Piezo driving technology: principles and examples

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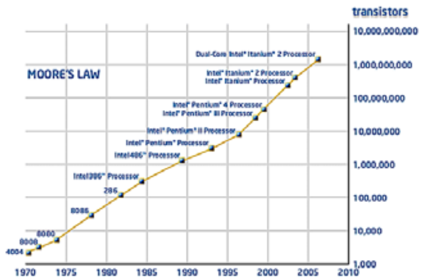
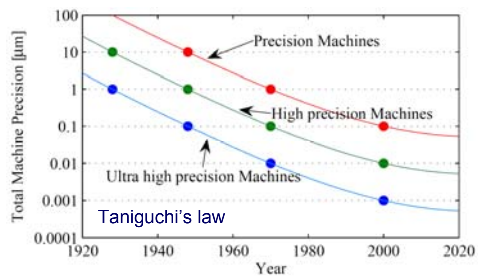
Overview

1. Introduction
2. Piezo driving technology: the basics
3. Piezo driving technology: examples
4. The Leuven motor
5. Summary

1. Introduction

- Currently: transition from micro to nano age in several industries
  - Semiconductor industry (faster CPU's and denser storage devices)
  - Production and manufacturing industry (precise components, eg. lenses)



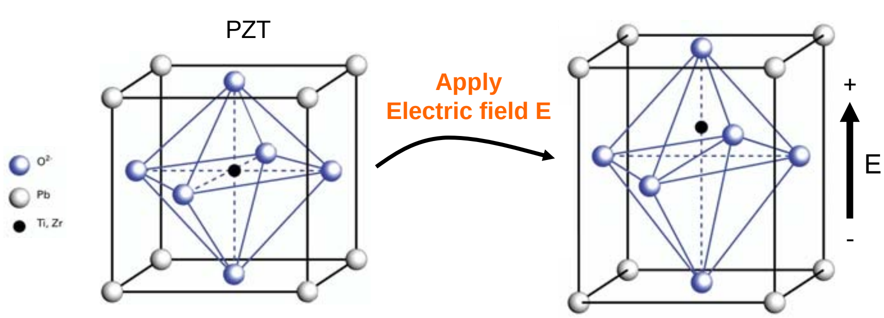


- To support this transition: growing demand for extremely accurate positioning systems in demanding environments, e.g. vacuum

  ⟶ **Piezo Driving Technology**

2. Piezo driving technology: the basics

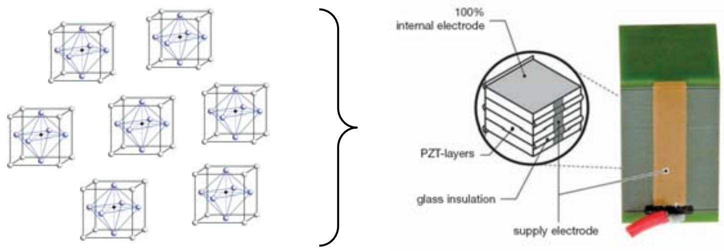
- Physical principle: inverse piezoelectric effect
  - Discovered in 1880 by Pierre and Jacques Curie
  - Most common material: PZT



Typical achievable strain ratio: 1/1000, e.g. 1 μm stroke for 1 mm PZT

2. Piezo driving technology: the basics

- Piezo actuators

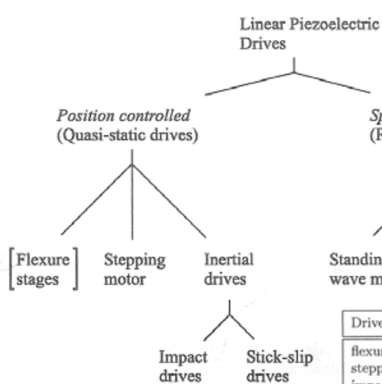


  - Single layer piezo actuators: up to several kV to achieve 1/1000 strain ratio
  - Multilayer piezo actuators = piezo stacks: a few 100 V are sufficient
  - Sub-nanometer resolution, high force density, high stiffness, no magnetic disturbance, vacuum compatible, but … **always a limited stroke**

Source images: http://www.physikinstrumente.com/ and http://www.piezomechanik.com/

2. Piezo driving technology: the basics

- Piezo motors
  - Many use piezo actuators as core elements
  - Several principles to achieve a large stroke

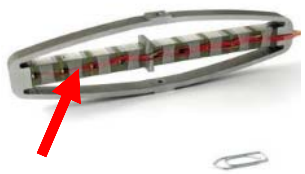


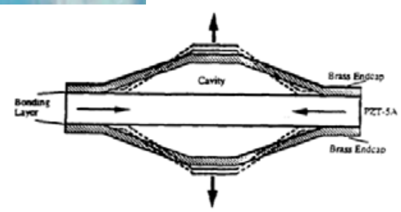
Drive principle	stroke	speed	force	resolution
flexure stage	0.1 mm	> 100 mm/s	> 10 N	< 1 nm
stepping drives	> 100 mm	10 mm/s	10 N	10 nm
impact force drives	10 mm	1 mm/s	1 N	0.1 – 1 µm
stick-slip drives	> 100 mm	1 mm/s	1 N	10 – 100 nm
standing wave motors	> 100 mm	> 100 mm/s	5 – 10 N	0.1 – 1 µm
traveling wave motors	> 100 mm	> 100 mm/s	5 N	10 – 100 nm

