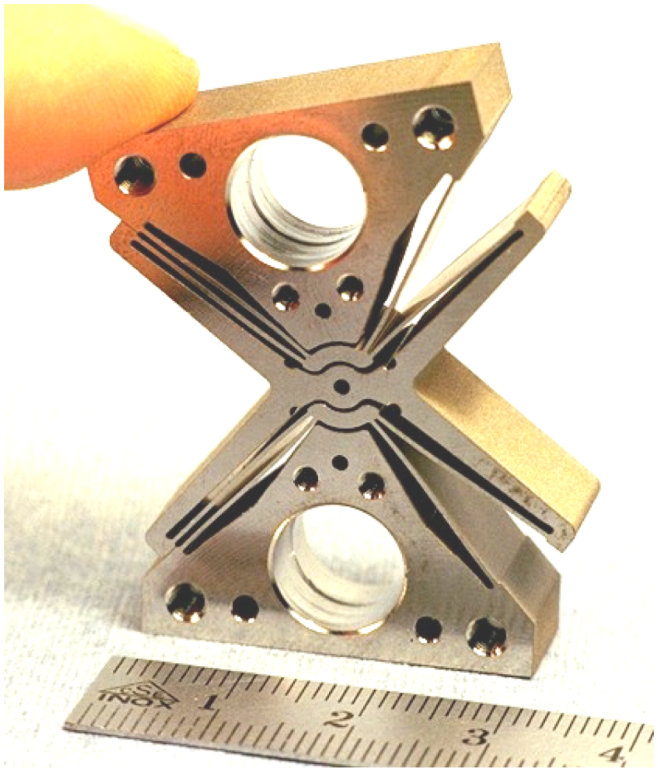
FLEXURE-MECHANISMS

Introduction

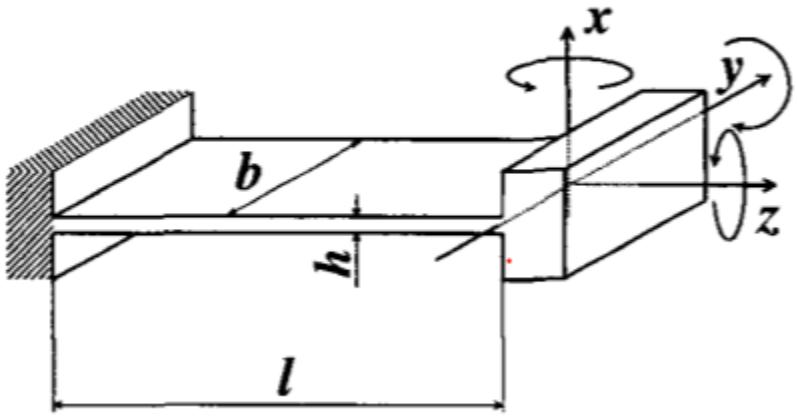


Prof. Simon Henein

Dr. Etienne Thalmann

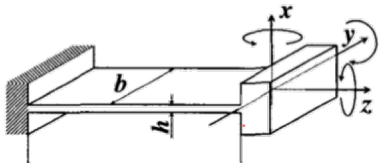
Basic flexure: the blade

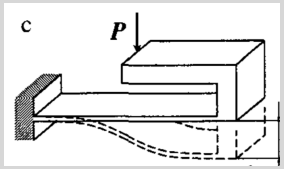
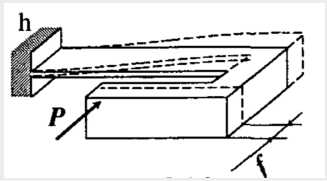
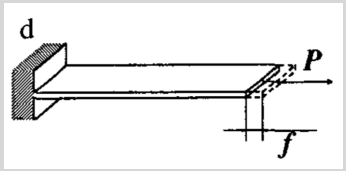
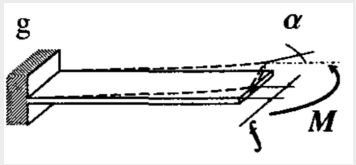
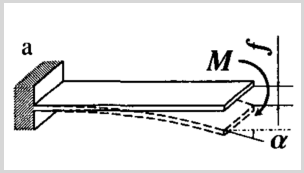
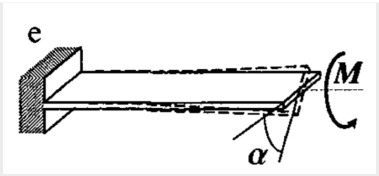
- $L >> b >> h$



Source: *Conception des structures articulées à guidages flexibles de haute précision,* Simon Henein,Thèse École polytechnique fédérale de Lausanne EPFL, n° 2194 (2000)

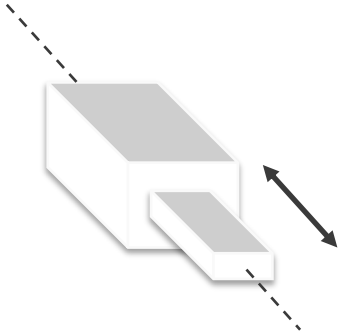
Blade degrees-of-freedom (DOFs)

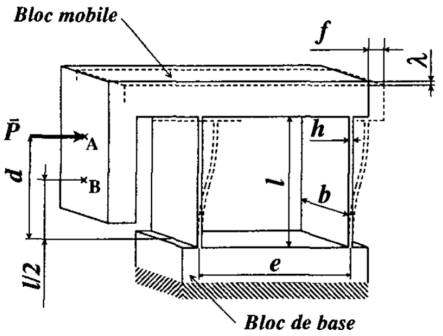


Motion	Illustration	Stiffness	DOF
Translation x		Low	Free
Translation y		High	Blocked
Translation z		High	Blocked
Rotation x		High	Blocked
Rotation y		Low	Free
Rotation z		Low	Free

