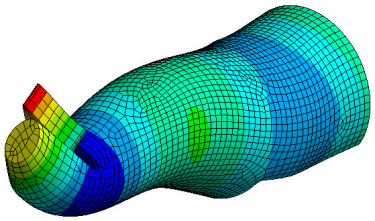

# Flexural Oscillators for the Vibration Assisted Machining

Prof. Dr.-Ing. C. Brecher

Dipl.-Ing. S. Hannig

UPT-Meeting, March 31th 2011, Aachen



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## Content



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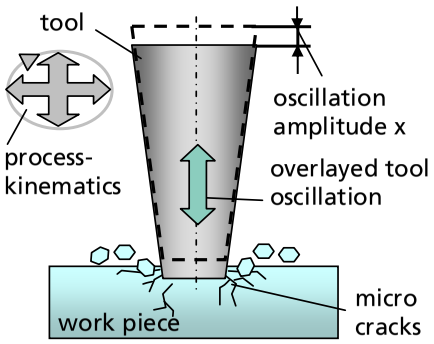
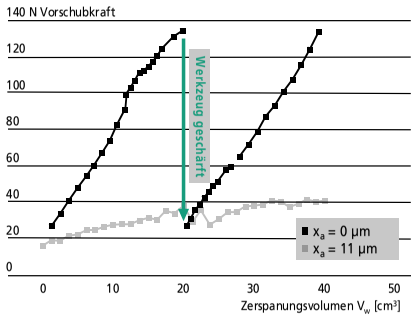
# Introduction
## Effects of Active Vibration Assistance in Machining Processes

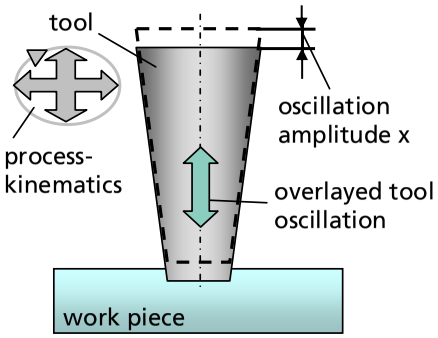
### Unregulated, resonance vibration

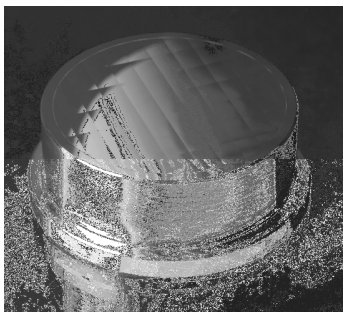



- Frequencies > 20 kHz, Ultrasonic
- Increase of material removal rate due to micro cracks in work piece surface of hard and brittle materials
- Reduction of process forces and tool wear due to discontinuous contact in process zone
- Reduction of thermal loads
- Machining of steel with diamond tools due to reduction of diffusion

### Position-controlled oscillation



- Defined infeed
- Frequencies f.e. 60 Hz -1,3 kHz (Hybrid-Slow-Fast-Tool)
- Defined free-form structures in optical surfaces due to controlled infeed
- Exact tool alignment and adjustment of surface unevennesses



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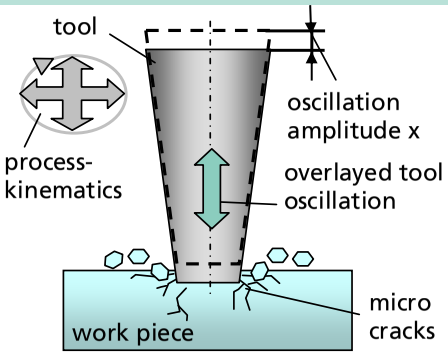
# Introduction
## Vibration Assisted Technologies: Ultrasonic Application

### Unregulated, resonance vibration







Active US-application with Longitudinal-systems



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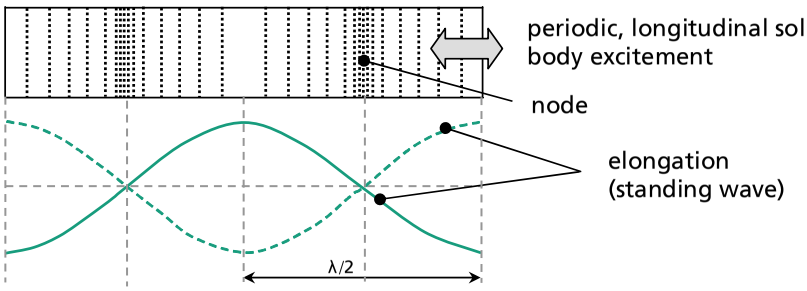
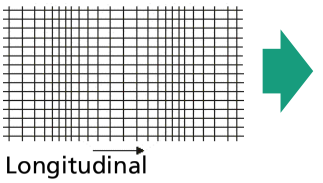
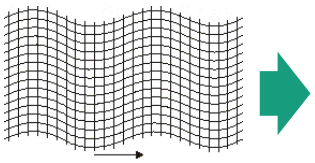
# Vibration Assisted Technologies: Ultrasonic Application

Sonic wave propagation in solid body / standing wave

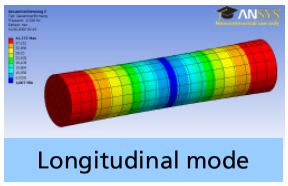


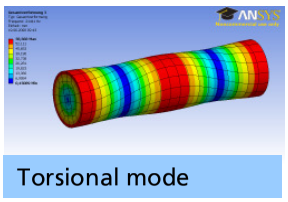

Wave propagation

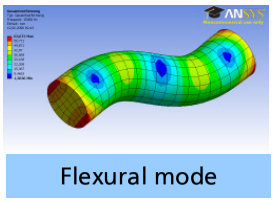


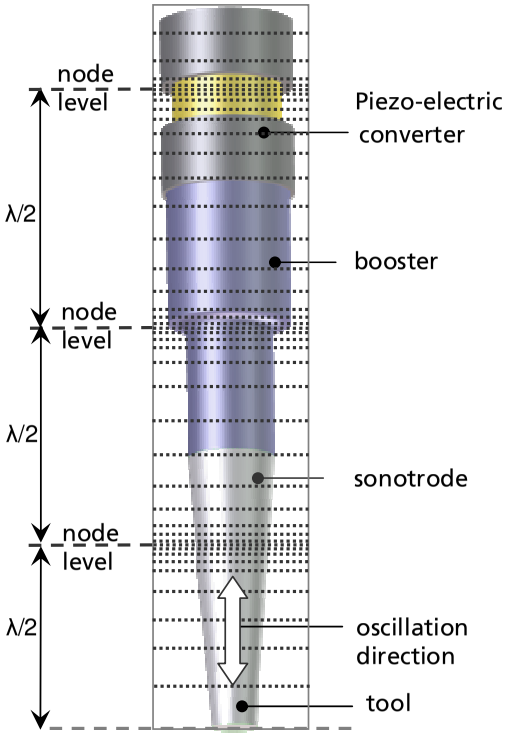

Solid body oscillation mode in resonance




Active Longitudinal-US-System



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## Content





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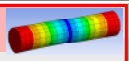
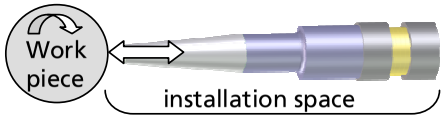
# Flexural Oscillators for Vibration Assisted Application
## Longitudinal Limitations and Flexural Potentials

**Longitudinal**

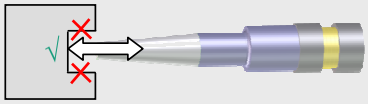


Only 1 oscillation direction!

