

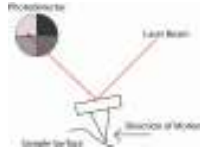
## Abstract

To improve the measurement of nanoscale friction, a new alternate method of lateral calibration for the atomic force microscope was examined. This method, which offers the advantage of reduced tip wear, was reviewed and analyzed, and fundamental flaws were identified in its derivation. After modifying this approach, we attempted to confirm our corrected model with a commonly accepted calibration method. The collected data displayed as yet unexplained oscillatory behavior, which showed strong correlations between lateral, drive, and error signals.

### Lateral Force Calibration

Lateral forces are recorded based on the twist of the cantilever arm. Calibration is necessary to translate from the voltage measured by the photodetector into a force measurement.

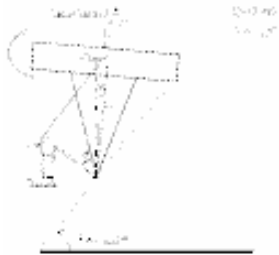
Commonly used methods often dull or damage the AFM tip, and also require complex controls not supported by all equipment.



### Asay and Kim's Direct Force Balance Method

A new method of lateral force calibration was presented in 2006 by researchers at Penn State. It eliminated many of the problems present in current methods by measuring the lateral calibration factor without scanning across the surface. Instead, lateral force-distance curves are taken on sloped surfaces to examine the lateral signal as a function of load force. This relationship is used in conjunction with the equilibrium conditions of the system to derive the lateral calibration factor.

### Analysis of Direct Force Balance System



#### Asay and Kim's Force Diagram

Inspection of the equilibrium system presented by Asay and Kim showed the absence of forces necessary to prevent motion of the tip on an angled surface.

Final Statement of Equilibrium

$$F_{lateral} = F_{load} \cos \theta \sin \theta$$

#### Corrected Force Diagram

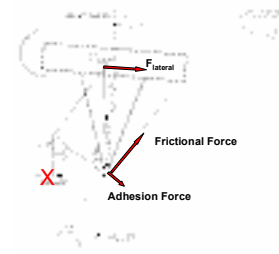
Adhesion and friction forces were added to the free body diagram, and the lateral force was moved from the tip to the cantilever arm. This gave rise to modified equations of equilibrium:

$$\Sigma F_y = F_{load} - (F_N - A) \cos \theta - F_f \sin \theta = 0$$

$$\Sigma F_x = F_x - (F_N - A) \sin \theta + F_f \cos \theta = 0$$

Assuming Amont's Law holds true in this situation, the above system, of equation presented a new Statement of Equilibrium.

$$F_{lateral} = \frac{F_{load} (\sin \theta - \mu \cos \theta) - 2\mu A}{\cos \theta + \mu \sin \theta}$$

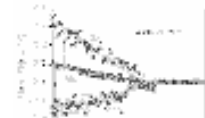


### Comparison of Experimental Data

#### Asay and Kim's Published Direct Force Balance Data

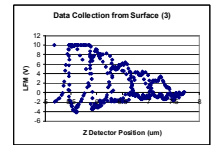
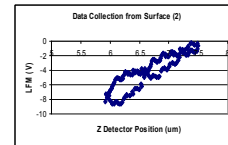
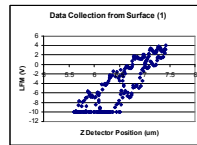


Diagram of calibration sample used for Direct Force Balance calibrations.



Data presented by Asay and Kim. Graph represents three datasets, corresponding to each of the three slopes on the calibration sample.

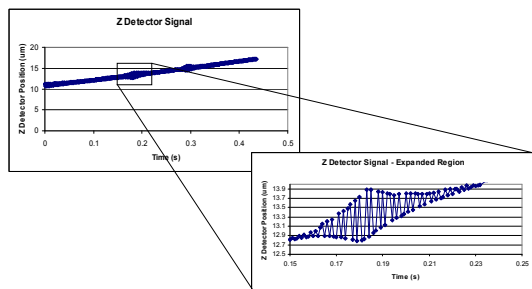
#### Collected Direct Force Balance Data



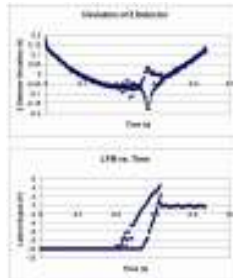
Each of these graphs represent an individual data set taken during the retraction portion of the lateral force-distance curve. The separation in the data, along with noted nonlinearities, prevented calibration using this data. Substantial analysis was performed to investigate the source of this behavior.

### Analysis of Experimental Data

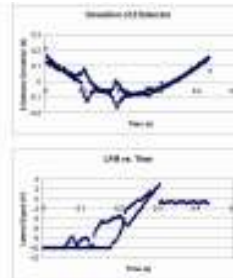
Upon inspection of the data, it was noted that the Z Detector signal was not linear with respect to time, as would be expected for force-distance measurements. This is shown in the below figure, with the non-linear portion expanded for clarity.



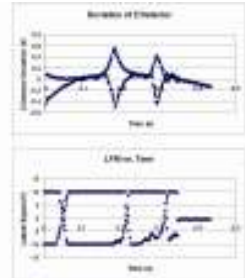
#### Analysis of Surface (1)



#### Analysis of Surface (2)



#### Analysis of Surface (3)



Deviation of Z-Detector was plotted by subtracting the expected linear representation from the recorded Z-Detector Signal. This resulting deviation was plotted with respect to time, and compared with the lateral signal versus time. A correlation between the deviations in both Z-Detector and Lateral signals is apparent.

### Conclusions

- Errors in Direct Force Balance method were found, and a new solution accounting for missing forces was derived.
- Unexpected oscillations in data prevented direct verification of new solution.
- Nonlinear behavior was investigated in both Z Detector and Lateral signals.

Possible explanations include:

- Slip-stick interaction
- Nonlinearity in piezo controller
- Other unidentified sources of noise
- Instrument malfunction
- Tested and obtained similar data with two separate scanheads
- Fundamental instrument design
- Communication with manufacturer suggests this is not the case

### Future Work

- Automate control of AFM for accepted method of calibration
- Find source of irregularity in force-distance curve
- Improve modeling of tip-surface interaction
- Future publication on the validity of Asay and Kim's method

### References and Acknowledgements

Asay, D.B., Kim, S.H. "Direct force balance method for atomic force microscopy lateral force calibration." *RSI 77* (2006)  
 Matei, G.A., et. al. "Precision and accuracy of thermal calibration of atomic force microscope cantilevers." *RSI 77* (2006)

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