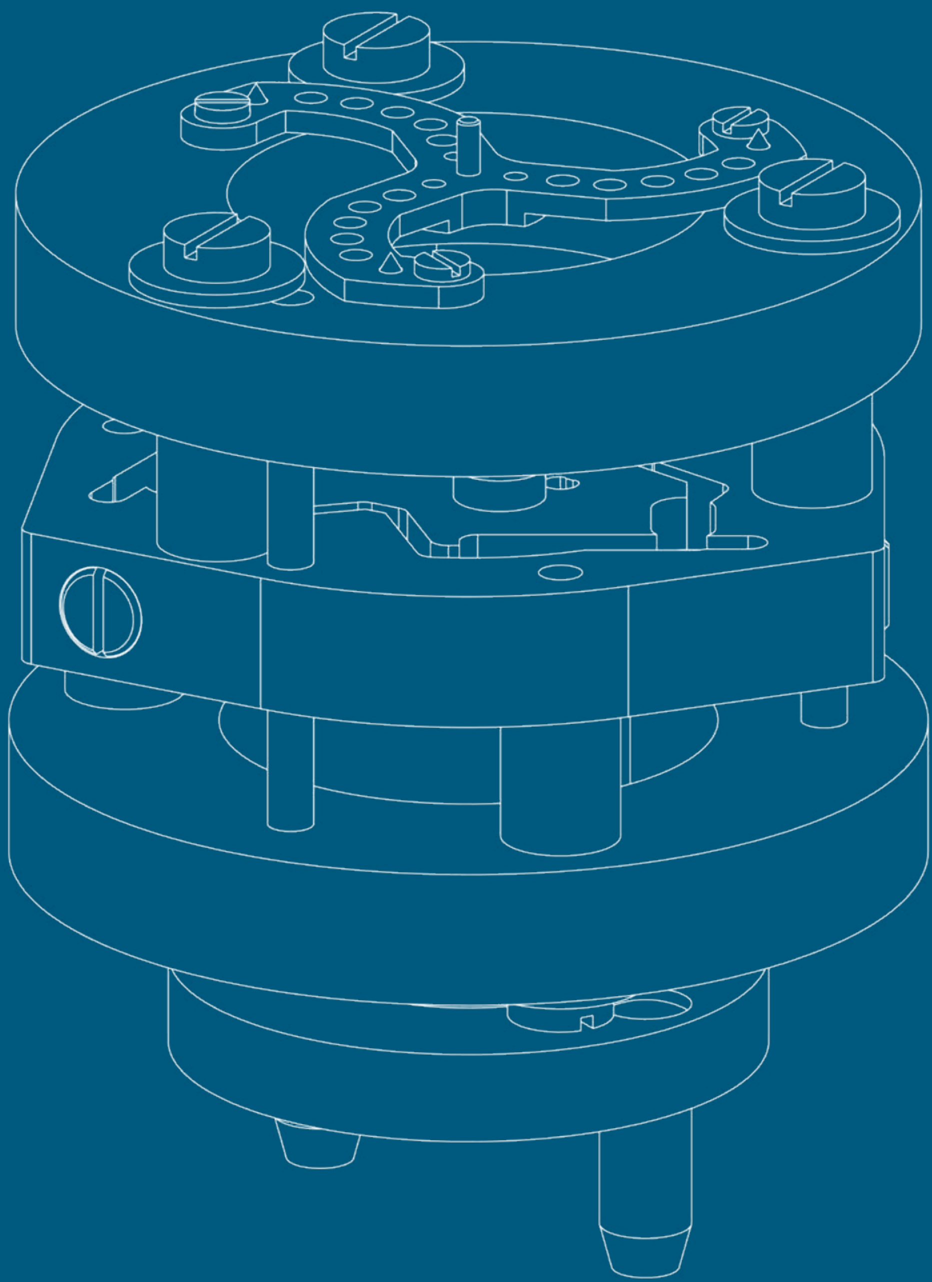
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Patek Philippe Chair

Micromechanical and Horological Design Laboratory
INSTANT-LAB

Annual Report 2017



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INTRODUCTION

In 2017, the Patek Philippe Chair in Micromechanical and Horological Design celebrated its fifth year. Instant-Lab, the name chosen for our laboratory, now has 17 collaborators : Professor Henein, an administrative assistant, 2 senior scientists, 2 postdoctoral scholars, 4 Ph.D. students, 5 scientific assistants and 2 technicians.

The laboratory specializes in creating new mechanisms featuring kinematic and technological innovation at the centimeter scale using a scientific approach inspired from mechanical design in fields such as classical horology, robotics and aerospace. Current projects apply to mechanical watchmaking and biomedical instrumentation, these fields being quite close, both technologically and in their industrial fabric. Beyond its academic mission to pursue excellence in fundamental research and teaching, the laboratory is also committed to establish ties with Swiss watchmaking culture and welcomes industrial collaboration with all Swiss watchmaking companies.

TEAM

Director

Prof. Simon Henein

Karine Frossard
Administrative assistant

Senior Scientists

Dr Charles Baur

Dr Ilan Vardi

Post-Docs

Dr Roland Bitterli

Dr Mohammad Kahrobaiyan

Scientific Assistants

Laura Convert

Nicolas Ferrier

Thomas Fussinger

Billy Nussbaumer

Jose Rivera

Ph.D. Students

Sebastian Fifanski

Michal Smreczak*

Etienne Thalmann

Mohamed Zanaty

Technicians

Romain Gillet

Arnaud Maurel

*External

RESEARCH PROJECTS

IsoSpring: continuous mechanical time

Mechanical timekeeping began in the Middle Ages with the invention of the escapement. After the introduction of oscillators in the 17th century, mechanical clocks and watches continued to rely on escapements. Despite numerous technical advances, today's escapements suffer from reduced mechanical efficiency. The IsoSpring project exploits ideas dating back to Isaac Newton to create a new time base which can be driven continuously, without the stop-and-go "ticking" of traditional mechanical clocks and watches. This solves the escapement problem by completely eliminating it: the mechanical watch can work without an escapement.

