New Linear Ultrasonic Micromotor for Precision Mechatronic Systems

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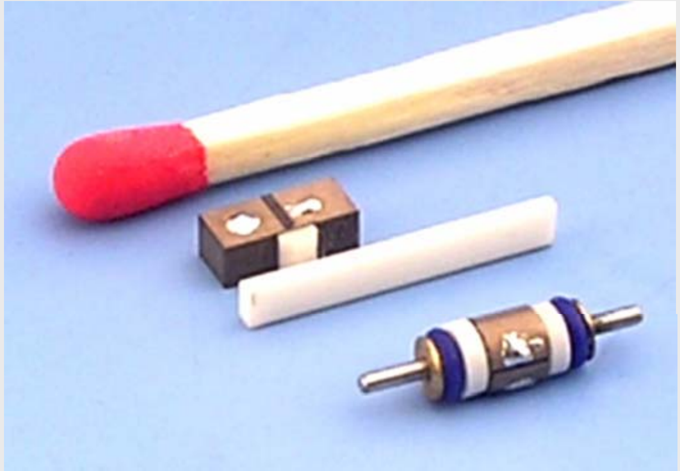
Overview

- Introduction
- PI*line*® Linear Ultrasonic Motors
- Working Principle and Design
- Working Principle and Design of the New Ultrasonic Motor
- FEM Simulation and Measurement with 3D Scanning Vibrometer
- Drive Characteristics of the New Micromotors
- Conclusions

PI Miniaturized Piezoelectric Ultrasonic Motors

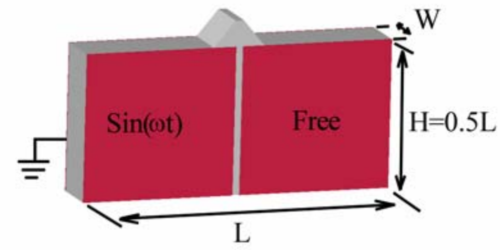
- PI has been active in piezoelectric ultrasonic motor (PUM) R&D for many years.
- Minature PUMs have also been subject to investigation at PI.
- PI developed a piezoelectric rotary traveling-wave motor with a stator measuring only 3x3 mm.
- The PILine® actuators can be scaled at will and can be used for practically any mechatronics application.
- The latest developments from PI are miniature linear PUMs with integrated guide grooves

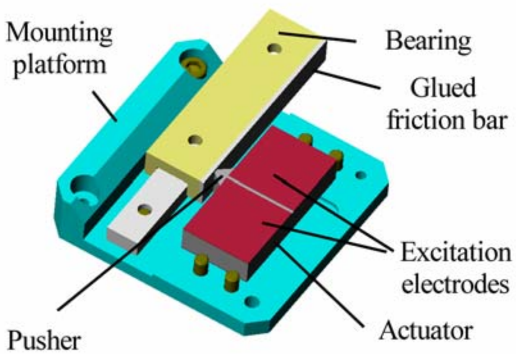


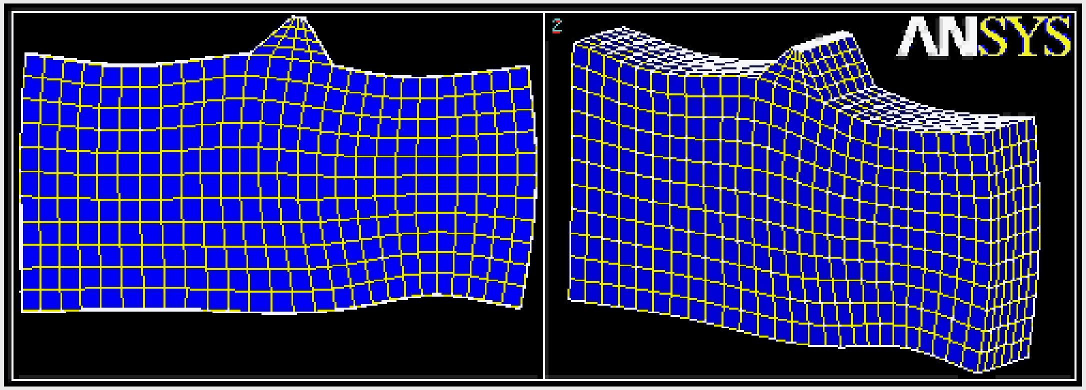
Miniature piezoelectric ultrasonic motors from PI (match for size comparison)

