



Intensive ultrasonic cleaning of surfaces by means of lead-free ultrasonic transducer with focusing sonotrode

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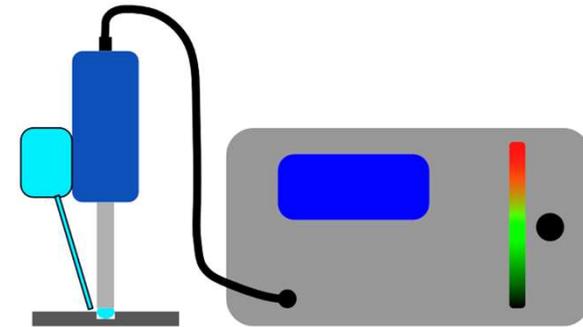
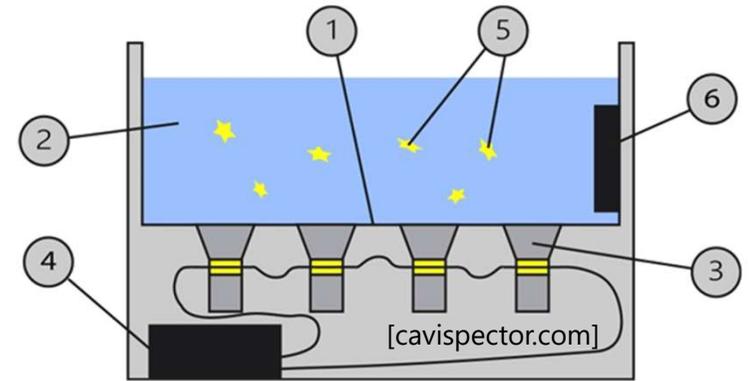
Agenda

- 1. Innovation concept for ultrasonic cleaner**
- 2. Lead-free bolted Langevin transducers**
(transducer and benchmark setup, benchmark results)
- 3. Focusing sonotrode**
(theory, FE-modelling and -simulation, experimental cleaning results)
- 4. Conclusions**



Innovation concept for ultrasonic cleaner

- Restriction of hazardous substances directive: Reduce environmental pollution from lead!
=> Replacement of PZT ceramics!
- New application: High intensity cleaning of e. g. tile joints
- Idea: Cleaning pen instead of bath

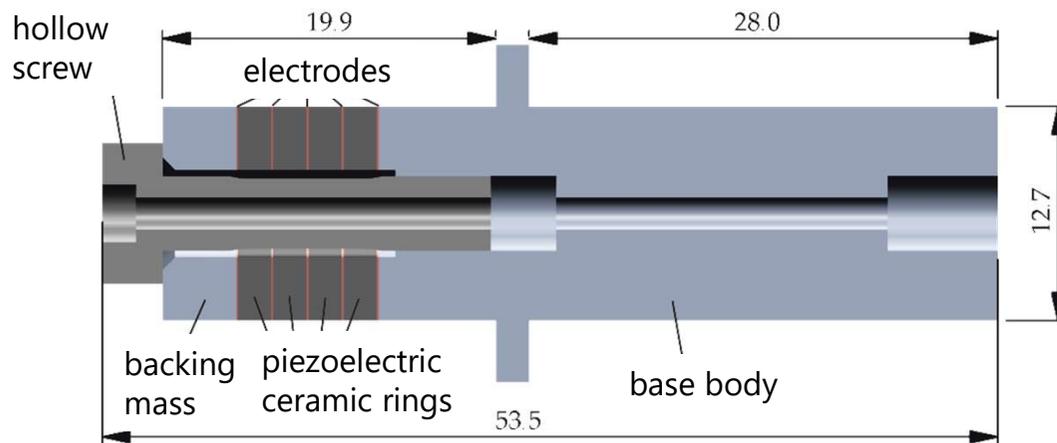




Lead-free bolted Langevin transducers

Transducer setup

- Standard design as used in many applications,
- Designed to achieve 1.5 m/s at transducer tip.



