Increasing the Dynamic Stiffness of Machine Tools by Means of Modal Analysis

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Structure

- Characteristics of chatter vibrations in turning machines
- Operational modal analysis on a turning machine
- Modal analysis on a turning machine
- Locating the weak spot, improve the dynamic stability
- Machining tests with improved dynamic behavior
- Conclusion
Characteristics of Chatter in Turning Processes

- Characteristics of self excited vibrations (chatter)
  - Energy supply by the process
  - Cycle of the energy supply depends on the dynamic behavior of the machine
- Remedy
  - Variation of cutting parameters (revolution speed, feed)
  - Redesign of the machine tool, increase of stiffness, increase of damping

Model to describe the origin of regenerative chatter

Stability limit of the process at:
\[ 1 + G_m \cdot G_p = 0 \rightarrow G_m = 1/G_p \]

Source: Tönshoff
Orthogonal Turning – Evaluating the Machine’s Dynamic Stability

Test parameters

- Workpiece material: CK 45
- Cutting speed $v_c$ (const.): 100 m/min
- Tool feed rate $f$: 0.1 mm/rev
- Tool width $b$: 3 mm - ...chatter occurs

Workpiece with chatter marks
Locating the Cause of the Dynamic Instability that Leads to Chatter

General approach

Operational modal analysis with cutting tests that lead to instabilities
- Vibration-, chatter frequency, vibration directions and amplitudes

Experimental modal analysis
- Eigenfrequencies, damping, Eigenmodes

Compare the results of the operational modal analysis with the results of the modal analysis
- Which Eigenmodes are being excited, what is the cause?

Selective redesign / stiffening of dynamically instable components

Cutting tests to evaluate the redesign

Equipment for modal analysis

LMS Testlab 6.0 software for modal- and operational modal analysis

LMS Scadas III frontend with 36 input channels

Shaker for continuous excitation

Tri-axial accelerometers

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Machining Tests with Simultaneous Operational Modal Analysis

Cutting process parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>CK 45</td>
</tr>
<tr>
<td>Cutting insert</td>
<td>Iscar GIF-5,5 E-0,14</td>
</tr>
<tr>
<td>Cutting material</td>
<td>IC 825 P10-P35</td>
</tr>
<tr>
<td>Tool holder</td>
<td>VDI 30-C2</td>
</tr>
<tr>
<td>Cutting velocity $v_c$</td>
<td>100 m/min</td>
</tr>
<tr>
<td>Feed $f$</td>
<td>0,1 mm/rev</td>
</tr>
<tr>
<td>Workpiece diameter</td>
<td>120 mm</td>
</tr>
<tr>
<td>Tool holder width</td>
<td><strong>5.5 mm</strong></td>
</tr>
<tr>
<td>Coolant</td>
<td>without</td>
</tr>
</tbody>
</table>

- 4 tri-axial accelerometers on the tool holder and the turret
- Cutting tests while recording the time signal
- Severe chatter occurred after a short operation time
Cutting Tests – Stable (4mm tool) – Unstable (5.5mm tool)

Timeplot of tool vibration

4mm tool width

Time variant frequency analysis of tool vibration

5.5mm tool width

Timeplot of tool vibration

5.5mm tool width

Time variant frequency analysis of tool vibration

5.5mm tool width
Vibration Animation of the Geometry Model in Time Domain

- Time dependent vibration of tool and turret induced by the machining process can be visualized with time animation toolbox.
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Modal Analysis – Driving Point at Tool Holder

Geometry model of turret and spindle with 83 nodes

- Tool turret
- Tri-axial accelerometers
- Excitation with impulse hammer
- Main spindle
- Tool holder
- Workpiece

X-axis
Z-axis
Modal Analysis – Locating the Modes from SUM FRF

- A clear peak can be found at 123 Hz in the SUM FRF
Critical Eigenmode at 122 Hz: Vibration of the turret gearbox in x-dir

Results: Tool holder vibrates in passive force direction (radial to the workpiece)
  ◆ Machining process is prone to chatter vibrations
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Methods to Improve the Dynamic Stability of the Machine

- Y-axis case has been stiffened
  - Result: Very low improvement
- Supporting and damping element has been integrated between y-axis case and turret gear box to support the turret
  - Result: Good improvement
FRF at Tool Holder without and with Supporting and Damping Element

- Red curve: No supporting element – lower damping of the natural frequency at 110 Hz
- Blue curve: With supporting and damping element – improved damping of the natural frequency at 110 Hz
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Cutting Tests with Improved Turning Machine

- Cutting tests with **6.5 mm** tool holder
- Significant lower vibration level during cutting tests
- No severe chatter marks on workpiece

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Cutting Test with Machine Tool at Initial Condition

- Time and time variant frequency analysis of the tool vibration signal in cutting force direction
- Rapid increase of the chatter vibrations to a high level – no stable machining operation possible
Cutting Test with Improved Machine Tool

- Time and time variant frequency analysis of the tool vibration signal in cutting force direction
- Significant lower vibration level at 122 Hz – stable machining operation
Conclusion

- The arise of chatter in machining operations is often a cause of dynamic instabilities

- Operational modal analysis reveals vibration frequencies and modes that occur during machining operations

- Modal analysis is suitable to discover the dynamic behavior of machine tools

- Analysis results can be used to improve the machine tool design in order to allow more stable metal cutting operations