An Exercise in Experimental Horological Archeology
Testing Verge and Foliot Clocks by Malcolm Bell 2012

Introduction.

I assume that the reader is familiar with Verge and Foliot clocks and their broad principle of working. However I include an outline introduction below.

I began researching Verge and Foliot clocks because I am an Engineer, not an Historian nor an Horologist. Therefore I empathise with the huge effort of creativity, physical demand and high intellectual requirement that was required of the men who made them. My objective is to try to ensure that the brilliant minds that gifted these instruments to us are recognised with the standing they deserve. In the process I immediately became involved in the question of equal and unequal hours (which I also explain in the following section). There are many books on the subject – but my own position remains ambiguous. I am inclined to assess that the verge escapement with a foliot was invented for unequal hours. Equally the verge escapement with a wheel balance was unarguably for equal hours. My testing has led me to a third option that might, with the addition of scholarship, provide us with a better insight. We are not yet at the point of firm conclusions.

It is commonly stated that verge and foliot clocks are substantially inaccurate timekeepers. Typically it is said they are no better than plus or minus half an hour a day. However papers by Houtkooper[1] and Maltin[2] have shown that these clocks were in fact relatively repeatable; capable of staying within one apparent minute within an apparent twelve hour period. Note the word "capable" meaning that well built and maintained they can do this but many of course were neither. Houtkooper and Maltin also discussed in some detail the use of the foliot, not merely for adjustment of the going rate of the clock, but whether or not it was used for the unequal, seasonal, hours of the canonical day or for the equal, fixed, hours of the civil world. With this in mind a series of tests were done to explore the range, sensitivity and characteristics of moving the cursor weights on the foliot by testing the clock in Salisbury Cathedral (Fig 1) and subsequently on clocks in the British Museum, notably the Hammond clock (Fig 2).

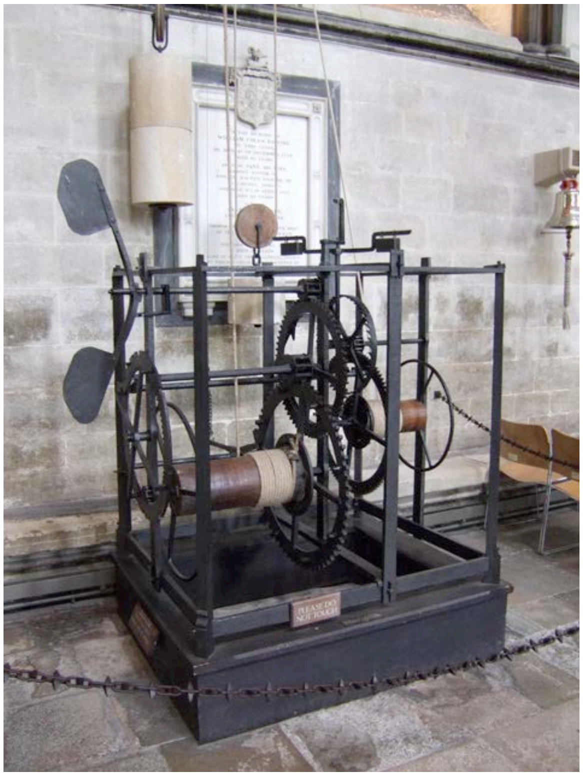

Figure 1 *The Salisbury Cathedral Clock*

In the course of this work an unexpected surprise arose. It was expected that moving the cursor weights out along the foliot beam would return some function of a square law as suggested by the standard equations for rotational inertia but a very different result was obtained. This new result may be an insight into developing a mathematics of the Verge and Foliot escapement to parallel the famous maths of the pendulum. This discovery is the essential conclusion of this paper.

