Russia IYPT

Coffee cup

Ianko Pavel

Alexey Budantsev

The problem

Physicists like drinking coffee, however walking between laboratories with a cup of coffee can be problematic.

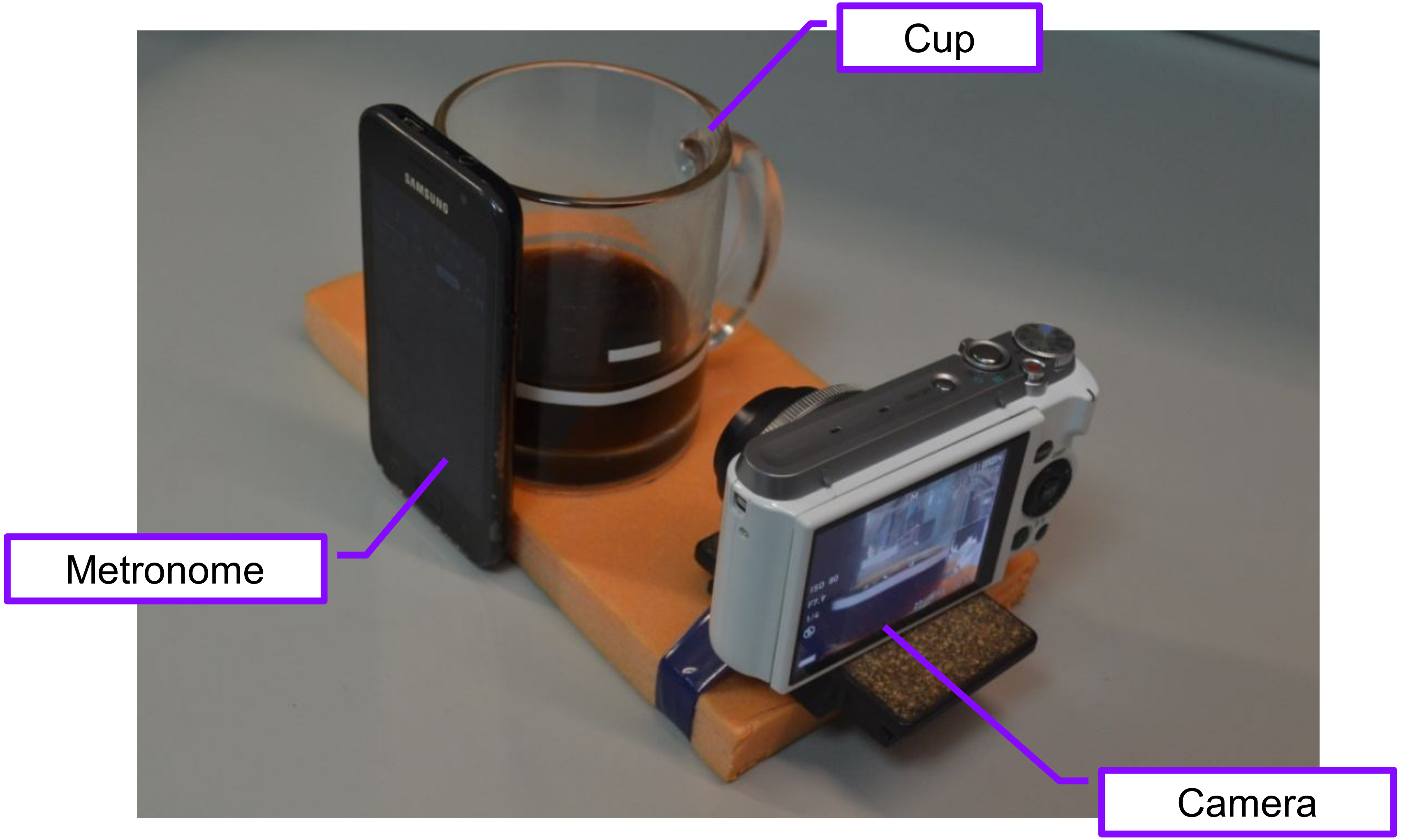
Main task

Investigate how the shape of the cup, speed of walking and other parameters affect the likelihood of coffee being spilt while walking.

First observations

Cylindrical cup

Mobile measurements



Natural step (2.5 Hz)

Quick step (3.5 Hz)

Even faster (4 Hz)

Preliminary conclusion

Excitation of coffee sloshing has a resonance character.

Plan of the report

Resonant excitation of sloshing modes

↓

Excitation during walking

↓

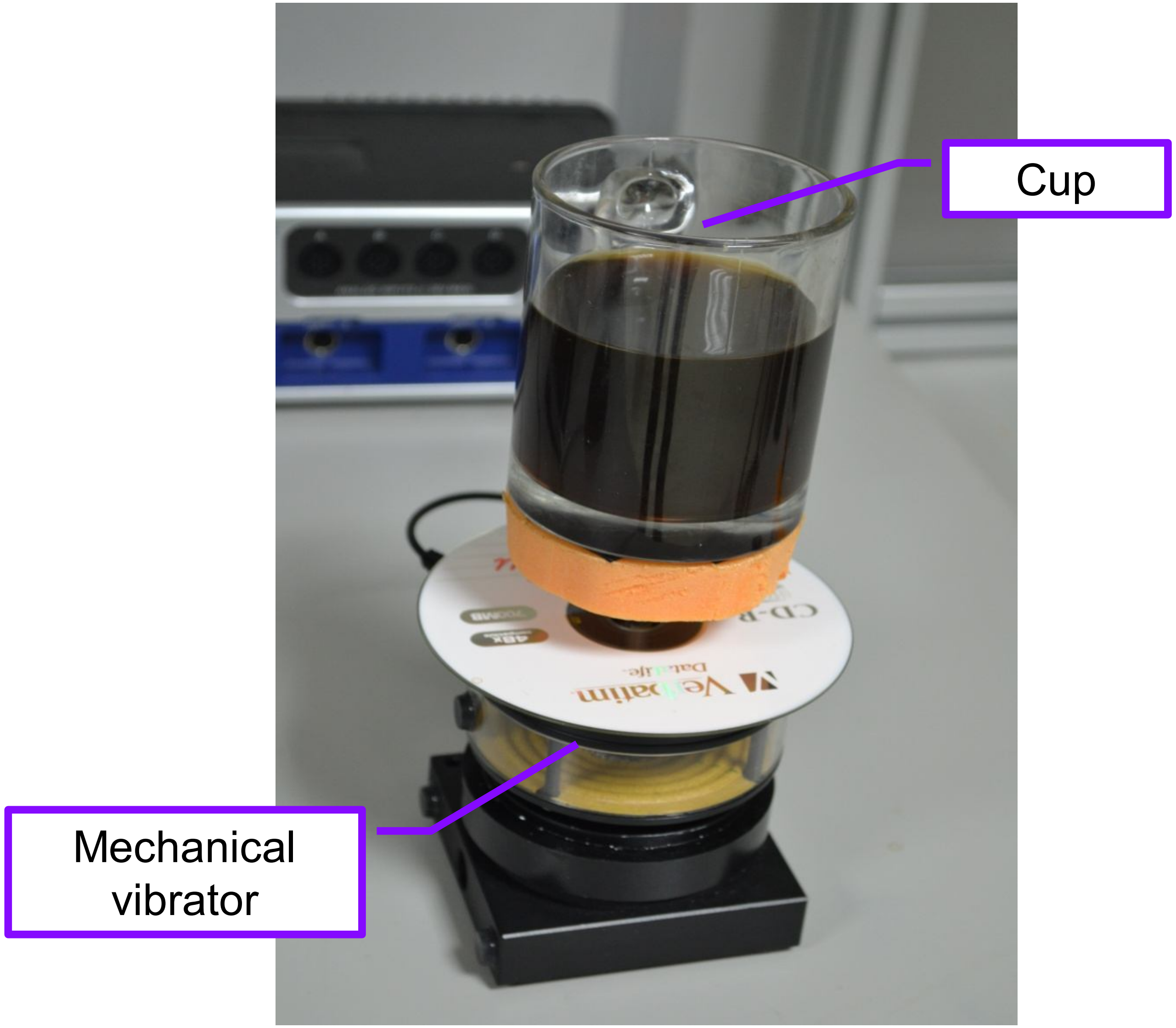
Human hand as a dumper

↓

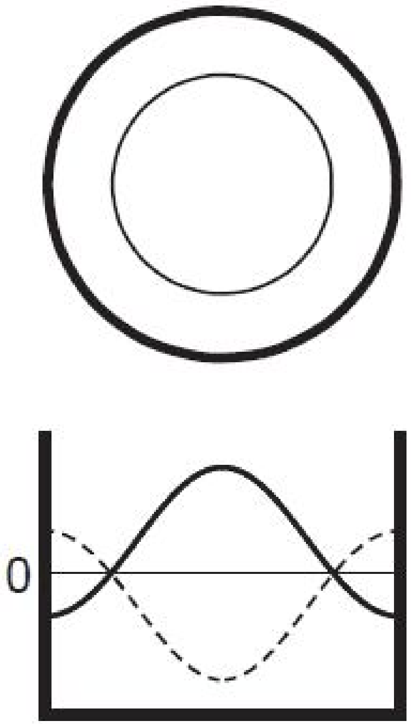
The shape of a cup

Forced oscillations

Setup for vertical excitations

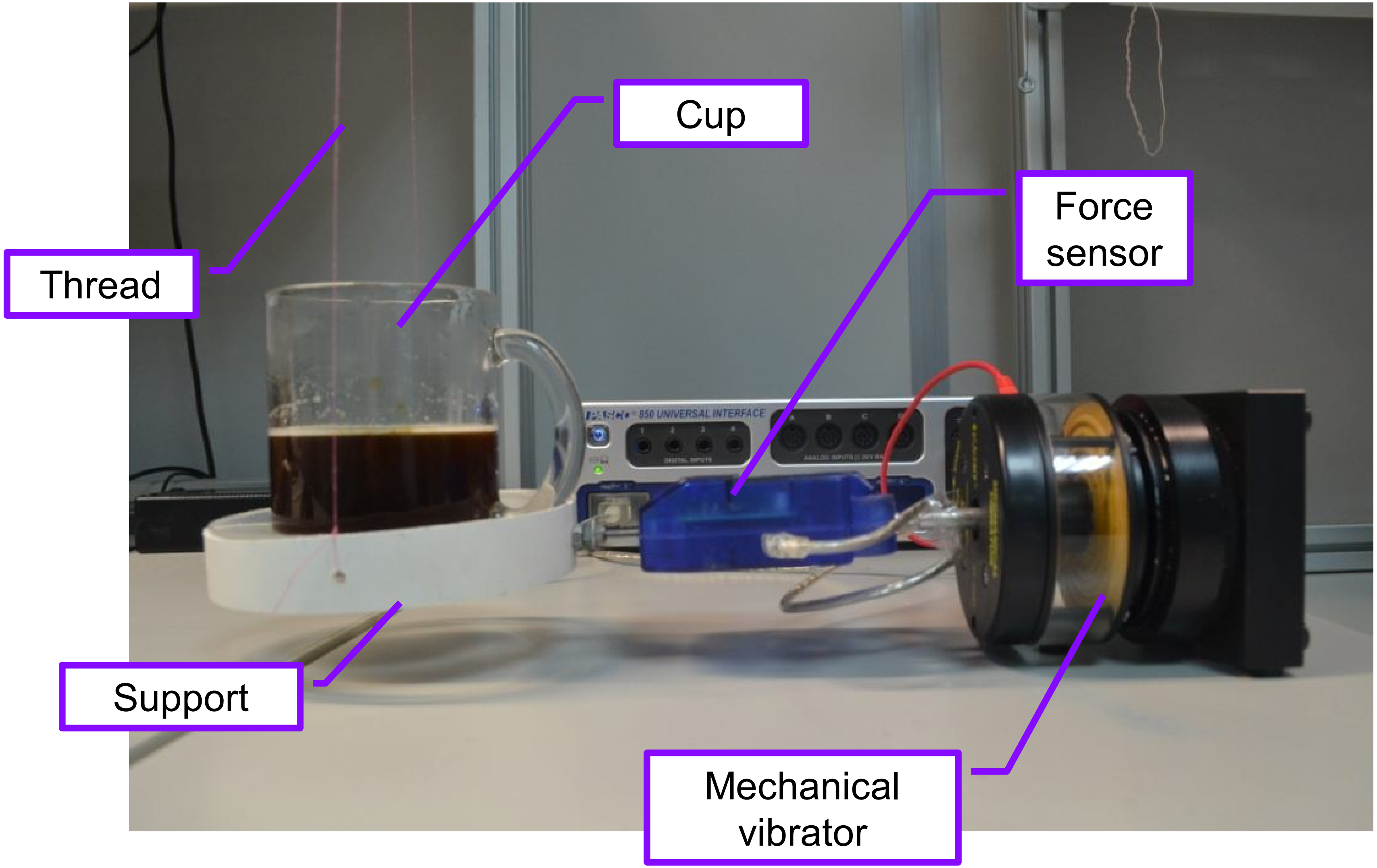


Radial oscillation mode (240 fps)

