

Intelligent Pinhole with Sub-Micrometer Resolution

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Abstract: An intelligent pinhole for confocal microscopy consisting of four position controlled blades forming a rectangular aperture from $3 \times 3 \mu\text{m}$ to $500 \times 500 \mu\text{m}$ was built. This aperture can be positioned without drift under computer control in a positioning range with a sub-micrometer precision. Each blade is suspended by an elastic hinges and moved by a linear magnetic actuator. An integrated position transducer with a reproducibility of better than 40 nm allows a settling time of less than 75 ms . The whole pinhole system is small sized ($40 \times 40 \times 20 \text{ mm}$) with an electrical consumption of less than 2 W . A first application in a scanning confocal microscope demonstrated the usefulness of such a micro-opto-mechanical system.

1. Introduction

New fabrication technologies [1,2] allow the realisation of a high precision miniaturized pinhole system with an integrated absolute positioning control. The key system requirements were challenging:

- a sub-micron resolution in x and y position,
- an aperture opening between 10 to $300 \mu\text{m}$ within a positioning range of $0.5 \times 0.5 \text{ mm}^2$.

Closed loop controls for drift compensation as well as a short settling time etc. are of prime importance for many applications.

2. Concept

Three basic concepts are important for this intelligent pinhole. First, the high-resolution requirements are best fulfilled with the elastic hinge guidance principle, known for no mechanical stick-slip and allowing an implementation into a planar structure. Second, an on-line position transducer integrated onto the moving part guarantees a controllable blade position, avoids hysteresis, compensates for systematic errors, and allows a precision assembling and calibration. Third, a linear moving actuator based on a permanent magnet constitutes a high force, low volume actuator with relatively low power consumption.

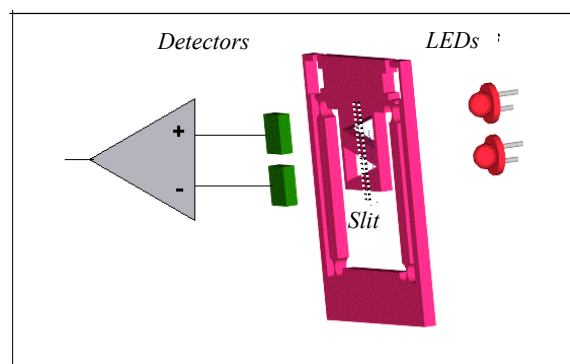


Fig 1 Position sensor principle- 2 LEDs illuminate across slits and opposite triangular openings photodiodes generating a differential signal for positioning

The position sensor (fig. 1) is constituted by two oppositely oriented triangular apertures on the moving part, illuminated homogeneously across a small slit and

sensed by two photodiodes. Miniaturized chip-LEDs with very high brightness are used as stable light sources. The photocurrent difference is used as the position output signal whereas the sum of these currents serves for the stabilization of the LED light and allows diminishing temperature dependent drifts. This sensor is well matched to the planar sandwich construction and does not need a precision assembly.

All these conceptual considerations led us to a planar sandwich construction based on two 90 degree rotated hinge plates, each of them comprising two elastic hinges guided parallel blades and moving magnet actuators, as shown in fig. 2.

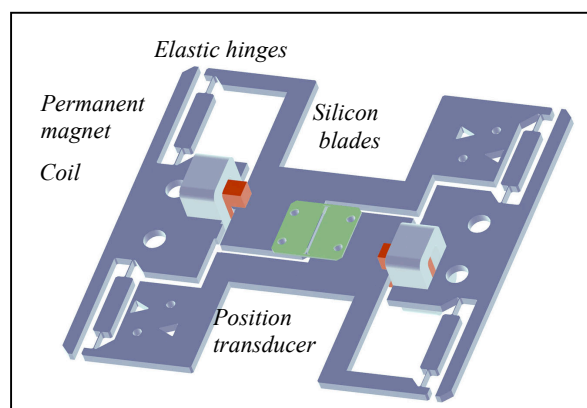


Fig. 2 Hinge plates with two parallel aperture blades.

Two such sandwich elements are assembled in order to minimize the distance between the sandwich elements ($\leq 50 \mu\text{m}$). This results in a rectangular aperture of variable width and a free positioning over the given area of positioning.

As presented in fig. 3, the planar sandwich construction comprises additional precision micro-machined plates for the slits, the LEDs, the detectors, and two electronics boards for signal processing and control. Assembly is facilitated by a precise pin location for all plane elements of the sandwich; no active alignment procedure during assembly is required.

