The Nanoconverter: a novel flexure-based mechanism to convert microns into nanometers

S. Henein[1&2], M. Stampanoni[2], U. Frommherz[2], M. Riina[2]
[1]*Centre Suisse d'Electronique et de Microtechnique, 2002 Neuchâtel, Switzerland*
[2]*Paul Scherrer Institut, 5232 Villigen PSI, Switzerland*

simon.henein@csem.ch

Abstract

The patented Nanoconverter is as planar flexure-based structure that attenuates linear movement amplitudes by a large constant reduction factor that can be chosen by design typically between 20 and 1000. It allows using conventional commercial actuators with micrometric accuracy to produce movements with nanometric accuracy. The first Nanoconverter is in use on the Differential-Phase-Contrast Interferometer of a Synchrotron Radiation Beamline. A wide spectrum of other applications is envisaged.

1 Introduction

Achieving motion accuracies below the 10 nanometer range is today generally achieved by combining frictionless flexure-based structures with piezoelectric actuators having complex control electronics (high voltages, close-loop control required).

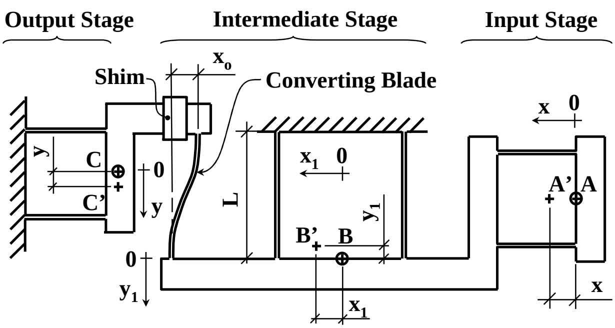

Figure 1: Working principle of the Nanoconverter

The patented Nanoconveter [1] is a novel flexure-based structure that allows using classical actuators (like Stepper of DC motors) having inherent accuracies in the micrometer range to achieve nanometric accuracy: “the Nanoconverter converts microns into nanometers”, in the same way as reduction gearboxes reduce the angular speed of a classical motors.

2 Working principle

A commercial linear actuator with micrometric motion accuracy drives horizontally the point A (figure 1) of the Input Stage to A’ (rectilinear displacement x). This motion is transmitted to the Intermediate Stage that is guided by a classical parallel-spring-stage (with blade length *L*): point B moves to B’. Due to the shortening of the blade projection, the motion of this stage is a well known parabolic translation [2]: $y_1 = -3x_1^2/(5L)$, where $x_1 \cong x$. A third blade of length *L* (called “Converting Blade”) that has an offset deformation x_0 links the Intermediate Stage to the Output stage. The Output Stage is guided vertically by a classical parallel-spring-stage. The motion x_1 causes the Converting Blade to shorten, following the same parabolic law as the two blades of the Intermediate Stage, but with an offset x_0. The resulting motion *y* of the Output Stage (motion from C to C’) is equal to the differential shortening of the blades (subtraction of two parabolas with an offset):

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

Therefore, if the origin of the *y* axis is adequately chosen, the displacement *y* of the Output Stage is simply proportional to the displacement *x* of the actuator, with a constant reduction ratio *i* that is inversely proportional to the offset x_0 (i.e. the reduction is purely linear). Choosing an offset x_0 that is small compared to the blade length *L* leads to very large demagnification ratios. This is mechanically very easy to carry out by using a shim as illustrated in figure 1 or by monolithical manufacturing like in figure 2.

3 Application and Experimental results

The Nanoconverter was originally developed for an optical instrument to be used on at least two beamlines of the Swiss Light Source (SLS) synchrotron of the Paul Scherrer Institut (PSI): TOMCAT (Tomographic Microscopy and Coherent Radiology Experiment, M. Stampanoni) and cSAXS (Coherent Small Angle X-ray

Scattering, F. Pfeiffer). The instrument is a Differential Phase Contrast (DPC) Interferometer that can be mounted on standard absorption setups to observe phase shift information [3]. This instrument consists of two optical gratings with pitches of a few microns. One of the gratings must be scanned with an accuracy in the order of 20 nanometers over a typical range of 30 microns during the x-ray exposure. The Nanoconverter has been designed to perform this scanning motion, using a commercial "pusher" (stepper motor with lead screw and nut, driving an output shaft axially).

