

OFFICIAL JOURNAL OF THE BRITISH HOROLOGICAL INSTITUTE

The Horological Journal



DECEMBER 2024

www.bhi.co.uk



Double Lever Escapement

*A Prototype Escapement that is an Evolution
of the George Daniels Co-axial*



David Cottrell

When thinking about the design of a second pocket watch it seemed obvious that it should have a tourbillon and make use of the co-axial escapement. At the same time I came across an article by Derek Pratt that explained the details behind his series of remontoire tourbillons, which made me see things a little differently¹. Not only did this understanding influence the design of the second pocket watch, it also led to the double lever escapement.

In the article, Pratt mentioned that he had noticed an increase in wear on escape wheels in watches with a one-minute tourbillon. The wear was particularly noticeable on the relatively delicate pointed teeth of a detent escapement or English lever; this being due to the momentum in the carriage that has to be absorbed at each locking. His inclusion of a remontoire isolated the escape wheel from the stored energy in the carriage, and this made me wonder if there was another approach that would give the escape wheel an easier life. In turn, this led to the various tourbillons created by Breguet with much longer rotational rates than those seen as the norm today. As a result, the idea of making a watch with a four-minute tourbillon came into being instead of the more common (and faster) one-minute versions seen today.

If you delve into the physics of an object in motion you find that the kinetic energy (the energy in a body due to its motion) is the product of its mass and velocity squared, the key point being the squaring of the velocity. The implication of this is that a reduction in the velocity of the carriage, as opposed to its mass, has a greater proportional impact on the energy that has to be absorbed by the locking teeth. Equally, the energy required to accelerate the carriage in the first place is reduced; which should mean that a lighter main spring can be used. So, while you can make the carriage (or any other moving part) lighter that will only take you so far.

The actual equation is $KE = \frac{1}{2} mv^2$ and it's worth putting some numbers in to illustrate the difference a change in velocity makes. If we assume the mass is 1 and the velocity is 10 then the KE is 50. But, if the velocity is halved to 5 then the KE is 12.5. So we can see that halving the velocity reduces the energy involved by a factor of 4, whereas reducing the mass by half would merely reduce the energy by the same proportion^{*}.

How does this link to the double lever escapement, which is an evolution of the principles embodied in the Daniels co-axial? While not mentioned at the time, Pocket Watch No. 2 was also intended as a large-scale prototype for a smaller wrist watch movement fitted with the co-axial escapement.

However, considerations of geometry mean that the co-axial escape wheel is required to have eight teeth at the wristwatch scale, as opposed to twelve in the larger pocket watch. It seemed a shame to go to the trouble and additional work of making a wrist watch with a four-minute tourbillon, only to add an escape wheel that is rotating faster than one would like due to it having a reduced number of teeth.

This suggested that it was worthwhile revisiting the geometry of the original Daniels design to see if there was another interpretation of the core principles that would accommodate a fifteen-tooth wheel at the smaller scale. If this were possible the nearly halving of the rotational speed compared to one with eight teeth could approach a factor of four reduction in energy for a given train count. Tangential locking and radial impulses would be retained, making it highly likely that lubrication should not be required.

The first thing to do was to understand why the reduction in teeth is necessary. This is helpfully explained by Daniels in *Watchmaking*² in the chapter that details the geometry of the escapement, where he explains that this is a result of the direct impulse being given to the balance from the escape wheel.

In the co-axial escapement the locking and impulse actions of the escapement are controlled separately by respective locking (A) and impulse (B) pallets, **Figure 1**. In particular, a pallet is added to the balance roller that interacts with the locking teeth on the escape wheel to give a direct impulse of energy to the balance. The geometry of this impulse is such that for safe interaction at the wristwatch scale the number of teeth in the escape wheel has to be reduced, usually to eight³. Whilst removing this direct impulse would free things up for more teeth, it also meant that a replacement for the lost impulse had to be found. The impulse in the opposite direction being given by a pallet on the lever that interacts with the inner set of raised teeth on the escape wheel.

To resolve this issue it made sense to re-trace the steps that lead up to the co-axial and follow the path that Daniels took, which started with his version of Breguet's Enchapment natural, the double train series of watches which culminated in his the Space Traveller watch. The key point with the Enchapment natural and other similar designs is that having two escape wheels rotating in opposite directions provides the necessary double impulse to the balance.

