Agenda

- Basics
- Cryogenic Media
- Machine Tool Solutions
- Cryo·tec™
- Testing & Results
Cryogenic Machining – Tooling Requirements 01 – Basics

Definition:
Cryo - genic: Greek roots
Kryos = Ice, Frost
Generare = create

State of the Art:
- Cryogenic media (mainly CO₂ and LN₂) have been applied since the 1950s
- Most cases external supply of the media
- Positive effects
  - Reduction of cutting temperature
  - Reduction of tool wear
  - Increase of work piece quality
  - Reduced contamination of work piece
Cryogenic Machining – Tooling Requirements
02 – Cryogenic Media

Cryogenic Media:

- Liquid Hydrogen (Boiling point at 1.013 bar: −252.882 °C)
- Liquid Nitrogen (Boiling point at 1.013 bar: −195.80 °C)
- Liquid Oxygen (Boiling point at 1.013 bar: −182.97 °C)
- Carbon Dioxide (Sublimation point at 1.013 bar: -78.5 °C)

Source: Linde 2014
# Cryogenic Machining – Tooling Requirements

## 02 – Cryogenic Media

<table>
<thead>
<tr>
<th>CO₂</th>
<th>LN₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>In liquid condition +20°C</td>
<td>In liquid condition -196 °C</td>
</tr>
<tr>
<td>Coolant effect: Sublimation</td>
<td>Coolant effect: Contact with liquid phase</td>
</tr>
<tr>
<td>No insulation in the tool body</td>
<td>Insulation of coolant channels mandatory</td>
</tr>
<tr>
<td>No insulations in the machine tools</td>
<td>Insulation of spindle and supply pipe</td>
</tr>
<tr>
<td>One, two and three internal channels</td>
<td>Only one internal channel</td>
</tr>
<tr>
<td>Combination of coolant and lubricants</td>
<td>Lubrication only external</td>
</tr>
<tr>
<td>Higher thermal absorption due to phase transformation</td>
<td>Permanent cooling</td>
</tr>
<tr>
<td></td>
<td>Risk of condensation and corrosion</td>
</tr>
</tbody>
</table>
Advantages of CO₂

- Easy to handle in liquid phase
- No spindle insulation necessary
- Rotating unit mostly retrofittable
- Cost-efficient production of CO₂
- Chemical by-product
Cryogenic Machining – Tooling Requirements
03 – Machine Tool Solutions

CO₂ Supply Systems

ChilAire (Cool Clean)

Rother Technology
Cryogenic Machining – Tooling Requirements
04 – One Chanel System Cryo·tec™

Special nozzle design

F2334R button cutter for turbine blade machining

Exit: Dry Ice Aerosol Mix

Sealing to avoid early expansion
* Six CO₂ exits on the relief side (clearance angle)

** MQL supply by „Cool Jet“ (Haimer)

Source: Haimer 2014
Cryogenic Machining – Tooling Requirements
04 – Two Channel System Cryo·tec™

Dry Ice
Air Aerosol
Aerosol Channel
Aerosol Channel
Spring loaded Lance
CO₂-Channel
CO₂
MQL
**Test Program**

**Documentation:**
- Flank wear $v_{b\text{max}}$

**Wear criteria:**
- $v_{b\text{max}} = 0.4$ mm

**Coolant: Internal**
- $\text{CO}_2$
- MQL
- Compressed air
- Coolant (Vasco7000, 10-12% Oil)

**Tool**
- Round Insert, Copy Milling F2334R.B22.050.Z05.06 CRYOTEC CO$_2$
- WSP: ROHX1204M0-(D57/F67)

**Cutting Data:**
- $v_c = 120, 100, 80, 60$ m/min
- $a_e = 28$ mm
- $a_p = 2.00$ mm
- $f_z = 0.18$ mm
Test Program - Material

Material:
- Ti6Al4V (3.7185)

Dimensions:
- Length 602 mm (23.70"")
- Width 296 mm (11.65"")
- Height 122 mm (4.80"
Milling Strategy

Side Plunging

Profile Milling
## Test program – Carbide Grades & Geometry

<table>
<thead>
<tr>
<th>Geometry</th>
<th>CVD</th>
<th>Special CVD</th>
<th>PVD</th>
<th>Special PVD</th>
<th>Special PVD</th>
<th>Special PVD</th>
<th>Special PVD</th>
<th>Special PVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROHX1204M0-F67</td>
<td>C_.1</td>
<td>C_.2</td>
<td>R</td>
<td>AP1</td>
<td>AP2</td>
<td>AP3</td>
<td>AP3P</td>
<td>DAP3P</td>
</tr>
<tr>
<td>Material up to</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>900N/mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WSM45X</td>
<td>C2.2</td>
<td>R1 = WSP45S</td>
<td>P2.2</td>
<td>P5.3</td>
<td>P11.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROHX1204M0-D57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material greater then 900N/mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C4.2</td>
<td>R2 = WSP45S</td>
<td>P7.3</td>
<td>P8.3</td>
<td>P12.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Comparison of Coolant

Coating comparison with vc=80m/min
Comparison of Coolant

Geometry Comparison with WSP45S

R1: WSP45S F67
R2: WSP45S D57
Cooling with Cryotec – Variation of CO$_2$-Exits

Exit variant of CO$_2$

<table>
<thead>
<tr>
<th></th>
<th>Under the Flank</th>
<th>In the opposite direction</th>
<th>Over the clamping unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>V2</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>V3</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

R1: WSP45S F67

- CT.R1.N.R.F.V1
- CT.R1.N.R.F.V2
- CT.R1.N.R.F.V3

Radtke | RCC SAM | October 2015
Coolant vs. CO$_2$ with Compressed Air

Cryogenic cooling is often very beneficial. However, in pocketing the lowest wear value was achieved in the cutting material P10.5 with coolant.
Using compressed air instead of MQL provides less wear values.
Variation of Cutting Speeds

Variation between $vc = 120/100/80/60$ m/min

R1: WSP45S F67
R2: WSP45S D57
P1.1: W3536 F67

Average cutting speed-
Ranges

Compared with coolant experiments
Conclusion

- PVD Coating with sharp edge cutting edge showed best results in all tests
- MQL is not suitable for the machining of Ti6Al4V
- Use of MQL with Cryogenics results in a slightly more wear than without
- Cryogenics cooling showed on average 26% reduction of insert wear
- Reducing C0₂ flow by 50% has little effect, less than 50% increases wear
- Using C0₂ temperature of workpiece, tool body, insert remain under +25.5°C
Engineering Kompetenz

Thank you very much!