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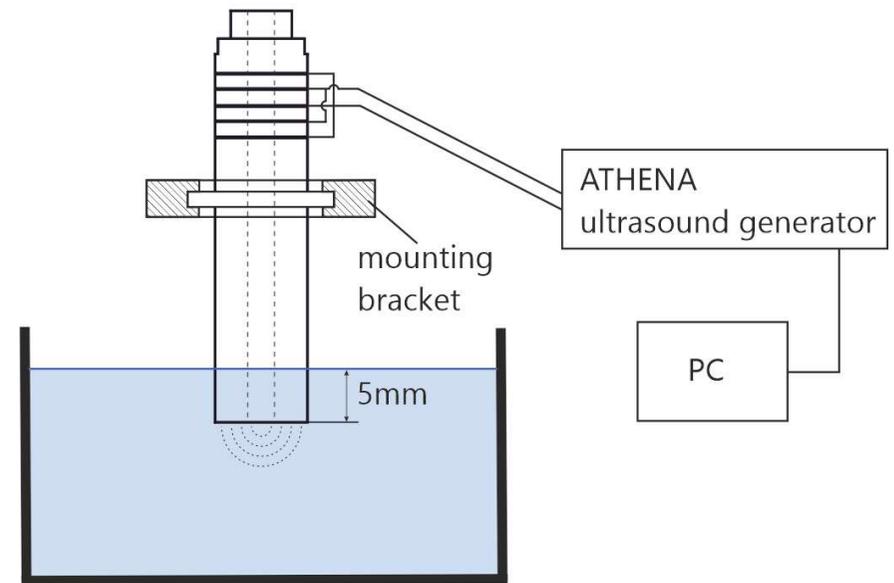




Lead-free bolted Langevin transducers

Benchmark Setup

- Weak clamping -> no influence on vibration
- Short time operation -> no significant heating, no cooling needed
- Immersion of transducer tip into non-resonantly tuned water basin

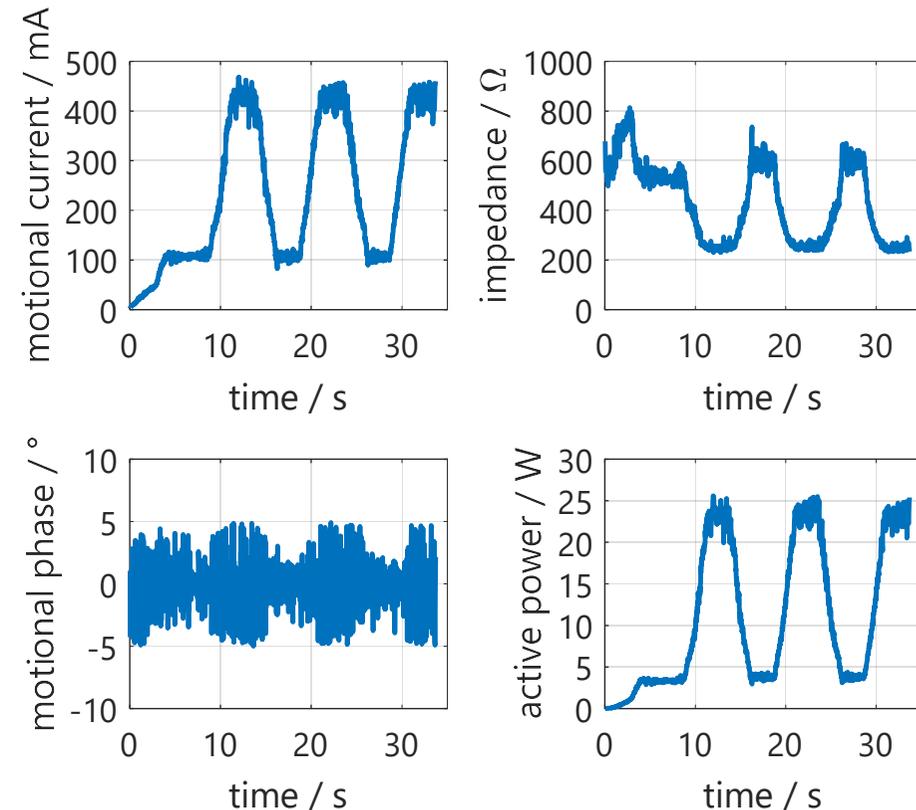




Lead-free bolted Langevin transducers

Benchmark Setup

- Weak clamping -> no influence on vibration
- Short time operation -> no significant heating, no cooling needed
- Immersion of transducer tip into non-resonantly tuned water basin
- Controlled operation in mechanical resonance (frequency and amplitude control)
- Recording of electrical quantities