Daniels saw that this concept could be simplified to a single escape wheel (with a co-axial impulse wheel) to give one direct and one indirect impulse to the balance in opposite directions. While reading through this work the realisation dawned on me that an escape wheel (or any toothed wheel) is, in effect, a series of levers working around a common pivot. You need a series of teeth (levers) so that once one has moved through an angle and imparted its energy the next one is in place and

* Kinetic energy is usually measured in units of Joules (J); one Joule is equal to $1 \text{ kg m}^2 / \text{s}^2$. For completeness the equivalent formula for a rotating body is $KE = \frac{1}{2} I\omega^2$ where I = Moment of inertia (Kg/M^2) and ω = angular velocity (radians/second).

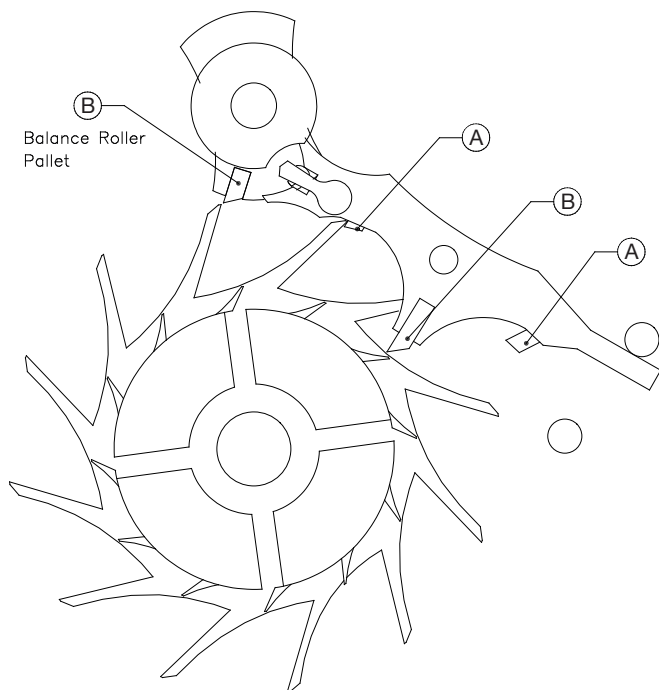


Figure 1. In the co-axial escapement, the locking and impulse actions of the escapement are controlled separately by respective locking (A) and impulse (B) pallets.

ready to continue the cycle. However, if there was a way of resetting one tooth back to its starting point then you would only need a second escape wheel with one tooth – which, of course, is a lever!

The other insight was that the lever in an escapement rocks back and forth between two fixed positions and that this could be used to reset the other ‘single toothed escape wheel’ back to its starting point. From this the concept of a ‘double lever’ escapement, **Figure 2**, came into being, consisting of a main lever (1) that would provide the impulse to the balance in both directions and working in conjunction with a small, light, secondary impulse lever (2) interacting with the main lever and escape wheel to give the missing impulse in the opposite direction.

The main lever is very similar to that used in the co-axial escapement in that it carries the locking pallets and a single impulse pallet that interacts with the inner, raised teeth of the escape wheel. To keep the layout compact a single banking pin (4) takes advantage of the revised profile of the main lever. The secondary impulse lever (2) interacts with the escape wheel locking teeth, is linked to the main lever via a pin (3) and pivots on the opposite side of the main lever to the escape wheel. The position of the secondary lever pivot means that the impulse from the escape wheel will provide energy to the main lever (via the pin) in the opposite direction to that of its own impulse pallet, **Figures 3–6**.

Laying out the Escapement

Appendix III in *Watchmaking* details how to lay out the extra flat version of the co-axial escapement suitable for a wristwatch with an eight-toothed escape wheel and 36 degree escape angle. This can be used as the starting point to define the locking pallets and lever fork/impulse pin relationship etc. Note that the half angle of the teeth needs to be changed from 22.5 to 12 degrees (assuming a fifteen-tooth escape wheel). The geometry for the impulse pallet on the balance roller is ignored.

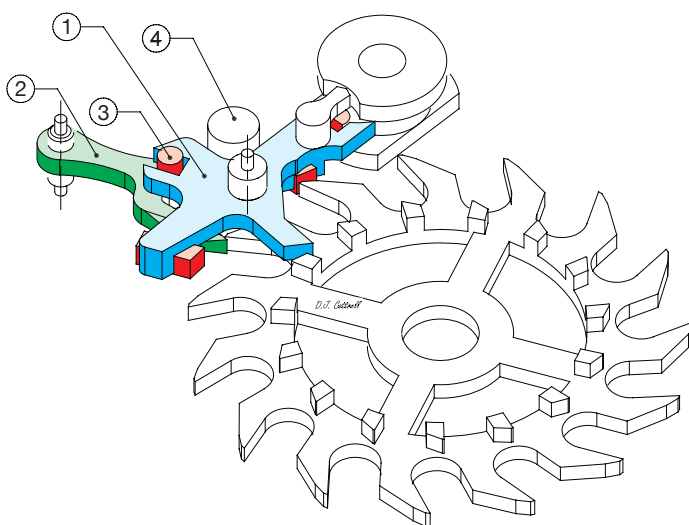


Figure 2. The concept of a ‘double lever’ escapement starts to come into being.

