Vibration-Induced Elasto-hydro-dynamic Adhesion of Thin Elastic Sheet

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Abstract: When a thin elastic sheet is vibrated close to a wall, it leads to an adhesive effect first described by Weston-Dawkes et al. Here we quantify and describe the adhesive force as a function of the vibration frequency, vibration amplitude and the size of the elastic sheet. We show that the adhesion force increases with increasing frequency, amplitude and radius of the thin elastic sheet.

Introduction: Adhesive techniques are widely known and used, the most popular of which are adhesive tapes. Here we explore a non-intuitive behavior that emerges when a thin elastic sheet is vibrated close to a surface. First described by Weston-Dawkes et al., this creates a strong adhesive force that is normal to the surface, with very little resistance to motion parallel to the surface. With the aim of constructing a theoretical framework for understanding this behavior, we quantify the adhesive force as a function of the vibration frequency, amplitude, and size of the thin elastic sheet.

Hypothesis: The air flows in the gap between the vibrating thin elastic sheet and the opposing surface are sufficient to create a viscous adhesive force. To quantify this requires a set of experiments.

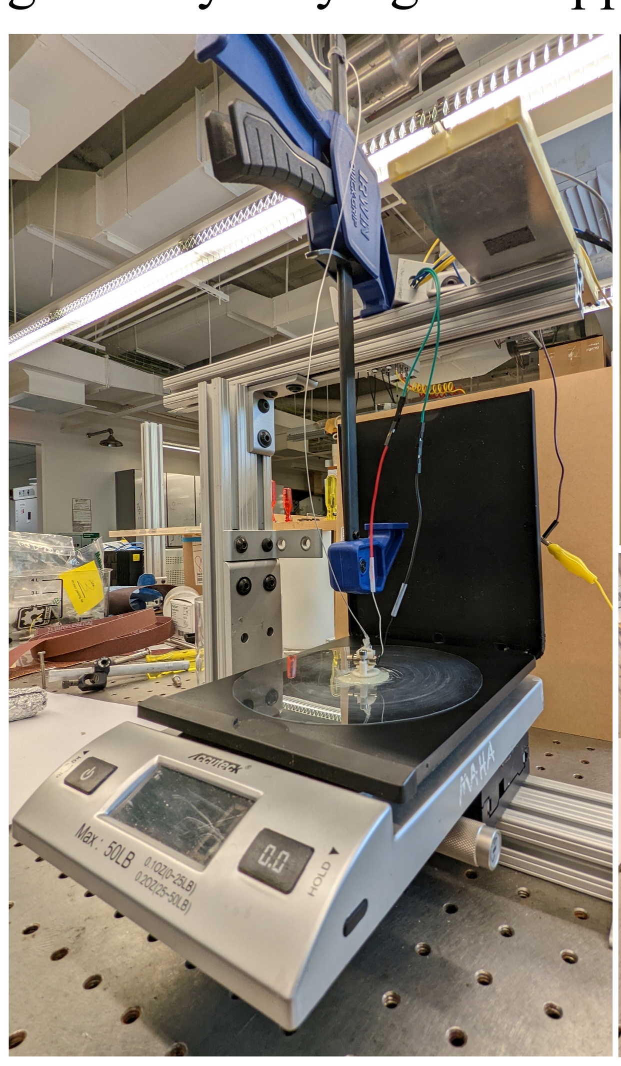
Goals: Design an experimental prototype and setup to determine how the maximum adhesive force of the prototype is influenced by the vibration frequency, amplitude, and the size of the elastic sheet.

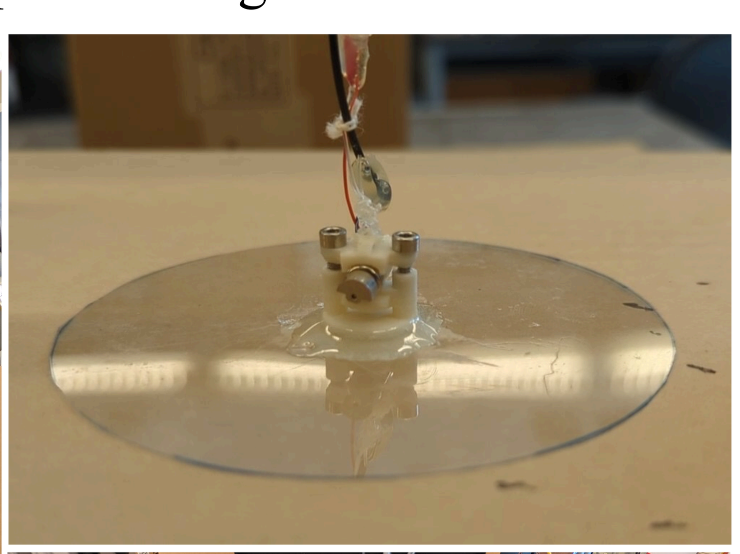
Methods: The measurement prototype was made of a flexible disk attached to an electric motor.