The result is a simplified mechanism having greatly increased efficiency and chronometric accuracy. This project is based on a new family of oscillators and maintaining mechanisms patented by the EPFL.

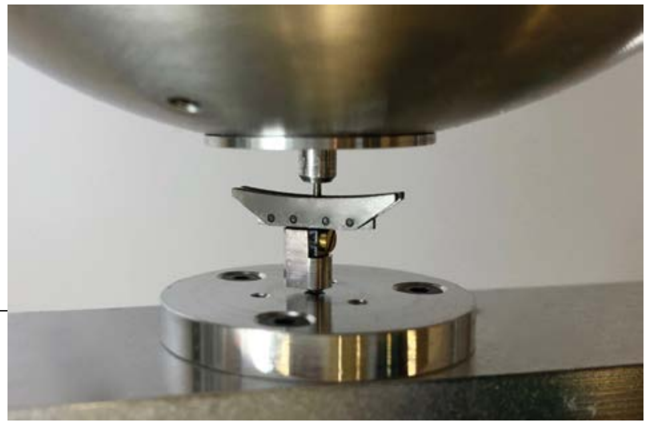
Our first proof of concept in 2013 was followed by more precise time-bases, the latest being a spherical oscillator. The resulting clock was exhibited at the International Museum of Horology in La Chaux-de-Fonds (MIH) as the showpiece of their exhibit of Neuchâteloise clocks in the Fall of 2017.

An industrial project was established in 2014 and successfully completed in 2017. Our current research is focused on miniaturizing to the watch scale.

IsoSpring oscillator maintained by a watch movement.

Our "Neuchâteloise" clock with spherical oscillator at the MIH.

IsoSpring crank replacing escapement.



RESEARCH PROJECTS

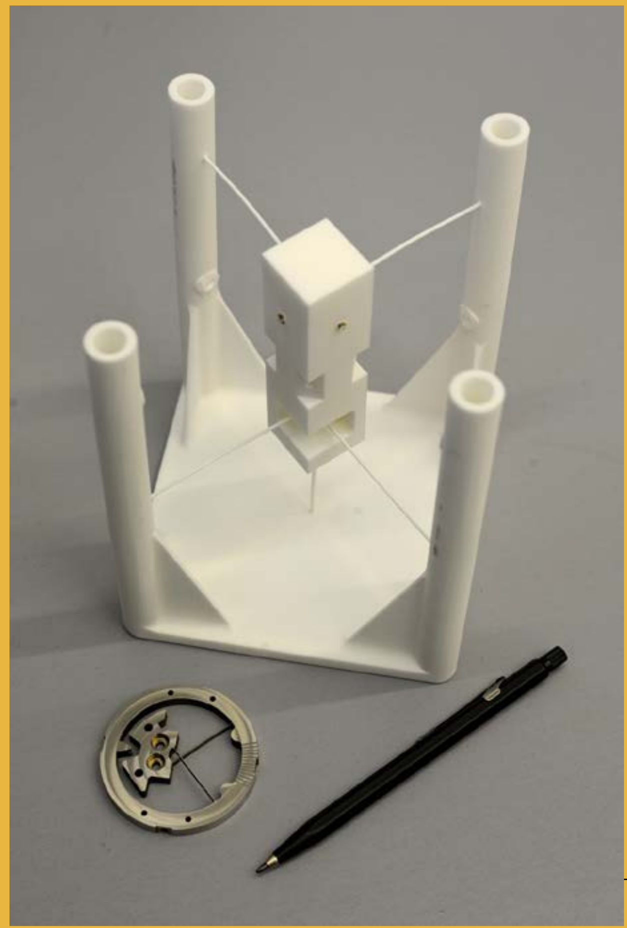
New escapement concept

Instant-Lab introduced **virtual impulse escapements** in which a double beat escapement becomes a dead beat escapement when the balance wheel is at its operating amplitude. In this way, the advantages of dead beat escapements : direct impulse, greater freedom in choosing impulse position, are preserved, while the disadvantages : sensitivity to shock and difficult self-start, are minimized.

Virtual impulse escapement demonstrator.