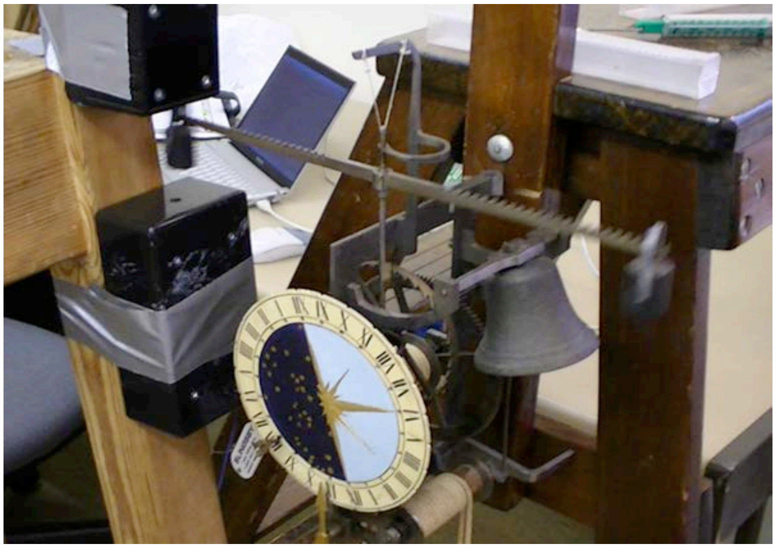

Figure 2 *The Hammond Clock at the British Museum*

In reporting this some thoughts on the use of the V&F with both equal and unequal hours are also included, more as questions than answers, although some approaches to those answers are suggested.

Summary of Findings (to 2012)

Recent tests on two verge and foliot clocks (Salisbury and the Hammond replica in the British Museum) are described. Four fundamental capabilities of the clocks were demonstrated.

1.0 These tests confirmed the work of previous modern researchers that these clocks are capable of an error of less than one minute in twelve hours.

2.0 On the Salisbury clock a single step along the foliot of one cursor makes a change in rate of typically five minutes and thirteen seconds. This is too big a step to be of use in fine rate regulation.

3.0 On the Salisbury clock and the Hammond the change in going rate varies directly with the linear movement of the cursors along the foliot and not, as expected, a function of a square law.

4.0 By testing a replica the Sinous Foliots illustrated in the V&A and Urbino intarsia panels were shown to be a technically elegant method to match the going rate of a V&F to the changing length of the summer days.

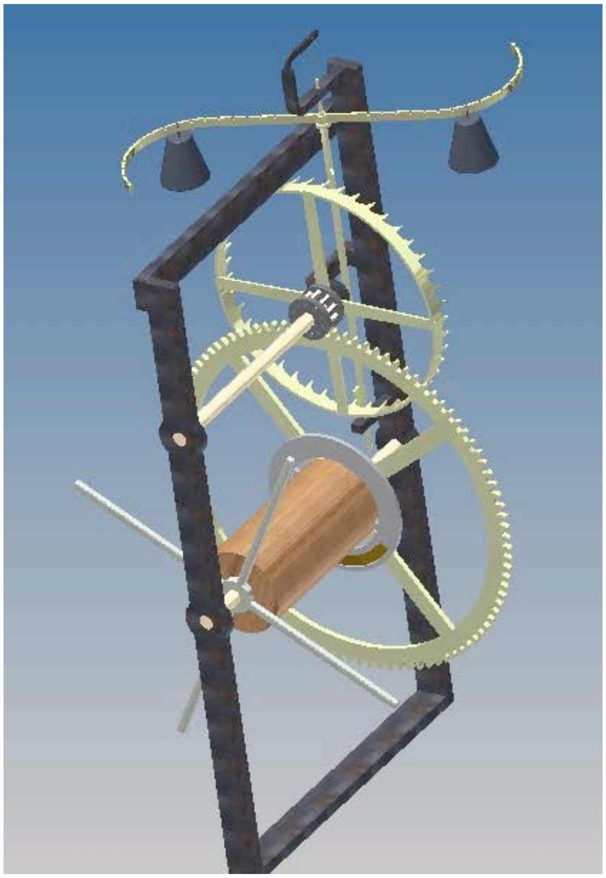

Figure 3 *Simplified assembly of V&F clock*

Outline of Verge and Foliot clocks and also of “equal” and “unequal” hours.

The basic function of Verge and Foliot clocks is shown in the model in Figure 3. This CAD illustration is based on a typical drive train of most V&F clocks. The term “verge” refers to the upright rod, like a Verger’s pole, at the top of the train on which about half way up are mounted two small flat plates called pallets that step in and out of the teeth of the conspicuous crown wheel. At the top of the verge is an horizontal beam with notches on its length and moveable weights called cursors hanging from it. This beam is called the foliot for reasons not clearly known but may refer either to the foliage of a tree or, because it swings in a rhythmic manner like the dancing fool of the middle ages.

In this figure the foliot is shown as an “ess” shape for reasons that will be explained later. In all known existing examples the beam to be perfectly straight in plan although in modern replicas is stepped in side elevation as on the Salisbury clock. See figure 7..