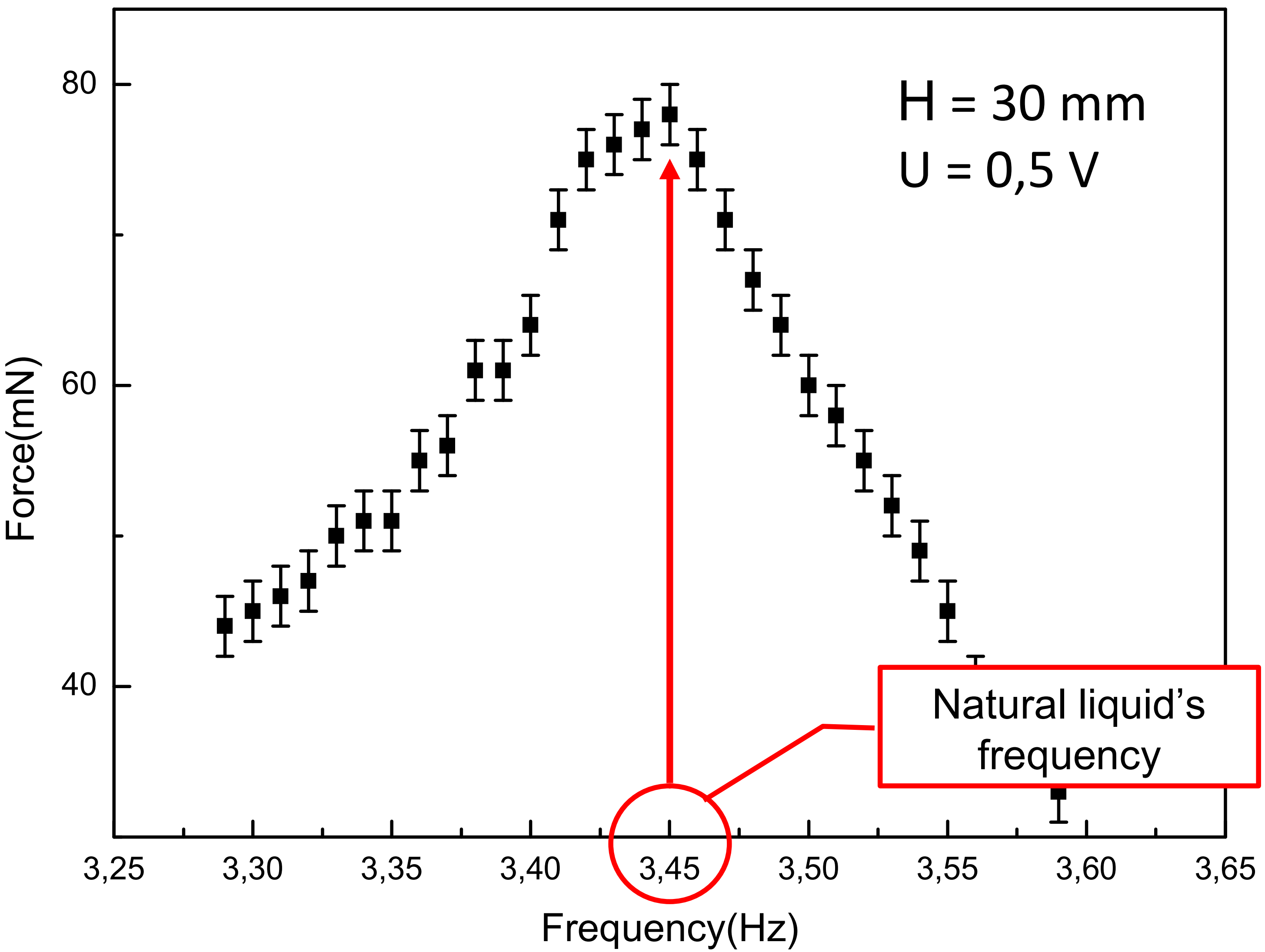


f = 3.8 Hz

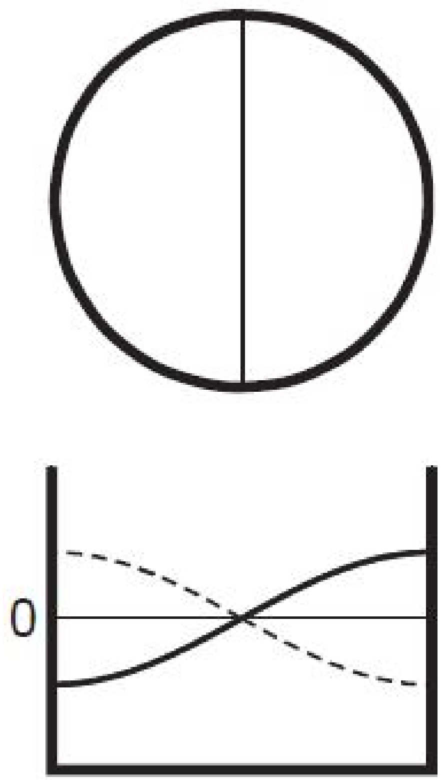
Setup for horizontal excitations

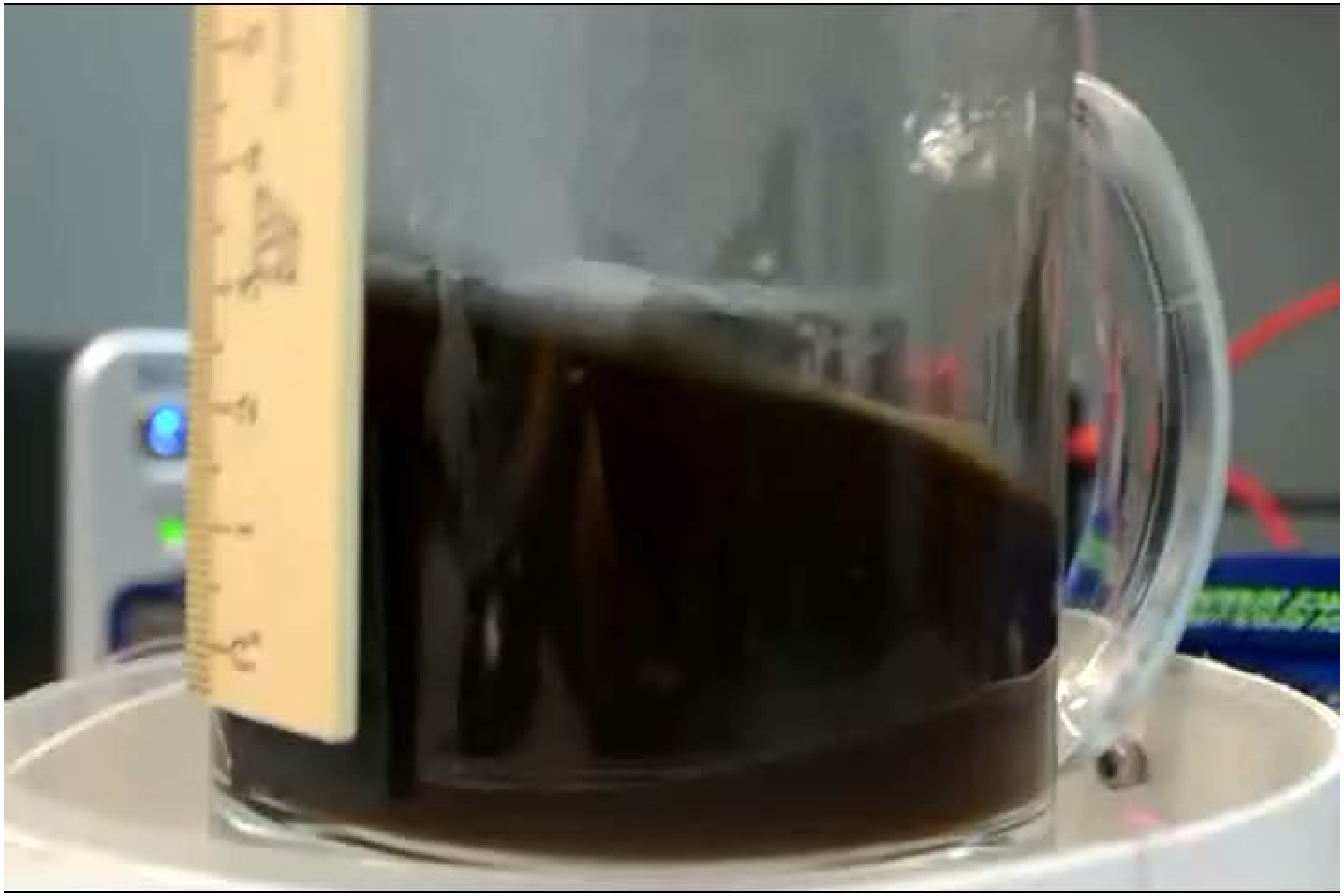


Force vs. frequency



Tilting oscillation mode (video)

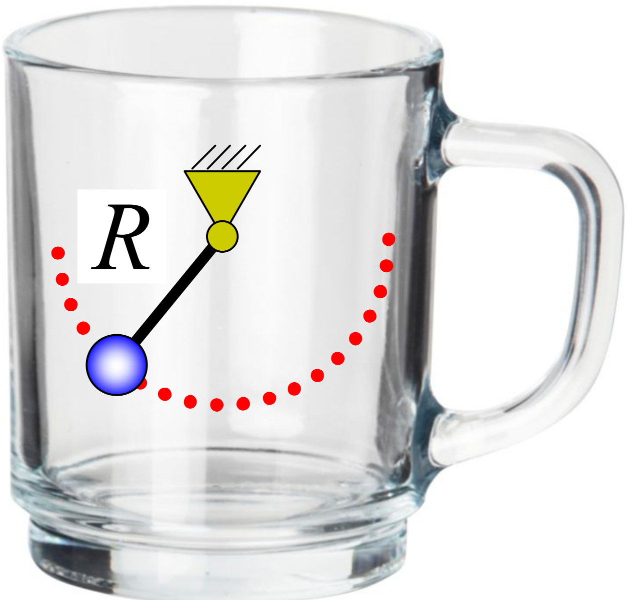




Resonance *f* = 3.5 Hz

Theoretical model. Pendulum hypothesis.

