Theory of Metal Cutting

Chapter 4
Typical Metal Cutting Operation
Machining or Metal Cutting

- Removing unwanted material
- Cutting/chipping/machining/metal cutting

To get desired

- Shape
- Size
- Surface finish
Typical Machining Example

Changing shape/size/finish

(a) Raw Material

(b) Finished Product

Unwanted material to be removed
Metal Cutting: features

✓ Closer dimensional accuracy
✓ Surface texture/finish
✓ Economical
✓ Complex shape
✓ Size
Metal Cutting: features

✗ Material loss (~50%)
✗ Scarcity of materials
✗ Special equipment
✗ Skilled operators
✗ Time required
✗ All materials cannot be machined

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Essentials of Metal Cutting Operation

- Machine Tool
- Cutting Tool
- Method
- Operator

A typical Cutting Tool

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**Machine Tool**

*Machine used for metal cutting*

- provision for holding workpiece
- provision for holding tool
- relative motion between them
- providing power/energy
Typical Machine tool

- Tool head
- Workpiece
- Vise
- Table
- Base
- Column
- Ram
Different Machine Tools

Type of surface –
flat/circular/complex

Metal Cutting Machine Tools
Metal Forming Machine Tools
Classification of Machine Tools

degree of specialization
  general/special

motion
  reciprocatory/rotary

automation
  manual/semi-auto/auto

surface
  cylidrical/flat

duty cycle
  L/M/H

energy
  conventional/non-conventional

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Mechanism of Metal Cutting

Tool & Workpiece interaction

- Tool penetration (depth of cut)
- Force
- Chip
- Relative motion between tool and workpiece (cutting speed)
Cutting Tools

- sharp edge/strong/hard/tough
- shape/size/method of holding

- Requirements
- Common materials
- Alloying
- Types
- Tool geometry

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Types of Tools

- Single Point
- Multipoint
Metal Cutting ..

Basics

Features

Essentials

Machine Tools

Different

Classification

Mechanism of Metal Cutting

Cutting Tools

Requirements

Tool Materials

Types of tools

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Geometry of Single Point Tool...

Tool Signature

8 – 14 – 6 – 8 – 8 – 19 – 1

8 – Back Rake Angle
14 – Side Rake Angle
6 – End-relief Angle
8 – Side Relief Angle
8 – End Cutting Edge Angle
19 – Side Cutting Edge Angle
1 – Nose Radius
Geometry of Single Point Tool...

**RH & LH Tool**

- **Right hand tool**
- **Left hand tool**

Side cutting

Edge
Orthogonal and Oblique Cutting

Orthogonal cutting

- Tool
- Chips
- Cutting edge at 90°
- Motion of Workpiece

Oblique cutting

- Tool
- Chips
- Cutting edge inclined
- Motion of Workpiece

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Types of Chips

- Continuous chip
- Discontinuous chip
- Built-up edge
Types of Chips ..

- Continuous Chip – chip breaker
- Discontinuous Chip
- Chip with Built-up Edge

- Workpiece material
- Tool geometry
- Cutting conditions

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Thermal Aspects in Machining

Heat generated in cutting operation effects:
1. Tool
2. Workpiece
3. Machine tool
   • Surface
   • accuracy

depends:
✓ Rate of Cutting ➔ cutting conditions
✓ Workpiece material

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Thermal Aspects in Machining.

Distribution of Heat

heat generated in machining operation → chips + tool + workpiece + environment

\[ Q = Q_1 + Q_2 + Q_3 + Q_4 \]

- \( Q_1 \) = heat taken away by the chips
- \( Q_2 \) = heat conducted into tool
- \( Q_3 \) = heat conducted into workpiece
- \( Q_4 \) = heat dissipated into environment

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Thermal Aspects in Machining...

Distribution of Heat...

Heat dissipation
• depends on cutting speed

To keep cutting zone temperature low

→ Cooling

→ Cutting Fluid

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Cutting Fluids

- absorb and carry away the heat
- cool the workpiece and tool.
- reduce the friction
- wash away the chips.
- carry away the built-up edges formed.
- give very fine surface finish
- prevent corrosion

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Operating Conditions

Conditions (motions) required for metal cutting to take place

Operating or Cutting Conditions

- Cutting Speed $v$ – m/s
- Feed $f$ – mm/s or mm/rev or mm/min
- Depth of Cut $d$ – mm
  - Material Removal Rate $MRR$ – m$^3$/s
  - Machining/Cutting Time
Tool Life

Wear of sharp edge \( \rightarrow \) dull tool

time between two successive resharpenings

Time for which tool cuts effectively

Influencing Factors

1. Operating/cutting conditions
2. Workpiece material
3. Tool material
4. Geometry of tool
5. Use of Coolant
Tool Life

Cutting Speed ($v$) vs. tool life ($T$)

Taylor's Expression or Tool Life Equation

Graph:
- Intercept ($\log C$)
- Slope ($n$)

Equation: $\log v = C - n \log T$
Tool Life..  
**Taylor’s Expression**

\[ \nu T^n = C \]

\( \nu \) = Cutting Speed (m/min)

\( T \) = Tool Life (min)

\( n, C \) are constants.  \( C = \) Intercept

\( n \) = Slope of line

\[ n = \tan \theta = \frac{\log \nu_1 - \log \nu_2}{\log T_1 - \log T_2} \]
## Tool Life...