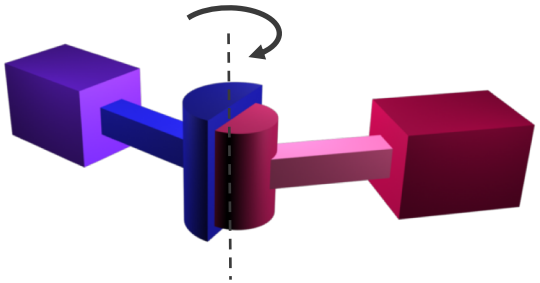
Ideal joints / flexure equivalent

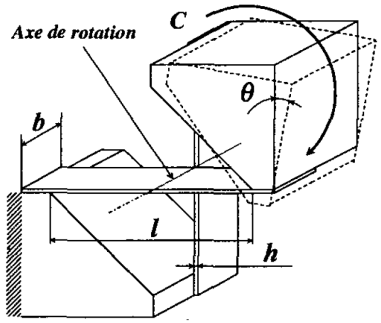
Prismatic joint



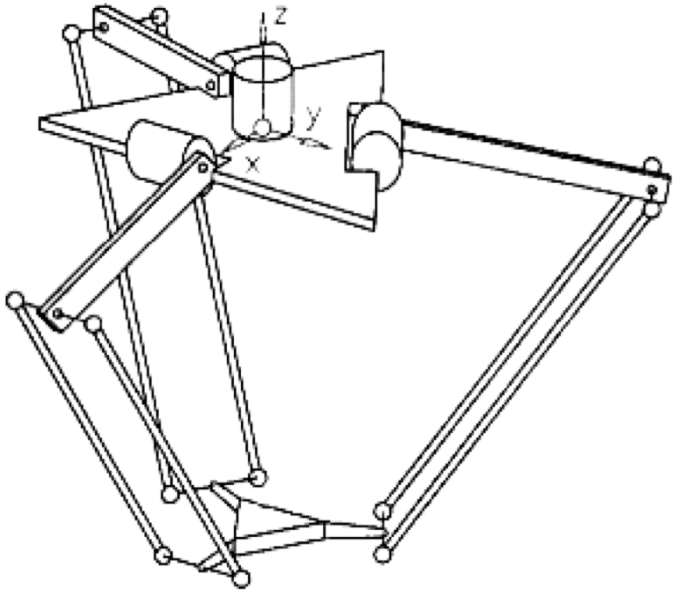


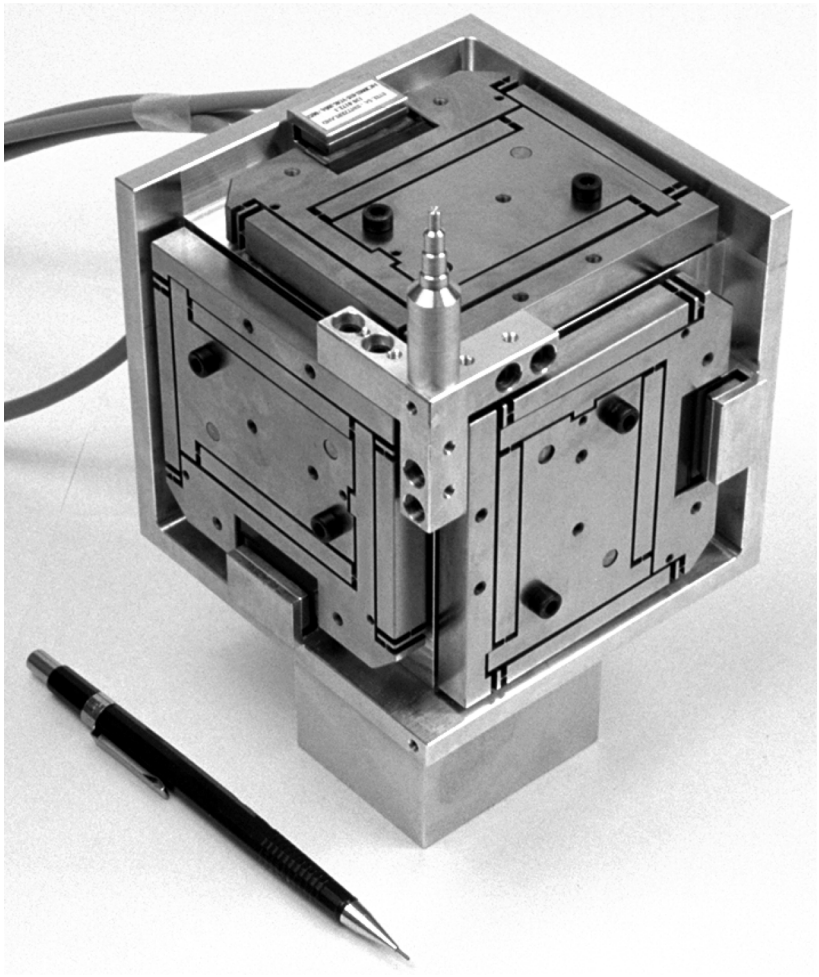
Revolute joint





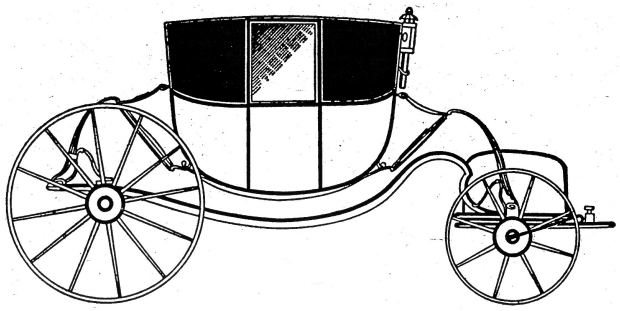
Ideal joints / flexure equivalent

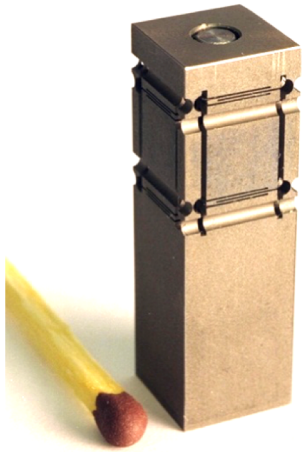


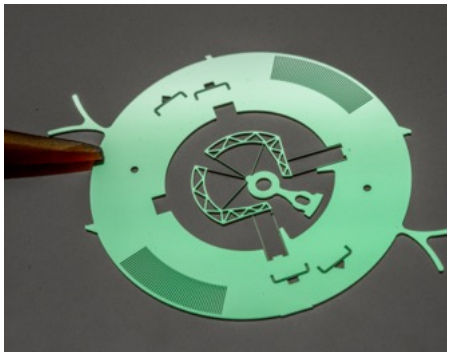


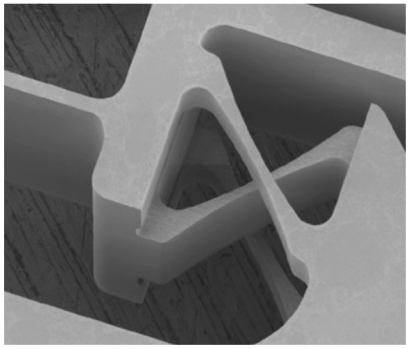
FLEXURE MECHANISMS

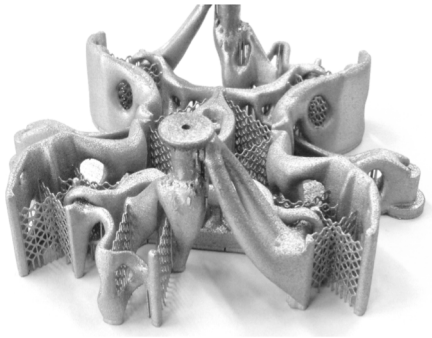
- Old approach
- New needs
  - Nanometric positioning precision
  - Applications in extreme environments (vacuum, cryogenics, space, cleanliness)
  - Long lifetimes
  - Simplified mechanisms
  - High efficiency systems
  - Microscale systems
- New manufacturing technologies
  - Wire Electrical-Discharge-Machining (EDM)
  - Silicon Etching Technologies (DRIE)
  - Laser microfabrication on glass
  - Additive manufacturing



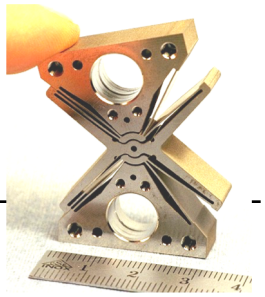








FLEXURE MECHANISMS



Advantages

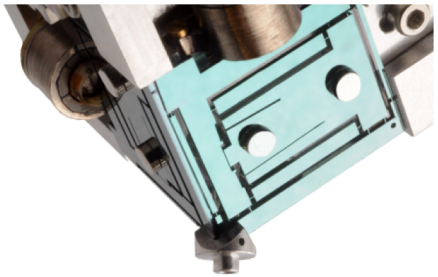
- No contact friction
  - High efficiency
  - No need to lubricate
  - No wear
  - No particles
- Monolithic (no assembly, less parts)
- High precision & repeatability of motion
- Compatible with extreme environments (vacuum, cryogenic or high temperatures, radiation)
- Scalable (good for miniaturization)
- Energy Storage

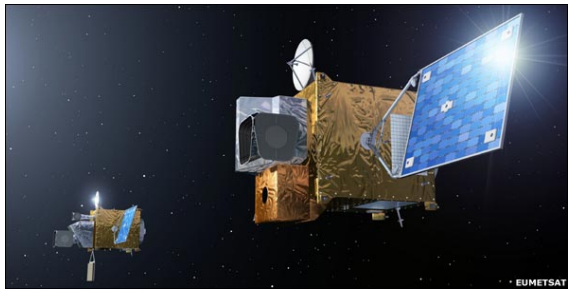
Challenges

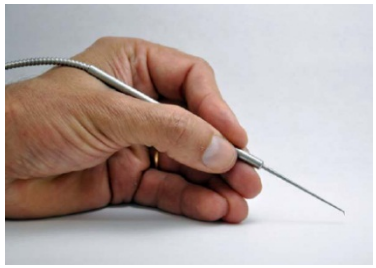
- Limited stroke
- Elastic restoring force
- Outer dimensions (flexure length to stroke ratio)
- Parasitic shift
- Support stiffness
- Analytical dimensioning tools
- Manufacturing and tolerances

Application Fields

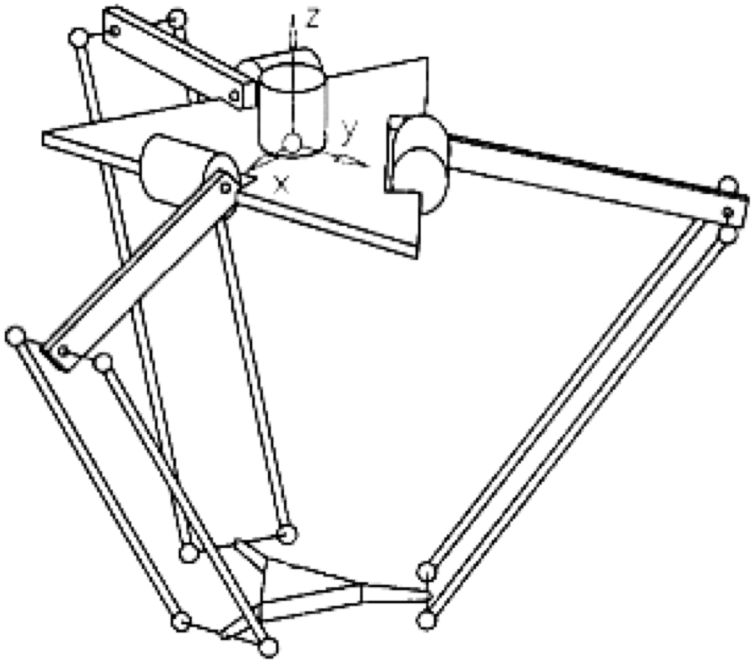
- ROBOTICS
- SPACE
- ASTROPHYSICS
- LABORATORY INSTRUMENTS
- MEDTECH
- WATCHMAKING
- …