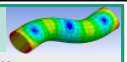
Oscillation direction determines installation space!




Limited accessibility for machining of complex geometries!

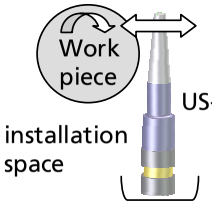


**Transversal**



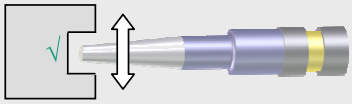
Multiple oscillation directions possible (elliptical)

➔ new structures
➔ new cutting conditions




Tool and system installation space can be reduced

Optimised accessibility ➔ machining of complex geometries possible



US-assisted machining

US-surgery devices

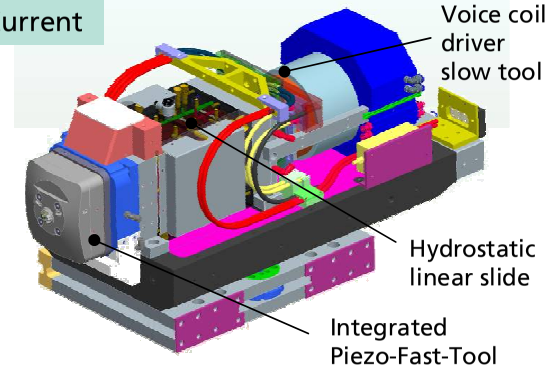
- Few know-how about design and application in transversal

➢ Development necessary!

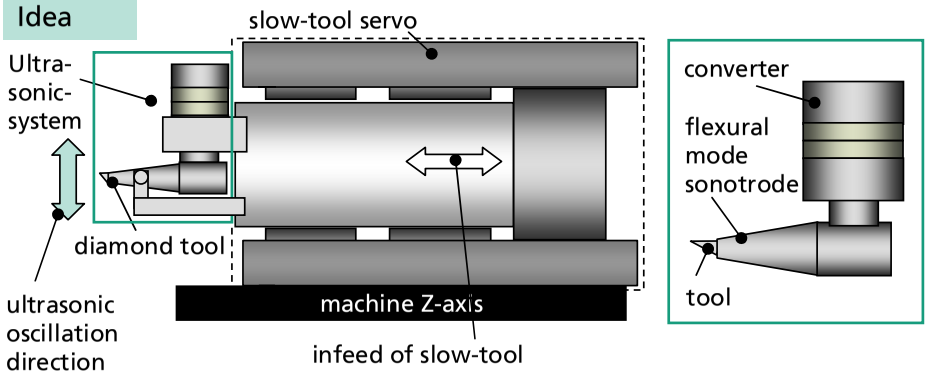


# Flexural Oscillators for Vibration Assisted Application
## Ultrasonic Assisted Turning with Ultrasonic Oscillators: Idea

Current




Idea




**Hybrid Slow-Fast-Tool for diamond turning**

- Hydrostatic Slow-Tool-Axes (Stroke 25 mm, Bandwidth 60 Hz position controlled) with integrated Piezo-Fast-Tool (Stroke 30 µm, Bandwidth 1300 Hz position controlled)

➢ Manufacturing of free-form optics with microstructures

**Current restrictions of Slow-Tool**

- Manufacture of freeform-surfaces in steel with diamond tools not possible
- Range of materials to be machined is limited (no steel, no ceramics)
- High tool wear

**Potential of integrated US-system**

- Development of Slow-tool with ultrasonic-system adapter

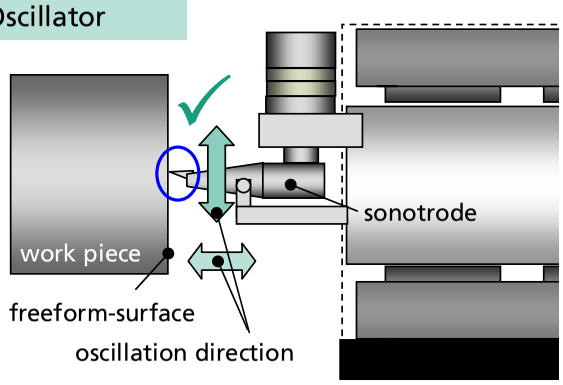
➢ Generation of free-form-surfaces in new ultra precise materials

➢ Reduction of tool wear

# Flexural Oscillators for Vibration Assisted Application

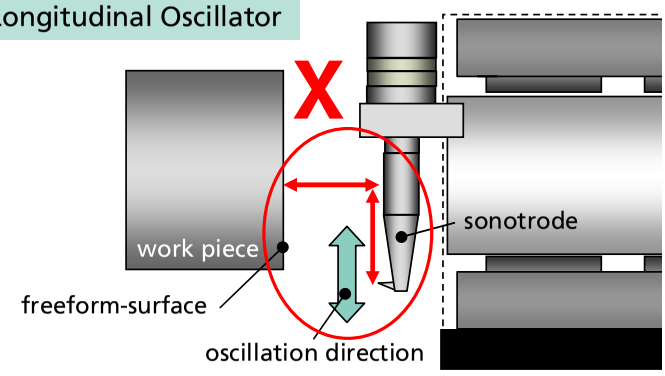
## Ultrasonic Assisted Turning with *Flexural* Ultrasonic Oscillators

