BOLTED LANGEVIN TRANSDUCERS WITH LEADFREE PIEZOELECTRIC CERAMICS

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Agenda

1. **Application of leadfree ceramics in actuators**

2. **Leadfree piezoelectric ceramics in bolted Langevin transducers**
   a. Small signal characteristics of ceramic rings
   b. Bolted Langevin transducer setup
   c. Transducer characteristics
   d. Benchmark

3. **Conclusions**

Application of leadfree ceramics in actuators

- Restriction of hazardous substances directive: Reduce environmental pollution from lead!
- Several companies sell leadfree ceramics
- Mass application of leadfree ceramics in nebulizers
- Many publications about transducers, but very few standard transducers on commercial market!

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Leadfree piezoelectric ceramics in bolted Langevin transducers

Small signal characteristics of ceramic rings

- Ceramic rings (Ø 12.7 mm × Ø 5.2 mm × 2 mm),
  PZT: PIC 181, BNT: Fuji M05BR, KNN: PIC 758, PIC HQ2

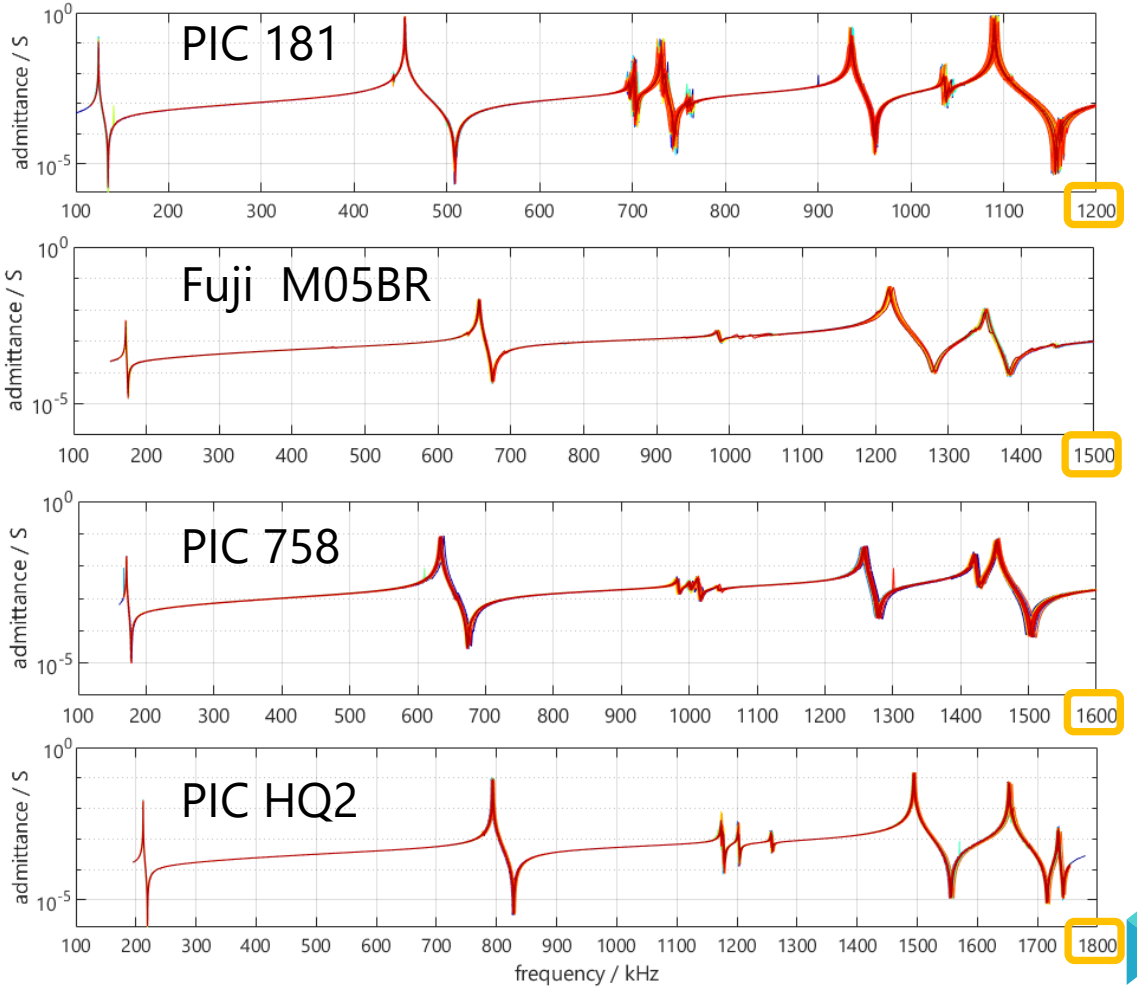
Leadfree piezoelectric ceramics in bolted Langevin transducers

Small signal characteristics of ceramic rings

- Ceramic rings (Ø 12.7 mm × Ø 5.2 mm × 2 mm),
  PZT: PIC 181, BNT: Fuji M05BR, KNN: PIC 758, PIC HQ2
- Sample scattering is low, resonance frequencies of the individual modes vary by less than 0.2 %.