3. Piezo driving technology: examples

- Quasi-static flexure stages
  - MadCity Labs Nano-Mini stage

  - Cedrat APA1000XL

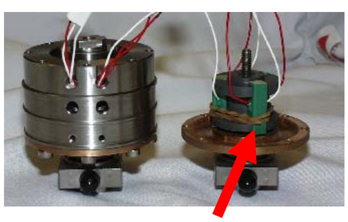


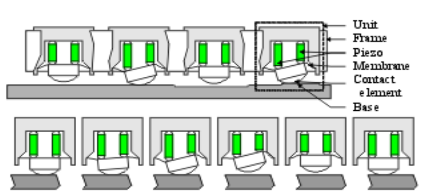


Source image: The “Cymbal” electromechanical actuator, A. Dogan, J.F. Fernandez, K. Uchino, R.E. Newnham, IEEE

3. Piezo driving technology: examples

- Quasi-static stepping motor: PMA planar piezo stepper

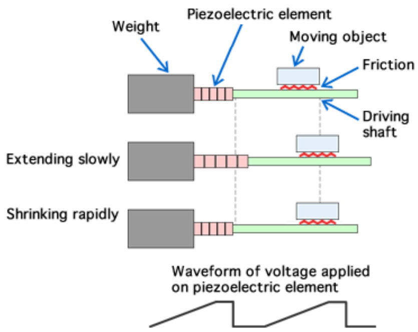




		Drive	Bearing
Positioning	Resolution	5nm	2.5nm
	Measurement accuracy	0.3 µm	0.1 µm
	Travel	ø100 mm	5 µm
	Velocity	2 mm/s	-
Stiffness	Passive (3 units)	55 N/µm	150 N/µm
	Active (3 units <50Hz)	120 N/µm	320 N/µm
	Passive (5 units)	70 N/µm	200 N/µm
	Active (5 units <50Hz)	150 N/µm	450 N/µm

3. Piezo driving technology: examples

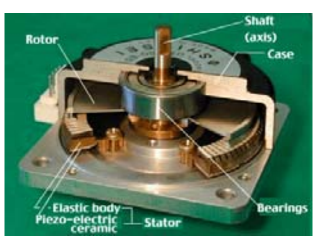
- Quasi-static inertial motor: Konica-Minolta



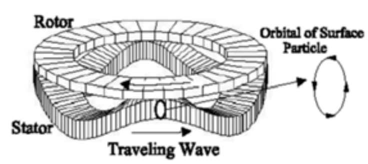
Source images: http://www.konicaminolta.com/

3. Piezo driving technology: examples

- Resonant traveling wave motor
  - Shinsei rotational motor

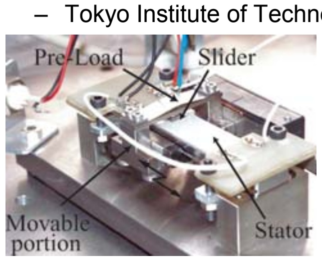


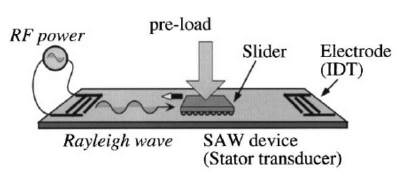
Source image: http://www.tky.3web.ne.jp/



Source image: Survey of the various operating principles of ultrasonic piezomotors, K. Spanner, Actuator 2006

  - Tokyo Institute of Technology Surface Acoustic Wave (SAW) motor



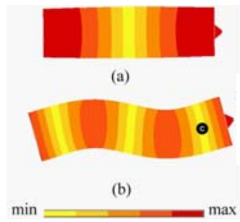


Source images: Surface acoustic wave motor with feedback considering dead zone, K. Spanner, IEEE

