Damping in Machine and Cutting Tools
A journey in search

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What is damping?

• Damping is good. Very good.

• As per dictionaries, damping is defined as any method of dispersing energy in a vibrating system, and as a result, damping reduces the amplitude of vibration with time.
Why do we need damping?
Why do we need damping?

\[ a_{lim} = -\frac{1}{2K_t\alpha \text{Real}(H(\omega_c))} \]

\[ a_{lim,crit} = \frac{-1}{2K_t\alpha \min(\text{Re}(H(\omega_c)))} \]
# Damping mechanisms in machine tools

<table>
<thead>
<tr>
<th></th>
<th>Viscous damping</th>
<th>Hysteric damping</th>
<th>Dry Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation</td>
<td>$m\ddot{x} + c\dot{x} + kx = f(t)$</td>
<td>$m\ddot{x} + k(1 + tan\delta)x = f(t)$</td>
<td>$mx + kx + \mu N\text{sign}(x) = f(t)$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Estructural Parts</th>
<th>Bolted Joints</th>
<th>Guideways</th>
<th>Rubber</th>
<th>Fluids</th>
<th>EddyCurrents</th>
</tr>
</thead>
</table>

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[1]: #/image1.png
[2]: #/image2.png
[3]: #/image3.png
[4]: #/image4.png
[5]: #/image5.png
[6]: #/image6.png
[7]: #/image7.png

Munoa, CIRP HPC 2018
Structure of this talk on damping

- Damping in materials
- Damping due to joints
- Passive damping
- Active damping
Damping due to materials
Damping in spindles

Koenigsberger and Tlusty, 1970
Damping

Over 90% of the damping is at the interfaces. Of the remainder, some is due to materials, and some due to heat loss.
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• Active damping
Influence of joints on damping

Koenigsberger and Tlusty, 1970
Influence of weld length on damping

Koenigsberger and Tlusty, 1970
Damping influenced by material and lubrication and preload

Guideway damping

\[ \psi = f(\zeta) \]
Influence of preload and surface condition on damping

![Graph showing the relationship between average damping ratio and contact pressure for different surface conditions and interface areas. The graph includes lines for different treatments: A - Hand polishing (dry), B - Hand polishing (lubricated), C - Grinded (long pattern), D - Grinded (short pattern).]
Damping in linear guideways
Accuracy vs. damping

- Metal-Metal
  - Low friction materials
    - Recirculating Roller/balls
      - Magnetic

- Hydrostatic
  - Aerostatic
    - + Damping
      - - Accuracy

Munoa, CIRP HPC 2018
Behavior of hydrostatic guides
Damping in tool and tool holder joints

\[ a_{lim} \approx 2k\zeta \]

Source: Namazi, UBC
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Vibration absorber in boring bars

\[ F_0 \sin(\omega t) \]

\[ k_m \]

\[ m_m \]

\[ x_m \]

\[ c_a \]

\[ k_a \]

\[ m_a \]

\[ x_a \]

Silent Tools®
Vibration absorber in boring bars

Spindle Speed: 3200 RPM; Depth of cut: 0.025mm; L/D = 8, Undamped tool

Spindle Speed: 3200 RPM; Depth of cut: 1.5mm; L/D = 8, Damped tool
Grooving

\[ w_{cr} \approx \frac{+1}{2K_{ct}Re[G_{xy}]} \]
Grooving: avoiding chatter with a damped tool
Damping snaking chatter in grooving?
Damped milling holder
Damped milling holder

![Graph showing amplitude vs frequency for different damping conditions]

Target mode

Modes after damping

Modes after damping

Frequency (Hz)

Amplitude (m/N)

1.2 x 10^{-5}

1.0

0.8

0.6

0.4

0.2

0.4

0.6

0.8

1.0

1.2 x 10^{-5}

Spindle speed (rpm)

Axial depth of cut (mm)

Sandvik cutter
Damped cutter
Undamped cutter

Yang et al. JVC, 2018
Self-tuning mass dampers

Diagram showing a vibration object with mass damper, added mass, and springs with stiffness $K_1$, $K_2$, and damping $C_1$, $C_2$. Graphs illustrate varying stiffness $K_2(N/m)$ with frequency (Hz) and response over time. Comparisons are made with conventional and MAQ STMD mass damper configurations.
Structure of this talk on damping

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• Active damping
Active damping

![Diagram of Active Damping System]

- **Amplifier**
  - Input: $u[V]$
- **DAC**
- **Controller**
- **Actuator**
  - Input: $F_{act}[N]$
  - Output: $[m/s^2]\ddot{x}$
- **Accelerometer**
- **Machine Tool**
  - Input: $F_c[N]$
Active damping
Active damping

Rough milling process
Active damping
In summary...

• Damping is good. Very good.

• Material level advances can only do so much for you.

• Should you cast or weld?

• The real damping is at the interfaces.

• When/where possible consider passive and/or active damping solutions.

• The journey in search continues ...
Thank you

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