Aalto University
School of Engineering

Other actuators

KON-C2004 Mechatronics Basics
Raine Viitala 19.11.2024

Feedback

These exercies were really fun and interesting. The difficulty was on point in my opinion.

Exercises were ok but I didn't like the Fourier Analysis assignment. Got a mental breakdown from that one but I guess I learned something which was good.

This weeks exercise was great. I especially appreciated the fourier transform exercise, it gave me a greeat intuition for what the fourier transform does and why it is useful. P.S. can there be a whole course about only lithography and ASML machines? I volunteer as TA.

reliant on correct completion of last exercise

The exercise are amazing and great to solve them but would like more sessions so we can get the help needed.
👍good exercise

fun and enjoyable

Very difficult but still doable

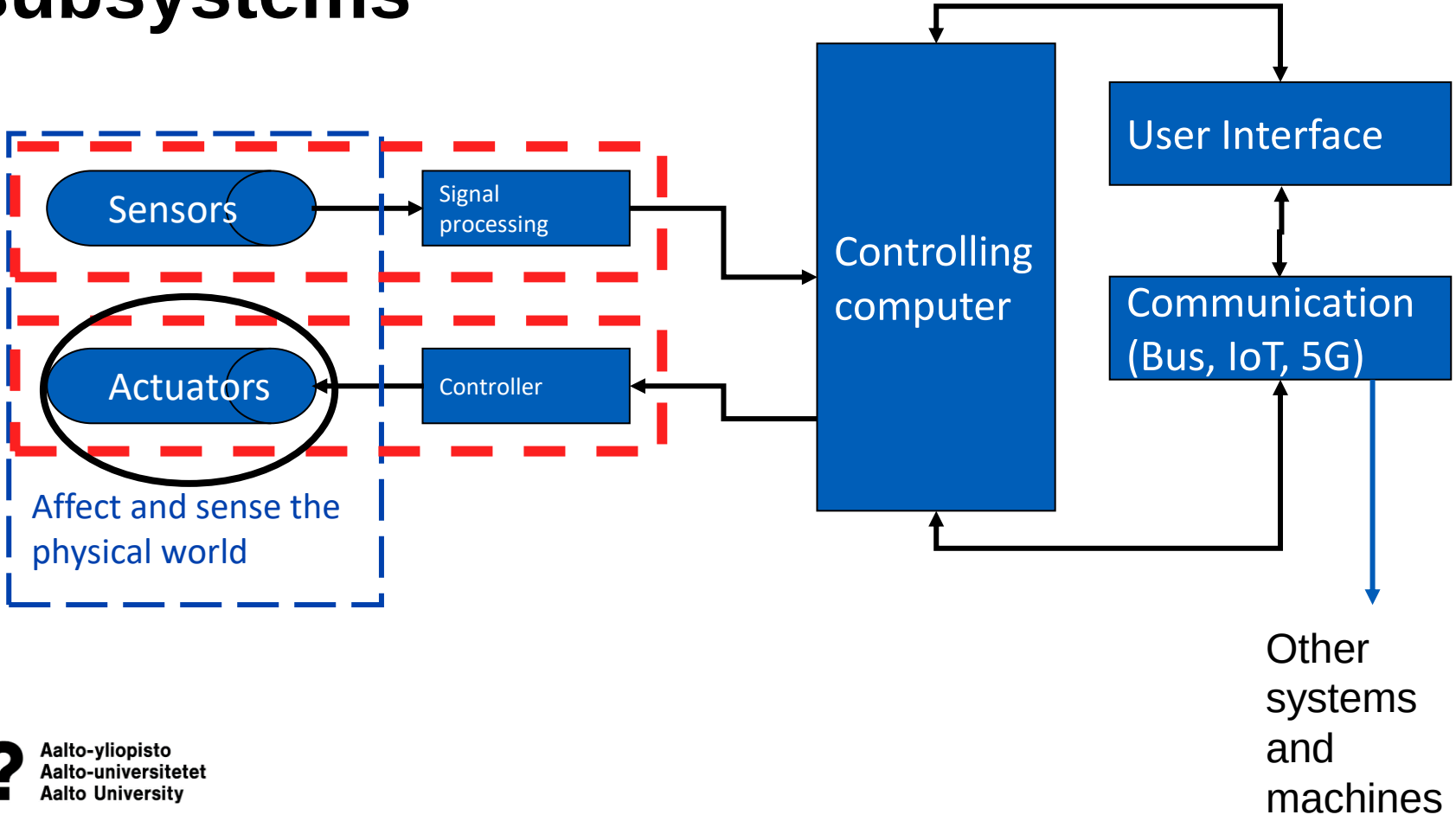
- More readable formating for the instructions, please. For example bullet points instead of wall of text.

This weeks exercises felt easier, i feel suspicious. Overall enjoyed the simulink exercise.

When do the hard exercises begin?

Sick

Mechatronic machine - subsystems



Lecture overview & learning outcome

Pneumatics

Linear motion with electromagnetic devices

- *Conversion from rotary motion*
- *Solenoid*
- *Voice coil*
- *Linear electric motors*

Active materials

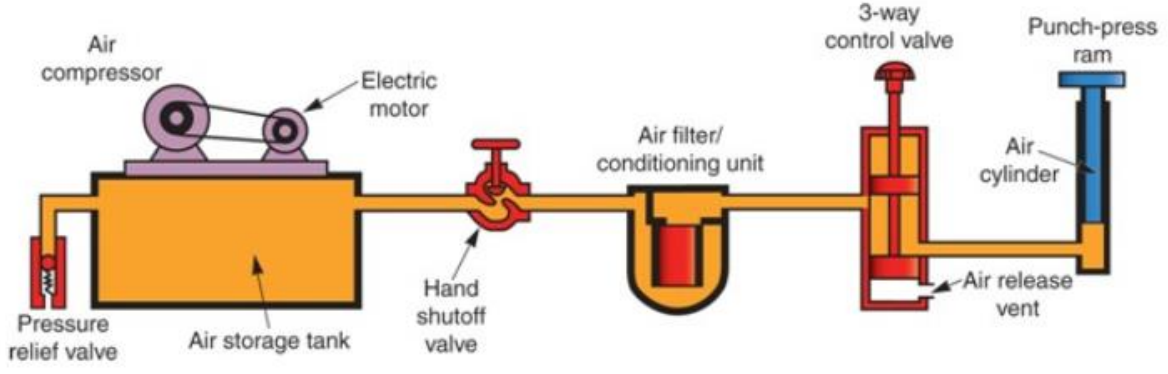
- *Piezoelectric actuators*
- *Magnetorheological fluid*

MEMS actuators

→ Know the operating principle of multiple ”other actuators”

Pneumatics

Pneumatics



Cheap actuators

Moderate forces

Clean and safe

- *Food industry*
- *Oil industry*

Fast, repetitive motions

- *Gripping, stamping, valve actuators etc.*

Usually open loop because of compressibility

- *Movements against a mechanical stop*
- *Servosystems also possible*

Pneumatic example

Air supply

Supply pressure

- *Typical range 2-10 bars (0.2-1 MPa)*
- *Usually 6-7 bars*

Components

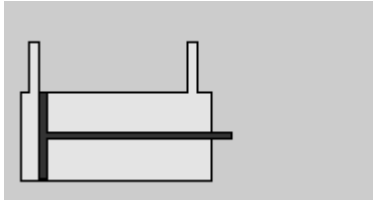
- *Air compressor*
- *Filter, dryer*
- *Storage tank*