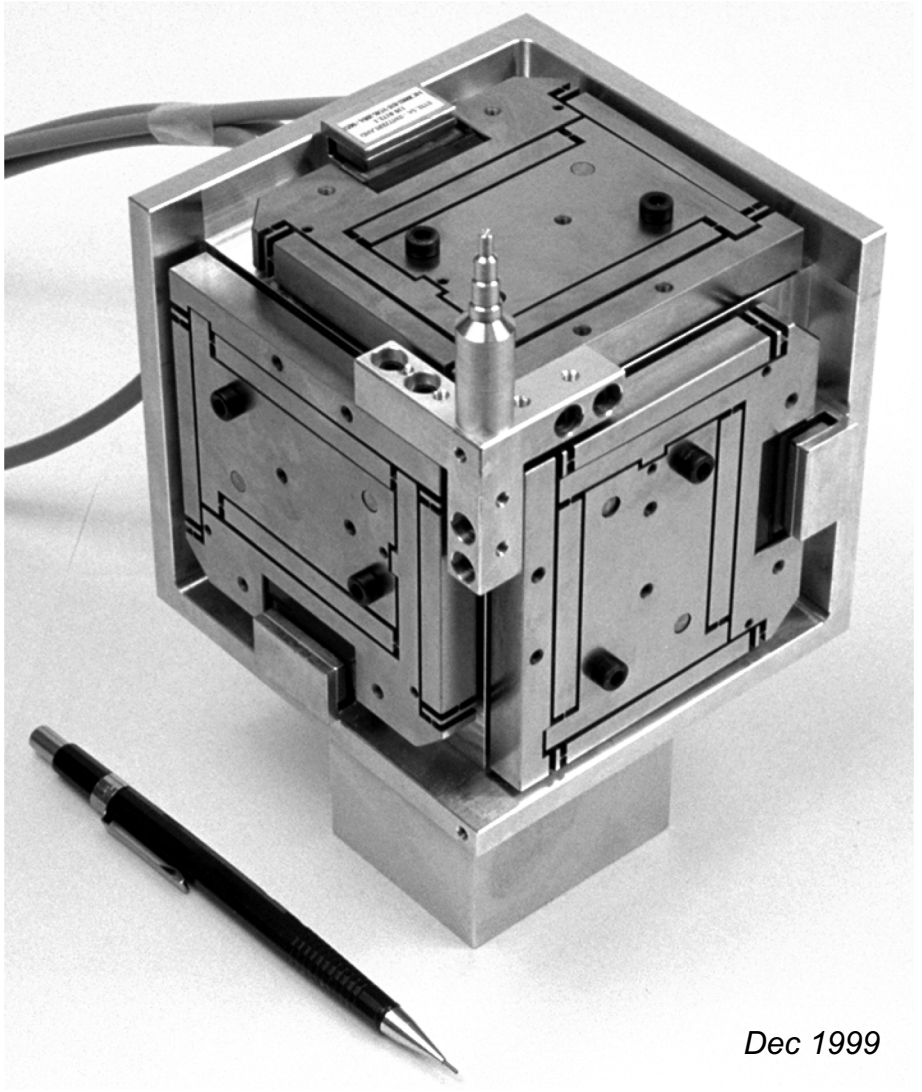






Delta-cube robot for micro-EDM machining

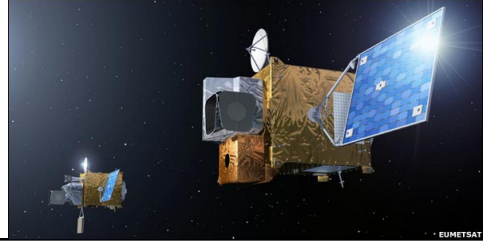


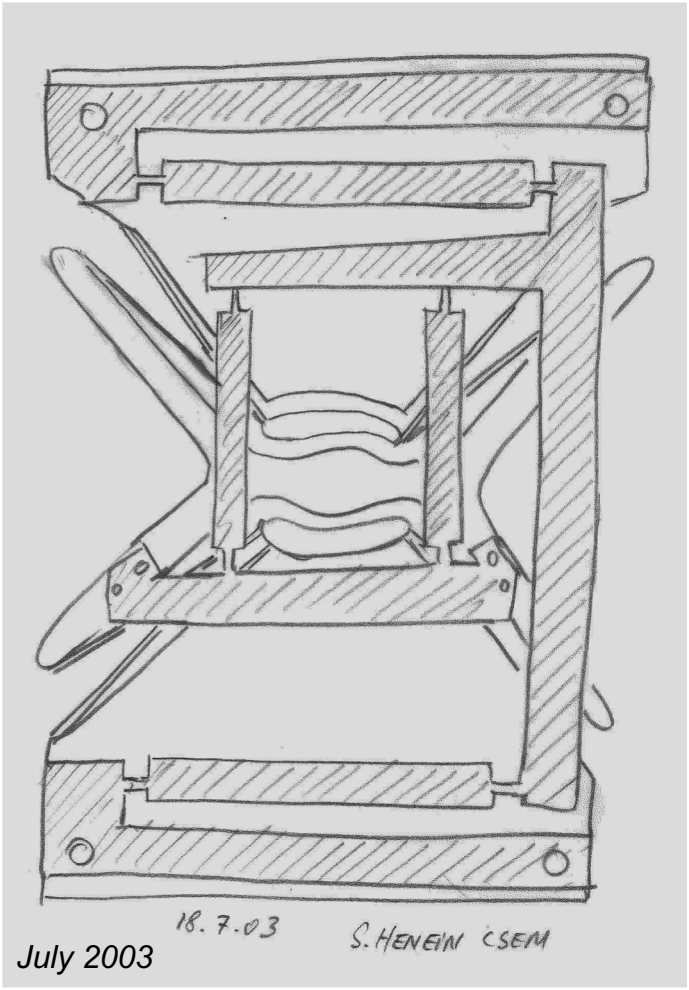


Henein S., Clavel R.& Bottinelli S., Fine positioning Device, US Patent 09/747,906, Assignee: AGIE SA, 1999

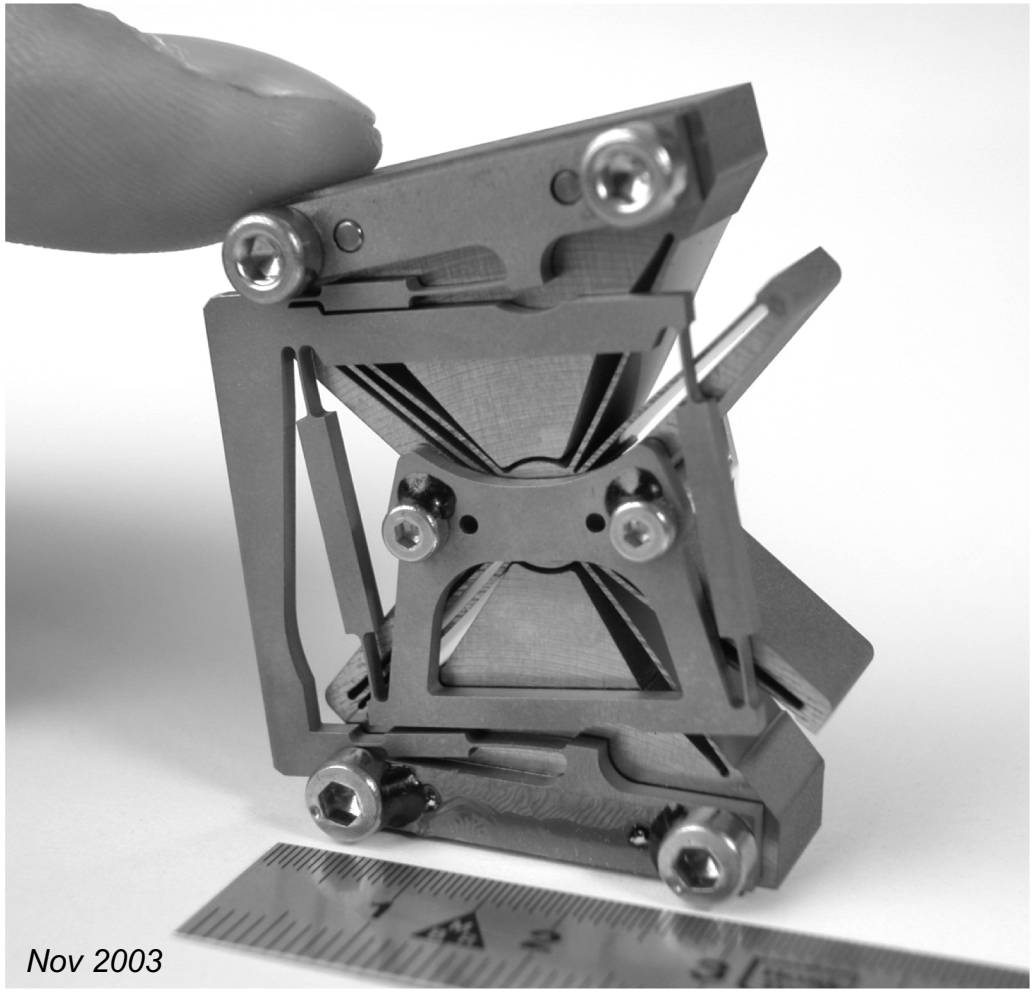
SPACE

Butterfly Flexure Pivot (mandate from ESA)





