

Regulated Electromagnetic Pendulum Drive



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Summary

carveshop.com designs and builds unique wood gear electromagnetic pendulum drive clocks that maintain perfect accuracy. While others have designed and built electromagnetic pendulum drive clocks, **carveshop.com** employs unique microcontroller electronics and software to maintain timekeeping accuracy.



*digital and traditional
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Electromagnetic Pendulum Drive Circuit

Pendulum speed adjustment

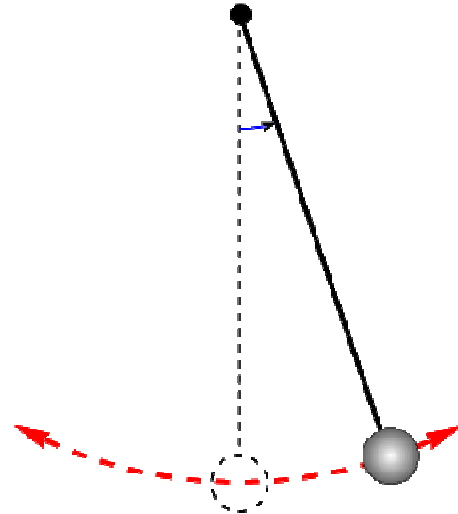
The **carveshop.com** electromagnetic pendulum drive employs a single coil to detect a swinging pendulum with an embedded rare earth magnet and then applies a pulse of current to the coil to repel the pendulum and keep it moving.

The period of swing of a gravity pendulum depends upon its length, the local force of gravity, and to a small degree the maximum angle that the pendulum swings away from the vertical. Since gravity is constant, we can ignore that factor. And since for most pendulum clocks the swing angle is small and does not vary significantly, it can often be ignored. So the period is set solely by the length of the pendulum. Accurate timekeeping is achieved by fine adjustments to the effective length of the pendulum, by adjusting the pendulum bob or weight up and down.

But all that assumes a perfect pendulum, with no friction and no expansion or contraction of the pendulum due to temperature and humidity. In fact, these factors change, causing changes to the period and timekeeping accuracy, particularly in wood gear clocks.

What can be done?

carveshop.com clock designs uses that last factor - the maximum swing angle of the pendulum - to maintain precise time.



The nominal swing angle of **carveshop.com** clocks is about 20 degrees. The weight on the pendulum is initially adjusted so that the period - the time that it takes for a complete back and forth motion - is exactly 1 second.

What would happen if the swing were increased to 25 degrees? Because of the greater distance traveled, it would take a little longer - not quite 0.5% longer - for a complete cycle. On the other hand, if we reduced the swing to only 15 degrees, the period would be shortened by somewhat less than 0.5%. So, if we allowed the swing angle to vary between about 15 and 25 degrees, we could adjust the speed of the clock almost 1%, actually up to about 10 minutes per day.

This is exactly what **carveshop.com** clocks do.

A microcontroller precisely measures the period of each and every swing of the pendulum. Then, using a modified PID (proportional - integral - differential) control algorithm, it adjusts the swing angle of the pendulum to speed up or slow down the pendulum and therefore the clock.



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Timekeeping accuracy is kept to within the tolerance of the watch crystal used by the microcontroller, which is within a few parts per million.

Special ratchet mechanism

To make this work, the ratchet mechanism which converts the pendulum's back-and-forth movement to rotary movement must take this variance in swing angle into account.

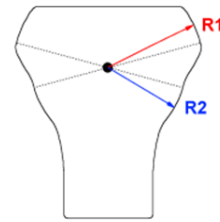
The back-and-forth movement **carveshop.com** clock pendulums must be converted to rotary movement to turn the gears and the hands. This is done with a ratchet and pawl mechanism.



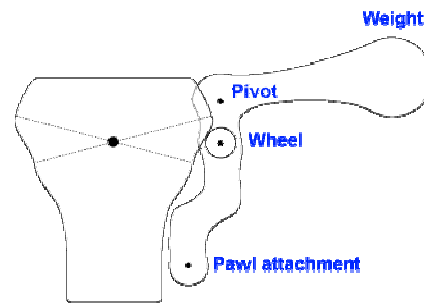
For this mechanism to function properly, the back-and-forth movement of the driving pawl must be within a certain range of travel. Too little, and the pawl won't pull the ratchet wheel far enough for it to jump to the next tooth on the wheel. Too much, and the pawl will jump two or more teeth.

