Optimizing Machining of Titanium Aerospace Parts
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Titanium Aircraft Parts
Presentation Topics

- Titanium 101
- Trends & drivers for new aircraft designs
- Machine tool and process constraints
- Application examples
- Extreme titanium machining results
Titanium – What is it and why do we use it?

Titanium is a natural element found on Earth

- It’s a surface mined metallic ore

Titanium is alloyed with iron, aluminum, vanadium, molybdenum, and others metal to create grades of what we call ‘titanium’

Titanium has the highest strength-to-weight ratio of any metal

- Titanium is 45% lighter than steel and stronger
- Titanium offers great stiffness and fatigue resistance
- Titanium has a high melting point, higher than steel
  - Ti = 1,649º C (3000º F)
  - Steel = 1540º C (2800º F)

Titanium is relatively light weight and highly corrosive-resistant material;

- Titanium is the perfect choice for heavy load/structural and/or connective aircraft parts
Titanium can be difficult to machine
- Titanium alloy is fairly hard, but not as hard as some heat-treated steels
- Forgings typically have a hard crust surface of impurities that make it difficult to cut thru the outer surface
- If machining generates extreme heat work hardening can occur making it even harder to machine
- Titanium is tough on cutting tools

Titanium is very ductile (formable) and extremely fatigue resistant making suitable for a variety of applications
- Medical, dental, and aerospace

It not uncommon for finished part to weigh less than 50% of rough material weight. *Sometimes they weigh much less!*
Titanium – Processing methods

High-torque / low-speed machining

- Common with large part manufacturing
- Parts are made from billets or forgings and require heavy stock removal and long cycle times
  - Processed with slow feedrate and at a low rpm
    - eg., 3 - 4 ipm @ 150 rpm
  - It is not uncommon for parts to be processed over different stations to machine all the features
  - Use large cutting tools for large part features
    - Allows heavier cuts and reduces cycle time
Optimizing 5-Axis Aircraft Parts Machining

Industry Trends & Drivers for Titanium Parts

- New Aircraft programs increasing world-wide demand – China, C919; Russia MS21; etc.
- Increased use of composites in aircraft designs is increasing Titanium content
  - Corrosion issues between aluminum & carbon-graphite composite materials
  - Superior strength to weight ratio vs. steel or aluminum
  - New Defense aircraft programs – eg., F-35 JSF
  - New Commercial aircraft programs – Boeing 787, Airbus A350XWB, etc.
- Aircraft parts are getting more complex and more accurate
- Multi-Spindle Roughing – Single Spindle Finishing
Industry Challenges for Titanium Parts

- New alloys like Ti 5553 more difficult to cut than older Ti 6Al4V
- Aircraft parts are getting more complex and more accurate
  - **Design for Assembly**
- World-wide availability of raw material is limited
- Currently not enough spindle capacity in the world to meet projected production rate requirements – Some Boeing reports suggest over 600 spindle shortfall to backlog demand
Determinate Assembly

- Digital Thread
- Sophisticated 3D modeling software
- Digital detail parts designs
  - Digital data drives machine tool cutter paths
- The finished machined parts, by design and digital manufacturing process:
  - Fit together without further fitting, shimming, or secondary machining processes
  - Simpler/less assembly tooling required
  - Interchangeable/replaceable parts
Critical Success Factors for Optimizing Titanium Machining
- Machine tool and process considerations

MRR (Metal Removal Rate) volume in³/min can be impacted by many factors:

- Available Spindle Torque (Nm or lb.ft); not necessarily high power
- High Dynamic Stiffness
  - High Structural Stiffness
  - Good vibration damping characteristics
- Stiff toolholder/spindle interface – bending moment limits
- Cutting tool life
- High performance coolant system
  - High pressure/high flow flood & through-spindle coolant system
- Cutting tool type and stiffness (tool breakage)
- Specific part features (ie., thin walls and/or floors)
- Cutting strategies
<table>
<thead>
<tr>
<th>Tool Interface</th>
<th>Bending Moment Limit</th>
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<tbody>
<tr>
<td>KM4X100</td>
<td>52,000 lb-in</td>
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<tr>
<td>KM4X125</td>
<td>70,000 lb-in</td>
</tr>
<tr>
<td>HSK100A</td>
<td>16,500 lb-in</td>
</tr>
<tr>
<td>HSK125A</td>
<td>23,900 lb-in</td>
</tr>
<tr>
<td>50-Taper</td>
<td>7,000 lb-in</td>
</tr>
<tr>
<td>50-Taper Simult-fit</td>
<td>7,800 lb-in</td>
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</tbody>
</table>

KM4X100 has 2x bending moment limit as HSK125A
KM4X125 has 3x bending moment limit as HSK125A
Titanium is a very poor conductor of heat.
Application Examples
CINCINNATI Aerospace Worldwide Installations*

Titanium spindle purchases trending 5:1 to aluminum in past 5 years

* Not all shown
High-Performance Machining of Titanium

Boeing Portland

Titanium, stainless and 4140 steel flap tracks

Various Titanium Landing gear Components

Giddings & Lewis HMC 1250
  Multiple 4-Axis & 5-Axis versions

T-REX fixed Spindle
  - 5,000 rpm
  - 2200 Nm (1623 lb-ft) torque continuous
  - Full power at 257 rpm

Tilt Spindle
  - 6,000 rpm
  - 1,161 Nm (856 lb-ft) torque continuous
  - Full power at 317 rpm
High-Performance Machining of Titanium

