective
- great variety of types and sizes of milling machines

Generally

the spindle with the cutter is rotating
the table has a linear movement with work moved against the cutter
Basic Concept:

column – and – knee construction:

- **Column**: mounted on the base, supports and includes the spindle and its drive.

- **motion of the work-piece (feed)** – three directions:
  - vertically – ways on the front column
  - transversely – ways on the knee through the saddle
  - longitudinally – on ways on the saddle through the table

* motions: manually or mechanically

* two types of motions – rapid for set up and slow for feed rates

FIGURE 25-11  Major components of a plain column-and-knee-type milling machine, which can have horizontal spindle or vertical spindle. (Top, from Manufacturing Productivity Handbook: courtesy of General Electric Company, bottom, courtesy of Cincinnati Milacron, Inc.)
Milling Machines:

**Horizontal**  Depending on the spindle position

**Vertical**

**Knee – vertical**

**FEEDS**  **Saddle – transverse**

**Table – longitudinal**

(size designation)

FIGURE 25-11  Major components of a plain column-and-knee-type milling machine, which can have horizontal spindle or vertical spindle. (Top, from Manufacturing Productivity Handbook; courtesy of General Electric Company, bottom, courtesy of Cincinnati Milacron, Inc.)
1. COLUMN AND KNEE TYPE MILLING MACHINES
2. BED TYPE MILLING MACHINES
3. PLANER TYPE MILLING MACHINES
4. ROTARY TABLE MILLING MACHINES
1. COLUMN AND KNEE TYPE MILLING MACHINES

a. Hand milling machines

small → horizontal or/and vertical spindle axis.

- Rigid construction and a power feeding mechanism to control the table movements
### Slab milling
(horizontal milling machine)

- Cutting speed
  
  \[ V = \pi DN \]
  
  \[ f = f_j N_n \]
  
  where: \( f_j \) is the feed per tooth
  
  \( N \) is the number of teeth of the cutter

- Machining time
  
  \[ T = \frac{L + 2A}{f} \]
  
  where:
  
  \( L \) is the length of the workpiece
  
  \[ A = \sqrt{\frac{d^2}{4} - \frac{(D - d)^2}{4}} \]
  
  = distance between the point of approach and the edge of the workpiece

- Metal-removal rate
  
  \[ M.R.R. = w \cdot d \cdot f \]
  
  where: \( W \) is the width of cut, i.e., either the width (or part of it) of the cutter engaged with the workpiece

### Face milling
(vertical milling machine)

- Cutting speed
  
  \[ V_{max} = \pi DN \]
  
  \[ V_{mean} = \frac{\pi DN}{2} \]
  
  \[ f = f_j N_n \]

- Machining time
  
  \[ T = \frac{L + 2A}{f} \]
  
  where:
  
  \( A = 0 \) for \( W = D \) up to \( D \)
  
  \( A = \sqrt{W(D - W)} \) for \( W < \frac{D}{2} \)

- Metal-removal rate
  
  \[ M.R.R. = w \cdot d \cdot f \]

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### Grinding

- Machining time
  
  \[ T = \frac{L + 2A}{f} \]
  
  where:
  
  \( L \) is the length of the workpiece and
  
  \[ A = \text{approach allowance} \]
  
  \[ A = \sqrt{\frac{d^2}{4} - \frac{(D - d)^2}{4}} \]
  
  where:
  
  \( d \) is the depth of cut

- Metal-removal rate
  
  \[ M.R.R. = W \cdot d \cdot f \]
  
  where: \( W \) is the width of cut

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b. Plain milling machines

- general – purpose machines and also used for production
- vertical types are used for drilling and boring
- for production, automatic table are available
- cutters installed on:
  1. Horizontal spindle supported by over – arm
  2. Vertical spindle
c. **Universal milling machines**

- tool room machines for accurate work
- the table has an additional movement – swivel horizontally and fitted with an **index head** or **dividing heads**
- swivelng feature permits cutting of **helices** on drills, **milling cutters and gears**.
- can be equipped with **vertical milling attachment, vices, etc.**
- **automatic cycle** can be provided for the movement of the table