⇒ Reproducibility of leadfree ceramics is as good as that one of PZT!

- Vibration modes remain almost the same (and in same order).
- Lower density of leadfree materials
  ⇒ Higher frequencies!



Leadfree piezoelectric ceramics in bolted Langevin transducers

Lead free ceramics …

- are lightweight,
- can achieve high Q_m,
- show lower permittivity,
- have lower electro-mechanical coupling.

⇒ The transducer design must be adapted …

- to match the desired resonance frequency,
- to yield sufficient power conversion.

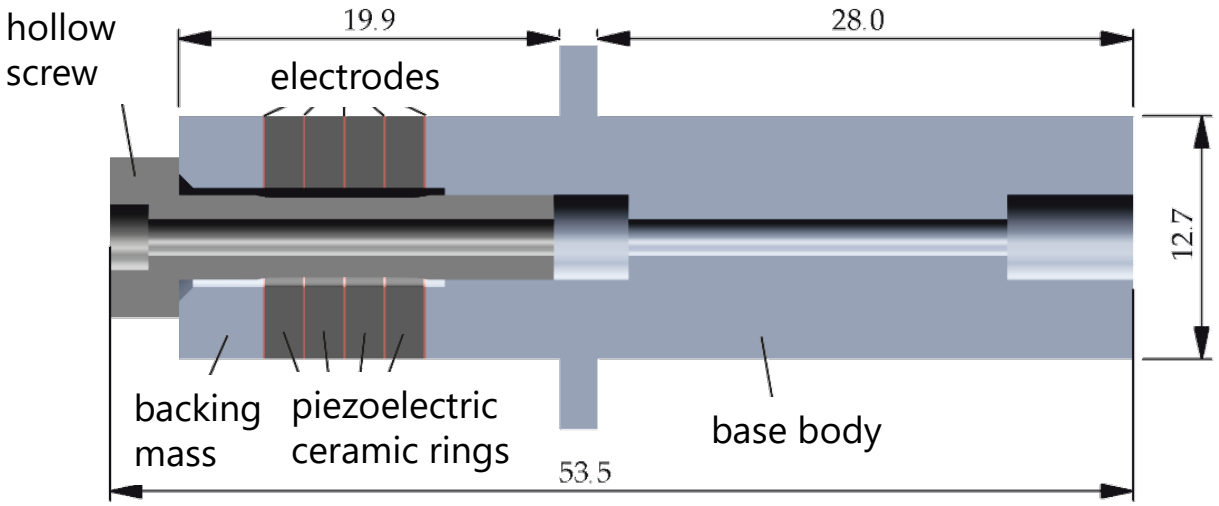
(not done in this study!)

Name	PIC 181	Fuji MB05BR	PIC 758	PIC HQ2
Material	PZT	BNT	KNN	KNN
ρ / kg/m^3	7850	5700	4800	4800
Q_m	2200	626	585	2500
$\varepsilon_{11}^T / \varepsilon_0$	1224	595	950	254
$\varepsilon_{33}^T / \varepsilon_0$	1135	441	850	228
e_{31} / N/Vm	−4.5	-0.8	−2.6	−2.2
e_{33} / N/Vm	14.7	8.4	12.6	7.0
e_{15} / N/Vm	11.0	7.2	9.0	3.3
c_{11}^E / GPa	152.3	164.7	151.6	190.0
c_{12}^E / GPa	89.1	68.0	68.3	60.0
c_{13}^E / GPa	85.5	70.2	81.5	82.0
c_{33}^E / GPa	131.4	142.0	146.3	194.5
c_{44}^E / GPa	28.3	43.2	31.5	30.0
k_{33}	0.66	0.45	0.57	0.50
d_{33} / pm/V	253	90	170	60

