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A 3-DOF force measurement device for quality inspection applications of microsystems

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Abstract
This paper presents the concept of a compact (28mmx28mmx28mm) three-axis X, Y, Z load cell, based around a mechanism similar to that of a delta robot, using parallelograms to allow compliance for translational forces but remaining stiff to parasitical torque.
Due to the load cell's modularity, the flexure plates can be dimensioned for different stiffness and therefore different measurement sensitivities. In this paper, the integration of the load cell in the Alemnis quality inspection setup is presented, a device which specialises in nano-indentation, ultimate strength tests, fatigue tests, creep, stiffness and assembly accuracy measurements of micro-devices. In this version, a measurement range of +/-0.5N in all axes was realised, with a resolution of below 0.5mN and a stiffness of 147mN/µm. Displacement is measured with capacitve sensors.

Keywords: force measurement, micro-assembly, delta robot, capacitive, sensor, stiffness

1. Introduction

In the frame of the Eurostars Project REMIQUA, a consortium composed of two SMEs (Alemnis GmbH in Switzerland and Percipio Robotics SA in France), one university (Pierre et Marie Curie - Paris 6 in France) and a research and development centre (CSEM SA in Switzerland) has been developing a modular and versatile platform specifically designed for the assembly and quality inspection of microsystems for prototyping and small-series production.

A central function required for these platforms is the measurement of interaction forces between manipulators and a sample. Contrary to setups where the force sensing capabilities are integrated in the grippers, the chosen approach measures force interactions at the level of the sample table. This allows higher dynamics of the grippers, and easier adaptation of the gripper design to different applications.

In this paper the development of the 3 axis (X, Y, Z) load cell will be presented, as well as its integration in the Alemnis quality inspection setup.

2. The Load Cell

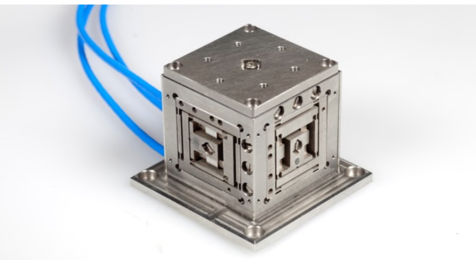

Figure 1. The 3 axis load cell (28mmx28mmx28mm) with sample table (top surface)

A requirement of the load cell was to measure linear forces along the main axes X, Y, Z, while being insensitive to parasitical torque due to due to Abbe errors, when interaction occurs at different places on the sample table.

This led to the investigation of flexure mechanisms with translational compliance, and high rotational stiffness. The chosen solution was based around a kinematic structure similar to that of the sugar cube delta robot [1], using three identical plates, each containing a flexure mechanism that each constrains one rotation. The centres of the plates are connected to each other at the interior of the load cell, and also to the sample table above.

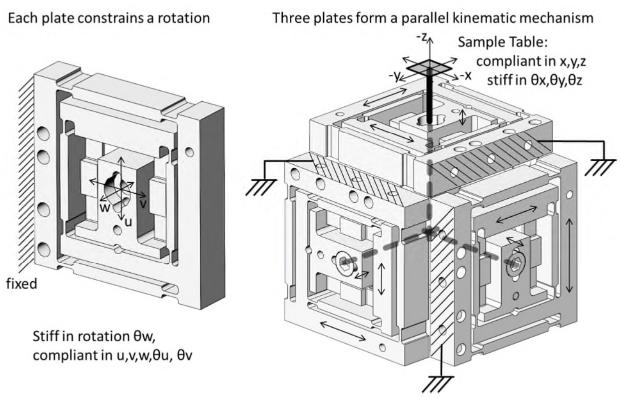

Figure 2. The delta robot based guiding mechanism

Due to the small displacement ranges (a few µm), the stiffness remains quite constant over the whole workspace. An advantage of the design is that the stiffness along each of the axes X, Y, Z can be chosen by dimensioning the flexure hinges appropriately. It could even be possible to tune the stiffness by adding an additional spring in parallel to each axis. Unfortunately there was not enough time to implement this during the project.

Force measurement is done by measuring the deformation of the structure via linear displacement measurements. Due to the hollow nature of the design, different measurement methods can be used. For the project, two variants were implemented, one using capacitive displacement sensors and one using strain gauge. In the quality control setup presented in this paper, the capacitive sensor version was used. Three flat capacitive sensors measure the X, Y, Z displacement of the central cube.

