From man to machine: the history of the winding of the Great Clock of Westminster

Keith Scobie-Youngs*

The following text is closely adapted from the script delivered as the Dingwall Beloe Lecture on 2 November 2023 at the British Museum. As part of the Elizabeth Tower project completed between 2017 and 2023, Keith Scobie-Youngs and his team from the Cumbria Clock Company worked with colleagues from the Westminster Palace clock team to restore and conserve the Great Clock, commonly known as Big Ben. An important element in this project was the decision to restore to working order an extraordinarily complicated and sophisticated automatic winding system, first installed just before the Great War, and which had fallen into disrepair. In his lecture, Keith charted both the challenges and the triumphs associated with this element of the larger project.

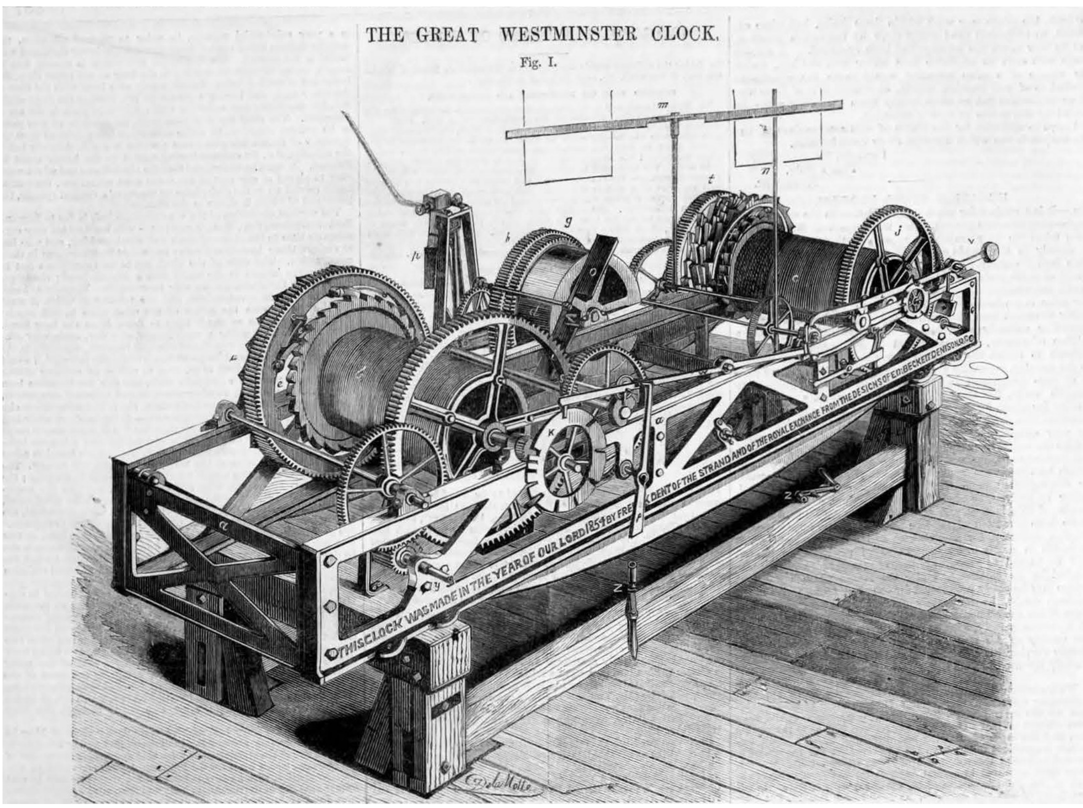

Fig. 1. Great Clock at the Dent workshops, *The Engineer* (31 October 1856).

The need for automatic winding

'*The work such as is hardly fit for anybody except convicts*' — These are the words of Edmund Denison in 1857 when discussing the hand-winding of the Great Clock of Westminster, before it was installed in the tower, still sitting in Dent's workshops at Somerset Wharf (see Fig. 1). The reason for

*Keith Scobie-Youngs FBHI, ACR (keith@clockmaker.co.uk) is the founder and director of the Cumbria Clock Company. He was Master of the Clockmakers' Company in 2024. He is a member of the AHS Council, and chairman of the AHS Turret Clock Group. His article 'Salisbury, Wells and Rye – the great clocks revisited' was published in *Antiquarian Horology* September 2018.

his statement was that he calculated that the weight required to drive the strike train alone was between four and five tons.

We know this did not turn out to be the case, and the explanation appears later, but Denison realised that some sort of power-assisted or automatic winding was going to be required, and in *Clocks and Locks* (1857) he discusses what the options were, and what had been considered. These ranged from the downright bizarre to the incredibly clever.

It was suggested that tidal power could be employed, and Denison agreed that it would have been entirely possible to do so, but only if had it been suggested before they had started to build the tower. Another option was to install turnstiles or plates on the surface of Westminster Bridge, so that as pedestrians strolled backwards and forwards over the River Thames they would slowly wind the weights of the clock. Even wind power was considered, but Denison rightly suggested Sir Charles Barry, the architect, would be unlikely to receive favourably a proposal to turn the top of the spire of the tower into a windmill cupola, even though it would have been entirely possible to wind the clock with such a mechanism.

A small steam engine was considered a practical proposal, but one did not already exist onsite from which power could be easily borrowed when required, and the additional cost of installing one and then running it would exceed the cost of the clock installation itself. In Denison's opinion only one option remained, the use of waterpower, but not tidal.

Denison's proposals for winding

He proposed that the striking and quarter trains could have been powered not by cast iron weights as they are now, but with the use of buckets, filled with water on an endless chain, like a water bucket elevator in reverse. This may seem a bit far-fetched as a design, but a standard UK bucket contains 18 litres, and 500 litres of water weighs 0.5 metric tonnes, equivalent to the driving force required by the striking train, or 28 buckets with a 175ft (53m) drop. Because the chain is endless, its weight and that of the buckets balance each other out.

He goes on to say that the reason that he did not proceed with the idea was because the architect did not discuss the design of the tower with him, and therefore there was no room in the weight shaft for the bucket chain to fall. This left hydraulic power, a power source that was gaining interest because of the development of the hydraulic crane, first designed by William Armstrong, later to become Baron Armstrong of Craigside fame. This new power source could soon be seen in the docks on the River Thames in the form of 'hydraulic devils', a name given to wonderful looking cranes, installed in the 1850s (see Fig. 2). Denison mentions two designs using similar principles by the engineer Jabez James, a remarkable though little-known engineer whose background is worth describing.

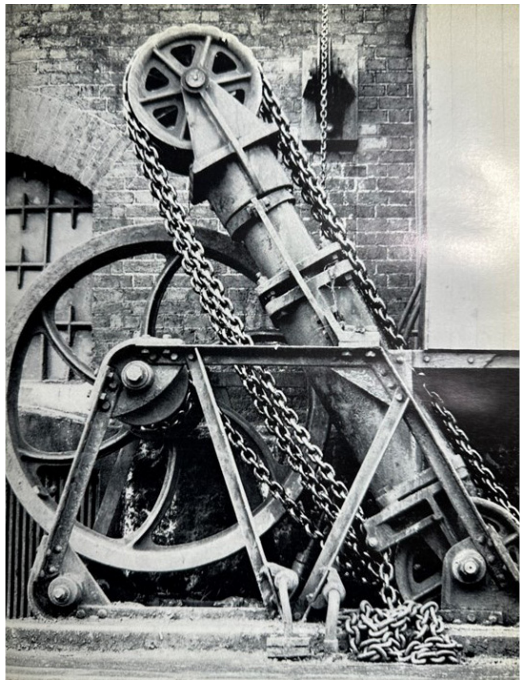

Fig. 2. A 'hydraulic devil' crane. Image Joseph McKeown, from Aubrey Wilson, *London's Industrial Heritage* (David and Charles, 1967).

Jabez James and his winding system proposals

Jabez James (1810–83) was apprenticed to his father at the age of sixteen for seven years, as a bellhanger and smith. He soon distinguished himself as a clever and intelligent workman and found employment as a journeyman for another bellhanger and locksmith, R. Miller, whom he succeeded, furnishing the factory with the best lathes and tools money could buy.

