High Performance Machining of Titanium
The Systems Approach
Agenda

• Challenges in machining Titanium
• Thermal Management
• Importance of Spindle Connections
• Maximizing Dynamic Stiffness
Challenges in Machining Titanium

Titanium Characteristics

- Good high temperature strength increases the work needed to cut Titanium.
- High work hardening and strain rate sensitivity exacerbate thermal issues in cutting Ti alloys.
- Titanium reacts with most materials at high temperatures to chemically wear tools.
- Poor thermal conductivity of Ti causes heat to partition to the tool instead of the chip.

90% of work from metal cutting is converted into heat

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Effect of Cutting Speed on Temperature

Current Ti cutting conditions

Double Cutting Speed

FEM predicts a 250° C increase in cutting temperature to double speed

50 m/min at 0.15 mm chip

100 m/min at 0.15 mm chip
**KSSM45 Milling Tool Development**

**Cutting Conditions**
- Workpiece: Ti6Al4v
- Hardness: 42 – 46 HRC
- Length of Pass: 254mm (10 in)
- Cutting Fluid: Water based Synth.
- Coolant Pressure: 300 psi.

**Cutting Parameters**
- Cutting Speed: 58 m/min (187 SFM)
- Chip load (fz): 0.25mm/tooth (0.010 ipt)
- Axial Depth of Cut = 2 mm (0.08 inch)
- Radial Depth of Cut = 81 mm (3.2 inch)

**KSSM45 Beyond Blast™ provided over 2 times better tool life than standard through spindle coolant delivery.**
**Cutting Conditions**

- **Workpiece:** Ti6Al4v
- **Hardness:** 42 – 46 HRC
- **Length of Pass:** 254mm (10 in)
- **Cutting Fluid:** Water based Synth.
- **Coolant Pressure:** 1000 psi.

**Cutting Parameters**

- **Cutting Speed:** 46 m/min (150 SFM) & 58 m/min (187 SFM)
- **Chip load (fz):** 0.25mm/tooth (0.010 ipt)
- **Axial Depth of Cut:** 3.8 mm (0.15 inch)
- **Radial Depth of Cut:** 51 mm (2.0 inch)

**DAISY Beyond Blast™ provided over 2.5 times better tool life than standard through spindle coolant delivery @ 150 SFM.**
Shim position determines coolant path

- **Turning**
  - Shim side 1 up
  - Position coolant slot toward end for turning

- **Facing**
  - Shim side 1 up
  - Rotate shim 90° for facing

- **Profiling**
  - Shim side 2 up (flip shim over)
  - Broader coolant dispersal for profiling
Cutting Conditions

Workpiece: Ti6Al4v
Hardness: 42 – 46 HRC
Cutting Fluid: Water based Synth.
Coolant Pressure: 100 and 1000 psi.

Cutting Parameters

Cutting Speed: 30 and 45.5 m/min (100 and 150 SFM)
Feed: 0.305 mm/rev (0.012 ipr)
Depth of Cur: 6.35 mm (0.25 inch)

Cutting Conditions

Workpiece: Ti6Al4v
Hardness: 42 – 46 HRC
Cutting Fluid: Water based Synth.
Coolant Pressure: 100 and 1000 psi.

Cutting Parameters

Cutting Speed: 91 m/min (300 SFM)
Feed: 0.2 mm/rev (0.008 ipr)
Depth of Cur: 1.27 mm (0.05 inch)
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- **Importance of Spindle Connections**
- Maximizing Dynamic Stiffness
Spindle Connections - Overview

Where we are today...

ASME B5.50
DIN 69871
ISO 7388
JIS B6339

ISO 7388
With Face contact

DIN 69893
ISO12164
(HSK)

ISO26623
(PSC System)

ISO26622
(KM System)

Kennametal’s Next Spindle Generation of KM™

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Kennametal’s Next Spindle Generation of KM™

- Highest rigidity and bending capacity among all connections
- Evenly distributed clamping force
- Simple design allows for front-loaded spindle configurations
- Balanced by design for high spindle speed capability
- Capable of performing in a wide range of operations from low speed, high torque to high speed, low torque.
Bending Characteristic – Comparison PSC / KM4X

Bending characteristic of the PSC can vary subjected to tolerances, load direction and other influences. Therefore the diagram shows two different exemplary characteristic lines of the PSC.

KM4X63 shows higher stiffness and separation bending moment than PSC63 at same clamping force

Data only valid for the investigated combination of Tool and Receiver, not for the overall system.
KM4X63 shows 4X higher stiffness at 600 Nm and 8X at 900 Nm
Load-Deflection Charts KM-HSK-Steep Taper

 normalized stiffness
Application Data – Ti Milling on HSK125A machine

Cutter Diameter: 80 mm
Number of flutes: 4
Projection Length: 250 mm
Cutting Speed: 50 m/min
ADOC: 63.5 mm
RDOC: 12.7 mm
Feed Rate: 142 mm/min
MRR: 361 cm³/min

Torque: 870 Nm
Bending Moment: 4620 Nm

Cutter Diameter: 300 mm
Number of Inserts: 20
Projection Length: 150 mm
Cutting Speed: 46 m/min
ADOC: 9.5 mm
RDOC: 150 mm
Feed Rate: 195 mm/min
MRR: 284 cm³/min

Torque: 2905 Nm
Bending Moment: 2860 Nm

*MRR is limited by maximum the bending moment of spindle interface*
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- **Maximizing Dynamic Stiffness**

Tunable Milling Adapter
Tunable Adapters provide significantly higher dynamic stiffness

- Optimal Dynamic Stiffness. Adapter can be tuned on the spindle to account for machine dynamics
- Improved surface quality and close tolerances
- Increased productivity. Larger depth of cut and feed rate.
- Significant reduction on vibration for extended tool life, longer spindle bearing life
It’s Not Just About the Tools:

A Complex Iterative Process

Design Part with CAD → Select Machine → Select Tools → Write & Optimize Program → Produce Part → Inspection

That Can be Optimized

Baseline

Optimized

The Opportunity

Forging/Casting
Machine Tool
Cutting Tools
Machining
Other

It Is About Partnerships, Digitization and Integration