# Recent advances in the development of the LNE metrological AFM

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**Abstract**

A metrological atomic force microscope (mAFM) has been developed at LNE [1, 2]. It can be used for traceable Atomic Force Microscope (AFM) measurement and calibration of transfer standards dedicated to scanning probe microscopy. It is based on an immobile AFM head working in a zero detection mode. All the displacements (i.e. the three translations) are produced by a home-made piezo-actuated three axis flexure stage that holds the sample. The displacement range is 60 $\mu$m for the $X$ and $Y$ axes and 15 $\mu$m for the $Z$ axis. The tip-sample relative position is measured with four dual pass differential interferometers. For the tip-sample relative position measurement, the expected uncertainty is in the order of 1 nm. This paper focuses on the first uncertainty components we have experimentally determined: the parasitic rotations of the translation stage, the stability of interferometer position measurement in ambient air and the interferometer nonlinearities.

## 1 Evaluation of the translation stage parasitic rotations

The translation stage used on the LNE mAFM is a three axis translation stages [1]. As parasitic rotational motion have a direct impact in uncertainty budget through Abbe error, it has to be considered carefully. In order to evaluate *in situ* the three parasitic rotations of the translation stage, we developed a dedicated measurement bench. It comprises a triple beam plane mirror interferometer (SIOS, SP-TR Series, with 0.1 nm resolution for length measurement and 0.01 $\mu$rad for angular measurement) and a mirror holder, kinematically mounted on the mAFM metrology frame. Because the interferometer is capable of two rotation measurements, the pitch and yaw rotations have been measured simultaneously in a first configuration and the roll rotation was measured in a second one. The parasitic rotations were evaluated under the control of the interferometers in close loop.

| | $T_X$ | | | $T_Y$ | | | $T_Z$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | $R_X$ | $R_Y$ | $R_Z$ | $R_X$ | $R_Y$ | $R_Z$ | $R_X$ | $R_Y$ | $R_Z$ |
| Absolute rotations (µrad) 60 µmx60µmx15µm | 1.94 | 18.8 | 2.12 | 10.53 | 3.62 | 2.3 | 3.38 | 4.78 | 6.5 |
| Relative rotations (µrad/µm) | 0.032 | 0.31 | 0.035 | 0.175 | 0.06 | 0.038 | 0.225 | 0.318 | 0.43 |

**Table 1: Parasitic rotations of the XYZ translation stage**

Even though the measured rotations are linear and repeatable (corrections will be possible), they are higher than expected (1µrad) and higher than the one previously measured on a prototype [2]. Many reasons explain some of the highest parasitic rotational motions measured for $T_XR_Y$ (0.31 µrad/m) and $T_YR_X$ (0.175 µrad/m) – see Table 1: (i) the location of the piezo actuators with respect to the guidance mechanism, (ii) a lack of isolation between the X, Y and Z axis and (iii) a defect on the flexure stage assembly. Some investigations will be led in order to reduce parasitic rotations. They'll be presented onto the poster.

## 2 Evaluation of interferometer measurement stability

We've experimented that the differential interferometer measurements in ambient air are sensitive to a differential variation of air index between the two arms. Fig. 1 shows that the noise level of such air index differential variation is about 20 nm peak-to-peak without any specific protections. On the other hand, thanks to an aluminium enclosure along the beam path, the air index is more homogeneous between the two arms and more stable over long time measurements, thus, the equivalent noise level is reduced with a ratio of 40 to the level of 0.5 nm peak-to-peak.

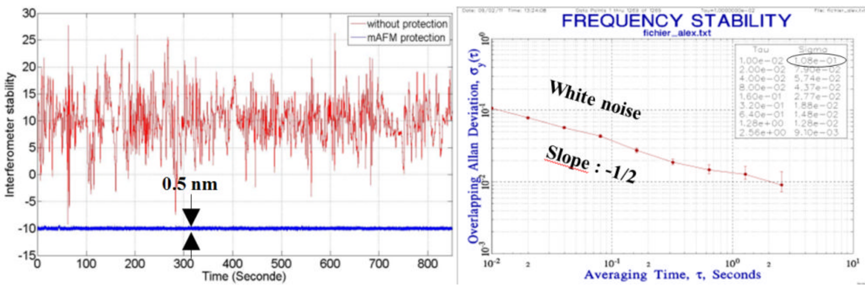


Figure 1: (left) interferometer stability measurements, (right) Allan deviation with the protection.

