High Volume Titanium cutting Challenge, Technology and Solutions

Rorschacherberg, September 15
Titanium Applications

Aircraft Structural Parts

- Ti6Al4V
- Ti 5Al 5V 5Mo 3Cr
- Ti Aluminide
Typical Ti aircraft component operations:

- Poket's: open & closed
- Ribs: straight and free-form
- Corner radii
- Undercuts
- Holes
- Web (face-side)

Typical Dimension:
- Rip height: 1,2” – 2,2”
- Wall thickness: 0,08” – 0,16”
- Floor thickness: 0,012” – 0,25”
Approach to Improve Productivity in Titanium chip removal

To increase the chip removal rate in titanium the achievable removal rate must be forced up with:

- Increasing the cutting feed without reducing tool live time
  - Depends very much on rigidity of machine tool, tool quality, coolant system, coolant quality
- Increasing the max cutting depth
  - Depending on machine tool, fixture, work piece
- Choice of best milling strategy
  - Depending on application engineer, CAM System

The machining process must be optimized for each application within a complete system of fixture, tools, coolant and milling strategy

The machine tool is the integrator whereby every reasonable milling process for titanium must be implemented optimal
Test of Milling Strategies

- Contrast of different approach
- With the definition of the milling strategy the tools, fixture and coolant strategy can be finalized
Example of Evaluation Strategy: Variation of cutting parameter, Evaluation tool life

<table>
<thead>
<tr>
<th>Test #</th>
<th>Vc ft/min</th>
<th>Fz inch</th>
<th>Ap inch</th>
<th>Ae inch:</th>
<th>Q inch³/min</th>
<th>t min</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>213</td>
<td>0.02</td>
<td>0.04</td>
<td>0.63</td>
<td>0.79</td>
<td>29:40</td>
</tr>
<tr>
<td>8</td>
<td>213</td>
<td>0.04</td>
<td>0.04</td>
<td>0.63</td>
<td>1.58</td>
<td>15:00</td>
</tr>
<tr>
<td>9</td>
<td>328</td>
<td>0.02</td>
<td>0.04</td>
<td>0.63</td>
<td>1.22</td>
<td>19:30</td>
</tr>
<tr>
<td>10</td>
<td>230</td>
<td>0.023</td>
<td>0.04</td>
<td>0.63</td>
<td>1.04</td>
<td>22:30</td>
</tr>
</tbody>
</table>

Test # 7
## Example of Evaluation Strategy: identification of cost optimal usage

<table>
<thead>
<tr>
<th>Typ</th>
<th>Test #</th>
<th>Vc ft/min</th>
<th>Fz inch</th>
<th>Q inch³/min</th>
<th>t min</th>
<th>Tool cost per hour</th>
<th>Tool cost in %</th>
<th>Machining Cost @ 150/hour</th>
<th>Machining Cost in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>roughing</td>
<td>7</td>
<td>213</td>
<td>0.02</td>
<td>0.79</td>
<td>29:40</td>
<td>31,50</td>
<td>-50%</td>
<td>74.0</td>
<td>+97%</td>
</tr>
<tr>
<td>roughing</td>
<td>8</td>
<td>213</td>
<td>0.04</td>
<td>1.58</td>
<td>15:00</td>
<td>64,00</td>
<td>0</td>
<td>37.50</td>
<td>0</td>
</tr>
<tr>
<td>roughing</td>
<td>9</td>
<td>328</td>
<td>0.02</td>
<td>1.22</td>
<td>19:30</td>
<td>53,50</td>
<td>-16%</td>
<td>48.70</td>
<td>+30%</td>
</tr>
<tr>
<td>roughing</td>
<td>10</td>
<td>230</td>
<td>0.023</td>
<td>1.04</td>
<td>22:30</td>
<td>42,50</td>
<td>-33%</td>
<td>56.50</td>
<td>+57%</td>
</tr>
</tbody>
</table>
Increasing Cutting Speed

After the optimal milling strategy is specified the best possible cutting speed for the system must be detected.