The geometry of the impulse pallet on the main lever uses the same approach as the co-axial. Note that it will not be interacting with a pinion, but with the inner ring of raised teeth on the escape wheel. It is also worth referring to the diagram in the escapement section of ‘*Watchmaking*’ that shows the geometry of a version by Omega (1045) that has twelve teeth. Note that the geometry of the impulse pallet on the secondary impulse lever uses the same principles of definition as the impulse pallet on the co-axial main lever, **Figure 7**.

The pivot point of the secondary lever relative to its pallet and the escape wheel pivot ensures a radial impulse. The pin connecting the two levers is on a line between the pivot of the respective main and secondary levers when the main lever is at the midpoint of its travel, **Figure 8**. There is scope for refining the various angles and lever ratios, experimentation will tell which work best.

The escapement, with a fifteen-tooth wheel, has been fitted to a modified Unitas movement, which has been happily running for many months as an initial test bed. To keep the mass of the moving parts down to a minimum neither of the impulse pallets has been jewelled; though they could be. The thinking being that the interactions between the pallets are relatively gentle radial ‘pushes’ where both contact surfaces are already in motion before they touch, as opposed to the hard stop of the locking pallets that are jewelled.

Strengths and Weaknesses

Any design has its strengths and weaknesses, and compromises often have to be made to reach a desired end. With escapements for example the lever is relatively straight-forward to make and is robust but has the drawback of needing lubrication which deteriorates and eventually impacts time keeping. The co-axial addresses the lubrication point, but introduces other challenges, such as the reduction in the number of teeth in the escape wheel, in addition to it being quite exacting to manufacture.

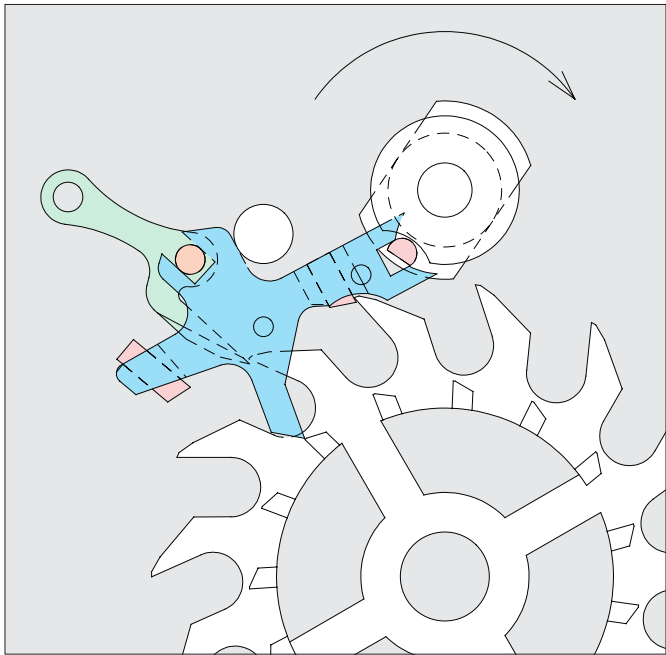


Figure 3. Entry pallet locked; secondary lever ready to receive an impulse from the escape wheel.