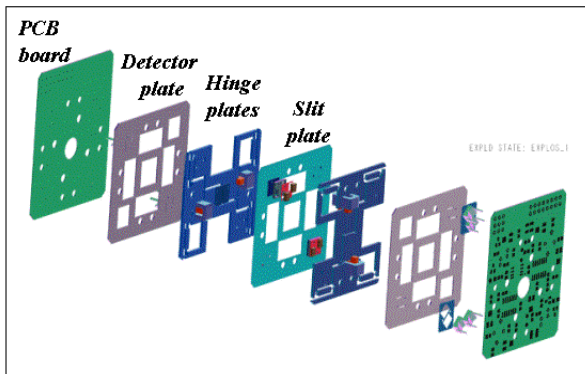


Fig. 3 Exploded view of the whole device presenting the different plate elements (hinge plate, slit plate, detector plate and SMD electronics boards).

To obtain the required precision and edge quality, the blades are micro-machined in silicon by pairs and fixed onto the moving plates. The two bridges linking the blades are broken after gluing, assuring a precise parallel position of the two blades (fig. 4)

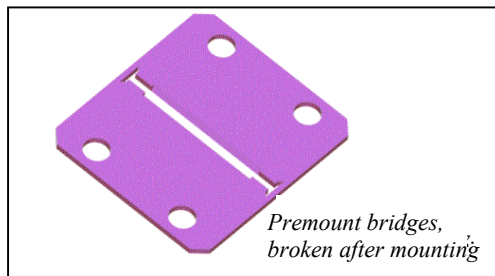


Fig 4 Silicon blades before mounting on the hinge plates.

3. Results

The crucial element of the system is the position transducer. Its linearity is determined by the precision of the triangles and the homogeneity of the illumination. As the illumination is difficult to control, the transducer response is not perfectly linear, but the residual systematic errors can be compensated easily by computer control resulting in an almost perfect linearization. The ultimate precision is given by the detector noise and was expressed as a noise equivalent positioning error. The detector noise is basically the shot noise and yields a noise equivalent position error of 6.2 nm (RMS) for a detection bandwidth of 10 kHz. For microscopy, the pinhole is computer controlled with a closed loop feedback control, which can be implemented with an analog PID controller or alternatively with a digital real time PID controller.

Fig.5 shows a first experimental calibration curve with a 4th order numerical fit and the residual error, i.e. the difference between the experimental and the numerical fit values. The standard error (one point) is 128 nm, partially due to the manual acquisition. A more elaborate implementation of this system in an automatic measuring microscope improved the reproducibility. Measuring over a range from 5 μm to

180 μm the reproducibility improved to 30 nm (RMS) with a linearity of approx. 1% as shown in fig. 6. Five back and forward moves are overlaid in fig. 6 proving the high reproducibility and a no-drift performance over several hours.

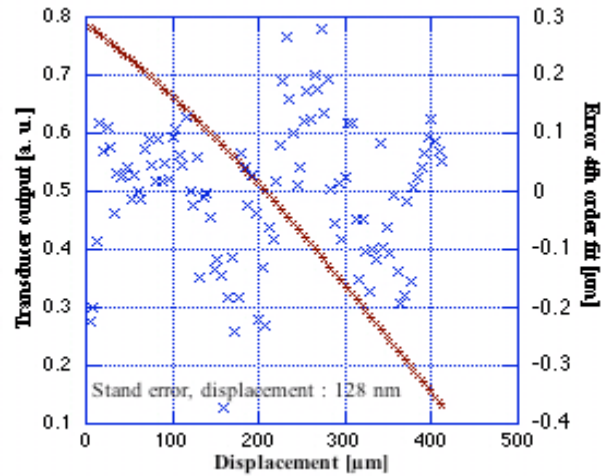


Fig 5 First calibration of the position sensor, displacement was measured with micrometer screw

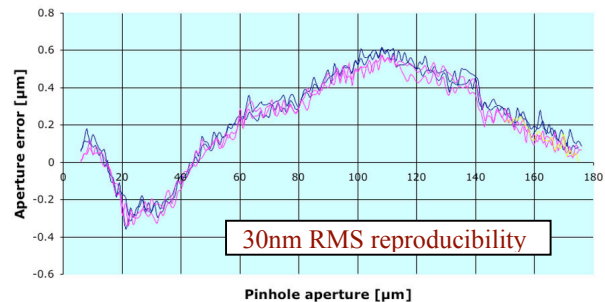


Fig. 6 Pinhole aperture reproducibility from 5 μm to 180 μm

4. Conclusions

A compact ultra-precise adjustable rectangular pinhole has been built. This smart pinhole with an integrated position sensor can be driven in closed loop under computer control, with a reproducibility of 30 nm. The application of this pinhole in a confocal microscope permits acquisition of high quality 3D images. The small volume of the whole system allows an easy fit in existing microscopes.

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6. References

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