Theory of cutting

Technology II – Jan Tomíček
Chip forming process

- Force → stress → work hardening → saturation (fully hardened material) → shear → continuous chip
Cutting force?

- Force
- resistance of material
- keeping together the blank
- must be overcome to cut
- creating new surfaces
- creating the chip
Cutting force

- Orthogonal cutting – 2D – 2 forces (components)
- Conventional (oblique) – 3D – 3 forces

F...total cutting force
Fc...cutting force/tangential
Ff...feed force/axial
Fp...back force/radial

Ft: tangential force
Fa: axial force or feed force
Fr: radial force
Geometrical constraints (OC)

• $F$...friction force
• $N$...normal force
• $F_s$...shear force
• $F_n$...normal to shear

• vector $F+N=R$
• vector $F_s+F_n=R'$
Geometrical constrains
Cutting Force and Thrust Force

- $F$, $N$, $F_s$, and $F_n$ cannot be directly measured.
- Forces acting on the tool that can be measured:
  - Cutting force $F_c$ and Thrust force $F_t$

Figure 21.10 Forces in metal cutting: (b) forces acting on the tool that can be measured.
Cutting force

• In the direction of cutting velocity vector
• The largest component 98% of power

\[ F_c > F_f > F_p \ (100\% > 40-50\% > 25\%) \]

!!!

\[ V_c > f > k \]
Force measurements

- Usually by measuring the components
- Use of dynamometers (1D, 2D, 3D)
Cutting forces

\[ F = \sqrt{F_c^2 + F_f^2 + F_p^2} \]

Cutting energy (Cutting power) required

\[ 60.P_c = F_c.v_c \]

Cutting force per unit area (specific cutting force)

\[ k_c = \frac{F_c}{A_c} \]
Chip crosssection area

- Influence of clearance angle

\[ h = f \cdot \sin \kappa_r \]

\[ b = \frac{a_p}{\sin \kappa_r} \]
Specific cutting force

Connection between specific cutting force and cutting power per **material removal rate**

\[ p_c = k_c = \frac{P_c}{Q} = \frac{F_c v_c}{A_D v_c} = \frac{F_c}{A_D} \]

Q – material removal rate (cm\(^3\).min\(^{-1}\))

Q = Ad.vc \hspace{1cm} \text{(roughing vs. finishing)}
Specific cutting force

\[ k_c = \frac{c_{kcap}}{a_p u_{kc}} \quad k_c = \frac{c_{kcf}}{f u_{kc}} \]

Ukc – empirical exponent
Ckc… - empirical constants

\[ F_c = k_c \cdot A_D = k_c \cdot a_p \cdot b_D \]
Material influence

Influence of Rm and manufacturing technology (chip thickness, cutting speed, tool rake etc.)

\[ k_c = C_k \cdot R_m \]

Ck values:
3 – 5...turning
4 – 10...milling
3 – 6...drilling
20 – 35...grinding
Fig. 2.19. Distribution of heat generated in machining to the chip, tool, and workpiece surface.

The figure illustrates the relative heat generation in different zones of the machining process:

1. Primary deformation zone, where the greatest amount of heat is generated due to plastic deformation of the work material.
2. Secondary deformation zone, where there is a significant amount of heat due to friction.
3. Contact zone, where the workpiece surface rubs the cutting tool, increasing heat generation.

Fig. 2.20 shows, as an example, the experimentally determined temperature distribution in the chip and the workpiece in cutting [1]. As the material is removed towards the cutting tool, the temperature increases.
Use of specific cutting force?

Q: What is the necessary force(power) of machine to perform some operation?

1) Estimate/Calculate specific cutting force

\[ k_c = C_k \cdot R_m \]

2) Calculate chip cross-section

\[ A_D = a_p \cdot f = b \cdot h \]

3) Calculate cutting force

\[ F_c = k_c \cdot A_D \]

4) Calculate power of machine

\[ P_c = \frac{F_c \cdot v_c}{60} \]
Heat & temperature

Power transforms to heat. Heat rises the temperature of the chip, the tool, the workpiece and the environment.
Heat sources

1) Primary deformation Zone – Plastic def.
2) Secondary deformation zone – additional plastic deformation, slide friction
3) New surface zone - friction
Procedure:
Work performed →
Heat generated →
Temperature rise
Temperature

X - chip
Y – surface chip
Z – new surface
Temperature

Cutting temperature – average value of the contact surfaces

\[ \theta_S = C_\theta \cdot a_d^{x\theta} \cdot f^{y\theta} \cdot V_c^{z\theta} \]

What happens if you multiply 2x the...

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>X – 0,1</td>
<td>Ad → 7%</td>
</tr>
<tr>
<td>Y – 0,25</td>
<td>F → 19%</td>
</tr>
<tr>
<td>Z – 0,4</td>
<td>Vc → 32%</td>
</tr>
</tbody>
</table>
Temperature effects?

• Tool wear
• Built up edge
• Power consumption/energy loss
Temperature relations

- Cutting speed – changes value and distribution
Temperature measurement

Problem:
How to measure the temperature inside material?

- Measurement of average temperature?
- Measurement of surface temperature
Thermocouple measurement

Work-tool thermocouple
standard thermocouple
Other measurements

- Calorimetric method –
- Decolourising agent/melting objects
- Infra ray detection
- Thermocouples
Cutting fluids

Active liquid creating the environment around cutting area.

Effects:
- Cooling
- Lubricating
- Cleaning
Fluids?

- Compressed air
- Oil mist
- Liquids (oil, water emulsions, special comp.)
Effects of High temperature

Tool:
• Rapid tool wear
• Thermal cracking
• Plastic deformation
• Built-up edge

Workpiece:
• thermal distortion
• geometrical inaccuracy
• Damaged surface (oxidation, corrosion...)
• Residual stress and cracks
• Heat treatment...