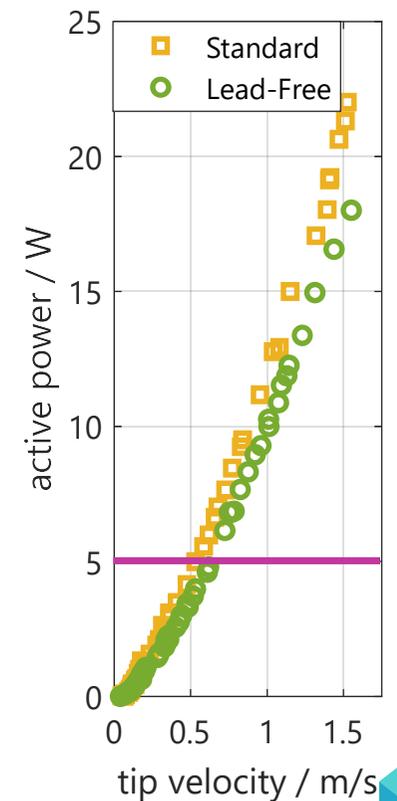
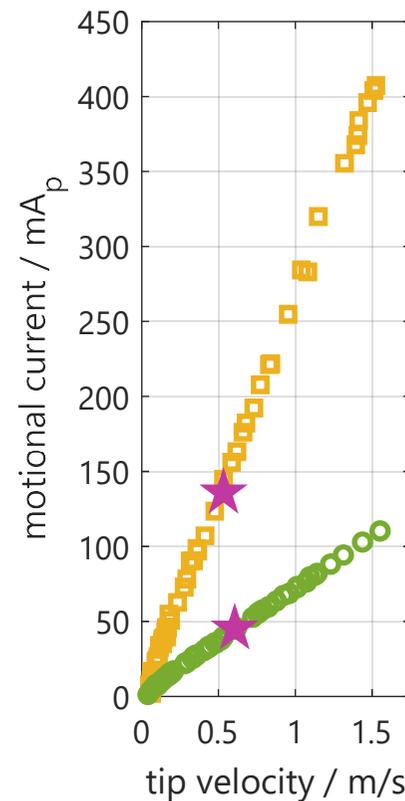
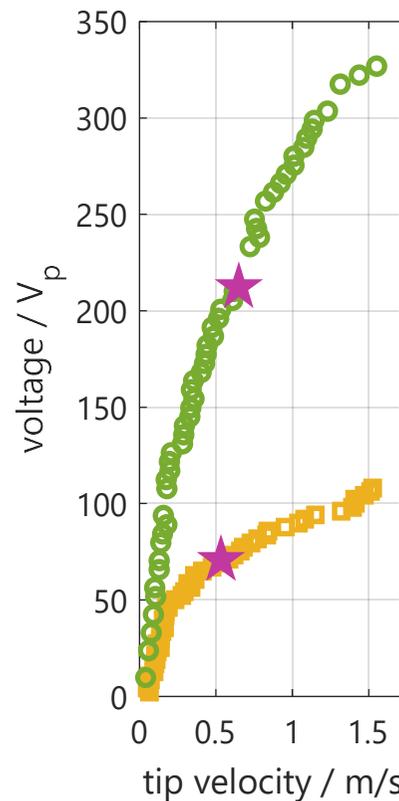




Lead-free piezoelectric ceramics in bolted Langevin transducers

Benchmark results

- Lead-free needs more voltage and less current.
- Vibration velocity is linear proportional to motional current at any load.
- Lead-free needs less active power.
- **Aim: Cleaning at low power!**