July 2003



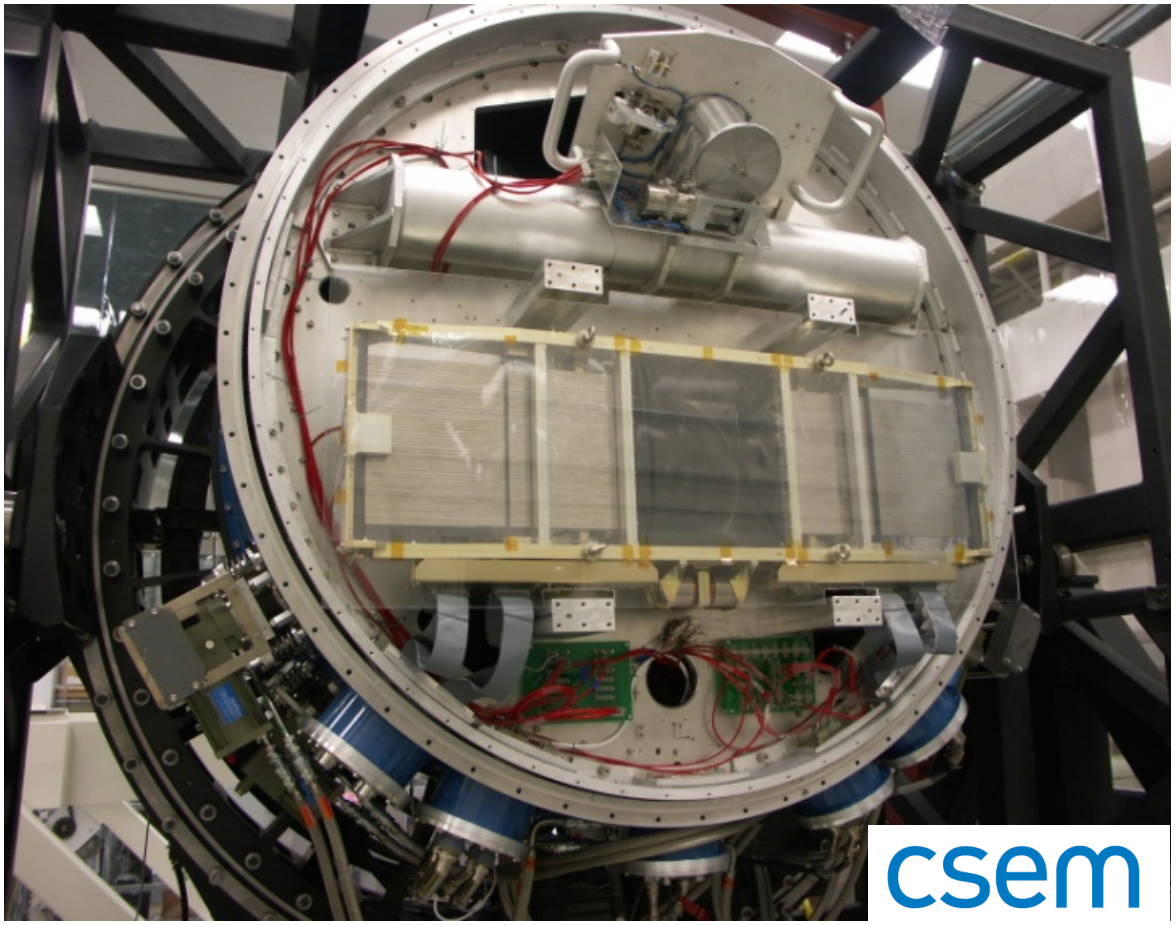
Nov 2003

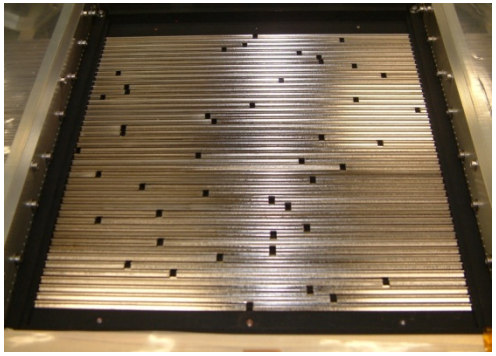
Henein S. et al., Flexure Pivot for Aerospace Mechanisms, ESA SP-524, Proc. 10th European Space Mechanisms & Tribology Symp., 2003

ASTROPHYSICS

KECK 10m Telescope, Hawaii

MOSFIRE Instument : Multi-Object Spectrometer for Infra-Red Exploration





Cryogenic Slit Mask Unit

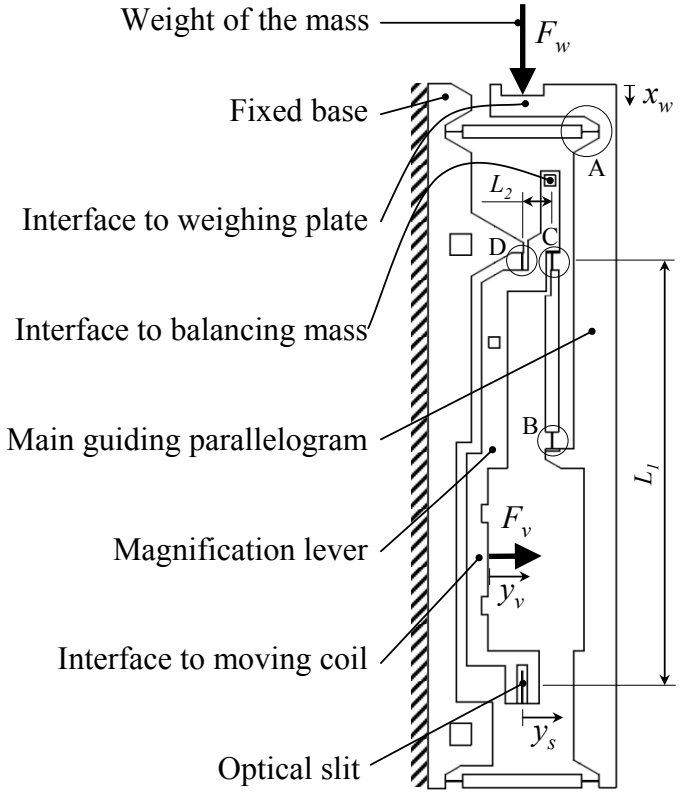
- -150° C
- 46 slits
- Field of view
  267 x 267 mm
- Accuracy ±30µm

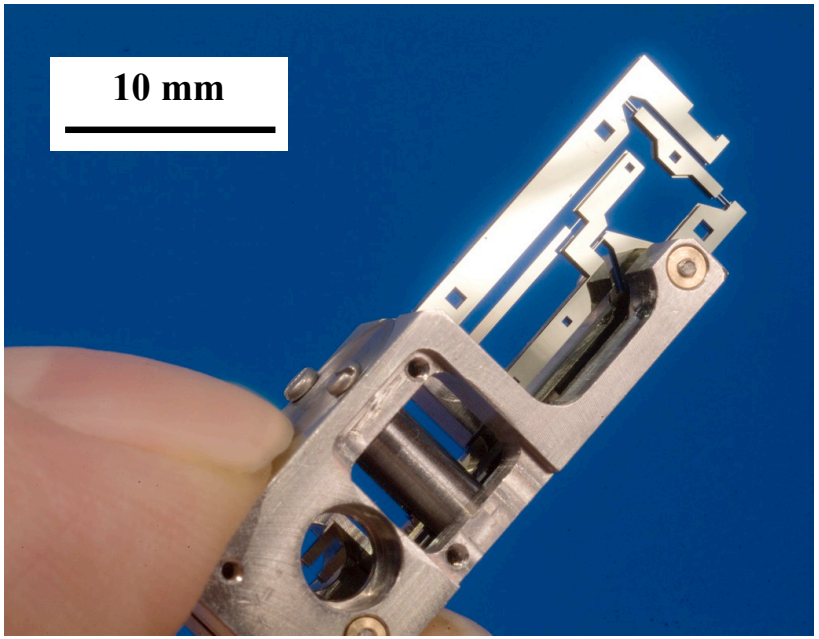
Peter Spanoudakis. et al. (2008), Configurable slit-mask unit of the Multi-Object Spectrometer for Infra-Red Exploration for the Keck telescope: Integration and Tests, SPIE Astro. Instr.,SPIE 7018-19