Let's look at how **carveshop.com** clocks deal with this problem.

Pendulum pivot geometry



carveshop.com clock pendulum pivots employ a special design. At about 15 degrees and more of travel in one direction, the pivot's outer surface is a constant larger radius (R1). At about 15 degrees of travel and more in the opposite direction, the outer radius is smaller (R2). In between, the radius constantly varies in a smooth curve.

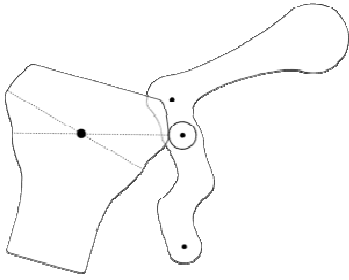


A lever is located next to the pivot. A wheel, actually a bearing, is in contact with the pivot's outer surface. The pawl is attached to the lever such that the movement of the lever at the pawl is amplified. A weight on the end of the lever keeps the wheel in contact with the pivot.

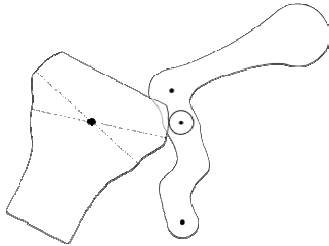


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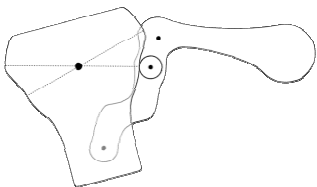
Electronics and software



When the pendulum swings left, the pivot pushes the lever right, and likewise the pawl (not shown) also moves to the right.

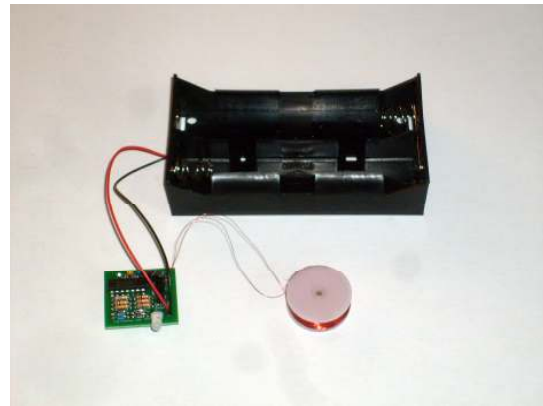


If the pendulum swings even more to the left, the wheel rides on the constant radius portion of the pivot, so the lever, and the pawl, move no farther.



Movement to the right is similar.

The result is that for any swing of the pendulum between 15 and 25 degrees, the range of movement of the lever, and therefore the driving pawl, is constant.



The pendulum drive electronics consists of a battery box, circuit board with microcontroller, and coil.

The coil is wound with 32 gauge wire on a 1.25" diameter bobbin with about 3/8" of space and a 1/4" non-ferrous core. Resistance is about 45 ohms.

When a magnet of the correct polarity passes over the coil, it induces a negative, then a positive current in the coil. A simple filter limits positive and negative voltage into the microcontroller's comparator input. The trigger voltage is set by R2 and R3 at about .3 volts.

After initialization, the microcontroller is programmed to remain in a low-power state until awakened by the pulse from the coil. Once awakened, the microcontroller turns on the coil driver to apply drive current to the coil. The timing of the application of this pulse is adjusted for maximum effectiveness and efficiency - it is beneficial to wait a bit after the trigger before applying the driving pulse. The applied pulse may vary anywhere from 15 to 35 mS as needed. The microcontroller, using a watch crystal timer reference, measures the duration of each and every swing of the



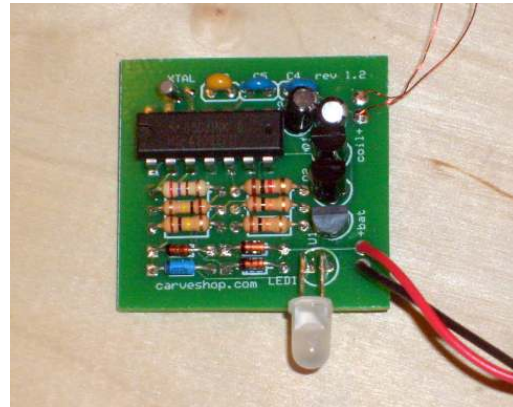
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pendulum. It employs a modified PID (proportional - integral - differential) control algorithm to determine the pulse duration to maintain accurate time.