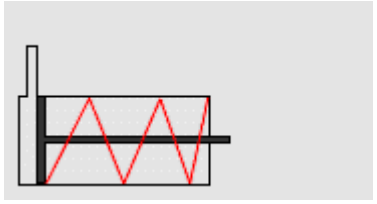
Low system efficiency

- *Heat produced by the compressor*
- *Leaks in piping*

Pneumatic cylinders

http://en.wikipedia.org/wiki/Pneumatic_cylinder





Force = pressure * piston area

Single or double acting

Force usually < 10 kN

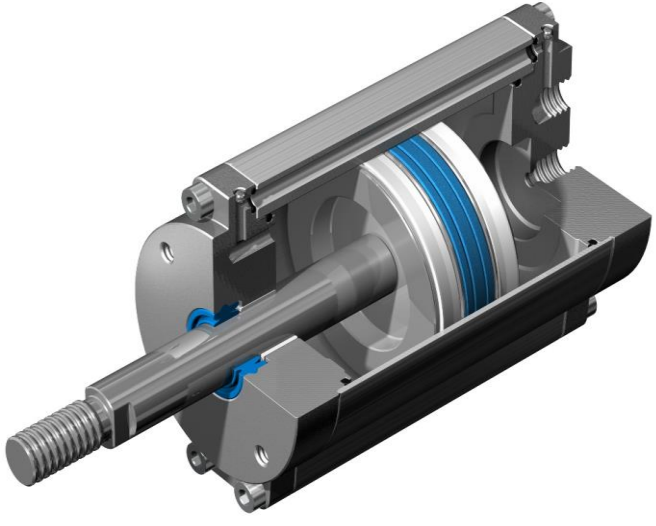
Stroke 1-3000 mm

Rodless

- *Very long strokes*

Telescope

- *Long stroke, compact when retracted*

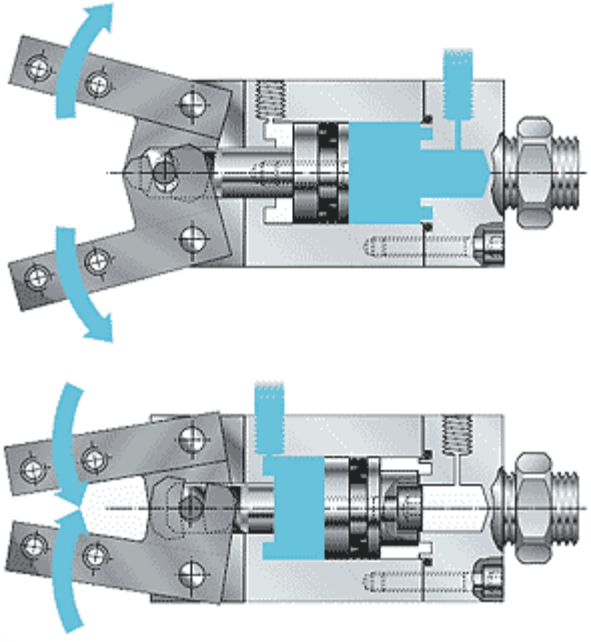


http://www.mathworks.com/matlabcentral/fileexchange/screenshots/3366/original.jpg

Pneumatic grippers

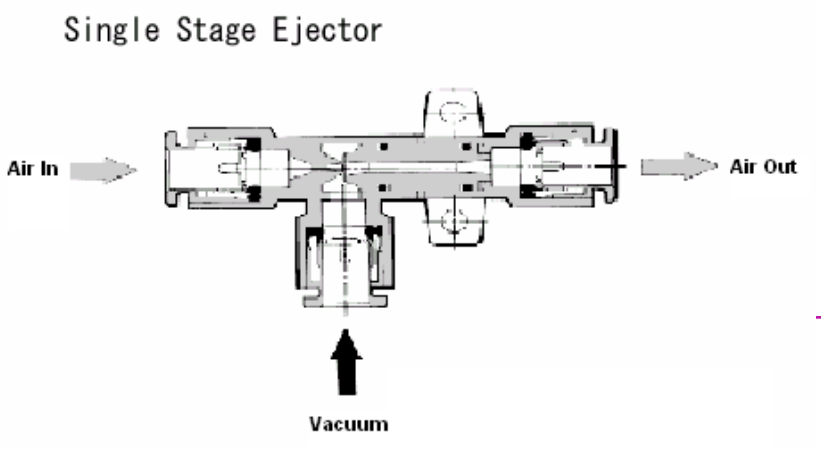
”Cylinder” grippers

- *Clamps or tooling jaws*
- *”Fingers”*



Vacuum grippers

- *Vacuum created with ejector*



http://www.deltatecnix.com/plc_prog.htm

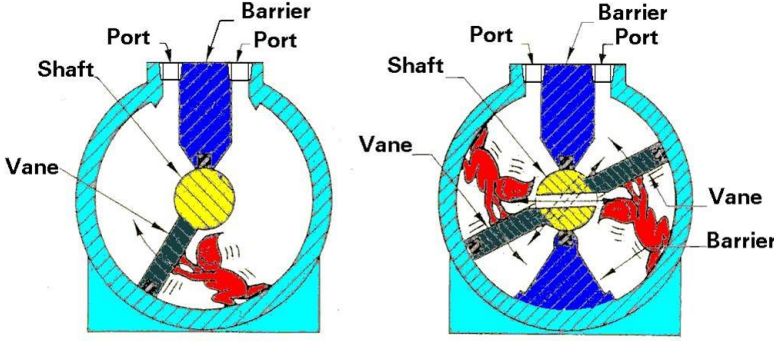
Pneumatic rotary actuators

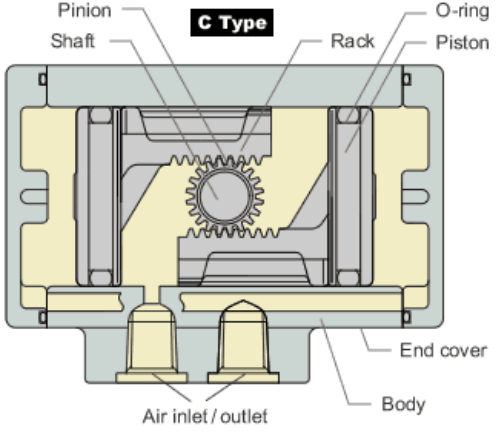
Motors

- *Used a lot in hand-held tools*
  - Sanders, power wrenches, grinders etc.
- *Starter motors for large electric or combustion motors*
- *Dental drill – rpm up to 400 000*