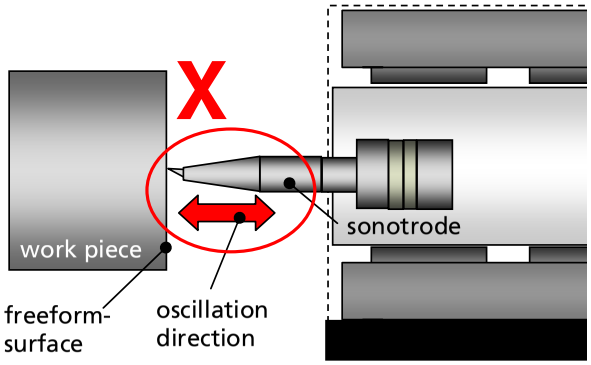
### Flexural Oscillator




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

### Longitudinal Oscillator

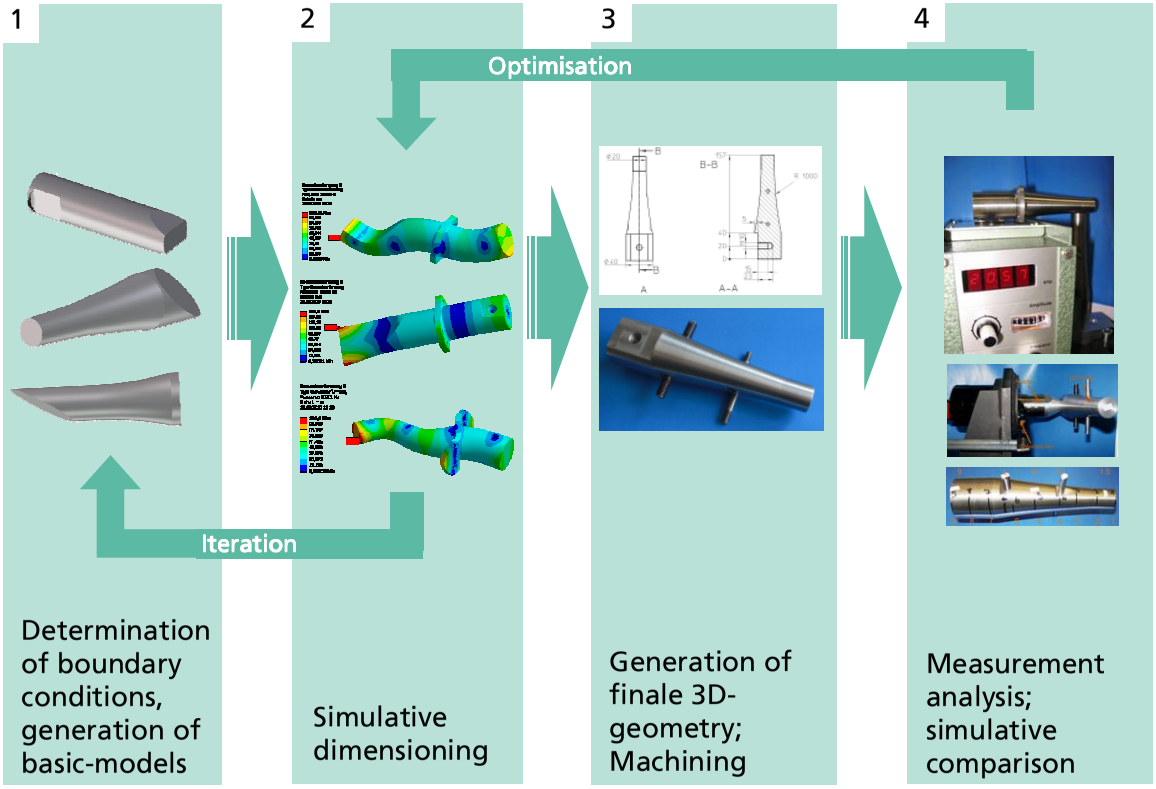





# Flexural Oscillators for Vibration Assisted Application

## Design Procedure in Principle

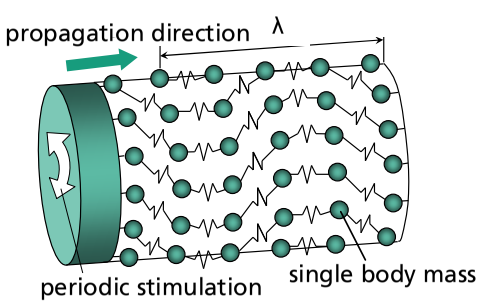


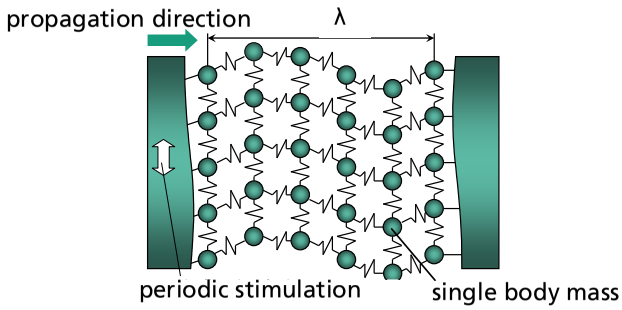
# Flexural Oscillators for Vibration Assisted Application
## Basic Modelling: Torsional and Flexural

1

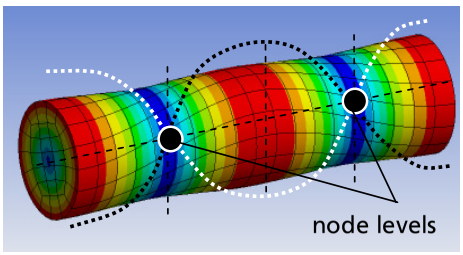
Determination of boundary conditions, generation of basic-models

Propagation of a transversal wave in a solid body

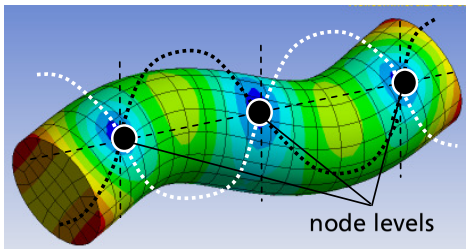



Transversal standing wave in resonance




Torsional mode (rod)




Flexural mode (rod)



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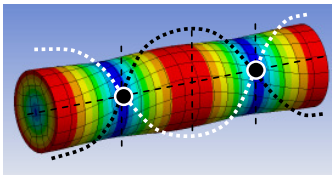
# Flexural Oscillators for Vibration Assisted Application
## Basic Modelling: Torsional Design versus Flexural Design

1

Determination of boundary conditions, generation of basic-models



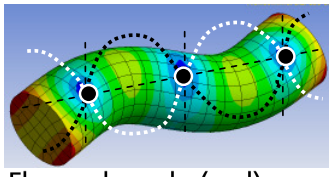
Torsional mode (rod)

Torsional wave is pure transversal wave (rods)

$$C_{T,Tors.} = \sqrt{\frac{E}{2\rho_0(1+\mu)}}$$

$$\lambda_{T,Tors.} = \frac{c_{T,Tors.}}{f}$$

- E (Young`s Modulus); $\rho_0$ (Density); μ (Poisson ratio)
- ➢ Sound speed $c_{Tors.}$ is material constant
- ➢ Wave length $\lambda_{T,Tors.}$ is depends on sound speed and frequency f



Flexural mode (rod)

Flexural wave in **rods**: Sound speed depends on frequency and diameter

$$C_{T,Flex}(f;r) = \sqrt{\pi \cdot f \cdot r} \cdot \sqrt[4]{\frac{E}{\rho_0}}$$

$$\lambda_{T,Flex.} = \frac{c_{T,Flex.}(f;r)}{f}$$

➢ Wave length $\lambda_{T,Tors}$ depends on frequency f and diameter 2r

➢ **Wave lengths in flexural waves in *rods* do not equates to wave length of pure transversal wave!**

Quelle: R. Millner - Ultraschalltechnik, H. Kuttruff - Physik und Technik des Ultraschalls



