Thermal Drift Study on SPMs

M. Balcon[1], F. Marinello[1], E. Savio[1], S. Carmignato[2]

[1]*DIMEG, Dip. di Innovazione Meccanica e Gestionale, University of Padua, Italy*
[2]*DTG, Dip. di Tecnica e Gestione dei Sistemi Industriali, University of Padua, Italy*

manuel.balcon@unipd.it

Abstract

Scanning probe microscopy (SPM) allows surface topography imaging with the highest resolution, as a result of accurate actuation (normally piezoelectric) combined with the sharpness of tips. The imaging process is inherently slow, and commonly suffers from instrumental drift. Its evaluation and control is an important issue for quantitative metrology. According to experience, drift is a time dependent phenomenon and therefore it influences measurement results in particular when high resolution imaging is performed by taking many profiles. In this work, a study is run to correlate thermal phenomena to SPMs drift distortions. Drift estimation is then cross-correlated to thermal analyses parallely carried out by means of a thermo-camera opportunely positioned. Eventually, it is discussed how the study can help proper instrument set up and optimization allowing reduction of distortions.

1 Introduction

Scanning probe microscopes scan the surface in a raster fashion and reconstruct sequentially the topography. Such imaging process is affected by distortions such as non-linearity of piezoelectric elements, creep, hysteresis, and thermal drift. Software compensation and closed-loop systems allow reducing these distortion effects, except the thermal drift. Thermal drift is an uncontrolled time dependent movement of the tip relatively to the sample surface. Resulting drift distortions affect in particular high resolution images (dense sampling normally requires long scan times) taken on small horizontal ranges (when drift distortions are larger than the pixel size). Properly understanding and characterizing drift is an important issue: finding measurement strategies to avoid, control or compensate it, allows improvement of the measurement quality and accuracy. Drift distortions are often regarded as temperature dependent phenomena, associated to temperature gradients and transients that occur in the instrument parts and in the measuring volume. However, up to now in the literature there is no experimental evidence of such dependency. It is not clear if the causes of drift are referable only to temperature or if also other factors like humidity, construction of the instrument and thermal expansion coefficients play a role [1]. In the present paper a set of experiments is reported, which comprised an open loop Atomic Force Microscope operated in connection with a thermographic camera. The investigation allowed to study drift, correlating it with temperature variations and other parameters. Eventually, further indications on how to reduce drift related distortions and measurement uncertainty are proposed.

2 Experimental investigations

An experimental investigation was designed and carried out using an open-loop Atomic Force Microscope (AFM, Dualscope DME 95-200). The instrument is operated in a laboratory with controlled temperature at 20±1°C (standard measuring room, class 3). Temperature of the scanner external surface was measured using an infrared thermocamera: this instrument creates a temperature map based on infrared radiation emissions. The focus of the investigation was to describe the drift behaviour during AFM measurements and correlate it with the temperature and with the most influencing scan parameters. The AFM was operated in contact mode; scan horizontal and vertical range and scan velocity have been identified as primary parameters to be monitored. Indeed, these parameters not only are the most important settings for the definition of an AFM measurement, but also can play an important role in the scanner thermal behaviour. In fact different measurement ranges and speed can modify the stress of the piezoelectric elements, determining heating gradients and transients. Horizontal (Δx and Δy) and vertical drift (Δz) was monitored using a test calibrated grating (a 1-D array of rectangular steps on a Si wafer). Measurements were repeated on the same profile: relative shifts (i.e. drifts distortions) were computed taking advantage of software developed by the authors and available for download as a plug-in at [3]. The experimental plan included nine different AFM settings with regard to scan horizontal range (5 μm, 20 μm, 50 μm), vertical range (0 μm, 0.1 μm, 0.6 μm) and scan rate (0.1 Hz, 0.5 Hz, 1 Hz); three repetitions with different probes were done for each setting; temperature was monitored with a frequency of 0.017 Hz over 150 minutes. The typical temperature behaviour is presented in Figure 1.