Semi-rotary devices

- *Vane type*
- *Rack and pinion type*





Pneumatic muscles and bellows

Single acting

High force

Short stroke

Bellows

- *Forces can be over 200 kN*
- *Short stroke <0,5 m*

Muscles

- *Maximum force up to a few kilonewtons*
- *Stroke ~25 % of nominal length*

http://pneumatics-en.timmer-pneumatik.de/artikel/artbild/maxi/ZHO-SP2.jpg

http://www.boblan.de/pictures/FESTO-FluidicMuscleInflated.jpg

Pneumatic muscles

Linear motion with electric devices

Converting rotation to linear movement: Screws

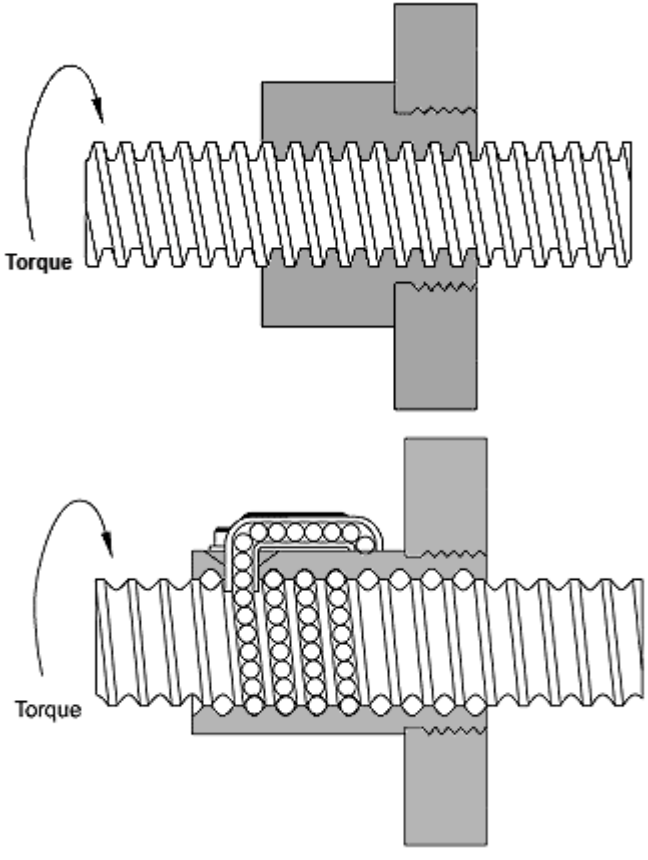
http://www.roton.com/page.aspx?id=28

Lead screw

- *Nut with internal thread*
- *Friction caused by sliding*
  - Not for continuous use

Ball screw

- *Nut with grooves and ball bearings*
  - Larger size
- *High force - minimal friction*
- *High accuracy*



