Exploiting symmetry to develop piezoelectric combined ncAFM/DLFM sensors

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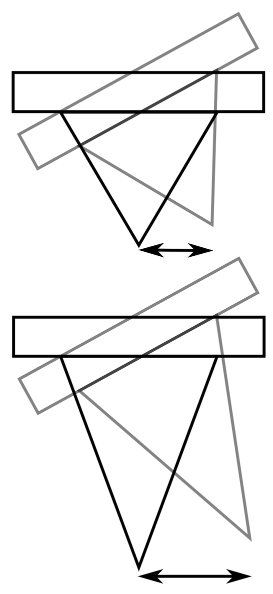
Introduction

- Dynamic force microscopy methods, non-contact atomic force microscopy (ncAFM) and dynamic lateral force microscopy (DLFM), are the only methods which can separate conservative and non-conservative forces.
- Simultaneous measurement of normal and lateral forces opens new doors to advanced measurements of both nano-scale friction and atomic/molecular manipulation.

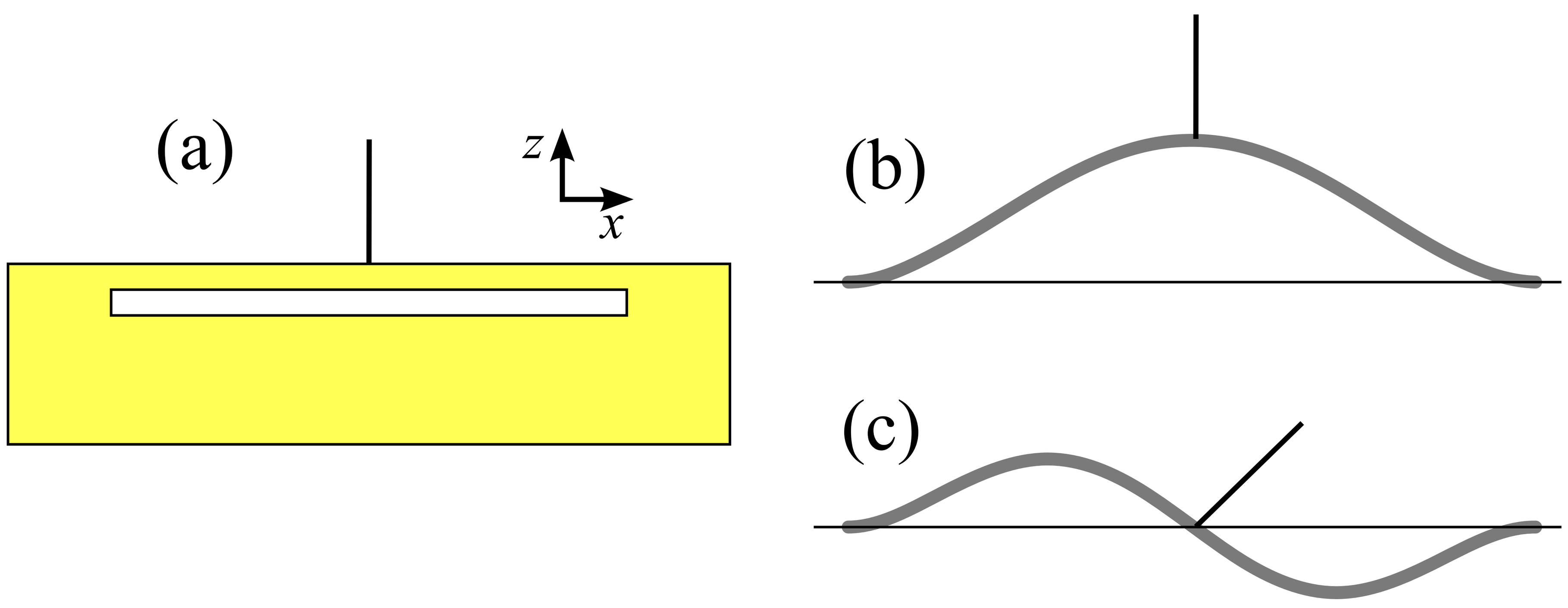
What about cantilevers?

Torsional modes of cantilevers have been used for DLFM. However, there are some issues:

- The force sensitivities and resonant frequencies of the two modes are significantly different.
- Reducing beam dimensions to increase lateral force sensitivity also lowers the normal spring constant, causing snap to contact instabilities.
- To increase force sensitivity of the torsional mode long tips can be introduced, however, this leads to unwanted lateral motion in the normal mode[1].



Proposed design



Instead we propose a design [2] which is symmetrical (a).

The symmetry ensures the tip motion for the first eigenmode is normal to the beam ***for any tip length*** (b). Thus, tip lengths can be extended to tune the lateral force sensitivity and the eigenfrequencies of the sensor.

Lateral motion comes from the second eigenmode rather than torsional modes (c), this increases the ease of calculating mechanical properties.

A further torsional mode could be excited to allow forces to be probed in ***three orthogonal axes***.