### Typical n & C VALUES

<table>
<thead>
<tr>
<th>Work material</th>
<th>Tool material</th>
<th>$n$</th>
<th>$C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>HSS</td>
<td>0.1-0.16</td>
<td>160-190</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>0.18-0.2</td>
<td>220-290</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>HSS</td>
<td>0.08-0.1</td>
<td>100-180</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>0.2-0.28</td>
<td>250-325</td>
</tr>
</tbody>
</table>
Tool Life...

Effect of depth of cut and feed on tool life

\[ \log v, \log f, \log d \]

\[ \log T \]

\[ \theta_1 > \theta_2 > \theta_3 \]

\[ vT^n f^{n_1} d^{n_2} = C \]
Machinability

Ease of machining

- Tool life
- Cutting Speed
- Force/power
- Accuracy/finish

A relative measure

- Cutting Forces/power
- Specific cutting speed – CS for tool life T
Machinability = \( \left( \frac{v_t}{v_s} \right) \times 100\% \)

- \( v_s \) – specific CS for standard material
- \( v_t \) – specific CS for test material

Machinability is affected by:
- Condition of machine/tool
- Cutting conditions
- Type of operation
- Work material

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EXAMPLE 4.1

While machining carbon steel by a tungsten based steel tool, tool life of 50 minutes was observed when machined with a cutting speed of 100 m/min. Determine (a) General Taylor’s tool life equation and (b) tool life for a cutting speed of 80 m/min. Assume $n = 0.09$.

Work material: **carbon steel**

Tool material: **tungsten based tool steel**
EXAMPLE 4.1

Solution

Given: \( v = 100 \text{ m/min}, \ T = 50 \text{ min}, \ n = 0.09 \)

Taylor’s Eqn. \( vT^n = C \)
or \( \log v + n \log T = \log C \)
or \( \log 100 + 0.09 \log 50 = \log C \)
or \( C = 142.20 \)

Hence: \( vT^{0.09} = 142.2 \)
EXAMPLE 4.1 ..

Solution

(b)

Given: \( v T^{0.09} = 142.2 \), \( v = 80 \text{ m/min} \), \( T = ? \)

\[
80 \cdot T^{0.09} = 142.2
\]

or

\[
T = 596.57 \text{ min}
\]

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**Example 4.3** A carbide-cutting tool when machined with mild steel workpiece material at a cutting speed of 50 m/min lasted for 100 minutes. Determine the life of the tool when the cutting speed is increased by 25%. At what speed the tool is to be used to get a tool life of 180 minutes. Assume $n = 0.26$ in the Taylor’s expression.
EXAMPLES

Solution: Given data: \( v_1 = 50 \text{ m/min}, \quad T_1 = 100 \text{ min}, \quad n = 0.26 \)

For 20% higher speed

\[ v_2 = 1.25 v_1 = 62.5 \text{ m/min} \]

We know that \( v_1 T_1^n = v_2 T_2^n \)

Substituting the values, we get

\[ T_2 = 42.39 \text{ minutes} \]
EXAMPLES

(b) Let $v_3$ be the cutting speed for tool life of 180-min.

We know that

$$v_1T_1^n = v_3T_3^n$$

Substituting the values, we get

$v_3 = 42.91$ m/min
**Example 4.4** In assessing machinability of different workpiece materials, the following data were obtained during machining:

<table>
<thead>
<tr>
<th>Work mat</th>
<th>Tool life</th>
<th>Cutting speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>150</td>
</tr>
<tr>
<td>B</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>250</td>
</tr>
</tbody>
</table>
EXAMPLES

- Estimate the relative machinability, considering material A as standard material and tool life as cutting speed of 50 m/min as criteria.

- **Solution** Consider material A
  - $V_1=100$ m/min. $t_1=25$ min $V_2=150$ m/min $t_2=10$ min.

- We know that
  - $\log V + n \log t = \log C$
EXAMPLES

- Substituting we get
  \[ \log 100 + n \log 25 = \log C \]
  \[ \log 150 + n \log 10 = \log C \]

- Solving equations (1) and (2), we get

- \( n = 0.43 \) and \( C = 403.55 \)

- Hence, tool life equation is \( V t^{0.43} = 403.55 \)
EXAMPLES

- To find speed at $t = 50$ min.
- Substitute $t = 50$ min equation (3) we get $V_{60} = 75$ m/min.
- Repeating the same procedure for material B we get $n=0.33$, $C=631$ and $V_{60} = 173.53$ m/min.
- Relative machinability $= \left[ \frac{V_{60} \text{ for test material}}{V_{60} \text{ for standard material}} \right] \times 100$
- $= \left[ \frac{173.53}{75} \right] \times 100$
- $= 231.37\%$