Clock Theory and the Blacksmith

1. This is a 16th century engraving of a clockmaker's workshop in Flanders, about midway through the blacksmiths influence on clockmaking. The story begins before the 13th century in Europe. To begin, in England the Worshipfull company of Blacksmiths formed in1200.
2. As we know blacksmiths were extremely talented and had to be flexible, making what ever the community around them needed. They were of coarse ironmongers (makers and sellers of nails and hardware), gunfounder, farrier, locksmith, the maker and repairer of tools and mechanical devises. This image is the blacksmiths wife making nails.
3. The gunfounder or "master of bombards" would make this gun or hand cannon used from about 1350 until 1470. So forging a partial cylindar that would hold up to gunpowder.
4. A nicely forged hand canon about 40" long, 35 pounds with 1" diameter barrel its wood handel to the left
5. This lock (Renaisance 1300 to 1600) shows elements in craftsmanship that show up again and again in early forged iron clocks. This is a double throw deadbolt lock with a single tumbler.
6. Complicated devises to figure out time like this astrolabe (1295) were well understood. They knew about telling time with the stars as well as sundials sand glasses and water clocks. But which "time" do you use? A sundial tracks how long it takes for the sun to go from horizon to horizon, (apparent solar time) and is unequal depending on the season. Also 9am here is not 9am miles away.
7. The astrolabe will track star time (sidereal time).How long it takes for the earth to make one full rotation. Time stays the same no mater the season. The north star to the big dipper becomes a clock.
8. However to match your sundial you need to do a calculation. Dipper time minus 2 times the number of months since march 6.
9. Geared devises were not unknown. This Astrolabe from about 1221 notes the relative position of the sun and moon. Note the triangle shaped teeth in the gearing.
10. Water clocks could track even hours but by adding a complication could try to indicate unequal hours. But the technical challenge was how to regulate the speed of the mechanism. They relied on friction which wasn't reliable.
11. A clockwork spit jack is another great example of a friction only release of power
12. The only way to change how fast or slow the mechanism works is to change the weight.
13. What was needed in the development of the clock was an escapement. A predictable and regular release of the power than runs the mechanism. That power was a weight. This is a replica of the earliest written description of a clock. Richard of Wallingford built this for St. Alban's Abbey 1327-1336. Note there are no hands to point the hours and minutes, but the mechanism will strike an hour count and has various complications. There is a mechanical astrolabe, a moon indication, it will indicate eclipses and various planetary motions. The important feature technically is this escapement. Note the two rings with protruding pegs. And this arm on top.

