Bandwidth enhancement for shear-force feedback by exploiting the nonlinear probe-sample interaction

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The combination of a high Q oscillators (200-700) with a relatively low resonant frequency (30-40kHz) as is the case with high Q tuning forks[1] used in near-field optical microscopy limits the feedback bandwidth. As feedback gains are increased, the system oscillates at a frequency that is approximately the width of the resonance peak -- typically 10's of Hertz. The oscillation is asymmetric (figure 1) as a result of the nonlinear interaction between the probe and the sample. When the probe is too far from the surface, it takes longer to find the surface due to the slow recovery time of the high Q oscillator. Alternately, when the probe is close to the surface, the vibration is rapidly quenched. We exploit the nonlinear interaction between the probe and the sample to increase the bandwidth of the feedback loop.

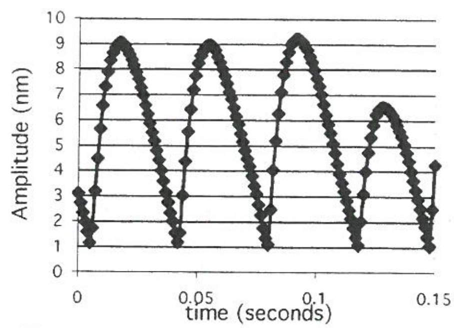

Figure 1: Asymmetric oscillations indicating the nonlinear tip-sample interaction

The nonlinear tip-sample interaction can be modeled as a tapping force producing an accurate representation of resonance curves at different probe sample separations[2]. We use this model to study the system dynamics by alternately adding in and removing the tapping force from the simple driven damped harmonic oscillator equation. We look at the 1/e fall and rise time of the signal respectively. We find that at resonance, the time response of the probe with the tapping off is much slower than the time response of the probe with the tapping on (figure 2a). However, as we move off resonance to either the low frequency or the high frequency side, we see an improvement in the time response. Additionally the time response for the two directions becomes the same on the high frequency side. We perform several experiments to investigate the time response of the feedback system. Figure 2b shows the time for the probe to find the feedback setpoint as an 8msec ramp pulse pulls the probe away from the surface. The gains are carefully optimized in each case to prevent overshoot. This experiment is analogous to the tapping off case for our model and we see similar behavior. Our experiments show that the time response is faster and the time for the in and out motion of probe becomes the same on the high frequency side of the resonance curve resulting in increased bandwidth.

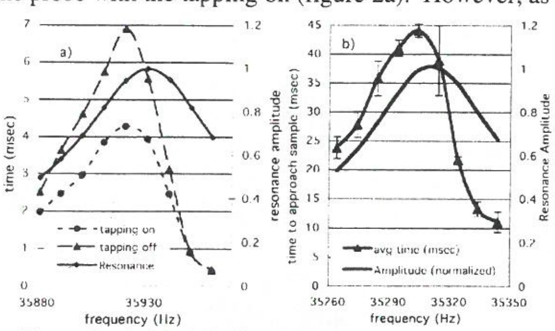

Figure 2: a) Model of the time response of the probe with tapping on and tapping off. b) Time for the probe to find a surface given an 8msec ramp away from the surface. The resonance curve is overlaid in a and b for reference.

References

[1] K. Karrai and R.D. Grober, *Appl. Phys. Lett.* **66**, 1842 (1995).
[2] M. J. Gregor, P.G. Blome, J. Schofer and R.G. Ulbrich, *Appl. Phys. Lett.* **68**, 307 (1996).