High quality factor oscillators for wrist watches

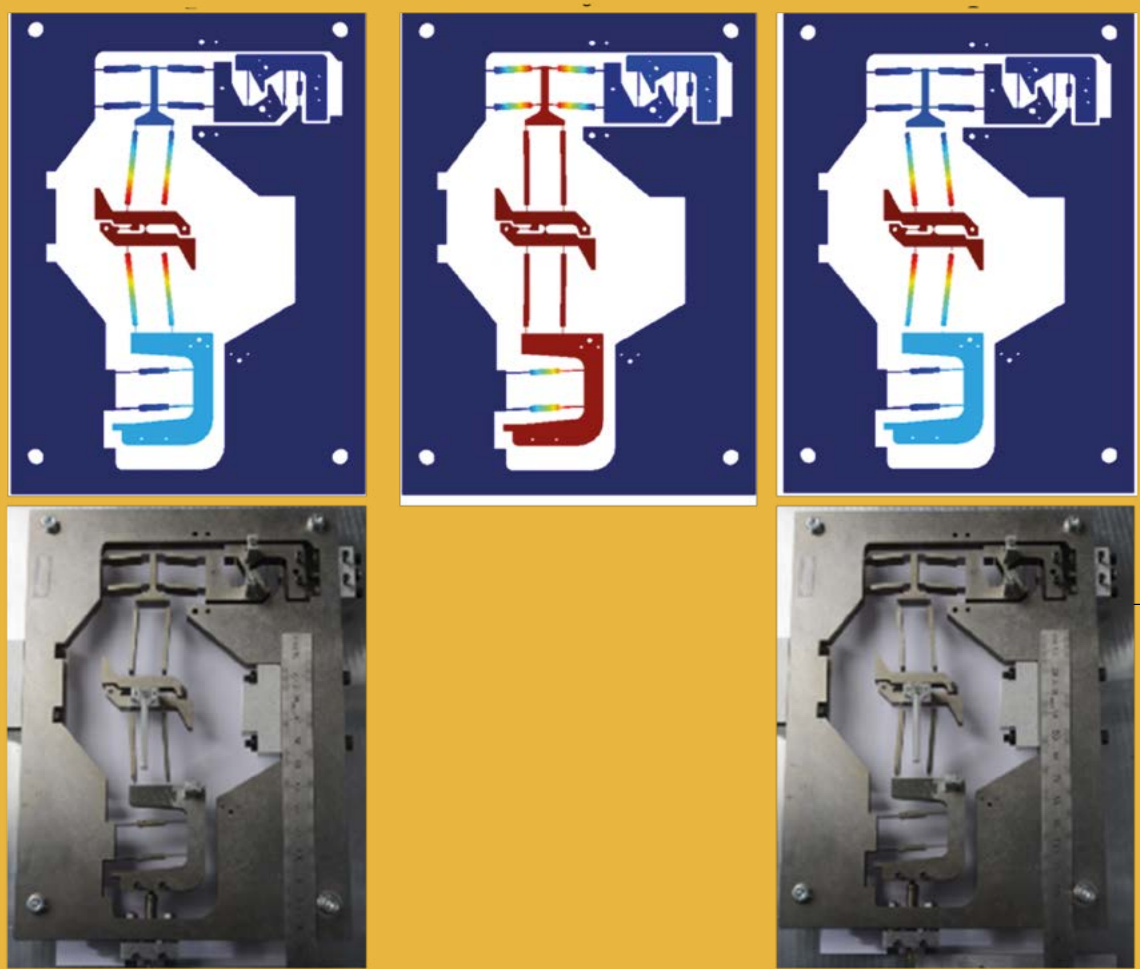
Current mechanical wrist watches have an oscillator consisting of a balance wheel mounted on jewelled bearings and a hairspring. The use of flexure bearings instead of traditional pivots leads to a significant increase in quality factor, i.e., reduced energy loss. As a result, power reserve can be significantly increased and chronometric precision can be improved thanks to reduced oscillator perturbation. However, these new oscillators are sensitive to gravity and have isochronism defects. This project explores novel flexure-based pivots minimizing these issues.



Gravity insensitive flexure pivot (GIFP) demonstrator.

Programmable multistable energy storage mechanisms

This project introduces the concept of programmable multistable mechanism in which the number and position of stable states of a multistable mechanism can be modified. A complete qualitative analysis of a generic multistable mechanism, the T-shaped mechanism, was established using analytical tools based on Euler-Bernoulli beam theory. These results were validated numerically using finite element analysis and experimentally using physical models. Applications include new surgical tools and programmable metamaterials.