14. This is called a strobe escapement, the arms are called a foliot. Note the adjustable weights, they can regulate how fast or slow the arms ossilate back and forth. The pegs are staggered either side and this "semiculus" releases each peg one by one.
15. A strobe escapement VIDEO. This is a different replica where they've added hour indication. but you get a sense of the clocks size and joinery used.
16. This is Richard of Wallinford working on his clock. Note his use of dividers. I'll go into the making of gears in a bit. But as a smith how would you solve the problem of indexing evenly spaced teeth on a gear. Note his bad complexion, he contracted leprosy and his clock and escapement went into obscurity.
17. What developed at the same time and became the standard for clocks for several 300 plus years, was the verge and foliot. It's distinctive features, a crown escape wheel and 2 flags on the verge. The crown wheel with verge and foliot lasted until about 1670
18. VIDEO this is the oldest working clock in England from 1386
19. It is the Salisbury cathedral clock. Again no hands to showing the time only a way to strike the hours. Two gears in the time train, two in the strike train. This large ring with inside teeth counts the hour strike. Each hour a pin lifts a lever to release the strike. Strike controlled by a fan. These first clocks were housed mostly inside churches or public towers and not seen. So not a lot of decorative forging. Mortis and tenon joinery with wedges.
20. Later there became a small demand (in churches, monasteries mostly, possibly in public offices) for smaller clocks with alarms rather than hour striking. Depending on where they were people told time in different ways. There was a "small clock", meaning the day was from 1-12 staring at midnight. Others used a "whole clock" 1-24 staring at midnight. In Italy time was 1-24 starting at sundown, Bohemia 1-24 starting at sunrise. So each community needed to signal their different daily events. An alarm would sound telling the bell ringer to alert the town. The crown wheel, foliot, weights could be hung from these sections. A peg positioned on the dial tripped a second crown wheel verge, the foliot is up inside the bell and rings until the weight hits the floor. *NOTE decorative filing, simple mortise and tennon joinery then pinned*
21. This clock has a simple undecorated framework but there are bumps around the dial means you could tell time at night. We only have one hour hand. A minute hand wont show up till later. These early clocks were accurate, by our standards, to only about 15 minutes per day. They often had to be wound twice a day or placed high up on a wall.
22. Now there was another system called "the great clock" which separated the day into 16 hours and the night into 8 hours. This clock has a 24 hour dial indicating daylight and night hours. Outer dial shows equal hours, inner dial adjusts for unequal hours The foliot could be adjusted to differing length of daylight and night between summer and winter. Again each town or religious community established their own timekeeping with rules like "No smith shall rise to set about their work before the call to parish mass and work no longer than curfew bells".
23. These early clocks had simple 2 or 3 gear trains. Simple uncomplicated frame, wedges to hold the dial and frame, decorative work by the bell. This clock has a 12 hour dial so a possible gear count could be Crown wheel 20 teeth and its pinion (smaller gear) 8 leafs, meshes with 48 tooth wheel, its pinion 8 meshes with this 1st wheel 72 teeth. Hidden behind the dial is typically a 4 tooth pinion meshing with the hand wheel of 48 teeth. It's the combination of tooth counts that allows the hour hand to rotate once in 12 hours with how fast the foliot oscillates back and forth.
24. The chamber clock with hour striking rather than alarm begins to show up. (german) Very similar in shape to the large public clock but meant to be a personal clock. The dial is 8.5" wide with bumps for telling time at night. This 4 posted frame structure becomes the

standard. But also look at how the wheels are made. Tenons on the end of the spokes embrace the wheel rim.

25. We talked about gear counts for time keeping. That same principle is used to add things like moon dials. If you use a 59 tooth moon disk (with 2 moons painted opposite each other on the disk) and have your hour hand push that disk twice per day, the disk will show the 29.5 day cycle of the moon.
26. Here is a Swiss clock with pierced dial. I love these little riveted decorations on the bell strap. But look at the square corner posts and how the bottom strap is attached at an angle to the post. The same with the strike lift lever is pivoted at an angle to the uprights. The bell strap is fitted by tension and wedges.
27. This is a Swedish clock with very clean lines and covers over the mechanism. This closing away of the mechanism does help keep some dirt away but will become the style of future clocks where the case is more important than the clock.
28. This clock from the Netherlands is incomplete. It has this solid top and bottom plate. The plates that hold the wheel pivots would be tenoned on the bottom then pined on top. Also look at how the wheels are placed.......
29. It's the same with this German clock. I don't exactly know how the train is arranged to make it sideways to the hour hand.
30. (Swiss)This is more the usual arrangement, time train to the front behind the dial, strike train behind.
31. Another German clock with moon. 20" tall. Have you noticed some decorative features that keep showing up.
32. This clock from 1583, has added even more complications, moon dial, quarter hour indication, 6 bell carillon on each hour played by the blacksmith with his hammers? He also bobs his head while the hour strikes.
33. This German clock has added more gearing to have a mechanical astrolabe, hour strike, quarter strike, and moon phase.
34. This is one of my favorite clocks. It's also about 20" tall. Hour strike and alarm, moon disk. I love studying each of the decorative elements.
35. Detail of top of clock. The clock has become a decorative object in it's own right.
36. This is a late 16th century clock. Again a carillon but with a brass tune barrel. The pegs for the tune can be rearranged to play different songs. The brass is a sign of big change for the blacksmith clockmaker.