Frequency estimation



$$\omega^2 \propto \frac{g}{R}$$

$$\omega^2 = \varepsilon \frac{g}{R} \tanh\left(\varepsilon \frac{H}{R}\right) \cdot \left(1 + \varepsilon^2 \frac{\sigma g}{\rho R^2}\right) \rightarrow \omega^2 = \varepsilon \frac{g}{R}$$

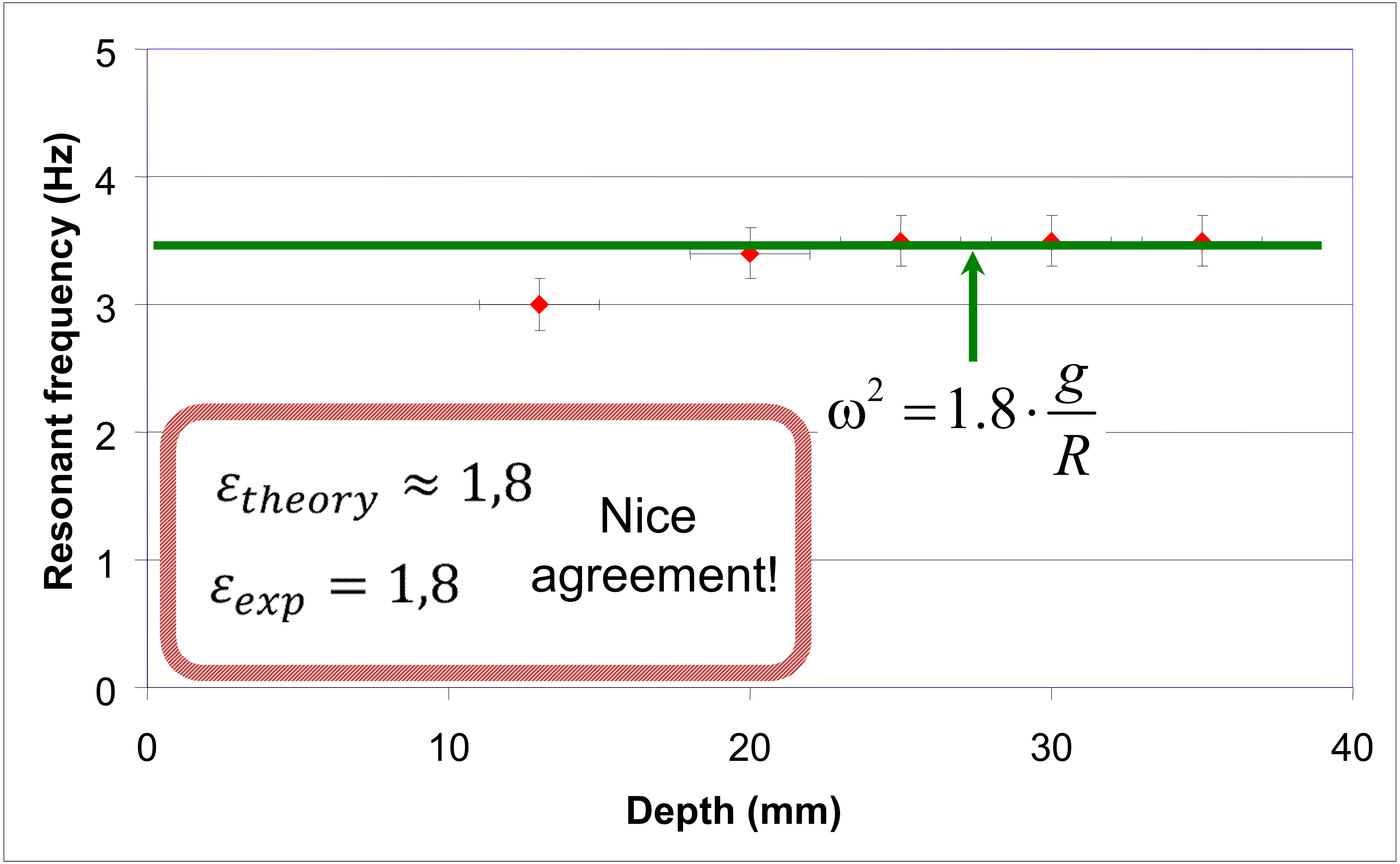
$$\underbrace{\tanh\left(\varepsilon \frac{H}{R}\right)}_{\approx 1} \qquad \underbrace{\varepsilon^2 \frac{\sigma g}{\rho R^2}}_{\approx 0,02}$$

Theory

$$\varepsilon \approx 1,8$$

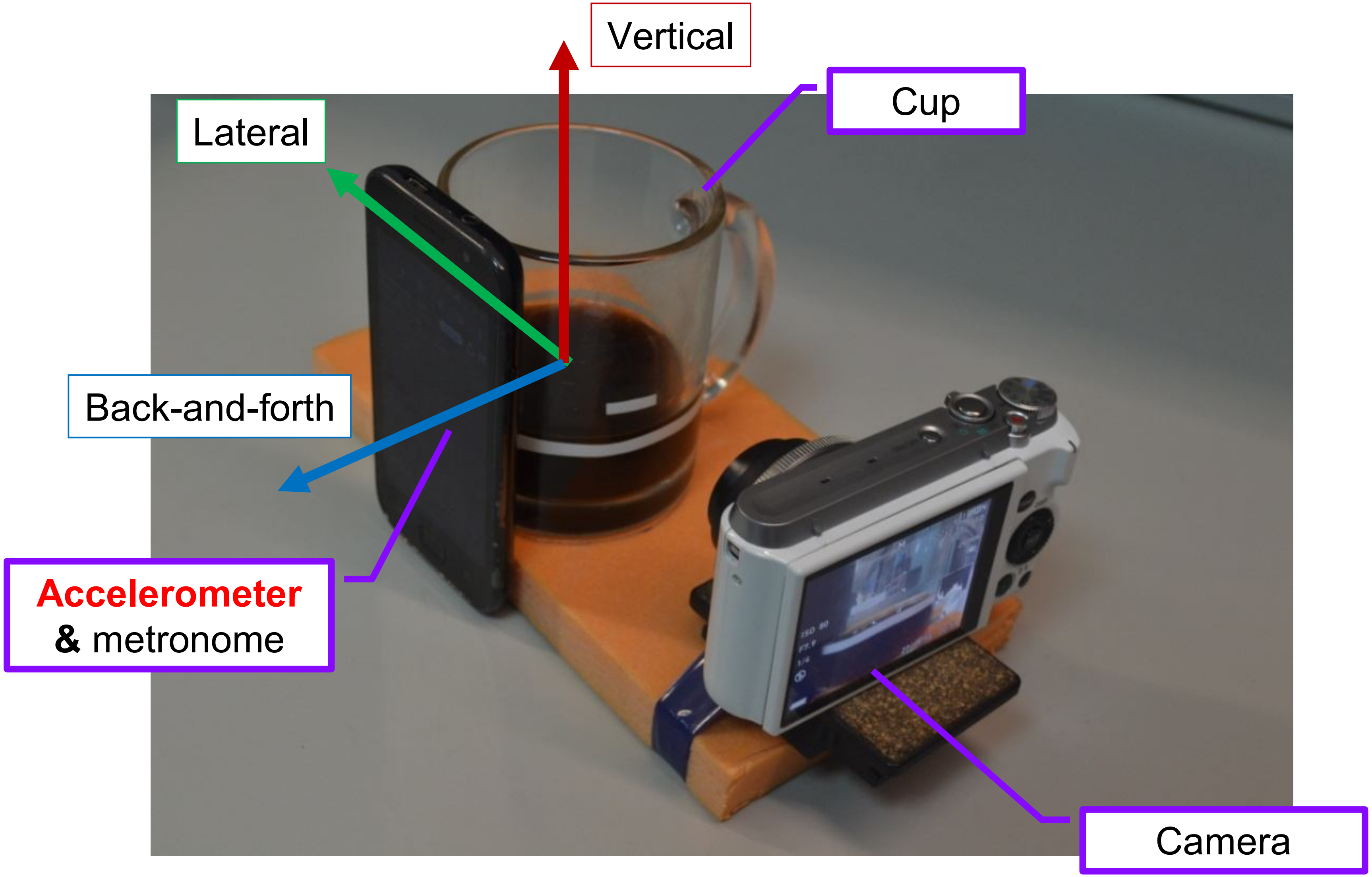
H. Lamb, Hydrodynamics (Dover, NY, 1945)