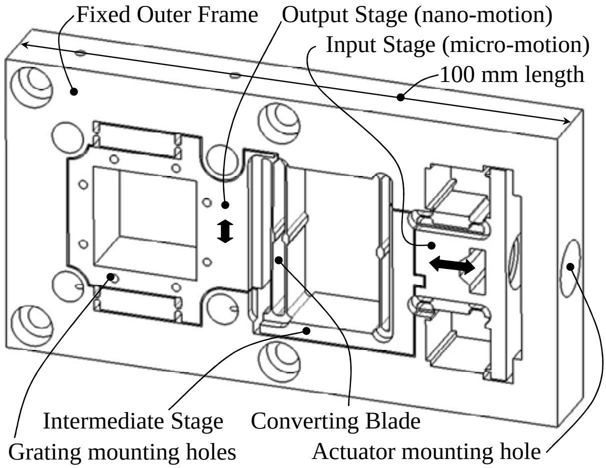

Figure 2: Monolithical Nanoconverter as it has been manufactured by wire-EDM

This design has a fixed reduction ratio of 100. The input motion range is ± 1.4 mm and the respective output motion range is therefore ± 14 microns. The accuracy of the selected commercial actuator is ± 1 microns, and the respective output resolution is therefore ± 10 nanometers. The Converting Blade has a length $L = 30$ mm and an offset of $x_0 = 0.25$ mm, (i.e. $i = 100$). The overall size of the Nanoconverter unit is 100 x 50 x 10 mm. This version of the Nanoconverter has been designed in order to be compatible with the commercial Linos standard optical elements (Linos Micro-bench). This structure was manufactured monolithically (no shim) by wire-Electrodischarge Machining (Wire-EDM) in Stainless Steel (Böhler W720).

In October 2006, the first Differental-Phase-Contrast interferometric images (fig. 3) where taken on the TOMCAT beamline, using the Nanoconverter to scan the grating.

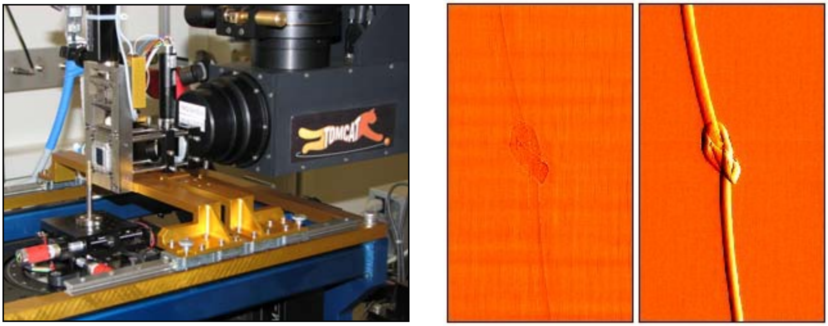

Figure 3: *Left*: Photograph of the Differential-Phase-Contrast Interferometer setup in the SLS Synchrotron Radiation TOMCAT Beamline. *Far right*: Phase gradient image of a human hair with knot compared to classical absorption image (middle). These images have been taken using the Nanoconveter.

4 Conclusion

It is well known in the state-of-the-art that flexures can be used as reducing mechanisms, but the known solutions have non-linear characteristics (i.e. the reduction factor is not constant over the motion range). In comparison, the Nanoconverter presents the following key advantages: constant reduction factor; very high reduction factors easily achievable (typically up to 1000); can be designed to be tunable using a simple tuning screw or shim to select the reduction factor over a wide range (typically 20 to 1000); simple planar structure that can be manufactured monolithically (no need for assembly) using a wide variety of techniques (e.g. wire-EDM, laser cutting, silicon etching, LIGA).

References:

[1] Device for converting a first motion into a second motion responsive to said first motion under a demagnification scale, S. Henein, Patent EP06021785, Holder: Paul Scherrer Institut, 2006.

[2] Conception des guidages flexibles, S. Henein, Presses Polytechniques et Universitaires Romandes, ISBN: 2-88074-481-4, 2001.

[3] Trends in synchrotron-based tomographic imaging: the SLS experience, M. Stampanoni et al., Proceedings of SPIE, Vol. 6318, Developments in X-Ray Tomography V, Ulrich Bonse, Editor, 2006.