LABORATORY INSTRUMENTS

Silicon Flexure-Based Micro-Balance

Footprint 9 x 9 mm, suitable for batch weighing processes





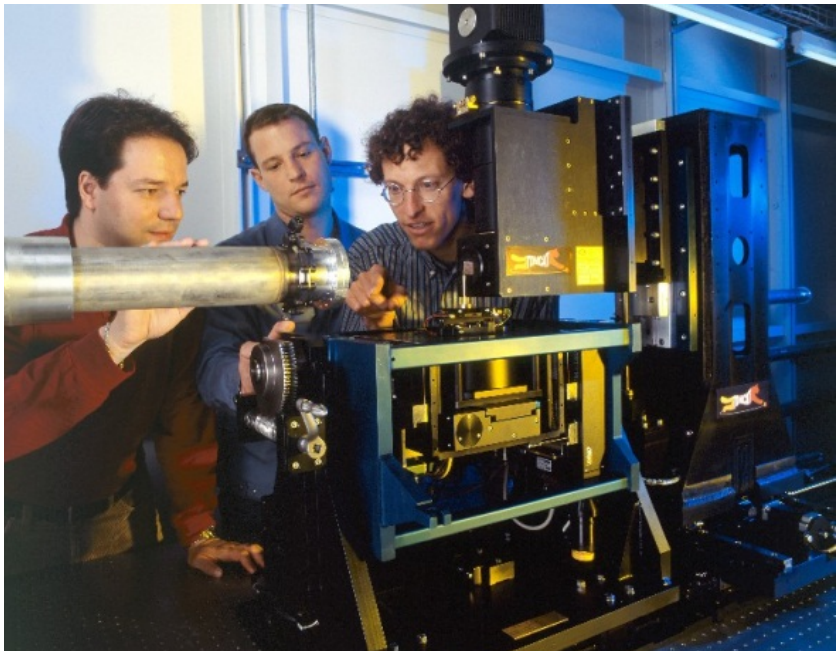
csem

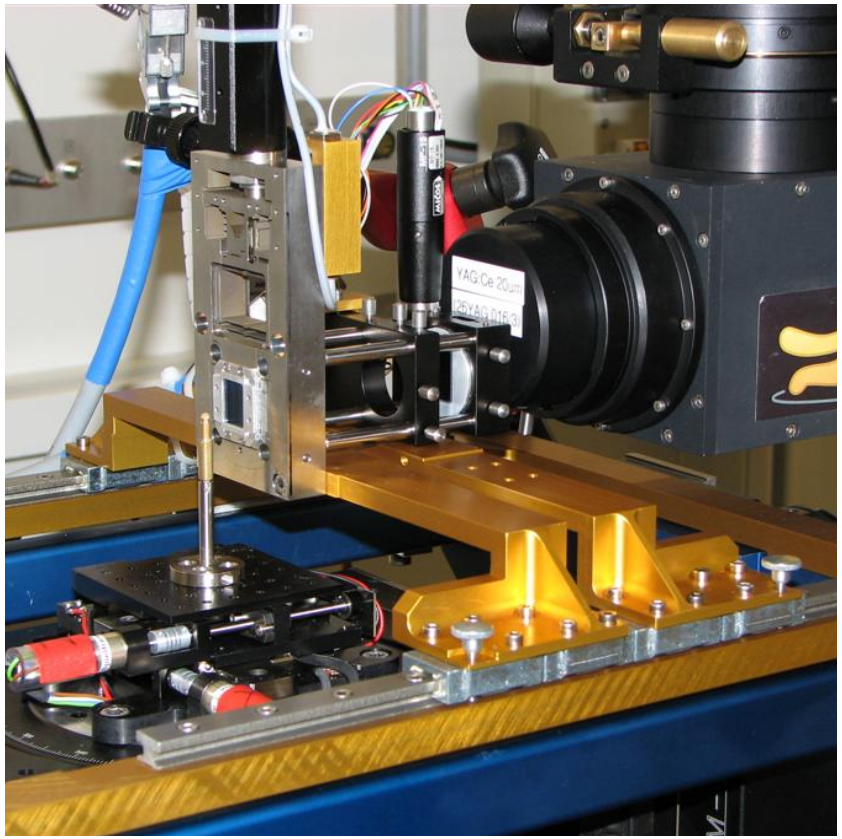
Henein S. et al. , Silicon Flexure-Based Micro-Balance for Batch Weighing Processes, Proc. of the EUSPEN Int. Conf., June 2009

LABORATORY INSTRUMENTS

Nanoconverter

Synchrotron Beamline Endstations



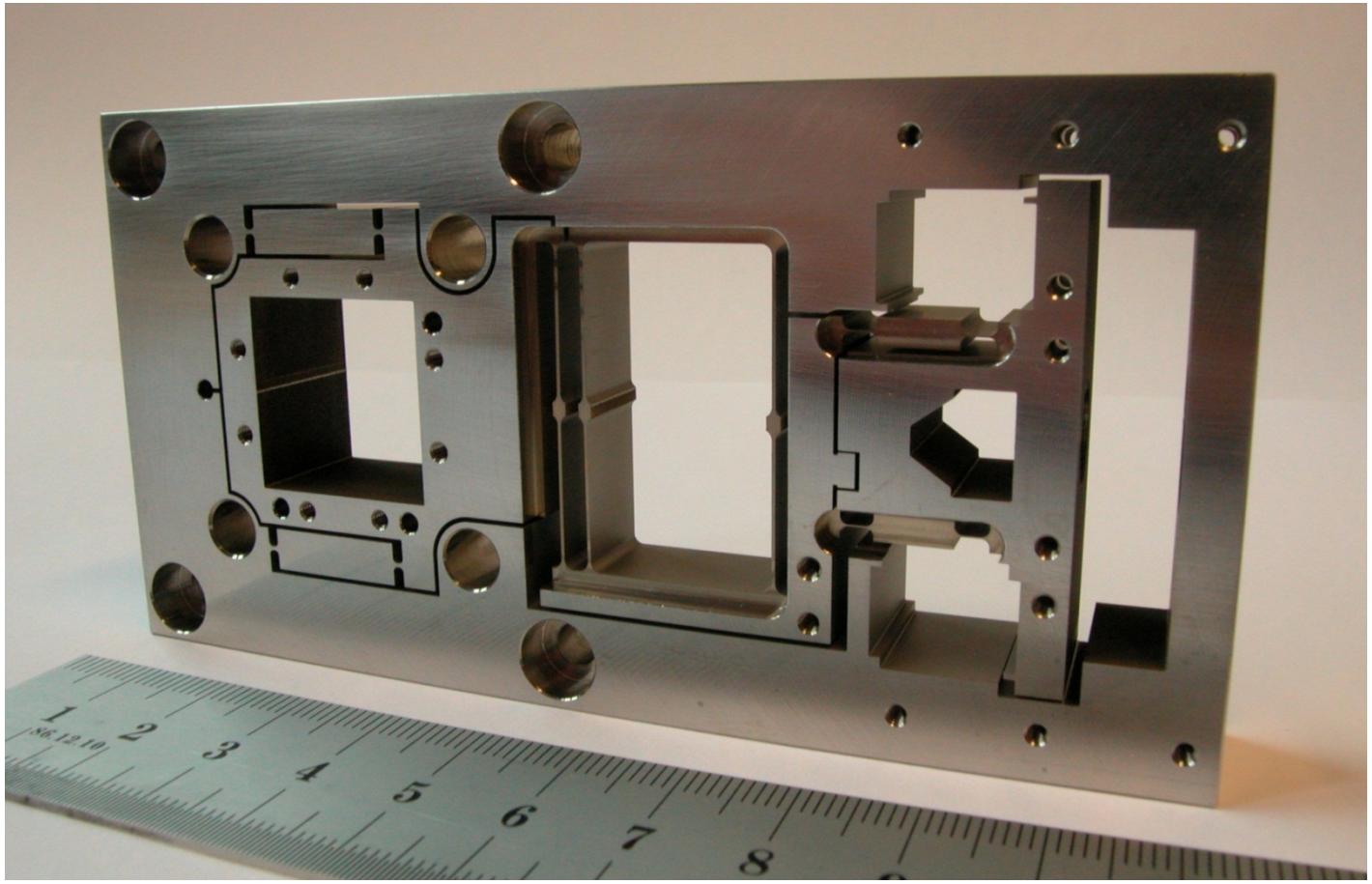


Henein S., Device for converting a first motion into a second motion responsive to said first motion under a demagnification scale, European Patent 06021785, Assignee: Paul Scherrer Institut, Villigen CH, 2006

LABORATORY INSTRUMENTS

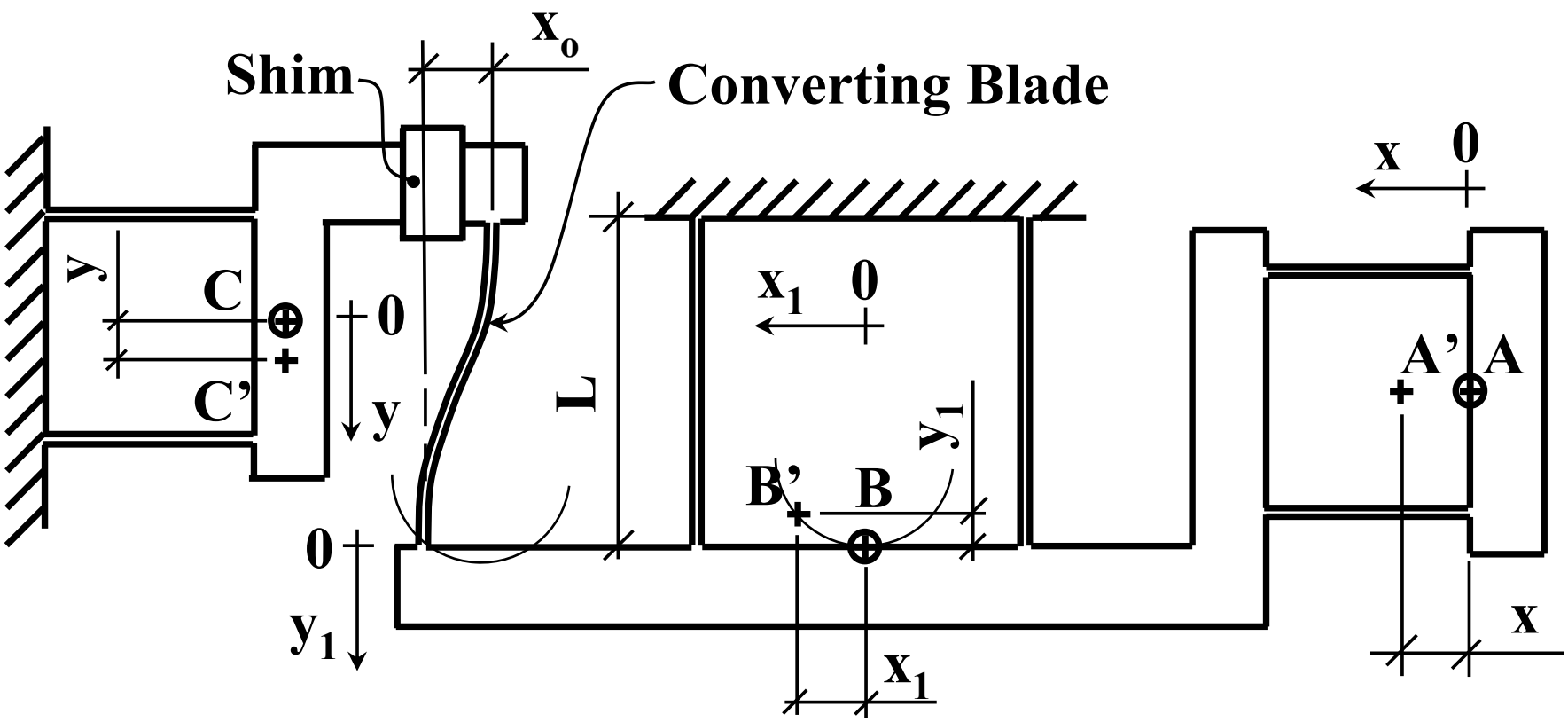
Nanoconverter

Monolithic mechanical transducer with a **constant reduction ratio of 1:100**



Henein S., Device for converting a first motion into a second motion responsive to said first motion under a demagnification scale, European Patent 06021785, Assignee: Paul Scherrer Institut, Villigen CH, 2006