Leadfree piezoelectric ceramics in bolted Langevin transducers

Bolted Langevin transducer setup

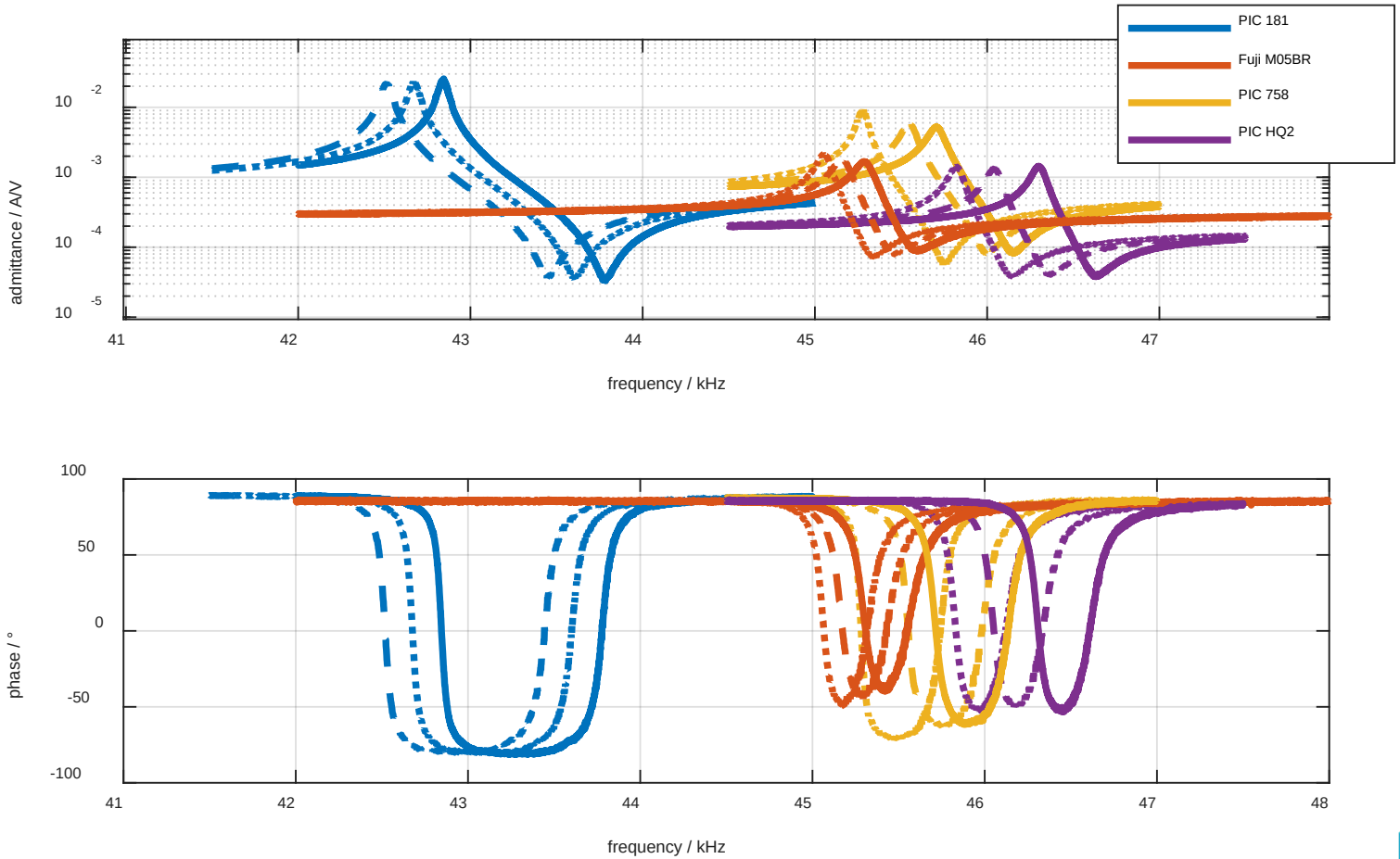
- Same dimensions for PZT and leadfree variants,
- Designed to achieve 1.5 m/s at transducer tip.