PI*line*® Linear Ultrasonic Motors

- Piezoceramic Plate
  - Size L×W×0.5L (X,Z,Y)
  - Polarized in the Z (width) direction
- Single-Phase Excitation
  - On the front are two exciter electrodes
  - The actuator is excited with a sine wave voltage applied to one or the other of the excitation electrodes
- Pusher is made of alumina

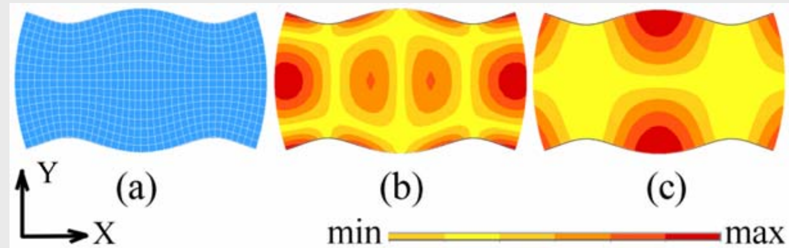




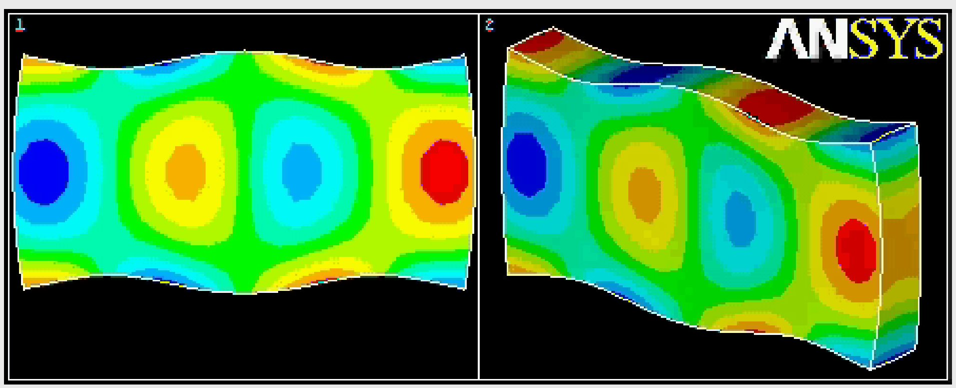


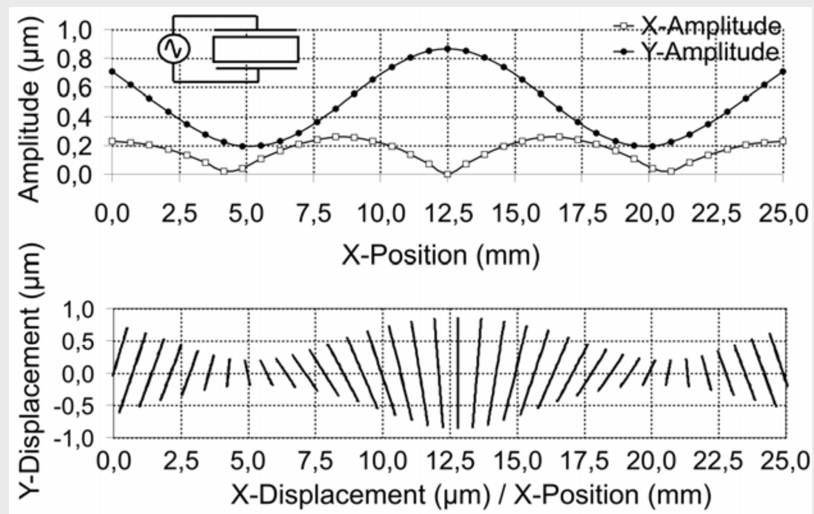
Extensional Vibration Modes of a Plate

- Symmetrical Excitation of the E(3,1) Mode
  - Theoretically described by superposition of standing waves in the X- and Y-directions
  - 3λ/2 in X-direction, λ/2 in Y-direction
  - Excitation with two symmetrical electrodes