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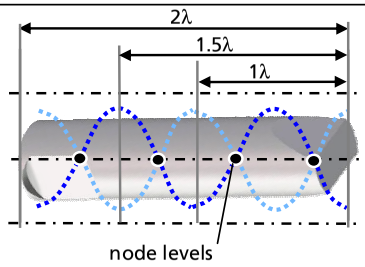
# Flexural Oscillators for Vibration Assisted Application
## Basic Modelling: Flexural Design

1

Determination of boundary conditions, generation of basic-models




flexural wave
reflect. flexural wave
} standing wave

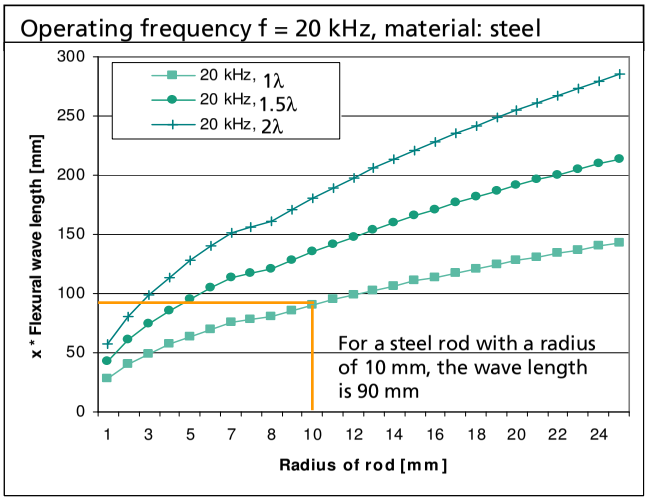
$$\lambda_{T,Flex.} = \frac{c_{T,Flex.}(f;r)}{f}$$

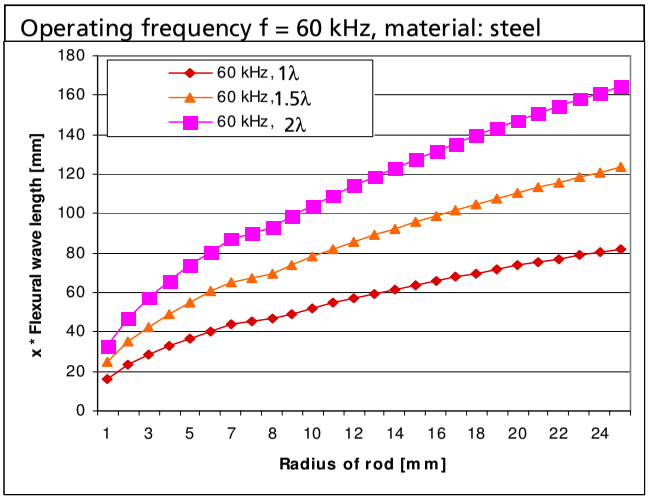
**Basic-modelling of rod in flexural mode**

1. Definition of operating frequency
2. Definition of material
3. Definition of node number (bearings)
4. Definition of installation space

➢ Determination of rod-radius and -length

➢ Itemisation of sonotrode from basic rod



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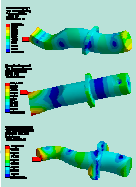
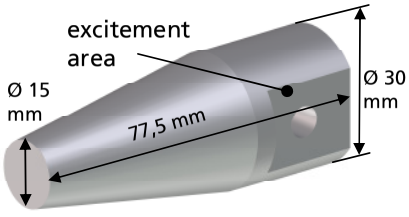
# Flexural Oscillators for Vibration Assisted Turning
## Dimensioning of *Sample* Oscillators, Modal Analysis

2

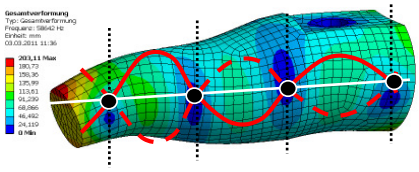


Simulative dimensioning

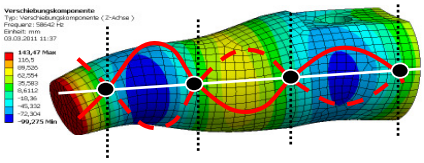
Model 1: Linear (Steel, No. 1.2083)




Total deformation

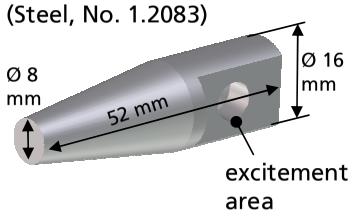


Y-deformation

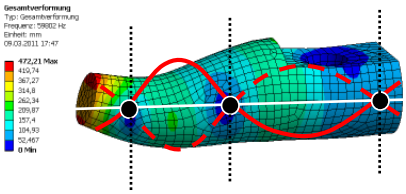


➔ Flexural resonance frequency 58,642 kHz; 4 nodes

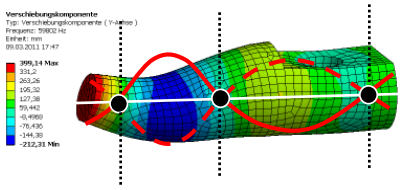
Model 2: Linear_small (Steel, No. 1.2083)




Total deformation

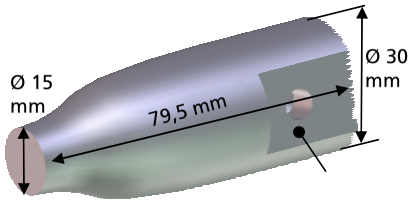


Y-deformation

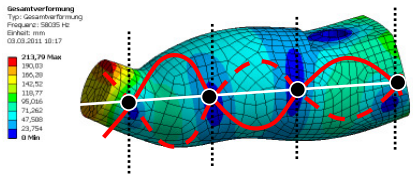


➔ Flexural resonance frequency 59,802 kHz; 3 nodes

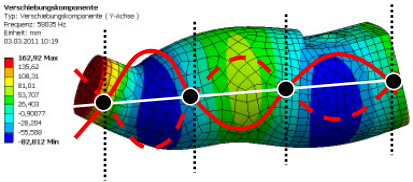
Model 3: Bezier (Steel, No. 1.2083)




Total deformation



Y-deformation



➔ Flexural resonance frequency 58,035 kHz; 4 nodes



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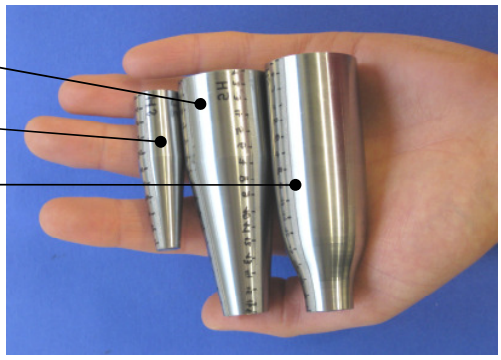
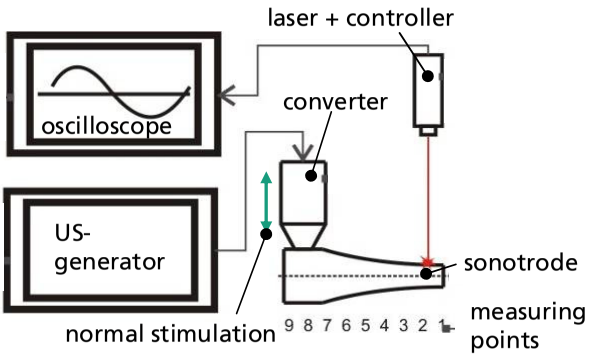
# Flexural Oscillators for Vibration Assisted Turning
## Experimental Mode Validation of *Sample* Oscillators

