Lecture 21

Mon: Final draft of paper one.

Read: 110 → 117 Mondsch.
Barnett Ch 10

Pendulums as regulators in clocks

A pendulum possesses a fundamental property that makes it suitable for regulating a clock.

> Any pendulum oscillates naturally and has an inherent period of oscillation.

Pendulums have additional properties useful for timekeeping. The period of a pendulum is

1) independent of the total mass of the pendulum
2) approximately independent of the amplitude of the swing
3) dependent on the length of the pendulum.

Galileo conducted the first scientific analysis of the pendulum and uncovered the facts above as well as slightly greater detail about the way in which the period depended on the length.

Matthews pg 91

Galileo did suggest a method for incorporating a pendulum into a clock. It would replace the verge and foliot as a regulator. This plan appeared at some stage in 1639-1641, However, he never built the clock before his death in 1642.

Demo: Science Museum Images

Huygens Pendulum Clock

The first practical pendulum clock was designed and constructed by Christian Huygens (1629-1695). The technique was to replace the foliot by a rigid pendulum.

Demo APS Huygens' Site

Demo: Favre YouTube Video

Landes pg 128
Mondschein pg 87

Huygens' clocks were far more accurate than the earlier verge and foliot clocks. Recall that verge and foliot clocks would lose perhaps 15min per day. Huygens' clocks evidently lost about 15s per day.

This was the result of fundamental changes in operation rather than a succession of small engineering improvements. To compare and contrast:

Verge + foliot	Pendulum	
foliot has no natural frequency or period	pendulum has natural frequency or period	Q. Why important?
foliot oscillates only because it is driven by crown wheel. Connection + forces interrupt motion	pendulum is only loosely connected to clock train	Q Why important?
period depends on driving mechanism	period does not depend on driving mechanism.	

1 Clock accuracy

a) The best verge and foliot clock would lose 15min per day (24hr). How many days would it take such a verge and foliot clock to be off by 12hr?

How many 15min periods in 12hr? There are 4 per hour.

So we need 48 periods of 15min.

$\Rightarrow$ 48 days

b) Huygens' pendulum clocks would lose 15s per day (24hr). How many days would it take such a pendulum clock to be off by 12hr?

How many 15s periods in 12hr?

$$12\text{hr} = 12\text{hr} \times \frac{60\text{min}}{\text{hr}} \times \frac{60\text{s}}{\text{hr}} = 43200\text{s}$$

How many 15s periods in 43200s?

$$\frac{43200\text{s}}{15\text{s}} = 2880$$

It would take 2880 days

Landes pg 128 (no ref?) This is a 60-fold improvement in accuracy. The obvious improvement in accuracy is such that apparently most verge + foliot mechanisms were converted to pendulum mechanisms in the late 1600s

Demo: Show various images of pendulum clocks from British Museum

Anchor Escapement

The early escapements that used a verge (with pallets) that was connected to a perdulum were such that the perdulum had to swing through wide angles. This affected its period.

Landes 132

The remedy for this was the anchor escapement which was devised in the 1670's. Robert Hooke is usually credited with this invention although that is disputed

Matthews 160-161

Demo: Tower Clock: Anchor Escapement.

Demo: Anchor escapement clock

Balance Spring

There are further limitations with perdulum clocks.

Q. What are possible limitations?

- clock would need to be maintened in a vertical position.
- clock would need to be somewhat large.
- clock would need a stable surface.

A way around this was to replaced the perdulum with an oscillating spring/mass arrangement.

Demo: Oscillating spring/mass

The exact arrangement involved a fine coiled spring attached to a rotating wheel. This was called a balance spring.

Demo: You Tube Balance Spring clock

The invention of the balance wheel was important because:

Q. Why important?

* such clocks did not have to be oriented vertically
* such clocks could be miniaturized.
* they are relatively stable when disturbed.

Landes 135-137 This seems to have appeared around 1675 either via Huygens or Hooke