Round the wooden drum a rope is attached and a large drive weight connects over a pulley on a suitable high point. This weight applies a torque to the drive drum which turns the large, or great, wheel that in turn drives the lantern pinion on the arbour that carries the crown wheel with its sideways facing saw shaped teeth. There are an odd number of these saw teeth and they engage in turn with the pallets on the vertical verge shaft. The consequence is that the torque from the crown wheel applies a force to the pallets on the verge which is thus rotated and so swings the foliot and its cursor weights. When the verge rotates the pallet it is pushing against swings out of the saw tooth and so allows the crown wheel to click round to engage the other pallet down below. The inertia of the foliot rewinds the drive weight a little in recoil before coming to rest and reversing. Thus back and forth, the foliot rotates in a partial arc. This is a resonant system of the foliot swinging against the drive weight which oscillates up and down in gravity in its largely downward path.

There is great discussion about the exact nature of this resonance, whether or not it is isochronous with the strong majority opinion being that it is not. The fact is that this system made the basis of all clocks for about three hundred years in the west from say 1350 to 1656, when the pendulum was first introduced. The Japanese continued to use the same method another two hundred years until about 1873 so it must have been reasonably good.

The alternative to the foliot beam was to fit a wheel balance – not unlike the wheel in a pocket watch but larger of course. Illustrations of most domestic clocks in the period show wall mounted bracket clocks with such wheels and there is an important summary of clock designs known as the “Almanus Manuscript” showing many wheel balance verge clocks. A wheel balance can only be used in equal hours requiring no seasonal adjustment.

In the early middle ages and earlier it is thought that the day length ran from around sunrise to sunset (or perhaps first light to final darkness). This period was divided into twelve parts called “hours”. As the year progressed so the length of the day changed from the long summer to the short winter day – the exact change varying with how far north you are. Therefore as the year progressed the length of the apparent hours changed and I use the terminology “unequal” for this meaning unequal with the season. It is also well known to call these solar hours. They are also called Ecclesiastical hours because they were critical to cycle of prayer in monasteries, cathedrals and convents. If a clock were used for unequal hours it would be stopped each night and restarted in the morning – to avoid this, the Japanese had two foliots on their clocks, one for day and one for night. In the west they probably used two clocks: one the big main one to ring the bells and a small alarum to waken the Sacristan in the morning.

The alternative to unequal hours is "equal" hours. Often also called Siderial time. These are the hours we use in the modern world, the day being measured in twenty four exactly equal parts from midnight to midnight without variation with the seasons.

So we have the problem with clocks. It is easier to make a clock that will divide the day into equal parts all year round. But to make one that can be varied with the season, running slow in the summer day and fast in the winter day is more of a challenge, some authors say impossible. Part of the purpose of my research is to try to throw some light onto this issue: were verge escapement clocks with foliots and their sliding cursors intended for unequal hours (as they were actually used in Japan for almost five hundred years) being adjusted every two weeks to track the season or were the adjustments only to correct their supposed unreliability?

Method of Testing.

It should be noted that the Salisbury clock does not have its original medieval V&F escapement having been rebuilt in the nineteen fifties to remove the pendulum escapement fitted at some unknown time replacing its original verge and foliot escapement. This replica escapement was derived from the Dover clock (now in the Kensington Science Museum) which was thought to be original but now doubted. However, the overall condition of the Salisbury clock makes it a candidate for testing because of its low wear and so was considered as representative of medieval clock rate keeping.

I tested by arranging a vertical infra-red light beam from an emitter to a receiver such that the swing of the foliot would cut the beam on each pass. The signal from the light beam was passed through a USB interface to my lap-top computer and, using the crystal clock in the computer, I recorded the elapsed time of every beat over a pre-set number of counts. I collected data over a number of conditions including three complete turns of the crown wheel and then in shorter runs for each of the cursor positions, repeating many times. I observed that the clock settles quickly to its running rate and I did not need to leave it more than two beats after making an adjustment before collecting data. I settled for counting five beats and then recording fifteen beats taken at random start points on the crown wheel, the average was taken over fourteen beats of course.

A note on the accuracy of the testing and the numbers reported here in this paper might be useful. The clock in my laptop may be thought of as giving a data "cut" at nine decimal places. However the optical sensing and the USB interface reduces the sensitivity and variation in ambient light, which varied the edge of the shadow penumbra, intensity will also effect the precise moment of switching of the optical sensors. Further, movement of the verge in its bearings will alter the precise cut of the light beam. Given these errors the data as recorded was rounded to five significant decimal places and averages were calculated from those. For ease of interpretation the data reported here is simplified and mostly it is to three decimal places of a second which is sufficient for the purposes of drawing the graphs and the primary conclusions drawn herein.

Results obtained from stepping the cursors on the Salisbury clock

As a Mechanical Engineer is was my assumption, from the classical equation for rotational inertia, that as the cursors were moved outwards along the foliot the frequency of beat would increase at some function of the square of ratio of the changes. Hence I expected that if I plotted the rate of the clock for each position of the cursor along the length of the foliot I would get a rising curve from which I may eventually be able to derive an appropriate formula.