Resonant frequency vs. depth

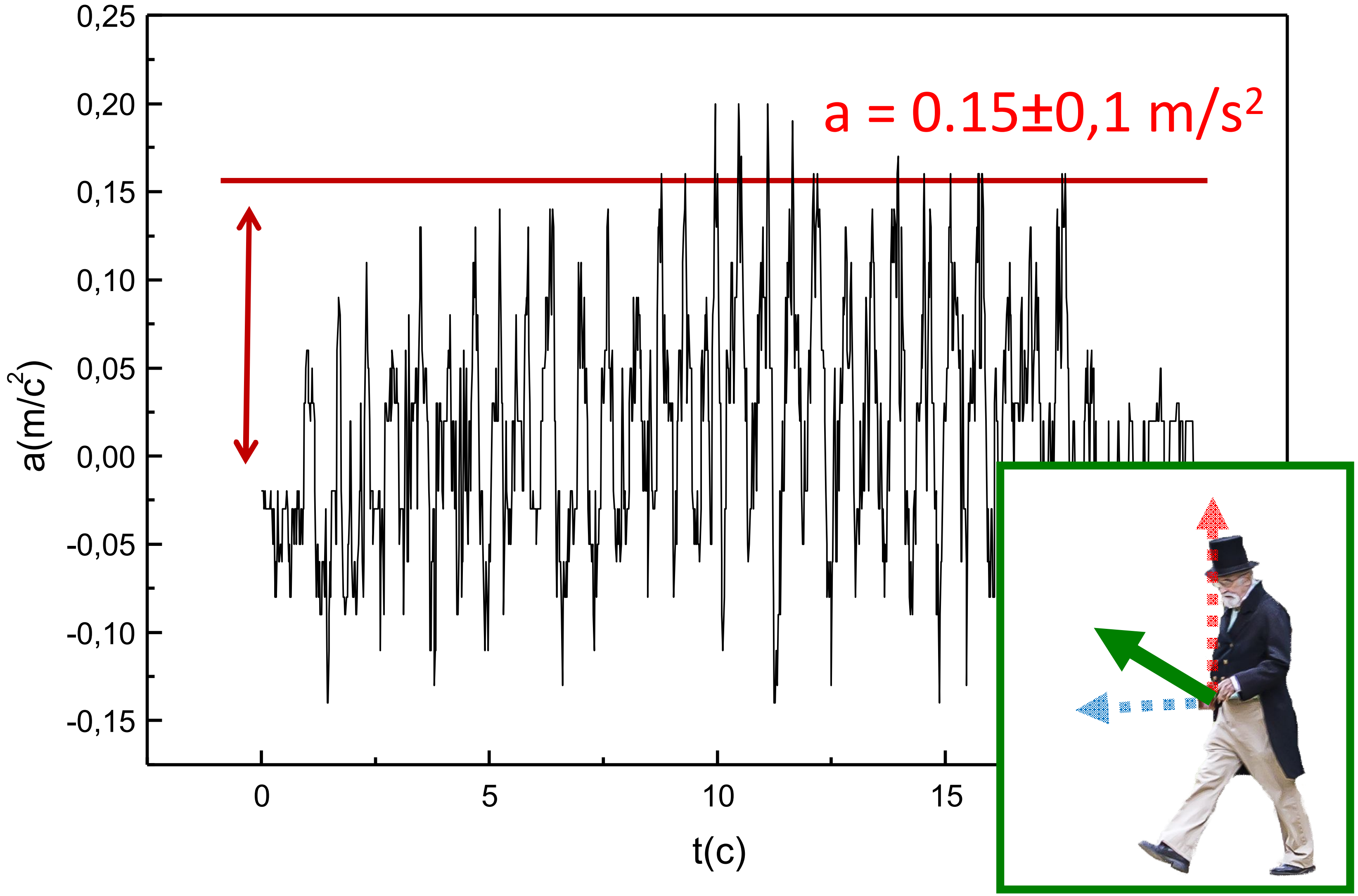


Acceleration of a cup during walking

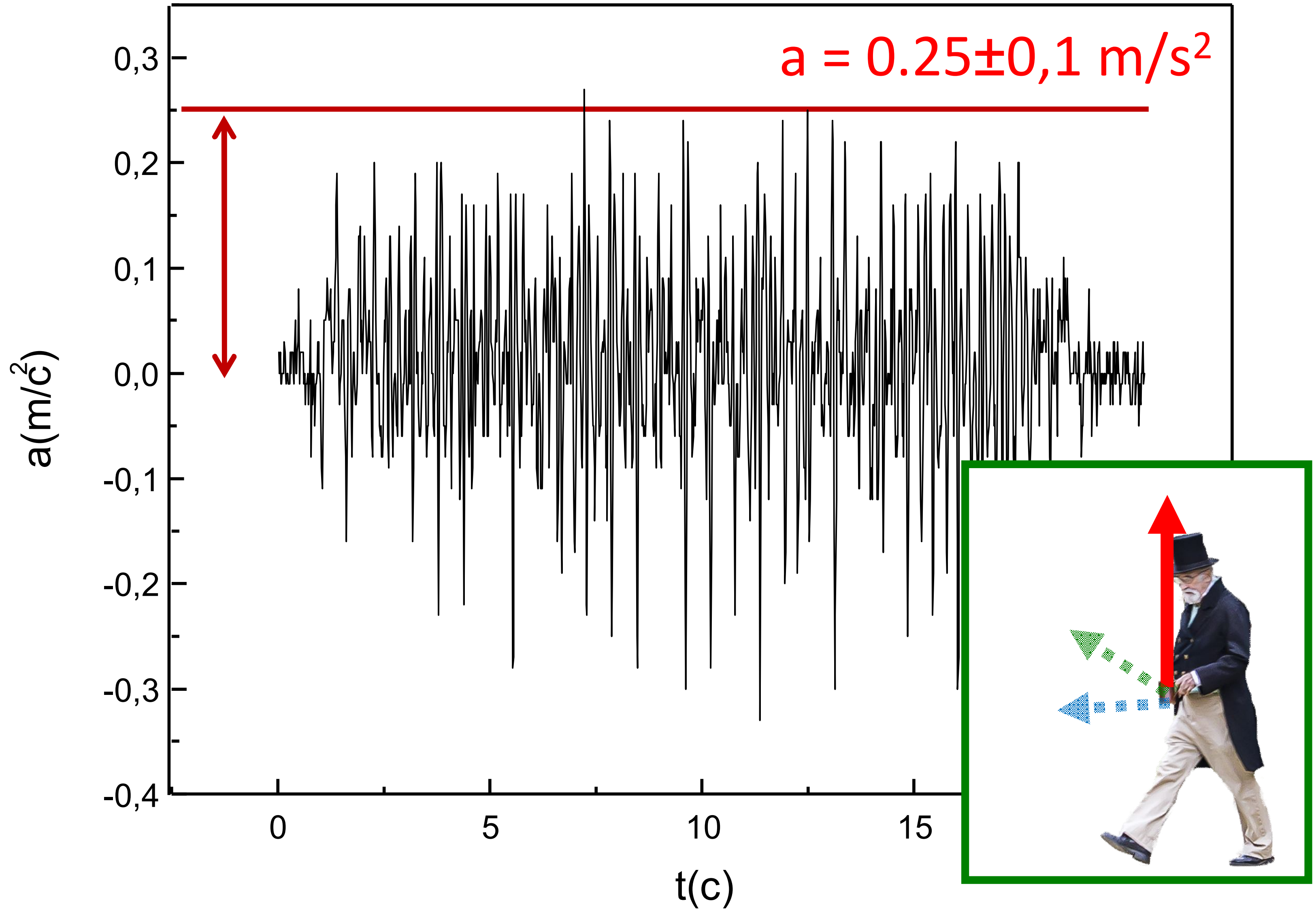
Mobile measurements



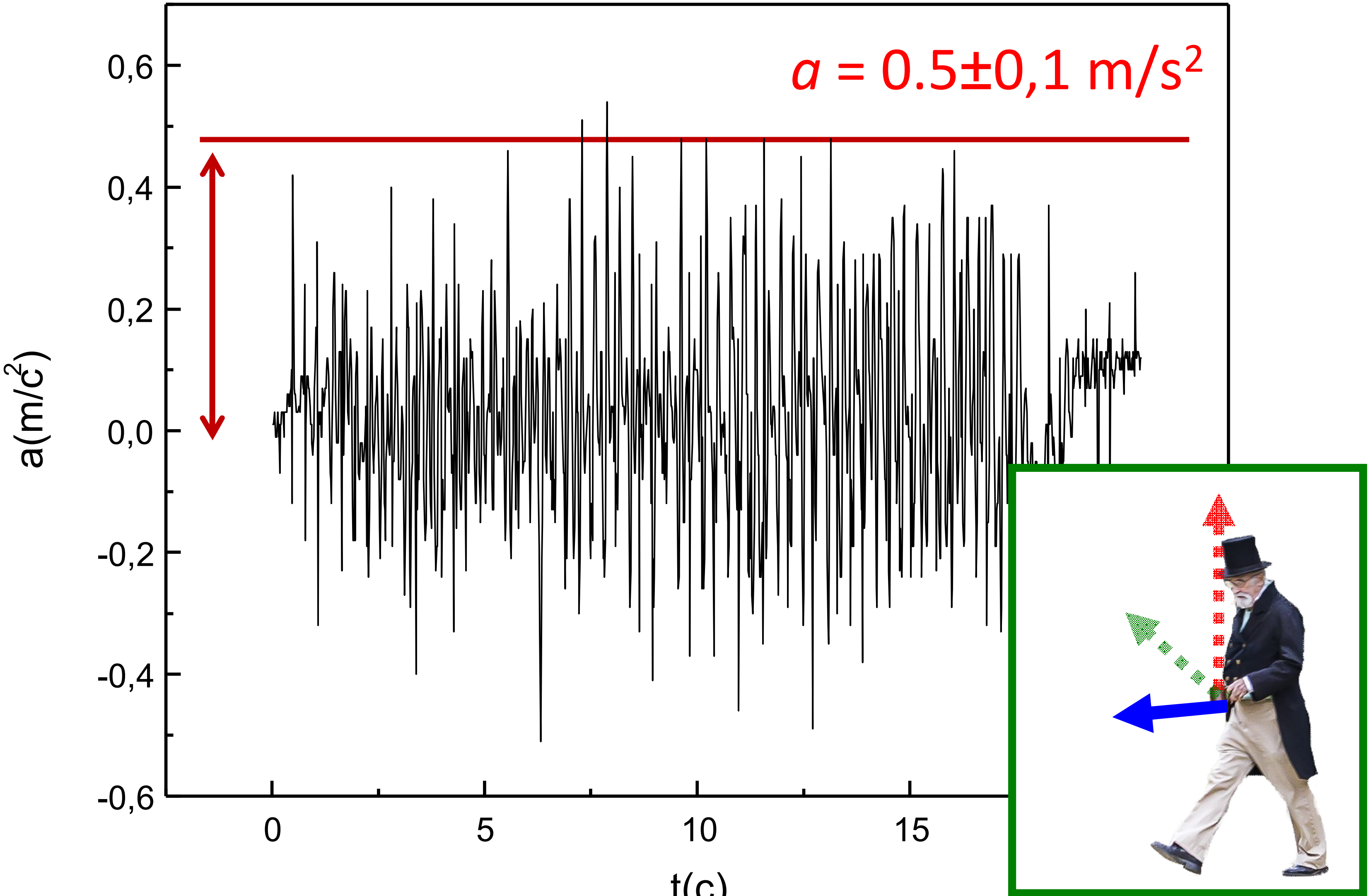
Lateral resonance acceleration



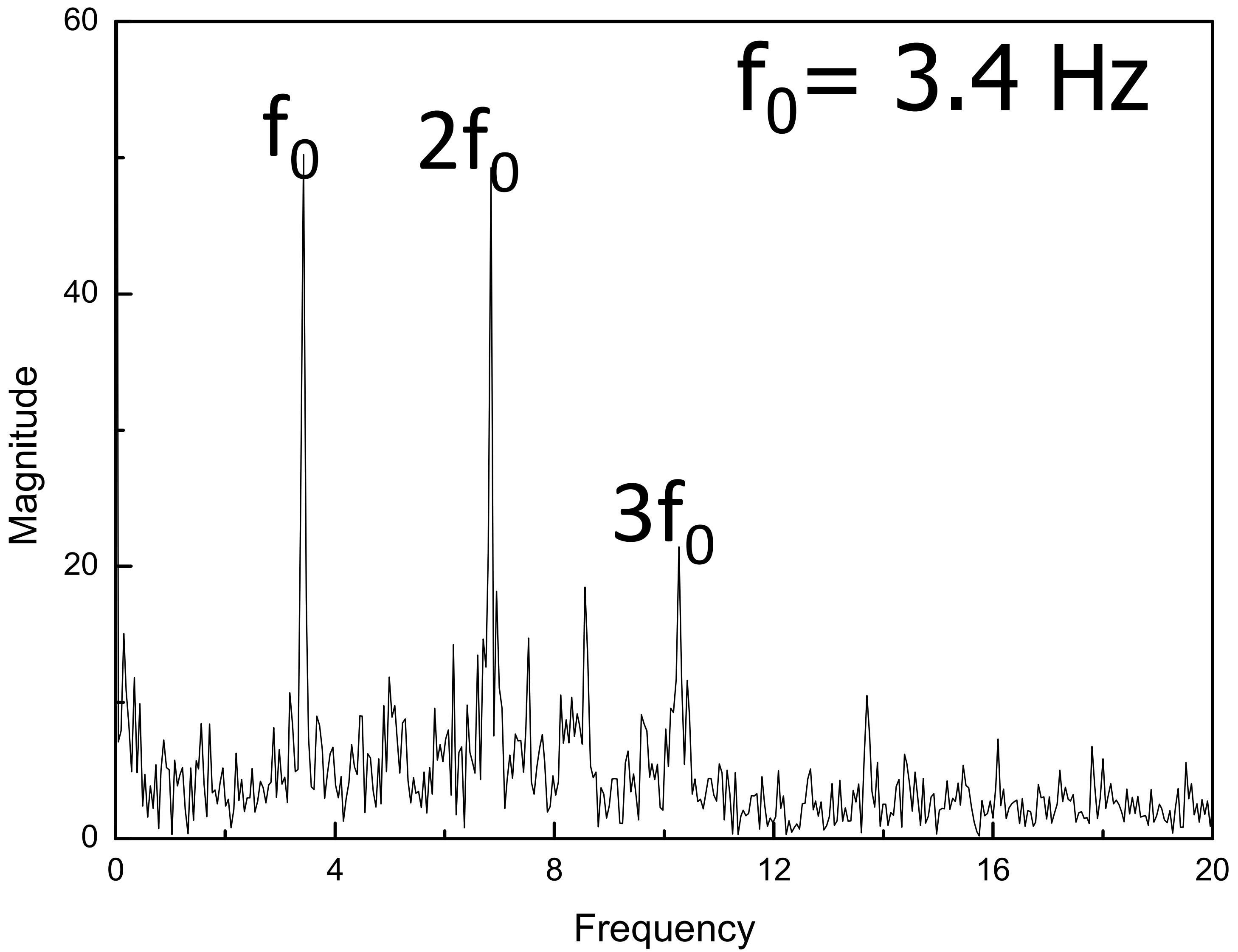
Vertical resonance acceleration



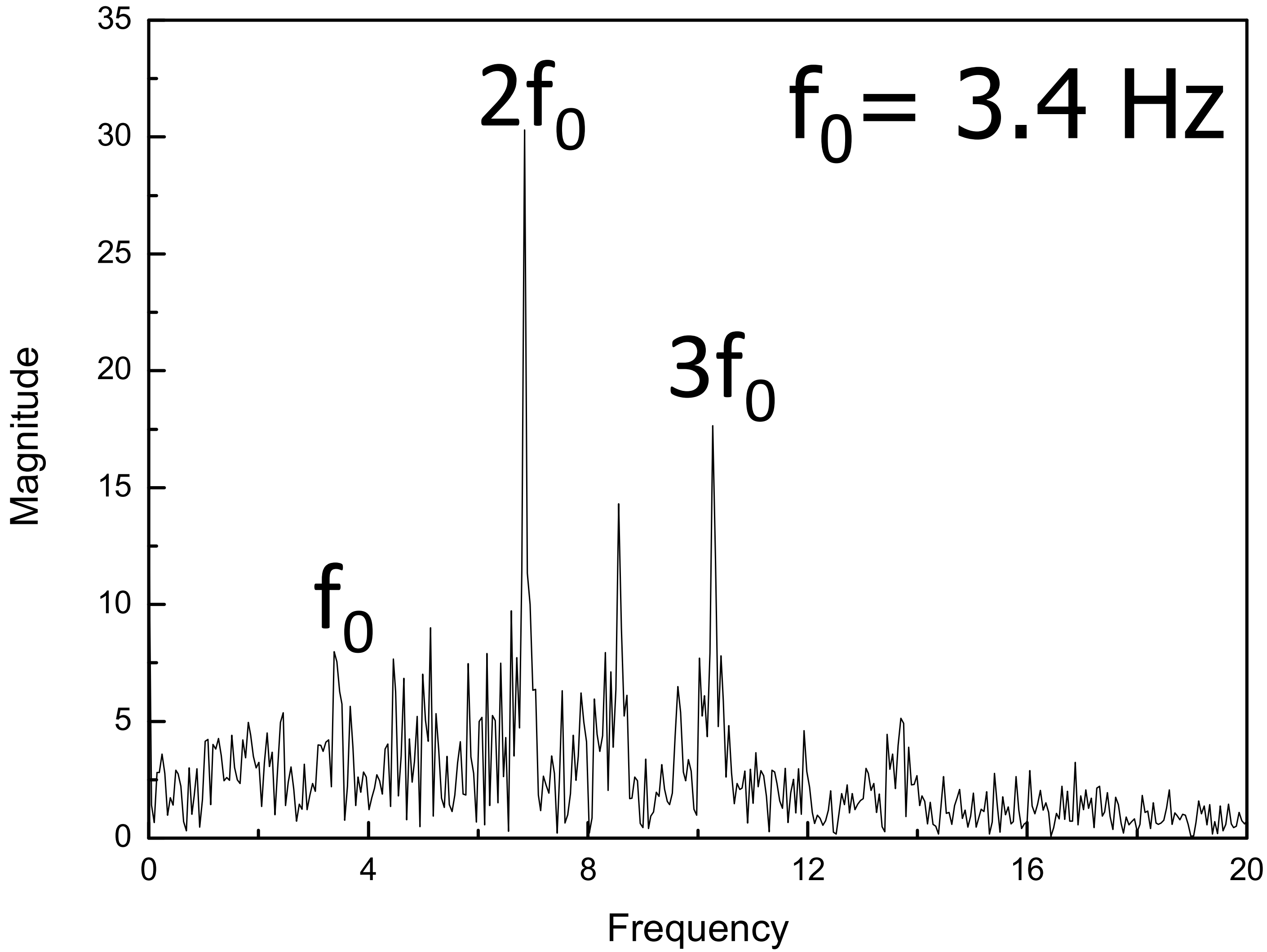