4

Measurement analysis; simulative comparison








### Test bench for oscillation mode validation

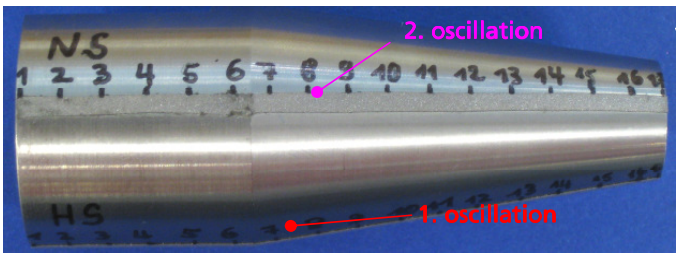
- Ultrasonic-converter
  - Eurosonic ESKP400/60
  - US-Generator ESGS 400/60
  - Frequency: 57-60 kHz
  - Oscillation amplitude: 0,5-1,5 µm (50 -100 %)
  - ➢ For tests: 50%
- Laservibrometer
- Oscilloscope
- 3 sample sonotrode models
  - Linear
  - Linear_small
  - Bezier

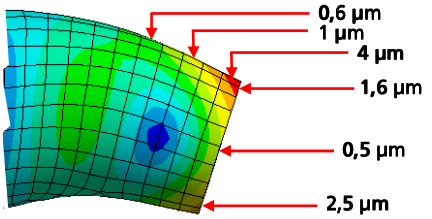


# Flexural Oscillators for Vibration Assisted Turning
## Experimental Mode Validation: *Sample Model 1* Sono_linear

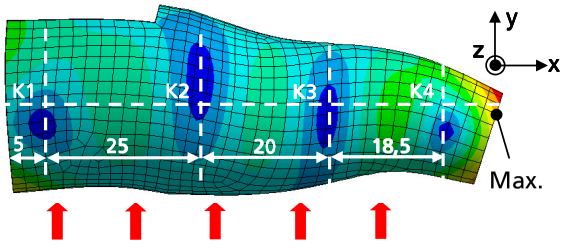
4

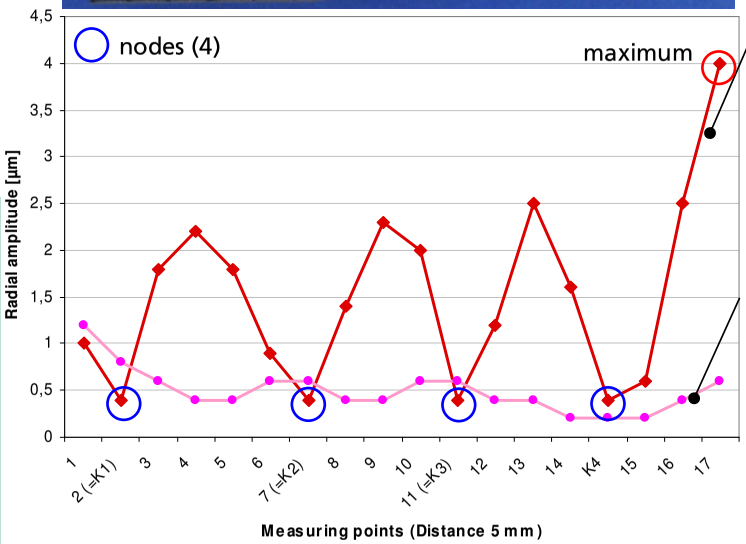
Measurement analysis; simulative comparison



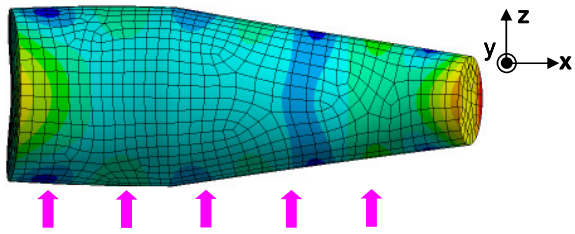




Radial measurement of 1. oscillation direction




Radial measurement of 2. oscillation direction

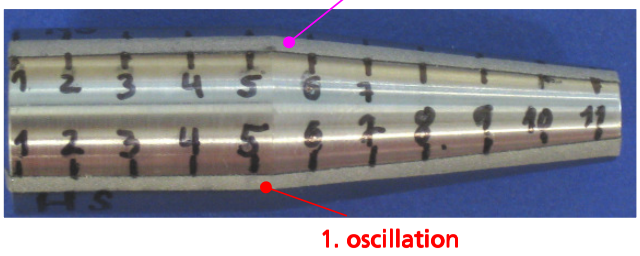


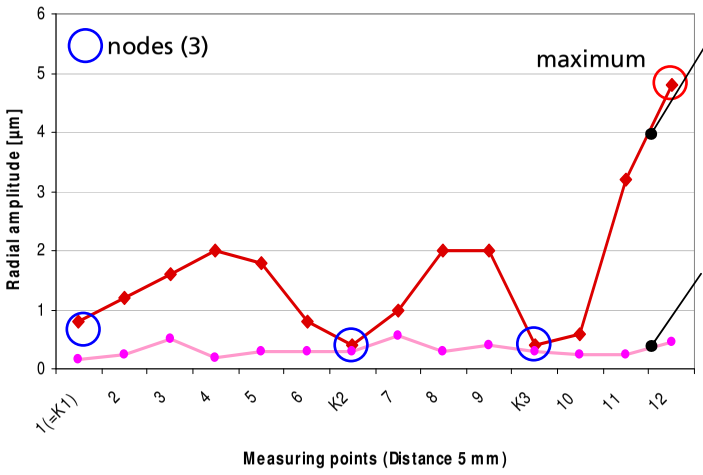
# Flexural Oscillators for Vibration Assisted Turning

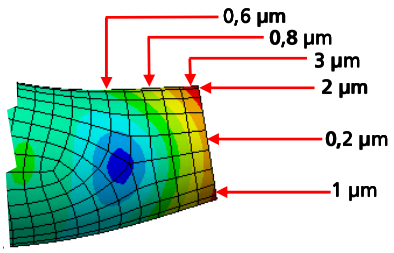
## Experimental Mode Validation: *Sample Model 2* Sono_linear_small