Plotting the mean beat per run of fourteen ticks against each of the steps outwards gives the graph in figure 4. The rate changed linearly with movement of the cursors. This means that moving the cursor out, say, the first three notches on the foliot, will slow the clock by exactly the same amount as moving the cursors out the last three at the outer end.

Figure 4 *The rate of change of beat with radial position of the cursors on the straight foliot.*

It must be noted that there is a "weave" through position 14. This is thought to be because of slight variation in the spacing of the notches on the foliot itself although that has not yet been physically measured and confirmed due to lack of time. Equally it could be because one of the gear pairs in the train was giving a minor torque variation at the pallets.

Given this result I was very concerned that I might have made a mistake or that there might be something wrong with the clock. After careful inspection of the clock and several re-runs of some of the data no source of error that might give this effect was observed. Worried, I approached the British Museum who have the wonderful Cassiobury turret clock and asked if I could test it. They were very willing and went to great trouble to arrange for me to have access to it out of public hours.

The Cassiobury, like the Salisbury, has a replica foliot with double hanger cursors derived somewhat from the Dover clock.. However it is very worn and the results were uncomfortably "noisy" and the range of movement was very limited and so did not provide a convincing conclusion, albeit not a contradiction (result are available for inspection if required). Fortunately, however, the Museum has a modern replica verge and foliot clock built by Mr Ian Hammond (figure 2) who was also looking at the same questions but died before reaching conclusions. He made a clock based on an interpretation of the type illustrated in the "Almanus Manuscript" by Brother Paulus circa 1480. All the clocks in the Almanus have wheel balances and Mr Hammond fitted a very long foliot instead. This was perfect for my purposes.

The Museum team set this clock up for me and I was able to make a trial. Ignore the overlapped wind in the picture on the going drum, this causes a change in the drive torque; I put that right before testing. The test was done over fifty beats for each datum. To my relief the result was close to linear given experimental tolerance (figure 5). The heavy over laid line is the calculated mean of the test to clarify just how close is the linearity but makes clear the that data was not absolutely perfect – probably as a function of variability within the clock drive train.

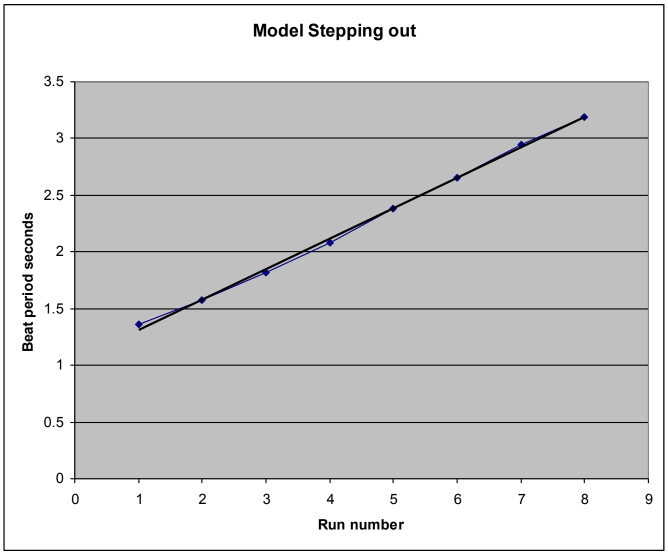

Figure 5 *The straight line result for the Hammond clock in the British Museum*

The conclusion is that all Verge and Foliot clocks with straight foliots change their rate in direct and equal proportion to the movement of the cursor weights in or out along the along the foliot regardless of where on the radius the change takes place.

<u>The repeatability of the clocks</u>

The data collected directly off the clocks at first seemed very variable, one tick successive on the one before seemed to have a greater period difference than I was comfortable with; there were variations of almost half a second from one beat to the next alternate beat (only alternate beats can be compared of course because my timer was not in the dead centre of resonance, that would have been impossible to achieve). I spent some time looking for possible causes of the "problem" but nothing obvious was apparent. So I tried an experiment with the data to compare one complete turn of the escape wheel with the next turn. The result is copied in figure 6: one run in blue and the other in purple, starting at the same tooth.