From this manufactory he produced machines of great accuracy for the Royal

Fig. 3. Name plate of Jabez James, on the bell frame of Big Ben. Photo Keith Scobie-Youngs.

Mint and the Royal Arsenal, and soon the name Jabez James came to be associated with the idea of mechanical excellence. He did a considerable amount of work for the Palace of Westminster, producing hinges, locks and gasoliers, and other internal metalwork. He made the bell frame above the Great Clock, where his name appears on a plaque (Fig. 3). He oversaw the lifting of the bell up the tower, and fabricated the four beautiful Pugin-designed dials we all admire, as well as helping install the clock movement itself. It is not surprising he applied his skills in designing a very clever and unique winding system (Fig. 4).

In 1859, he applied for a patent for a winding system featuring a flat cast-iron bed, approximately six to seven feet in length (1.8m–2.1m). Mounted on this bed are three pairs of rectangular-section pillars: one pair at each end and a central pair. A crosshead track connects the left-hand and central pairs. A capping plate is bolted onto the left-hand and central pillars, incorporating a corresponding integral track for the crosshead.

The left-hand pillar pair houses centrally located bearings designed to support the main shaft. This shaft carries a sprocket and a unidirectional ratchet wheel to prevent reverse motion. On the right-hand side of the central pillars, a cantilevered valve chest for the power cylinder is mounted. The right-hand pillar pair supports a freewheeling sprocket.

A continuous chain runs between the two sprockets, looping above and below the cylinder and passing through apertures in both

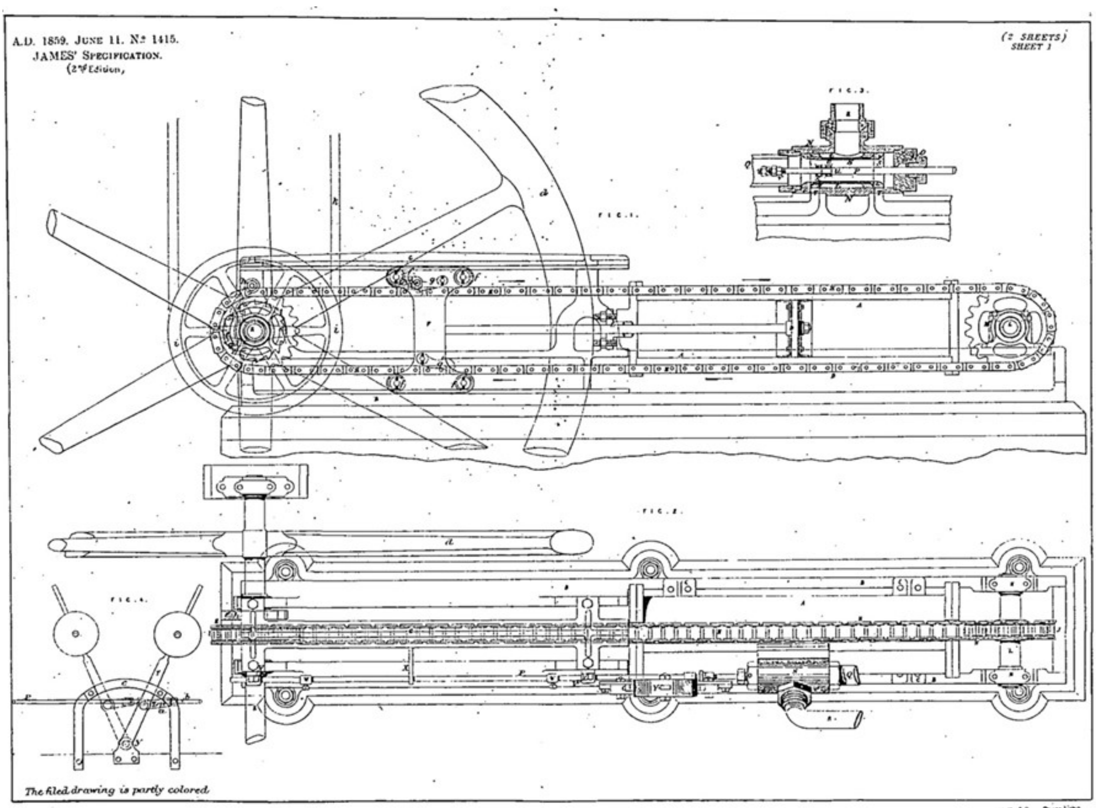

Fig. 4. Jabez James's winding system. Drawing from UK patent No. 1415 (11 June 1859).

the cylinder mounting plate and the crosshead, eventually connecting to the left-hand sprocket on the main shaft. A pawl mounted on the crosshead engages the top section of the chain to impart leftward movement. Similarly, a second pawl above the bottom chain section imparts rightward movement. Each pawl trails when the other imparts motion, ensuring alternating drive.

A piston valve with a hollow, waisted piston is secured near the bed at the power cylinder's port location. A sliding valve-operating rod with two adjustable tappets extends from the main shaft's left-hand pillar, through the central mounting pillars, into the piston valve, and exits through a gland in the right-hand end cover plate into the exhaust pipe.

From the side of the crosshead, a projecting bar extends over and just clear of the valve push rod. This bar engages one of the adjustable tappets, shifting the piston valve to its correct position relative to the power piston. This operation controls the entry of high-pressure water into the double-acting power cylinder and directs the exhaust through exposed ports.

A weighted, inverted pendulum-style lever, pivoted at the bed plate's side, connects to the piston rod. Inside the piston valve, the rod end slides through a bridging piece and is guided by stops that control the poised and falling positions of the weight—creating a moment of lost motion in the sequence.

The operation begins with both the power piston and valve piston in their extreme right-hand positions. In this state, pressurized water flows around the valve's waisted section and through the exposed inlet port, driving the power piston to the left. Simultaneously, water is expelled through the exposed exhaust port. On the return stroke, this process reverses. The exhaust port, now on the gland end of the valve cylinder, channels water through the hollow piston valve and into the exhaust pipe.

A barrel attached to the main shaft would have carried a rope extending up the tower to the clock's barrel, enabling the weights to be wound automatically.

I believe he realised this would reduce the running time as half the barrel would be taken up by the winding rope, and he therefore proposed a second method. This involved an endless chain passing up the tower, and his machine would climb the chain and act as the weight itself. For those familiar with turret clock automatic winding systems, such a concept is instantly recognisable, echoing the winding system employed by Thwaites & Reed, some hundred years later, in their 'monkey-on-a-stick' design, which employed an electric motor.

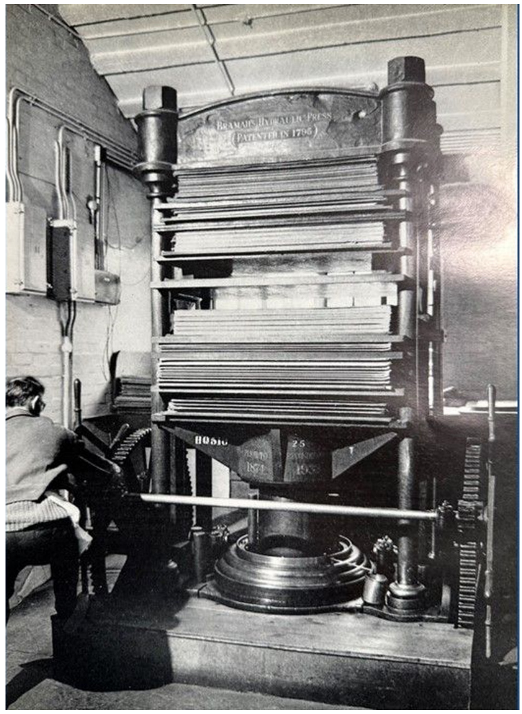

Fig. 5. A Bramah press, *c.*1795, originally used as a map press. Image Joseph McKeown, from Aubrey Wilson, *London's Industrial Heritage* (David and Charles, 1967).