Leadfree piezoelectric ceramics in bolted Langevin transducers

Transducer characteristics

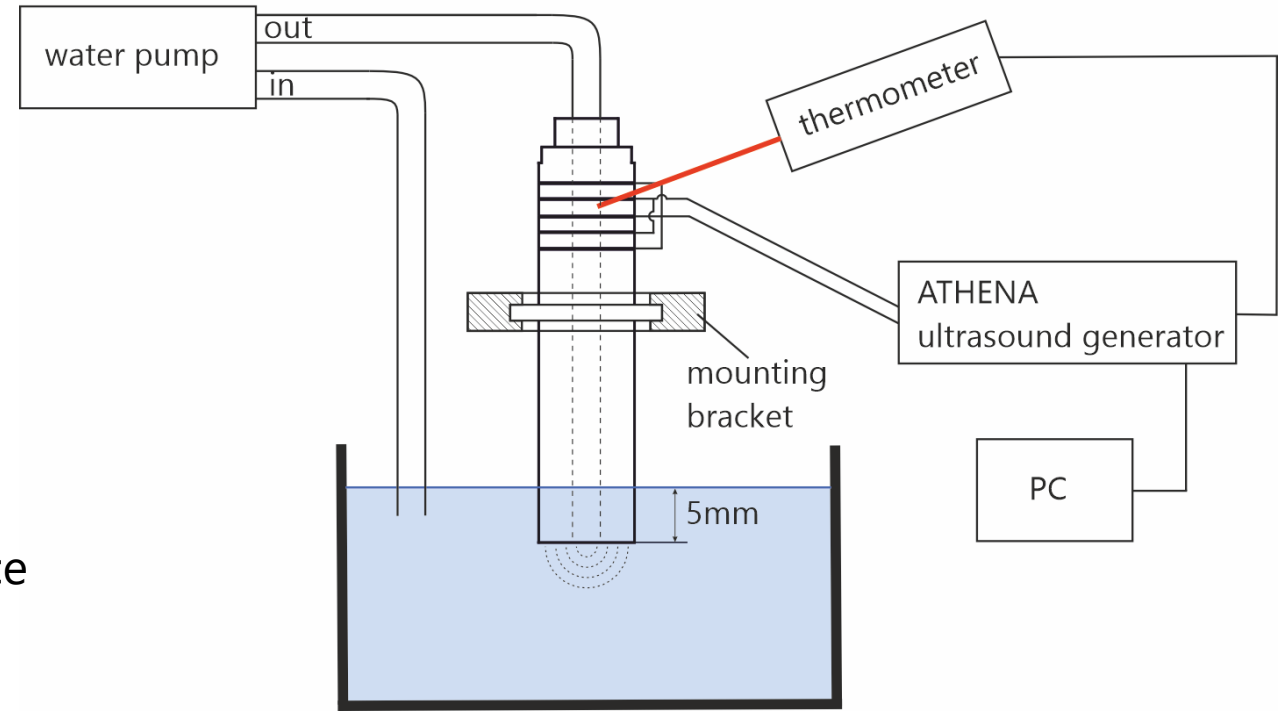
- Higher frequencies
- Lower admittances
- Lower electro-mechanical coupling
- About the same variance of individual transducers



Leadfree piezoelectric ceramics in bolted Langevin transducers

Benchmark Setup

- Same dimensions for all variants
- Weak clamping of the transducer near to vibration node
- Immersion of transducer tip in non-resonantly tuned water basin
- Optional transducer cooling from the inside by water stream (500 mL/min)
- Controlled operation in mechanical resonance (frequency and amplitude control)
- Recording of electrical quantities and temperature

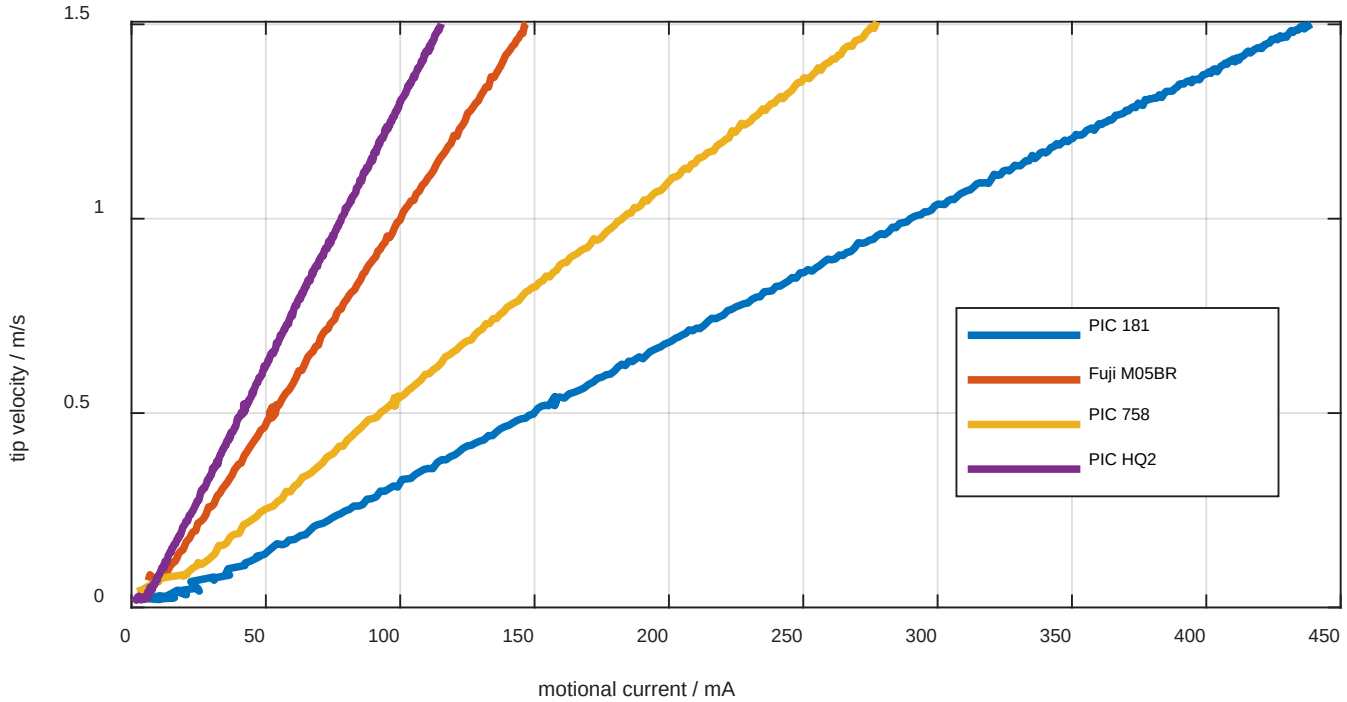


Leadfree piezoelectric ceramics in bolted Langevin transducers

Benchmark

- Free vibration, no cooling
- Short time test ⇒ no heat-up
- Good linearity of tip velocity and motional current

⇒ Is motional current a good measure to control transducer amplitude, even under load?