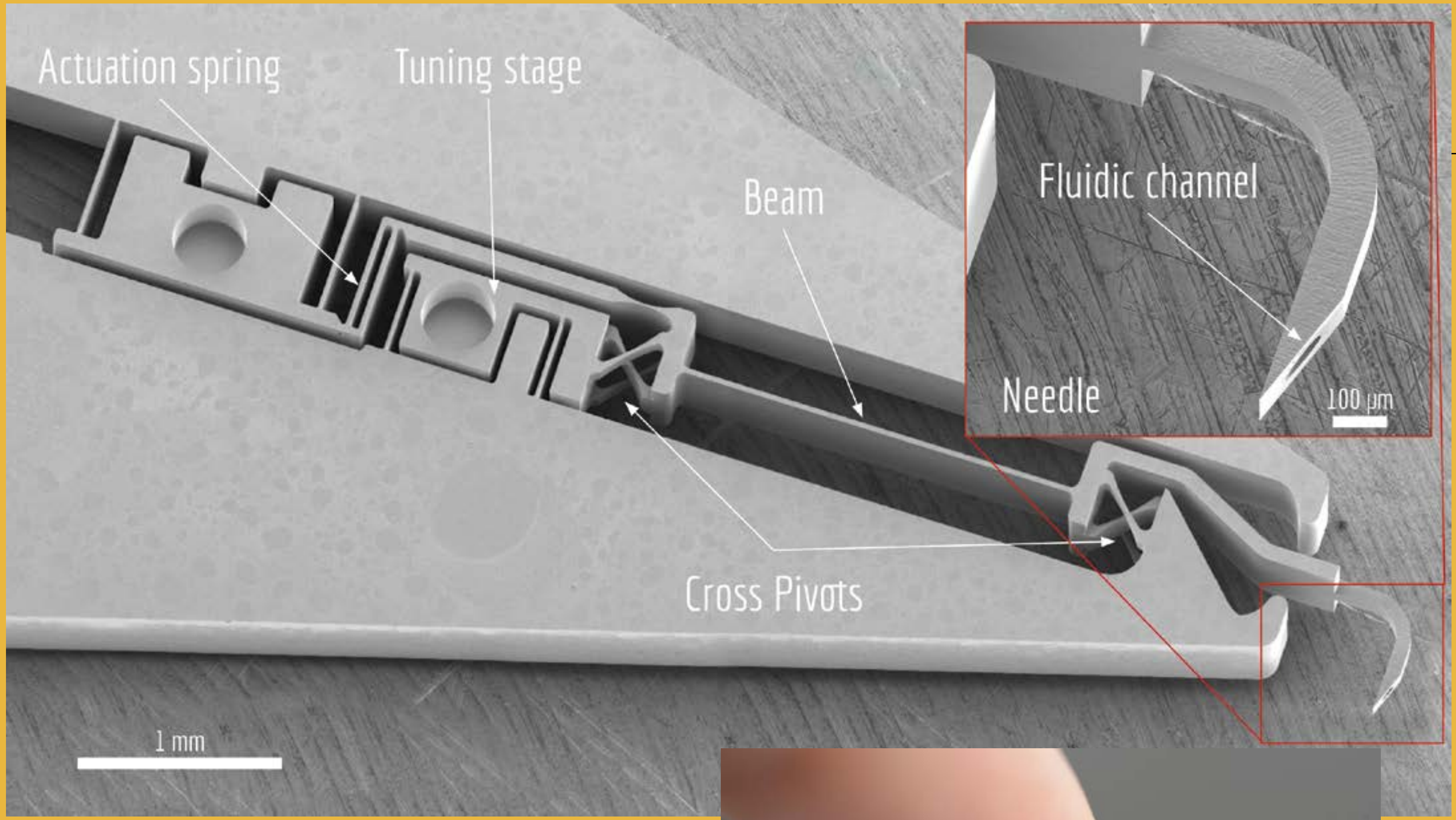


Stable and unstable states of the T-shaped mechanism.

RESEARCH PROJECTS

CTI Safe Puncture Optimized Tool (SPOT) for retinal vein cannulation

Retinal Vein Occlusion is a vascular disorder causing severe loss of vision. Retinal vein cannulation and injection of therapeutic agents in the affected vein is a promising treatment but the small size and fragility of retinal veins as well as the surgeon limited hand gesture precision and force perception makes this procedure too delicate for routine operations. The project aims at providing a compliant mechanical tool relying on a new programmable multistable mechanism to safely cannulate veins. This mechanism has the advantage that puncturing stroke and force can be predetermined so that puncturing is independent of surgeon manipulation. The feasibility of this project was demonstrated by a prototype made by femto-laser printing, one of the first buckled mechanisms manufactured in glass. This project is funded by FemtoPrint SA and the Commission for Technology and Innovation CTI (Switzerland) and run in collaboration with Pr. Th. Wolfensberger, Hôpital Ophtalmique Jules-Gonin, Lausanne.



Programmable multistable mechanism for retinal vein cannulation.

Retinal vein cannulation needle manufactured in glass.

SNSF Adjustable midsole intervention footwear for patients with medial compartment knee osteoarthritis (ADVANCER)

This project consists of a geometrically adjustable shoe orthotic to balance knee and hip loads which could otherwise lead to cartilage wear and tear, thus avoiding surgical intervention. Our proposed solutions are based on flexible elements combined with metamaterial. This Swiss National Science Foundation project is a collaboration with CHUV (Centre Hospitalier Universitaire Vaudois). Different prototypes were realized and successfully tested at CHUV. We are currently examining if the proposed device can be developed into a commercial product. One patent is pending.

Geometrically adjustable shoe orthotic.

SPIRITS: Interactive intelligent robotics and 3d printing for surgery and interventional radiology

The SPIRITS (Simple Printed Interactive Robotics for Interventional Therapy and Surgery) project involves developing a robotic device for image-guided surgery and interventional radiology with a number of innovations, such as a tactile transducer, an intelligent needle, new 3d printing methods and new actuators and robots. This Interreg project is a collaboration between leading institutions: INSA Strasbourg, Hochschule Furtwangen, University Hospital Mannheim, Fachhochschule Nordwestschweiz, EPFL.

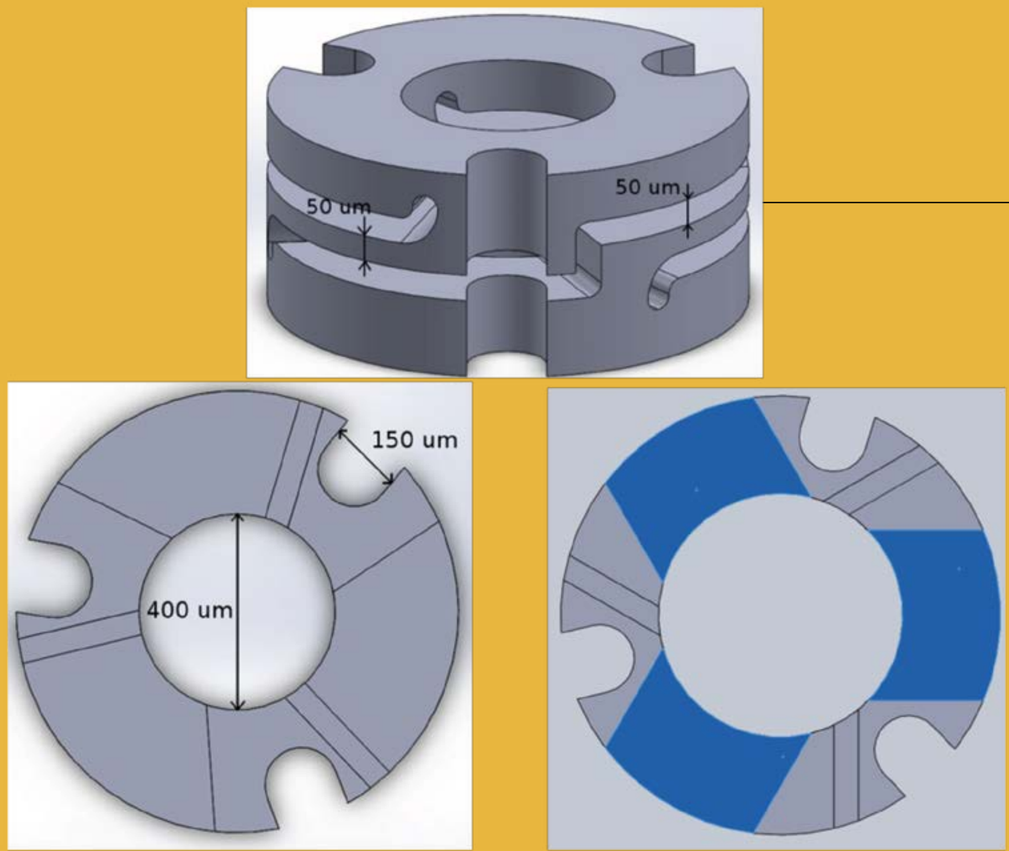
SPIRITS team.