Both of these designs were clever and would likely have worked. However, Denison did not approve, commenting they would require considerable maintenance, in addition to which the quarters and hours would have to remain silent while winding was underway, as there was no provision for hand-winding. Denison therefore came up with his own suggestion, also hydraulic, based on the hydraulic ram or press developed in the late eighteenth century by Joseph Bramah (Fig. 5). This used a column of water from a header tank 200 feet (60m) above, which filled the cylinder below the piston, thus forcing it upwards. A detailed description of this winding system can be found in Frederick Dent's *Treatise on Clock and Watch Work* (1855), and the 3rd edition of Denison's *Clocks, Watches and Bells*.

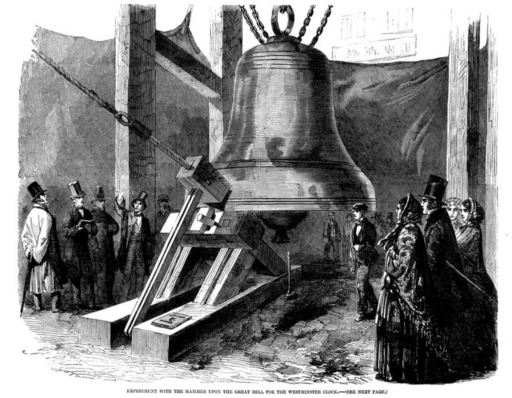

Fig. 6. The first bell. *Illustrated London News* (27 December 1856).

He proposed that a hydraulic ram was positioned below each of the striking and quarter weights. Each weight, instead of reaching the ground, would descend on to the top of a piston moving in a short cylinder, the hour-part cylinder about 14 inches (35cm) in diameter, and the quarter one 12 inches (30cm). The hour weight falls 3 feet (0.9m) in striking twelve, and soon after striking, the 24-hour wheel, which is driven directly by a pinion on the arbor of the great wheel of the going train, would open a slide valve at the bottom of the cylinder, using a lever and a long rope from the clock, and let water in from a tank about 200 feet (60m) above, which in turn would drive the piston up a little more than 3 feet (0.9m), thus lifting the clock weight resting upon it. While rising, a comparatively small weight hung on the other side of the barrel would wind it up rather more than one turn, gathering the line necessary for striking twelve.

When the piston reached near the top of the cylinder it would shut the valve, and so it would remain until the pin in the 24-hour wheel opened the out-port of the cylinder, allowing water to escape and the piston to fall under its own weight, leaving the weight hanging ready to provide power for the striking train, just as if it had been wound by hand. The water would remain turned off until after 4 o'clock, as it would not be required, and would then be turned on after 6 o'clock. Little more than one full cylinder of water would be utilised each twelve hours. The quarter weight would be wound up in the same way every hour, only requiring a rise of less than 2 feet (0.6m).

If hand-winding were required, the small winding weights might be taken off, or their ropes might be arranged to drop off the barrels after a given amount of winding, and then the arrangement would proceed as if there were no water apparatus involved. With regard to the going train, he suggests that this should be left hand-wound, as little time is involved, and because of the desirability of a man visiting the clock once each week, to receive the time from Greenwich, and to regulate the clock if necessary.

Fig. 7. The second bell, Big Ben. Drawing by Thomas Kimber, AHS Archives.

Hand-winding adopted

However, the need for fitting a power-assisted or automatic winding system ceased in late October 1857, when the great bell, which had been sitting in Palace Yard, struck by a hammer weighing in excess of ½ ton, developed a crack 40 inches (101cm) in length, making it unusable (Fig. 6). The first bell was heavier than anticipated owing to an error during casting, leading to the bell being thicker in the waist, thus requiring a heavier hammer to sound it. This was the reason for Denison calculating the strike weight needing to be 5 tonnes, a weight he considered impossible to be wound by hand, leading to his decision to consider automatic or power-assisted winding of the striking and quarter trains.

Fig. 8. Footprints worn into the floor. Image Lumen Photography.

The second bell (Fig. 7) was lighter, and thinner in the waist, requiring a hammer only half the weight of the first, and therefore the clock could be wound by hand. In Denison's words, 'the winding of the striking part by hand is now quite easy and can be done by a man in considerably less than a common day's work'.

The striking and quarter trains have a running period of four days, while the going train will run for eleven days. To wind both the striking and the quarter trains, the winding handle must be turned 120 times to put a single turn of cable onto each barrel. There are 62 turns on each barrel, meaning the winding handle must be turned at least 7500 times for a full wind, and this does not account for the turns that are lost when the clock strikes, and the quarters are sounded.

A 'common day's work' leaves its marks, as shown in Fig. 8. During the recent conservation work in the tower, these footprints were found, worn into the floor of the clock room, left by the people who wound the Great Clock for the fifty-four years before the electric winding system was fitted. Perhaps unsurprisingly since this equates to approximately 1,215,000 rotations of the winding handles (Fig. 9).

Interrupting hand-winding to allow chiming and striking

Denison was aware that, in winding the clock, the men would have their heads down and could be lost in the physical activity of raising the massive weights, and in doing so become unaware of the time and continue their activity through the quarters or hours. This would

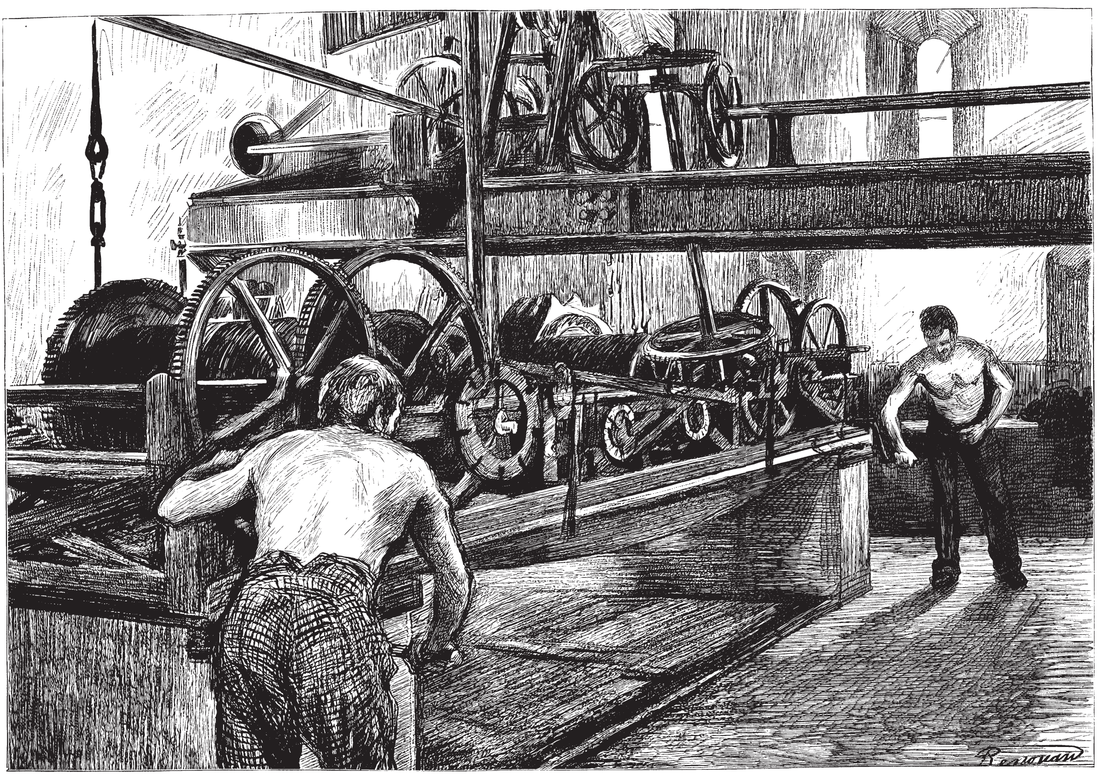

Fig. 9. 'Winding up the clock', *The Graphic* (1887), Chris McKay Archive, AHS.