1. Different disk sizes of radius 3cm, 4.5cm, 5.1cm, and 7cm were cut from .007-inch-thick clear craft plastic sheets. The disks were glued to 6mm x 14mm micro vibration motors using epoxy glue. All freshly glued motors were left to sit for at least 20 minutes before being used for experiments.

2. The device was placed on a scale with a string attached at the top. The string was connected to a lever and was used to apply upwards force to the contraption.

3. With some chosen disk size, motor frequency and amplitude, upwards force was slowly applied to the device until the flexible disk detached from the scale. The readings shown on the scale just before detachment was then recorded. This test was done with different disk sizes, motor frequencies, and amplitudes (⌀ = 4, 5, 6mm). The motor frequency range of 0 - 333Hz was gotten by varying the supplied voltage from 0 - 3V





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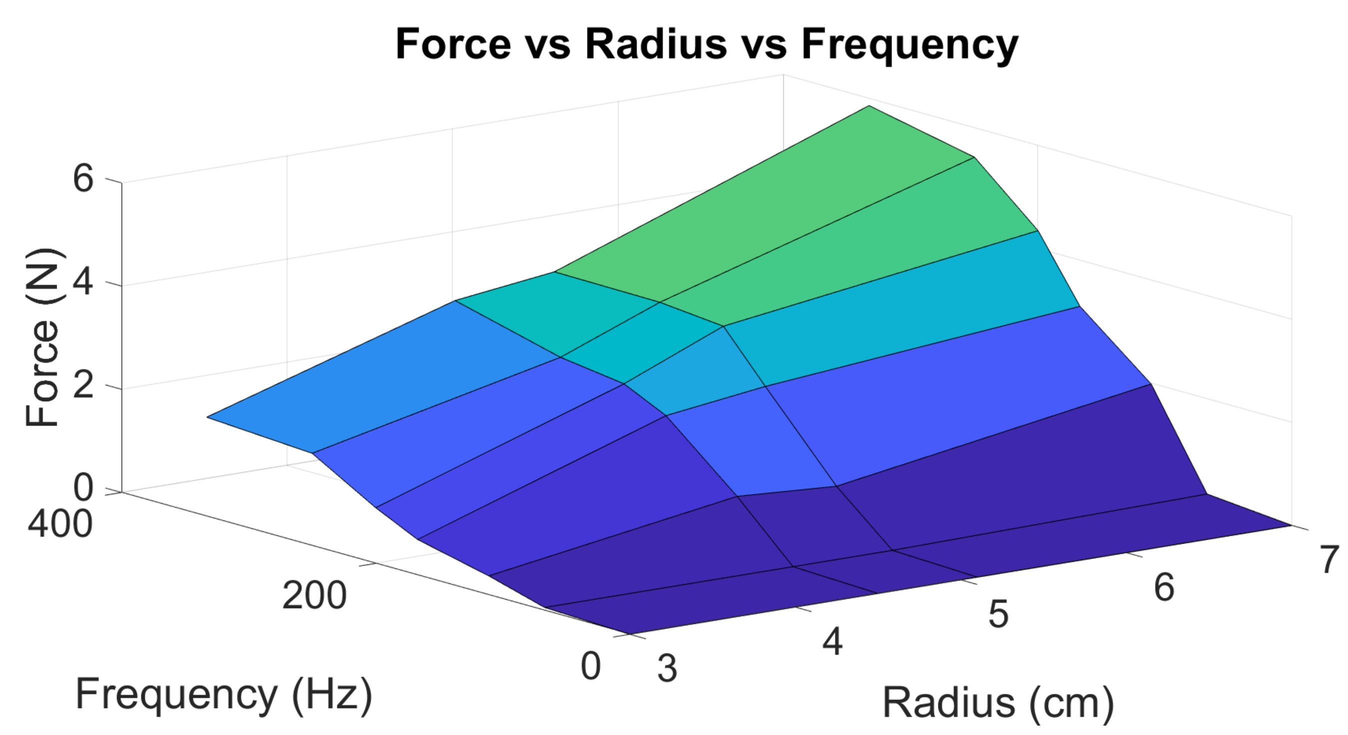
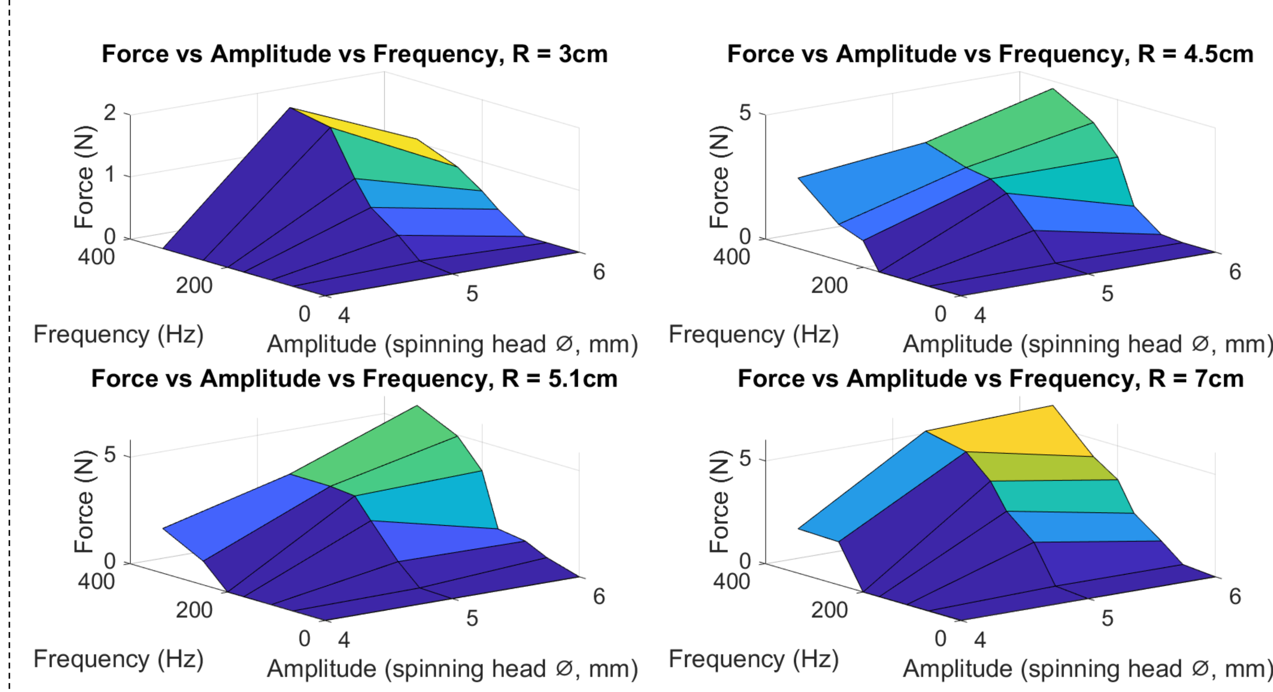
Results and Discussion:

Influence of frequency and disk radius on maximum adhesive force:



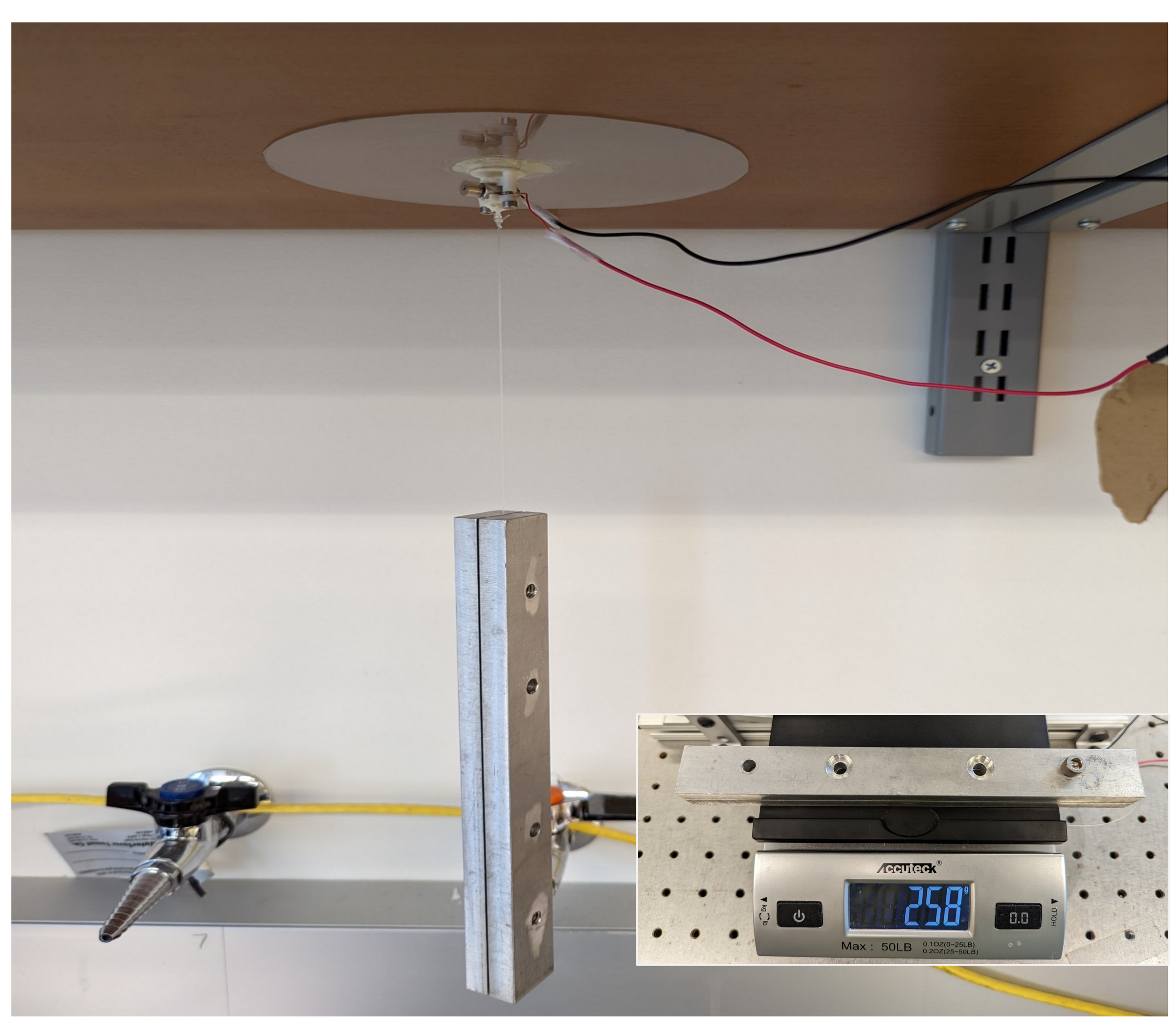
The above figure shows that the maximum adhesive force achieved by the contraption, before failure, depends on the motor frequency and disk radius, with higher frequencies and radius resulting in a higher max adhesive force

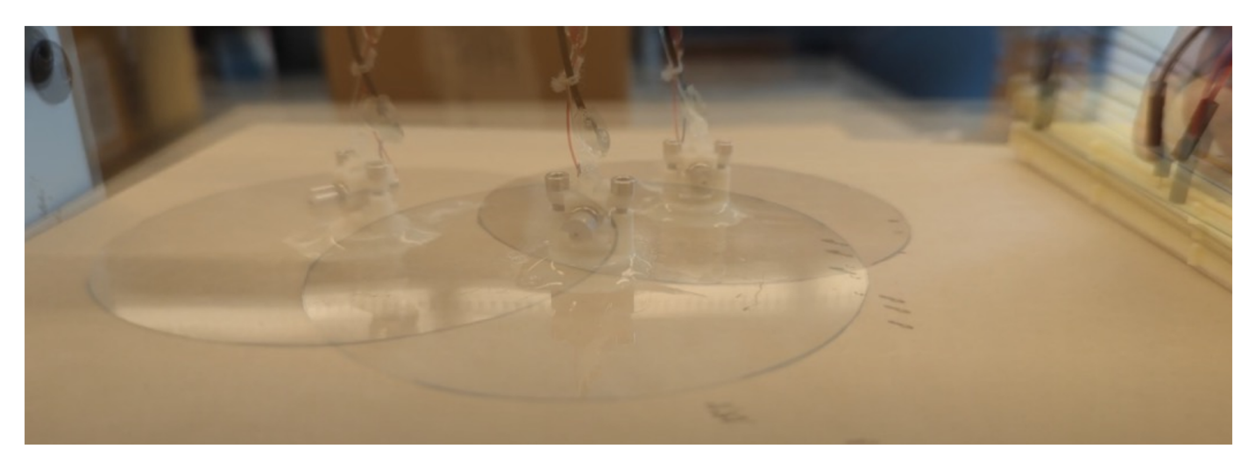
Effect of motor amplitude on maximum adhesive force:



The figures above show that increasing amplitude results in increased adhesive force. This trend occurs in all tested disk radii except for the smallest tested disk radius of 3cm.

A 258g load is carried by a 6g device (7cm disk radius, frequency of 333Hz, spinning head dia. of 6mm)





Conclusions:

- An experimental device was constructed and used to determine that the maximum adhesive force of the device is proportional to the disk radius, vibration frequency, and amplitude.
- The 6g device can carry load more than 40 times its own weight.
- The device showed strong adhesion normal to the surface of adhesion, with little resistance to motion parallel to the surface, allowing for potential use cases in robotics as the original authors suggested.

References:

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