4

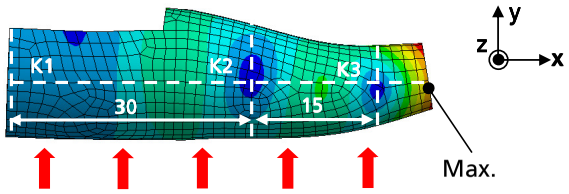
Measurement analysis; simulative comparison



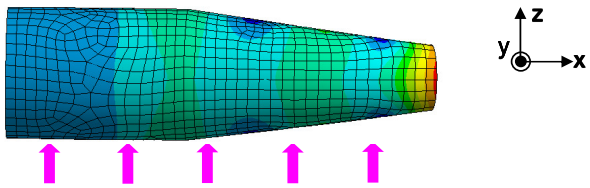




Radial measurement of 1. oscillation direction




Radial measurement of 2. oscillation direction





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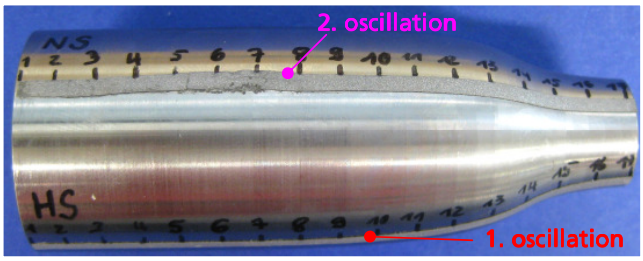
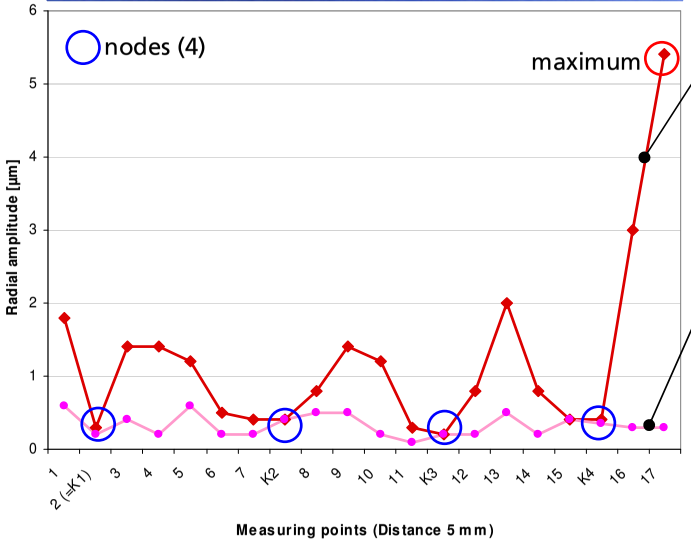
# Flexural Oscillators for Vibration Assisted Turning

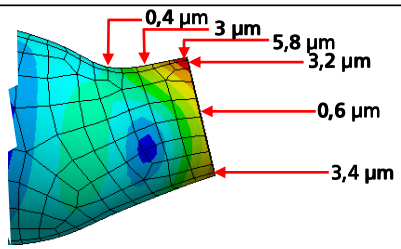
## Experimental Mode Validation: *Sample Model 3* Sono_bezier

4

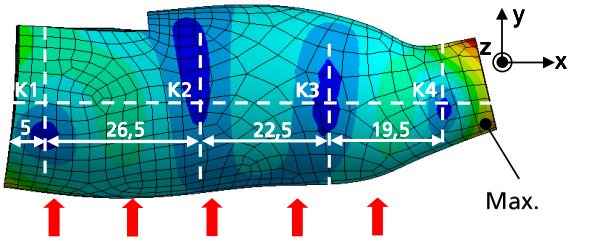
Measurement analysis; simulative comparison



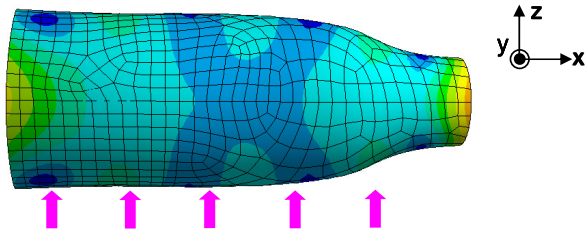




Radial measurement of 1. oscillation direction




Radial measurement of 2. oscillation direction





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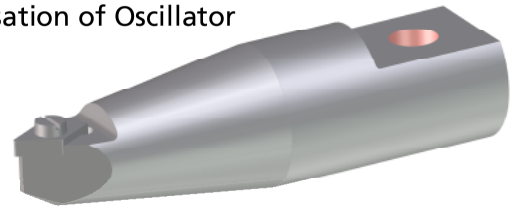
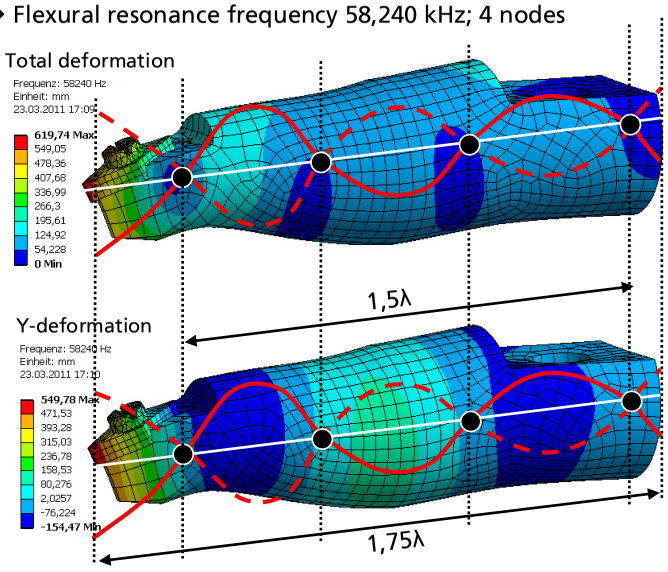
## Optimisation of Oscillator-Geometry and Integration into Machine System