Back-and-forth resonance acceleration



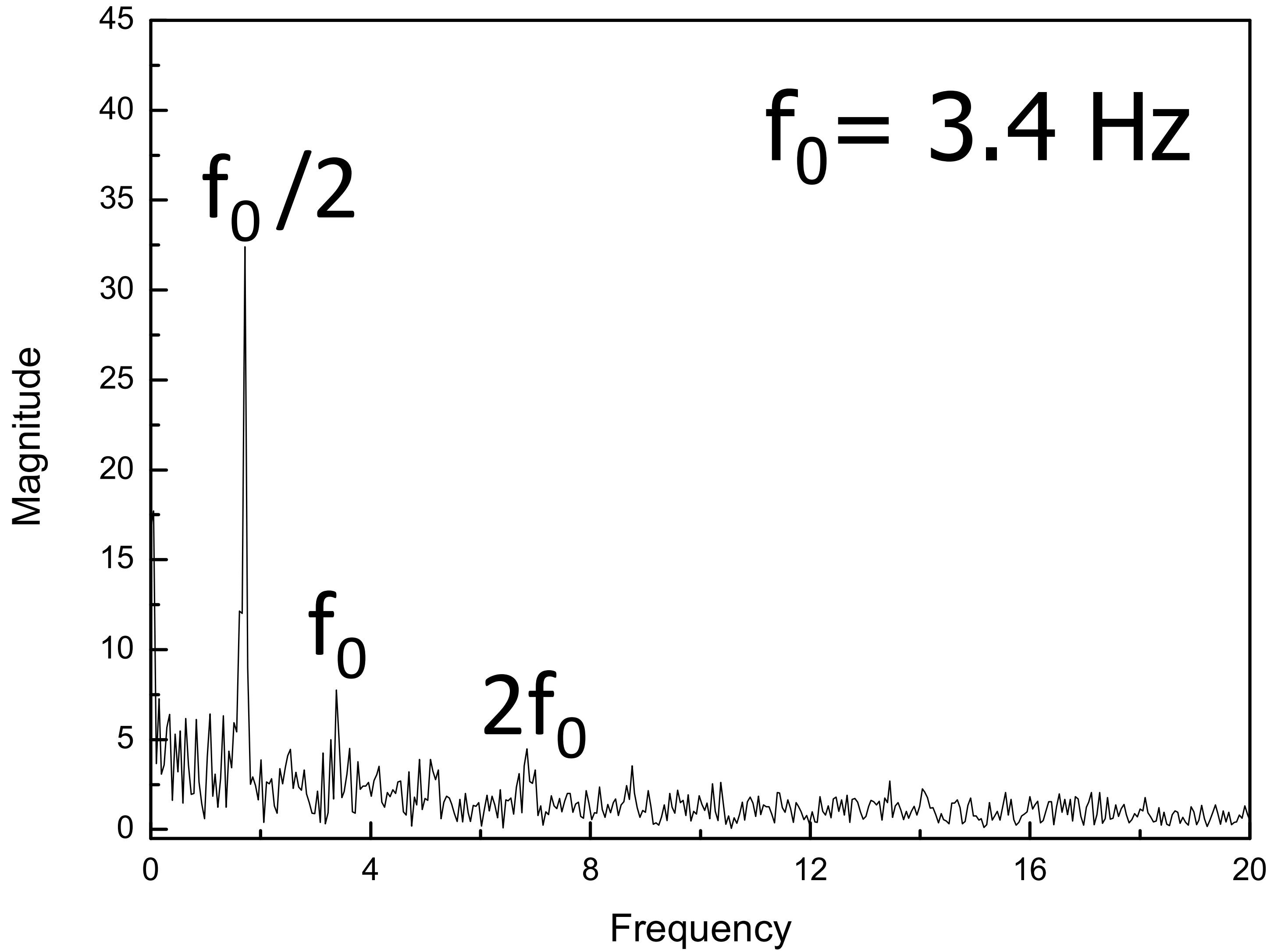
Back-and-forth acceleration spectrum



Vertical acceleration spectrum



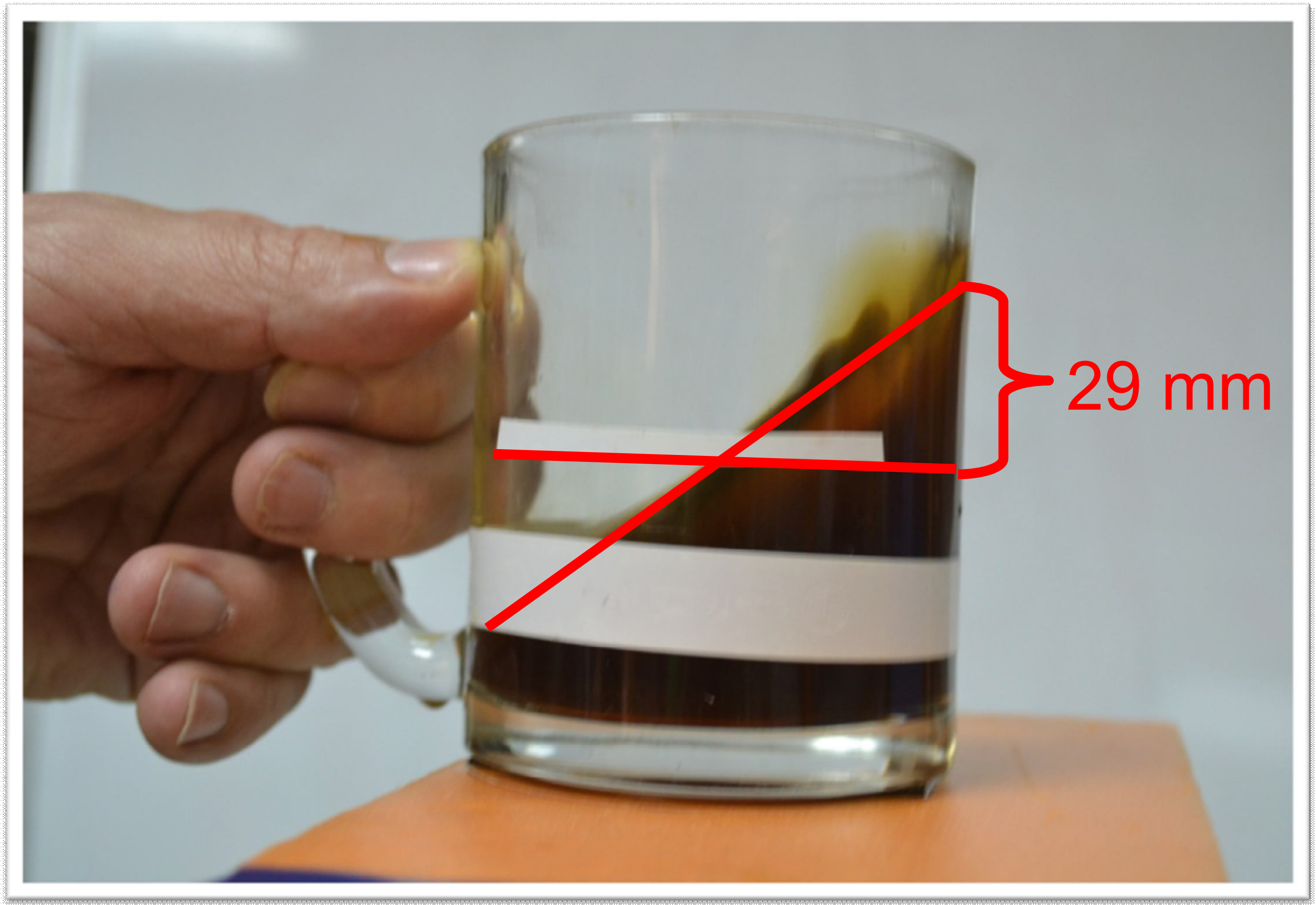
Lateral acceleration spectrum



Conclusion

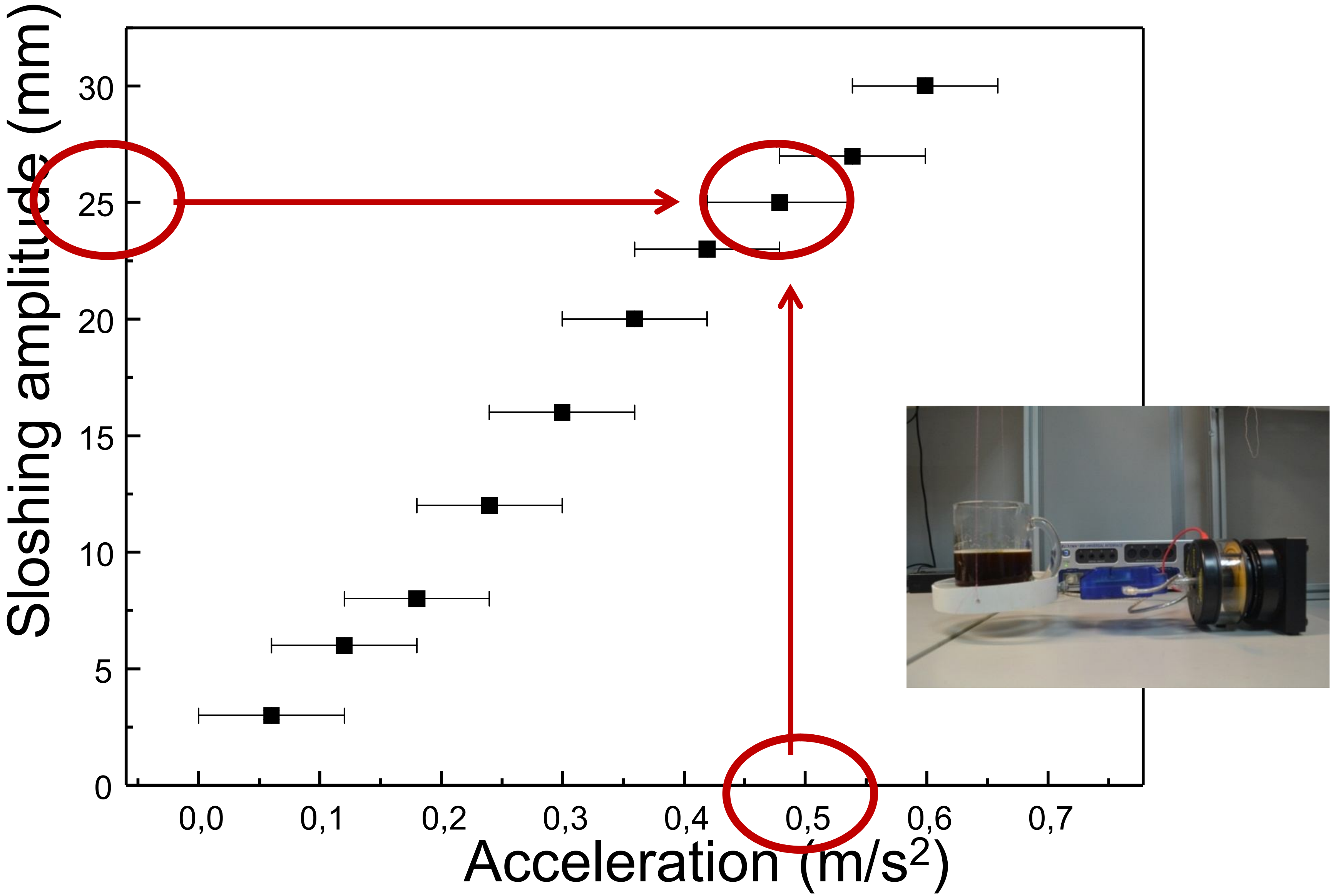
Back-and-forth acceleration makes a dominant contribution in coffee sloshing.