**FIGURE 25-17** End milling a helical groove on a horizontal spindle milling machine using a universal dividing head and a universal milling attachment. *(Courtesy of Cincinnati Milacron, Inc.)*
d. Ram type universal milling machine

- the spindle head can be swirled about the horizontal axis at the end of horizontally adjustable ram

- milling can be done at any angle \( \Rightarrow \) can become more universal being fitted with a swiveled table
FIGURE 25-12 Four types of milling machine tools.
2. **BED TYPE MILLING MACHINES**

- for production purposes
- more rigid, less universal
- table – only Longitudinal motion, mounted on the **bed**
- spindle – can be moved vertically
- Easy to operate by **non skilled person**
- Long table ➔ long work-pieces can be mounted and machined in same clamping.

- Simplex, Duplex and Triplex machines ➔ equipped with one, two or three **HEADS**.
3. PLANER TYPE MILLING MACHINES

- have single – point tools and are slow.
- use several milling heads.
4 ROTARY TABLE MILLING MACHINES

- for face milling mainly
- work passes through several milling cutters
- work-pieces can be loaded and unloaded **without stopping** the machine

PROFILERS AND DUPLICATORS PROFILERS

- Can reproduce a two–dimensional profile
- A stylus follow a template and controls the movement of spindles.
- Spindles; four, two or one – controlled by hydraulically or mechanically

DUPLICATORS

- Reproduce forms in three dimensions
- Used to machine moulds and dies (blades, impellers and propellers)
- The stylus movement following a pattern is replaced by numerically or computer controlled machines.

* Pantograph rolling machine
- pantograph linkage principle
FIGURE 25-14  Small knee-type vertical spindle milling machine modified with tracer control system for X and Y control.

FIGURE 25-15  Principle of operation of a hydraulic tracer.
ACCESSORIES FOR MILLING

A. For fixing the works

- Universal milling attachment can be swirled about horizontal or two horizontal axes.
- Slotting attachment
- Boring attachments
- Angular spindle head
- Grinding heads
- Universal dividing heads

UNIVERSAL DIVIDING HEADS

- Provides means for holding and indexing work-piece through any desired arc(angle) of rotation.
- Work can be held between centers or in chuck that is mounted in the spindle hold of the divider.
- Work can be held on the divider’s table as well.
**Mechanism:**

40:1, 90:1, 120:1 worm – gear reduction unit. The spindle is making one revolution per 40 turns of input hand – crank

- There is an index plate mounted behind the crank
- There is a number of holds arranged in concentric circles and equally spaced, each circle has a different no. of holes.
- A pin on the crank handle can be adjusted to engage with a hole of any circle

* The crank can be turned to an accurate fractional part of a complete circle which corresponds to the angular distance between any two holes on the index plate

**yields → precise angular distance**

Number of turns of the crank = \( \frac{40}{\text{cuts per rev}} \)

Number of holes to be indexed = \( 40 \times \text{no. holes / circle} \) cuts per revolution

The circle must be selected such that the number of holes to be an EVEN MULTIPLE of the cuts/revolution.
There are _adjustable sector arms_ \( \rightarrow \) repeat the motion without counting the no. of holes

**SPIRAL MILLING (helix)**

- The dividing heads can be used to provide continuous relationship between the feed rate and the work-piece rotation. Ex: helical grooves.
- Numerically controlled dividing heads are used \( \rightarrow \) much more complex operations than a mechanical one (powered \( \rightarrow \) shorter time)

Other accessories
- Vices
- fixtures

**CUTTING TIME CALCULATIONS**

Usually, the cutting tool is multiple – point
- Feed is usually in mm/tooth ft
- Feed/minute \( f_m \)
  \[ f_m = ft \times n \times RPM <mm/min> \]
- Cutting time \( CT \):
  \[ CT = (L + La) / f_m <min> \]
- Material Removing Rate
  \[ MRR = \text{vol}_{\text{removed materal}} / CT <in^3/min> \]