Lead screw example

Converting rotation to linear movement: Gears and belts

Rack & pinion

- *Rack = linear gear*
- *Pinion = circular gear*

Chain & sprocket

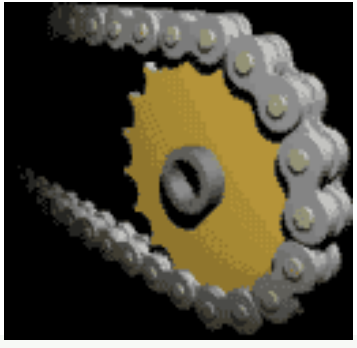
Belt

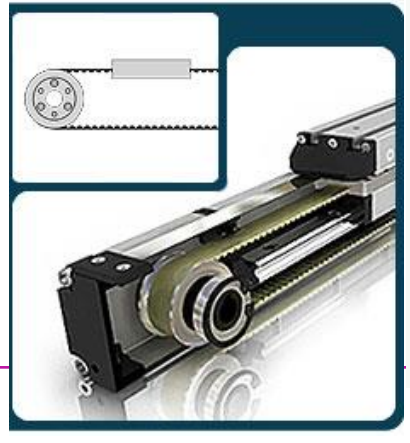
- *Timing belt*
- *Flat belt*

Cam

http://en.wikipedia.org/wiki/Rack_and_pinion

http://en.wikipedia.org/wiki/Roller_chain

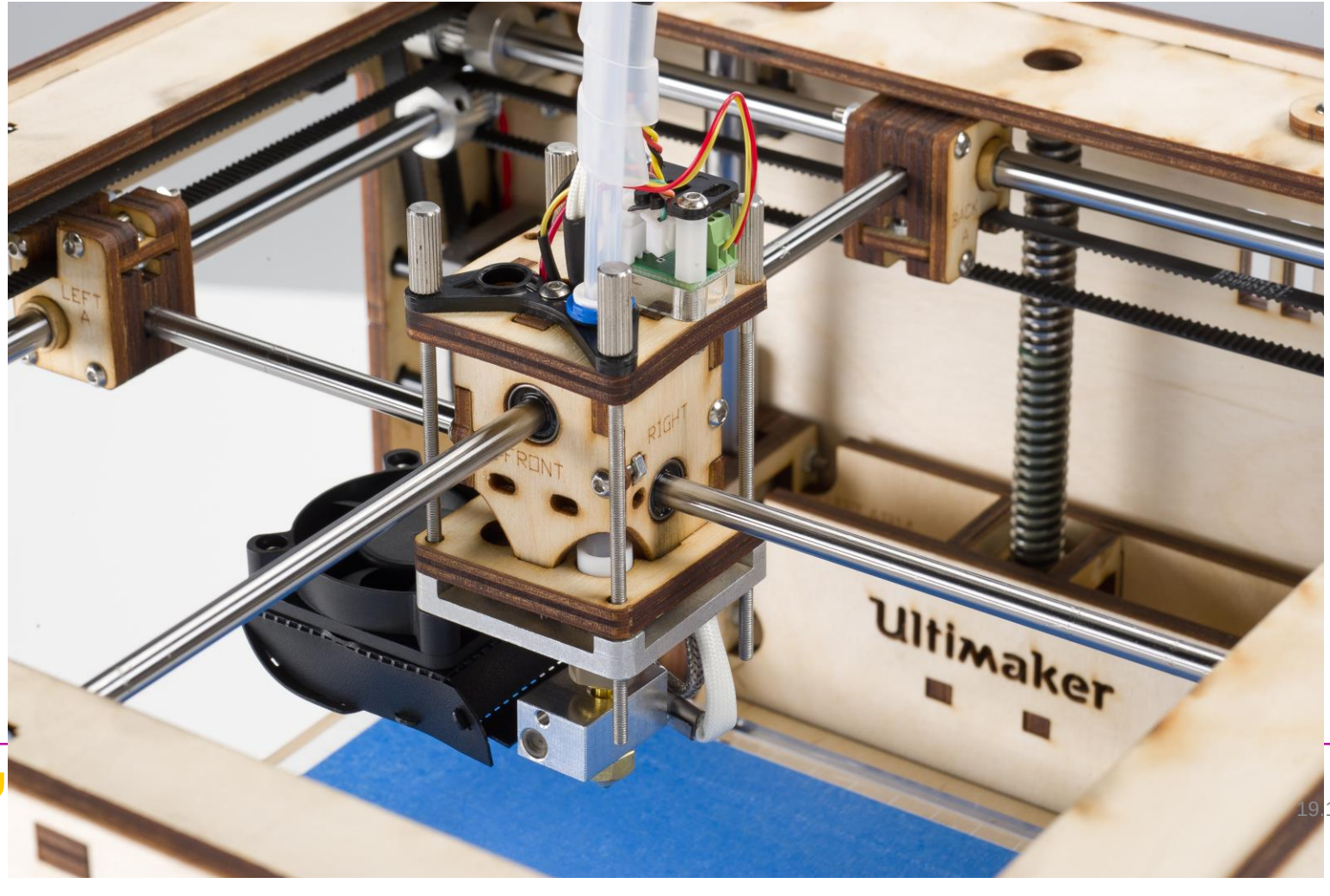




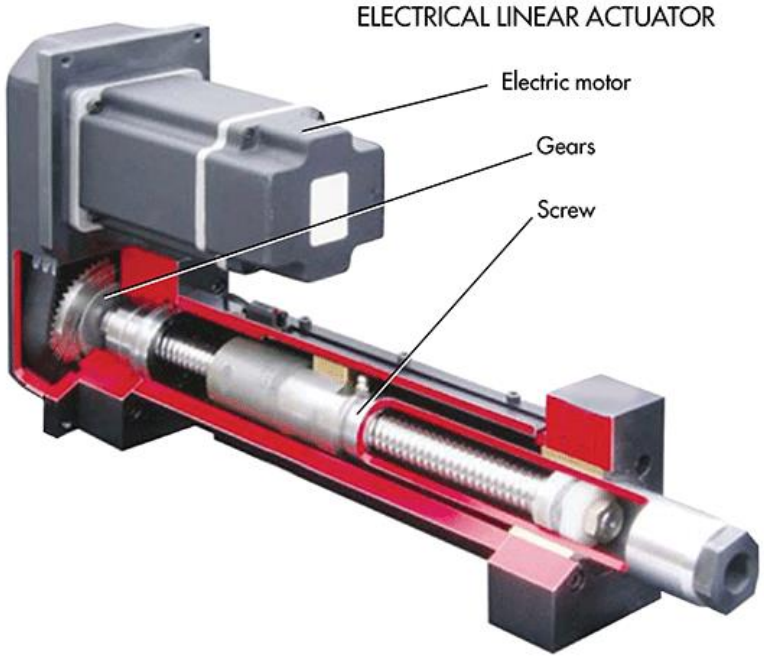
http://www.pbclinear.com/Blog/How-to-Adjust-Belt-Tension-on-an-MT-Series-Actuator

http://en.wikipedia.org/wiki/Cam

Example: Ultimaker 3D printer



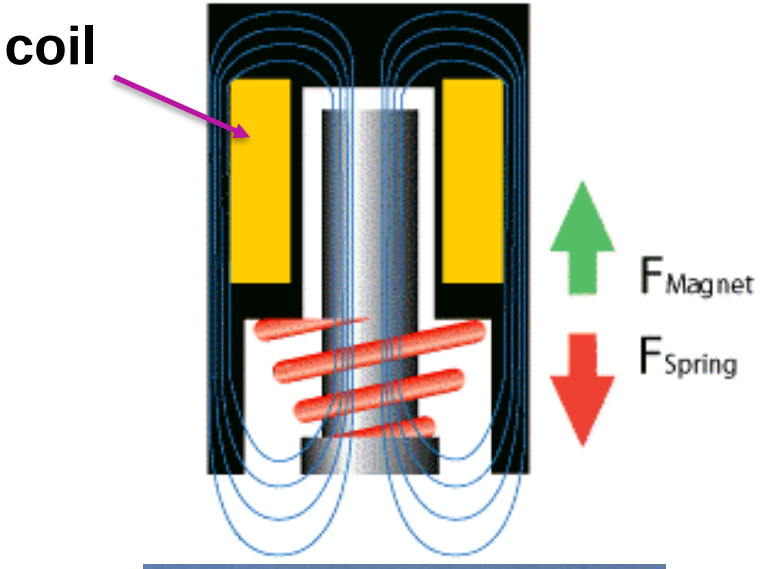
Electric linear actuator



http://machinedesign.com/linear-motion/what-s-difference-between-pneumatic-hydraulic-and-electrical-actuators

http://www.iai-gmbh.de/en/press-and-media/press-information/press-informationen-newsreader/items/x-y-z-electric-cylinders-take-the-air-out-of-linear-motion.html

Solenoid



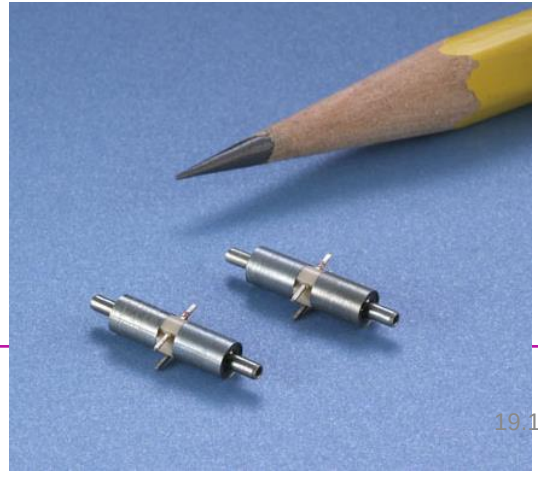
End to end linear movement

Larger movement -> smaller force

Single acting

- *Other direction with a return spring or another solenoid*

Often used as actuators for hydraulic and pneumatic valves



Solenoid example

Voice coil

High force - up to kilonewtons

Stroke up to a few centimeters

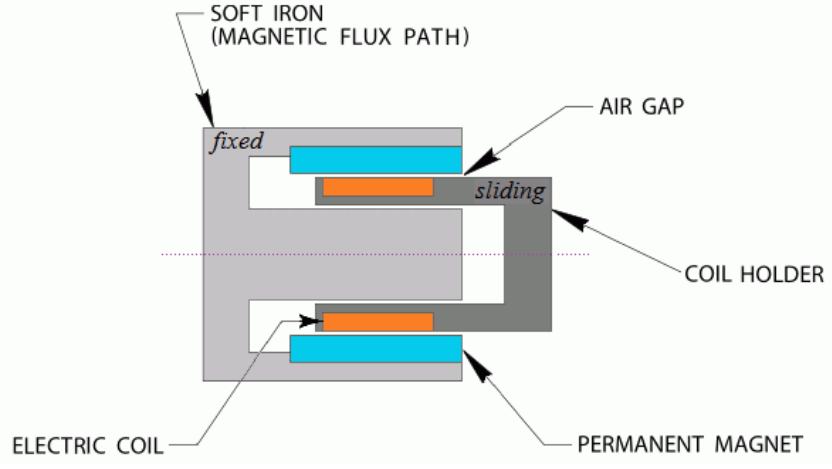
Low moving mass – high dynamics

Accurate position control

- *with internal or external position feedback sensors*

Used for example in speakers and hard disks

Permanent magnet and coil



Voice coil example

Voice coil principle

Linear motors

Moving coils on a rail of magnets

High speed – up to 6 m/s

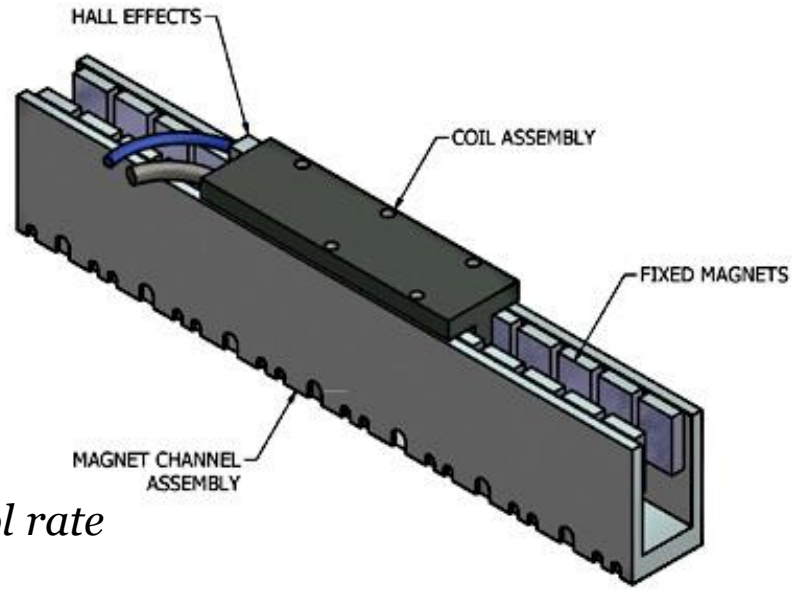
High accuracy

- *Depending on feedback resolution*
- *No backlash*
- *Stiffness depends on driving current and control rate*