Fig. 10. The damper spring is pressed up against one of the arms, when locked. Image: Andrew Strangeway.

Fig. 11. Original stop levers for the hand-winding process. Image Lumen Photography.

lead to the trains not releasing, and the bells sounding out of synchronisation with the time on the dials. He therefore designed a method of stopping the winding each quarter, and just before the hour.

Most of his system has been removed, but a few parts remain and, helped by a brief description he gave in his book, we have been able to work out how it operated. Both the striking and quarter trains were fitted with long levers which acted on a short arm on the

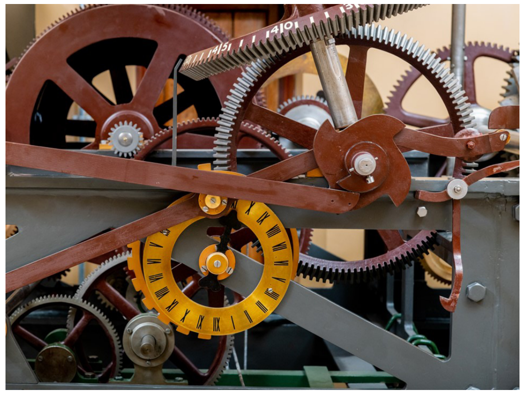

Fig. 12. Quarter release cam used in locking during the hand-winding process. Image Lumen Photography.

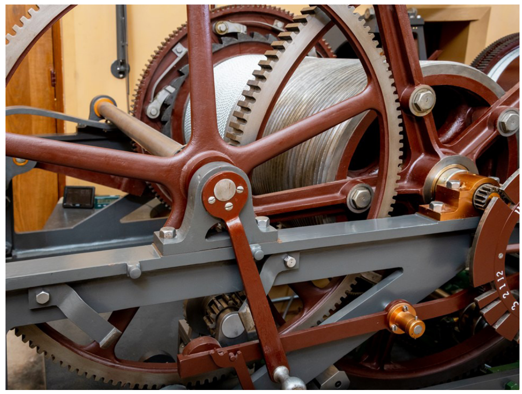

Fig. 13. Eccentric bush and lever used in disengaging the winding pinion. Image Lumen Photography.

winding arbor, fitted with a damper spring (Figs 10 and 11). Before winding, the relevant lever was lifted up onto a hook. Part of each lever rode on a cam, marked out with the quarters (Fig. 12). The cam slowly lifts each lever, and just before the clock is about to strike the lever is released off the hook, dropping and acting against the short arm of the winding arbor, immediately preventing any further winding. In some ways this resembles the stopwork on a fusee clock.

The clock winder then operates an arm, pivoted on an eccentric bush, moving the winding pinion out of engagement with the winding wheel on the barrel itself (Fig. 13). The clock can then strike or sound the quarters. When striking has finished, the clock winder can re-engage the winding pinion, lift the winding arbor locking lever back onto its hook, and the job of winding can be restarted.

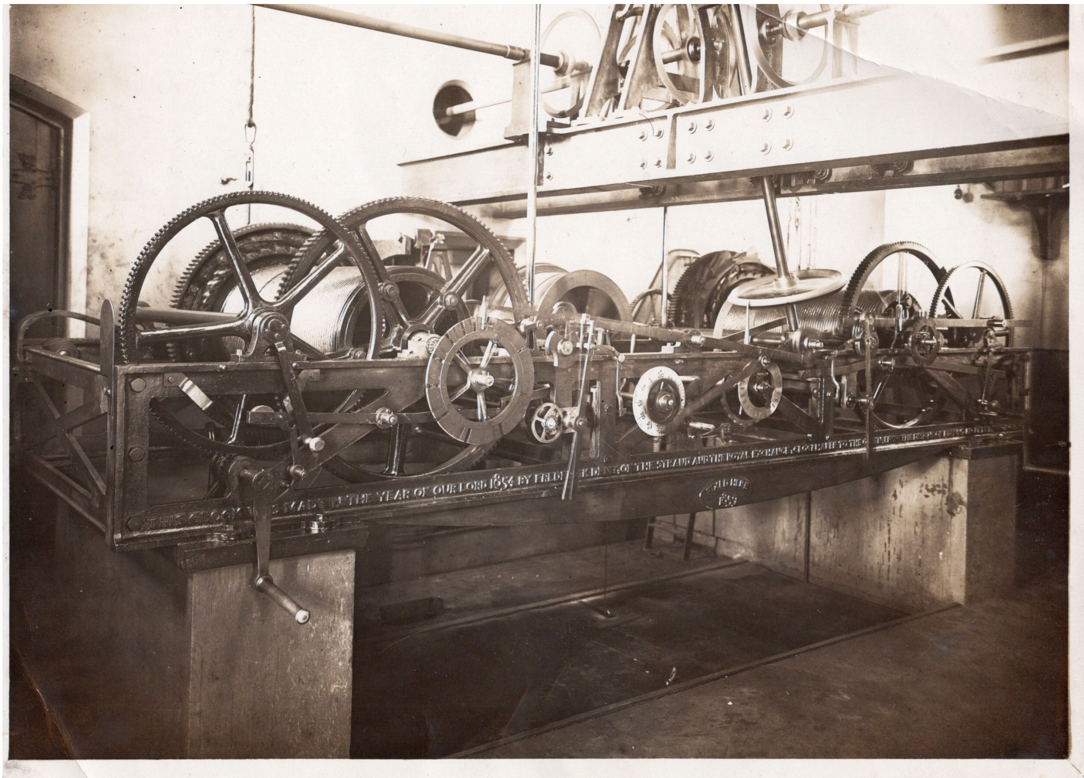

Fig. 14. The clock when still hand-wound. Image TR Robinson archive. Pre-1913.

There was also another lever, engaged by the weight lines, preventing the winder from lifting the weights too far, once again through engagement with the short lever on the winding arbor. Fig. 14 shows the clock while still hand-wound, and the levers and hooks are visible. This method of winding must have proved to be reliable, as it was not until 1909, fifty years after the clock had been installed, that Dent, who had been maintaining and winding the clock since its installation, first mentioned the possible installation of an electric winding system.

Electric power winding at last

A letter from Dent, dated 26 January 1909, sent to the Office of Works, set out an offer to install a mechanical method of winding that would not alter the existing mechanism, and which would wind the existing weights, leaving hand-winding possible in the event of an emergency. Dent also offered to pay for supplying the machinery, including the switchboard, the meter and the cost of the power consumed, on the understanding that their current contract for maintaining the clock would be extended for another twenty years.

On 4 February 1909, Dent received a reply stating that their terms were acceptable. However, it appears the system took a long time to design and build. A year and a half after being given permission to install the system, a letter from the Office of Works dated 22 August 1910, concerning the power supply for the winding system, makes it clear that it was not yet in operation. It was not until sometime in 1912 or 1913 that the system was commissioned. For those of us who worked on its repair and recommissioning, we fully understand why it took so long.

