Thermally stable probe mount for a metrological atomic force microscope

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Abstract

In the design of the metrological atomic force microscope (mAFM), the commercial scanhead is adapted to reach a high thermal stability. To achieve this, an Invar support for the probe is kinematically connected to the aluminium commercial head. The interface between both parts allow for thermal expansion with minimum introduction of internal stress, while maintaining sufficient stiffness in the design. This paper describes and evaluates the novel design of the thermally stable probe mount. FEM-simulations of the thermal expansion show a minimum impact of the introduced stress on the accuracy of the mAFM.

1 Introduction

Atomic force microscopes (AFMs) are able to measure dimensions of nanoscale structures with high resolution. In mAFMs, the use of interferometers to register sample movements results in measurements traceable to the length standard [1].

A high thermal stability requires a careful choice of materials for the metrology frame and the scanhead. Most commercial scanheads, however, have a standard design with a piezo element to obtain a scanning motion of the probe tip. Because the mAFM uses a separate stage to perform this scanning action, the function of the piezo element is limited. Moreover, since piezo material can expand significantly due to thermal fluctuations, it was necessary to redesign the commercial scanhead into a thermally stable probe mount for use in the mAFM. The adapted design partially consists of Invar components, which typically show a limited thermal expansion. Because the introduction of materials with different thermal expansion coefficients can lead to high internal stresses, the design of the interfaces between the components is critical.

2 Design of the mAFM

Figure 1 shows the design of the mAFM. The metrology system consists of three orthogonally placed interferometers and the probe mount which includes the cantilever deflection optics. These components are mounted on an Invar metrology frame. A fine positioning stage, mounted on the positioning frame, moves the sample holder in a scanning motion, while the probe tip remains fixed in space. During such a scan, the interferometers accurately measure the displacements of the sample holder in three directions. To allow the sample to approach the tip, the positioning frame has an integrated coarse approach mechanism.

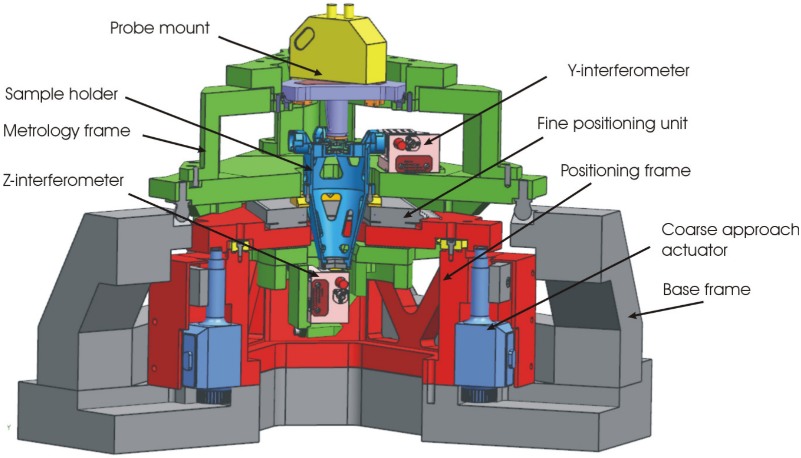

Figure 1: section view of the mAFM (X-interferometer not shown).

3 Thermally stable probe mount

3.1 Design

The left hand side of figure 2 shows the design of the thermally stable probe mount. The cantilever deflection optics of the commercial scanhead is mounted on an aluminium interface part. The cantilever support disk, on the other hand, is mounted on an Invar interface part with a tube welded on the bottom. Both interfaces are connected kinematically using three leaf springs which allow thermal expansion with limited internal stresses (figure 2, right).

Repeatable repositioning of the entire probe mount with the deflection optics is possible by means of a kinematic ball-groove interface. This way, the probe will remain in the Abbe point (the intersection of the three interferometer axes) after probe replacement. The piezo tube of the commercial scanhead is not connected to the cantilever support disk and hence is not part of the metrology loop. However, the piezo tube cannot be removed, since it includes optics for the optical camera.