Leadfree piezoelectric ceramics in bolted Langevin transducers

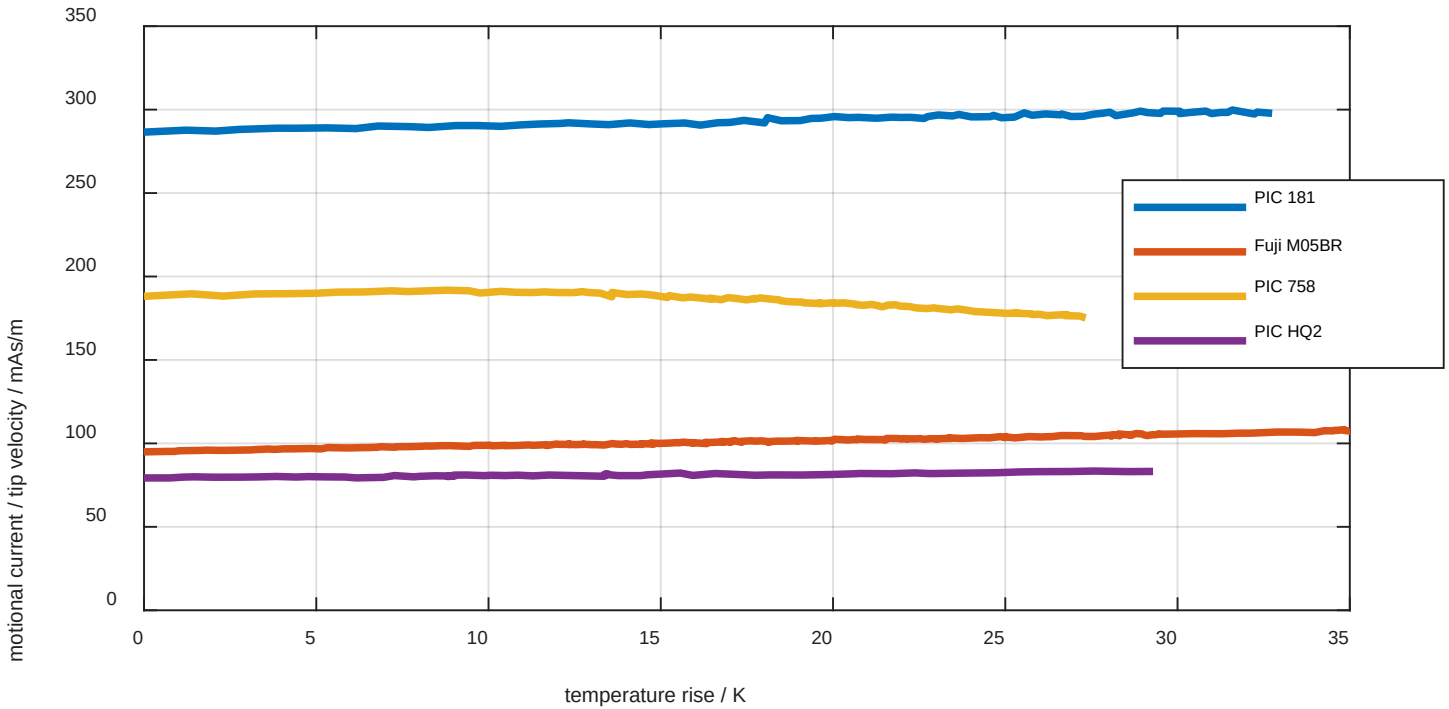
Benchmark

- Free vibration, no cooling
- Continuous drive at maximum amplitude until temperature rise of ≈ 30 K

⇒ Ratio of motional current and tip velocity depends on temperature:

- PIC 181: + 0.12 %/K
- Fuji M05BR: + 0.38 %/K
- PIC 758: nonlinear drop
- PIC HQ2: + 0.17 %/K