The CAD model shown in Fig. 15 shows how complex the system is, and immediately suggests an operative would need to be well-trained to use it. Dent continued to maintain the clock and this winding system until 1970, after which the contract passed to Thwaites & Reed. By then, it would appear only the strike and quarter trains were being wound by the winding system. The author later worked with Albert Fairey, former winder with Thwaites

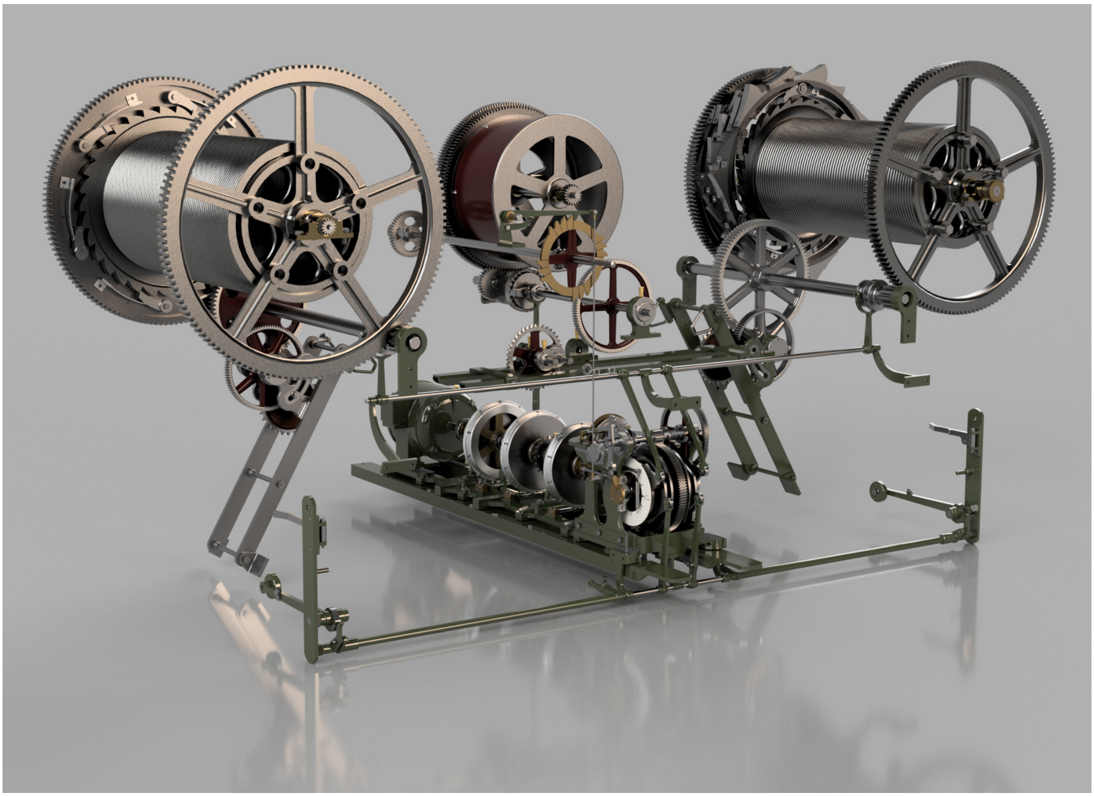

Fig. 15. General arrangement of the winding mechanism. Image Cumbria Clock Company.

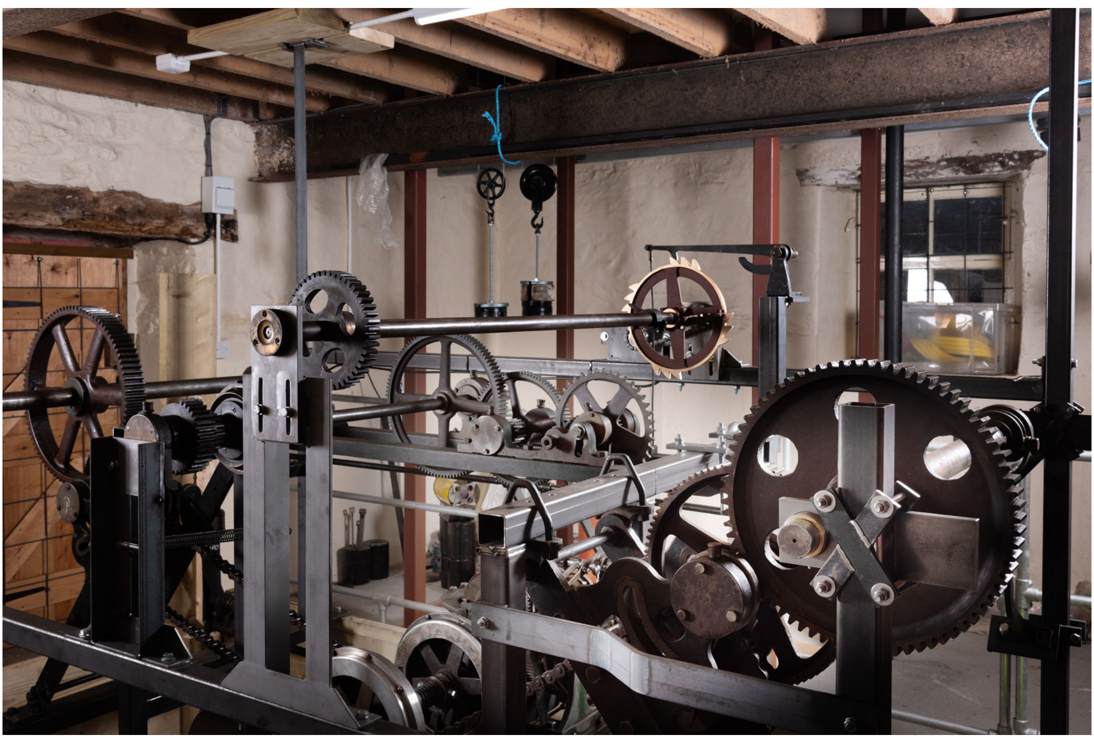

Fig. 16. The mechanism assembled for initial testing and understanding. Image Cumbria Clock Company.

Fig. 17. The mechanism back in position below the clock, ready for testing. Image Lumen Photography.

& Reed, and he confirmed he would wind the going train by hand. This would suggest that the knowledge of using the system was already in decline when Dent lost the contract.

When members of the current Palace clock team took over from Mr Tricky and Mr Blowers (originally employed by Thwaites & Reed, but later part of the Palace of Westminster Maintenance Team), the winding system no longer featured automatic indexing in its operation. A routine had developed in which it was necessary to engage and dis-engage the necessary levers and cams by hand, and then use the motor to wind up the weights. It would appear the Houses of Parliament were never given a set of instructions for the winding unit, and one can perhaps detect protectionism on the part of Dent, who had supplied the system at their own cost. They will have wanted to protect in-house knowledge and intellectual property. Recently, when Parliament wished to service and refurbish the clock movement, it was decided to fully overhaul the winding system and bring it back to full working order.

First, the mechanism was reassembled in the workshops, with a view to understanding how it worked, and to ensure all the parts were present (Fig. 16). Any separate parts associated with the clock have been stored in a vast off-site facility for many years, and some parts of the winding system required tracking down there, in a hunt reminiscent of an Indiana Jones tale. Having successfully reunited all the parts, a long process of cleaning, repair and testing unfolded. Eventually the winding system was returned to Parliament, and installed under the clock, where a second phase of testing and adjusting commenced (Fig. 17). There is clearly a large difference between remote testing, with little load, and testing on-site with a requirement to lift 2.5 tonnes of cast iron. This phase lasted several weeks, and our respect for the original designers deepened.