BREAK? So lets take a 10 minute break Then I'll trace how innovations changed clocks and how we tell time.

37. The building of clocks up to the end of the 16th century were all by hand including making wheels and pinions. Remember Richard of Wallingford and his caliper. Using an index plate calipers could scribe tooth spaces
38. Clocks can still be found with these scribe marks in place
39. Or trammel on an index plate
40. Would make punch marks on the wheel teeth then the spaces where sawed by hand and filed to round the top of the tooth. Up to this point a tooth profile was made by rule of thumb....
41. Remember it's the ratios between the number of teeth in the wheels to the number of teeth their mating pinions, from the escape wheel to the hour hand, that will make that hand move around the dial once in 12 hours. (Later when clocks became more accurate

and a minute hand was added the principle stayed the same. More wheels and pinions were added.) A typical tooth count………….

42. The size of the wheel in relation to its mating pinion must be the same ratio. More sophisticated wheel theory came later. *THEN big technology advances would begin to change clocks drastically.*
43. One of those advances was the development of the main spring as a power source rather than weights allows the table clock to evolved. Springs had one big issue, they produced more power when first wound then less power at the end of their wind. Therefore the fusee was developed evening out the torque. This spring is completely wound down. At full wind the cable attached to the spring barrel will get wraped around all the steps on the fusee. Also brass is showing up more, here the case but also the fusee and spring barrels. Hour hand, alarm disk, quarter hour indication
44. Smaller and smaller table clocks became the challenge, still just an hour hand, bumps to read the time at night, but the dial is about 2”and the clock is just over 1.5” tall (1540)
45. The spring barrel and fusee, crown wheel, and foliot
46. Another development to even out the power of springs was called a stackfreed. This eccentric cam on the spring barrel, spring adds more friction when fully wound…
47. There was also a device called a Geneva stop. The gear on the winding arbor has a different tooth count than this idler so the cams bump together to stop the unwind
48. The cams then turn and bypass until full wind. The theory is to use the middle part of the mainspring
49. In about 1600 Galeleo noticed that an object of a certain length swings at a fixed rate. Galeleo was a physician wanting to measure a patients pulse. A pendulum could regulate a clock much more accurately.
50. It was applied to a crown wheel and verge making a minute hand possible. We’ve come up to 1631. Brass became the material of choice for building clocks. In England the clockmakers created a separate guild away from the blacksmith Guild. *So we leave the blacksmiths and follow the evolution of the clock.*
51. The anchor recoil escapement was invented about 1671 making clocks even more accurate
52. VIDEO even though the action of escape wheel has this forward then slight backward motion, that’s the distinctive recoil. A 36” long pendulum oscillates at 3600 beats per hour. (3600 :- 60 minutes= 60 seconds) Now a second hand could be attached to the escape wheel.
53. VIDEO That recoil motion is noticeable on the second hand
54. The longer pendulum was vulnerable out in the open thus the development of tall case clock (Grandfather clock).
55. Some times a clock with crown wheel and verge were converted to anchor escapement loosing a piece of their history. Or the clocks were built with anchor and longer pendulum then put inside these wood cases. It’s a transition period. The iron work is less and less. Hour striking up to this point has been with a count wheel.
56. VIDEO just like the clock at Salisbury cathedral this is a count wheel system still used on a modern clock. This can get out of sequence as when activated the count wheel always goes to the next half hour then hour count.
57. VIDEO 1676 rack striking developed. This snail determines the hour count. At the hour the rack is released and the tail falls on the snail and the hour is counted. This never is out of sequence with the hands.
58. The hair spring was invented in 1674 making a circular foliot will act more like a pendulum. This evolves into the balance wheel making small table clocks more portable.