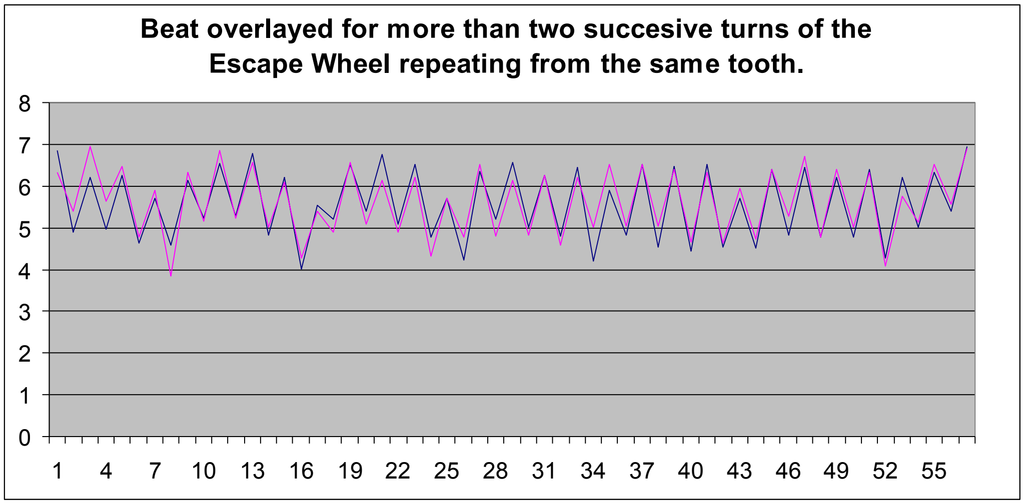

Figure 6 *Two complete sequential turns of the crown-wheel overlaid to illustrate the close repeatability and lack of randomness of each beat.*

The important thing to notice is that the beat pattern at first sight looks very random but: it is very clear that the two runs almost exactly duplicates the other showing the apparent variability arises, not from randomness but directly from mechanical characteristics of the clock; characteristics that repeat exactly every turn of the crown wheel. There are some mismatches (at "tick" 3 and 8 for example) which almost certainly are a function of the other gear pairs in the train. I think that the close repetition of this data is reassuring and that the clock is largely devoid of the randomness normally reported about V&F clocks and suggests confidence in their normal repeatability.

First review of results.

The primary conclusion of both Maltin and Houtkooper was that V&F clocks can run at an error of about plus or minus one minute in an apparent twelve hour period (this is distinct from saying this is sustainable over long periods of time). This was confirmed in my testing and adds to the appreciation that they were practical timekeepers in their context. A report in Wikipedia, subsequently edited by somebody, presented by a respected horologist who tested an highly original clock, the Cotehele clock, gave a fixed hours repeatability of better than two minutes in twenty four hours which aligns with the one minute in twelve that the above testers and I report. On this basis it is concluded that these four independent tests on four different clocks confirm that properly built and maintained Verge and Foliot clocks had the capability to be repeatable to better than two minutes in twelve apparent hours when originally built. Their widespread adoption in the fourteenth century to replace water clocks and sundials as primary timekeepers was justifiably predicated on this precision. Their continued use in Japan for over four hundred years underlines this probability.

From the results it is also safe to state that any one step anywhere on the foliot will give the same rate change. On the Salisbury clock the movement of one cursor by one notch, anywhere on the beam, gives a rate change of about five minutes twelve seconds per twelve hour day. It actually varied very slightly in practise from tooth to tooth because they are not exactly spaced along the length of the foliot. It seems unlikely that a step change this large would be of any benefit in regulating the rate of the clock if any attempt at precision was to be made. If that were the objective then much finer steps would have been made. Period illustrations of V&F clocks actually show very large steps. Additions or subtraction of small masses from the main drive weight would achieve that result more easily and precisely. Remember in a V&F, unlike pendulum clocks, the mass of the drive weight is completely integral to the resonant system and hence the rate.

If should be considered that the notches on the replica Salisbury clock foliot may be relatively finely pitched compared with how the original may have been, copied as it was from the probably 19thC replica foliot on the Dover clock. I say this on the basis of the historic Llanthony foliot which has widely spaced notches and at first estimate may have given a rate change nearer ten minutes per step. . If the Llanthony foliot notches were for fine regulation they would surely have been cut more closely? For clarity, the Dover clock is a large turret clock reported to have been found in original condition in Dover Castle in 1872 but now some doubt the exact originality of this instrument but it was much copied as authentic. The Llanthony Foliot was found buried in Llanthony Abbey and may be one of the few, if not only, actual original medieval foliots anywhere. . It has widely spaced, but uneven, notches along its length and strongly suggests that these were not simply for rate regulation.

