NANO-POSITIONING USING INTERFEROMETRIC METHODS INTO A MINIATURISED DEVICE

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Abstract The positioning into micro fabrication systems is an important part for general operational success. The robustness of the positioning subsystem generates the accuracy of displacements specific to this kind of technical applications. The authors focused on the obtaining for an experimental device that has permitted to develop an interferometric measure method for sub micrometric displacements using optical devices. The high accuracy requested by micro applications involves Nano measure level and the capacity to develop data flow for movement control at this scale in real time. The wavelength of utilised laser beam is 633 nm and became the measure unit for positioning system. Also the measuring part is completed by another part referred to actuation, more precisely to piezoelectric actuation. A dynamic measure method was developed in this paper, utilising piezoelectric actuators designed for oscillating working actions. Finally we present here the performance of interferometric device that is conceived for feedback positional control, following construction of Nano-positioning closed loop command into the next paper.

Keywords: Nano-positioning, optics, interferometry, actuator, piezoelectric.

1. Introduction

Positioning elements in Nano and Micro systems involves the use of specific actuators. They don’t present sufficient linearity to build robotic applications with linear command board. Therefore, for obtaining a precise displacement, it is indispensable the positioning control which must be integrated within the system.

Today, the automation field offers many tools from modern control theory to build complex mathematical working models and to lead the displacement execution with a quantified known resolution even in non-optical microscopy domain [1]. A robust positioning system integrates driving axis that must be free from nonlinear behaviour and direction dependency [2]. The technical performance must be reflected also in repeatability of system. Utilising interferometric methods for positioning control it can become tangible very high repeatability (ex.: system based on a heterodyne interferometric sensor obtained a repeatability limited to 0.5 nm) [3].

Another aspect that raises issues in piezoelectric actuators that must be integrated for obtaining Nano positioning function is hysteresis [4-8]. A characterization of piezoelectric device is needed for feedback laws defining and applying, all oriented to construct closed loop command board. Micro robotic systems uses both open and closed loops for develop own functions [9] applying combination for these 2 kind of execution function, but by far the best method is to combine 2 sensorial activities [10] to control the same action. This type is known by technical literacy as sensor-fusion [11-12].

The Michelson interferometry is a classical method to measure small displacement for angular [13] or linear movements using the two wave sources resulted by one single interfering into a same propagation path. The crossing orthogonal reflective plan on this path will generate the phenomena named “pulsing eye”. The performance of measuring in Michelson case depends by wave’s length and represents the precision of measuring. The method is a very precisely one ordinary at tens nanometre level [14] and it can be applied even at atomic level [15].

Combining optics with electronics and software, it can be obtained high accuracy displacement transducers, based on interferometric sensor and represent most precise modality to implement a feedback control for closed loop positioning commands.

2. Principle of the device. The work goals of the paper

The device includes a Michelson interferometer. The principle is shown in figure 1 (a – schematic for device system, b – real device system), adapted for particular case of experimental device achieved in lab. The light from source traverses the splitter (4) which allows 50% of the radiation to be transmitted to the translatable mirror (6) and the other 50% of the radiation is reflected to the fixed mirror (8) [16].
Nano-Positioning Using Interferometric Methods Into A Miniaturised Device

Figure 1: Michelson interferometer principle. a) Theoretical schematic b) Real miniaturised

After returning from mirror (6), 50% of the light is reflected to vertical plan of sensorial element (7). Likewise, 50% of the light returning from (8) is transmitted to the same plan of (7). The two beams (reflected by (6) and (8)) resulted from the same source (1, 2 and 3) are superposed creating the desired interference [17]. One of two mirrors is mobile, respectively (9) piezoelectric element. Capable to develop small displacements, especially under 1 micrometer limit, the (9) element generates experimental quantified linear movements of (8) mirror. The fix mirror (6) is based on fix support (5). The (10) support sustains the whole system representing the quota zero on vertical axis for mechanical relative positioning of all elements.

The analogue signal is proportional with incident photons flow on orthogonal plan (7) that captures the interference effect, named “pulsing eye”. The analogue signal is coupled at one of the analogue pins of IO101 interface within a real-time computer SpeedGoat (not represented in figure 1) that is operable using Simulink programming models. In the next chapters, it will be presented the particular programming model and the resulted graphics specific for experimental determinations.

The most important technical aspect is the characterization of piezoelectric element (9), that is special made for frequency working and it presents a non-linear own function of voltage-displacements.

After this determination this element becomes the open loop displacement generator. The precise known displacements executed by piezoelectric it will induces movement to mirror (8) and it creates an oscillating reflective surface that will modify the interference state. The final goal refers to obtaining of precise counting device. This device is designated for counting the waves which are succeeding within dynamic frame specific for centre of "pulsing eye". This succession is determinate by relative distance between mirror (8) and beamsplitter (4).

