

Due Dec 10

1. *Steady state vibration response far from sample* Plot the amplitude and phase response (i.e. how the “observed” tip amplitude in the AFM and phase vary as a function of drive frequency) of a cantilever of equivalent stiffness $k=1$ N/m, fundamental frequency 50kHz with Q-factors of 50, 10 and 1. Low Q-values are one way to mimic operation in liquids. Do this separately for magnetically (directly) excited and piezo (base) excited cantilevers. Comment on what you observe in the comparison between magnetic and piezo excitation especially at low Q. What implications could these observations have on tapping mode AFM?

2. *Attractive and repulsive regimes of oscillation* Using VEDA DAC (basic) tool investigate how the transition from the net attractive to repulsive regime depends on different properties. Use the DMT contact mechanics model which is default in the DAC tool. You will consider 3 cantilevers (A) $k=1$ N/m, $\omega_0=50$ kHz, $Q=75$, $A_0=50$ nm (B) $k=10$ N/m, $\omega_0=100$ kHz, $Q=150$, $A_0=20$ nm, and (C) $k=40$ N/m, $\omega_0=300$ kHz, $Q=400$, $A_0=5$ nm (these are very typical values for commercial cantilevers). Plot (i) A , ϕ , average force vs. Z , (ii) repeat for drive frequencies slightly off resonance, i.e say 0.1% below and above resonance. Summarize your findings in terms of what strategies would you adopt to remain in the attractive regime (to minimize forces) or to remain in repulsive regime (to make sure that you get good phase contrast).

3. *Practical issues.* While imaging a polymer sample ($E^*=1$ GPa) with a tapping mode cantilever in air ($k=20$ N/m, $\text{freq}=250$ kHz, $Q=200$), what initial amplitude and setpoint ratio to choose to keep the imaging forces <5 nN? Choose DMT model with $F_{ad}=1.5$ nN, and a typical Hamaker constant value of 10^{-20} J.

4. *Theory.* The analytical expressions for energy dissipation and virial were derived for magnetically (directly) excited cantilevers. Here you are asked to repeat the derivation for acoustically (dither piezo) excited cantilevers. The corresponding point mass model is as follows where k, c are the correct equivalent stiffness and damping constant of the oscillator. The corresponding equations of motion are

$$m\ddot{x} = -k(x - y) - c\dot{x} + F_{ts}(d, \dot{d})$$

Or,

$$\frac{\ddot{x}}{\omega_0^2} + x + \frac{1}{\omega_0 Q} \dot{x} = y(t) + \frac{F_{ts}}{k};$$

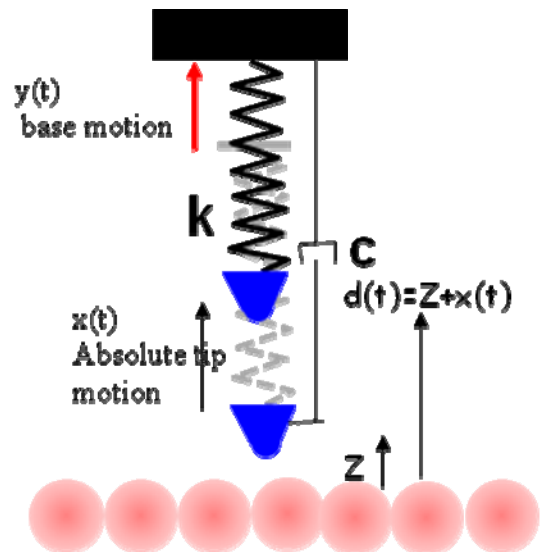
$$\text{with } \omega_0 = \sqrt{\frac{k}{m}}, Q = \frac{m\omega_0}{c}$$

In terms of measured motion $z(t) = x(t) - y(t)$

$$\frac{\ddot{z}}{\omega_0^2} + z + \frac{1}{\omega_0 Q} \dot{z} = -\frac{\ddot{y}}{\omega_0^2} - \frac{1}{\omega_0 Q} \dot{y} + \frac{F_{ts}}{k} \quad (1)$$

$$\text{Let } y(t) = Y_0 \cos(\omega t)$$

$$x(t) = A \cos(\omega t - \phi) \quad \text{so that} \quad \dot{x}(t) = \dot{d}(t) = -A\omega \sin(\omega t - \phi)$$



Recall the difference between the absolute and measured tip motion in acoustically (dither piezo) excited AFM.

- (a) First of all derive expressions for the virial and energy dissipation in terms of the oscillator operating conditions and amplitude and phase etc.
- (b) Why is it important to map the energy dissipation and virial over a sample in tapping mode AFM? What complementary information would they provide?