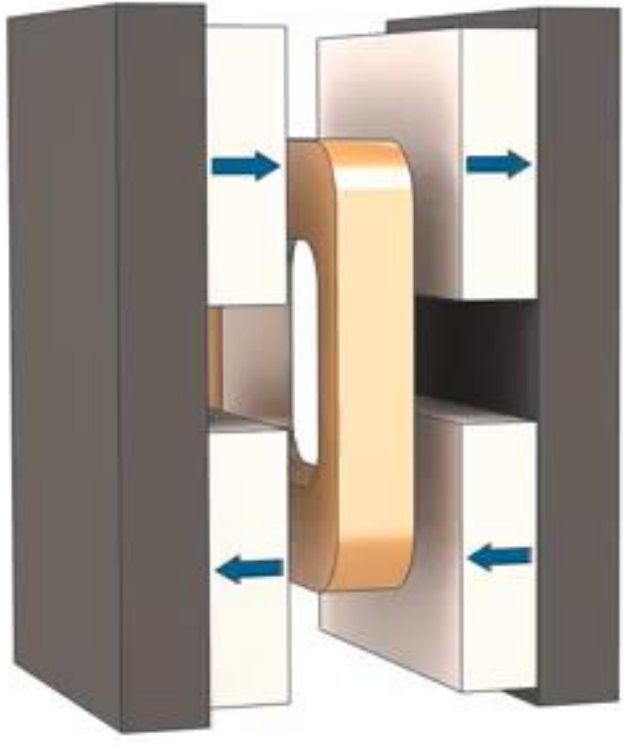
High reliability

Moderate force

Expensive



Linear motor principle



Linear motor example

Active materials

Piezoelectric stack actuators

Very high force / size

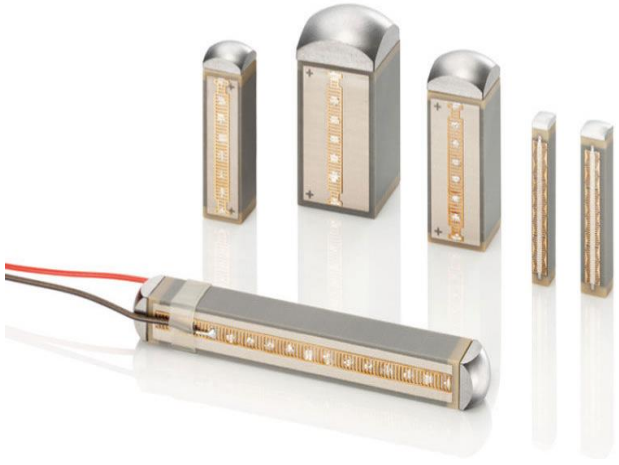
- *For example ø10 mm actuator -> 1 kN*
- *Comparable to hydraulics*

Very low displacement

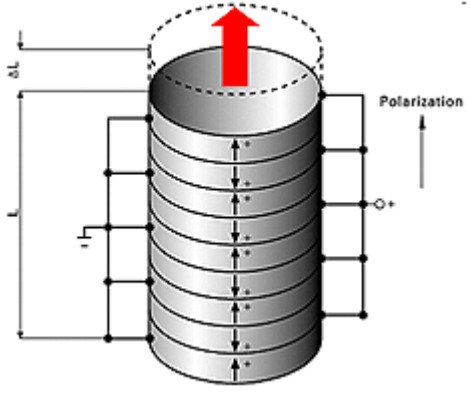
- *About 0,1 % of length – 1 µm per 1 mm*
- *Positioning resolution in nanometers*
- *Can be amplified -> reduced stiffness and dynamics*

High dynamics

- *Sub-millisecond response*
- *Frequencies up to 100 kHz*



http://img.directindustry.com/images_di/photo-g/piezoelectric-actuators-linear-multilayer-13949-4710033.jpg