Output Stage **Intermediate Stage** **Input Stage**



$$y_1 = -3x_1^2/(5L) \qquad x_1 \cong x$$

$$y = \frac{3(x+x_0)^2}{5L} - \frac{3x^2}{5L} = \frac{6x_0}{5L}x + \frac{3x_0^2}{5L}$$

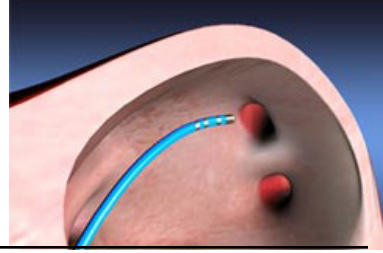
Reduction factor:

$$\boxed{i = \frac{x}{y} = \frac{5L}{6x_0}}$$

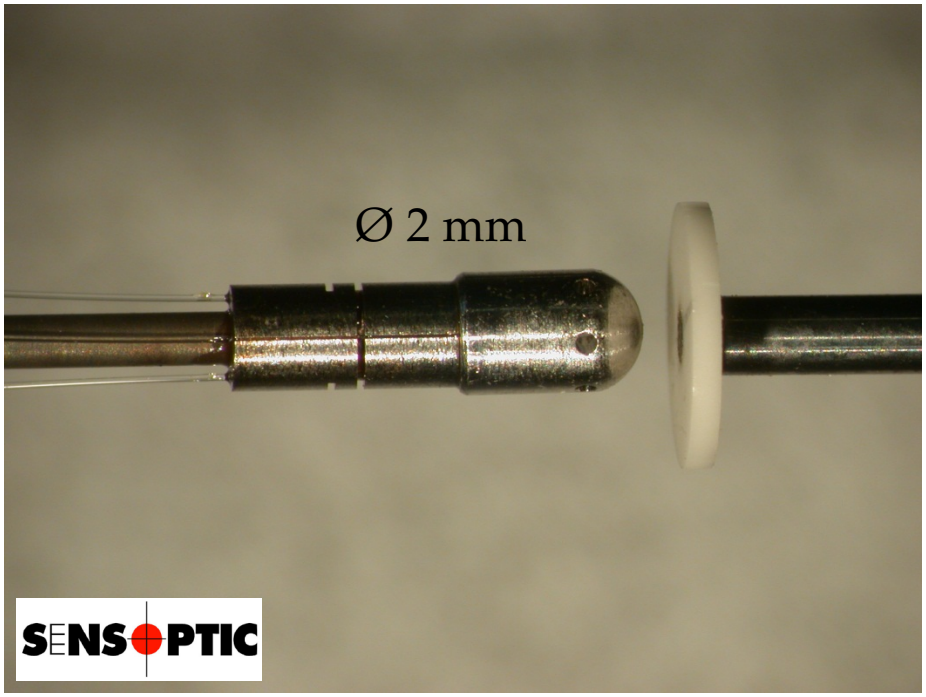
Henein, S. et al., The Nanoconverter: a novel flexure-based mechanism to convert microns into nanometers, Proc. of the 7th EUSPEN International Conference, Bremen, 2007

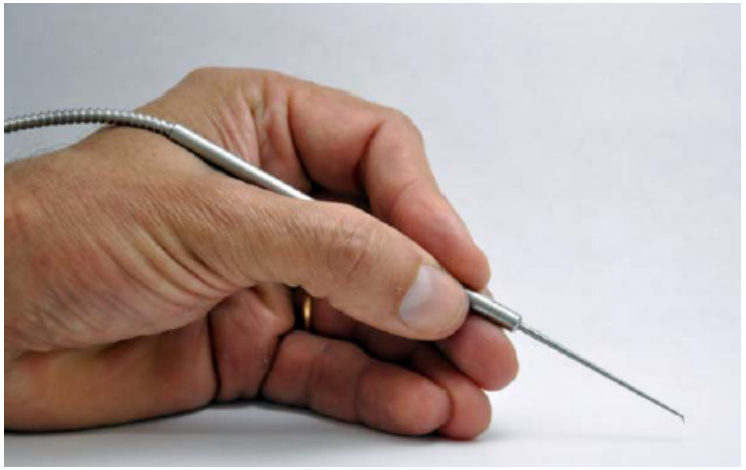
M E D T E C H

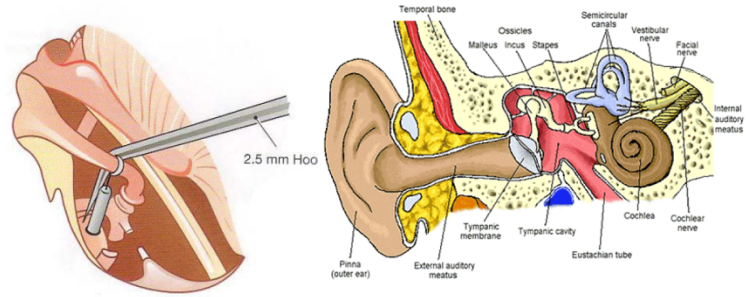
Tri-axial in vivo force sensors



- Treatment of cardiac fibrillation
- Palpation of the ossicular chain in otology



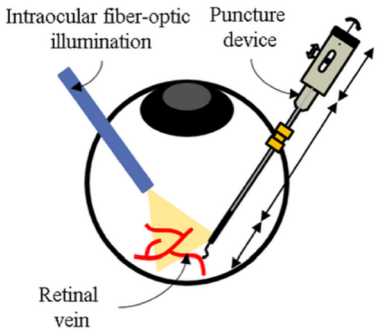




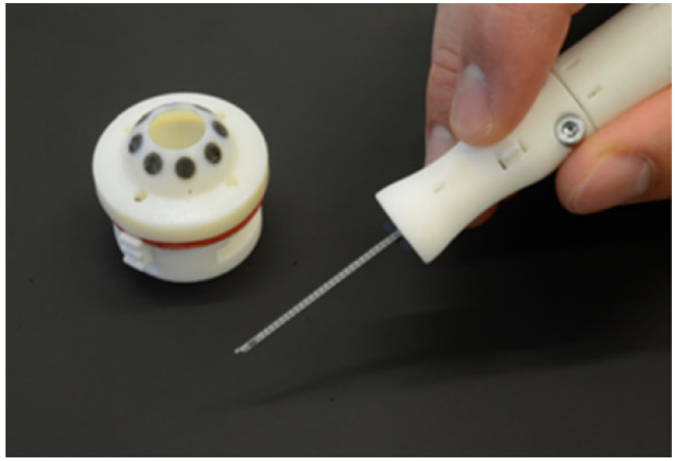
Henein S., Bertholds A. & Llosas P., Optical measuring element having a single piece structure, US Patent 2010/0328675, Assignee: Kistler Holding AG, 2010

MEDTECH

Medical device for safe surgical puncturing



- Treatment of retinal vein occlusion
- Adjustable stroke and puncturing force is independent of operator applied displacement



(a)

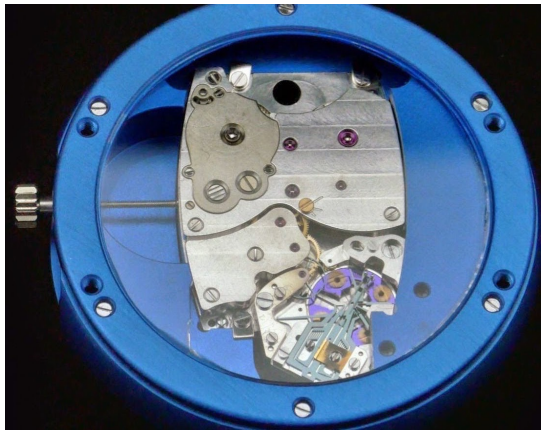
Download

(b)

Zanaty, M., Fussinger, T., Rogg, A., Lovera, A., Lambelet, D., Vardi, I., Wolfensberger, T. J., Baur, C., & Henein, S. (2019). Programmable Multistable Mechanisms for Safe Surgical Puncturing. Journal of Medical Devices, 13(2), 021002.