3. The characterisation of piezoelectric actuator utilised for mobile mirror in experimental

The piezoelectric actuator is designated for frequency working up to 135 kHz (+20%). We utilised this element for low frequency, reason for that we characterised the device for cycling displacements range (1Hz experimental determination).

The main data from technical datasheet of piezoelectric actuator P-883.11 /Pigma Company:
- Nominal displacement (0 – 100 V dc): 6.5 ±20% (micrometers)

The experimental conditions for supply signal: Frequency = 1Hz and Amplitude = 50 V dc. The principle of experiment, the source signal excitation and the resulted graphics for 10 cycles of successive oscillatory up-down displacements are shown in figure 2 (a, b, c).
Regarding the piezoelectric element characterization we concluded with next observation and determination:

- The device don’t return in the zero start displacement point
- Dynamic range of displacement for (0 – 100 V dc), average values: 0.6 um – 3.1 um
- The total up-down distance is 2.5 um

4. The description of device hardware/software

The lighting source is a He-Ne gas laser, THORLAB HNLS0008L-EC model. The transport of light to the experimental MOEMS device is achieved utilising a fiber port connection optical device and a fiber optic adapted for 633 nm IR. The hardware of measuring subsystem has a one single sensorial element: phototransistor. This electronic device was chosen in correspondence with wavelength of laser source, with the other words the sensitivity is almost at the maximum value for this wavelength photonic signal.

The phototransistor and circuit diagram of connection is shown in Figure 4 (a,b). We can connect this device in two ways, respectively direct or inverse output analogue signal proportionality with excitation photonic signal. The utilised type was the second one.
The achieved Simulink programming model (figure 4 c) intercepts the analogue signal values supplied by excited phototransistor and store these data into *.csv file. After each storing it follows the computing session that refers to calculate the total number of local maximums succession.

The experimental results

The experiment strategy had one goal: Determination of accuracy for MOEMS device.

- Measurement Accuracy of experimental model of MOEMS

The experiment for accuracy consisted into applying of increasing number of up-down cycles for piezoelectric element respecting the characterization experiment conditions (50V/1Hz for supply signal). The experiment time for one wavelengths number determination is included in the range [10 - 30] s, increment +1.

In the table 1 are presented experimental data for accuracy determination.

<table>
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<th>Crt. No.</th>
<th>Time</th>
<th>( N_{\text{exp}} ) [wavelengths]</th>
<th>( N_{k+1} - N_k ) [wavelengths]</th>
<th>Crt. No.</th>
<th>Time</th>
<th>( N_{\text{exp}} ) [wavelengths]</th>
<th>( N_{k+1} - N_k ) [wavelengths]</th>
<th>Crt. No.</th>
<th>Time</th>
<th>( N_{\text{exp}} ) [wavelengths]</th>
<th>( N_{k+1} - N_k ) [wavelengths]</th>
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Interpreting the data from the above table, it observed that the resulted accuracy is less than 1 wavelength (650 nm).

Theoretical value for 5 um displacement can be calculated with the simple formula: \( S[\text{um}]/0.633[\text{wavelengths/um}]=7.89[\text{wavelengths}] \).
On observe that the weighted average resulted from above table is (13/20) x [wave.lengths/um] + (7/20) x [wave.lengths/um] = 7.35 [wave.lengths/um].

The theoretical error is related to theoretical 7.89 [wavelengths] corresponding to real 5 um displacement measurement. It results a maximal measuring error by 6.84%.

5. Conclusions

The miniaturising of system was a passed challenge. The alignment between beamsplitter and phototransistor was obtained through iterative tries, usual practice for this kind of experimental models. The iterations were assisted by interactive measuring of analogue signal generates by sensor.

The experimental frame was uncovered for testing the influences of day light. We concluded that it was no issues in this direction, because the sensitivity of phototransistor is oriented for certain wavelength value (700 nm).

The values for obtained repeatability and accuracy are very acceptable in this phase of system evolution. After this session of experimental model developing and testing, we identified more possibilities for future improvement and up-grade for entire MOEMS system. An example in this direction is an alignment CCD adjacent device that it will help to achieve a precise positioning of sensor relative to beamsplitter.

The software can be improved too with an analysing module for analogue signal that will predict the position of mobile mirror at a half-wavelength resolution and probably lower than that.

The resulted 6.84% theoretical error for measuring capacity of experimental model, it opens the way to achieve a professional measuring device using the tested principle of Michelson interferometer. The utilised lab conditions were common ones. In special white-room conditions, the tests and device tuning can be increased at maximum optimal values.

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6. References