Optimization of Cutting Processes by Multiaxial-Vibration Assisted Machining

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Outline

1 Motivation – vibration assisted machining
2 Design of multi-axial vibration system
3 Machining tests
4 Summary/Outlook
Machining center for US assisted grinding

Gildemeister Ultrasonic 70 linear

- Main spindle
- Rotor of power transmission
- Stator of inductively coupled power transmission
- Housing of piezo-actuator
- Tool clamping
- Grinding tool

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Scratch test

ø100mm

specimen
sonotrode
membrane
piezo-actuator
housing

84 mm

ø 168 mm

Grain
50µm

α

Hermle C20

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Motivation - 1D-vibration vs. 2D-/3D-vibration

1D-US-vibration

- increase of material removal rate in machining of brittle-hard materials
- significant increase of tool life with (ultrasonic) vibration, especially in boring operation
- improvements in chip flushing
- tool-workpiece interaction shows significant influence on dynamic coupling of US vibration
- active control of vibration amplitude is difficult

3D-vibration

- direct adjustment and control of amplitude and frequency for discontinuous cut
- no US-resonance effect
- applying optimized direction of vibration (e.g. orbital drilling)
- different mode shapes possible
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Design concept of 2D-/3D - actuator

- balance mass
- air bearings
- working table
- cover
- housing
- air bearings
- balance mass
- base
- actuator
- connecting tube

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Technical specification:

- **Dimensions**: $L \times W \times H = 350 \times 350 \times 95 \text{ mm}^3$
- **Platform dimensions**: $L \times W = 170 \times 170 \text{ mm}^2$
- **Max. payload**: 20 kg
- **Max. amplitude**: $X / Y = 25 \mu m / 25 \mu m$
- **Stiffness**: $k_{xx} / k_{yy} = 14 \text{ N/}\mu\text{m} / 14 \text{ N/}\mu\text{m}$
- **Max. frequency**: $f_{\text{max}} = 500\text{Hz}$
- **Mode shape**: Free adjustable
Experimental platform - control concept

- Electric power
- Generator
- Control unit
- User
- NC
- Stroke
- Acceleration

- Piezo actor (2 stacks)
- Position sensor X
- Acceleration sensor
- Position sensor X

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Machining tests in SiSiC

**Workpiece material**: SiSiC
full slot machining

**Tool**: mounted point, galvanic bond
- diameter: \( D = 2 \text{ mm} \) - \( D = 3 \text{ mm} \)
- thickness: \( x = 0.7 \text{ mm} \) - \( x = 1 \text{ mm} \)
- grain: D64 - D107
- concentration: C200 - C200
- shape: code 6 - code 8

Splintery vs. blocky
Experimental setup

2D-vibration

2D-mode shapes examples

3D-vibration: coupling via angular arrangement

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Machining SiSiC - wear behavior

![Graph showing wear behavior](image)

**Tool-nr. 2**
- **D** = 3 mm, 8D107, C200
- **a_p** = 0.02 mm
- **a_e** = 3 mm
- **v_w** = 360 mm/min
- **v_c** = 75.5 m/min
- **n_s** = 8.000U/min
- Coolant: emulsion, 60 bar

**without vibration**

**3D-U-vibration**, angular orientation 45°
- Frequency/amplitude (P-P) in X: 107 Hz/12µm
- Frequency/amplitude (P-P) in Y: 214 Hz/7µm
- Frequency/amplitude (P-P) in Z: 214 Hz/7µm
- Phase shift vibration X and Y: 270°
Chip breaking in duplex steel - preliminary test

Turning operation on machining center, \( f = 178 \text{ Hz}, A = 10 \text{ µm}, \text{ cir.} \)

- Material: X2CrNiMoN22-5-3, \( D = 76,4 \text{ mm} \)
- Tool: HC - CVD
- Cutting speed: \( v_c = 60 \text{ m/min} \)
- Feed rate: \( f = 0,05 \text{ mm} \)
- Cutting depth: \( a_p = 0,2 \text{ mm} \)
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Use of multiaxial-vibration assisted machining:
- application specific adaption of vibration by 2D / 3D
- significant increase of tool life with vibration assisted machining in SiSiC
- improvements in chip formation and flushing

Continuative research work:
- use in machining of metallic materials
- optimization of active amplitude control