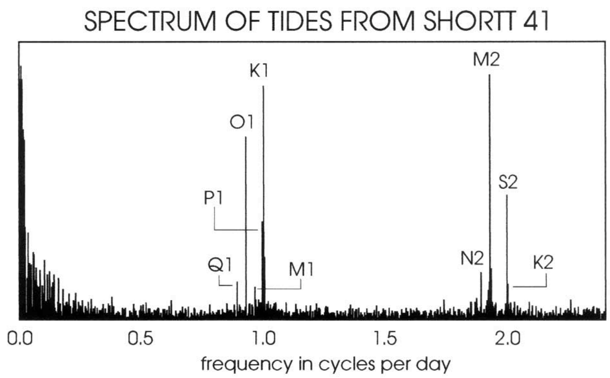
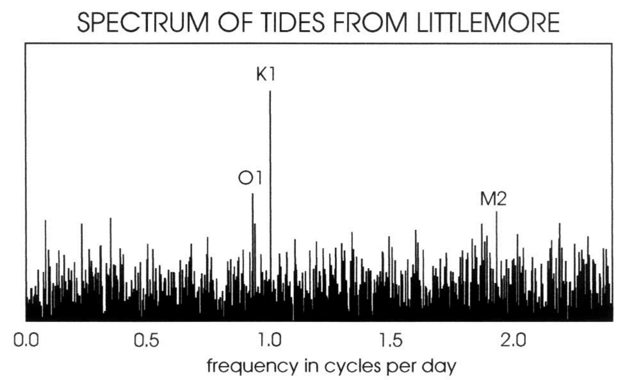
**Some thoughts on the Littlemore clock**
Bryan Mumford

The Littlemore clock is widely regarded as the most accurate pendulum clock ever made. But it was not perfect, and it was evidently a source of disappointment to Professor Hall. According to Philip Woodward, as read by Timothy Treffry at the Time Symposium in Portland this year, Hall said “So it’s curtains then” when he was informed that the analysis of his data did not show the tidal forces as well as Boucheron’s work with Shortt clock number 41.

The two clocks are compared in the graphs below. There appears to be much more noise in the Littlemore data and only three of the tidal events are visible.




I have come to believe that Hall’s disappointment may be partially attributed to a false assumption about one aspect of his design. Specifically, he assumed that his method of measuring the amplitude was accurate. To measure amplitude, Hall gated a one megahertz oscillator with a window that was mounted at the tip of his pendulum. The microsecond counts from this oscillator were added up each beat for one minute. This resulted in a seven digit number in the vicinity of 2,944,000. He then discarded the lower three digits of this number and used the upper four digits as his working value for amplitude. The problem is that Hall was not measuring amplitude directly. He was measuring the velocity of the pendulum as a representation of amplitude.

I’ve recently added a new feature to the MicroSet timer. It measures the amount of time a sensor is blocked at the end of each reading. If the sensor is placed at the center of swing, this is analogous to the measurement Hall used for the amplitude of the Littlemore clock. I have found that this measurement doesn’t always represent amplitude accurately.

Figure 1 shows some representative readings. I used MicroSet to record both the velocity at the center of swing (as Hall did), and the amplitude of the pendulum more directly (by measuring how long the pendulum spent beyond a sensor placed at one side of the swing just short of the maximum amplitude). In the graph below, the top trace is the duration of overswing at the side. The bottom trace is pendulum velocity at the center of swing. The center trace is the rate of the pendulum.

The clock is a Self Winding clock which rewinds every hour. In the five hours shown, five rewinding events are visible. The rate (center trace) does not change, but the velocity and the amplitude measurements indicate an increase in amplitude every time the clock winds. Both measurements change together in the same direction and the same scale. This graph suggests that velocity is an accurate representation of amplitude.

