New calculation method for ultrasonic systems and application for machining optical freeform-surfaces on steel with diamond

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Content

1 Introduction

2 Automated Calculation and Optimization of Ultrasonic Oscillators

3 Application – Ultrasonic Assisted Turning with Flexural Oscillator

4 Summary

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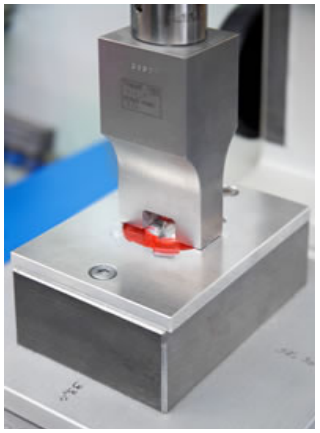
Introduction
Oscillation Assistance

Conventional kinematics + oscillation ➡ Process optimization

Air hammer

Ultrasonic cleaner



Ultrasonic welding

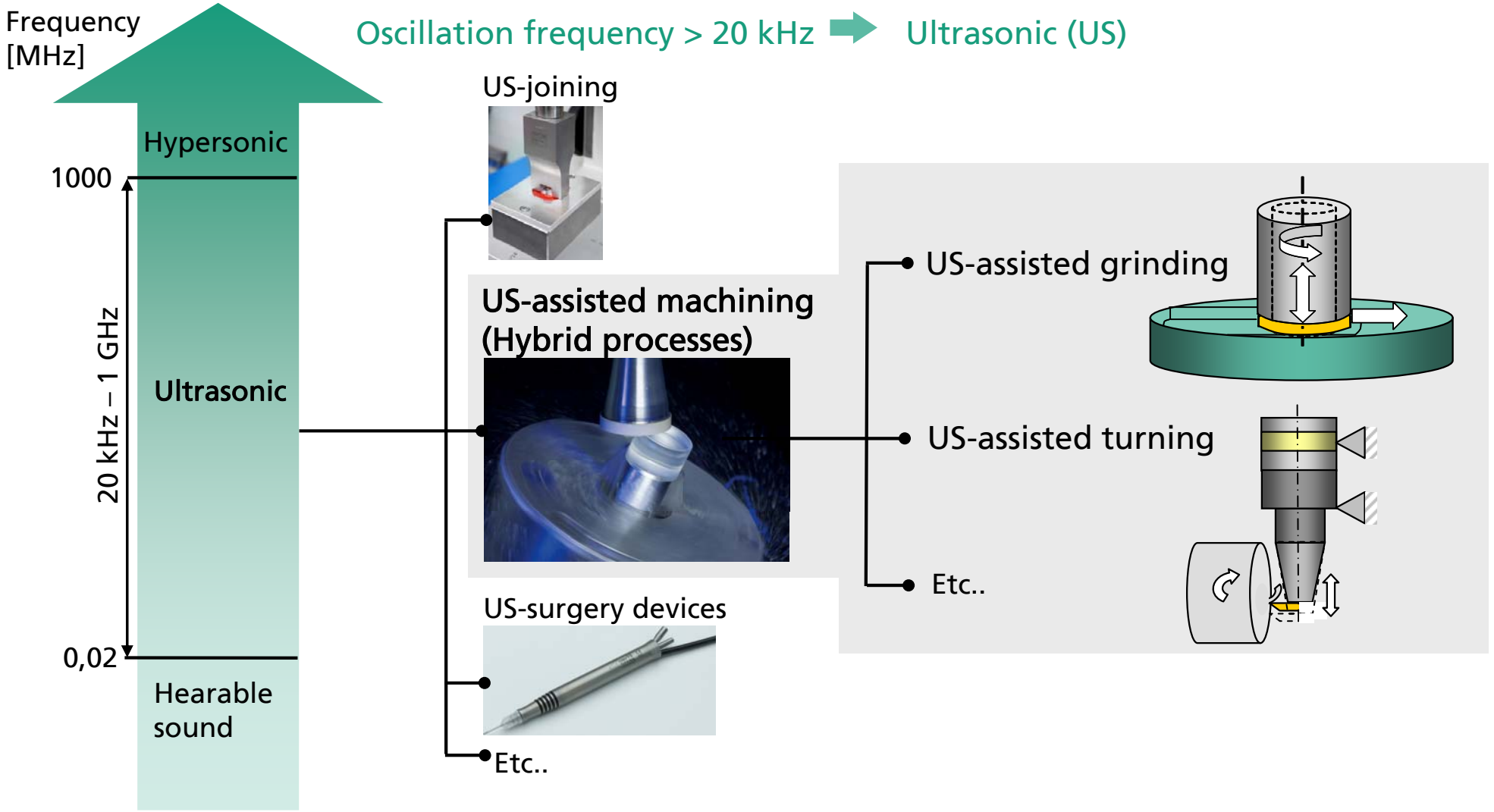
Oscillation assisted machining

Roto hammer

Electrical toothbrush

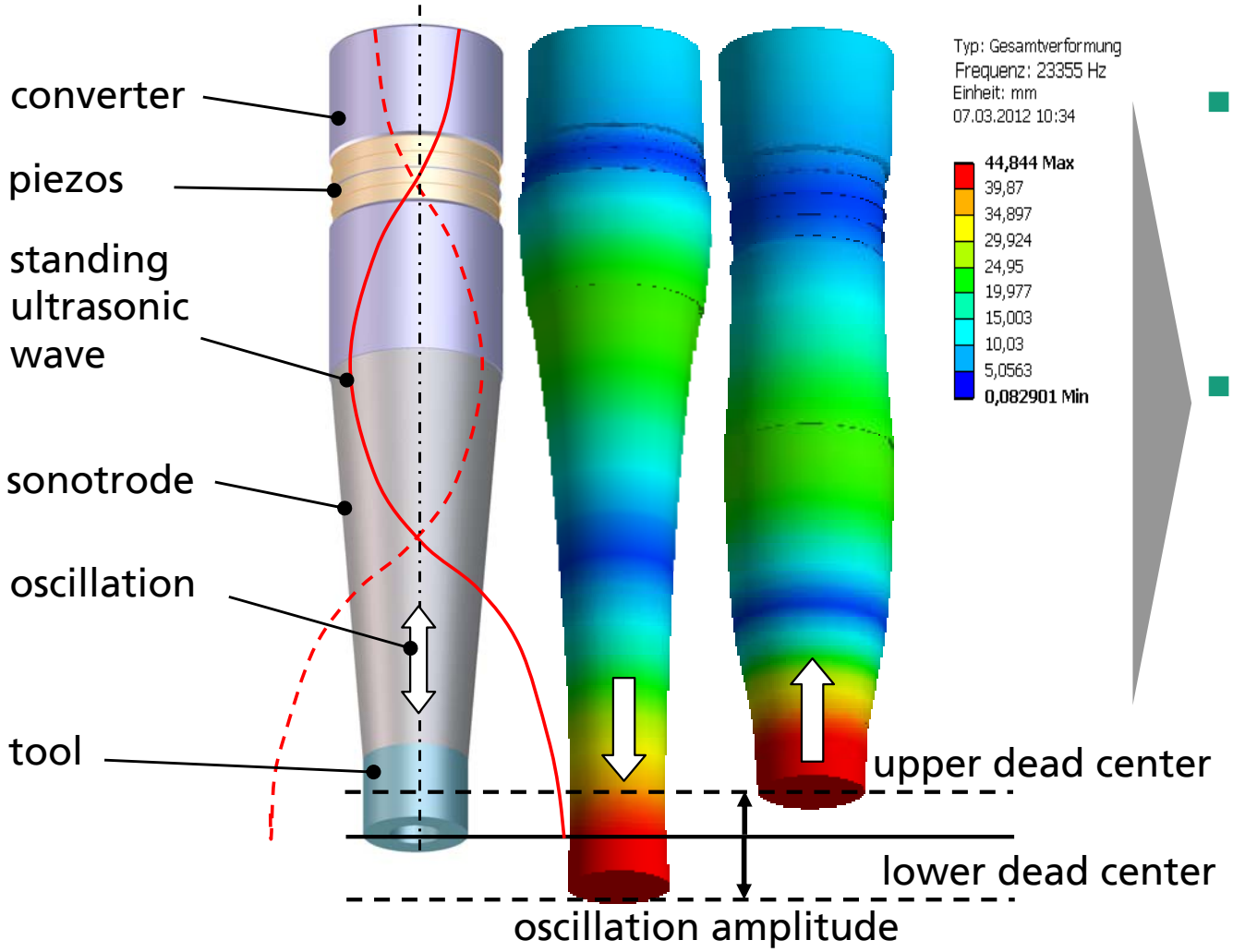
Introduction

Ultrasonic and Applications in Technology



Introduction

Common Ultrasonic Oscillation System



- Every component oscillates in the same resonance frequency in tension-compression-mode (Longitudinalmode)
