Topology Optimization of Machine Tools to improve the Stability in high performing Metal Cutting Processes

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Simulation Disciplines at Machine Tools

- Thermal
- Static
- Dynamic
Mechanical Structures in complex Systems

17 Volumes
12 elastic Couplings

Designspace
Non-Desigarea

2 Volumes
3 Couplings
Modeling of the mechanical Structure for Optimization
Optimization Strategies

Static Topology Optimization
with weighted load cases (up to now max. 44)
• moving loads (weight)
• acceleration loads (quasi-static)
• process loads

Combined Topology Optimization
static loads + eigenfrequencies
specific frequency constraints

\[ f_1 = 60 \text{ Hz} > f_1^* \]
\[ f_2 = 90 \text{ Hz} > f_2^* \]
\[ f_3 = 120 \text{ Hz} > f_3^* \]
Initial model for head (Realistic boundary conditions)

Flexible beam elements for boundary conditions

Loadcase 1 (x-direction)

Loadcase 2 (y-direction)

Beam elements attached to rigid mass

Beam elements attached to rigid mass
Minimize: Maximize of \( \{ \text{abs}(u_x), \text{abs}(u_y) \} \)

Mass < \text{Mass}^* = 35\%

\[
\begin{array}{|c|c|}
\hline
\text{Number} & \text{Eigenfrequency} \\
\hline
1 & \sim 0 \\
2 & \sim 0 \\
3 & \sim 0 \\
4 & 2.4 \\
5 & 3.0 \\
6 & 3.5 \\
\hline
\end{array}
\]

Important: the static optimization showed that the frequency responses also have to be considered in the optimization. The rigid mass is no more attached to structure !!!!
Frequency optimization

Maximize the eigenfrequencies from $f_1$ to $f_6$

Mass < Mass* = 35%

<table>
<thead>
<tr>
<th>Number</th>
<th>Eigenfrequency</th>
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<tbody>
<tr>
<td>1</td>
<td>83</td>
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<tr>
<td>2</td>
<td>105</td>
</tr>
<tr>
<td>3</td>
<td>112</td>
</tr>
</tbody>
</table>

Shaft hardly attached to structure.

**Important**: Model the correct physical boundary conditions. The optimization should include static and frequency results.
Combined static and frequency optimization

Purpose: To improve the static stiffness for both loadcases including constraints on the eigenfrequencies.

Objective: Minimize: Maximize of \{ \text{abs}(u_x), \text{abs}(u_y) \}

Constraints: Mass < Mass* = 35%

\begin{align*}
& f_1 > f_1^* = 60 \text{ Hz} & & f_1 > f_1^* = 75 \text{ Hz} \\
& f_2 > f_2^* = 90 \text{ Hz} & & f_2 > f_2^* = 100 \text{ Hz} \\
& f_3 > f_3^* = 120 \text{ Hz} & & f_3 > f_3^* = 125 \text{ Hz} \\
& f_4 > f_4^* = 150 \text{ Hz} & & f_4 > f_4^* = 150 \text{ Hz} \\
& f_5 > f_5^* = 180 \text{ Hz} & & f_5 > f_5^* = 175 \text{ Hz} \\
& f_6 > f_6^* = 210 \text{ Hz} & & f_6 > f_6^* = 200 \text{ Hz}
\end{align*}

Example 1

Example 2
Combined static and frequency optimization: Topology

Example 1:

<table>
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Example 2:

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<td>268</td>
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<tr>
<td>6</td>
<td>265</td>
<td>377</td>
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</table>
Examples for Topology optimized Machine Components

- Tool Changer Arm
- Rod and Plain Eye
- hydr. Rundtisch Brake
Examples for Topology optimized Machine Components

Machine Stand
Examples for Topology optimized Machine Components

Machine Stand

Milling and Boring Carriage