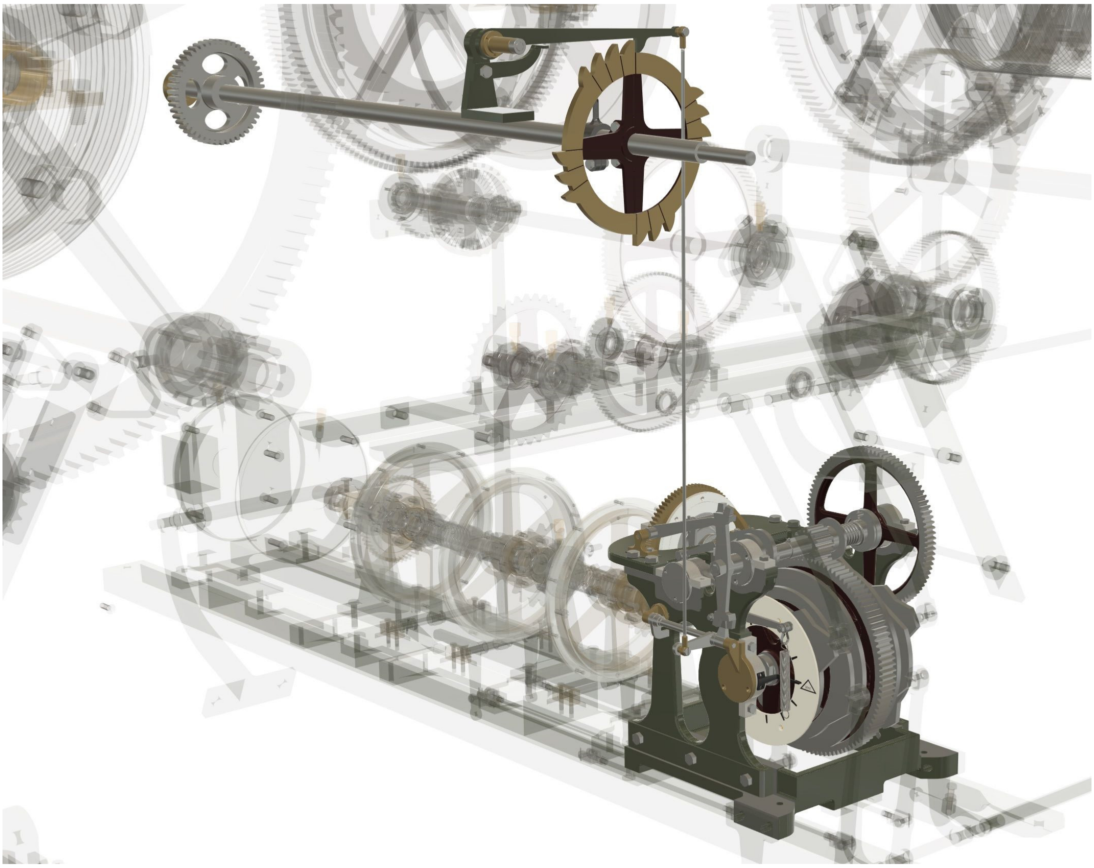

Fig. 18. A general arrangement view, with a detent lowered onto the shark fin wheel, at top. Image Cumbria Clock Company. Image Cumbria Clock Company.

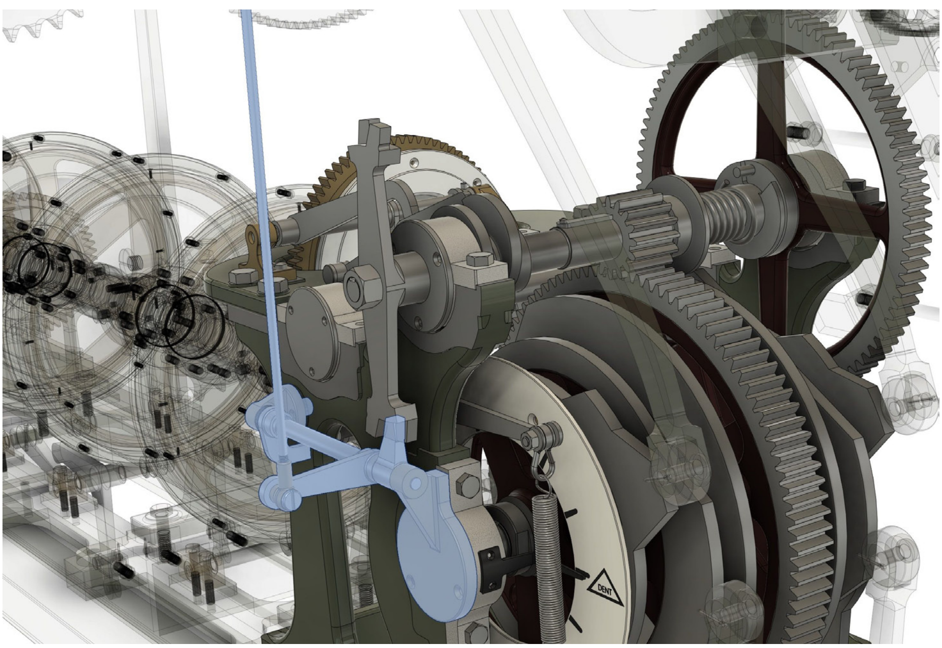

Fig. 19. The release arm (highlighted). Image Cumbria Clock Company.

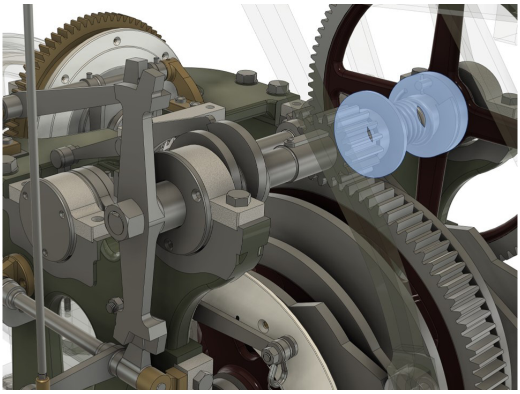

Fig. 20. The remontoir spring assembly. Image Cumbria Clock Company.

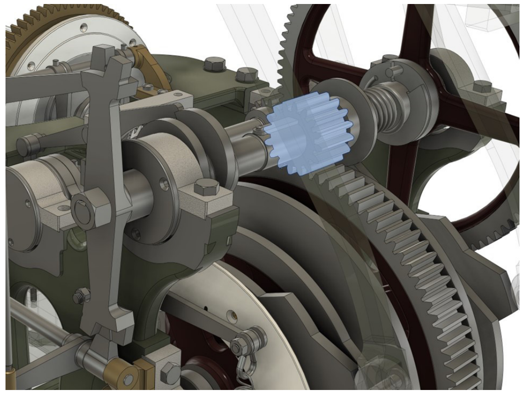

Fig. 21. Moveable drive pinion, now disengaged. Image Cumbria Clock Company.

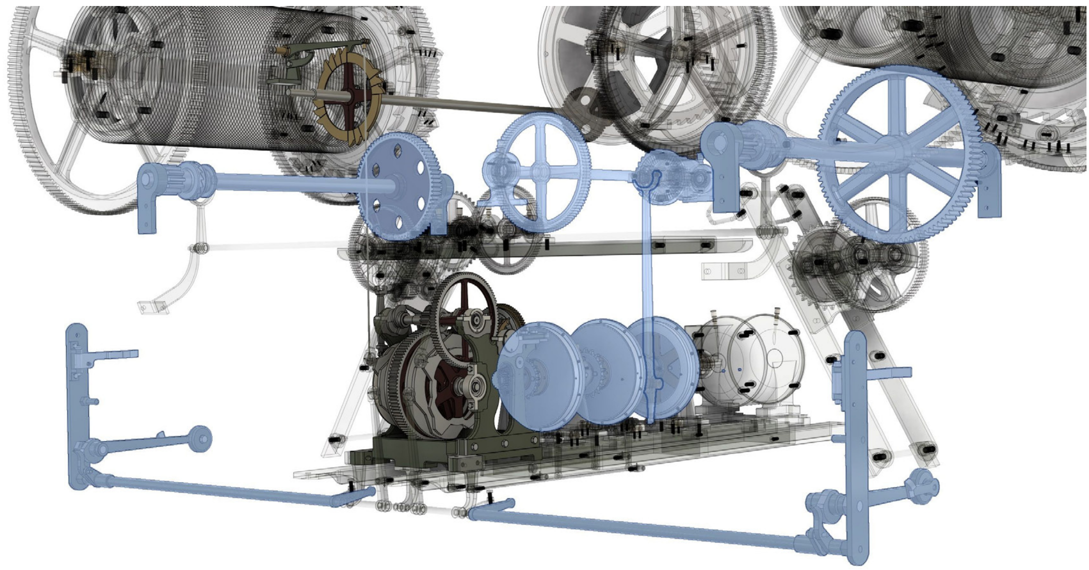

Fig. 22. The barrel drive dogs are engaged, but the driveshaft clutch assemblies are disengaged. They will be engaged by lifting the two arms to the lower left and right. Image Cumbria Clock Company.

Operation of the winding system

The following description is illustrated by a series of figures, but would also be more easily understood by reference to a film which can be viewed at https://tinyurl.com/bigbenwinding or at https://youtu.be/JMfftuIJ1iA.