http://www.physikinstrumente.com/product-detail-page/p-604-202820.html

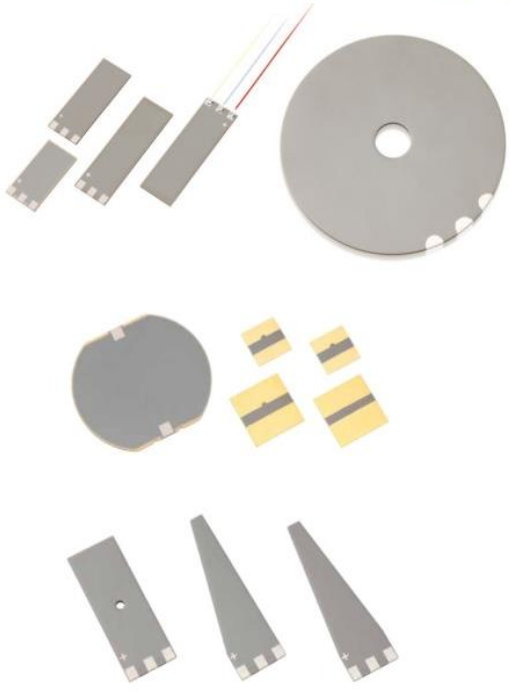
Piezoelectric benders

Larger movement

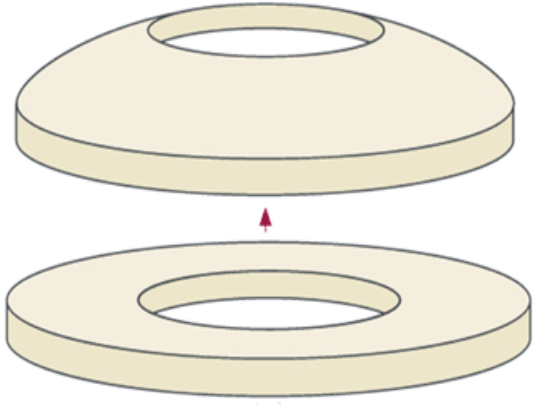
- *Up to a millimeter*

Low force

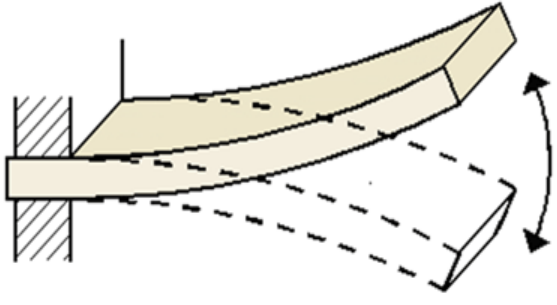
- *Benders <2 N*
- *Ring benders <20 N*



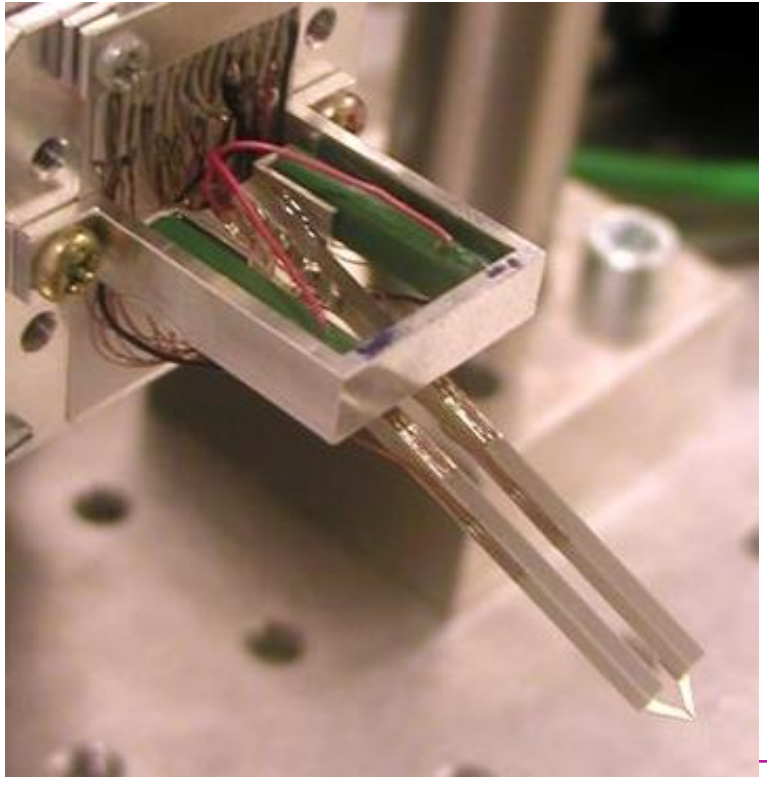
http://www.opli.net/img/magazine/eo/2012/news/bimorph_pc_pi.jpg



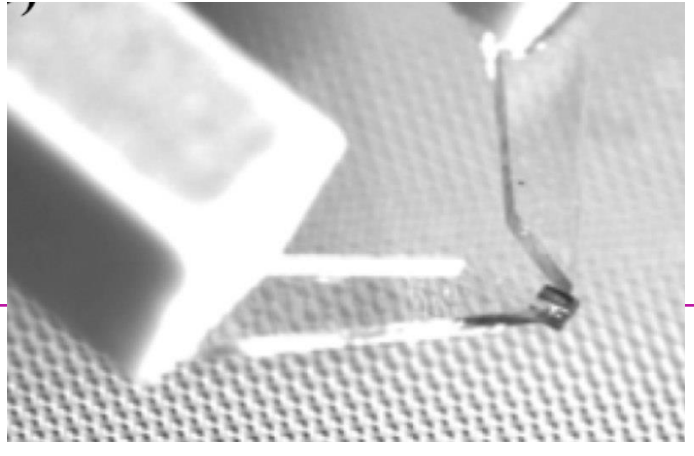
http://www.noliac.com/Actuators-7787.aspx



Piezo example application: micro gripper

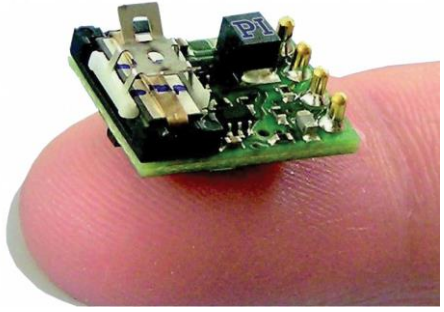


- **Handles small components**
  - *10-500 μm*
- **2 double benders and 2 stacks**
- **6 degrees of freedom**
- **10 strain gages for position feedback**



Piezoelectric motor

http://www.motioncontroltips.com/faq-what-are-piezo-elements-and-piezo-motors/



”Piezoelectric stepping motor”