⇒ Should be considered for precise process control

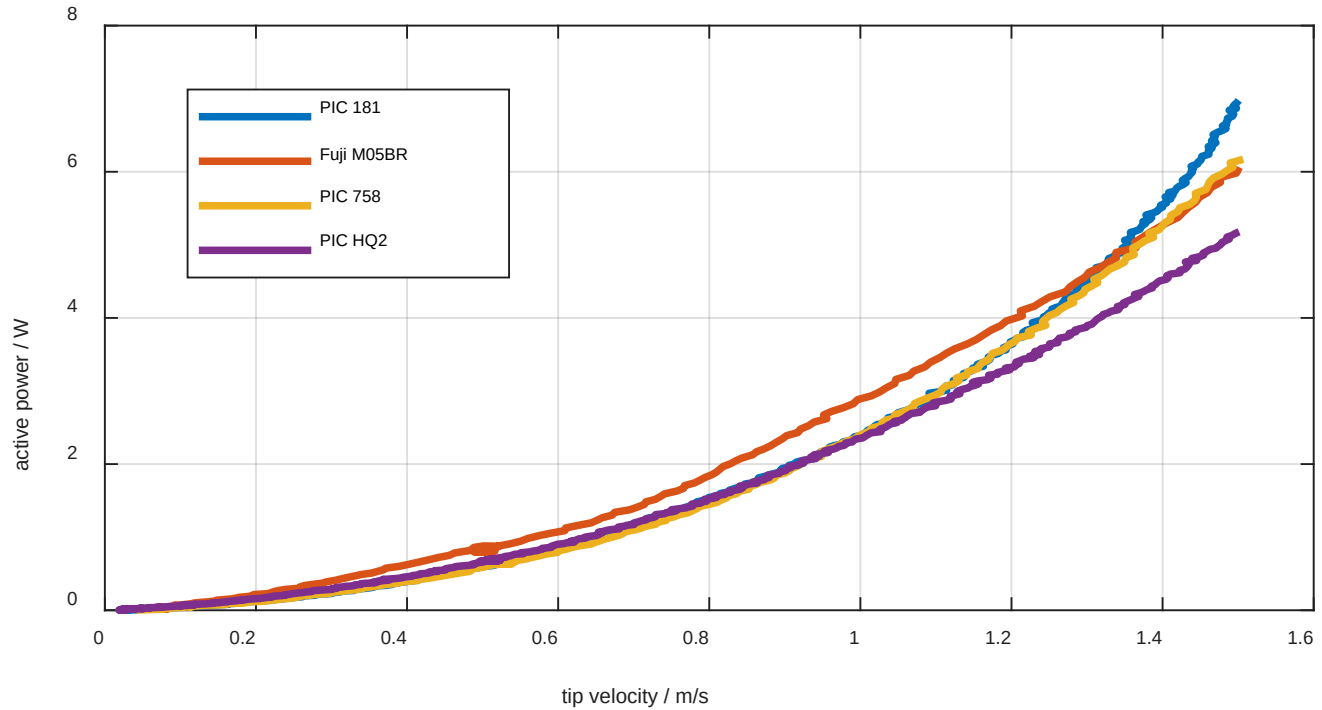


Leadfree piezoelectric ceramics in bolted Langevin transducers

Benchmark

- Free vibration, no cooling
- Short time test ⇒ no heat-up
- At maximum amplitude
  15 – 28 % less power need
  by leadfree variants (!)

  (correlates with falling Q_m
  with vibration amplitude)