- Standing compression-wave excites tool to pump-oscillation

Content

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3 Application – Ultrasonic Assisted Turning with Flexural Oscillator

4 Summary

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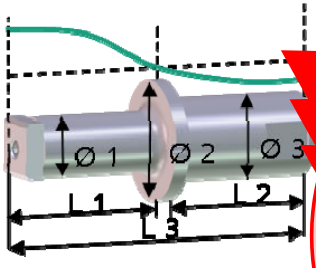
Automated Calculation and Optimization of Ultrasonic Oscillators

Conventional Manufacturing of Ultrasonic Oscillator

Machining

Measurement analysis



Rudimental dimensioning

- Analytic
- Experience
- FEM (much Iteration)

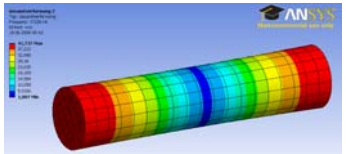
Time- and resource-consuming iteration

Trial-and-Error

Reworking

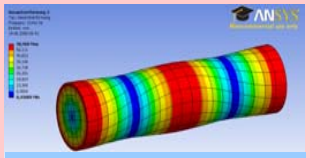
Rejects

Finished oscillator; only one oscillation mode (longitudinal)

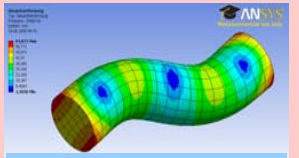


Longitudinal

Complex oscillation modes rarely calculated or applied!



Torsional



Flexural

Developer

2 weeks!