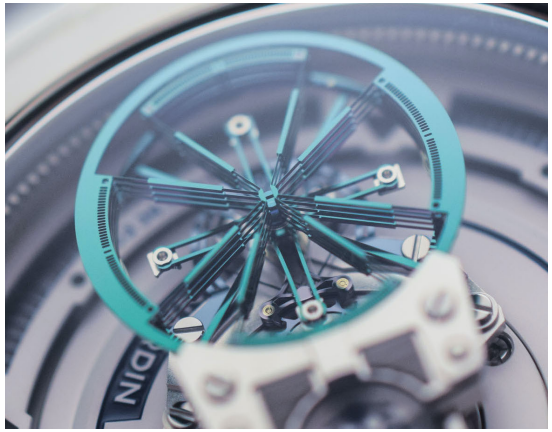
WATCHMAKING

Flexure pivot oscillators



Genequand System, VMF & CSEM (2014)

Defy Lab, Zenith (2017)

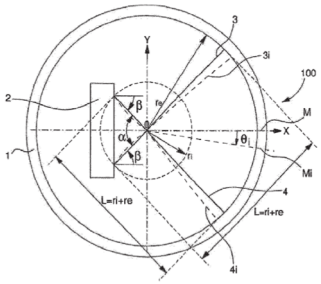


Freak NeXt, Ulysse Nardin (2019)

Slimline monolithic, Frédérique Constant (2021)