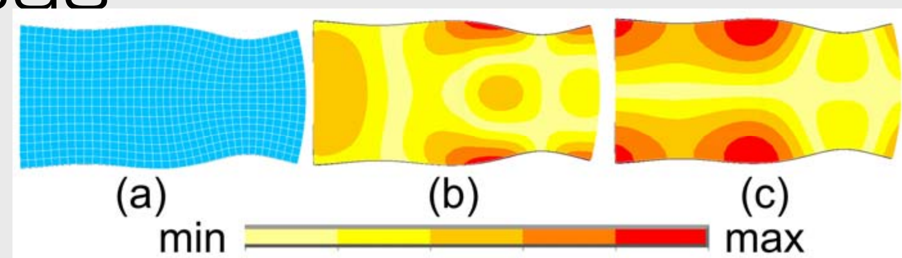


E(3,1) Modes in a rectangular piezoceramic plate. (a) Deformation; (b) Length oscillation velocity distribution (X-direction); (c) height *oscillation velocity distribution (Y-direction); (FEM simulation).*



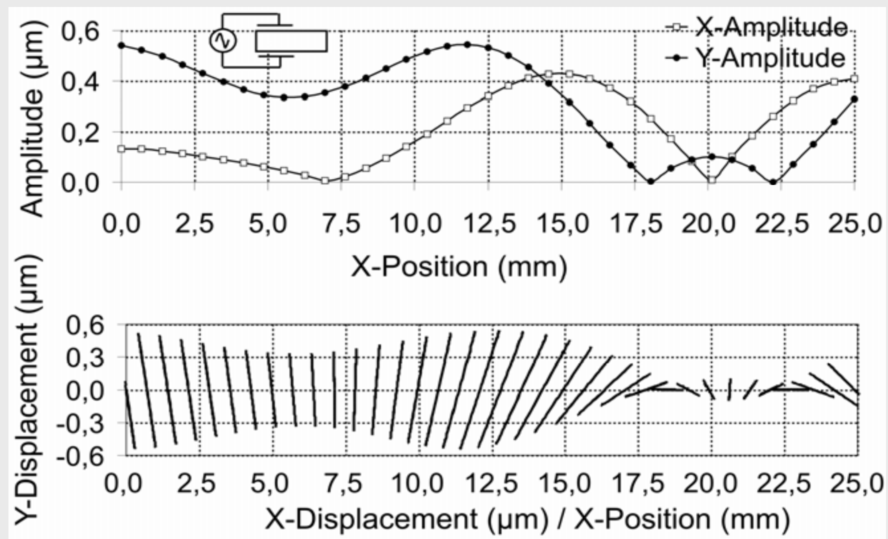


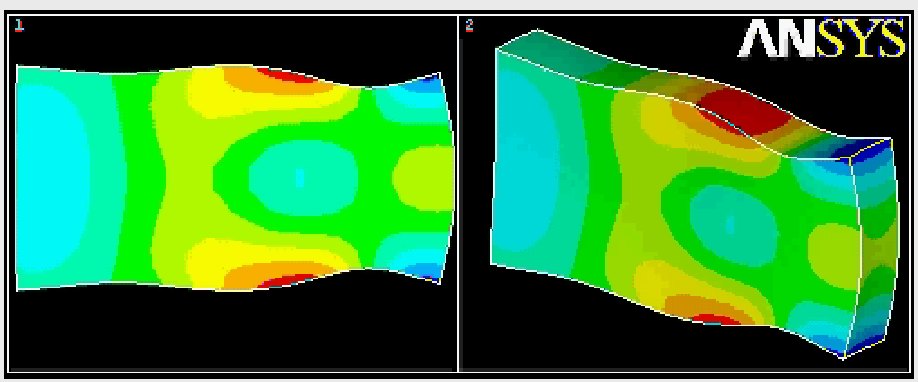
The Asymmetric Excitation of the E(3,1) Mode



Asymmetric excitation *E(3,1) (a) Deformation; (b) Length oscillation velocity distribution (X-direction); (c) height oscillation velocity distribution (Y-direction); (FEM simulation).*

- An asymmetric E(3,1) excitation is accomplished using the split electrode
- Shifted standing wave in X-direction
- Increased X displacement amplitudes at the center of the top/bottom edges