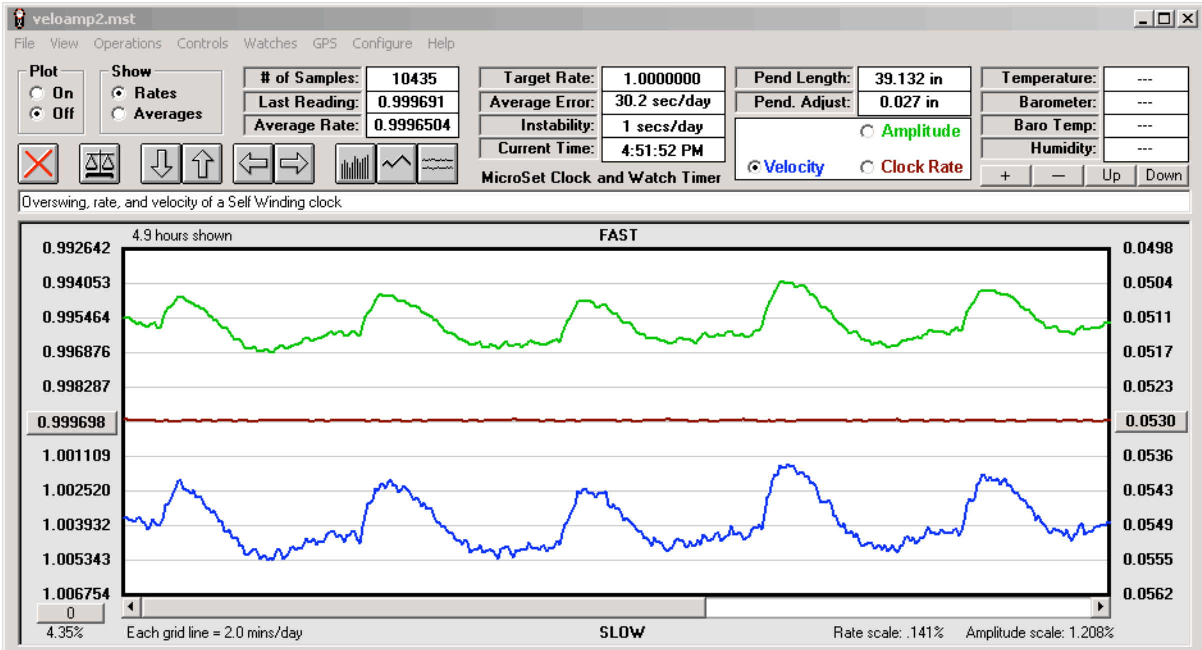



Figure 1 – Self Winding clock

Further experiments show that these two measurements don't always agree.

Hall's disappointment was that he was not able to detect the tides clearly. Consider how these gravitational changes would effect his pendulum. As a tidal force developed, it would reduce the force of gravity. This would alter the rate of the pendulum by way of the relationship T = pi * sqrt(l/g). The rate of the pendulum would decrease with decreased gravity. The change in rate would manifest as lower velocity, but the amplitude mechanism would view this as a decrease in amplitude that had not actually occurred. The clock would then get an impulse more often than was needed, and the amplitude would not be controlled as intended. Ironically, the very events Hall was hoping to measure would be the cause of a disruption in his clock.

Figure 2 shows a recreation of this issue. I used MicroSet to record both the velocity at the center of swing and the amplitude at the side of swing. The top trace is the duration of overswing at the side. The bottom trace is pendulum velocity at the center. The middle trace is the rate of the pendulum.

I attempted to simulate a tidal force, a change in gravity, by applying a repulsive magnetic force to the bottom of the bob. A small neodymium magnet was placed on the tip of the bob and a coil of wire arranged below it. The coil was driven by a variable power supply. As the voltage to the coil was increased, the magnet at the tip of the bob was repelled, counteracting the force of gravity. The power was applied gradually, over several beats, so as not to deliver an impulse at one instant and introduce escapement error.

As the magnetic field was increased, the beat time of the pendulum decreased as you would expect. This is clearly visible on three occasions in the middle trace.

At the same time, the velocity of the pendulum through the center of swing (the bottom trace) decreased as you would expect.

But the actual amplitude of the pendulum, as measured by the amount of overswing at the side (the top trace), increased. In this experiment the velocity figure Hall was using indicated that the amplitude changed in the opposite direction of what actually occurred.