At this point it might be worth considering the effect of temperature. Certainly the foliots expand and contract with the heat and cold in their towers. This change in length is said to demand the movement of the cursors to compensate for the effect. This can now be rejected as impractical. The coefficient of expansion of iron is of the order of 11.8 x $10^{-6 \text{ per } o}$C. Effectively this is the percentage change in length per degree temperature change. So over say a total of 60 degrees C the change in length for a fifteen inch radius foliot will be of the order of eleven thousandths of an inch. Scaled to rate change on the Salisbury clock this amounts to a rounded one and a quarter seconds in twenty four hours. In medieval terms that is wholly undetectable. Temperature was not a problem with verge and foliot clocks and did not need to be corrected for – and indeed in all practical terms could not be corrected for.

Maltin and Houtkooper both discuss the use of the foliot to adjust the rate of the clock to match the seasonally changing day length from sunrise to sunset.. It is my increasingly confident opinion that this is exactly why adjustable foliots were used . In the ecclesiastical world, who could afford to build these great clocks and their towers, the demand was for unequal hours and so they used clocks with foliots. Astronomers and later; medieval secular groups would have used wheel balances for the equal hours that they demanded.

Exploring whether these clocks could be used for unequal hours I tested the full rate range of the Salisbury clock. If the Salisbury clock were to have its rate changed to cover the complete seasonal unequal hours from midwinter eight hours to midsummer sixteen day light hours (about 51 degrees latitude) then it would need to have a beat (half cycle) period in modern fixed time of 2.64 seconds to 5.28 seconds. “Day” is here defined as from sunrise to sunset.

My testing showed that as currently set up the Salisbury has a range of 3.9 seconds to 5.25 seconds. This is very nearly slow enough for the long summer days but 1.3 seconds too slow for the short winter days. The weights need to move inboard a little more.

However the foliot is cranked, or stepped, in replica of the Dover clock, see figure 7. This means that although the cursors in Salisbury can be moved outwards far enough they cannot be moved inboard enough because they collide with the step in the crank shape.. There is no essential technical reason for this crank except that it lifts the cursor weights very clear of any parts of the clock’s structural framework. If the bearing in the potence (the upper bearing and gallows from which the verge hangs) were just a little higher, and this too is a modern “replica”, a straight foliot could have been employed.

An alternative way of looking at this situation is that the cursors have double hangers. These substantially reduce the range of movement that is available in comparison to a single hanger arrangement. In all period illustrations known to the author of cursors they each have only a single hanger, that is, they are simple weights hanging from a single loop , as in my CAD model (fig 1) and on the Hammond clock. All the surviving small clocks and the Japanese Daiymo Dokei (the Japanese equivalent) clocks are like this. Double hanger cursors seem to date from the “discovery” of the Dover clock. In single hanger cursors the centre of gravity of the mass is below the hanger and giving a greater range of movement. .

Figure 7 *The Foliot and Cursors on the Salisbury Clock.*

It can be seen from the photograph that the mass centre movement is limited to actually less than half the available ratchet length of the foliot. If the masses hung from a single hanger and were of a more convenient shape, the mass could be moved much further in and out on the existing foliot, despite the crank. I estimate that a revised pair of cursors with single hangers will give the clock the rate range for the full seasonal variation without any change to the foliot.

<u>Further discussion: - An hypothesis proposing, by way of a question, an alternative to the polarity of the equal/unequal hours debate.</u>

Building on the discovery about rate linearity an effort was made to envisage how V&Fs might have been used in practise to match to the changing day length. If they were stepped every two weeks that can result, around the equinox, in an apparent error of half an hour over twelve hours at the time of change: the clock being set either too slow or fast in anticipation of the day lengthening or contracting over the next fourteen days. This is based on day length changes of four minutes a day around the equinoxes which is of the order of twenty eight minutes in one week. It is this effect that may have given historical reporters and contemporary scholars the impression that there was something inherently unreliable about the clocks whereas the issue arises from the method of use.

The graph, figure 8, shows a clock being stepped every four weeks for clarity in illustration showing in this case that an apparent error of up to an hour a day can result at the time of stepping, rapidly diminishing to zero then up to an hour again before stepping again. The Japanese used bi-weekly steps to half this effect.

Figure 8 *The relationship between the true daylight day length and the step changes of the clock rate with monthly steps. In reality the steps would be every two weeks (as they were in Japan).*

To me a rather beautiful question also now arises out of the debate over whether these clocks were used with unequal hours or were constrained to equal hours.