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Automated Calculation and Optimization of Ultrasonic Oscillators

Innovative Manufacturing of Ultrasonic-Component

Boundary conditions and requirements

Design program

MatLab

Optimization algorithms

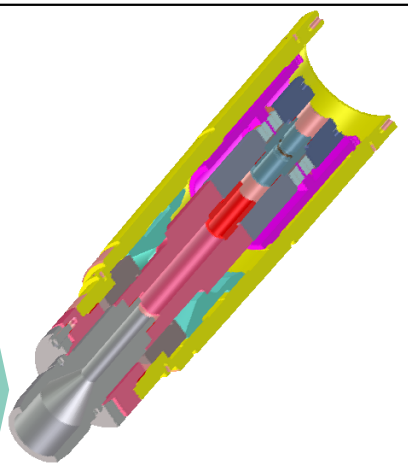
ANSYS

FEM

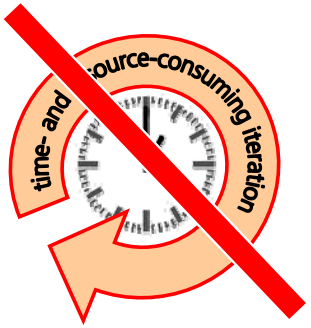
Automatic geometry optimization and evaluation

- Any oscillation modes
- Any geometry
- Multiple material/component systems

Measurement analysis



Finished ultrasonic system



Developer | Automated design | Developer

2 days!

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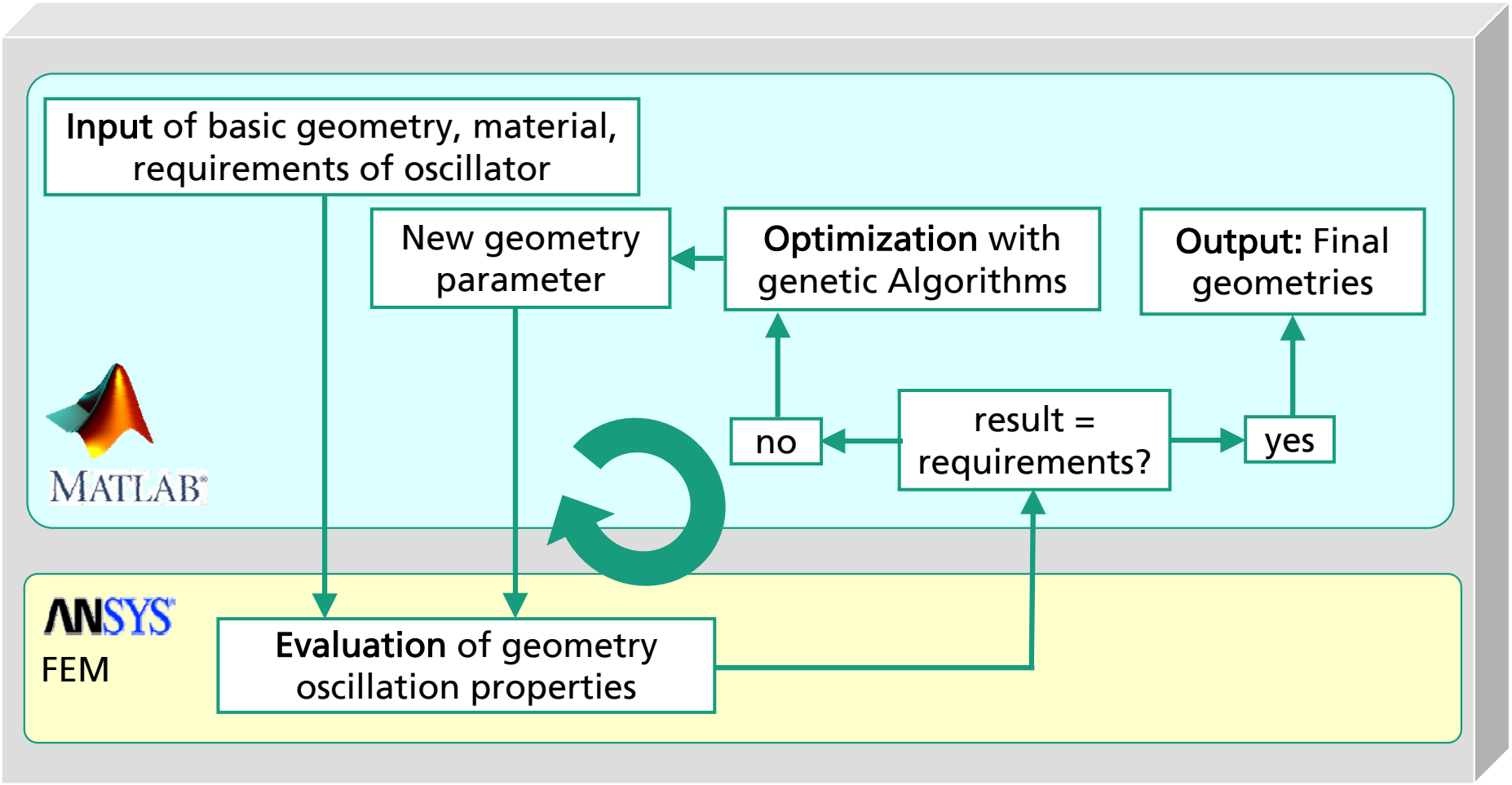
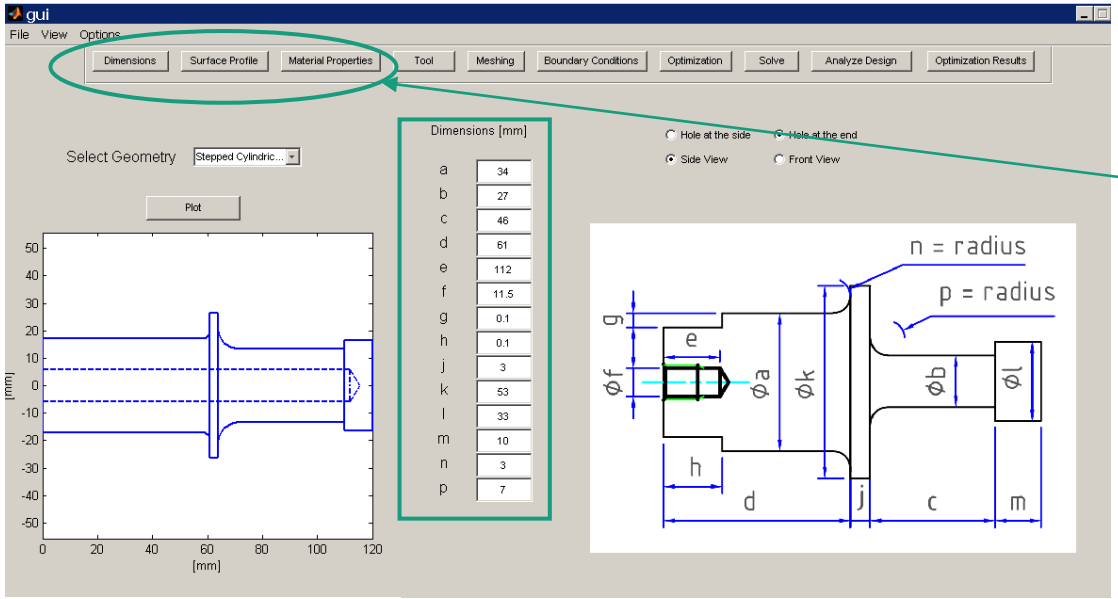
Automated Calculation and Optimization of Ultrasonic Oscillators