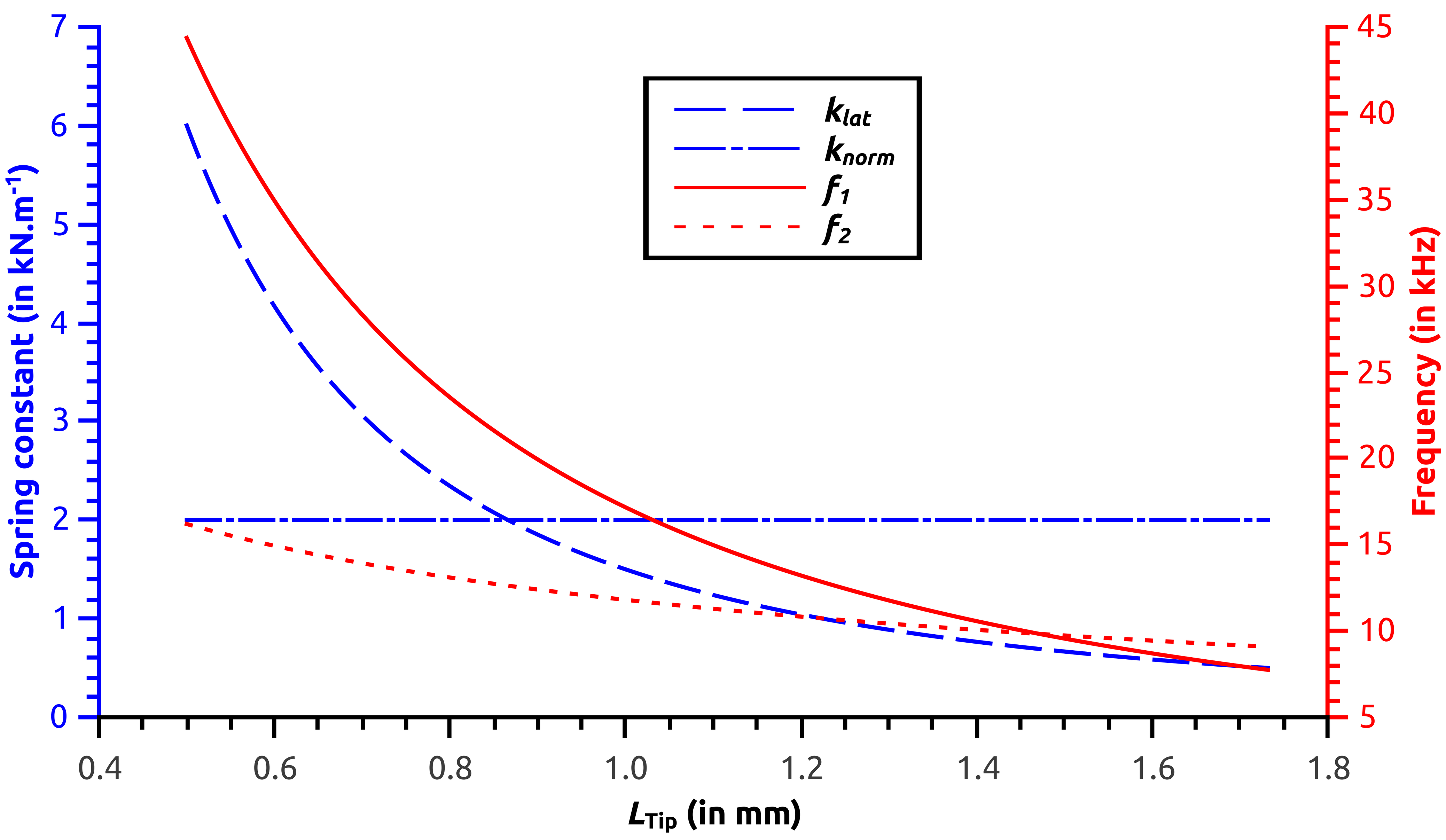
Expected performance

Using a dynamic Euler-Bernoulli model with boundary conditions which account for tip mass and inertia we can estimate the effective spring constants and eigenfrequencies of the two modes.

This sensor is modelled as a quartz beam clamped at both ends, the tip is modelled as a rigid tungsten rod.

Dimensions:

- Beam length = 3 mm
- Beam width (y) = 100 μm
- Beam thickness (z) = 76.1 μm
- Tip diameter = 150 μm



Scaling of spring constants

Normal

$$k_{\text{norm}} = \frac{192EI}{L^3}$$

Lateral

$$k_{\text{lat}} = \frac{16EI}{LL_{\text{tip}}^2}$$

where L is the length of the beam, L_{tip} is the length of the tip, I is the second moment of area of the beam, and E is the Young's modulus of quartz.

Experimental viability

+A sensor of the dimensions used to the left is of similar size to the qPlus sensor (and has similar mechanical properties). If manufactured on a similar tip mount it would require no alteration to qPlus compatible microscopes.

+If a thin wire is attached to the tungsten tip the sensor can also be used for STM. However, one must be careful not to affect the resonance.

-No commercially available quartz oscillators.

-Operation is very dependent on tip positioning. Manufacture may require expensive micro-manipulators.

References

[1] Stirling, J. and Shaw, G. A., Beilstein J. Nanotechnol. **4**, 10 (2013)

[2] Stirling, J., Beilstein J. Nanotechnol. **4**, 370 (2013)