Fig. 18 shows a general arrangement of the system. First a detent is lowered onto what has now been named the 'shark fin wheel', visible to the top of the image. The motor is started and the cam control system rotates and locks off on the release arm highlighted in Fig. 19. The locking action is ensured by the locking faces being kept together by the remontoir spring on the end of the arbor (Fig. 20), which is tensioned by the momentum in the cam assembly. With the remontoir spring wound, the cam assembly drive pinion can then be disengaged by sliding it to the left (Fig. 21). The number on the cam assembly is now set to correspond with that on the shark fin wheel.

Fig. 22 shows a general arrangement at this point. With the cam drum in this position the barrel drive dogs are engaged, but the driveshaft clutch assemblies are disengaged. By lifting the two arms to the left and right of the clock movement, the driveshaft clutch assemblies are brought into engagement. As

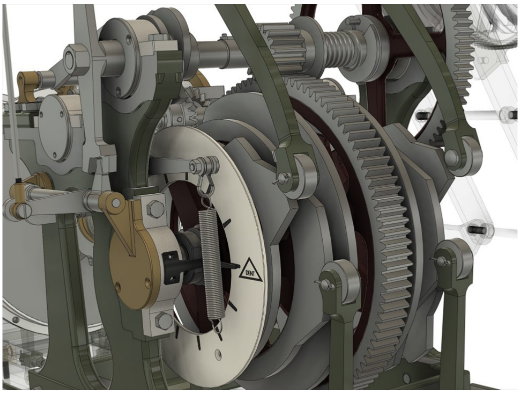

Fig. 23. The cam plates and cam followers. Image Cumbria Clock Company.

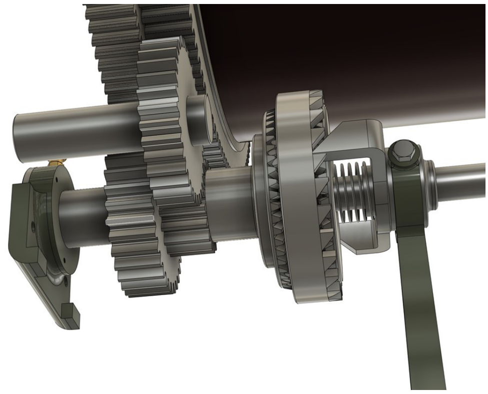

Fig. 24. The going train epicyclic system. Image Cumbria Clock Company.

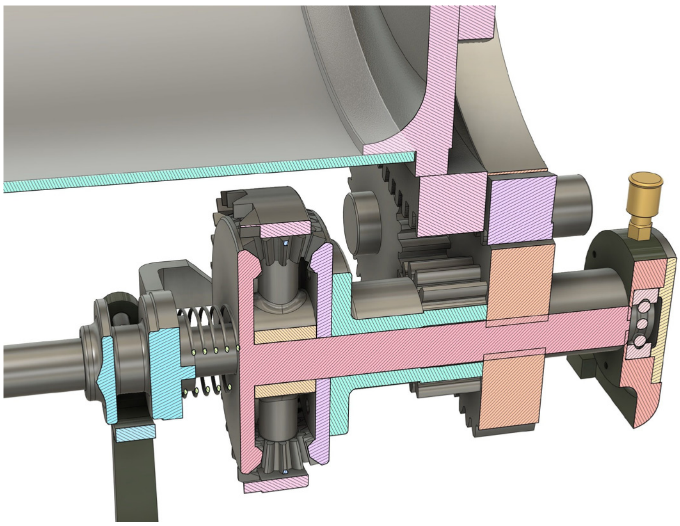

Fig. 25. Cross-section of going train epicyclic system. Image Cumbria Clock Company.

soon as this occurs, both the striking and quarter reduction gear trains start to drive the dog clutches, which in turn engage with the winding wheels on the weight barrels, and the clock weights start to be lifted.

Fig. 23 shows an arrangement of cam plates and cam followers. By lifting the arms, the cam rollers are brought into contact with the cams of the cam control unit. The cam control unit has six cams, two for each train. One operates the dog clutches, and the other the drive clutches. The cam plates are shaped to move the cam followers so they can engage and disengage the clutches and dog clutches as required.

Fig. 24 shows the going train epicyclic system. Just before the hour, the maintaining wheel is engaged with the main wheel, thus anchoring the epicyclic system to the main wheel. Some of the teeth have been removed, so that, when not in use, the epicyclic system is completely disconnected from the clock and therefore causes no drag in the going train. Then the winding pinion is moved from its neutral position and engaged with the winding wheel on the barrel of the going train. A handle is pulled out at the front of the clock movement which lifts the drive clutch knockout counterweight into position. When the release detent operating on the shark fin wheel drops off at position 10, the drive dog engages at the same time as the drive clutch and the going train starts to wind.

Fig. 25 shows a cross section of the epicyclic system. The maintaining power is generated by the epicyclic gearing, in this case a set of bevels,

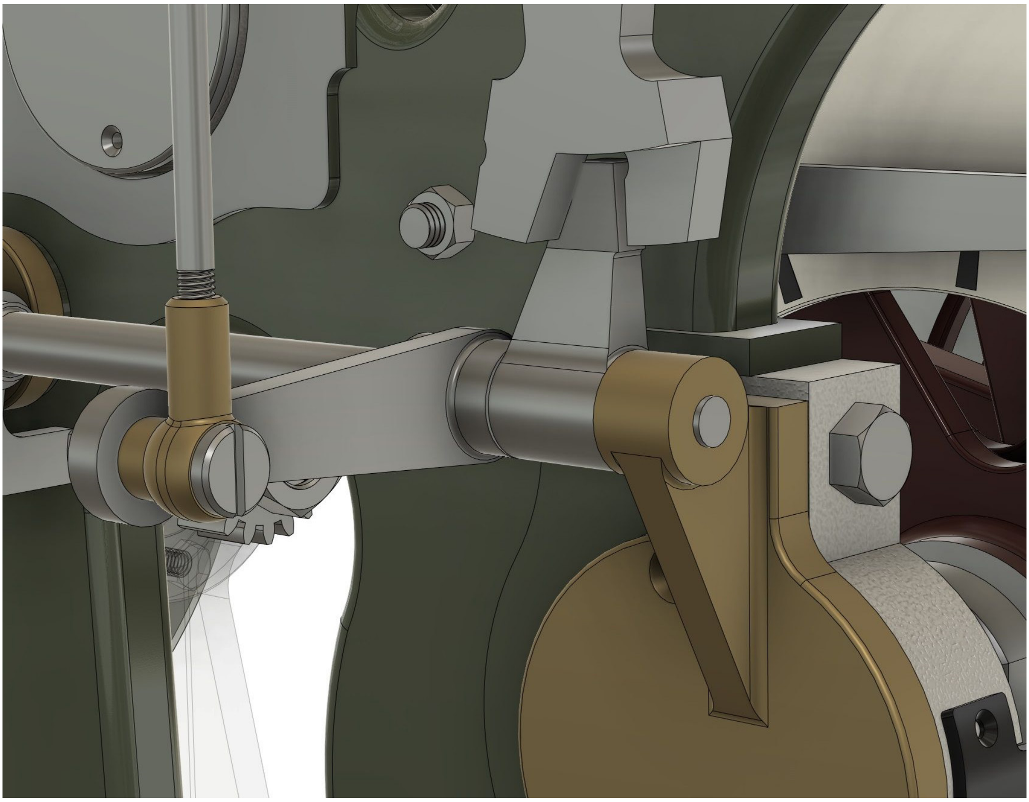

Fig. 26. The release lever. Image Cumbria Clock Company.

so as the weight is wound up, maintaining power is given by the wheel anchored to the going train main wheel. The indexing of the cam drum is undertaken in eight stages.