Main Structure of the Program

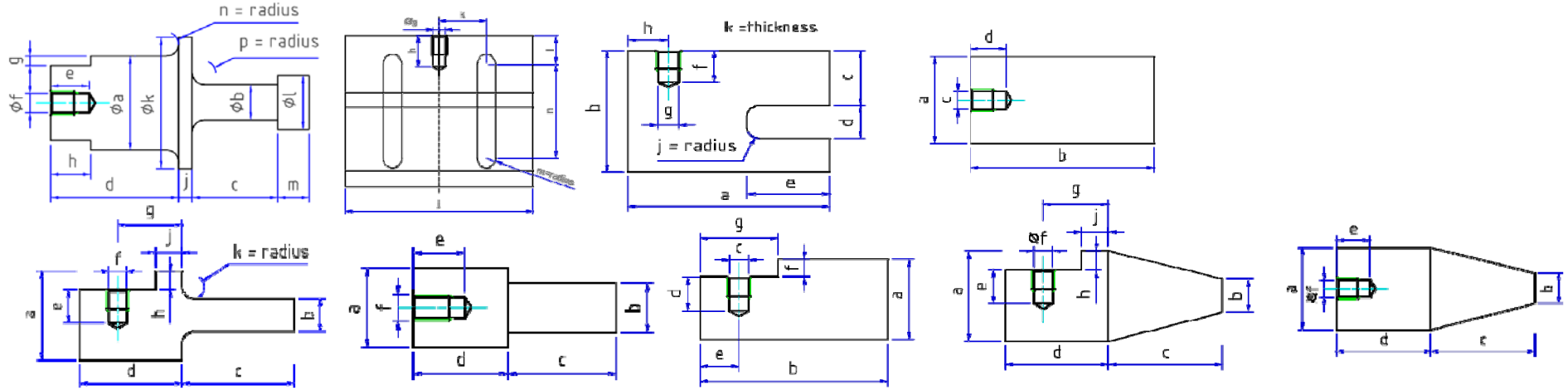


Automated Calculation and Optimization of Ultrasonic Oscillators

GUI: Definition of Start Geometry

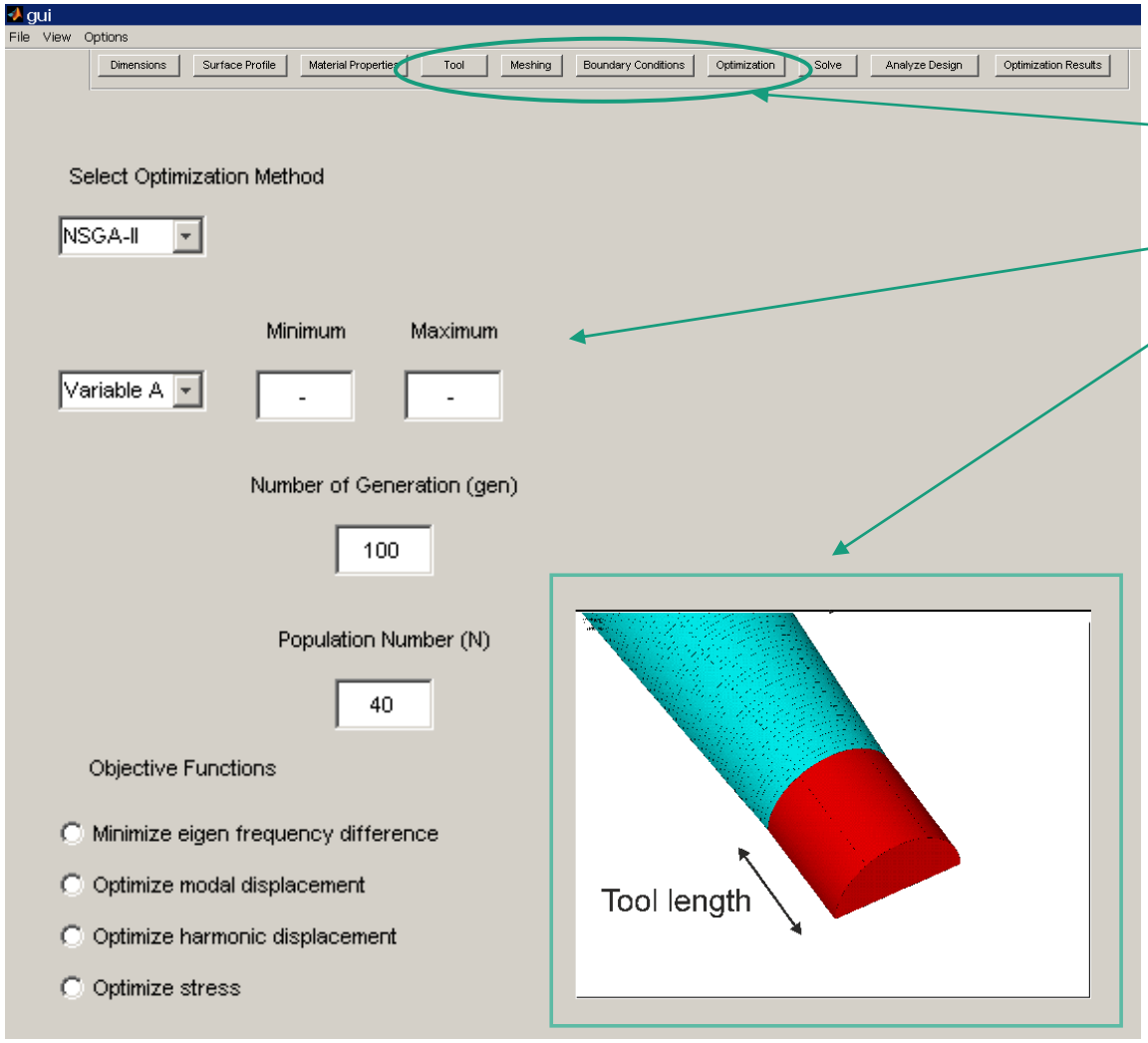


- Definition of oscillator start geometry and material
  - Dimensions