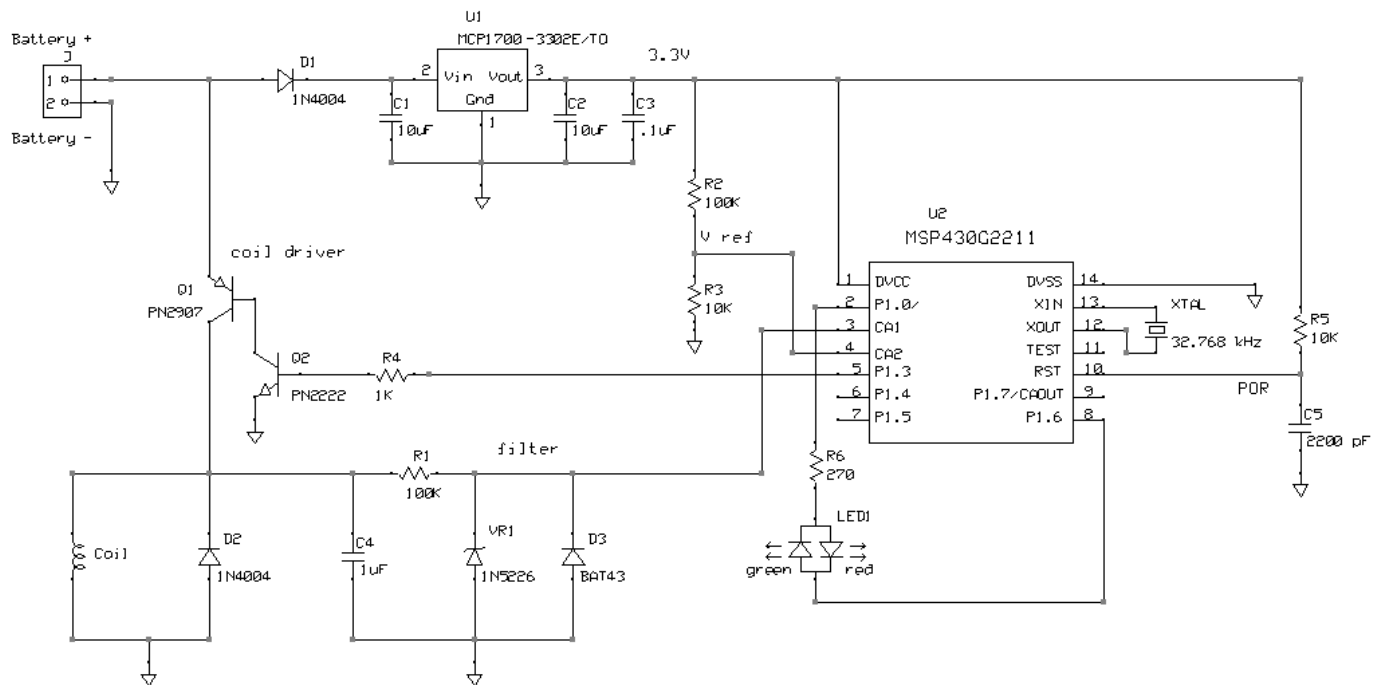
Because the microcontroller can only adjust pendulum speed by about 1%, the pendulum must be manually adjusted to within that tolerance by raising or lowering a pendulum bob. To make that initial adjustment easier, the circuit uses a bicolor LED. If the pendulum is swinging to fast, the LED blinks green. If swinging to slow, it blinks red. When the pendulum is swinging within the tolerance range, the LED will not light. Using the LED, the pendulum bob can be properly adjusted within a couple of minutes, as opposed to hours of days without this feature.

Another feature of the circuit is an aid to proper magnet polarity. When batteries are first inserted, the microcontroller blinks the LED

red for one second, then green, to confirm operation. It then applies a pulse of current to the coil. If the pendulum is repelled, magnet and coil polarities are correct. If it is attracted (it will generally wiggle in place), magnet or coil polarity needs to be reversed.



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