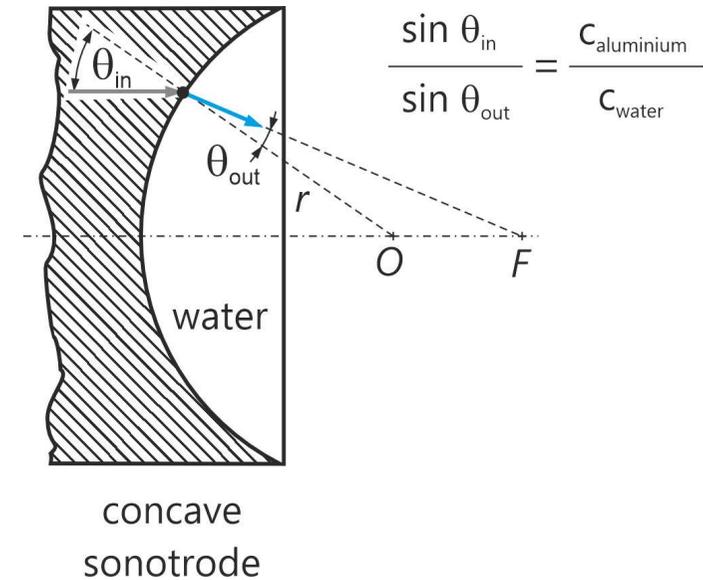


Focusing sonotrode

Theoretical background

- Vibration amplification by a boosting sonotrode
=> system gets more sensitive, control issues might arise
- Focusing is theoretically possible:
 - Interference of standing waves (Huygens)
 - Reflection and refraction (Snellius)
- Simplified analytical solutions yield only for sonotrode diameter \gg wavelength
(12.7 mm $<$ 32 mm!)

⇒ FE-calculation needed

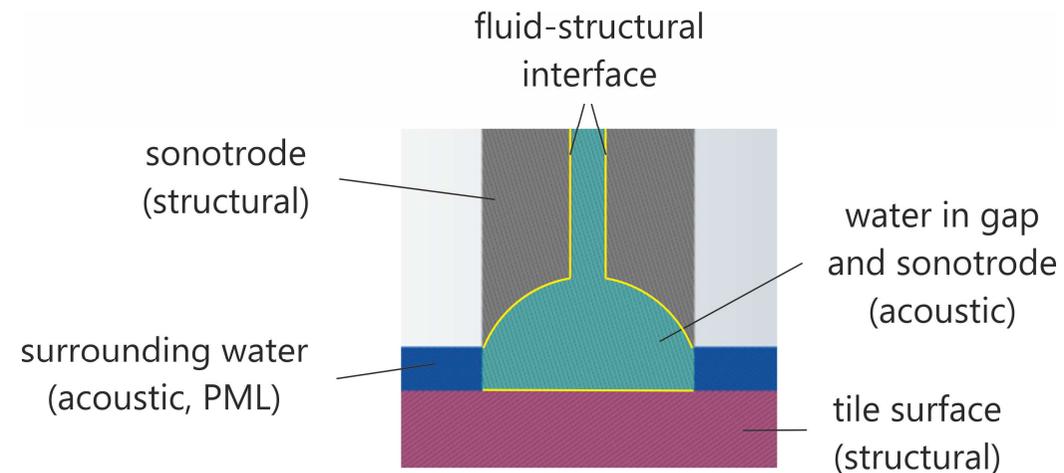




Focusing sonotrode

FE-model assumptions

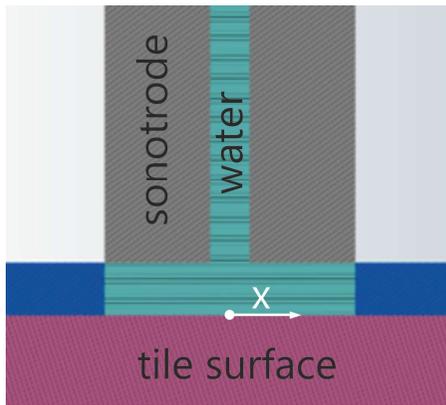
- Cleaning is proportional to pressure
⇒ Calculation of pressure distribution on surface as a measure for cleaning potential
- Geometry optimization needs multiple calculations
⇒ no CFD, no bubble dynamics, etc.
instead, harmonic acoustics simulation with fluid-structural-interaction
- Water in the gap between sonotrode and surface is compressible (!) – as it will splash out
- No reflections from the surrounding water (**P**erfectly **M**atched **L**ayer)



