Macroscopic AFM – Plan

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01/12/2020

Preliminary Knowledge

AFM is commonly used to find information about the surface of an object, passing over microscopic mountains and trenches. To ensure the tip is able to detect these properly it has to be thinner than the trough that it is scanning so that it can reach the bottom (or near it in non-contact mode) and thus determine the depth. The average tip size is only 20 nm, and can be made from a range of materials, however silicon based ones are most common.

Contact Mode

In contact mode the tip is dragged across the surface of the material, to minimise damage this is done at a distance where the force from the surface is repulsive. This still leads to lots of problems, the tip is can become damaged and as such the same reading will give different results when taken at a later time; with delicate matierals such as biological samples, contact mode can permanently damage them.

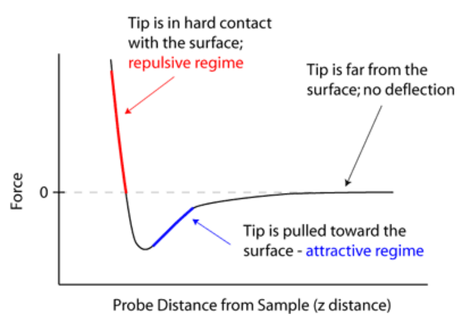

Figure 1: Force-distance curve for an AFM tip[1]

Non-contact mode

To avoid such fates a new method was devised, non-contact mode. The cantilever is oscilated at its resonant frequency, when in close proximity to the surface van der Waals forces attract the tip, this decreases its resonant frequency and from this data a surface can be plotted.

Plan

The aim of this experiment is to show how the principles of an Atomic Force Microscope still apply at the macroscopic level. To collect similar data and show how this would be applied at the nanoscale.

The fundamental frequeny of the steel cantilever can be determined from the following equation:

$$f_m = C_m \left(\frac{EI}{\mu l^4} \right)^{\frac{1}{2}}$$

- $m \in \mathbb{N}$
- $C_1 = 0.5596, C_2 = 3.5069$
- $E = 190 \pm 20$ GPa is the Young's modulus for steel
- $\mu = 0.042 \pm 0.005$ kgm is the density of steel
- $l = 208 \pm 1$ mm is the length of the cantilever
- $I = \frac{bd^3}{12}$ is the moment of inertia of the cantilever
- $b = 4.25 \pm 0.01$ mm is shown in the diagram below in Figure: 3
- $d = 1.50 \pm 0.01$ mm is again shown below in Figure: 3

$$\frac{C_2}{C_1} = \frac{f_2}{f_1} = 2\pi$$

The ratio between the frequencies is 2π, this differes from a standing wave where the ratio is 2.

In order for this equation to be valid the force exerted by the surface, or the *stress* exerted on the cantilever must be elastic, the metal cannot plastically deform. The stress vs strain graph must not go past the yield strength point marked in Figure: 2.

$$\text{Stress, } \sigma = \frac{Force}{Area}$$
$$\text{Strain, } \epsilon = \frac{\Delta l}{l_0}$$

Where Δl is the change in length of the material and l_0 is the original length before any stress is exerted.

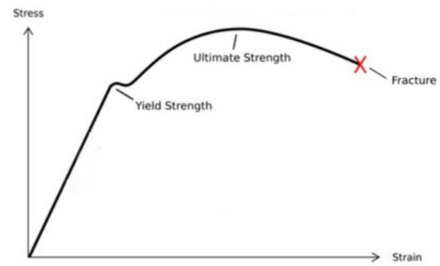

Figure 2: Stress vs Strain for a ductile matieral

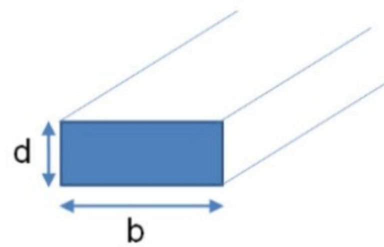

Figure 3: Definition of b and d

Note that the values of b, d and l will vary for the actual experiment and so will have to be measured. Finding the funamnetal frequnecy (f_1) of this hypothetical cantilever gives us.

$$f_1 = 30 \pm 2.43\,\mathrm{Hz}$$

$$f_2 = 188.5 \pm 15.27\,\mathrm{Hz}$$

This is quite a wide margin of uncertainty, however it is accurate enough to give us a rough region of where to locate the fundamnetal frequency, from the beginning of this region fine increments can be used to find the exact measuremeant.