Fig. 26 shows the release lever. The cycle of actions is as follows:

1. The release detent is lifted by one of the shark fins to a point where the release lever allows the release arm on the remontoir arbor to move from the locked position to the warn position

2. When the release detent drops off the shark fin, the remontoir arbor is released, driven by the remontoir spring. This allows the cam barrel clutch to engage, and drives the remontoir arbor through 180 degrees, which then locks off. The momentum in locking off winds the remontoir spring. This operation indexes the cam barrel in one sequence.

3. The engagement and disengagement of the cam barrel clutch is undertaken by an ingenious lever and cam assembly, which toggles the clutch from its engaged to disengaged position (Fig. 27). There are two levers: one at the top and one at the bottom, operating on two cams, which are slightly out of phase.

4. In the locked off position the top lever has disengaged the clutch.

5. Upon going to warn, the lever moves closer to the drop off point of the operating cam. The clutch still remains disengaged.

6. When the release lever drops, and the remontoir arbor is released, the lever drops off the cam and the clutch is engaged.

7. This allows the main shaft to drive the cam barrel, so that it operates the cam followers accordingly.

8. Just before the locking face of the release arm of the remontoir arbor comes into contact with the locking face of the release lever, the lower lever disengages the clutch, allowing the mass of the cam barrel to drive the arbor

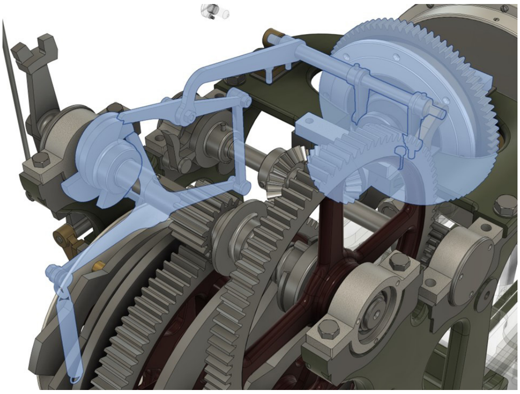

Fig. 27. Cam barrel clutch. Image Cumbria Clock Company.

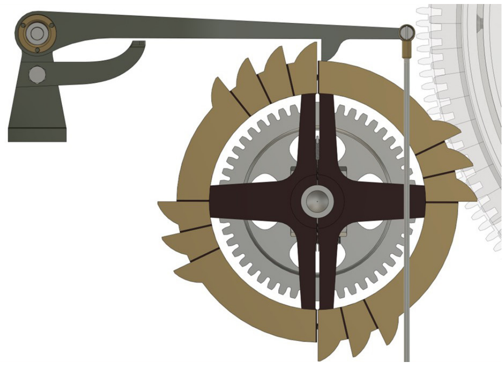

Fig. 28. Shark fin wheel, showing three groups of three teeth, and one group of four.

forward onto the locking face, and to wind the remontoir spring.

(See Fig. 28). The shark fin wheel, fitted to the hour arbor on the clock movement, controls when the cam barrel is released, to allow the clutches to engage and disengage accordingly. There are three groups of three shark fins and one group of four on the circumference of the wheel.

The groups of three are for quarter past, half past and quarter to the hour. The group of four is for the hour, and also for bringing into operation the going train winding. The sequences activated by the groups of three are as follows:

1. The first disengages the drive clutch. As the drive to the reduction gears finishes, the cast iron clock weight drives the reduction gears backwards, allowing the weight to be taken on the barrel clicks and off the dog clutches.

2. The second draws back the dog clutch, making sure it is out of engagement. The clock is then in a position where it can strike and sound the quarters.

3. When the clock trains are locked off, the third fin re-engages the drive clutch and the dog clutch and winding starts again.

The going train winding system is operated in the same way as the other two trains, with the cam followers operating the dog clutch and drive clutch. When the weights reach the top of their wind, the cables release the drive clutch engagement arms and stop the drive to the trains, allowing the trains to run backwards onto the clicks. The motor is then switched off. The winding pinion is disengaged, and the release leave is put back up on its hook. The pinion is disengaged so that the cam indexing drum can be set in the neutral position, indicated by the DENT symbol. The whole procedure takes forty minutes, a vast improvement on four hours of manual winding for two men. The restored and complete system is shown back in position under the clock in Fig. 29 (next page).

Conclusion

In all, it is a most ingenious machine, supposedly designed by Thomas William Buckney (1880–1955), an engineer's draughtsman with Dent (as he described himself in the 1911 Census), and son of Thomas Buckney (1838–1900), the senior partner in the firm from 1881 until his death. It was also said that Dent allowed one month's training for their clockmakers before being allowed to wind the clock themselves. For those involved with the reinstatement of the winding system, this was one of the most challenging parts of the entire project, but equally one of the most rewarding. Fortunately, with the 3D renderings we have been able to create, and with all the information documented, the clockmakers of the future should not have to face the same problems in understanding how the system works, and should therefore be able to keep this mechanical wonder working for countless decades to come.

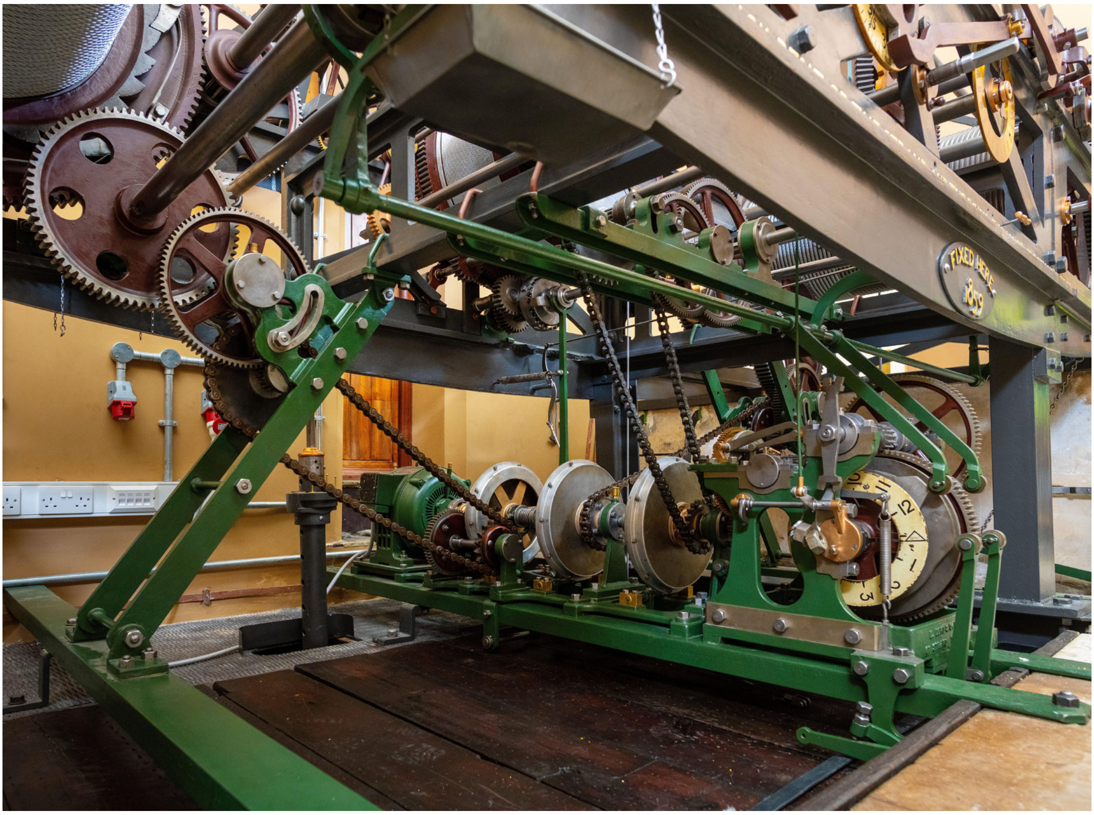

Fig. 29. The completed machine, in position. Image Lumen Photography.

Fig. 30. Winding up the clock, the old-fashioned way. On these four frames from a video-recording we see the author to the left and Andrew Strangeway of the Palace Clock Team to the right. Image Cumbria Clock Company.