We measured the standard deviation by using two reference methods: Allan variance and power spectral density. The two methods gave the same experimental standard deviation value, equal to 0.108 nm, which validates the measurement principle [5]. We also evaluated the long term position stability over 50 hours with the protection. The Allan deviation vs. averaging time shows that below 5 seconds, white noise is dominant. Over 5 seconds, the drift became relevant. This experiment showed that the beam path enclosure increases the interferometer measurement quality and reduces the associated errors.

## 3 Evaluation of the interferometer non-linearity

The four differential interferometers have nonlinearity due to polarisation mixing mainly caused by misalignment and imperfection of optics used in the interferometer head. To evaluate its nonlinearities, we implemented an experimental setup which comprises an interferometer module from Renishaw (RLD-X3-DI)[3] with two mirrors, one is attached to the XYZ translation stage (Physik Instrumente P-517C) [4] ,the second one is linked to the mAFM tip. A 20 mm thick aluminium enclosure reduces the effect of air index fluctuations and the interferometer drift during the experiment. To minimize the error induced by air turbulence, the path length of the interferometer is as short as possible (10 cm). A 0.2 Hz triangle wave is applied to the stage controller to provide fine displacement in the range of several micrometers along the interferometer axis. The measurements of the stage capacitive sensor are also used for comparison with interferometer measurement. As shown on Figure 1, the nonlinearity is determined by measuring the residual displacement when the first order of the interferometer versus capacitive sensor curve is removed.

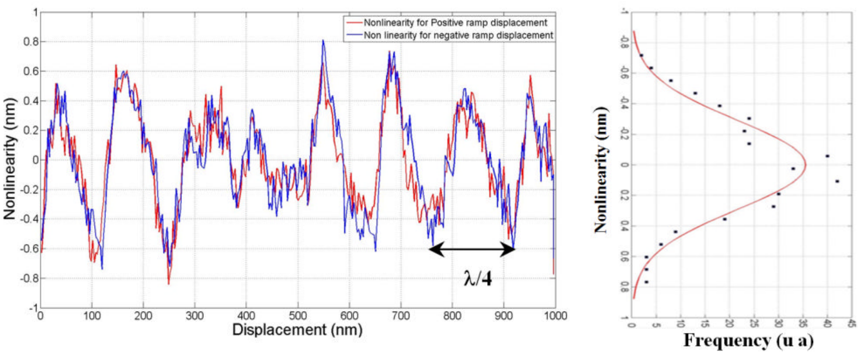


Figure 2: Interferometer nonlinearity (left) and its associated distribution (right)

The Lissajous representation (sine vs. cosine signal) gives information about the quadrature signals quality of interferometers. For a 100% Lissajous strength, the nonlinearity is 1.41 nm peak-to-peak. Its periodicity is consistent with the one expected for a double pass interferometer ($\lambda/4 \approx 158$ nm). The distribution associated to the nonlinearity is normal with a standard deviation of 0.47 nm. In order to evaluate the impact of the interferometers misalignment, we evaluated the nonlinearity error variation with respect to the Lissajous signal strength. The Lissajous signal strength must be over 50% to perform interferometric measurements with low nonlinearity error (i.e. 1.41 nm peak to peak). Below 50%, the nonlinearity error becomes significant (i.e. more than 4 nm peak to peak) and does not meet the expected uncertainty requirements for the tip-sample relative position measurement. Thus, it would be useful to find an optimal alignment before starting measurements on the mAFM.

**Conclusion**

Experimental investigations gave the first uncertainty components of the LNE mAFM. The interferometers nonlinearity could be decreased using Heydemann correction method in a next future. At the moment, the nonlinearity error is not critical in the uncertainty budget. The interferometer's stability evaluation shows the importance of protecting them to reduce the refractive index variations between the two arms of each interferometer. To lower Abbe error to 1 nm, new configurations for the actuation of flexure stage will be investigated and presented. All those experimentally determined uncertainty components will be used to modelize the mAFM measurement process and to investigate its measurement uncertainty. The first part of this virtual AFM, describing the differential interferometer measurement will also be described onto the poster.

**References:**

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