Development of a High-Resolution Positioner for 3D Nanometrology of Microparts

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Abstract

There is currently a need for real 3D nanometrology of microparts, with true capacity for performing 3D part positioning. A high-resolution three-dimensional positioning system for microparts has been developed enabling measurements of the majority of possible geometrical features of micro- and nano-parts. In addition, a reference mark system has been included to maintain the coordinate system after repositioning the part or sensor. The thermal behaviour of the positioner is of critical importance due to the fact that thermal expansion can produce displacements bigger than measurements to be made. Therefore, low-thermal-expansion materials and piezoelectric motors with zero heat generation in the stop position have been chosen. Thermal simulations have been performed, and it has been concluded that the estimated thermal deformations meet the established requirements. To summarise the challenges involved in the design and manufacturing of this positioning system, we highlight its miniaturisation, light weight, high thermal stability and virtually zero heat generation during the stop position.

1 Introduction

The developed positioning system allows for 3D measurement in NanoCMMs and enables measurements to be taken inside holes and gaps, on steep slopes, and behind obstructions. This can be performed without changing the reference coordinate system while taking measurements. Currently various architectures have been developed for micropositioning tasks, among which are those based on three-degrees-of-freedom positioning with a low-angle tilting capability for the part [1]. Present design described in this paper extends the tilting range to the full spatial orientation of the part to be measured.

2 Design of the positioner

2.1 Mechanical design

The positioning system consists of two rotary piezoelectric motors assembled in an orthogonal arrangement. In Figure 1, the design of the system and prototype are shown, with the parts listed as follows: (1) piezoelectric motor A; (2) piezoelectric motor B; (3) base plate; (4) joint disk; (5) mobile platform; (6) part holding tray; (7) reference marks; (8) part to be measured; (9) bearing; and (10) shaft.

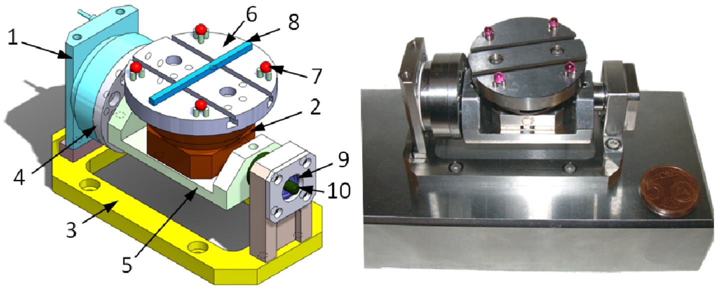

Figure 1. Positioning system and prototype.

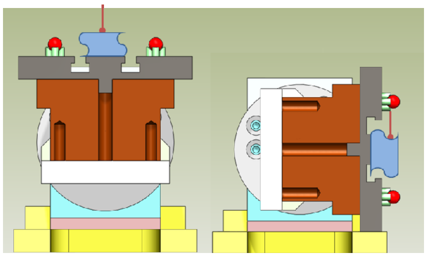
Figure 2. Capability of positioning part in space

This configuration makes possible any spatial orientation of the part to be measured. It is possible to vertically access every structural element of the part through the use of different types of sensors, as shown in Figure 2. Selected commercial inertial motors convert the limited displacement of a piezoelectric element into an unlimited rotary motion through an intermittent frictional coupling [2]. After a certain position is reached, the current applied to the piezoelectric element is zero. Therefore, the heat generated in the stop position is zero, and there is no electronic noise or drift. This system can be run in a closed loop to initially move the part using a resistive encoder (potentiometric measurement) which has a coarse repeatability detailed below; the open-loop command then is used to locate the part with a higher resolution, making it possible to advance with coarse-stepping or fine-stepping modes. The position of the coordinate system can then be calculated with high precision by measuring the reference marks, which consist of precision ruby balls located on the part-holding plate. The full specifications are as follows:

- System volume and weight: 75 mm x 50 mm x 50 mm and 400 g.
- Part to be measured: a maximum of 20 mm x 20 mm x 20 mm and 20 g.
- Positioning range: ±π/2 rad in axis A, and 2π rad in axis B.
- Positioning in closed loop: encoder resolution of 0.1047 mrad, and repeatability of 0.8726 mrad.
- Positioning in open loop: resolution of 0.0174 mrad in coarse stepping mode, and 0.0174 µrad in fine stepping mode.
- Reference marks: ruby spheres 3 mm in diameter, sphericity of 0.075 µm, and surface roughness of 0.007 µm.

2.2 Thermal study

The thermal effects derived from changes in temperature are critical, especially when long measurement times are required. Most of the components of the system are made of invar, except for the titanium commercial actuators. An analysis of the thermal behaviour of the system was performed using the finite element method. The contour conditions imposed were room temperature (293 K) and free convection. The actuator voltage and frequency were set to 35 V and 10 Hz, to produce 2.5E-06 W of power. Two different studies were performed: i) a stationary thermal study with maximum temperatures and displacement fields (Figure 3); and ii) a transient cool-down study with temperatures and displacement curves to be used by end-users to establish the cool-down time before taking measurements.

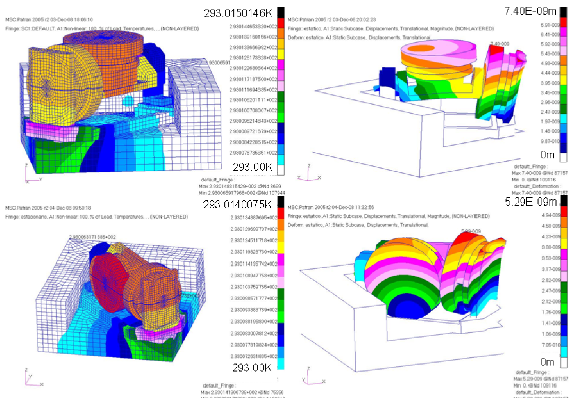

Figure 3. Final temperature and displacement fields of the system

2.3 Integration of the positioner in the NanoCMM machine

Communication between the positioner and NanoCMM machine is based on standard communication protocol I++, increasing the interoperability between different subsystems. In Figure 4, the architecture defined for a NanoCMM is shown, including the positioner.

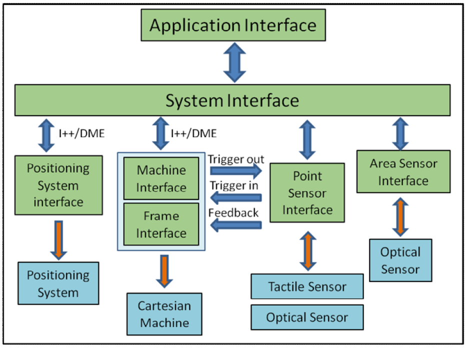

Figure 4. NanoCMM system and hardware architecture

The hardware equipment of the controller is based on two independent modules: a control module that directly manages the actuators, including the power stages, and an interface module consisting of an embedded industrial PC for I++ communication implemented in the developed software. This module possesses two interface capabilities: i) the application port, which supports I++ standard commands for a control module, such as the position command, trajectories generation and the stop command; and ii) the monitor port, with additional functionalities such as parameter settings and manual operation, which may be local or remote via http.

3. Conclusions

To summarise the challenges involved in the design and manufacture of this positioning system, its miniaturisation, light weight, high thermal stability, and zero heat generation during stop position have been highlighted. This development will make real 3D measurement in NanoCMMs possible.

Acknowledgements

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References:

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