  - Surface profile
  - Material properties



Automated Calculation and Optimization of Ultrasonic Oscillators

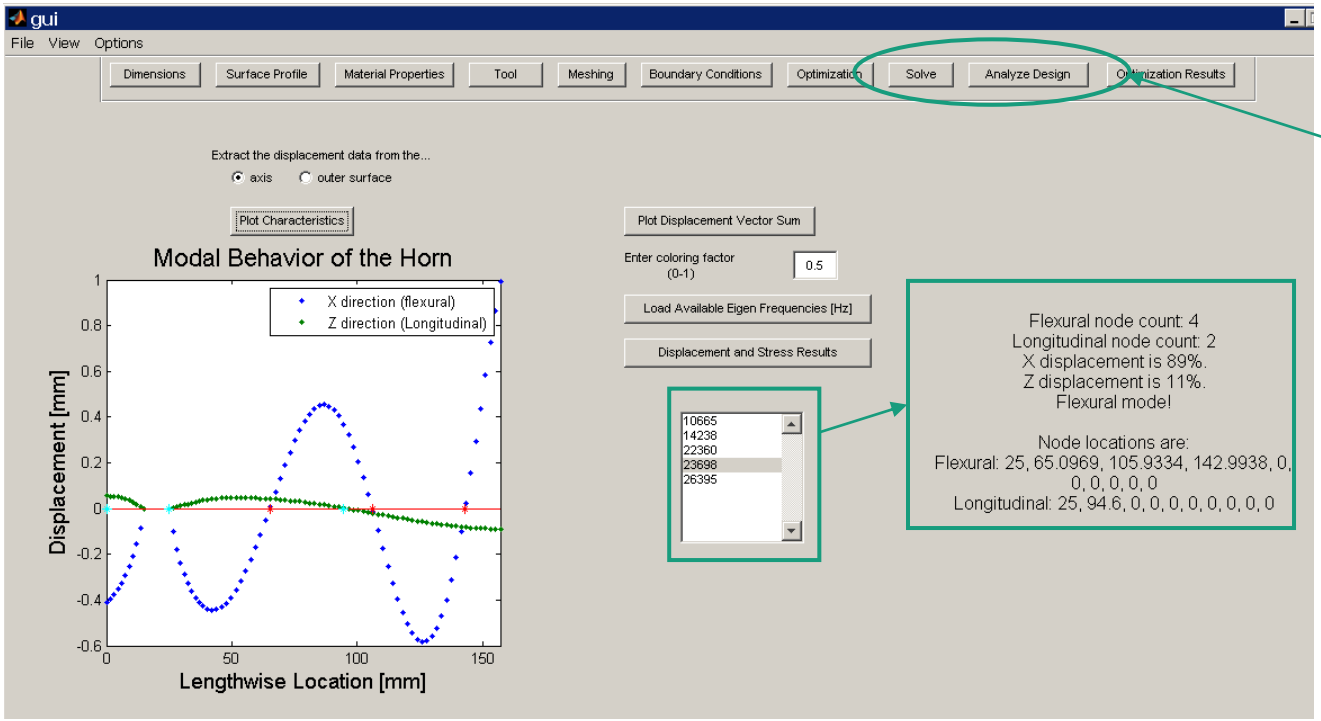
GUI: Boundary Conditions and Variables



- Definition of:
  - Boundary conditions
  - Meshing
  - Optimization parameters
  - Tool