Amplitude during walking



Back-and-forth acceleration 0.5 m/s^2

Horizontal excitation experiment



Human hand as a dumper

Human hand as a damper

Frequencies of human walking

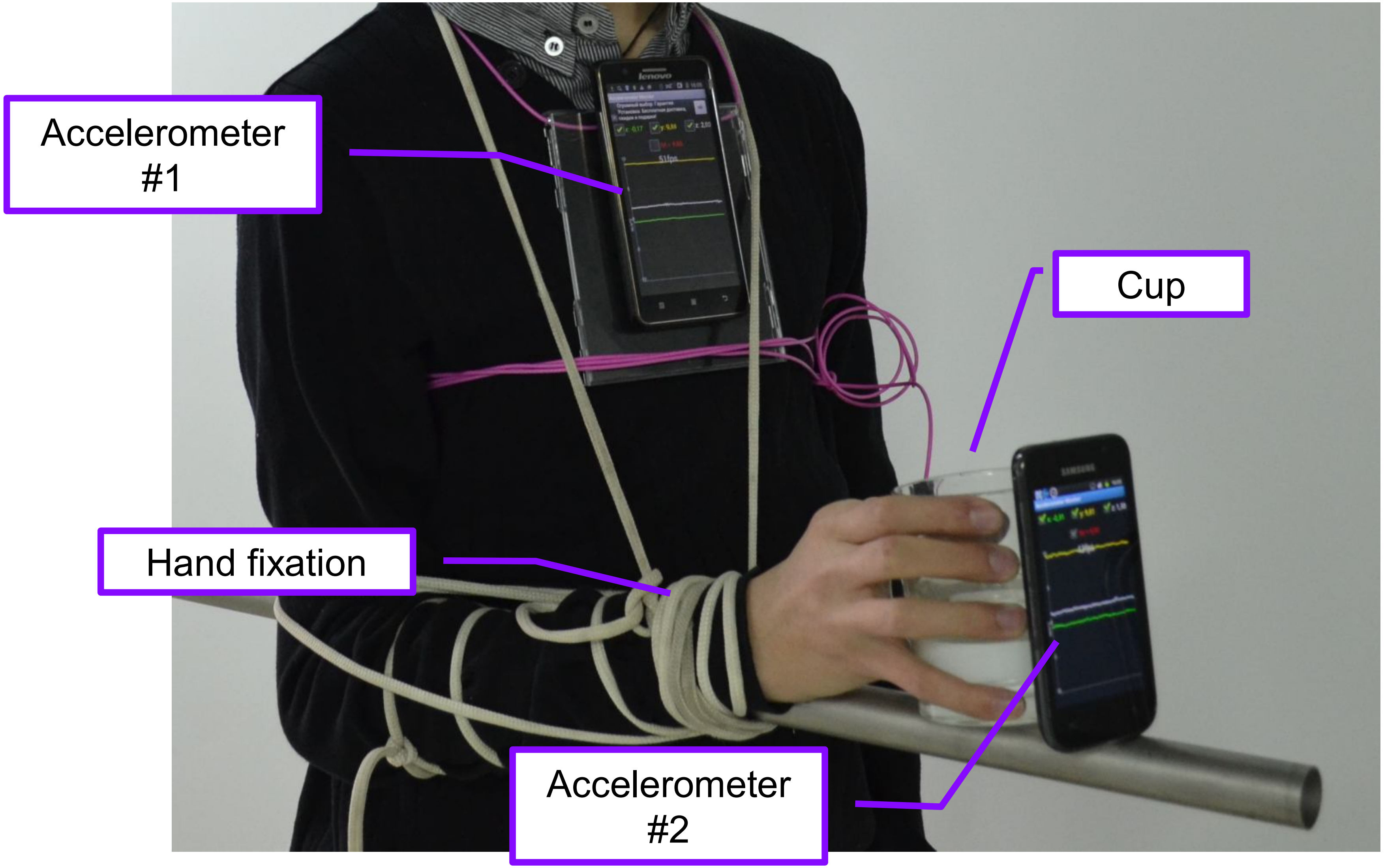
↓

Due to its own natural frequencies human hand damps this excitation

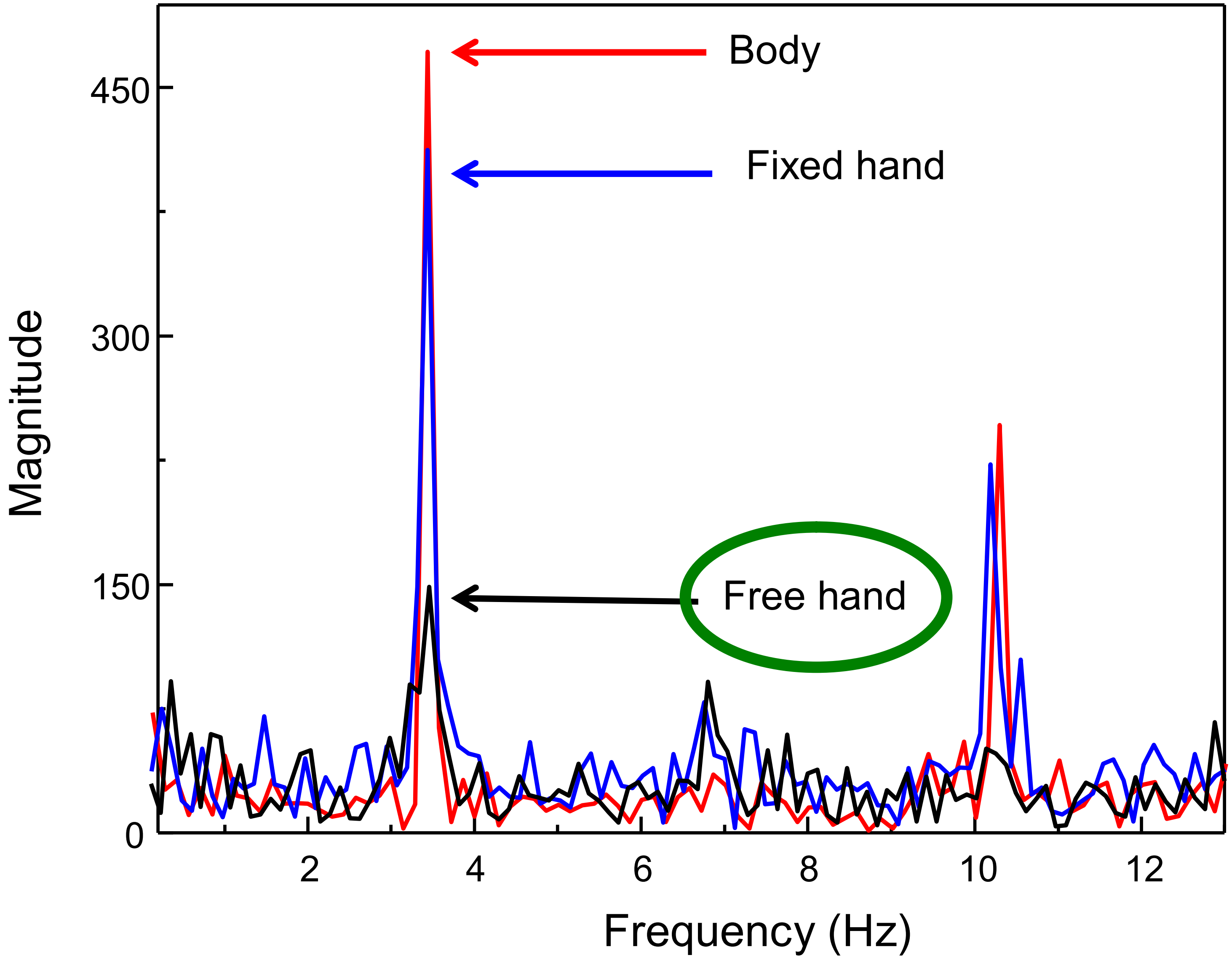
↓

Natural frequencies of liquid oscillations in the cup

Experiment with fixed hand



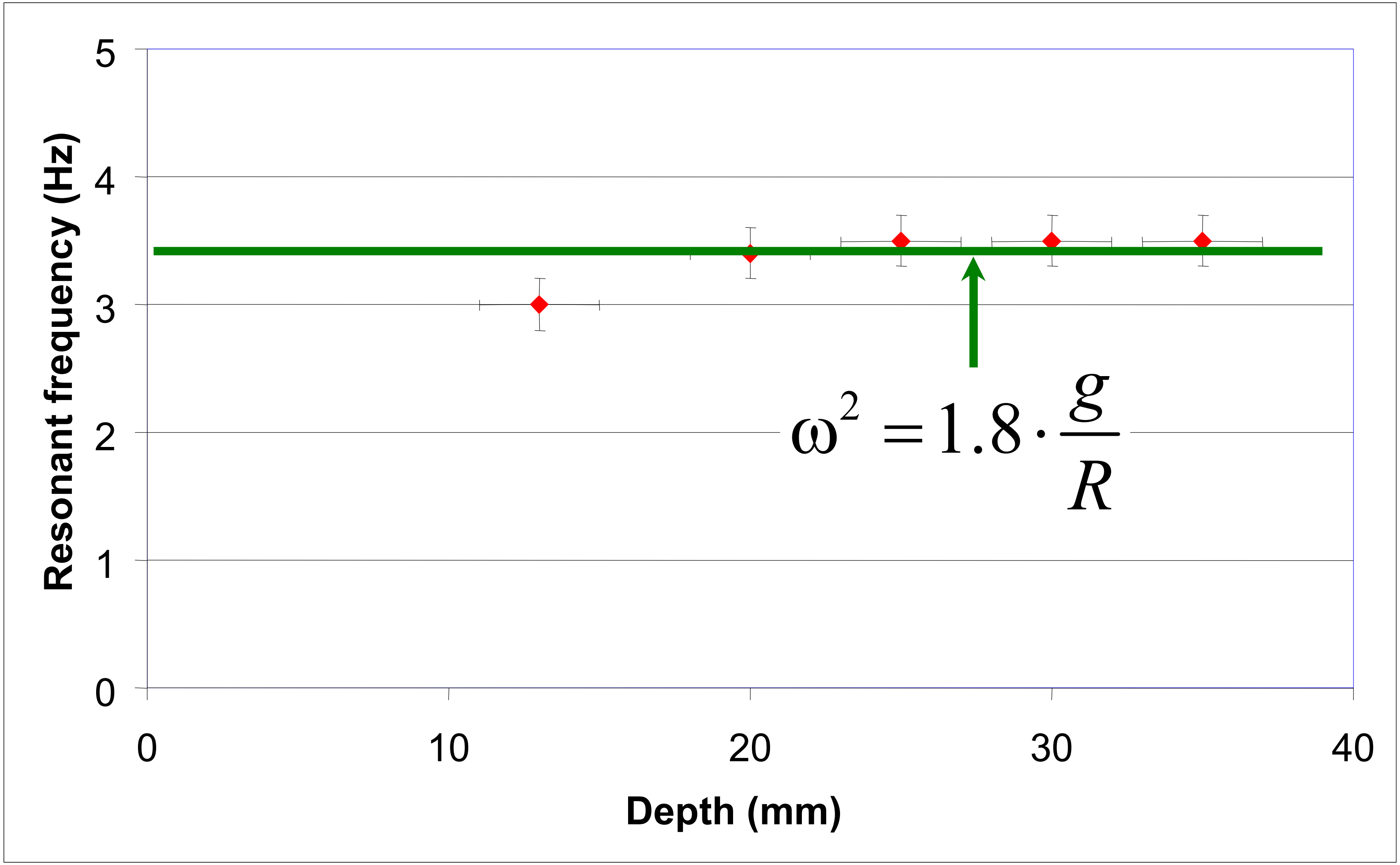
Acceleration spectrum