- *Small steps -> high precision*

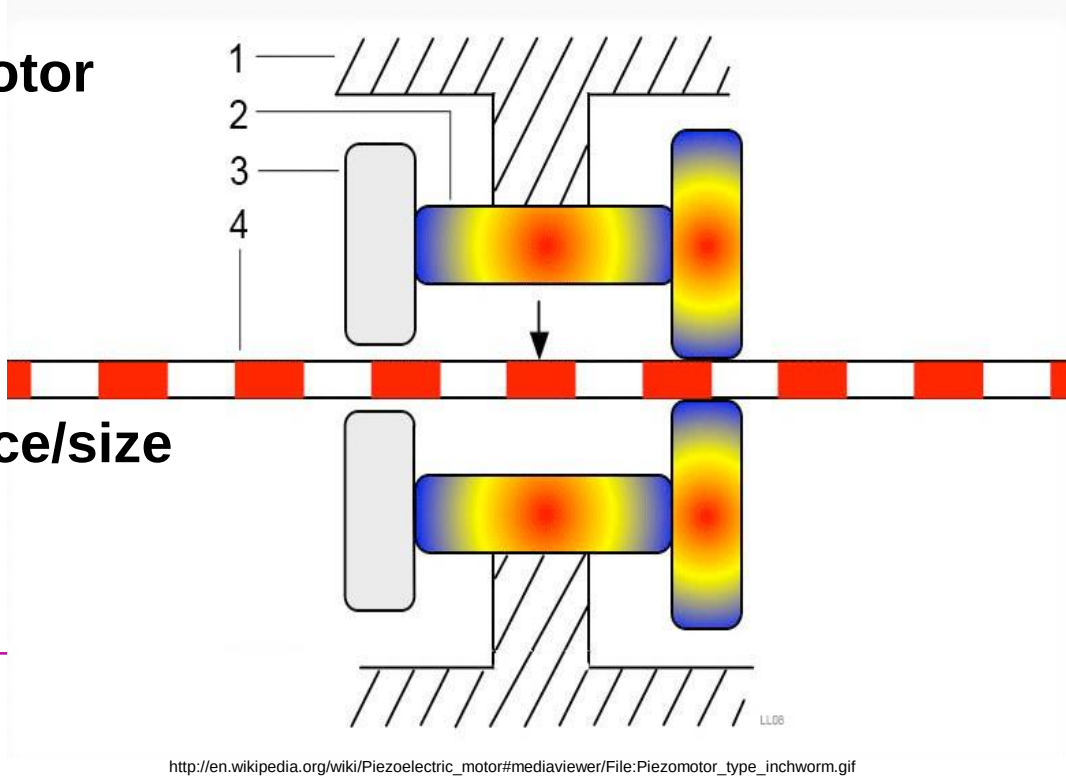
Also known as ultrasonic motor

- *Stepping frequency >20 kHz*

Used widely as camera autofocus motor

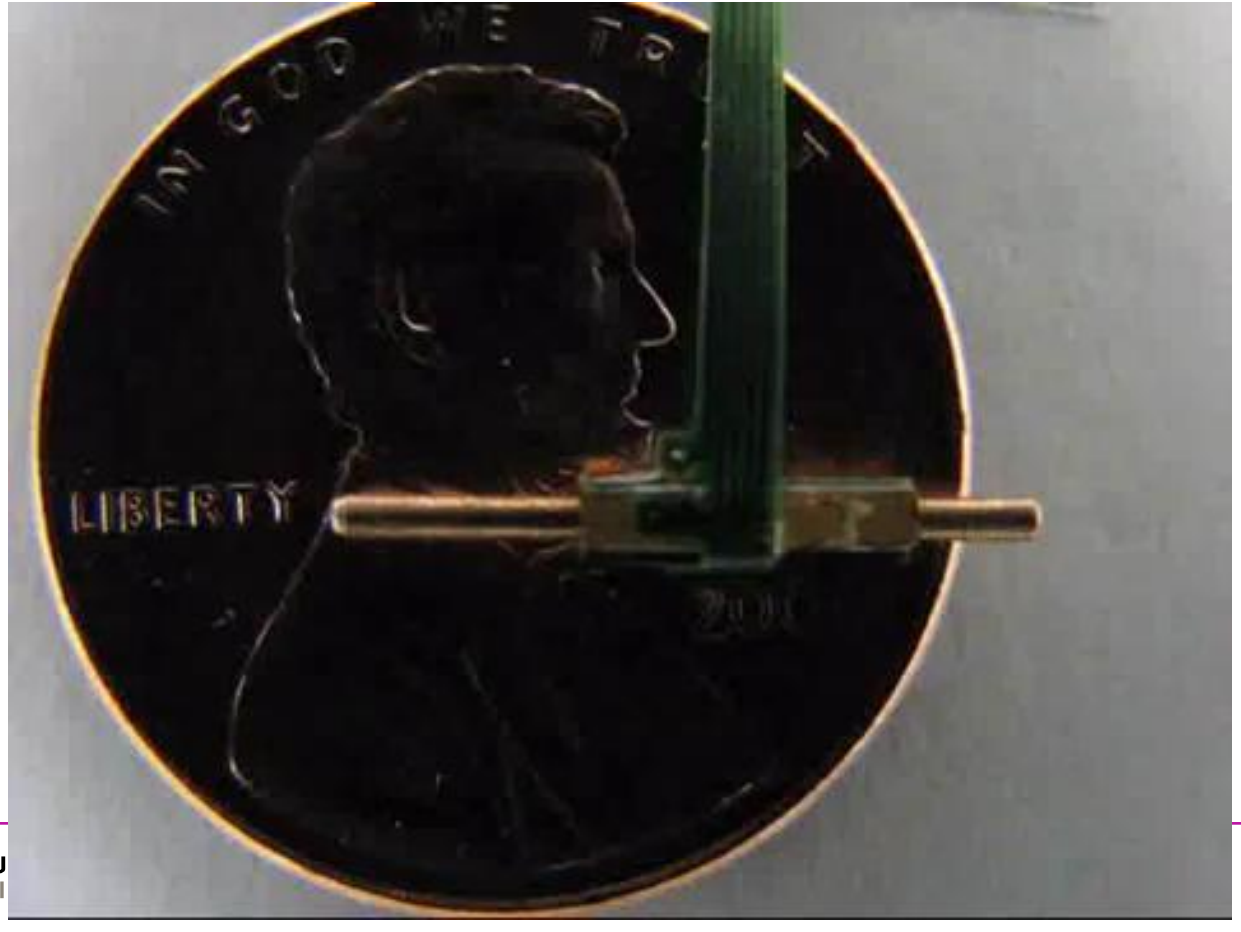
Rotating or linear

Low cost, compact, high force/size



http://en.wikipedia.org/wiki/Piezoelectric_motor#mediaviewer/File:Piezomotor_type_inchworm.gif

Miniature piezoelectric linear motor

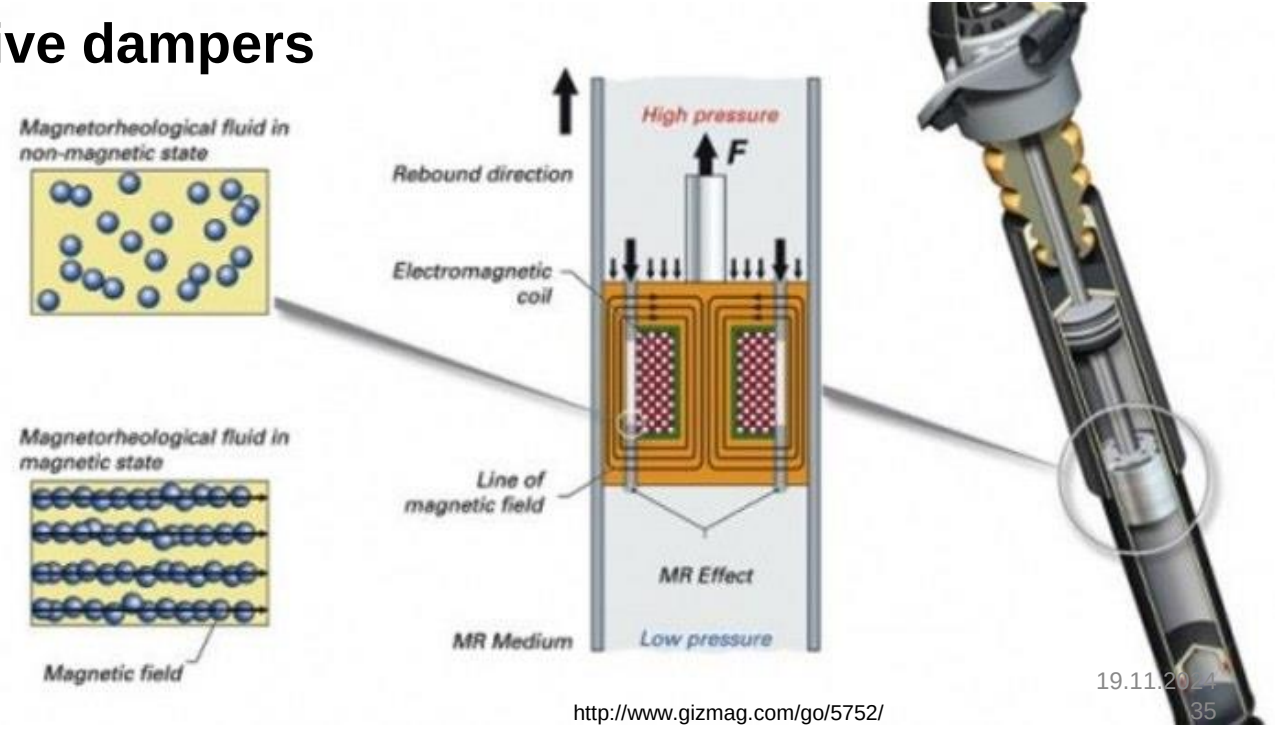


Magnetorheological (MR) fluid

Hydraulic fluid (oil) with iron particles

Magnetic field controls the yield stress (”viscosity”) of the fluid

Applied in semiactive dampers



http://www.gizmag.com/go/5752/

Other active materials

Magnetostrictive materials

- *Change in magnetic field – 0.1-0.2 % strain in material*
- *High force*

Electrostrictive materials

- *Electric field*

Shape memory alloys (SMA, memory metal)