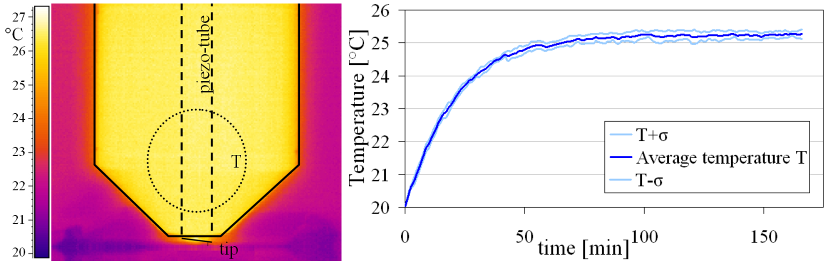

Figure 1: Left - thermographic image of AFM scanner after one hour exercise; the dotted circle indicates the region where temperature is monitored. Right - temperature behaviour with time: when the instrument is turned on and start measuring, it goes through a temperature transient which after about two hours stabilizes at a constant value of about 5°C over the initial temperature.

Both horizontal and vertical drift estimated at different instrument setting were studied correlated to temperature ramp during the transient. The investigation indicated a strong correlation between temperature variation and average drift distortion: after linear regression with different setting conditions, an R-squared value > 0.9 was constantly detected. In particular in Figure 2 the case at standard scanning conditions (range 20 µm, height 0.1 µm, scan rate 0.5 Hz) is reported. Such dependency is very important: indeed demonstrates that measurement drift is strongly influenced by instrument thermal behaviour. Other sources (like electronic noise or vibrations), here not yet studied, can be of influence for drift distortion, but certainly thermal instability plays the most important role. This is of the highest importance, since indicates that to reduce drift, operations have to focus on thermal stability.

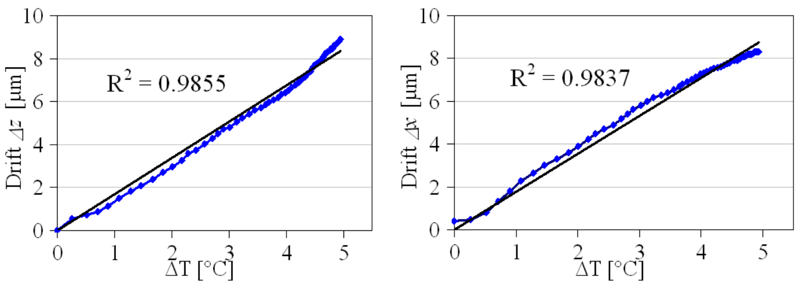

Figure 2: Vertical (left) and horizontal (right) drift distortions vs temperature increase during the first hour operation: high correlation is demonstrated by high R^2 values.

3 Discussion and conclusions

Experimental investigations gave evidence that the behaviour reported in Figure 1 is independent from the instrument settings. In other words, scan horizontal and vertical range and scan velocity (which determines the way the piezoelectric tube is actuated) do not sensibly influence the temperature transient (variation are within instrument temperature repeatability). Also, independently from scan settings, the instrument stabilizes after two hours, to constant drift (systematic behaviour) with short-time temperature oscillations (i.e. considering 10 minutes intervals) comprised within ±0.1°C (stochastic behaviour). After stabilization, the correlation between temperature residual oscillations and drift distortions precipitates, showing that other sources (such as vibrations) contribute to SPM scanning instabilities.

Mapping of drift distortions and temperature allows some important operations

1) Identify the temperature transient, i.e. the warm up time needed to stabilize the instrument. This is measured recognizing where temperature (see graph of Figure 1) moves from a parabolic to a linear behaviour.

2) Characterize the short time instability: size and frequency of short time instabilities help to define scan time (i.e. velocity) and scan range which minimize the short time drift, therefore minimizing uncertainty contribution;

3) Thermographic maps allow recognizing temperature gradients within the instrument, the stage and the sample: this can help optimization of instrument set up, by insulating heat sources, or conditioning critical components.

The approach here applied for a single instrument, is of interest to study specific AFMs and define best instrument practice and set up. For the specific open loop instrument here implemented, optimization allows reduction of drift distortions from 1 nm/s to less than 0.15 nm/s.

References:

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[2] Mokabery B., Requicha A.A.G., Towards Automatic Nanomanipulation: Drift Compensation in Scanning Probe Microscopes, IEEE ICRA Proc., 2004.

[3] www.imagemet.com, plug-ins for SPIP™.