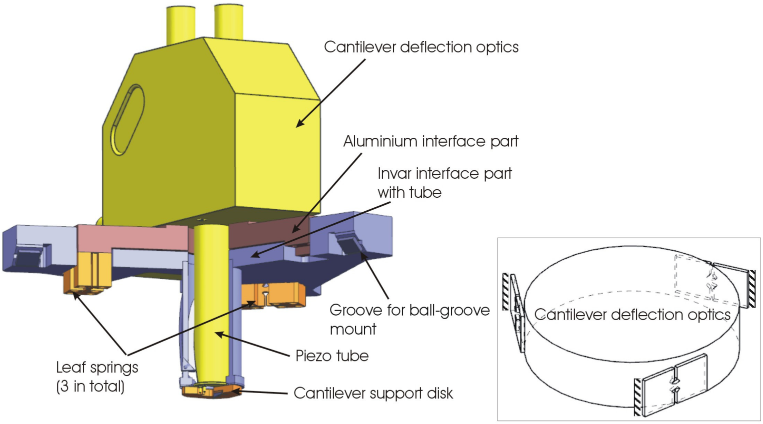

Figure 2: section view of the thermally stable probe mount.

3.2 Simulations

In order to evaluate the thermal and mechanical stability of the probe mount, a FEM-model was created. The stiffness of the ball-groove kinematic interface was modelled using equivalent spring elements with the stiffness of the Hertzian contact.

Figure 3 (left) shows the expansion of the probe mount due to a uniform temperature change of 1ºC.

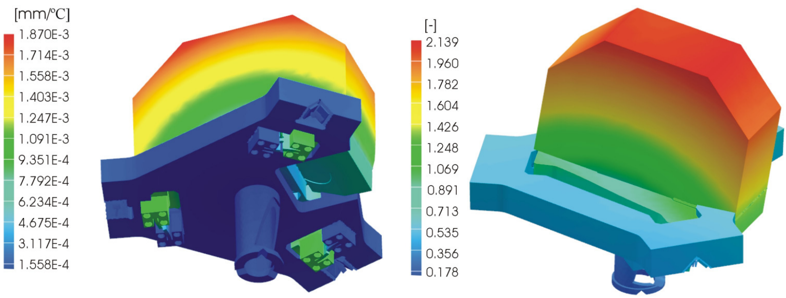

Figure 3: displacement during thermal expansion with ΔT = 1ºC (left) and dimensionless displacement field of 1st eigenmode at eigenfrequency 410 Hz (right).

In order to estimate the influence of the internal leaf spring stresses on the deformation of the probe mount, this simulation was compared with a simulation of a stressfree expanding probe mount. Optimisation lead to an estimated stress-induced deformation error of 12 nm/ºC. Since the thermal variations of the environment should be limited to 0.01ºC, the error is 0.12 nm.

Because the leaf spring design is a compromise between thermal and mechanical stability, the eigenfrequency of the system was calculated as well. Figure 3 (right) shows the first dynamic eigenmode of the probe mount. The optimised value of this eigenmode was estimated to be at 410 Hz.

4 Mock-up prototype

The left hand side of figure 4 shows the mock-up prototype of the mAFM. The polyamide metrology and positioning frame were built using selective laser sintering techniques. Both frames are mounted on an aluminium base frame. Figure 4 also shows an image of the novel probe mount. The entire probe mount can be easily removed from its kinematic mount on the metrology frame.

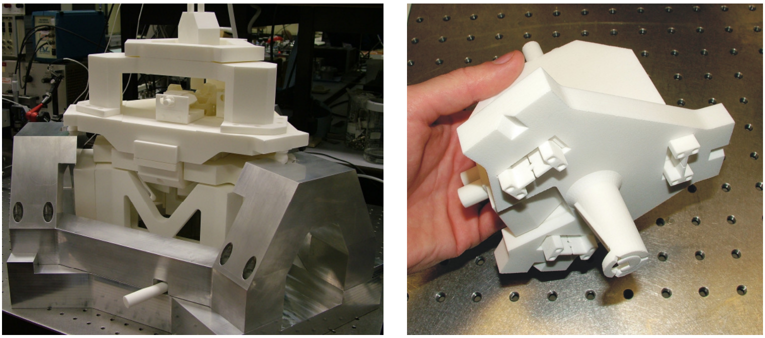

Figure 4: mock-up prototype of the mAFM (left) and the novel probe mount (right).

5 Acknowledgement

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References:

[1] H.-U. Danzebrink et al., Advances in Scanning Force Microscopy for Dimensional Metrology, Annals of the CIRP, 55(2), 2006