- *Change in temperature -> change in shape*

(Ferro-) Magnetic shape memory alloys

- *Change in magnetic field – up to 10 % change in dimensions*

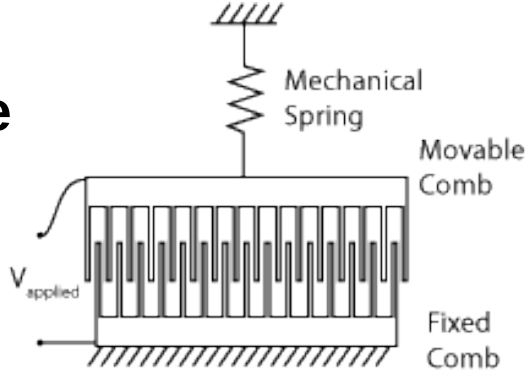
MEMS actuators

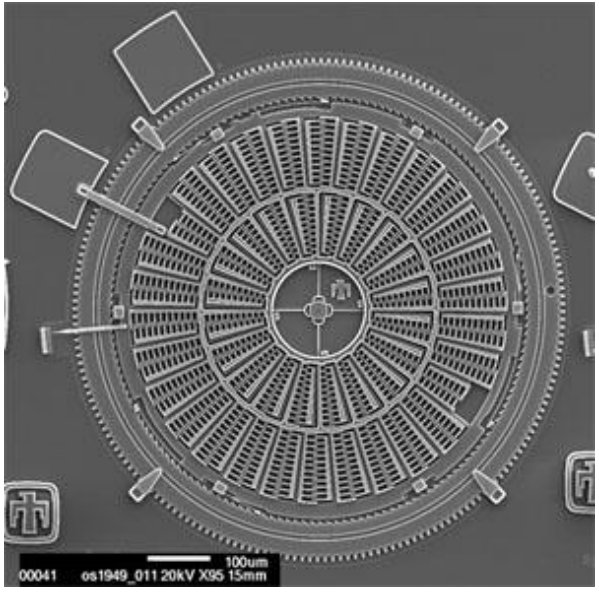
MEMS actuators

https://www.mems.sandia.gov/about/actuators.html#ref4

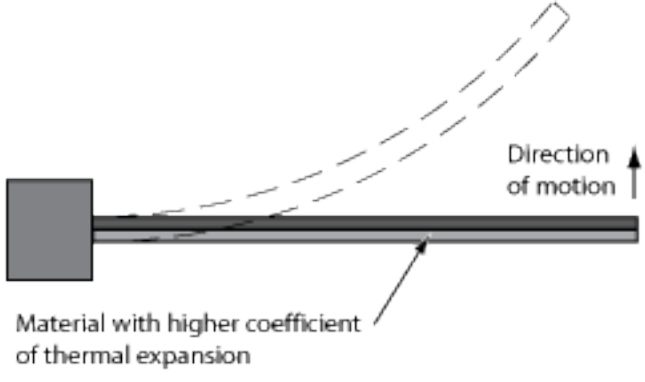
Electrostatic comb drive

- *Displacement max few micrometers*



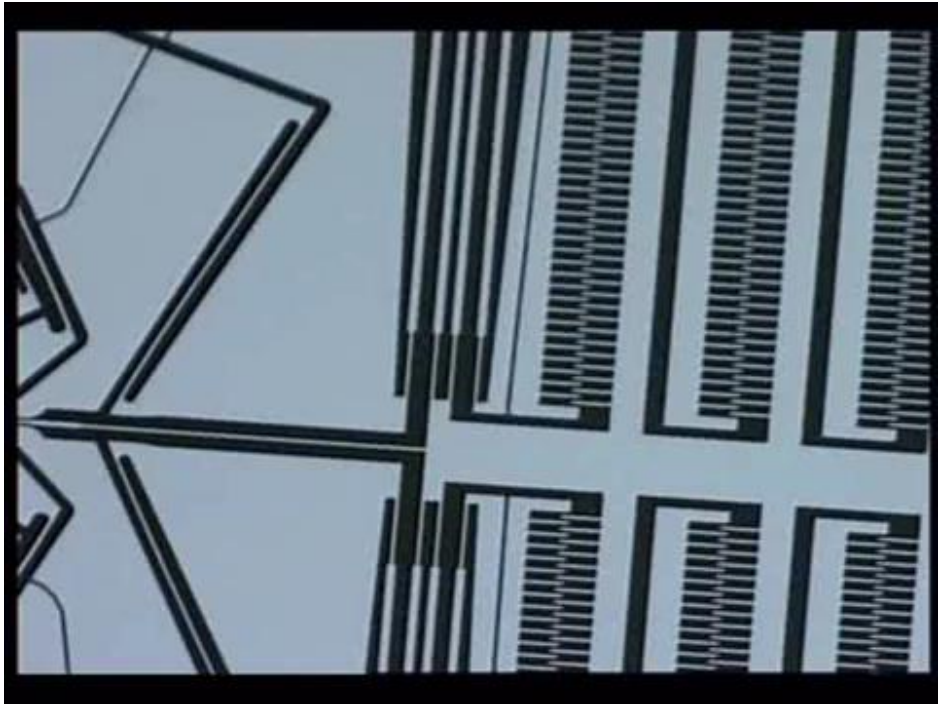


Thermal actuators



http://compliantmechanisms.byu.edu/content/introduction-microelectromechanical-systems-mems

Comb drive

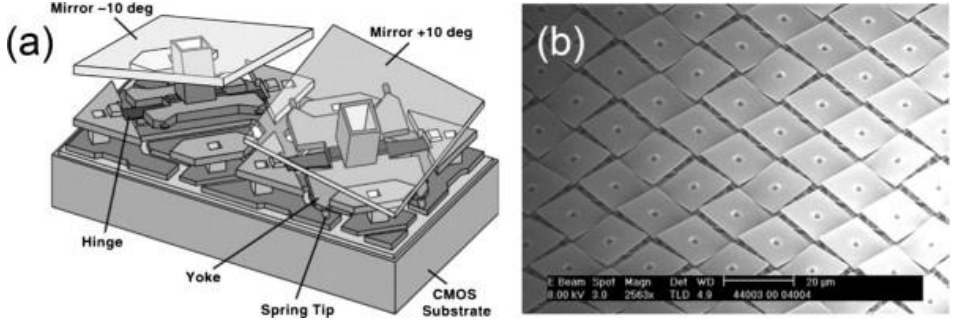


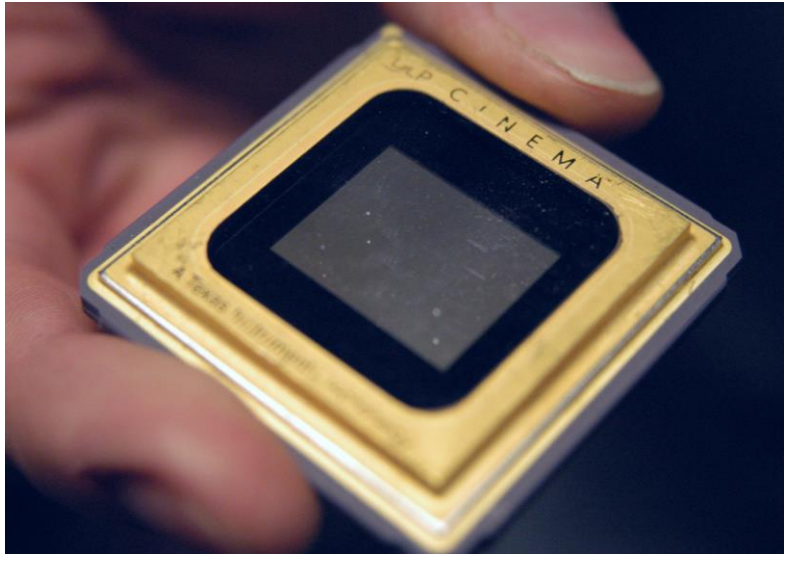
MEMS stepper with integrated position sensor

MEMS example: Digital micromirror device

Digital micromirror device (DMD)

- *4k projector -> 8 million tiny rotatable mirrors*





https://en.wikipedia.org/wiki/Digital_micromirror_device

Summary

Pneumatics is widely used in factories

- *Cheap, safe and robust*
- *Energy inefficient*

Solenoid vs voice coil

Ball/lead screws vs linear motors

Active materials have their niche applications

MEMS open new possibilities