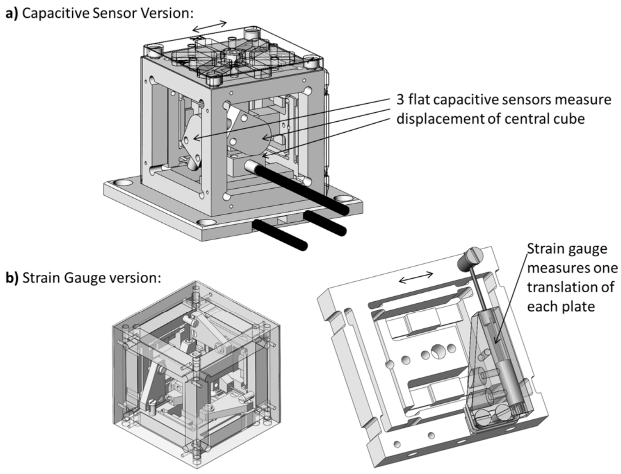

Figure 3. Variants using different sensors: a) using capacitive sensors, b) using strain gauges. In the strain gauge version, each strain gauge measures one translation of each plate.

But also other variants using interferometric displacement sensors are imaginable. For applications, where lower stiffness is accepted, and hence longer strokes, even interpolated linear encoders, LVDTs, fibre-optical devices or CSEM's SpaceCoder technology[2] could be used. Further variants include electromagnetic force compensating systems, which keep the measurement surface in a constant position, albeit with higher technical complexity.

3. The Alemnis quality inspection instrument

Following the introduction of new materials (Si, fused silica, electrodeposited Ni alloys) and of new manufacturing processes (DRIE, laser machining, electrodeposition) for the fabrication of micro mechanical components, many questions have arisen concerning their mechanical behaviour. Silicon can be very appealing for certain applications, but due to its brittleness several challenges are related to its introduction into micro-devices. Similarly, the LIGA process allows for a high degree of flexibility in the design and cost effective batch processes. However, these electrodeposited materials do not present the same properties as the bulk material, in particular their Young's modulus and long term stability is not yet satisfactory [3, 4].

For these reasons, and in order to design and produce reliable and innovative micro mechanisms, it is necessary to have a better understanding of the material at the micro- and nano-scale. Alemnis quality inspection instrument aims to address these questions.

3.1. Description of the Instrument

The instrument is based on an Alemnis indenter platform (figure 4) equipped with the above mentioned load cell developed in cooperation with CSEM. A miniature microscope and a set of micro-grippers can also be integrated in the setup (not shown in the picture).

Force measurement:
- 3-axis (x-y-z)
- range +/- 0.5N
- stiffness 147mN/μm
- error < 0.1% FS
- cross coupling < 2.5%

Positioning :
- 3 axis (x-y-z)
- range 25mm
- resolution 1nm
- high stability for creep and fatigue tests
- High vacuum compatible

Figure 4. The test instrument equipped with the 3-axis force sensor

3.2. Preliminary tests

Test procedures are currently being implemented, which include (but are not limited to), nano-indentation [5], ultimate strength tests, fatigue tests, creep, stiffness and assembly accuracy measurements. The tests are conducted on a set of bench-mark micro-devices to assess and to improve the fabrication and assembly processes.

In a normal laboratory environment, with the test platform bolted on an optical bench, the load cell's measured RMS noise was 40μN at 200Hz (averaged over 125 samples) and 450μN at 25kHz (sample rate, no averaging).

As a benchmark test, the bending stiffness of a sample consisting of a stainless steel rod (300μm in diameter, 8 mm free length) with a 500μm diameter sphere glued on it, was measured. The system scanned a pre-defined area to find by physical contact the location of the sample. Then a given lateral displacement was applied (typically up to 200μm, still in the elastic domain). The forces vs displacements were plotted for 100 cycles and the corresponding stiffness is calculated.

No changes in the stiffness were noticed over the 100 or even 200 cycles, confirming reasonable measurement stability.

4. Conclusions

The load cell concept proposed by CSEM was successfully designed and implemented in the Alemnis quality inspection instrument. First tests have shown satisfactory results. The consortium is convinced that the concept has potential for other applications, where multi axis linear force measurements are required.

5. Acknowledgments

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References

[1] S. Henein et Al. 2011 Silicon flexures for the SugarCube Delta Robot *Proceedings of the 11th Euspen International Conference* 6-9
[2] E. Grenet et Al. 2011 spaceCoder: a Nanometric 3D Position Sensing Device *CSEM Scientific & Technical Report (2011)* 89
[3] L. Philippe, Z. Wang, I. Peyrot, A.W. Hassel and J. Michler 2009 Nanomechanics of rhenium wires: Elastic modulus, yield strength and strain hardening *Acta Materialia* **57** 14
[4] G. Genolet et. Al. 2014 Caractérisation des paramètres de fluage de composant UV-LiGA à l'aide d'une optimisation paramétrique *Journée d'Etude 2014, Société Suisse de Chronométrie*
[5] Rudy Ghisleni, Karolina Rzepiejewska-Malyska, Laetitia Philippe, Patrick Schwaller and Johann Michler 2009 In Situ SEM Indentation Experiments: Instruments, Methodology, and Applications, *Microscopy Research and Technique* **72** 242–249