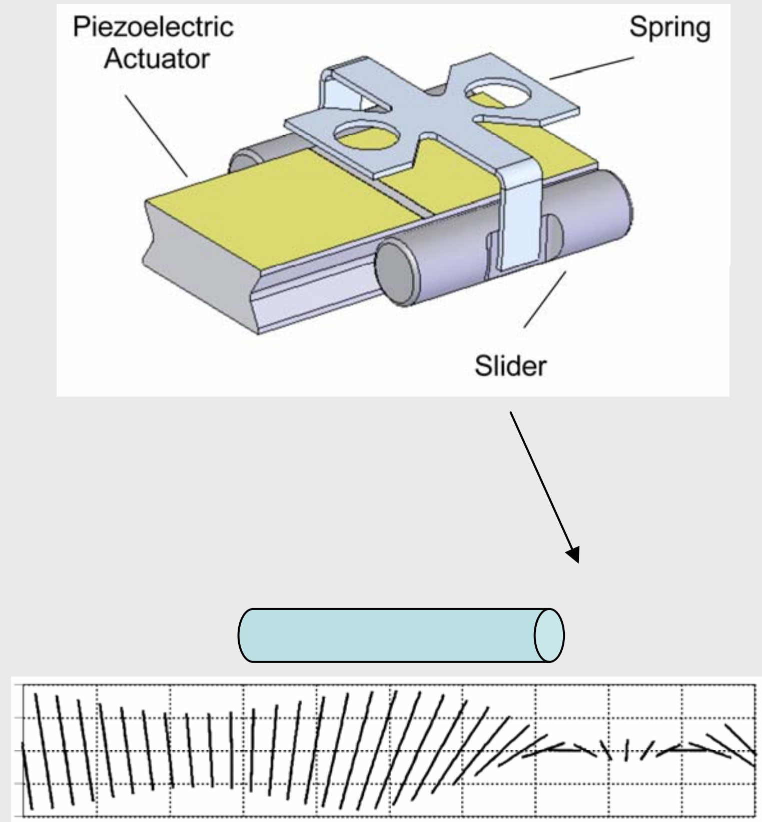


Working Principle and Design of the New Ultrasonic Micromotor

- Same working principle as the PILine® linear motor
- Very simple design

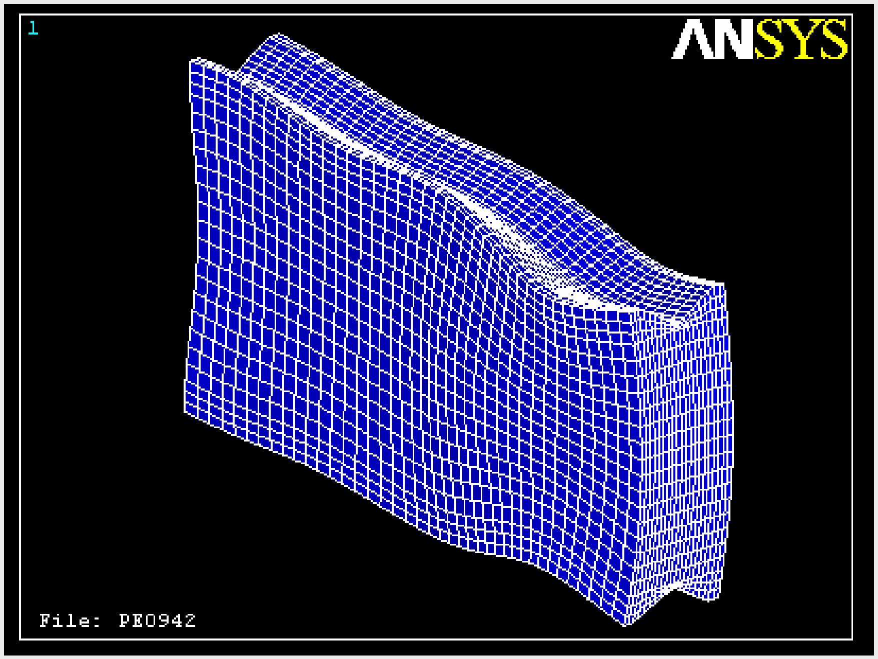
  -Resonator (actuator)