- **Tool** (impact: Geometry, cutting edge radius, coating)
  - approach: difference in tool life between leading manufacturer is up to factor 2-3

- **Coolant System** (kind for coolant system, medium consistency, pressure, coolant quantity)
  - approach:
    - difference in tool life between leading Coolant manufacturer is up to factor 2
    - difference in tool life in the way coolant is applied to the cutting edge - factor 2
    - difference in tool life depending on pressure of internal cooling - factor 1,3
Increasing Cutting Depth

Along with the general performance parameter like spindle-RPM or torque the effective achievable cutting depth is reduced through instability of the system (chatter). This chatter is triggered through the weakest link in the chain:

- Tool
- Spindle
- Machine structure
- Fixture
- Work Piece

A well balanced system is essential for productive machining. Optimizing beyond the weakest link does not have any importance of the general performance.
Increasing Productivity and Tool Life

Cryogenic cooling with CO₂

- CO₂ under pressure as coolant (expansion at tool tip leads to cooling effect, not cool while transported to the tool)
- Can be used through spindle or external, with or without minimum quantity lubrication

PRODUCTIVITY

+70% chip removal rate compared with dry machining

Reinhard Fitz, Sales Director North American Operation
Finishing with the Starrag “Dengeln” process

- Smoothing of the aerofoil surface with an oscillating tungsten carbide ball (up to 700 Hz)
  - Excellent surface qualities plus introduction of compressive stresses
- Complete implementation
  - automated operation
  - programming CAM

(Taken from a shot peening brochure from the MIC Group)
Example Tools

Long tools are most the limiting element for heavy cutting depth.

Starrag approach:
A the compact design of the rotary head will reduce the collision contour and hence allows shorter tools.
Example Spindle

A long, slim shaft diameter of a motor spindle many time limits the achievable cutting depth.

Starrag Approach:
We use geared spindles with significant bigger shaft diameter and shorter distance between the bearings whereby the system benefits of a better bending stiffness.

Reinhard Fitz, Sales Director North American Operation
Example Machine Structure

The machine structure (sliding carriage, column, …..) can activate vibrations and hence limit the cutting depth.

Starrag Approach:

**Optimize and improve the structure through cutting test, experimental Modal analyses and through FEM simulation.**
Accomplished Results

Starrag works on all level with a systematic approach to locate and improve limiting factors,

In cutting Titanium following results could be achieved:
- Cutting Speed > 150 m/min (>491 ft/min)  
  (Common Standard 196 – 262 ft/min)
- Cutting depth > 100 mm (> 4 in)  
  (Common Standard 0.8 in)
- Removal Rate > 800 cm³/min (> 49.8 in³/min)  
  (Common Standard 6.3 in³/min)

For efficient Titanium cutting the best available operation strategy, tools and coolant systems must be applied.

Starrag machines are build to benefit the full potential of this operation strategies.

Reinhard Fitz, Sales Director North American Operation
E03900 case study

Work Piece
- Demo structure part
- Blank 380x515x82.5 (15“x20.3“x3.5“)

Material
- Titanium Ti-6Al-4V

Operation
- Drilling
- Roughing
- 5-Axis simultaneous milling

Benefit
- Best strategy and MMR
- Best surface quality
- no manual rework
**E03900**

- Setup 1: 174min
- Setup 2: 58min
- Setup 3: 110min

- Total machining time: 5h 42min
Solutions for Titanium Machining

**STC**
Small parts  
Roughing and finishing

- Spindle rpm: up to 8,000
- Spindle Torque: up to 959 ft lbs
- Pallet size:
  - STC Series: up to 1800mm
  - BTP: 2000 x 5000mm

**BTP**
Medium to large parts  
Roughing and finishing  
**Twin Spindle**
Solutions for Titanium Machining

**ECOFORCE TI 9 / 13**
Medium to large parts
Roughing and finishing
A/C Head

**ECOFORCE TI 24**
Medium to large parts
Roughing and finishing
Head exchange

- Spindle rpm: 3,000 up to 8,000
- Spindle Torque S1: up to 4,056 ft lbs
- Pallet size: starting with 2000 x 4000

Reinhard Fitz, Sales Director North American Operation

Titanium 2015, October 4-7, Orlando, FL
ECOFORCE Ti 9/13– Typical parts