Automated Calculation and Optimization of Ultrasonic Oscillators

GUI: Solution Display



- Solve
  - Definition of analysis (modal or harmonic)
  - Input frequency interval
- Result: Optimized geometry variables according to user requirements
  - Required frequency
  - Required oscillation mode
  - Node positions and quantity
  - Displacement, stress

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2 Automated Calculation and Optimization of Ultrasonic Oscillators

3 Application – Ultrasonic Assisted Turning with Flexural Oscillator

4 Summary

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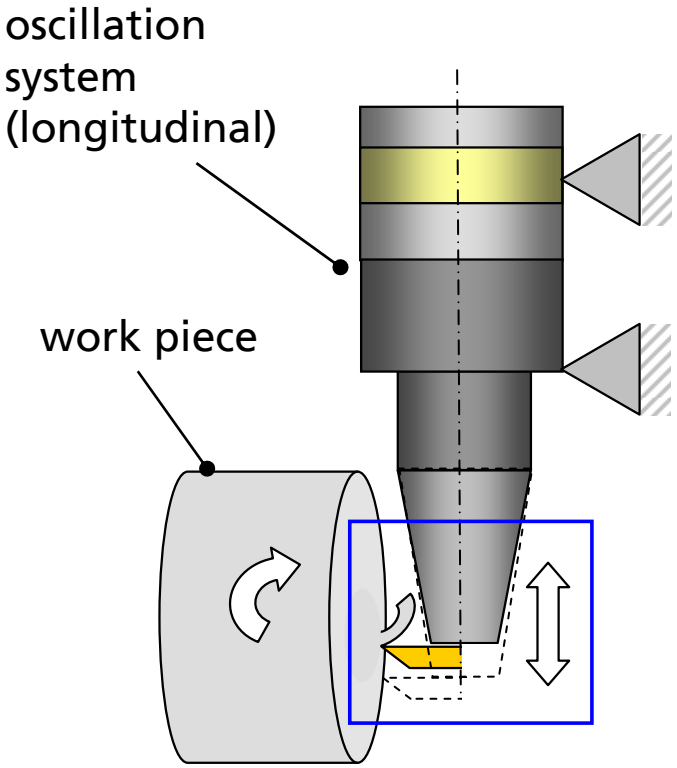
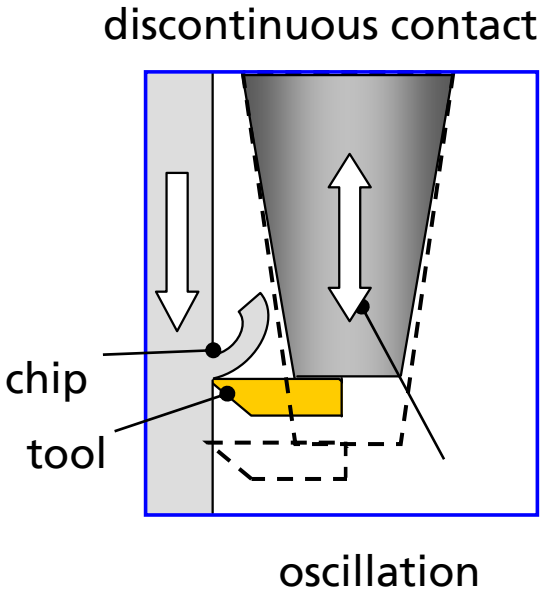
Application – Ultrasonic Assisted Turning with Flexural Oscillator

Ultrasonic Assisted Turning





- Kinematics + axial ultrasonic oscillation of tool
- High frequently interrupt of cut
- ➢ Reduces process forces!
- ➢ Interrupts wear process!
- ➢ Increase of tool life!
- ➢ Steel with diamond tools machinable!

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Application – Ultrasonic Assisted Turning with Flexural Oscillator

Ultrasonic Assisted Turning

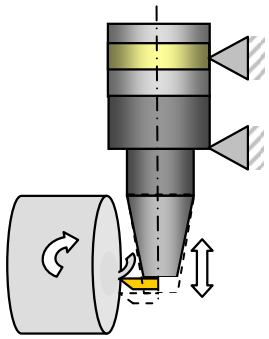
Conventional production of free formed optics	US-assisted production of free formed optics

mold making and coating

molding

evaluation

US-assisted mold making ~~and coating~~



molding

evaluation

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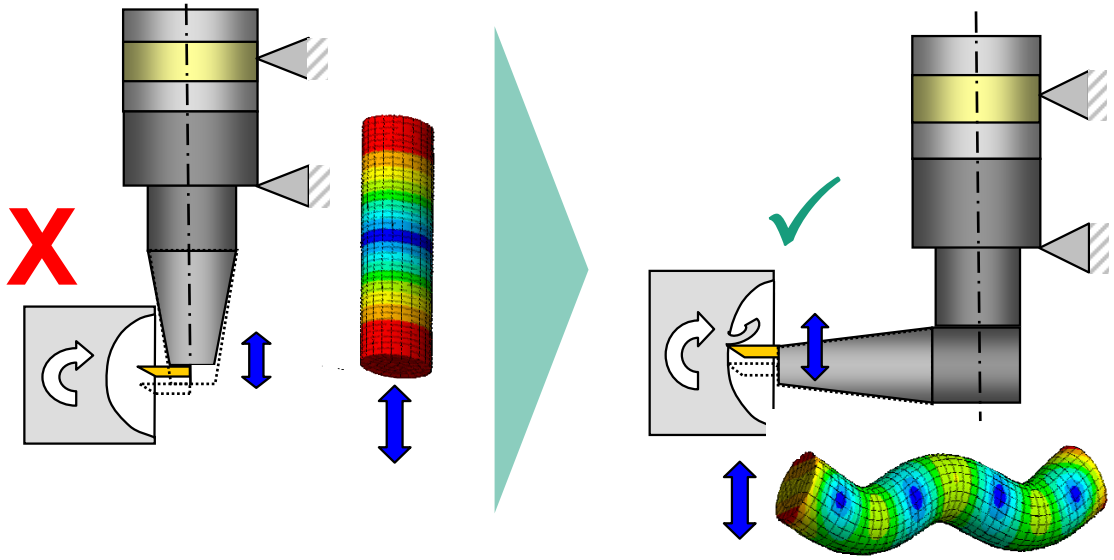
Application – Ultrasonic Assisted Turning with Flexural Oscillator