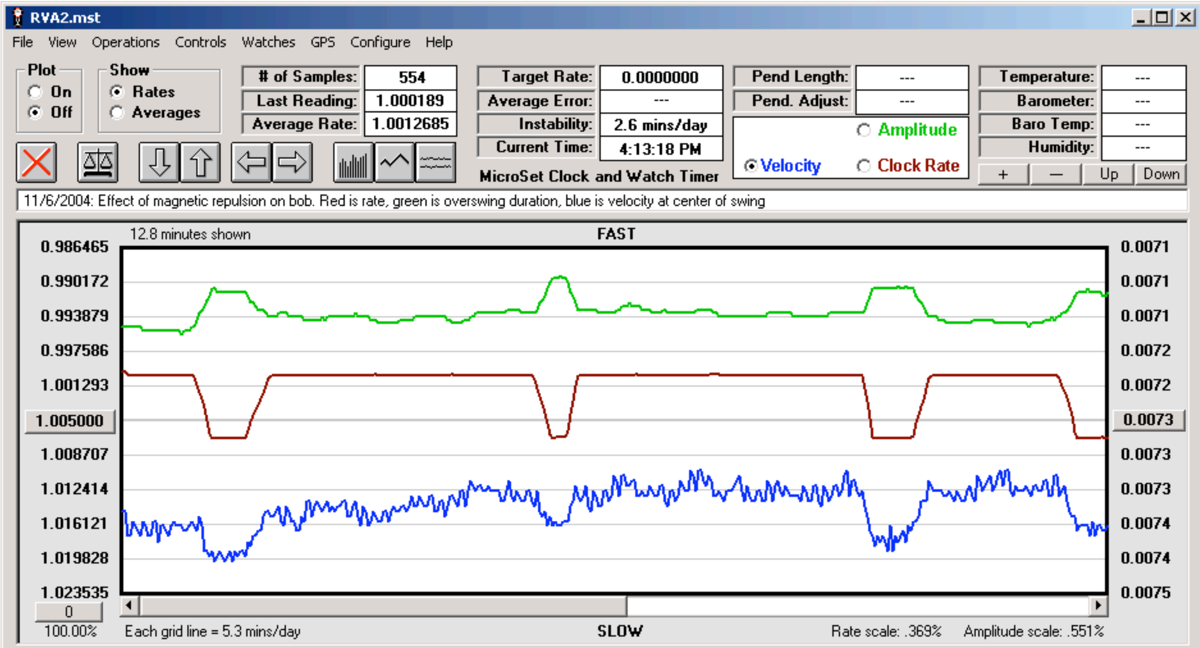



Figure 2 – Amplitude and velocity disagree

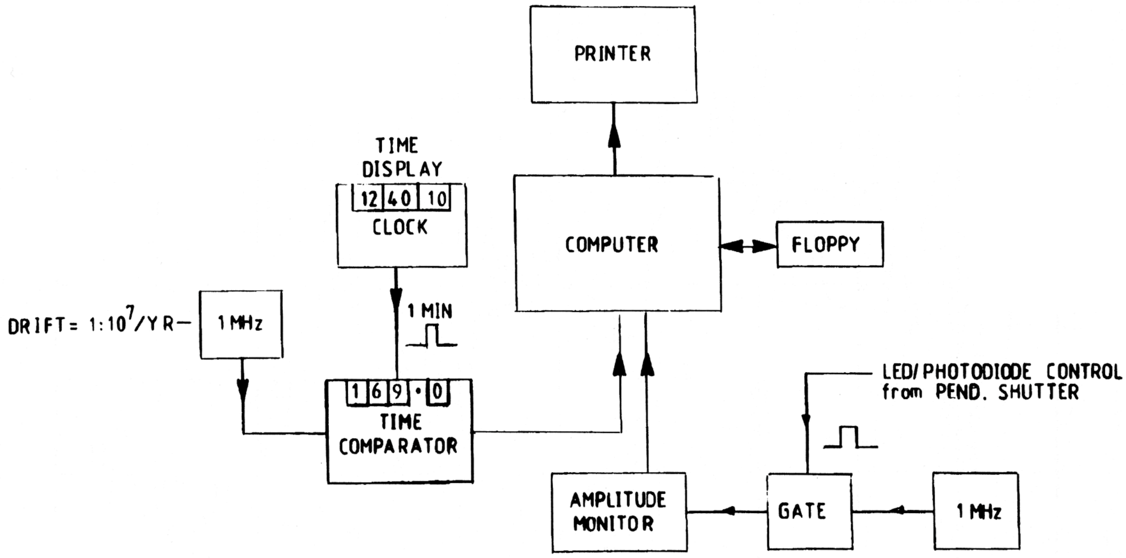
It's my belief that Hall's clock would have been improved by measuring the amplitude more directly, at the side of swing, rather than using an analog of amplitude that was removed from a more direct measurement.

One might also argue that constant control of the amplitude may have been the cause of the additional noise in Hall's data, and that the clock may have run better without any amplitude control at all.

Tom Van Baak has proposed another flaw in Hall's method of amplitude control -- it relies on a quartz timebase to measure the velocity. If there were imperfections in this timebase, they would be transmitted to the pendulum. For example, if the counter were to run fast, the amplitude would appear as if it were smaller, and an impulse might be delivered too frequently.

We have tried to find a description of Hall's timebase for the amplitude control, but the information available to us is incomplete. In Figure 9, from Hall's presentation in HSN 1994-4 (see below), a one megahertz timebase in the clock readout system is indicated as having a drift of less than 1:10^7 per year. But it's not clear whether the same timebase was used to count the amplitude. The inventory of materials in Columbia, PA (where the clock now sits) doesn't answer this question.

If the high precision timebase was used in Hall's amplitude control, it would have introduced little additional error. But if he used a separate, less precise timebase, subtle imperfections (such as temperature changes) would result in additional distortions to the amplitude control. In any case, it's asking for trouble to place a quartz timebase within the feedback loop of the pendulum because it has the potential of steering the pendulum.




CLOCK READOUT SYSTEM

Fig. 9