Kongsberg Vapenfabrik
ThyssenKrupp
BMW Rolls-Royce
Volvo Aero
MTU/

Titanium/Inconel
- Jet Engine housings
- Compressors
- Turbine disks
- Rings

Giddings & Lewis Vertical Turning Centers
High-Performance Machining of Titanium

Boeing – Portland Oregon

Titanium & Stainless steel flap carriages & flap tracks

Cincinnati 5-Axis TC-40 Cell

Full part turnkeys
High-Performance Machining of Titanium

GKN Monitor Aerospace – Amityville, NY

Roughing and finishing defense aircraft bulkheads (2-up)
High-Performance Machining of Titanium

Rolls Royce – Barnoldswick, UK

Titanium and Stainless Steel Fan Blades for Boeing 787 Engines

(4) Cincinnati MEGA 4-Axis in CINCRON Cell
High-Performance Machining of Titanium

Tect Aerospace – Wichita, KS

Roughing and Finishing Titanium Components

(3) Machine Cincinnati MEGA 5, CINCRON Cell

Application turnkey

Pylon
High-Performance Machining of Titanium

Goodrich – Tullahoma, TN

Roughing and Finishing Titanium Landing Gear Components for Airbus, Boeing and Lockheed Martin

(4) Cincinnati U5 Universal Machining Centers and
(5) Cincinnati 6-Spindle Profilers
High-Performance Machining of Titanium

Goodrich & ADI

Large Titanium Landing Gear components

Giddings & Lewis Horizontal Boring Mills
Recent Partnerships in Titanium Productivity

**UBM** (Ural Boeing Manufacturing)
- Joint venture – Boeing/VSMPO
- Greenfield facility with Cincinnati as exclusive machine tool supplier

**VSMPO**
- Strategy to machine parts at Mill to reduce logistics and related cost
- First order 2007

**VASO**
- Airbus Titanium Component Supplier

**Hongdu Aviation** – China
- Heavy growth in Titanium machining
- Cincinnati is preferred supplier
Titanium Processing Solutions in Growing Aerospace Markets - $79M Investment (Phase 1)

**UBM - Boeing**
- (6) 5-Spindle 5-Axis Ti WR Gantries
  - 3500 rpm 2523 Nm torque HSK125A spindles
  - 787 wing box parts; 27 different part numbers
- (4) MEGA 5 HMC
- (4) HMC-1600

**VSMPO**
- (4) 3-Spindle Ti WR Gantries
- (2) 4 Spindle Ti WR Gantries
- (2) 5 Spindle Ti WR Gantries
- CINCRON Cell with (3) MEGA 4-axis and (1) MEGA 5-axis
- (2) CINCRON Cells each with (1) H5 1000 and (3) HPC 4-axis

✓ Application Team Key Solution – Truck Beam & Inner Cylinder
UBM – Russia

Titanium side of body connecting components for Boeing Wide Body Commercial Aircraft
New Generation 3 & 5-Axis XT Profilers

XT-Profilers utilize Cincinnati’s field-proven spindle carriers

- High torque: 2520 Nm (1860 ft-lb) S1 continuous rating per spindle
- Over 1/3 hp (0.25 kW) per rpm
- Maximum torque up to 195 rpm
- 68 hp (51 kW) S1 continuous rating per Spindle
- Spindle taper alternatives:
  - HSK125A
  - KM4X100
  - KM4X125
Fives Cincinnati 5-Axis 5-Spindle XT Profiler
XT Profiler Testing Conditions

- Test Material – 6Al4V Titanium
- 5-up – all (5) spindles simultaneously
- Cutting Tools
  - Kennametal HARVI cutters
  - 3” diameter indexable carbide
  - 9” gage length modular
- Coolant
  - Houghton Hocut®

* Test cuts designed for **peak MRR**; results will vary depending on material, tooling and cutting parameters
X & Y-Axis Profile & Slot Cuts

**Profile Cuts**

Metal Removal Rate
- 12.83 in³/min per spindle
- 64.15 in³/min for (5) spindles

**Slot Cuts**

Metal Removal Rate*
- 20.0 in³/min per spindle
- **100 in³/min for (5) spindles!**
  1639 cm³/min

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*Note: Slot Cuts' metal removal rate includes the additional 100 in³/min for (5) spindles.
True Full 5-Axis Cuts

5-Axis Bobsled Cut – full slot single pass
16 in³/min per spindle
80 in³/min for (5) spindles
* limited by insufficient chip relief on cutter body
Fretting corrosion
Summary results of XT Profiler Test Cuts

Cutting Test Results Comparison
Per Spindle MRR

<table>
<thead>
<tr>
<th></th>
<th>Round-2 HSK125A MRR</th>
<th>Round-1 KM4X100 MRR</th>
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<tbody>
<tr>
<td>Profile</td>
<td>10.4 in³/min</td>
<td>12.8 in³/min</td>
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<tr>
<td>Full Slot</td>
<td>9.9 in³/min</td>
<td>20 in³/min</td>
</tr>
<tr>
<td>5-Axis Bobsled</td>
<td>7.8 in³/min</td>
<td>16 in³/min</td>
</tr>
<tr>
<td>Stellram HFM</td>
<td>11.0 in³/min</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Fives Cincinnati
Fives Giddings & Lewis
Fives Liné Machines
Fives Forest Liné