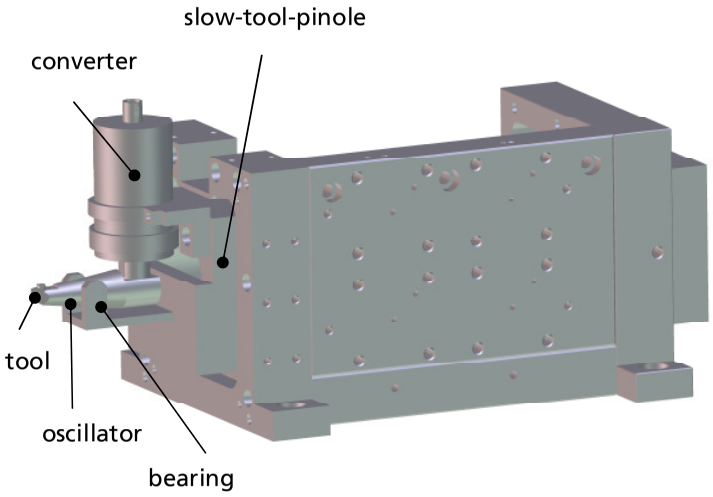
Optimisation of Oscillator



➔ Flexural resonance frequency 58,240 kHz; 4 nodes




Possible integration into machine system



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## Content





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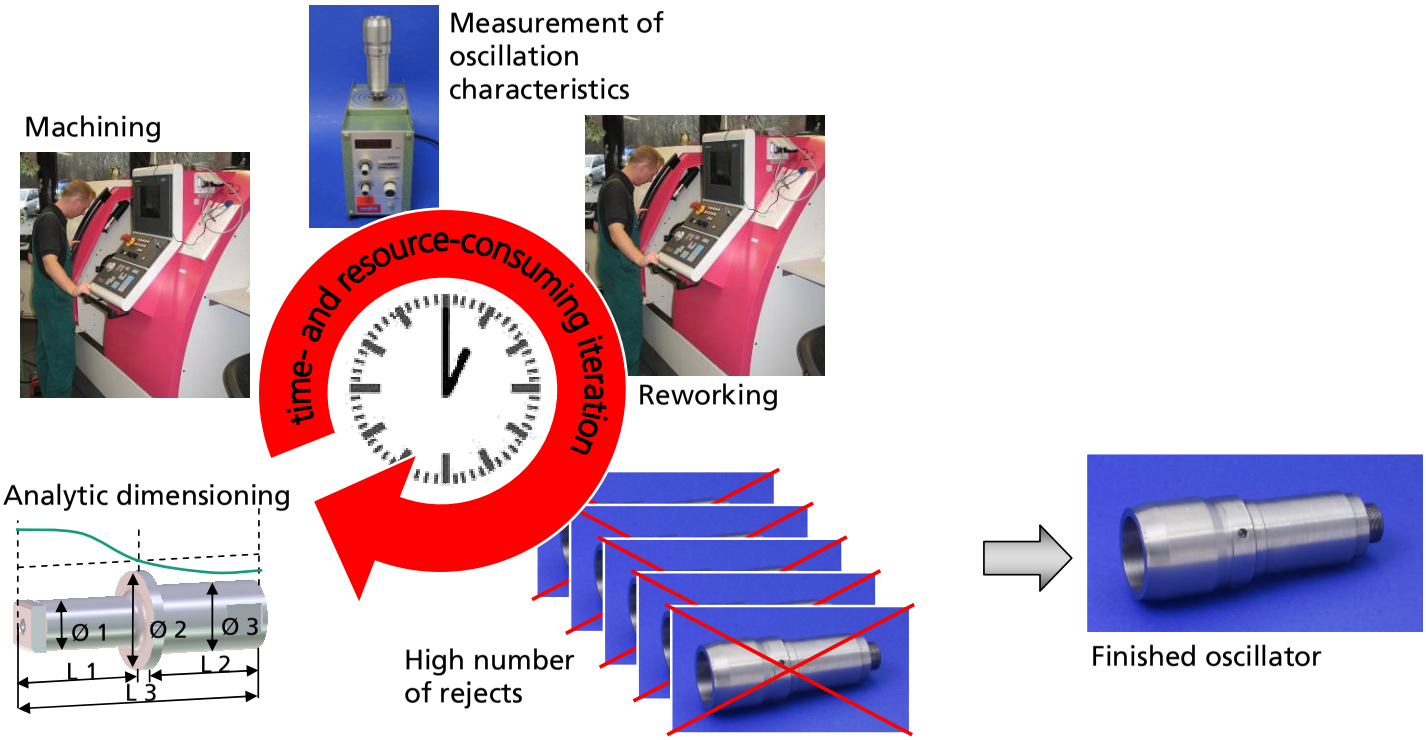
# AiF-Project: Automated Design of Ultrasonic Oscillators
## Conventional Manufacturing Process for Ultrasonic Components



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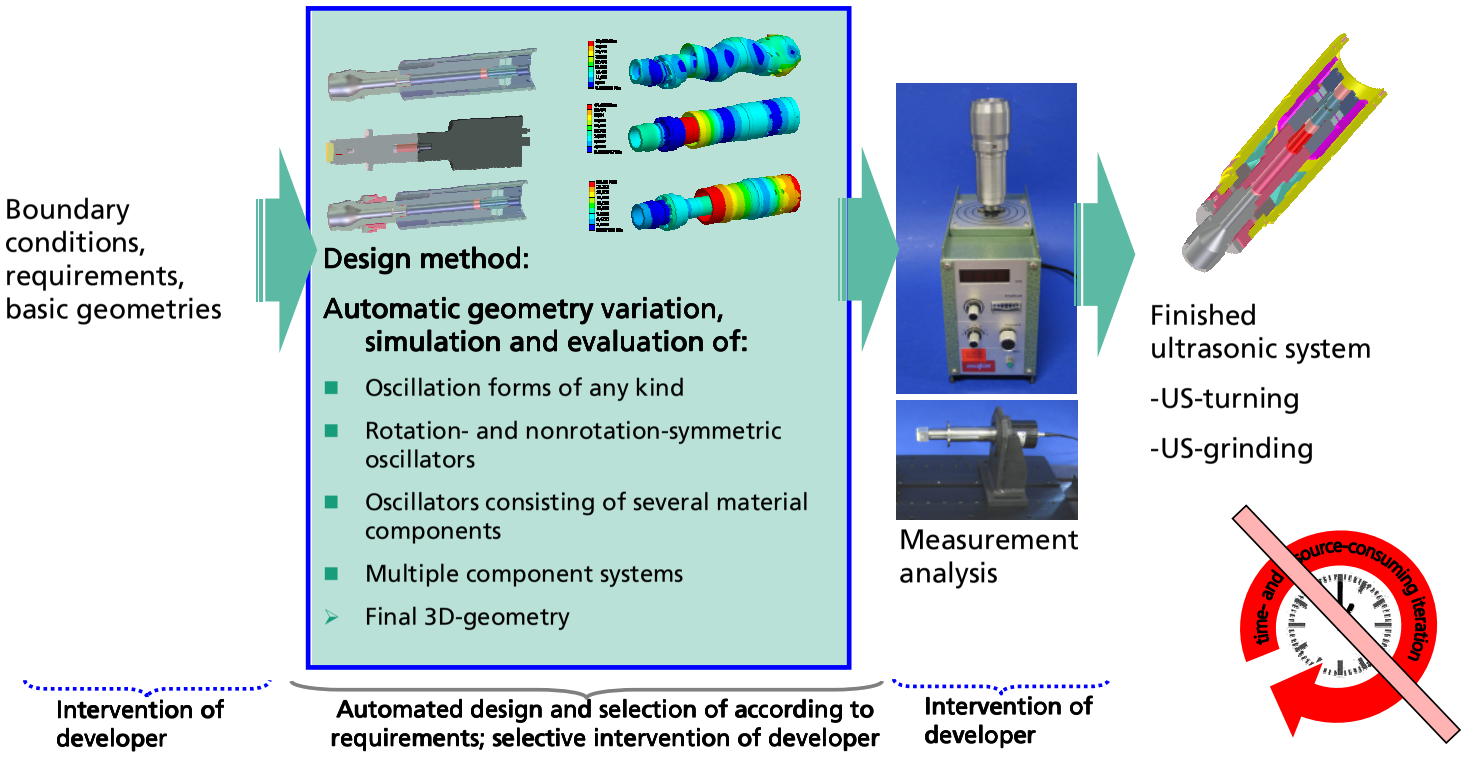
# AiF-Project: Automated Design of Ultrasonic Oscillators
## Project Idea