Spinal screw placement tool

This Instant-Lab project develops low cost passive alignment tools for spinal pedicle screw placement. The goal is to improve the surgeon's ability to accurately insert a pedicle screw following a predetermined trajectory. This reduces the risk of plunging which can damage soft tissue, nerves, or the spinal cord.

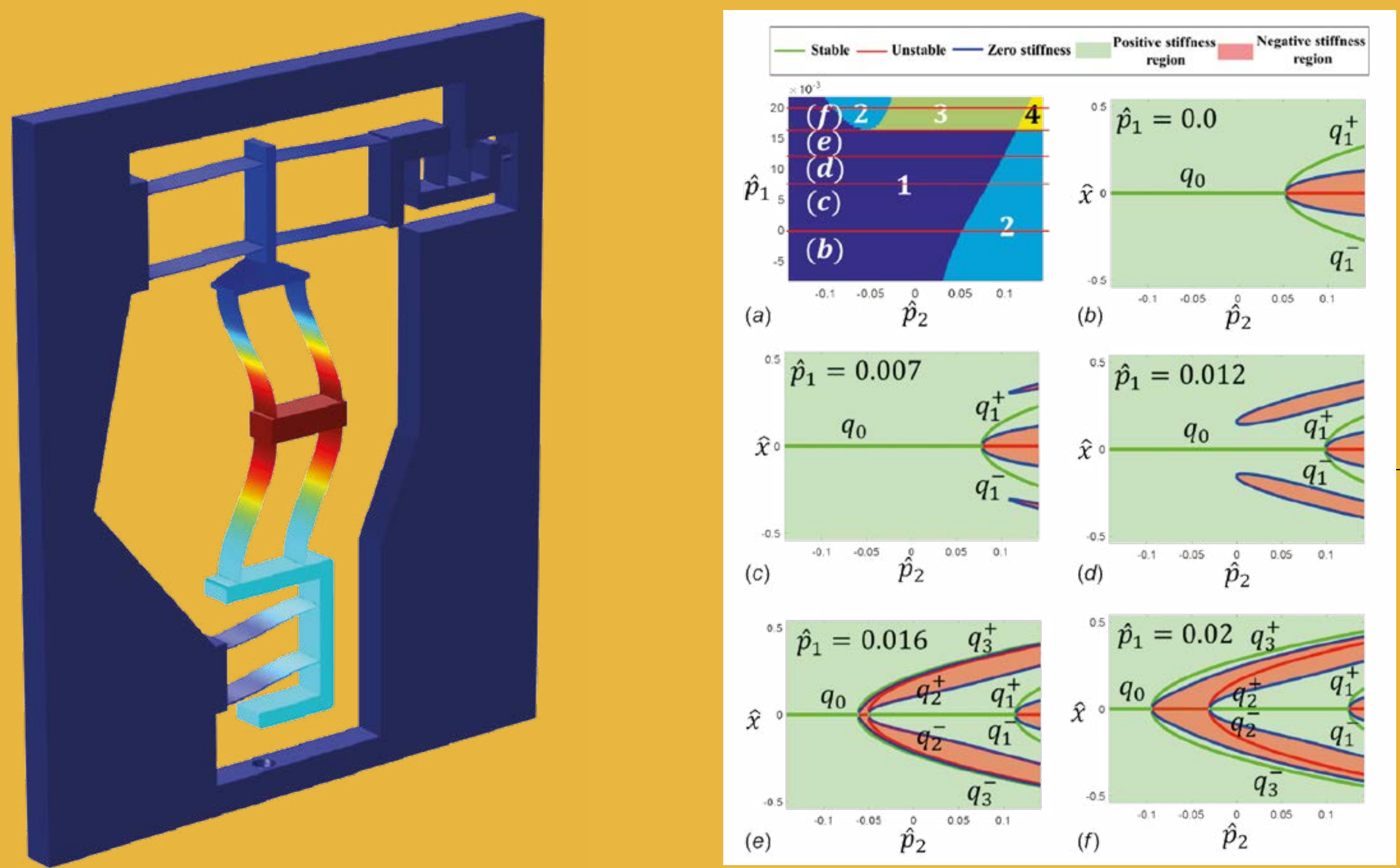
RESEARCH — Ph.D. THESES

Sebastian Fifanski, preliminary thesis title: *Miniature flexure structures for contact force sensing in pointed tools*.
Expected completion January 2019.



Force-sensing flexure.