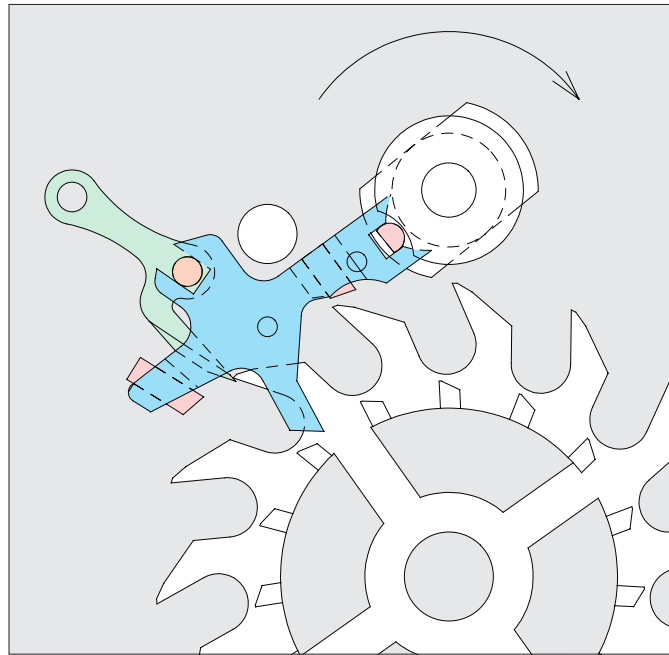


Figure 4. Impulse from the escape wheel to the secondary lever.

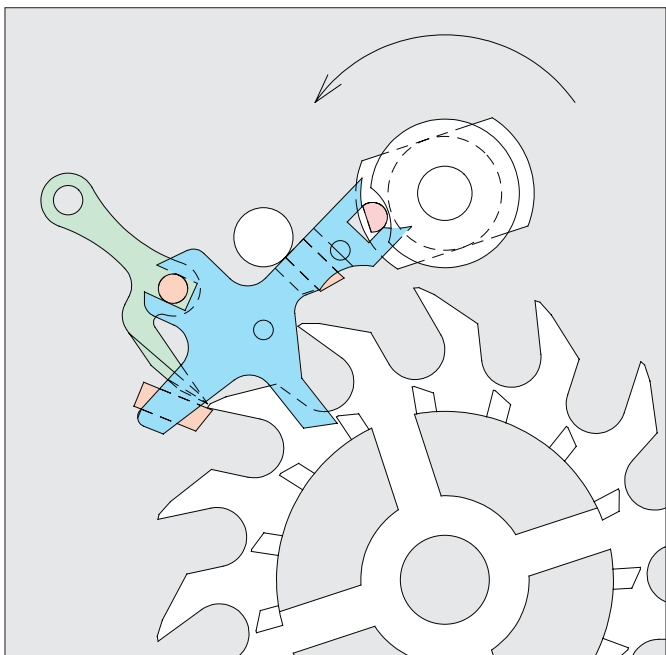


Figure 5. Exit pallet locked; main lever ready to receive an impulse from the inner ring of raised teeth.

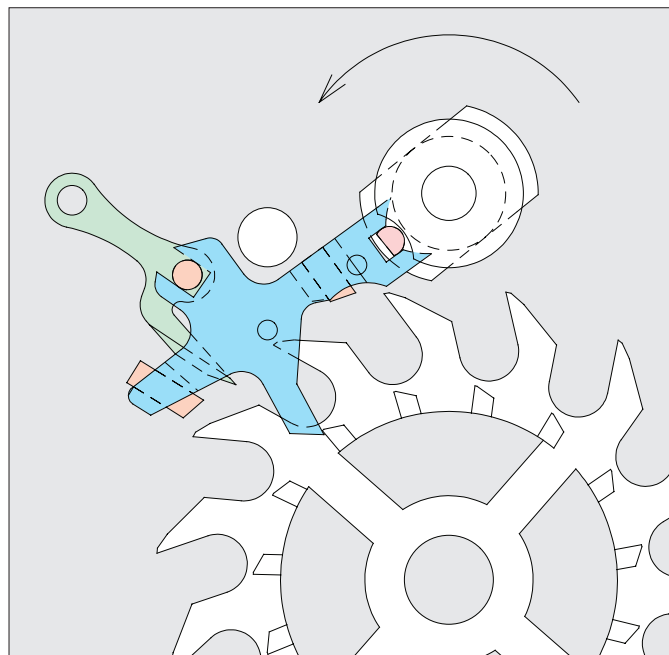


Figure 6. Escape wheel raised teeth giving impulse to the pallet on the main lever.