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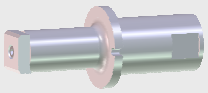
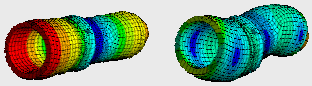
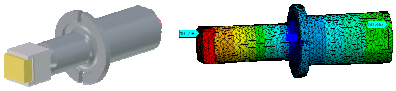
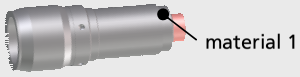
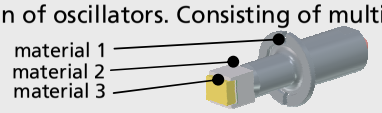
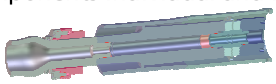
# AiF-Project: Automated Design of Ultrasonic Oscillators

## State of the Art and Research Objective

| State of the Art | Research Objective: Design method |
|---|---|
| Restriction on longitudinal-oscillators!  | Design of longitudinal- **and** transversal oscillators (3-dimensional)  ➔ New cutting conditions, applications, etc. |
| Restriction on rotation-symmetric oscillators (unidimensional design)  | Design of rotation- and non-rotationsymmetric oscillators (3-dimensional)!  ➔ Innovative, application-specific oscillators |
| Restriction on uni-material oscillators   | Design of oscillators. Consisting of multi-material components   ➔ Innovative, application-specific oscillators |
| Restriction on design of individual components  | Design of components individual and in interaction  ➔ Optimal oscillation properties for total system |
| Change of requirements / boundary conditions  Lack of knowledge about correlations ➔ Time-and resources-consuming redesign | Change of requirements / boundary conditions ➔ Knowledge about influences ➔ Quick and transparent redesign, decrease of rejects |



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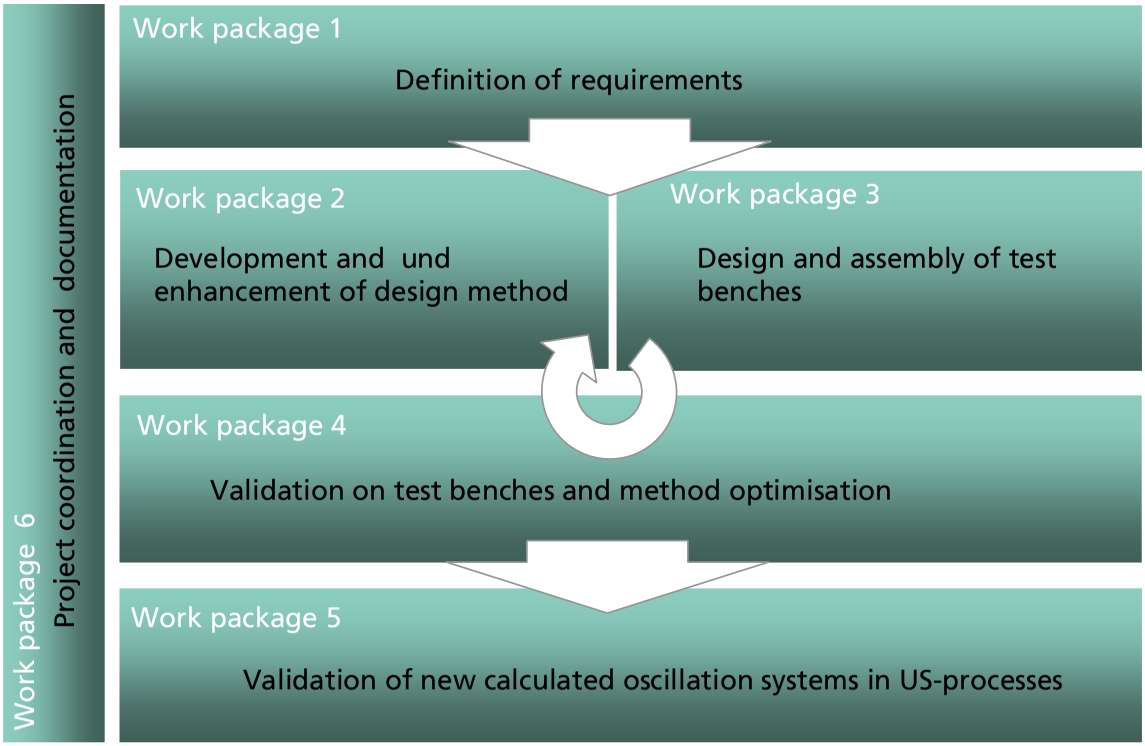
# AiF-Project: Automated Design of Ultrasonic Oscillators

## Project Procedure



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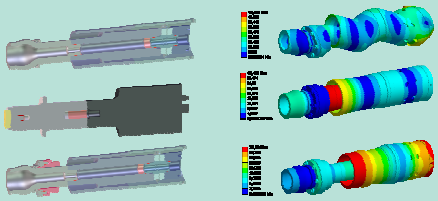
# Project Procedure: Work Package 2 – Design Method

**Work package 2**

Development and und enhancement of design method



**Design method:**

**Automatic geometry variation, simulation and evaluation of:**

- Oscillation forms of any kind
- Rotation- and nonrotation-symmetric oscillators
- Oscillators consisting of several material components
- Multiple component systems

➢ Final 3D-geometry

Boundary conditions, requirements, basic geometries for several elements

Mathematical Programm → Design of geometric variants of elements

ANSYS Finite-Elemente-Analysis → Calculation of each geometric variant

Mathematical Programm → Selection of variants concerning requirements; couple selected elements to total system variants

ANSYS Finite-Elemente-Analysis → Calculation of each total system variant

Mathematical Programm → Selection of total system variants concerning requirements



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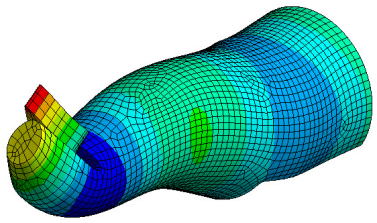
# Summary and Outlook



- Summary
  - Generation of sample models for flexural 60kHz-resonance-oscillators
  - Simulative dimensioning and detailing of the sample models with FEM-modal analysis
  - Machining and measurement analysis of the sample models
  - Validation of flexural mode, frequency and node levels
  - FEM convenient tool to calculate flexural sonotrodes
  - Optimisation of flexural oscillator for diamond turning
- Outlook
  - Optimisation of flexural oscillator for diamond turning
  - Machining tests with flexural oscillator
  - Start of AiF-Project



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