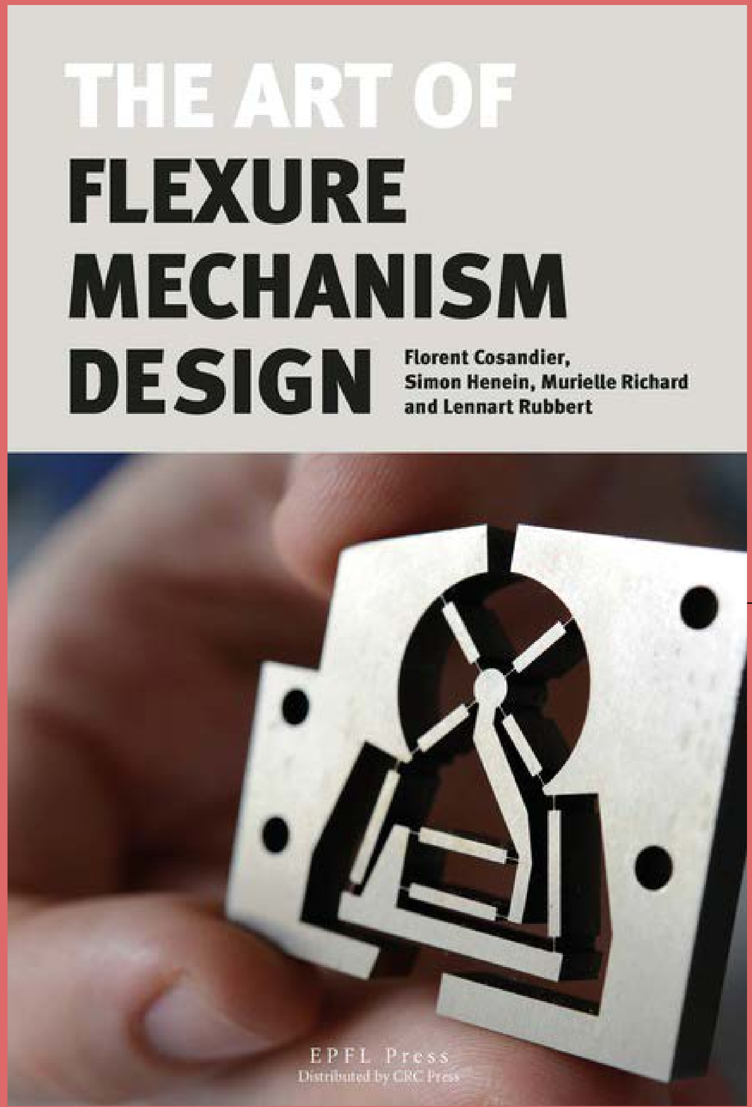
Mohamed Zanaty, preliminary thesis title: *Programmable multistable mechanisms*.
Expected completion October 2018.



T-shaped mechanism and its qualitative stability behavior.

Etienne Thalmann, preliminary thesis title: *Non-linear flexure-based oscillators*.
Expected completion September 2021.

Michal Smreczak in collaboration with **Imina Technologies SA**, preliminary thesis title: *Load cell with tunable stiffness dedicated to force measurement at the nano-Newton range*.
Expected completion September 2021.



S. FIFAŃSKI et al. Surgetica 2017 Strasbourg, France – 20 - 22 Nov.

VivoForce instrument for retinal microsurgery

Sebastian FIFAŃSKI[1], Jose RIVERA[1], Marine CLOGENSON[1], Charles BAUR[1], Axel BERTHOLDS[2], Pere LLOSAS[2] Thomas WOLFENSBERGER[3] and Simon HENEIN[1]

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Avenue de France 15, CH-1004, Lausanne, Switzerland

We introduce an innovative 0.6mm diameter force sensing instrument allowing for safer epiretinal membrane peeling surgery. Force sensing relies on flexures and Fabry-Pérot interferometry.

1 Introduction

Our VivoForce instrument applies to retinal microsurgery. Epiretinal membranes severely degrade human vision and must be surgically peeled from the retina, a delicate procedure since the retina must not be damaged. The principal difficulty is the limitation of human performance at the required millinewton force range [1].

Current surgery relies on classical passive tools such as a membrane pick or forceps. This results in significant risk of retinal damage and long surgery time (up to 40 minutes) so the procedure is highly dependent on surgeon skill and experience. Our proposed force sensing instrument minimizes the possibility of irreversible retinal damage, thus simplifying the procedure and making it accessible to a wider range of surgeons. Other instruments for this application have fiber Bragg grating based force sensing [2,3,4], so diminished axial sensitivity. Moreover, only our mechano-optical transducer is monolithic, facilitating assembly.

This work was supported by the Swiss Commission for Technology and Innovation (CTI).

2 Tool development

2.1 Specifications and utilization

Our instrument is inserted into the eye with the force sensing element inside the eye. Standard retinal surgery requires removal of the vitreous gel and replacing it with 20°C water. Since body temperature slowly heats this water, the instrument must operate at a range of 20°C to 34°C.

The instrument peels away the epiretinal membrane with peak forces up to 15mN and the force sensor is calibrated to a resolution of ~0.03 mN. Peeling is done with a 23 gauge hook. The instrument is operated by the surgeon's hand and can be easily adapted to robotic surgery.

Force sensing is indicated by increasing frequency sounds as force approaches maximal limit, and a warning sound when above. Force is also recorded in real time and displayed on a screen, so an assistant can inform the surgeon of his measured force.

VivoForce instrument
Cannula
Force sensing element
Epiretinal membrane

Figure 1: Epiretinal membrane peeling setup

2.2 Measurement principle

The force sensing load cell of our instrument consists of a mecano-optical transducer realized by flexures (compliant mechanisms) [5] by exploiting the

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PUBLICATIONS

Journal articles

P.-Y. Donzé, I. Vardi, S. Henein, *La R&D commune entreprises-université dans l'industrie horlogère de 1900 à nos jours*, Bulletin de la Société Suisse de Chronométrie 83 (2017), p. 21-28.

S. Henein, I.Vardi, *Une horlogerie mécanique sans tic-tac*, Pour la Science 474 (avril 2017), p. 48-54.

S. Henein, I. Vardi, *Horloge neuchâteloise du XXI[e] siècle équipée de l'oscillateur IsoSpring*, Chronométrophilia 82 (été / Sommer 2018), p. 107-113.

M.H. Kahrobaiyan, E. Thalmann, L. Rubbert, I. Vardi, S. Henein, *Gravity-Insensitive Flexure Pivot Oscillators*, to appear Journal of Mechanical Design.

I. Vardi, L. Rubbert, R. Bitterli, N. Ferrier, M. Kahrobaiyan, B. Nussbaumer, S. Henein, *Theory and design of spherical oscillator mechanisms*, to appear Precision Engineering.

I. Vardi, R. Bitterli, L. Convert, E. Thalmann, S. Henein, *Echappements à impulsion virtuelle*, to appear Bulletin de la Société Suisse de Chronométrie.