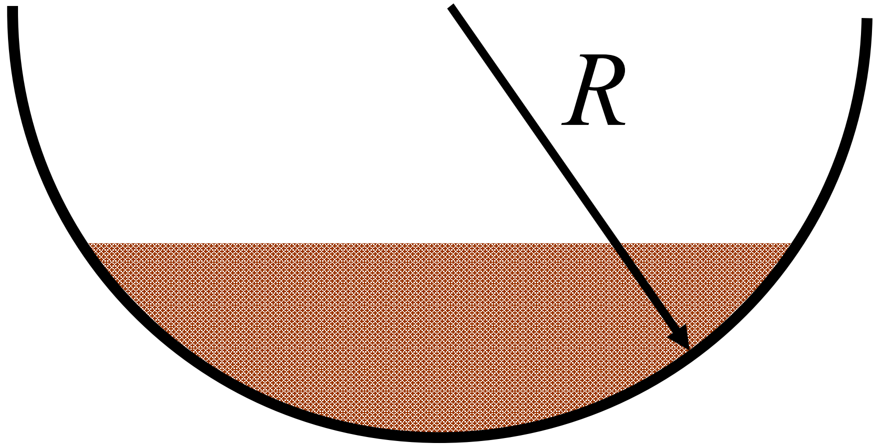
Cup geometry

Cylindrical cup

Resonant frequency vs. depth



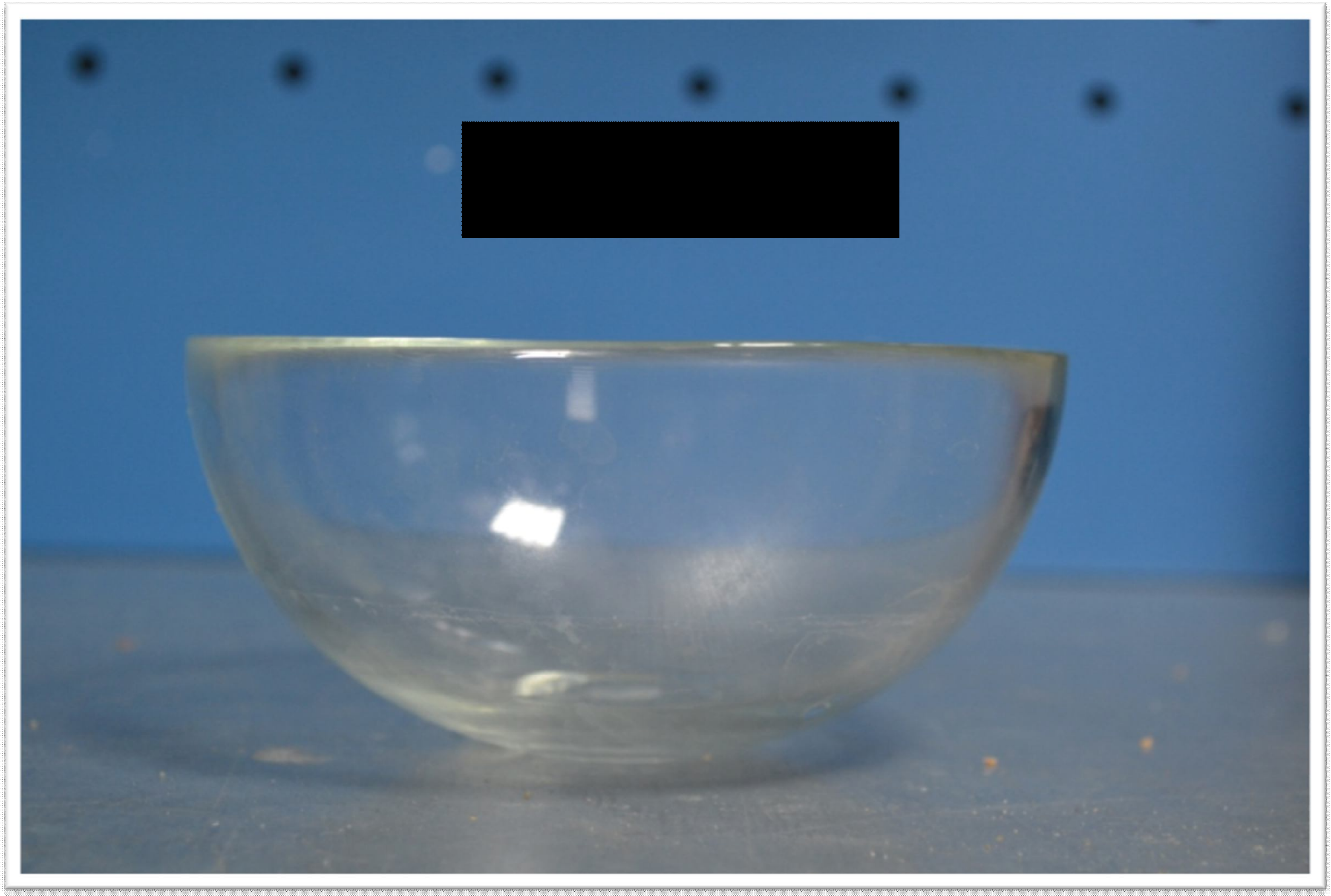
Model



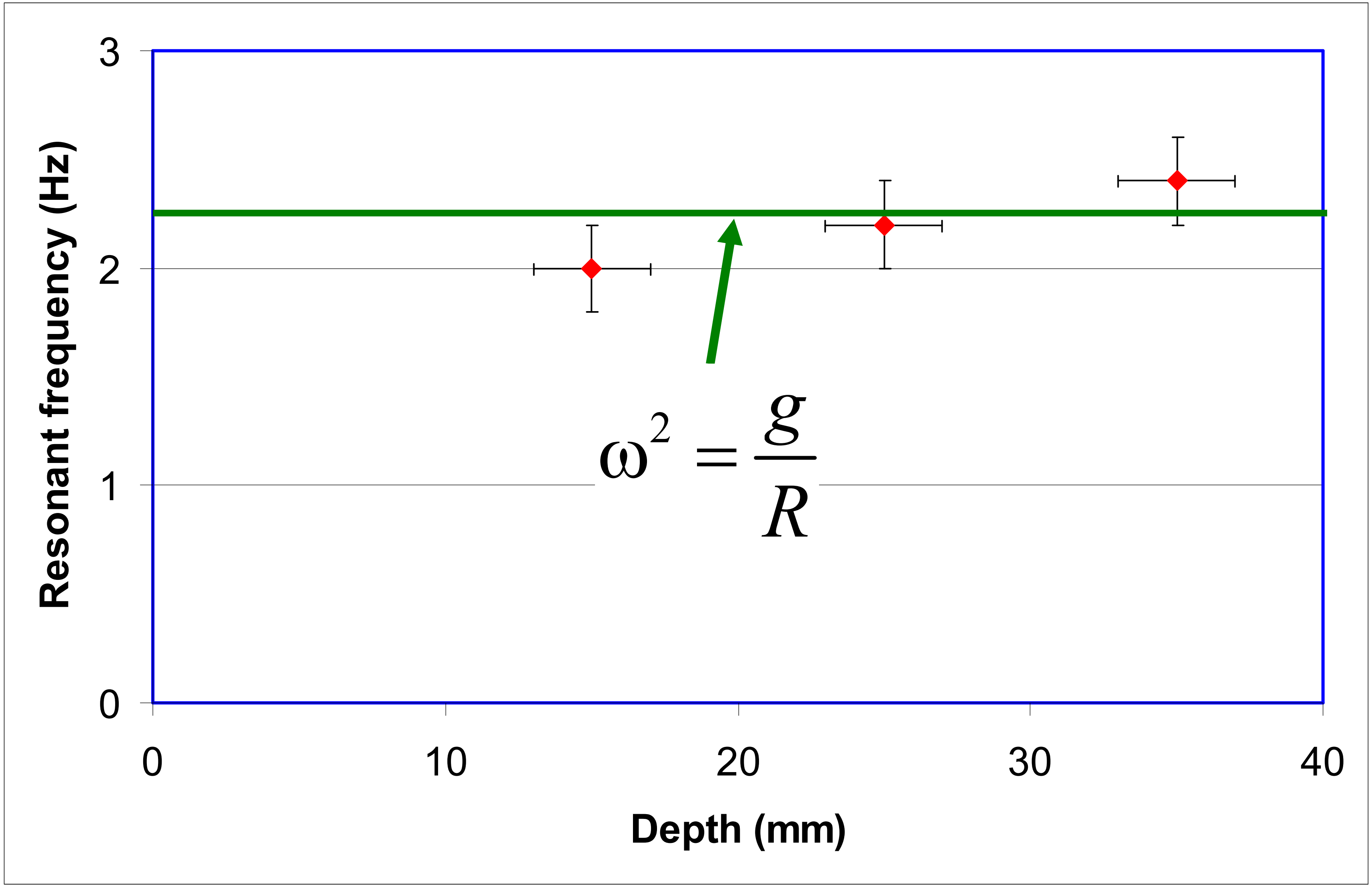
$$\omega^2 \approx \frac{g}{R}$$

Resonant frequency weakly depends on the depth until the depth becomes comparable with the radius

Hemispherical cup

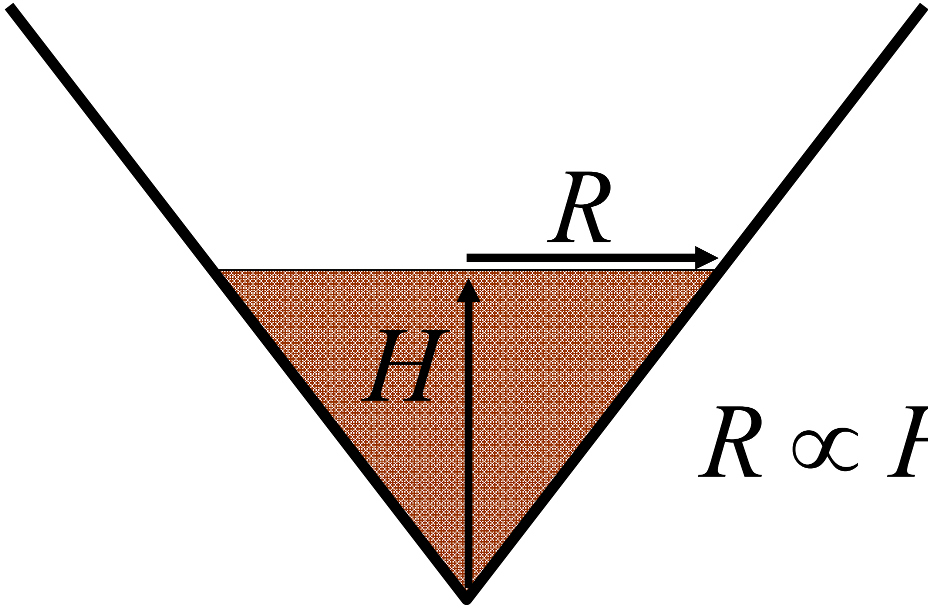


Experiment



3
2
1
0
Resonant frequency (Hz)
0
10
20
30
40
Depth (mm)
$\omega^2 = \frac{g}{R}$