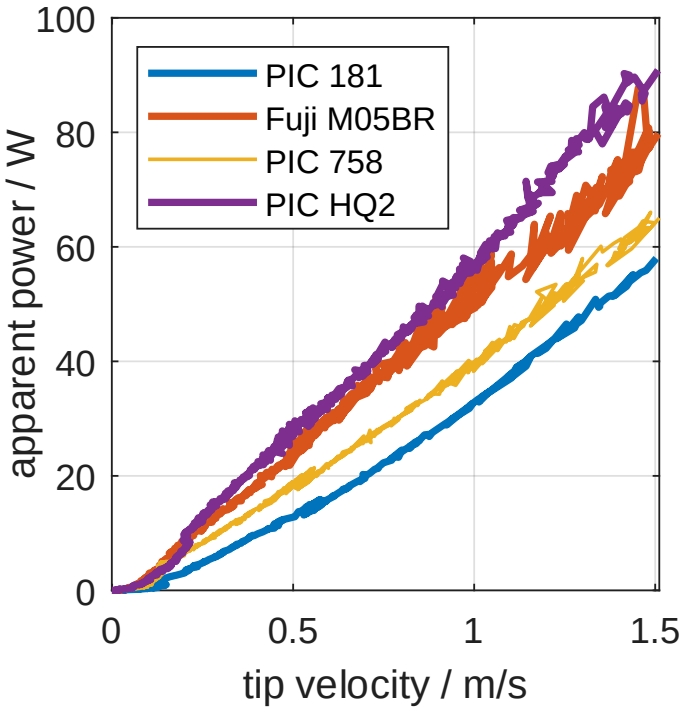


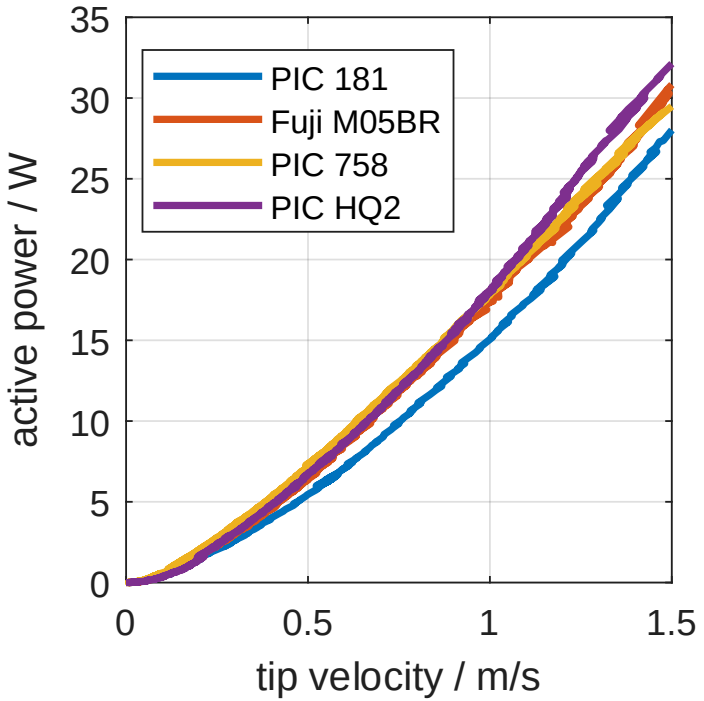
Leadfree piezoelectric ceramics in bolted Langevin transducers

Benchmark

- Water load, no cooling
- Short time test ⇒ no heat-up
- When operated at mechanical resonance without reactive load compensation, leadfree variants need more apparent and active power.

(correlates with smaller energy conversion rate and additional losses in electronics)