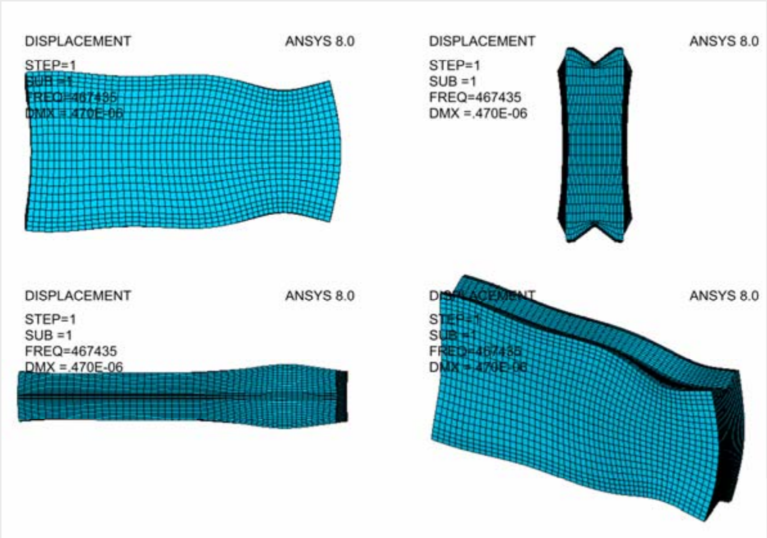
  -Spring bonded to two sliders
- The actuator plate has guide grooves cut in the long edges
- Two sliders are pressed against the ceramic actuator by the integrated spring

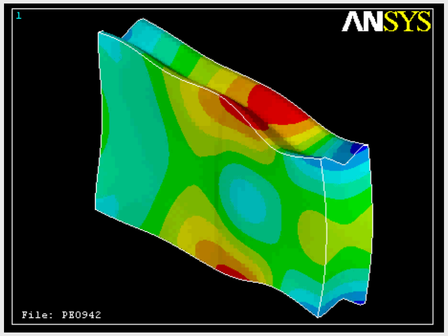


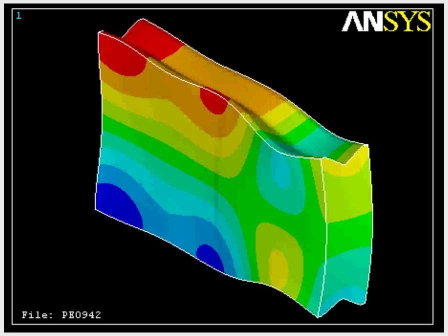
FEM Simulation

- All the simulations, calculations and the optimization of ultrasonic motors were done with the help of ANSYS FEM software