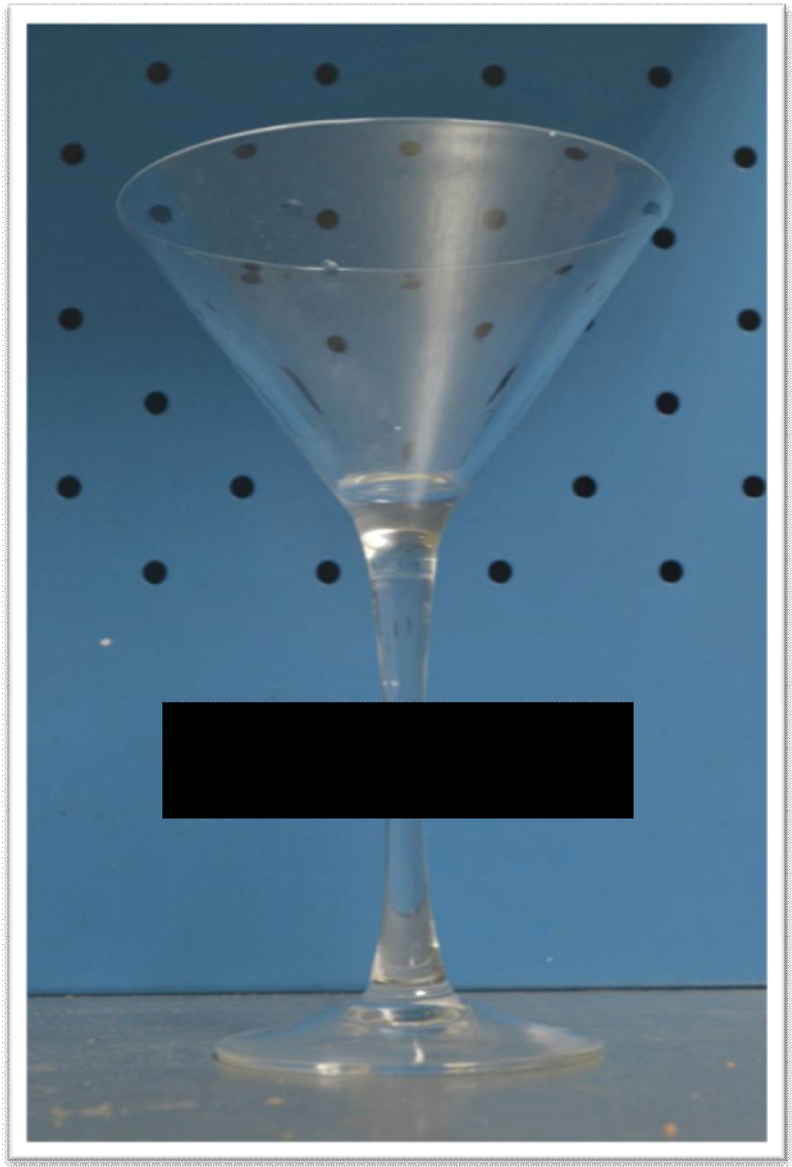
Model



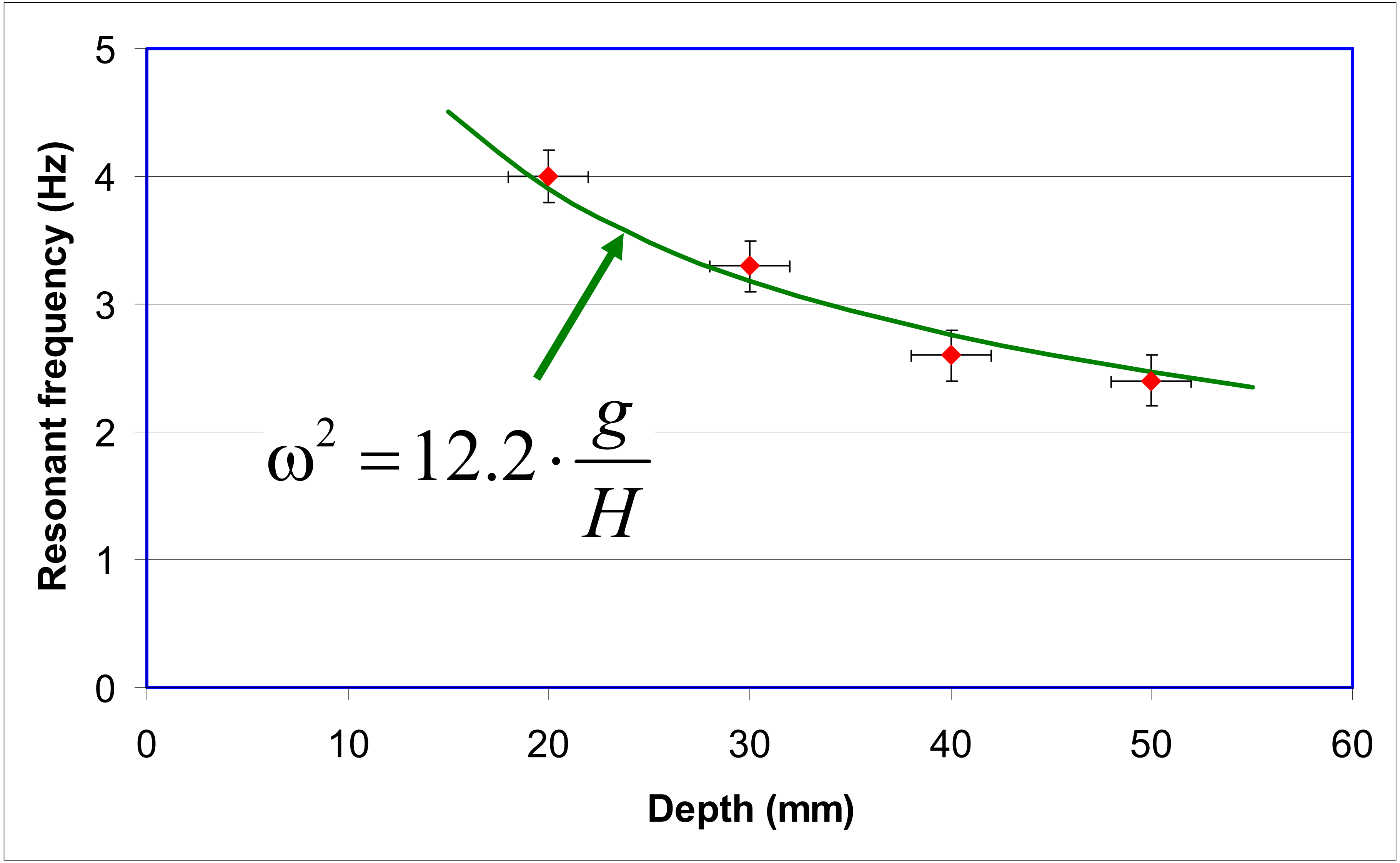
$$R \propto H$$

$$\omega^2 \propto \frac{g}{R} \propto \frac{g}{H}$$

Conical glass

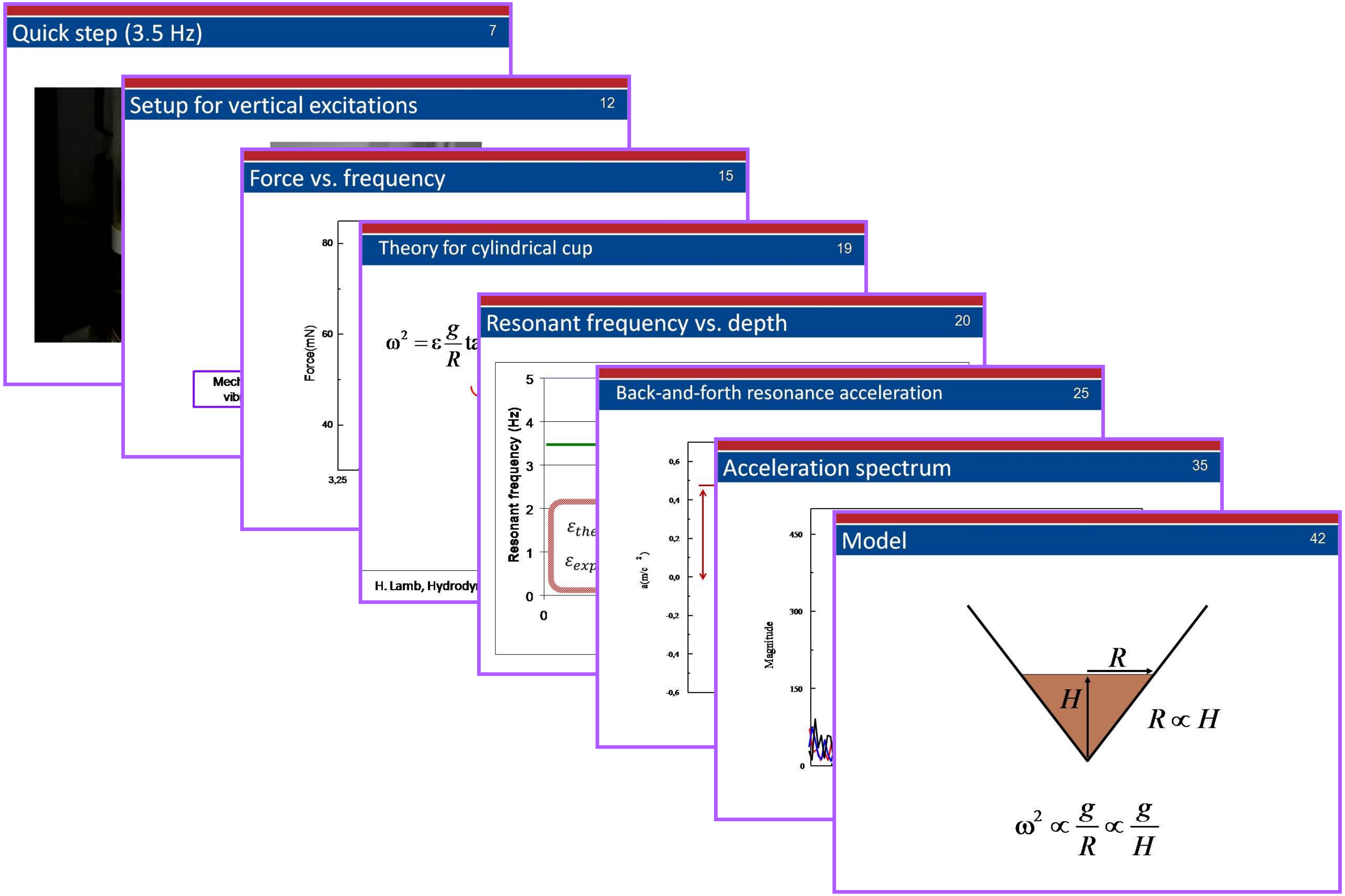


Resonant frequency vs. depth



Summary

Conclusions



References

- Ikeda T., Murakami S. (2005) "Autoparametric resonances in a structure/fluid interaction system carrying a cylindrical liquid tank." *J. Sound Vibr*. **285**, 517–546.
- Mayer H.C., Krechetnikov R. (2012) "Walking with coffee: Why does it spill?" *Phys. Rev. E* **85**, 046117

Thank you for your attention!

- The frequency of your steps should not be equal to the natural frequency of coffee oscillations.
- Relax your hand and it will act as a damper for coffee sloshing.
- Small cups are better than large ones, for their natural frequencies are higher.