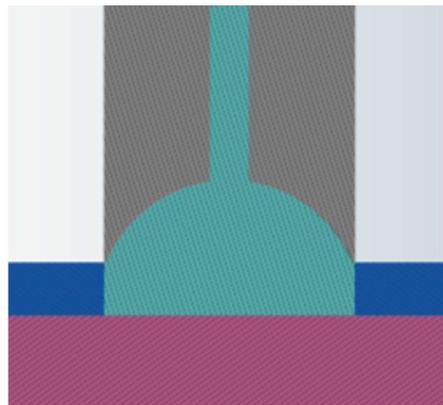


Focusing sonotrode

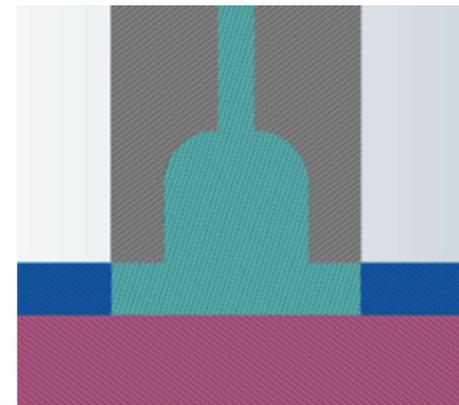
FE-model geometries



plane sonotrode



concave sonotrode



blind hole sonotrode





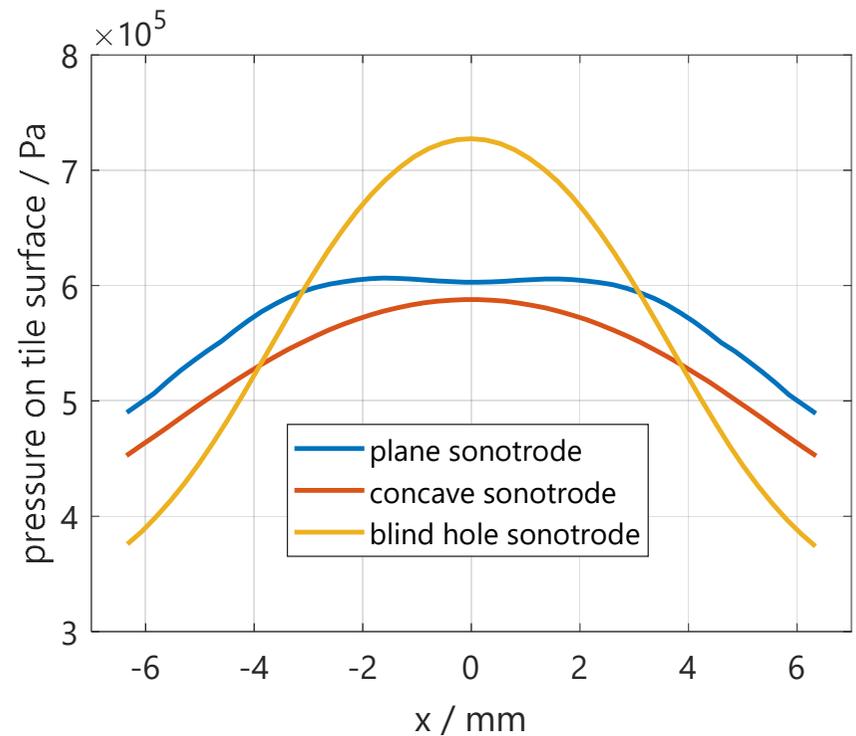
Focusing sonotrode

FE-model setup

- 3 sonotrodes: plane, concave, blind hole
- Harmonic acoustics simulation
(resonant excitation with 1 μm vibration amplitude at sonotrode free end)

Simulation results

- Concave sonotrode focuses, but plane sonotrode yields higher pressure.
- Blind hole sonotrode achieves good results.