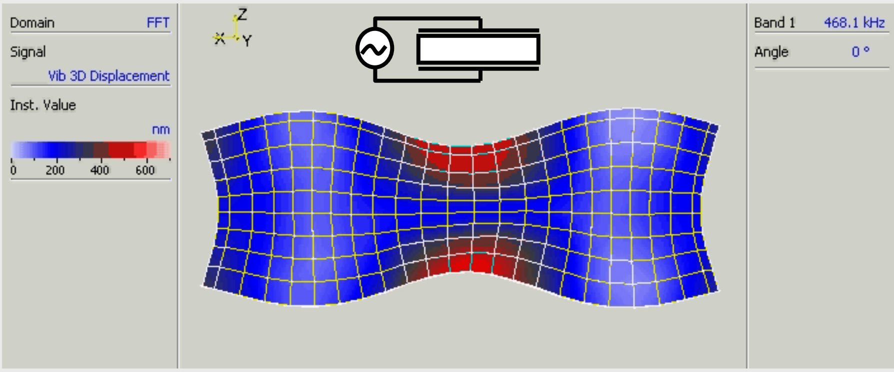




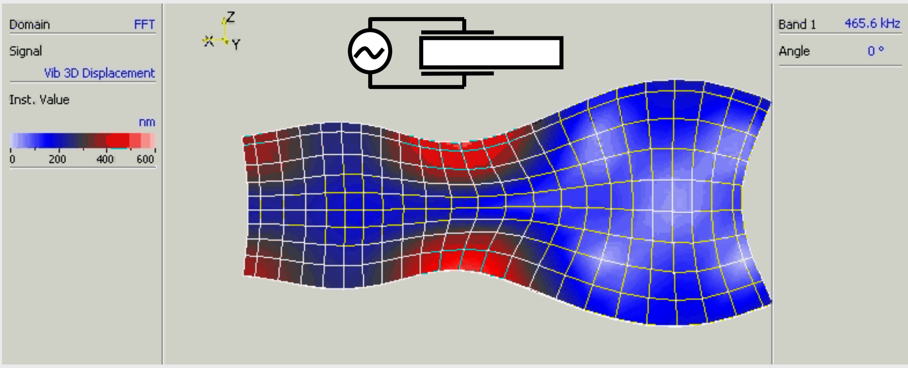


Measurement with 3D Scanning Vibrometer

- The PSV-300-3D laser measuring system from Polytec in Germany can scan an object and determine the vibratory motion of the individual surface points in three dimensions
- Noncontact measurement of all three vibration vector components simultaneously
- Intuitive 3-D animation of the measurement results with separation of out-of-plane and in-plane vector components



Symmetric excited E(3,1) Mode in a rectangular piezoceramic plate. (Measurement)



Asymmetrically excited E(3,1) mode in a rectangular piezoceramic plate. (Measurement)

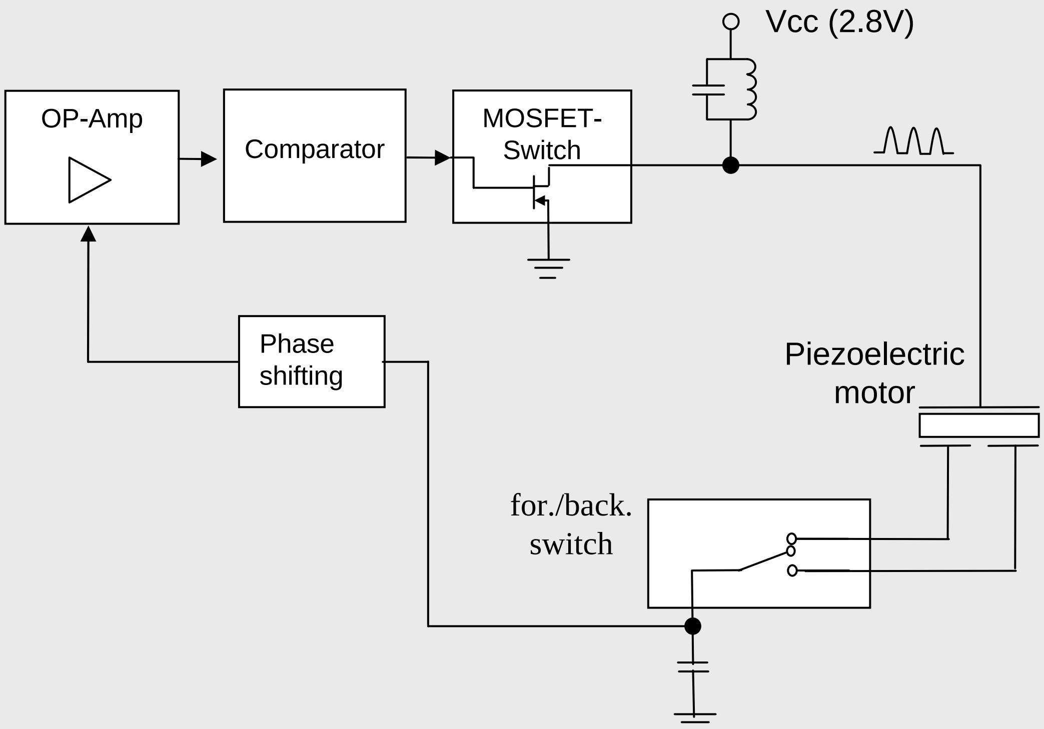
Self-Tuning Oscillator Drive Circuit

- Two conditions have to be fulfilled for a circuit to oscillate:

  -Amplitude Condition: the loop gain must be equal to or grater than 1

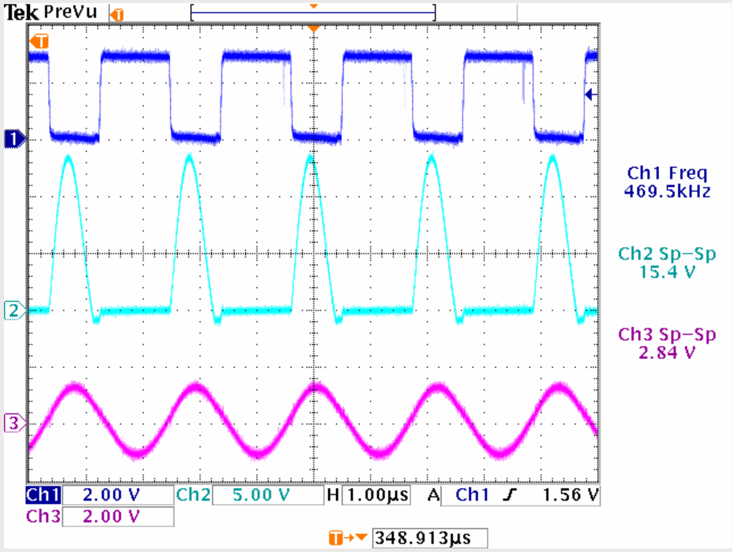
  -Phase Condition: the loop phase shift must be equal 360° (or zero)

- Half-wave current switching parallel resonant boost converter
- The current trough the motor will be used as a feedback



Self-Tuning Oscillator Drive Circuit

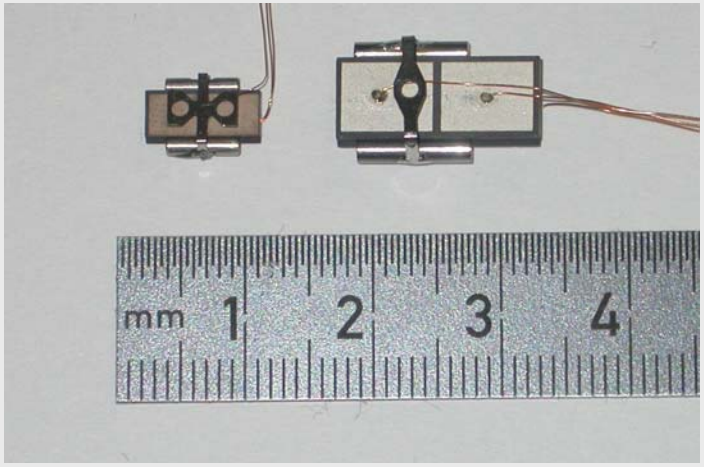
- A self-tuning drive circuit
- The drive electronics can operate on a supply voltage starting at 2 V
- With a 3 V supply it generates an output voltage of 15 Vpp
- The resonant frequency of the 9-mm motor is 470 kHz.

