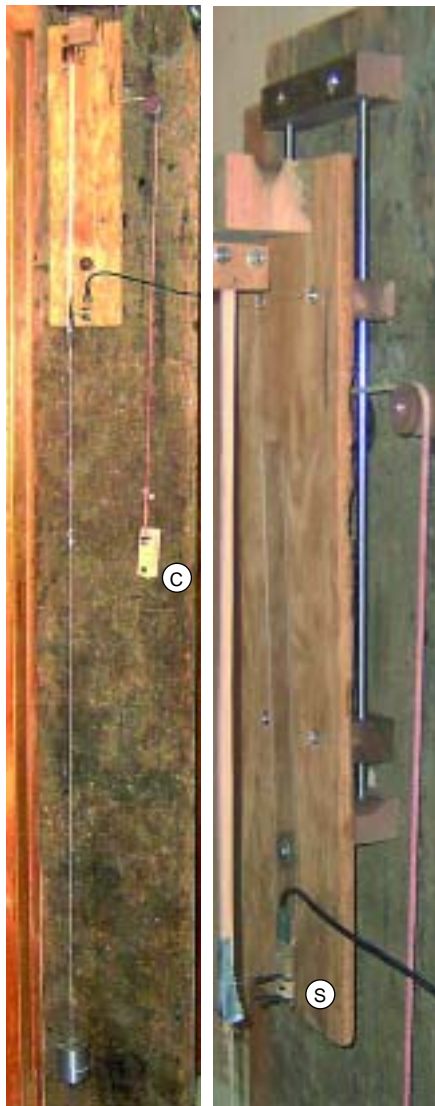


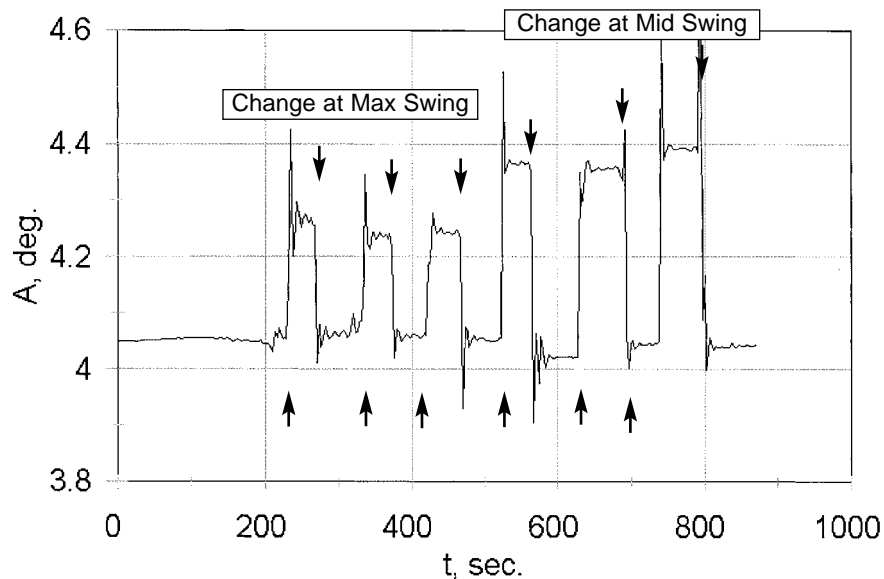
Observations of a Lifted Pendulum

Ned Bigelow takes an experimental approach to vertical disturbance



1. Apparatus for pendulum lifting experiments. The pendulum suspension is mounted on a board (detail right) which is raised and lowered at will by turning a crank. C. Amplitude is sensed at S.

IN HOPE of getting a better understanding of how the vertical motion of a pendulum affects its energy, I made a pendulum apparatus, 1, 2, that could be lifted and lowered quickly while its amplitude of swing was accurately measured. The experimental rig consists of a $\frac{3}{8}$ " plywood carriage sliding on a pair of ground steel rods. On the carriage is a flexure suspension holding a wood rod with a 0.5 mm wire near the lower end passing through a MICROSET optical sensor. A string from the end of the rod continues down to a 1.8 Kg lead bob. A thin stranded



3. Amplitude change with raising and lowering.

steel cable attached to the carriage passes over two pulleys and down to a crank. These parts are all screwed to a heavy plank that is clamped to a door frame.

The crank enables the motion to start and stop more smoothly than would fixed stops. The time to turn the crank a half turn is 0.5 s. The pendulum period is 2.766 s. This lets me pull the carriage up or let it down 3.0 cm by a half turn of the crank while the bob is close to centre of swing. The ratio of lift to pendulum radius (189.9 cm) is 0.0158.

A graph of the amplitude changes, 3, shows what happens with raising and lowering. Six up and down cycles are shown. The first three are for motion as close to end of swing as possible judging by eye. The last three are for motion at the centre of swing.

Amplitude measurements were made using the sensor-offset method of Smith¹. The Q of this pendulum is 4930 so amplitude decay over the span of these measurements would be about 15%. Amplitudes were adjusted to remove this factor. The average relative change in amplitude with lifting near centre of swing is +0.084. The average relative change for lifting near the end of swing is +0.047.

The results are not at all what I expected. From energy calculations based on work to overcome centrifugal force

added to gravity, I would expect relative amplitude change, DA/A , to equal Lift/Radius. Instead it is over 5 times as much. I also would have expected amplitude to fall with lifting at the end of swing but it rises instead. If lifting anywhere in the cycle increases amplitude, a pendulum rising in an elevator at constant velocity would keep increasing in amplitude. This is obviously impossible so some more complex explanation involving accelerations is called for.

Operation has also demonstrated how 'pumping' on a swing can increase amplitude. Since the drop in amplitude when lowered at end of swing is less than the rise when lifted near centre of swing, the net result is a gain. □

Philip Woodward comments:

An earlier lifting experiment by Ned Bigelow appeared to make the theory I set out in *HJ* (April, p.146) untenable. Nevertheless, as it was supported by computer simulations (unpublished) based directly on the equations of motion, I refused to abandon it.

It now turns out that my theory and the equations of motion were both wrong. By e-mail, Ned corrected my phase diagram, and after a search I found the error in my equations of motion. The corrected theory* and fresh

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* The time error for a lift as given in the box on (April) p.147 should be doubled, the 'rogue term' of unity in the expression for amplitude change should be deleted, and what remains should be doubled.

1. Smith, D J, 'Measuring Pendulum Amplitude with the MICROSET'. HSN 1997-5.

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simulations now agree precisely and confirm my original hypothesis that pendulums in phase quadrature should cancel vertical vibrations totally. However, the experimental results described here defy explanation by either of us.

A clue must be sought in Ned's suggestion regarding the acceleration and deceleration of the lift, for these are the only properties of the motion to affect the pendulum. I pin my faith in computer simulations which, when carried out correctly, outstrip in accuracy what actually takes place on the bench in this highly sensitive experiment.

I am deeply indebted to Ned Bigelow for his willingness to participate in an exercise that is turning out to be a kind of thriller. Although none of this is of any practical importance to ordinary clockmakers, it is a branch of scientific horology we ought to master, as I am sure the BHI team engaged on Project 150 will agree. □