Let me be clear, the current consensus is that by the end of the fourteenth century equal hours were effectively universal in Europe. But, I ask the question of whether unequal hours were still being used with V&F clocks much later than this and hence they were still being built late into the fifteenth century in the West? In the Ecclesiastical world why would they change, equal hours would give them many problems with their seasonal cycle of prayer from dawn to dusk. In the countryside fixed day lengths would be even more difficult, both groups would want the "old way". If so, how?

There is a problem with unequal hours that I have not seen asked elsewhere: surely people did not spend sixteen hours a day in bed over the months around the winter solstice? Surely not? Before sunrise and after sunset in mid winter there is a long period of weak light which extends the day out to maybe ten or even more usable hours – if only for feeding and penning livestock and checking property. Twilight is formally divided in the world of science into three periods; Civil, Nautical and Astronomical. Each of these is defined by the time it takes the sun to sink six degrees below the horizon at the equinox. In typical European latitudes about twenty five minutes per period. I have read a book at relaxed arms-length outside on a clear starlight but moonless night for about an hour after formal sundown. There was still sufficient light to do other simple physical tasks, like bring in stock, feed animals or stack firewood until that time or a little after. Medieval eyes used to the dark would have done much better than mine. So, for artisan and country workers the midwinter day of eight hours sunlight can be extended at both ends by more than an hour. However, in midwinter this far north the effect lasts longer, perhaps as much as fifty percent. So, almost twelve hours are available in midwinter for practised eyes without much need for the extremely expensive assisted light. This starts to make the situation more reasonable but still puts people in bed for twelve hours.

In the Victoria and Albert Museum there is an intarsia panel showing a Sacristan's cupboard. In the cupboard is a verge and foliot alarum clock. There is also in Urbino a remarkably similar intarsia of a Sacristan's cupboard. Both believed to be from the late fifteenth century. See figures 9, 10, & 11 below.

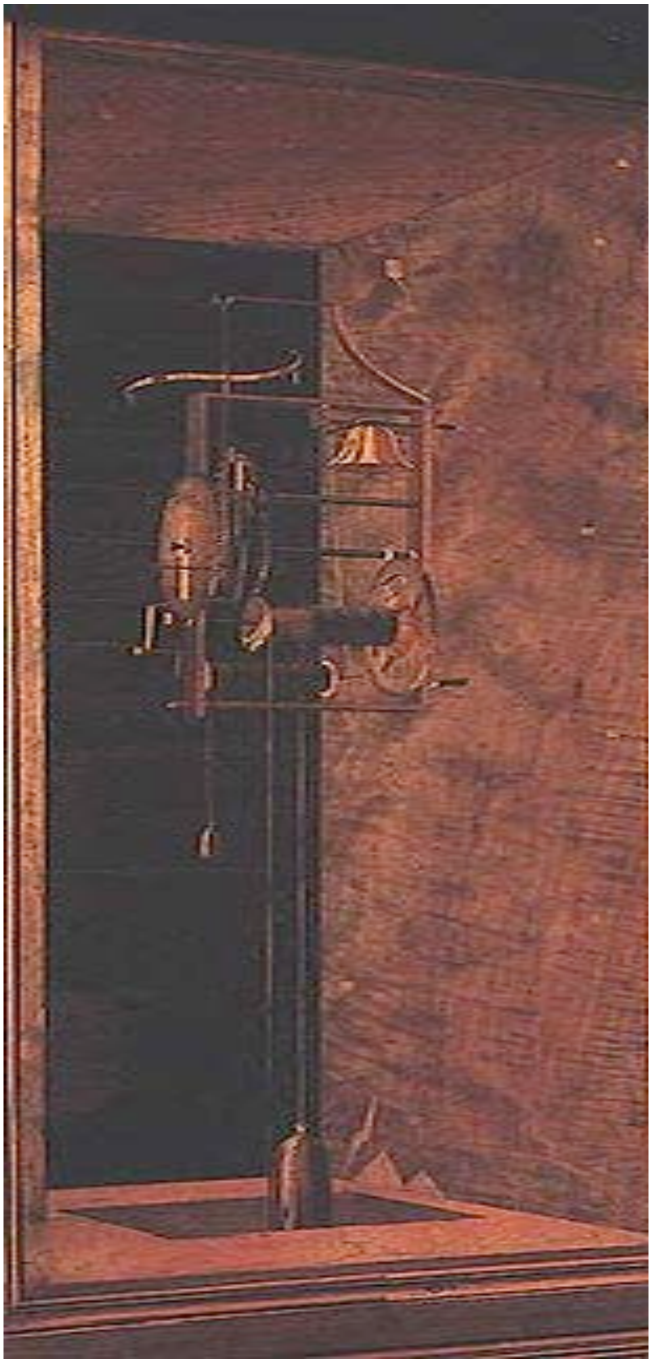

Fig 9. *The Urbino clock showing the curved foliot beam.*

Figure 10 *The intarsia panel in the Victorian and Albert museum (copyright V&A)*