M. Zanaty, I. Vardi, S. Henein, *Programmable Multistable Mechanisms: Synthesis and Modeling*, to appear Journal of Mechanical Design.

M. Zanaty, S. Henein, *Experimental Characterization of a T-shaped Programmable Multistable Mechanism*, to appear Journal of Mechanical Design.

Books

F. Cosandier, S. Henein, M. Richard, L. Rubbert, *The Art of flexure mechanism design*, PPUR-EPFL press (2017), 290 p.

Patents

M. Kahrobaiyan, I. Vardi, S. Henein, *Two degree of freedom mechanical oscillator*, EP 17155984, February 2017.

M. Zanaty, C. Baur, S. Henein, *Device for controlled puncturing of an object*, PCT / EP2017 / 068344, July 2017.

J. Rivera Gutiérrez, S. Fifanski, C. Baur, *Device with tuneable-stiffness for footwear*, PCT / IB2017 / 056142, October 2017.

M. Zanaty, S. Henein. *Système multistable programmable*, EP3266737A1, July 2016.

Conference proceedings

S. Fifanski, J. Rivera Gutiérrez, M. Clogenson, C. Baur, A. Bertholds, P. Llosas, T. Wolfensberger, S. Henein, *VivoForce instrument for retinal microsurgery*, Surgetica 2017, Strasbourg, November 20-22, 2017, p. 155-157.

M.H. Kahrobaiyan, M. Zanaty, S. Henein, *An Analytical Model for Beam Flexure Modules Based on Timoshenko Beam Theory*, ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Cleveland, Ohio, USA, August 6-9, 2017.

M. Zanaty, A. Rogg, T. Fussinger, A. Lovera, C. Baur, Y. Bellouard, S. Henein, *Safe Puncture Tool for Retinal Vein Cannulation*, Design of Medical Devices (2017), Nov. 14-15, Eindhoven (Netherlands).

LECTURES, INVITED TALKS, POSTERS

S. Fifanski, *VivoForce instrument for retinal microsurgery*, Surgetica 2017, Strasbourg, France, November 2017.

S. Fifanski, *Instruments for intraocular microsurgery*, The Hamlyn Symposium on Medical Robotics, Imperial College, London, United Kingdom, June 2018.

S. Henein, *Les ressorts intimes du temps*, lecture/performance, La Chaux-de-Fonds, September 27, 2017.

E. Thalmann, *Cours sur l'horlogerie*, Cycle d'orientation des Liddes, Sierre, March 10, 2017.

M. Zanaty, *An Analytical Model for Beam Flexure Modules Based on Timoshenko Beam Theory*, ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Cleveland (USA), August 6-9, 2017.

M. Zanaty, *Safe Puncture Tool for Retinal Vein Cannulation*, Design of Medical Devices (2017), Nov. 14-15, Eindhoven (Netherlands).

DISSEMINATION

Colloques horlogers

In 2017, Instant-Lab and the FSRM launched a series of lectures by world renowned personalities in the field of horology. This ongoing lectures series features artisans, scientists and business persons. The three speakers this year were all Gaïa Prize recipients:

François Junod, Automatier, March 23, 2017.
Pierre Thomann, *La mesure précise du temps : les horloges atomiques et leurs applications*, June 19, 2017.
Antoine Simonin, *Formateur d'horlogers du monde*, December 11, 2017.

Visitors

Managers group of Faulhaber conducted by Mrs. Nicola Thibaudeau CEO of MPS, laboratory visit, Microcity, April 10, 2017.

Dr. Alan Finkel, Australia's Chief Scientist, April 27, 2017.

Instant-Lab at the MIH

Our spherical oscillator clock was featured at the International Museum of Horology in La Chaux-de-Fonds as the showpiece of their exhibit of Neuchâteloises clocks in the Fall of 2017.

Instant-Lab in the Press

La pendule neuchâteloise du 21ème siècle,
Simon Henein, Revue FH, January, 2017, p. 60-61.

Il ose s'attaquer au tic-tac,
Aurélie Faesch-Despont, L'Express, May 13, 2017, p. 35.

Das mechanische Uhren-Schwingsystem IsoSpring : Eine runde Sache,
Timm Delfs, Bellevue NZZ, June 6, 2017, online.

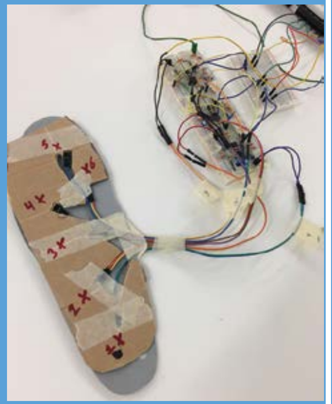
Les futurs ingénieurs sur les planches de l'Arsenic,
Sarah Aubort, EPFL Magazine n°10, September, 2017, p.35.

Horloge révolutionnaire,
Claire-Lise Droz, L'Express, August 17, 2017, p. 5.

Press conferences

Presentation of the Aquanaut Travel Time Ref. 5650G "Patek Philippe Advanced Research" watch incorporating novel flexures into the time zone setting mechanism, Baselworld, March 23, 2017.