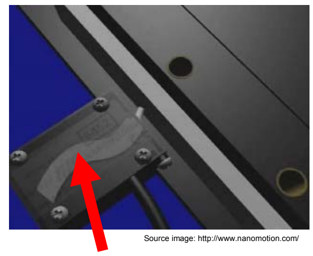
3. Piezo driving technology: examples

- Resonant standing wave motor
  - Nanomotion HR1

Source image: http://www.nanomotion.com/

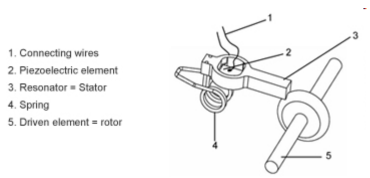


Source image: WISCHNEWSKIY W., KOVALEV S., RAPP J., Actuator 2004



Source image: http://www.nanomotion.com/

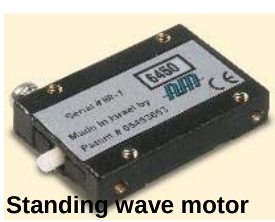
  - Elliptec X15G



Source images: http://www.elliptec.com/

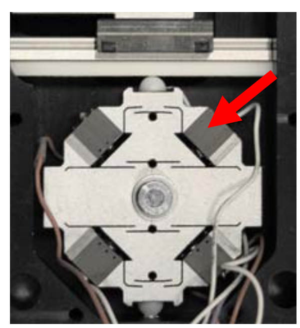
4. The Leuven motor

\+ sub nanometer resolution
\+ high stiffness
\- micrometer stroke



Inertial motor

\- sub micrometer resolution
\- limited stiffness
\+ unlimited stroke

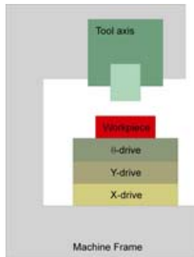


Leuven motor
+ sub nanometer resolution
+ high stiffness
+ unlimited stroke
+ high speed

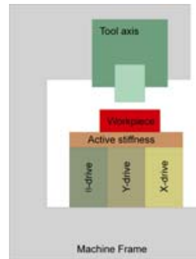
4. The Leuven motor

- Case study: planar nanopositioning system

Classic approach



New concept



Classic approach:

– **Serial stacking** of linear positioning system
– **External bearing**

→ {
- Loss of stiffness
- Cumulative position errors
- Loss of bandwidth

New concept:

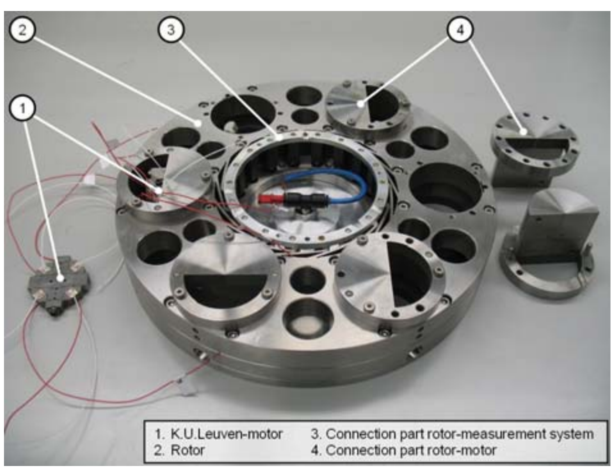
– **Parallel** integration of degrees of freedom
– **Combined bearing and driving** functionality
– **Active compensation**

→ {
- High stiffness
- High accuracy
- High bandwidth

3. The Leuven motor

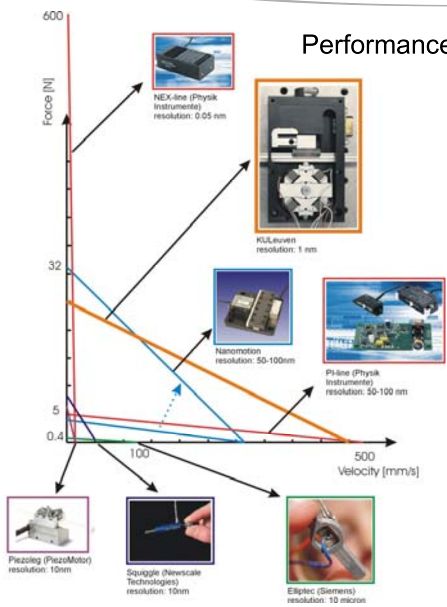
- Case study: planar nanopositioning system
  – Combined driving and bearing functionality
  – Parallel integration of degrees of freedom

} → - High stiffness (~ 100 N/μm)
- Compact



4. The Leuven motor

Performance projection and application domain



Market area	Examples
Nanometrology	Electron microscopes, coordinate measurement machines, wafer inspection machines
Precision manufacturing	EDM machines, micro milling, ELID grinding
Semiconductor	Wafer steppers, E-beam lithography
Medical technology	Robotic surgery, MRI scanners

5. Summary

- Growing industrial demand for more accurate positioning systems in demanding environments
- To fulfill this demand, novel systems are being developed based on the piezo electric effect: piezo driving technology
- General strongpoints of piezo driving technology
  - Extremely accurate
  - High force density
  - Comparatively high efficiency (< 30 W applications)
  - High holding force without power consumption
  - Environmental compatibility
    - Applications requiring no magnetic disturbance
    - (Ultra-high) vacuum applications
    - Cryogenic applications

5. Summary

- Principles to overcome the short piezo actuator stroke
  - Flexure stage
  - Stepping drive
  - Inertial drive
  - Traveling wave drive
  - Standing wave drive

Drive principle	stroke	speed	force	resolution
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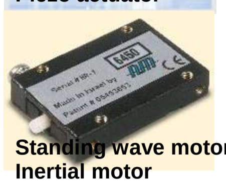
- Leuven motor


Piezo actuator


Standing wave motor
Inertial motor


L… motor
…anometer resolution
…gh stiffness
unlimited stroke
+ high speed

Demo during coffee break!