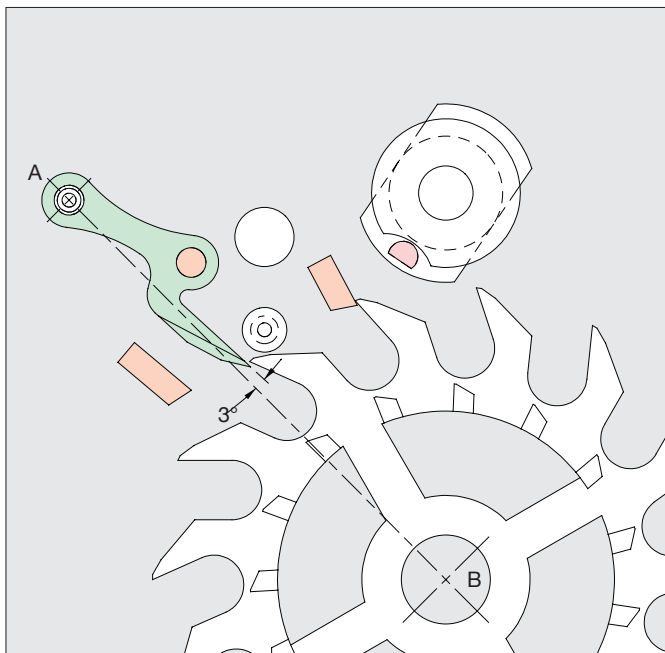


Figure 7. To ensure safe intersection of the secondary impulse pallet with the locking teeth the pallet is set 3 degrees before the centre line A-B (main lever hidden for clarity)

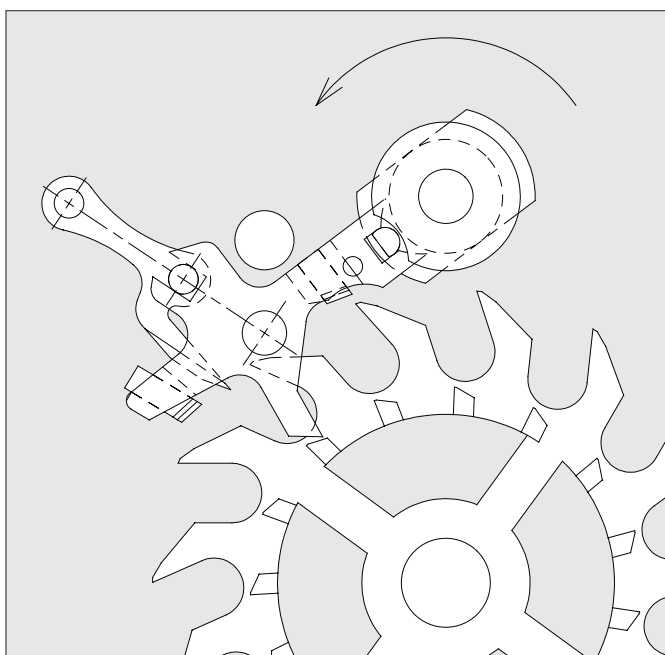


Figure 8. Main and secondary lever pin geometry at the midpoint of movement.

The double lever design is an attempt to apply the key principles of the co-axial such that lubrication is not required while at the same time freeing up the tooth count of the escape wheel. The approach taken also reduces to an extent the very tight tolerances required of the original design.

It goes without saying that the components need to be well made, as is the case for any escapement. However, the removal of the roller pallet does reduce the number of interdependent dimensions. In the co-axial the roller impulse pallet has to clear the escape wheel teeth in both directions of the rotating balance, meaning that the locking on both entry and exit must occur at the correct geometrical point. This limits the allowable tolerance build-up in the manufacture of the individual components, as well as the three main pivot points of balance, escape wheel and lever. With the double lever design the impulse geometry is more directly related to the respective entry and locking pallets and is not interlinked in this manner.

In addition, it is possible to arrange that the secondary impulse lever acts on the raised impulse teeth as opposed to the locking teeth, thus relieving the locking teeth of additional work and therefore wear. However, such an arrangement results in a longer and therefore heavier secondary lever, which is not desirable.

While the use of a second impulse lever adds mass as well as friction from the additional pivots, careful design can help minimise the impact of both. For example, making the impulse lever in one piece, without a pallet jewel, helps to keep the mass down.

Following the successful running of the Unitas test bed a patent application was made (and has been accepted/filed) in case the concept has some commercial value. If nothing else it is hoped that this alternative way of applying the tangential locking and radial impulse embedded in the co-axial design will encourage others to come up with new approaches, with their own take on the balance between advantages and compromise.

REFERENCES

1. Derek F. Pratt, 'A Tourbillon indicating full seconds with carriage-mounted remontoire, twin barrels and up & down indicator', *The Horological Journal*, vol. 134 (July 1991), pp9–15.
2. George Daniels, *Watchmaking* (London: Thames and Hudson Ltd, 2013), p245.

www.instagram.com/djcottrellwatches

All images © David Cottrell.