Modeling the hysteresis of a scanning probe microscope

Most scanning probe microscopes use piezoelectric actuators in open loop configurations. Therefore a major problem related to these instruments is the image distortion due to the hysteresis effect of the piezo. In order to eliminate the distortions, cost effective software control based on a model for hysteresis can be applied to the scanner. We describe a new rate-independent model for the hysteresis of a piezo scanner. Two reference standards were used to determine the accuracy of the model: a one-dimensional grating with a period of 3.0 μm and a two-dimensional grating with 200 nm pitch. The structures were scanned for different scan ranges varying from 5 V peak to peak to 440 V peak to peak, so that 99% of the scanners' full motion range was covered. A least-squares fit of the experiments to the hysteresis model provided standard deviations per scan range of around 0.2%. This represents an uncertainty of 1 pixel. Since our model is based on a differential equation, it is flexible even to simulate arbitrary experimental conditions such as a sudden change in the offset.
Modelling online for hysteresis of a scanning Probe Microscope

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Online correction of scanning probe microscopes with pixel accuracy
In this project "Online Control of Scanning Probe Microscopes with Pixel Accuracy", the development of an algorithm is described that enhances the measurement uncertainty of software controlled SPM by one order of magnitude from 2% to 0.2 %. The SPM is globally used as a metrological instruments for dimensional and length measurements. The sample surfaces are scanned 3-dimensionally, typically within the ranges up to 150 µm x 150 µm x 6 µm. This is done by moving a sharp tip systematically across the sample while simultaneously recording the height of the tip. Typically, the tip has a radius of curvature of 10 nm and an opening angle of 30.0 °. Even atomic resolution can be achieved. The scan movement of the tip is not linear however. This is caused by the propelling device of the SPM for the scan motion - a
piezoelectric ceramic. The two major non-linear responses of the piezo to the applied control voltage are rate-independent hysteresis between the scanner's position and the voltage and time-dependent creep of the ceramic. Hysteresis leads to a non-linear mapping of distances while creep changes the actual sensitivity of the ceramic. The non-linearity of a hysteresis loop is in the order of 2-20% depending on the piezo material used and the scan range. The change in sensitivity is up to 20% as well, depending on the scan frequency. Current software controlled SPM are equipped with an algorithm that changes the shape of the control voltage online in a way to produce a linear piezo movement. The algorithm typically contains 5 - 7 parameters which have to be calibrated manually. Still, non-linear errors remain in the order of 1-2%. One pixel in a 512x512 image corresponds to 0.2% per direction. This goal of measurement accuracy is reached with the algorithm developed in this thesis. Three different SPM are analyzed for their non-linearity. Two commercial tube scanners are applied with a maximum scan range in x and y of 40.0 µm and 160.0 µm as well as one specially designed stack scanner with a maximum range of 5.0 µm. For the tube scanners, a 1-dimensional line pattern with a reference period of 3.0 µm and a 2-dimensional grating with a reference pitch distance of 200.0 nm are applied as length standards. The non-linearity of the scanner is then traceable to the distances on the samples. The stack scanner is equipped with capacitive sensors that measure the position of the scanner during the scan process. The signal of the sensors can be used as closed loop feedback signal. At first a model is set up to describe the measured hysteresis. An ordinary linear differential equation proves to yield the desired accuracy of 0.2% when simulating the measured hysteresis. This is done with 5 model parameters and verified for 99% of the scan range of the SPM. In addition to this, the model is not restricted to a periodic scan movement in the lateral plane as most online models are. It is flexible enough to even describe the random rate-independent movement in the z-direction. After simulating the hysteresis, the model is enhanced in order to describe time-dependent creep during the scan motion. The new model contains 7 parameters and yields the desired accuracy of 0.2% for a large choice of scan ranges and scan frequencies. The parameters are determined in a numerically optimum way by using a least-squares-fitting technique. After having successfully simulated the measured non-linearities, the model is inverted in order to form an algorithm for online correction during the scan process. Also the online algorithm is tested on two different scanners. The residual non-linearity of online corrected images is in the order of 0.2 % for both scanners: The error in length changes between ± 1% from experiment to experiment. Within one experiment however, the variation of the errors is 0.3%. Therefore it is concluded that the online algorithm is stable within the set goal of 0.2% measuring uncertainty, but the piezo changes arbitrarily in the its sensitivity. Further results of this thesis include the simulation of transient hysteresis as occurs at a change of scan conditions. This is also applied to the z-direction. Here an overshoot at a large step is qualitatively simulated and explained by hysteretic behaviour.

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Projects:

Investigation of photocatalytic activity of TiO2 coatings on metallic substrates prepared using PVD process
Department of Mechanical Engineering
Period: 01/04/2011 → 19/12/2014
Number of participants: 6
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Kelly, Peter James (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

**Universal and Flexible 3D Coordinate Metrology for Micro and Nano Components Production**
Department of Mechanical Engineering
Period: 01/09/2007 → 02/02/2011
Number of participants: 8
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Source: Internal funding (public)
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Project: PhD

**Optimal correction of Scanning Probe Microscopy Images**
Department of Mathematics
Period: 01/08/1997 → 09/02/2001
Number of participants: 3
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