59. The next big innovation was a tool. In France about 1700 a wheel cutting engine was invented. Using an index plate with your wheel mounted above
60. This is an early German version, blacksmith made. index plate,wheel blank, slotting saw
61. Another view. These early machines retain the best of the blacksmiths craftsmanship. In this machine a bow was used to rotate the cutter. It was still a small slitting saw
62. This wheel cutting engine that I brought with me came from a family of American blacksmith/clockmaker's. It is unconfirmed whether it was made by the Milliken family or just used by them throughout the1700's in Massachusetts.
63. The wheels that come off the machine one still needed hand filing to profile the tooth tops. Profiled cutters or rounding up tools came later.
64. 1714 the British parliament offered largest ever reward to find the solution to longitude.
65. It became an argument between the astronomers using star reckoning or could a carpenter turned clockmaker make an accurate clock that would work at sea. Members of the board of longitude were predominantly astronomers and how could a pendulum clock work on a ship. Or a novelty spring clock be accurate enough.
66. In about1725 the dead beat escapement was invented. There is no backward rotation of the escape wheel like in the recoile escape. This increased the accuracy of clocks again.
67. VIDEO dead beat
68. The cylinder escape was invented about the same time. This escapement was used in the earliest pocket watches
69. VIDEO It was complicated to make
70. H1 is built in 1735 by John Harrison that country carpenter/clockmaker. It was his first attempt to solve the problem of longitude. Truly the beginning of precision timekeeping. Seconds dial at top, minutes to the left, hours to the right, day of the month on the bottom. But it is till a pendulum clock and the pendulum was disrupted by the rolling action of the ship.
71. Remember the rule of thumb used to file the tops of wheel teeth. The theory of epicycloidal tooth profiles for clock work was developed by 1740. Most of us are familiar with an involute tooth profile characterized by this flat top
72. Clockmakers determined that this tooth profile had much less friction in a gear train. With involute gears there is gearing down, meaning a pinion drives the larger gear. Remember in clocks the wheel drives the pinion, (termed gearing up). These are the important dimensions the clockmaker needs when designing a gear train. OD, ID, *Pitch diameter (the theoretical working plane),* center distance between wheel and pinion, addendum, dedendum.
73. So using this new theory of gearing the sizing and position of wheels and pinions is based on either one of two systems. Most clockmakers find it easier to stay in metric
74. These are the basic formulas you need when designing clock wheels and pinions or when replacing missing parts. We are up to 1750. The beginning of the industrial revolution and one of the first catalogues of tools for watch and clockmakers published by John Wykes of Liverpool.
75. In 1762 John Harrison finishes H4. The marine chronometer that solves longitude at sea.
76. This portrait of Harrison represents timekeeping on land, a grid iron pendulum, then timekeeping at sea, H3 in the background and H 4 the final solution held in his hand
77. 1769 the detached lever escapement was invented. It was easy and cheep to manufacture making watches more affordable.
78. VIDEO

79. From1830 to1850 1st railroad and steam ship routes were established. As travel speeds rose and railroad networks became more dense major accidents happened like this one in 1842 france. Remember each town still was using their own time keeping.
80. Standard time with 4 time zones was instituted in the US and Canada by the railroads on November 18 1883.
81. 1884 Greenwich England became 0 degree longitude and established the international dateline and 24 timezones.
82. Another accident in 1891 in Michagan which highlighted the importance of accurate watches for the exclusive use on the railroads. Standards as to precise functioning of quality as well as handling features were established. The caliber had to be 18 or 16. From an old Lancashire England system of measuring case size. No fewer than 17 wheel bearing jewels, the balance had to be adjusted to run within close tolerances in 5 positions, had to be lever set not stem set, plane white dial with 12 at stem. And they needed to be serviced and calibrated regularly.
83. Now with satellite technology mechanical clocks and watches have become curiosities and pure luxury items. The blacksmith clockmaker was hugely influential in the story of timekeeping. It's their skills that I continue to study.
84. It was clocks like these that drew me to blacksmithing. I still find it hugely fascinating trying to figure out how those smiths made these beautiful clocks.

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