Above documents available online
instantlab.epfl.ch/Media



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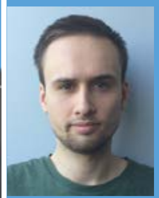
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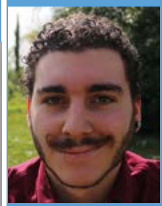
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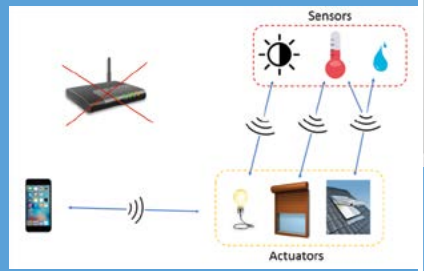


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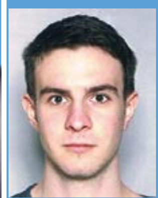
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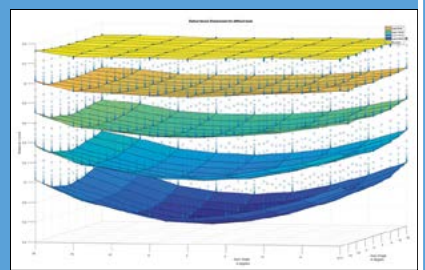

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TEACHING

The laboratory is strongly involved in teaching. Focus is on training creative design and learning the analytical tools necessary to model, simulate and predict mechanism behavior.

EPFL

Conception de mécanismes I & II (2017-2018)
Lecturer : Prof. S. Henein ; Section : Microtechnique (140 students) ; Bachelor semesters 2 and 3 ; three hours per week.

Construction mécanique I & II (2017-2018)
Lecturers : Course under the responsibility of Prof. S. Henein and Prof. J. Schiffman taught by two external lecturers ; Sections : Microtechnique / Génie mécanique (500 students) ; Bachelor semesters 1 and 2 ; three hours per week.

Collective creation : improvised arts and engineering I & II (2017-2018)
Lecturers : Prof. S. Henein, J. Valterio and guest lectures. 24 students ; open to all sections ; Master semesters 1 and 2 ; three hours per week. Year-long course, EPFL Social and Human Sciences (SHS) program, developed in cooperation with the Centre d'art scénique contemporain (Arsenic), Lausanne.

Semester (S) and master (M) projects

a. Sole for progressive weight application, Mainum Al-Tayar (S)
b. Flexure based tool improvement for limited hand mobility, Seif Eddine Jemli (S)
c. Interface utilisateur de contrôle d'un système domotique de capteurs et actuateurs BLE, Paul Alderton (S)
d. Développement d'une aiguille intelligente pour radiologie interventionnelle robotisée, Nathanel Ferraroli (S)
e. Rehabilitation insole for progressive weight application, Aurélie Balsa (S)
f. Programmation of microcontrolers for a decentralized system Bluetooth, Nicolas Rabany (S)
g. Développement d'une plateforme web pour de l'édition de contenu, Théo Sicard en collaboration avec EPF Sceaux France (S)
h. Réalité augmentée sur des objets portés, Paul Guillermier en collaboration avec EPF Sceaux France (S)
i. Adaptive and Modular Sample Delivery system for Planetary Rovers, Antoine Tardy (M)
j. Ducted wind turbines : analysis of OpenProp as a duct design tool and manufacturing strategy for a new shrouded turbine, Frédéric Junod (M)

A BRIDGE TO THE HUMANITIES

In 2017, Professor Henein conceived a new course linking the engineering and humanities faculties of the EPFL. “Collective creation: improvised arts and engineering.” The year-long course, which was launched in September 2017, is part of EPFL’s Social and Human Sciences (SHS) program. It was developed in cooperation with the Arsenic Theater (Centre d’art scénique contemporain) in Lausanne.

The course examines the creative process in engineering design and improvisation within the performing arts. Experts in a wide range of disciplines, ranging from theater to mathematics, present the students with creativity as expressed in their field of expertise. Workshops explore improvisation through theater, music, dance and the performance arts. The 24 students will stage their final project with a dress rehearsal on May 16 2018 and give their final presentation before their examiners on May 23. Both events will be open to the public.

Professor Henein emphasizes collaborative work: “Collectively, our creative potential is huge – much greater than that of each one of us individually – but to fully tap into it, we have to be able to create together. That’s why this class delves so deeply into this skill, which will be crucial in the students’ future careers. We look at intuition, expression, listening, trust and self-reflection. The students are exposed to a wide range of approaches to the creative process, from the hard sciences to engineering and stage performance. All these influences will play a part in their professional work.”

This course is open to all first-year Master’s students at EPFL and classes run in three-period blocks every week throughout the school year. The course will be given again in September 2018.

CONCLUSION AND PERSPECTIVE

In 2014, Prof. Simon Henein announced the IsoSpring project to make the first mechanical watch without escapement. This led to patents and a large-scale industrial project which was successfully completed in 2017. This research project is now focused on miniaturizing IsoSpring to the watch scale.

Complementary to the IsoSpring concept is our new virtual escapement which bridges the gap between double beat and dead beat escapements and our ongoing research on high quality factor watch oscillators.

Our laboratory is also committed to the dissemination and transmission of horological culture. To that end, we launched a series of lectures by personalities in all aspects of horology, this year featuring an artisan building automata, a scientist explaining atomic clocks and a businessman describing his adventures teaching watchmaking in Africa.

2017 also saw advances in our medical research with the fabrication of a millimeter scale medical device featuring flexure mechanisms realized in fused silica (glass). These features allow for safe puncturing of very delicate veins inside the human eye for the treatment of retinal vein occlusion.

We also began a collaboration in the SPIRITS project which gathers several prestigious research institutions.

These projects led to journal publications which will appear in 2018.

We published The Art of Flexure Mechanism Design, edited by Simon Henein and Lennart Rubbert, the definitive textbook on the subject.

This year saw our group initiate a new course bridging engineering and humanities. This course examines creativity in the conception of engineering mechanisms as well as in improvisation in the performing arts. This course is a collaboration with the Centre d'Art Scénique Contemporain in Lausanne.

The Instant-Lab team continues to employ 17 collaborators covering a full range of skills.

Perspectives

After the successful completion of the IsoSpring project, our goal is to have a functional wristwatch with an IsoSpring time base in 2019.

We are also engaging in fundamental scientific research complementary to our industrial projects.

We are more than ever involved in teaching, with participation in a new metrology course and a course in structural mechanics, as well as continuing teaching in the Social and Human Sciences program.

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