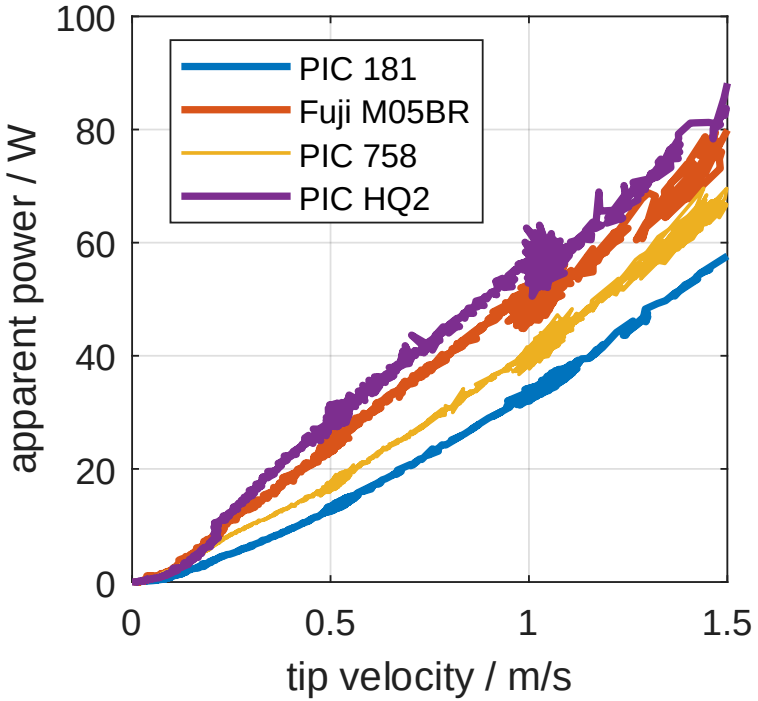


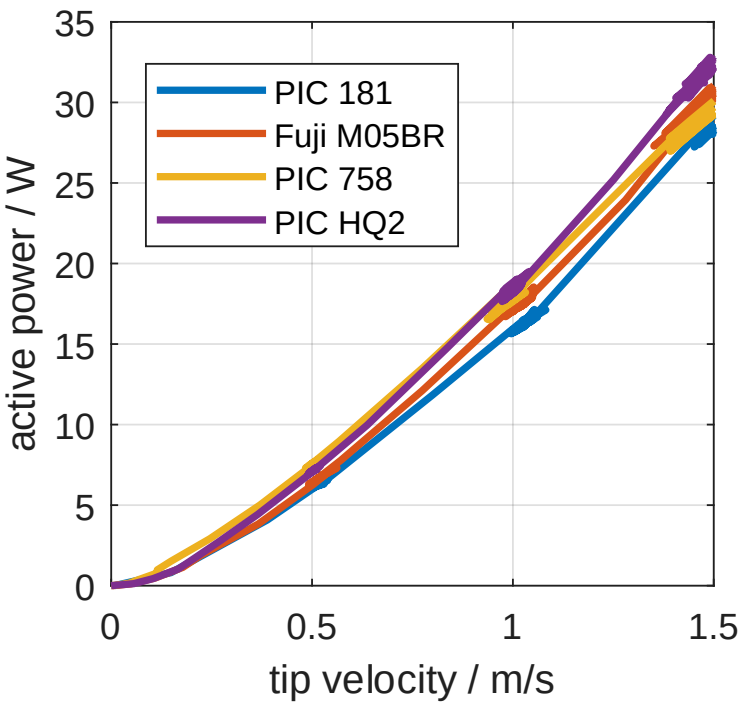


Leadfree piezoelectric ceramics in bolted Langevin transducers

Benchmark

- Water load, with cooling
- Continuous operation until temperature stabilization in three steps (0.5, 1 and 1.5 m/s)
- Again: Leadfree variants need more power
- But …

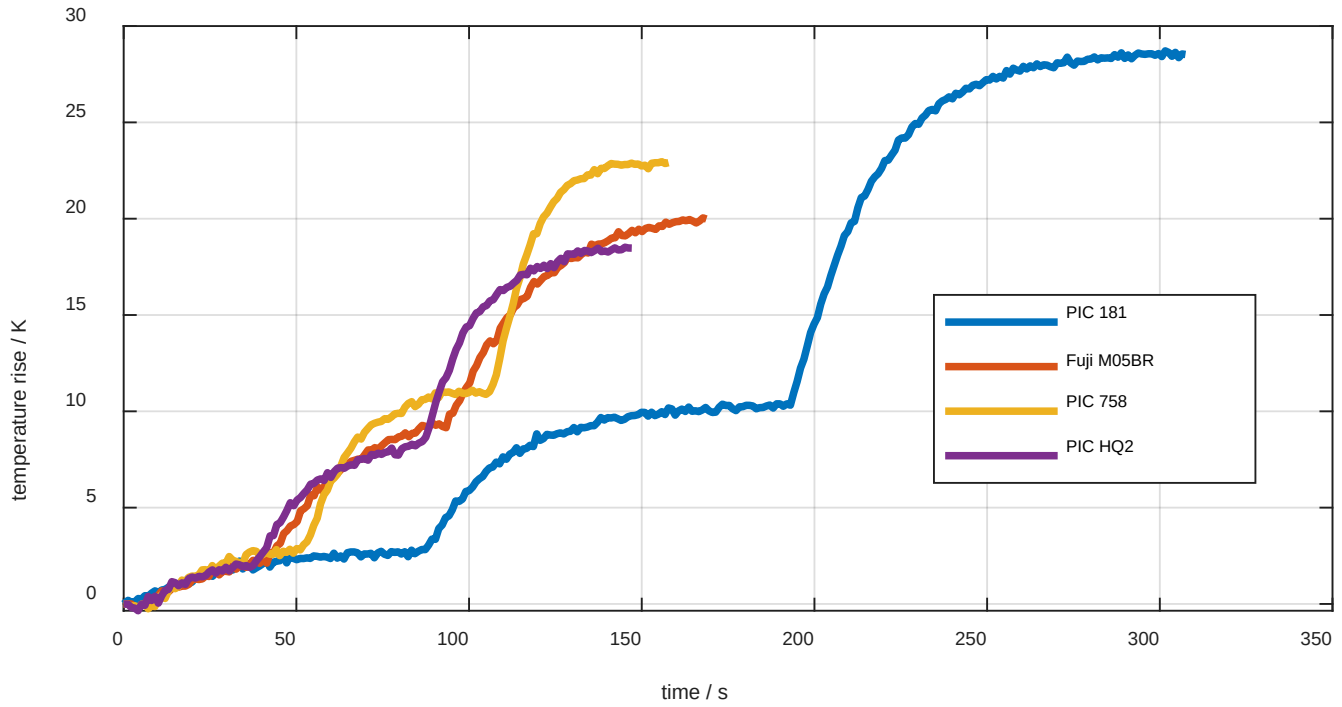




Leadfree piezoelectric ceramics in bolted Langevin transducers

Benchmark

- Water load, with cooling
- Continuous operation until temperature stabilization in three steps (0.5, 1 and 1.5 m/s)
- Temperature stabilizes faster and heat up is up to 35 % lower!



Conclusions

Lead free piezoelectric ceramics for bolted Langevin transducers

- are available on market,
- can compete with standard PZT in terms of reproducibility,
- have lower weight, lower conversion efficiency and heat up less than PZT.

During transducer design some aspects must be considered:

- geometry must be adapted to fit given frequencies or impedances,
- the piezo volume must be increased to gain same maximum power as PZT.

Thank you for your attention!

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Lead-Free Ceramics in Prestressed Ultrasonic Transducers

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