Vibration and Balance Problems in Wood Machining

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Higher Speeds Cause More Vibration Problems

**High Speed Planers**
10 years ago: 12,000 ipm (1000 feet per minute)
Today: 24,000 ipm (2000 feet per minute)

**CNC Routers**
10 years ago: 15,000 rpm, 500 ipm
Today: 30,000 rpm, 2500 ipm
Force $\sim mr(\text{RPM})^2$; $m =$ unbalance mass, $r =$ mass radius

- Unbalance $(mr)$ is constant for rigid rotors
- Force due to unbalance increases with the square of RPM
Types of Unbalance

Static Unbalance

Dynamic Unbalance
(statically balanced)
Case Studies of Wood Machining Problems Caused by Vibration

- CNC Router Spindle Bearing Failures
- Moulder Surface Quality Problems
- Circular Sawing Quality Problems
- Tool Wear / Breakage Problems
Case Study #1: CNC Routers
The Spindle is the Heart of a High Speed CNC Router

- Motor rpm, power, and torque characteristics
- Spindle rotor critical speed behavior
- Spindle rotor bearing type, orientation, and speed rating
- Bearing lubrication and cooling provisions
- Bearing design for plunge cutting (thrust)
- Bearing contamination issues (dust)
- Provisions for thermal elongation of rotor
- Tolerances on fit, concentricity, and balance
- Spindle break-in procedures
- Power inverter performance
- **Sensitivity to Unbalance**
Vibration Severity Chart

1.0 in/sec (very bad)
0.5 in/sec (bad)
0.2 in/sec (fair)
0.1 in/sec (good)
0.05 in/sec (excellent)
Balance Tolerance Depends on Spindle Design

Typically heavier spindles can tolerate more unbalance than light weight spindles.

![Graph showing the relationship between spindle RPM and vibration levels for different unbalance values.](image)

**Vibration (mm/s)**

**Spindle RPM**

- 0 g-mm
- 5 g-mm
- 10 g-mm
- 15 g-mm

*typical spindle vibration tolerance*
Tool Chuck Considerations

Rigidity

• Type of Chuck Connection to the Spindle Shaft
• Type of Tool Connection to Chuck

Torque Transmission

• The Torque Associated With High Speed / High Power Machining Far Exceeds Conventional Machining.

System Damping

• The Nature of the Connection of the Tool to the Chuck Influences the System Damping, Tool Chatter, Tool Deflection, and Dynamic Balance.

Balance Considerations

• Chucks for High Speed Applications Should Be Balanced to ISO Grade G-1.0. (This is Not a Standard Balance Specification)
Balance Grade Considerations

ISO G 1.0 Balance Grade Corresponds to Less than 10 gram-mm for Spindle rpm of 20,000 and Less than 5 gram-mm for 30,000 rpm.

- Typical unbalance for brazed tools exceeds 15 gram-mm.
- Typical unbalance for solid carbide tools is less than 5 gram-mm.
- Tool chucks may have 25 gram-mm or more unbalance and still be labeled as balanced for high speed.

As Spindle Speeds Increase, Achieving a Suitable Balance Will Become Increasingly Difficult and May Necessitate the Use of In-Place Balancing Devices.
CNC ROUTER HORSEPOWER / GULLET LOADING CHART
(Horsepower = net - idle; Gullet loading = % of total capacity)

<table>
<thead>
<tr>
<th>Feed Rate (inches / minute)</th>
<th>SPINDLE RPM = 20,000</th>
<th></th>
<th>SPINDLE RPM = 30,000</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cutter Diameter (inches)</td>
<td></td>
<td>Cutter Diameter (inches)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>0.325</td>
<td>0.50</td>
<td>0.25</td>
</tr>
<tr>
<td>500</td>
<td>1.3 / 60%</td>
<td>2.1 / 40%</td>
<td>3.4 / 30%</td>
<td>1.7 / 40%</td>
</tr>
<tr>
<td>1000</td>
<td>1.6 / 120% stress = 80%</td>
<td>3.0 / 80%</td>
<td>4.6 / 60%</td>
<td>2.3 / 80%</td>
</tr>
<tr>
<td>1500</td>
<td>3.6 / 120% stress = 40%</td>
<td>5.5 / 90%</td>
<td>2.8 / 125% stress = 80%</td>
<td>4.5 / 85%</td>
</tr>
<tr>
<td>2000</td>
<td>6.3 / 120% stress = 25%</td>
<td></td>
<td>5.2 / 110% stress = 35%</td>
<td>8.0 / 85%</td>
</tr>
<tr>
<td>2500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Cutting 3/4” thick plywood with 25 degree helical (upshear) cutter.
Forces for Straight Cutting Edge

Cutting Forces (lbf)

Power (hp)

Cutter geometry and cutting conditions
- Cutter diameter: 0.25 in
- Helix angle: 0 degrees
- Number of teeth: 2
- Spindle speed: 20000 rpm
- Feed speed: 500 ipm
- Depth of cut: 0.1 in
- Width of cut: 0.75 in
- Average power: 0.68 hp
Forces for Spiral Cutting Edge

Cutting Forces (lbf)

Power (hp)

Torque (in-lbf)

Cutter geometry and cutting conditions:
- Cutter diameter: 0.25 in
- Helix angle: 25 degrees
- Number of teeth: 2
- Spindle speed: 20000 rpm
- Feed speed: 500 ipm
- Depth of cut: 0.1 in
- Width of cut: 0.75 in
- Average power: 0.47 hp
Case Study # 2: Moulders
Laser Profilometer on Moulder
Optimizing Moulder Tooling Performance

- Precision Cutterhead Arbor
- Precision Cutterhead Centering
- Precision Cutterhead Grinding
- Precision Cutterhead Balancing
Effect of Unbalance on Tip Path

The detrimental effect of unbalance on precision cutting tools is illustrated at left. The unbalance force causes the center of rotation to be displaced from the shaft centerline resulting in an eccentric tip path.
Balance Tolerance Nomogram

Rotor rpm | Tolerance (gram-inches) | Rotor weight (lb.)
---|---|---
10,000 | 0.05 | 5.0
7,200 | 0.5 |
5,000 | | 5.0
3,600 | | 10.0
2,000 | | 20.0
1,000 | | 50.0
500 | |
Surface Quality for Different Balance Grades

ISO G1 Tool Unbalance

ISO G16 Tool Unbalance

![Graphs showing surface quality for different balance grades.](image-url)
Case Study # 3: Circular Saw Blades
One Diameter Vibration Mode
ILLUSTRATION OF "STEP" CUT

Unstable blade cuts wide kerf as blade enters workpiece

Workpiece acts as a guide as blade becomes engaged which stabilizes blade

The severity of the step in the workpiece is directly related to the amount of blade unbalance.
Case Study # 4: Tool Wear
Study of the Effect of Selected Machining Parameters on Carbide Tool Wear

- Tool Material
- Tool Edge Quality
- Workpiece Material
- Material Processed (total)
- Material Processed
- Number of Tooth Impacts
- Tool / Workpiece Vibration
  Unbalance
  Workpiece Hold Down

- Cutterhead Diameter
- Cutting Angles
- Depth of Cut
- Feed per Tooth
- Peripheral Speed
- Climb / Conventional Cut
Micro-Graphs of Tool Edge

Low Vibration Level

High Vibration Level
ACKNOWLEDGMENTS

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