The uncertainty was found through the following formula

$$\begin{aligned}
\delta f &= \sqrt{\left(\frac{\partial f}{\partial \mu}\delta\mu\right)^2 + \left(\frac{\partial f}{\partial E}\delta E\right)^2 + \dots} \\
C &= \frac{1}{2}C_1(f_1)^{-\frac{1}{2}} = 5.2 \cdot 10^{-3} \\
\left(\frac{\partial f}{\partial \mu}\delta\mu\right) &= -C\frac{Ebd^3}{12\mu^2 l^4}\delta\mu = -1.788 \\
\left(\frac{\partial f}{\partial l}\delta l\right) &= -C\frac{4Ebd^3}{12\mu^2 l^5}\delta l = -0.288 \\
\left(\frac{\partial f}{\partial E}\delta E\right) &= C\frac{bd^3}{12\mu^2 l^4}\delta E = 1.581 \\
\left(\frac{\partial f}{\partial b}\delta b\right) &= C\frac{Ed^3}{12\mu^2 l^4}\delta b = 0.0353 \\
\left(\frac{\partial f}{\partial d}\delta d\right) &= C\frac{3Ebd^2}{12\mu^2 l^4}\delta d = 0.3 \\
\delta f &= 2.43\text{Hz}
\end{aligned}$$

Experiment

1. Measure the dimensions of the cantilever (b and d) and note the uncertainty.

2. Set up the experiment as seen in Figure: 4. Ensure there is no magnet beneath the cantilever tip and vary the signal of the oscilator until a rough region of resonance frequency is found. Start recording data before this region, record the amplitude the laser makes on the wall and the frequency at which this occurs. Record data in finer steps as the amplitude begins to increase quicker. Note the uncertainty of the oscilator and graph paper used to find the amplitude.

Frequency(f) / Hz	Amplitude / cm
18	2
20	5
20.5	10
⋮	⋮

   Plot a resonance frequency curve as shown in Figure: 5. The Q-value can be calculated by $\frac{f_1}{\text{bandwidth at70.7\%}}$. This shows how fast an oscilattion will decay, a larger Q value will oscillate for longer.

3. Move one of the magnets beneath the tip and again record the fundamental frequency, plot a resonance curve and calulate the Q value. How has the fundamental frequency changed?

4. Find the second harmonic frequency of the cantilever

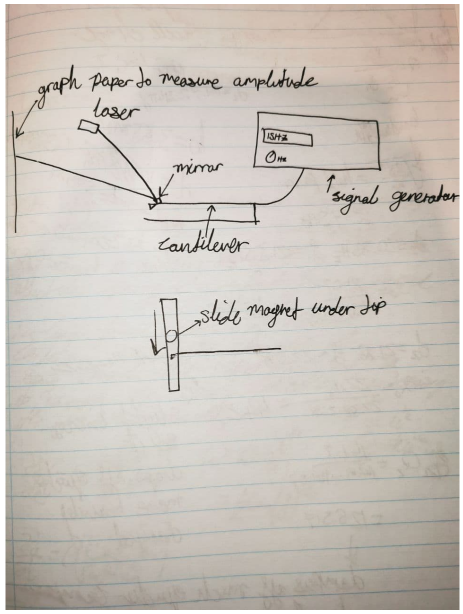

Figure 4: Setup

References

[1] nanoscience.com https://www.nanoscience.com/techniques/atomic-force-microscopy/

[2] wikibooks.com https://en.wikibooks.org/wiki/A-level_Physics_(Advancing_Physics)/Resonance/

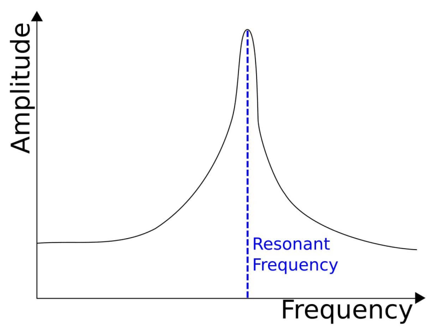

Figure 5: Resonance frequency curve [2]