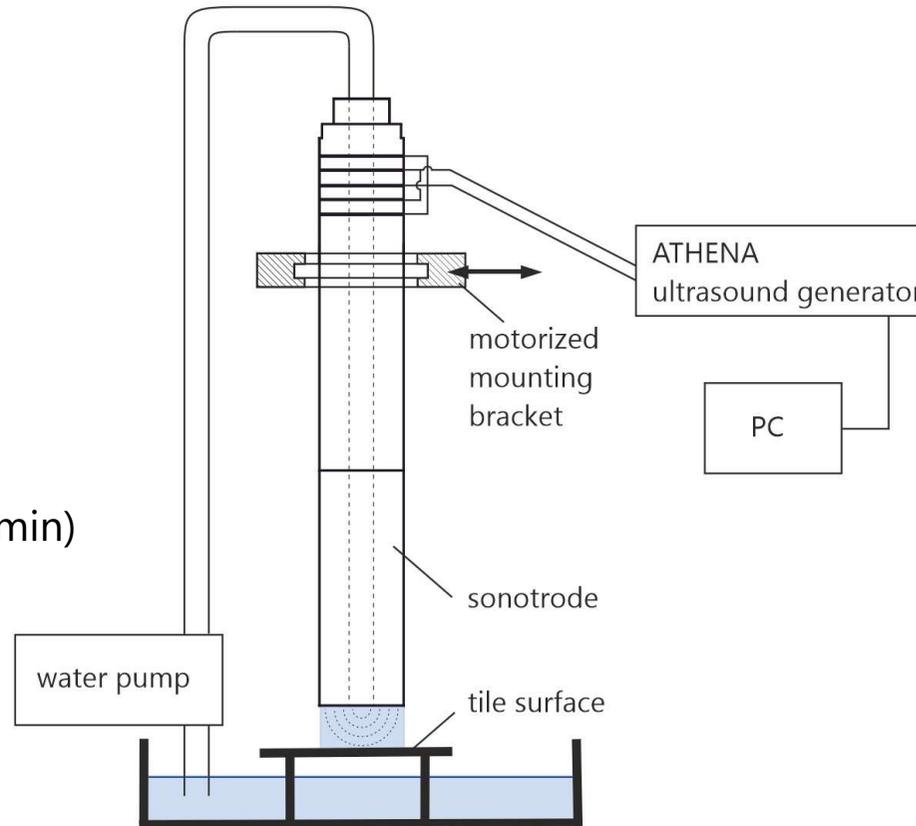




Focusing sonotrode

Experimental setup

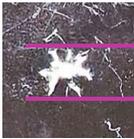
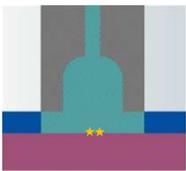
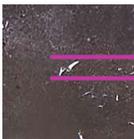
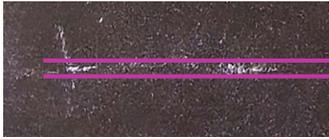
- Motorized mounting bracket
- Controlled operation in mechanical resonance (frequency and amplitude control)
- Cooling by water flux (100 ml/min)
- Tile with thin lacquer layer





Focusing sonotrode

Experimental cleaning results

PIC HQ2	vibration = 0.5 m/s power ≈ 7 W sonication: 10 s	vibration = 1.5 m/s power ≈ 40 W (!) feed speed ≈ 10 mm/s	vibration = 1.5 m/s power ≈ 40 W (!) feed speed < 1 mm/s
	 7 mm	 9 mm	 7 mm
	 2 mm	 1.5 mm	 2 mm 11 mm





Conclusions

Lead-free bolted Langevin transducers...

- need some design changes to fit PZT - characteristics (frequency, impedance, maximum power)
- can compete with standard PZT in low power applications,
- have lower weight and lower mechanical losses than PZT.

Focusing sonotrode

- Focusing works, even at comparable low frequency.
- Cleaning surfaces at low power is possible, but takes time.
- At high power, de-focusing appears.





Thank you for your attention!



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