Ultrasonic Assisted Turning with *Flexural* Ultrasonic Oscillators

Longitudinal Oscillator

Flexural Oscillator



- Why flexural?
  - Oscillation direction
  - Accessibility
  - Installation space

- Machining of complex hardened steel molds with diamond tools!
- Direct machining of free form glass-optics with diamond tools!

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Application – Ultrasonic Assisted Turning with Flexural Oscillator

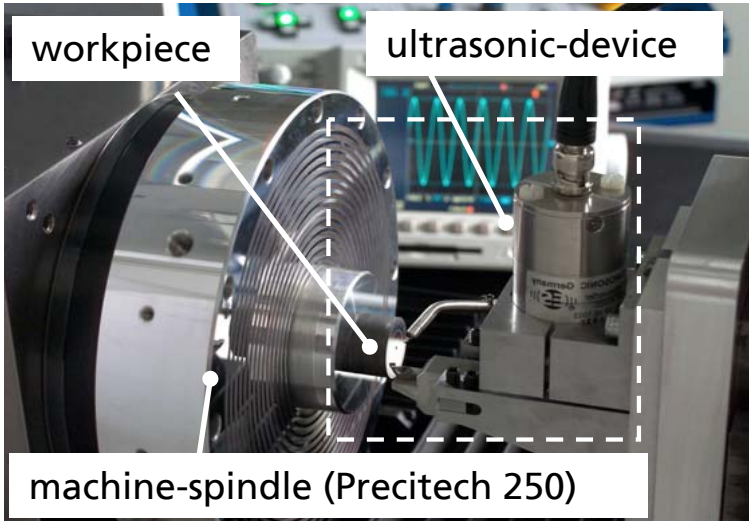
Ultrasonic Assisted Turning with Flexural System

Oscillator shape calculated with:

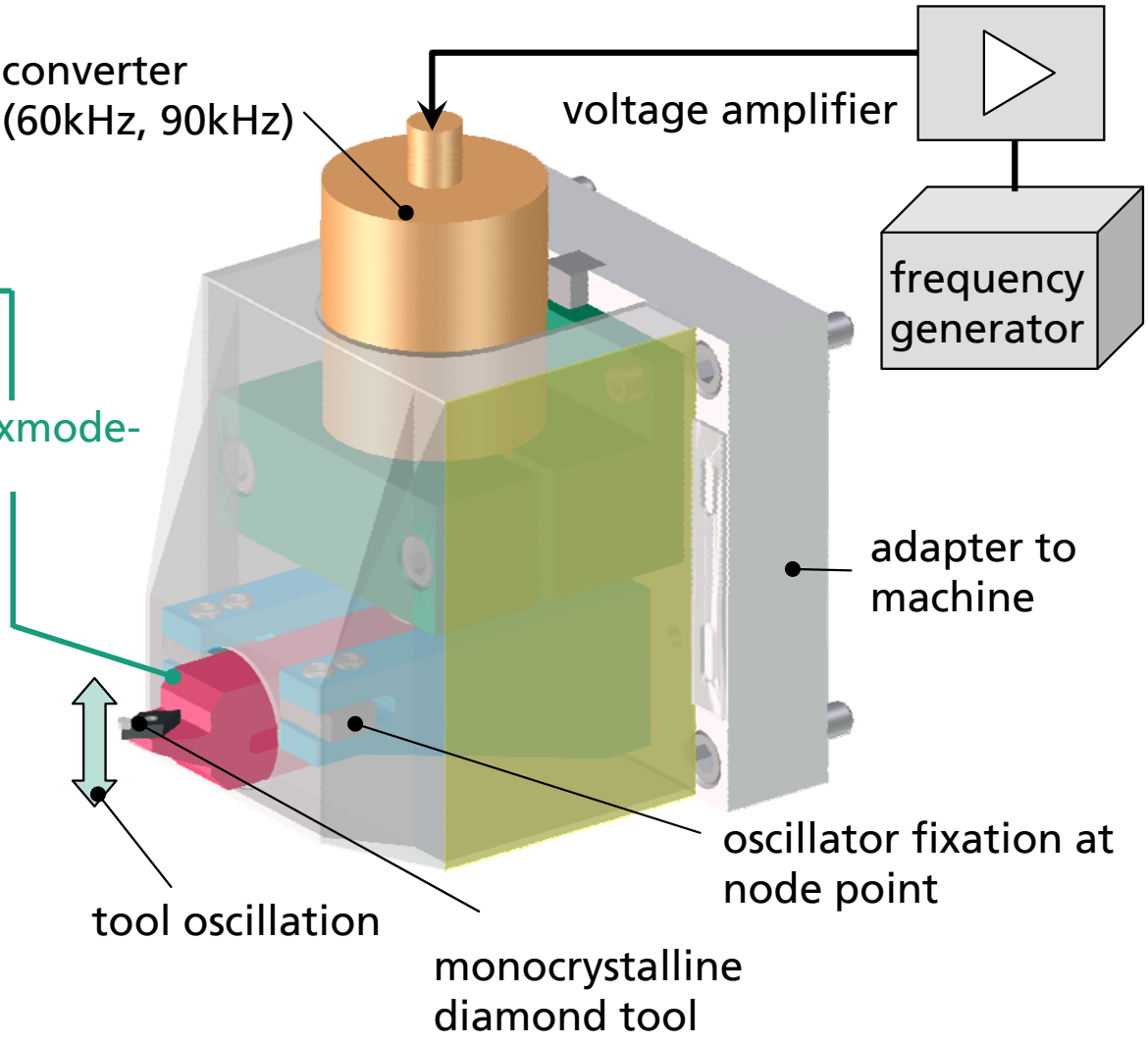
Design program

Optimization algorithms

ANSYS



flexural-mixmode-oscillator



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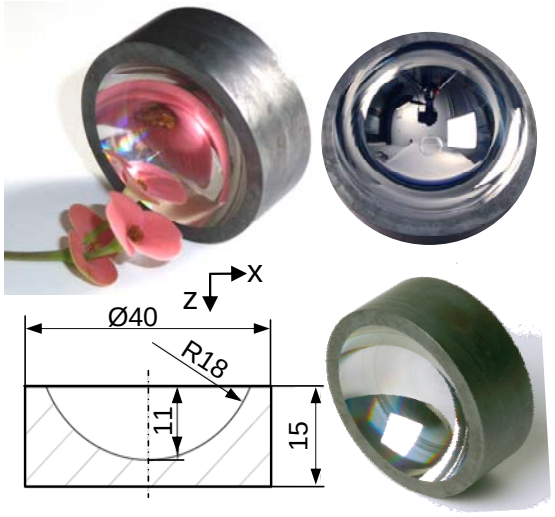
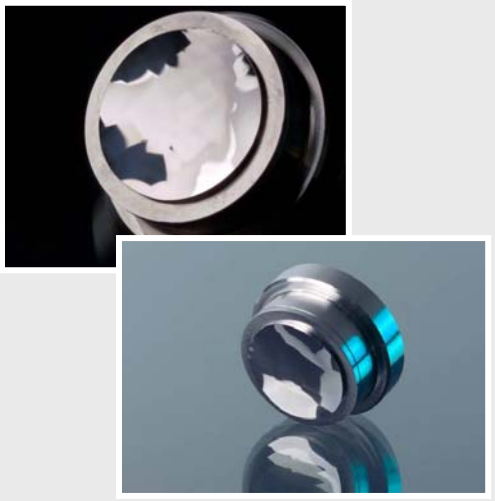
Application – Ultrasonic Assisted Turning with Flexural Oscillator

Machining Tests – Examples



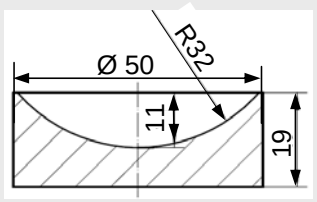
Deep concave mold (steel)

- Hardness: HRC 53
- Infeed: 5 (Z), 2 (X) µm
- Rotation: 30 U/min
- Feed rate: 3 µm/U
- Amplitude: 2 µm
- Frequency: 60,4 kHz
- Tool: MKD
- **Ra: 4,25 nm**



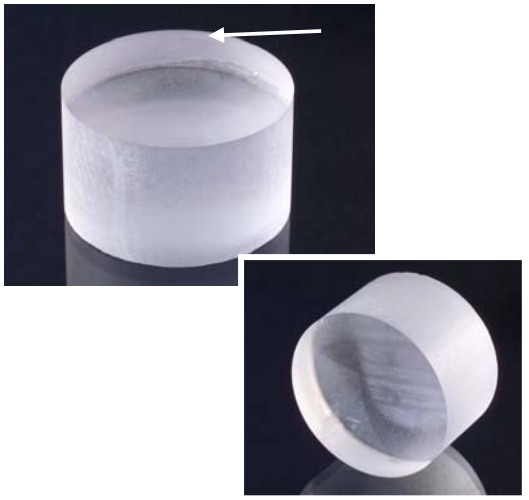
Free form mold (steel)

- Hardness: HRC 20
- Infeed: variabel
- Rotation: 20 U/min
- Feed rate: variabel
- Amplitude: 2 µm
- Frequency: 60,4 kHz
- Tool: MKD
- **Ra: 13,3 nm**



Deep concave mold (steel)

- Hardness: HRC 53
- Infeed: 6 µm
- Rotation: 50 U/min
- Feed rate: 2 µm/U
- Amplitude: 2 µm
- Frequency: 60,4 kHz
- Tool: MKD
- **Ra: 18,2 nm**



Glass

- Glass-type: NBK7
- Diameter: 40 mm
- Infeed: 5 µm
- Rotation: 25 U/min
- Feed rate: 3 µm/U
- Amplitude: 2 µm
- Frequency: 60,38 kHz
- **Ra: 2-3 nm**

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Content

1 Introduction

2 Automated Calculation and Optimization of Ultrasonic Oscillators

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4 Summary

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Summary

- Summary
  - Development of calculation method for automated design and optimization of ultrasonic oscillators
  - Innovative ultrasonic system with flexural oscillator for ultrasonic assisted turning of complex work piece shapes with diamond tools

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