Development of a metrological atomic force microscope prototype

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Abstract

In the past years, KULeuven developed a metrological atomic force microscope (mAFM) with a 1 nm target accuracy for each axis over a range of 100 μm x 100 μm x 100 μm. The design of the mAFM is now complete and the machine is in the process of assembly. This paper first presents the components of the prototype after manufacturing. The second part of the paper explains the operation of the metrological AFM on the control level.

1 Introduction

mAFMs are used in nanometrology for providing traceable measurements of sample surfaces [1]. Figure 1 illustrates the design of the mAFM, developed at KULeuven. The metrology frame, made of Invar, supports all the measurement components and is designed to meet strict requirements with respect to thermal stability.

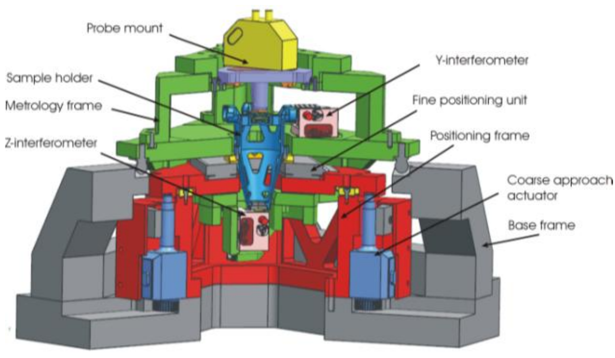

Figure 1: Design of the mAFM.

The positioning frame, made of aluminium, supports the fine positioning unit (FPU) and the coarse approach actuators. Both frames are supported by the aluminium base frame. The Invar sample holder is placed on the FPU, while the fixed probe is supported by an Invar probe mount.

Figure 2 shows the optical camera frame, which is an auxiliary unit for positioning of the sample. A focus stage allows axial positioning of the lens system for focus control. The operator can manually move two shafts for coarse XY-positioning of the sample. To prevent rotation, the shafts are not fully cylindrical.

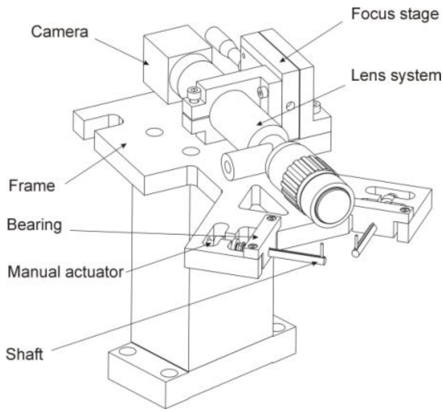

Figure 2: The optical camera frame.

The next paragraph explains how the components were manufactured, taking into account the specific requirements for each of the frames. In parallel with the manufacturing of the components, the interfacing of the different commercial controllers was implemented. The latter is described in the last paragraph.

2 Manufacturing of components

2.1 Metrology frame

The parts of the metrology frame were designed to offer a high thermal and mechanical stability. In order to limit Abbe and cosine errors, these parts need to be machined accurately. The Invar interface of the probe mount with the metrology frame is shown in figure 3 (left). Three symmetrically placed pockets with reference holes are used for the location of the V-groove mounts.

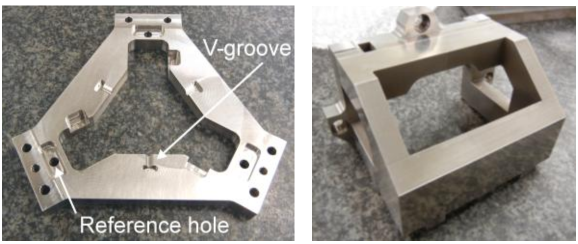

Figure 3: (left) Interface of the AFM probe mount and (right) housing for the Z-interferometer.

The three machined V-grooves are used for a sample extraction tool. Figure 3 (right) shows the Invar housing of the Z-interferometer, which allows a stiff and lightweight support. All Invar components were heat treated for stress relief. This heat treatment was the same for all components, in order to eliminate differences in thermal properties. A nickel coating prevents corrosion of the parts. When necessary, during machining, pieces were clamped on specially produced jigs, which limit deformation of the parts. Especially for some of the bigger parts this procedure was used (figure 4).

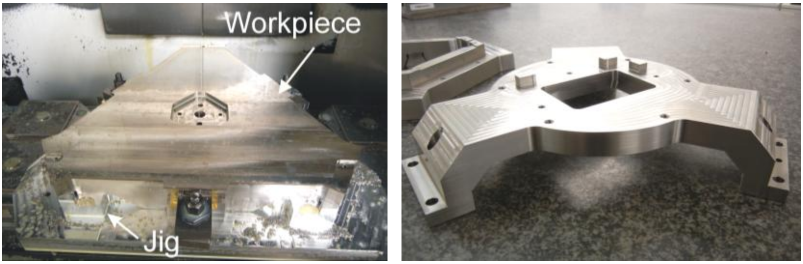

Figure 4: (left) Large XY-interferometer support during machining and (right) finished support for the Z-interferometer housing.

2.2 Positioning frame

Critical components of the positioning frame are the three aluminium leaf springs for kinematic mounting and guiding of the sample holder for the coarse approach. These springs need to be flexible enough in order to limit their internal stress, but stiff enough to reach a high natural frequency of the system. For obtaining maximal symmetry, all springs were cut from the same aluminium block on a wire EDM-machine (figure 5). The aluminium clamps for mounting of the coarse approach actuators were also machined this way.

Figure 5: (left) Springs for the coarse approach and (right) clamps for the coarse approach actuators.

2.3 Optical camera frame and coarse XY-positioning

Figure 6 shows the components of the optical camera frame. Except for the two brass quasi-cylindrical shafts, all parts were made of anodised aluminium. The materials have been selected in order to reach a good sliding contact between the components. Both aluminium and brass parts of the guides were machined by wire EDM to achieve the required accuracy.

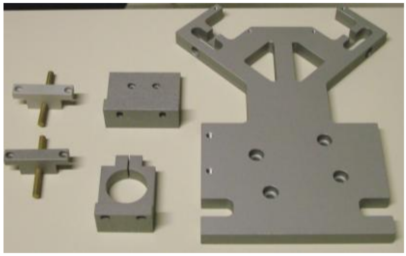

Figure 6: Components of the optical camera frame.

3 Interfacing of the controllers

Concurrently with the manufacturing of components, steps were taken to implement the controller of the mAFM. In X- and Y-directions, the control is done by means of position commands through the USB-interface of the FPU's commercial controller. In the Z-direction, the required performance is higher and therefore another control loop was implemented. Here, the analogue high voltage signals of a commercial AFM-controller, meant for the piezos of a commercial scanhead, were bypassed to an electronics box. This electronics box transformed the signals into low voltage signals for the FPU's controller. For validation, a sample was scanned in a magnetic force mode (figure 7).

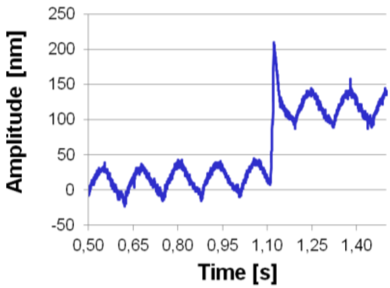

Figure 7: Output of the electronics box (magnetic force mode signal). The probe is lifted at the end of a scan line.

4 Acknowledgement

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Reference:

[1] A. Yacoot, L. Koenders, Meas. Sci. Technol. **22** (2011) 122001