Machine Tool Design for Titanium Machining

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Introduction

Titanium has the best strength to weight ratio of all metals. It is together with CFK is material of choice for today’s aerospace industry.

Examples
- Turbine blades, blisks and impellers
- Structural parts and turbine casings

In comparison to other materials, its toughness and low thermal conductivity makes it hard to cut
- Material removal rate Aluminum 900 in³/min
- Material removal rate Titanium 30 in³/min

Tough material and long operating times require strong and stable machines
Example workpieces
Many of the parts are very big and therefore require large machines

Since the machine times are often in the region between 10 and > 100h the machines must be very stable to keep thermal drift to a minimum

– requires homogeneous design
– is improved by using thermal compensation

Achievable stability: Thermal drift within 10 hours over full spindle range (up to 8'000 rpm) in the area of 1 micro inch)
Titanium machining

Current developments in Titanium machining

The technology of Titanium cutting has changed tremendously with the developments of new tools

- Cutting speeds
  - for roughing of about 250 ft/min (old profilers 50 ft/min)
  - for finishing of about 500 ft/min
- Radial and axial immersions are much lower, but the material removal rate has multiplied (24 to 48 in³/min)

Consequences for machine tools

- Machines with high dynamic capabilities (e.g. acceleration, feed rates) are required
- High spindle speeds > 5'000 rpm are required for efficient finishing
- Spindle torque can remain within comparable low boundaries (~800 lbs ft)
- Process stability must be extremely high
Machine tool dynamics

Dynamic cuts
- Spindle speed 5‘500 rpm
- Feed rate 150 in/min

Movement of the tool center point requires rapid motions of the axes
- High velocities and acceleration of the axes
- Short distance from tool tip to rotary axis

Conventional milling head

Starrag milling head
Ideal Main Spindle for Titanium Machining

Face milling
Full cut, DoC = 6 mm, Vc = 80, feed/tooth= 0.14 mm

Contouring
DoC = 1 x Dia., WoC = ½ x Dia., Vc = 80, feed/tooth= 0.13 mm

Trends due to
- higher machine stability
- improved tools
- improved cooling

5’600 rpm / 959 ft lbs 100% duty

8’000 rpm / 693 ft lbs 100% duty

Finishing, Vc = 500 ft/min

Dia 6 mm: 7960 rpm
Dia 8 mm: 5970 rpm
Dia 10 mm: 4780 rpm

a) Face mill 45° Dia 160 mm
b) Porcupine Dia. 80 mm
c) End mill Dia. 20 mm
d) Conical Ball end mill Dia. 6 mm
Spindle requirements

High cutting speeds and high material removal rates result in

- High spindle speeds
- High heat generation and therefore the need of an efficient cooling system (Starrag: internal cooling with 1450 psi)
- High damping and stiffness of the machine as well as the spindle system
- Possible with excellent robustness of a geared spindle
Stiffness and Damping

Machine design must be balanced since achievable cutting depths are limited by the weak spot of the system, e.g.

- spindle rotor
- spindle support
- structural vibration of the machine

Instable cuts reduce tool life and destroy the workpiece surface
Stiffness and Damping

Short distance between tool tip and A-axis
- Minimal load during roughing operations
- With a tool length of 180 mm there is up to a 50 % reduction in effect torque acting on the A-axis!

→ High stiffness on the tool tip resulting in the highest machining quality and tool life.
Stability and Damping

Unstable cuts are sometimes unavoidable because the weak spot of the system are
- vibration of the fixture
- vibration of the tool
- vibration of the workpiece

Chatter analysis on machine to support finding stable conditions: Sensor support integrated on machine

Tool freq. = 15.9 Hz
Chatter freq. = 46.8 Hz
Conclusion

While Titanium is still a hard to cut material, new tools and process strategies allow much higher productivity.
For achieving highest efficiencies and accuracies in Titanium cutting, the machine tools must have
- highest thermal stability
- much higher dynamic capabilities
- a balanced machine design for process stability without dominant weak spots
- analysis capabilities for supporting the process engineer to optimize the strategy