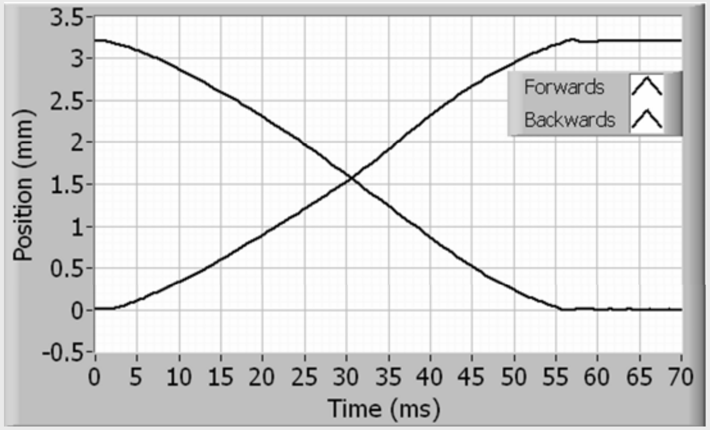


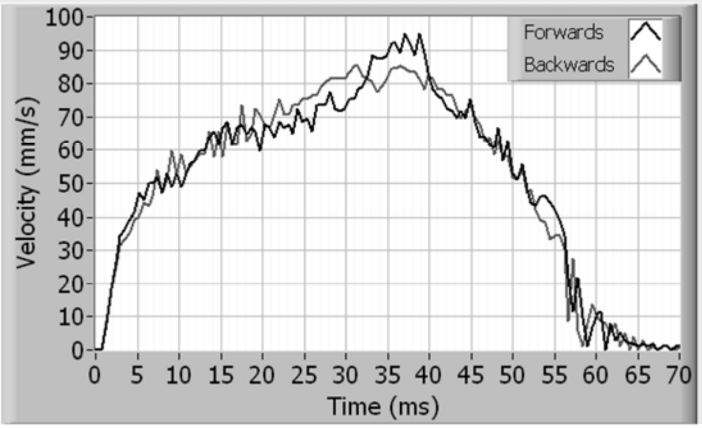
Drive electronics signal. Ch1: Signal at the switching transistor;; Ch2: Voltage at the motor Ch3: Feedback Signal.

Drive Characteristics of the New Micromotors

- In open-loop, the 9 mm motor attains a speed of up to 100 mm/s (@ 15V)
- A maximum speed of 180 mm/s can be reached
- With a voltage of 25 V, the 9 mm motors generate maximum forces of up to 150 mN
- The smallest possible steps in open-loop mode are 100 nm







Positioning Test Measurement with PILine® Ultrasonic Piezomotor Controller

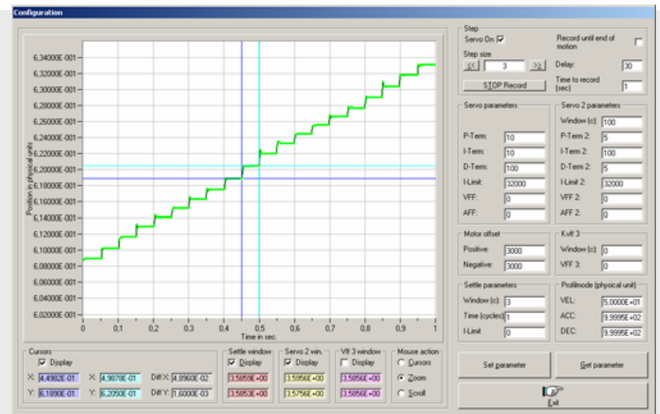
- PILine® Motor Controller
- Incremental linear scales are used for position feedback

Pulse width	Step width	Repeatability
50 µs	0.4µm	±0.1 µm
100 µs	1µm	±0.2 µm
200 µs	2.6µm	±0.3µm
500 µs	5.1µm	±0.4µm
1 ms	10µ	±1µm

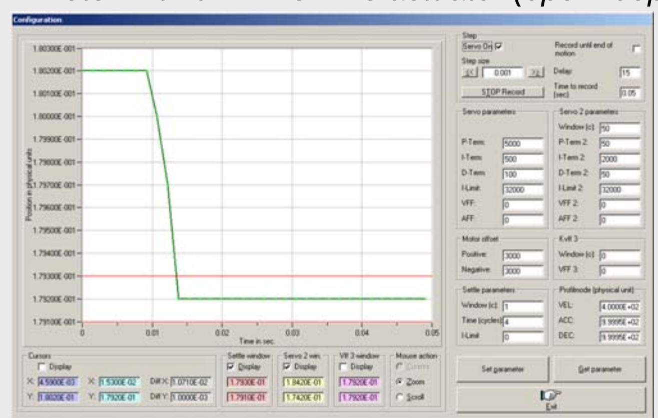
Open-loop positioning of the motor with 9×4×1.5mm3 actuator

Step width	Settle window	Settling time
1mm	3 Counts (0,3µm)	60 ms
10µm	3 Counts (0,3µm)	22ms
1µm	3 Counts (0,3µm)	18ms
0,5 µm	1 Count (0,1µm)	35ms
0.1 µm	0 Counts	33ms

Closed-loop positioning of the motor with 9×4×1.5mm3 actuator



100µs, 20Hz,1µm step of the motor with 9×4×1.5mm3 actuator (open-loop)



Less then 18ms settling time for a 1µm step of the motor with 9×4×1.5mm^3 actuator (closed-loop)

Conclusions

- A new type of piezoelectric ultrasonic motor has been developed
- Dimensions can be easily reduced down to a few millimeters
- Motors achieves more then 2 million cycles with no problems
- Drive electronics can easily be implemented in ASIC technology
- New motors are well-suited for moving small components, like optics (autofocus, zoom), relays, switches, shutters, etc.