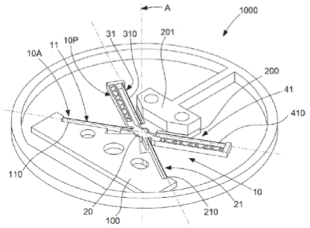
WATCHMAKING

Flexure pivot oscillators

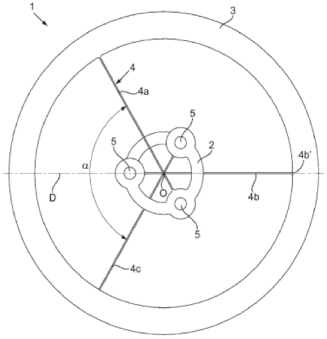


WO2016096677A1, 2016

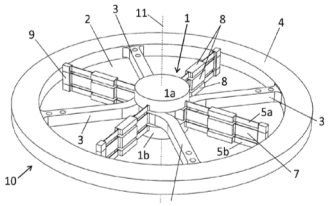
Robuschi et al., 2017



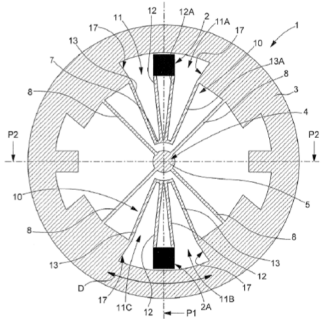
EP3206089A1, 2017



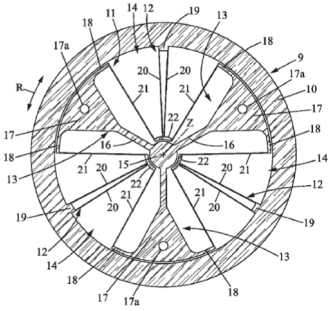
EP3410229A1, 2018



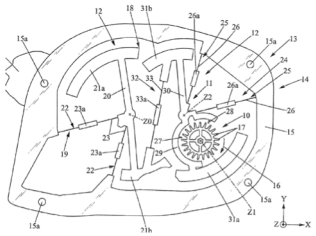
US20180088529A1, 2018



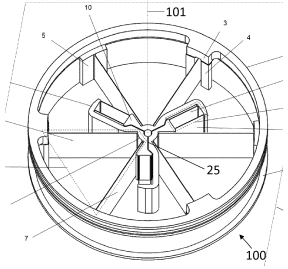
CH703464A2, 2012



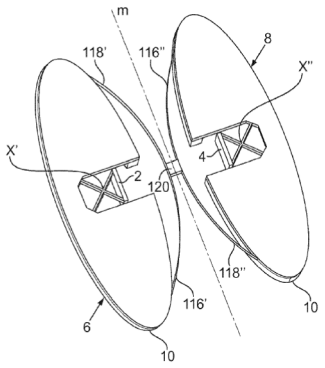
WO2016079068A1, 2016



FR3071075A1, 2019



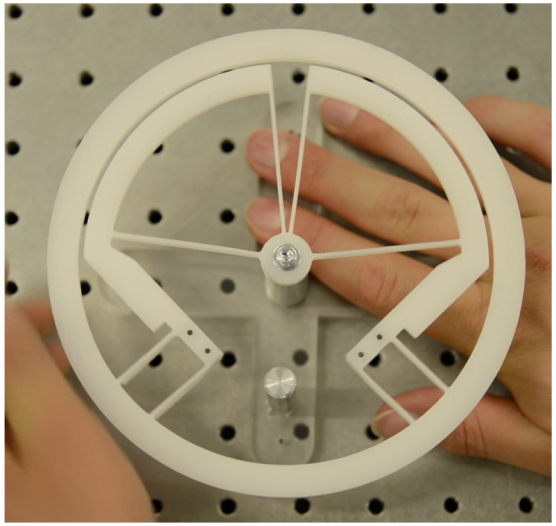
EP3476748, 2017



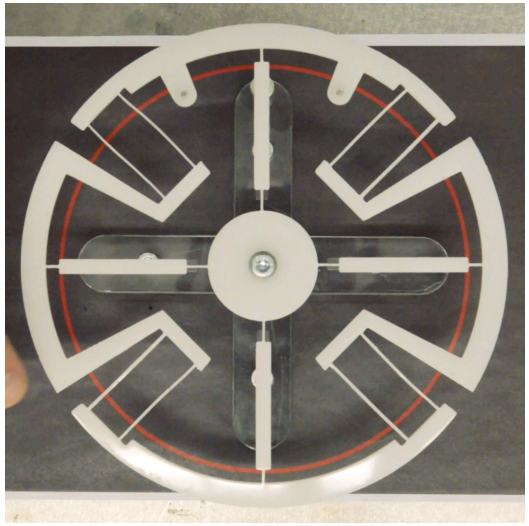
EP3336613A1, 2018

WATCHMAKING

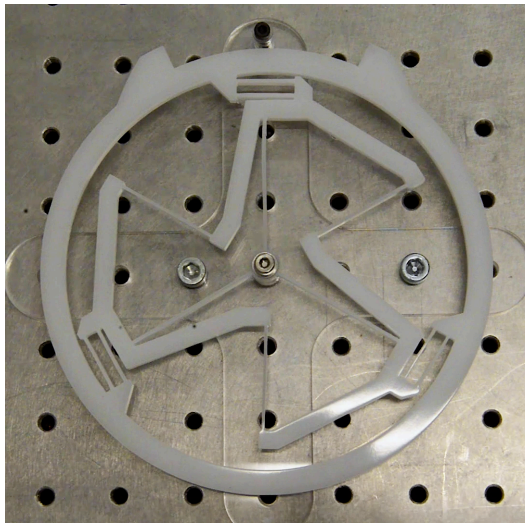
Flexure pivot oscillators



Co-RCC
2019



RDCO
2019

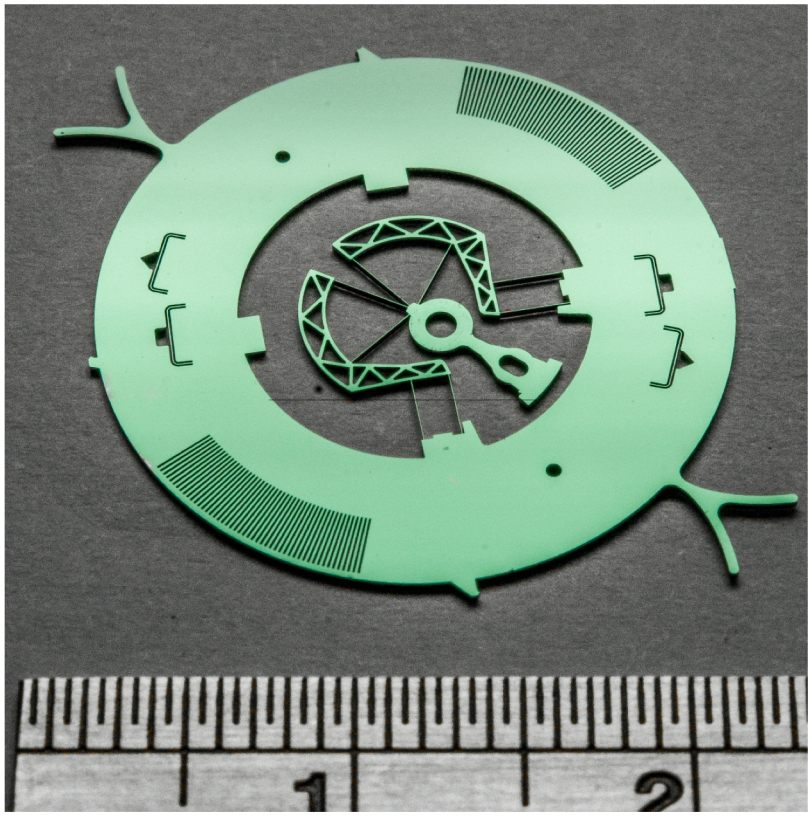


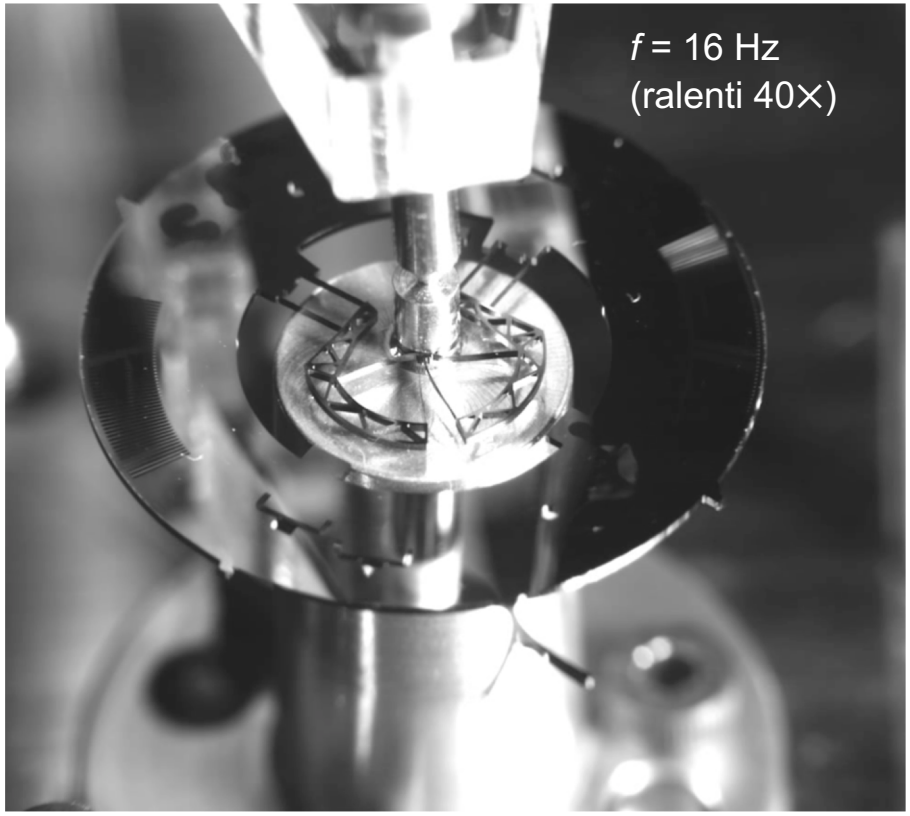
TRIVOT
2020

- *Kahrobaiyan M.H., Thalmann E., Henein S. WO 2020 016131 A1 – "Flexure Pivot Oscillator Insensitive to gravity"*
- *Thalmann, E., Kahrobaiyan, M. H., Vardi, I., and Henein, S. (2020). Flexure Pivot Oscillator With Intrinsically Tuned Isochronism. Journal of Mechanical Design, 142(7).*
- *Thalmann, E. & Henein, S. (2021), Design of a Flexure Rotational Time Base with Varying Inertia, Journal of Mechanical Design, MD-20-1597.*
- *Thalmann, E., & Henein, S. (2021). Design of a Triple Crossed Flexure Pivot with Minimized Parasitic Shift. Proceedings of the ASME 2021 IDETC-CIE Conference.*

WATCHMAKING

Flexure pivot oscillators

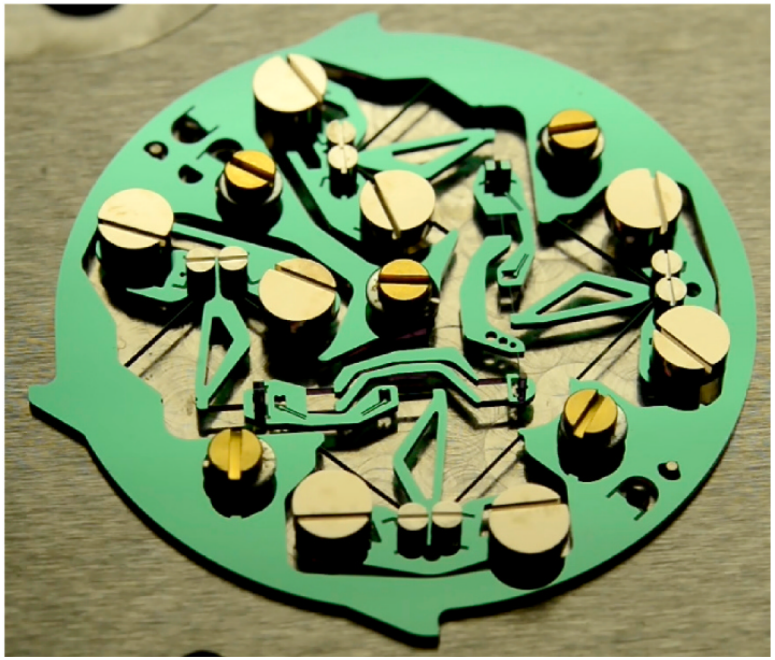


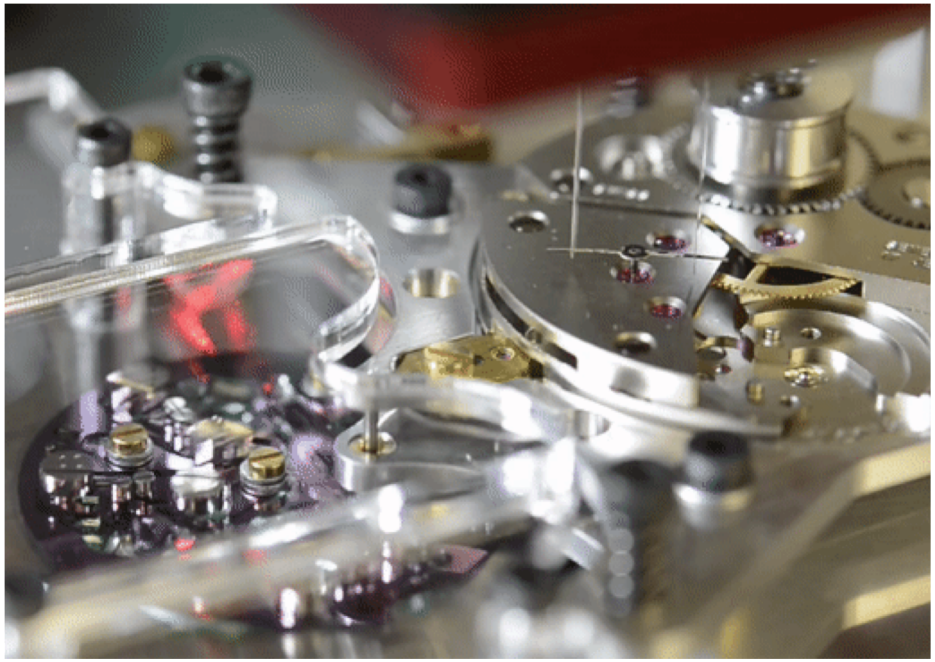


Thalmann, E. (2020). Flexure Pivot Oscillators for Mechanical Watches [EPFL]. https://doi.org/10.5075/epfl-thesis-8802

WATCHMAKING

2-DOF Flexure oscillators



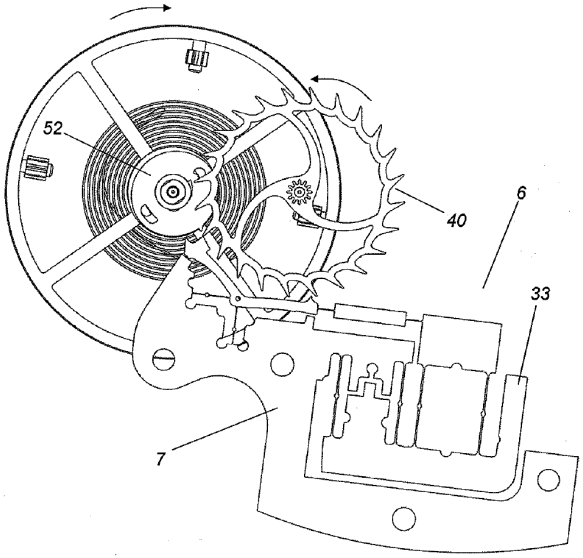


Schneegans, H., Thalmann, E., & Henein, S. (2021). Shaking force balancing of a 2-DOF isotropic horological oscillator. Precision Engineering, 72,

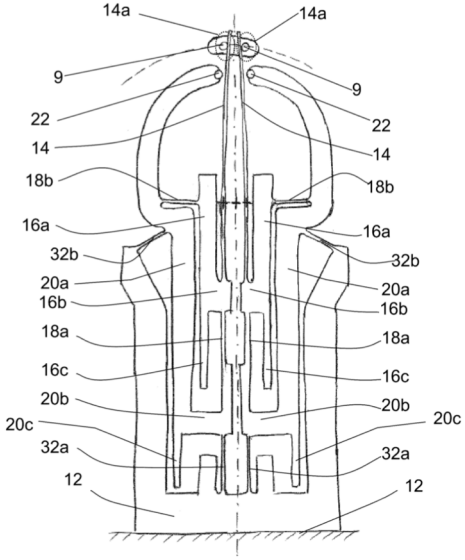
WATCHMAKING

Other mechanisms

Flexure anchor



Isochronism corrector



Time zone setting (Patek Philippe, 2017)

- *Colpo F. & Henein S, Immobilizing device for a toothed wheel, Europen Patent 20100405072*
- *Henein, S. and Schwab, P. (2014). Isochronism corrector for clockwork escapement and escapement provided with such a corrector. Patent Number: US8672536B2.*