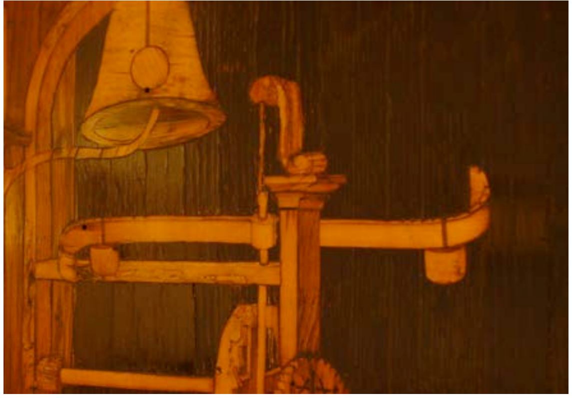

Figure 11 *Enlargement of the foliot on the V&A panel Fig 10 and 11 photos taken by the author with the permission of the V&A.*

Remarkably both of the clocks shown have foliots with curved ends. The perspective of the panels suggests that these curves are in the horizontal plane. At first sight these bowed foliots are unexpected, have no commonly known surviving parallels in practise and no normal explanation. Contemporary horologists say these foliots are “artistic license” and “impossibly curved” and were not actually present in the real clocks. I suggest an alternative explanation. My reason for this starts with the reality that in the Renaissance period work of this kind was commissioned by a patron to be precise examples of the new understanding of perspective. In the case of the Urbino clock perhaps the patron was Federico Montefeltro who set high standards. Makers of intarsia were very conscious of being considered second division artists and so went to extraordinary lengths to reproduce their images with immense precision. It would not have occurred to them to introduce “artistic license” either at risk of undermining their own reputation as observers and worse, the wrath of their patron who would reject the work. To have survived in Urbino of all places this example must have been stunningly accurate in every single detail – foliot included. Equally it is unlikely that two different artists at two places should have taken the same liberty with the same detail of the clocks having got all the other components exact.

We must look again at these panels and assume that they mean what they tell us – that there were many examples of bowed foliots. It is our duty to understand them as documents, not dismiss them as inconvenient and inexplicable.

There is a pleasingly elegant explanation. As already indicated in the graph showing the changing day length this happens over the year in something approximating to a sine curve. It is not actually a sine curve but that is an adequate description. So the movement of the cursors on the foliot have also to move radially in a progressive manner accordingly. For the straight foliot on the Salisbury something close to four steps in April, then three, three again, two and one will give a rough match to take the clock to the middle of June, then miss one then step out in reverse order to the end of September. This would be adequate for most working and ecclesiastical purposes in the fourteenth century one might suppose. However it requires a table to keep track and therefore a literate operator. But, if the foliot is curved correctly and has on it a series of widely and equally spaced notches the cursor can be moved out one notch at a time and as it moves round the curve it will reduce its true radial movement and so more nearly match the change in day length. An illiterate operator could then simply move the cursor one step every two weeks and the clock will run correctly.

This was just an hypothesis albeit based in Science and Engineering principle. So I made an example to test. The first challenge was to design the curve. This turned out to be amazingly simple once I had set out the geometry in CAD (computer aided design). To go into the exact procedure here will be extensive but what came out of it was that a perfect radius for the bend was all that was needed, not any kind of complex parabola or sine curve. Making one therefore was also relatively simple and I did so, figure 12, such that it would fit the Hammond clock. It was fascinating to make something that had not been made or seen for perhaps five hundred years.

Fig 12 *Model sinous foliot and replica of Llanthony foliot for testing at the BM.*

The test was conducted in early 2012 in the British Museum and produced a result rather better than expected. As part of the project I had prepared a graph of how the day changes over the summer season and then calculated what the period would be from my design and accordingly developed the day curve. We tested the beam on the clock, figure 13, and laid the results over the target shape and it fitted almost perfectly. There was no doubt that this use of a sinous foliot with equally spaced notches could match the summer changing unequal hours. This validates the intarsia panels as valid records of what could be done for the summer season and that such shapes are possible and practical. In fact they also bring a side benefit – if the maker gets the curve slightly wrong or wishes to adjust the going rate of the clock marginally then all he has to do is bend the beam a little. He does not have to file out the notches or re-cut notches in new places.

Fig 13 *Hammond clock in the British Museum fitted with sinous foliot. Compare with the pictures of the intarsia panels.*

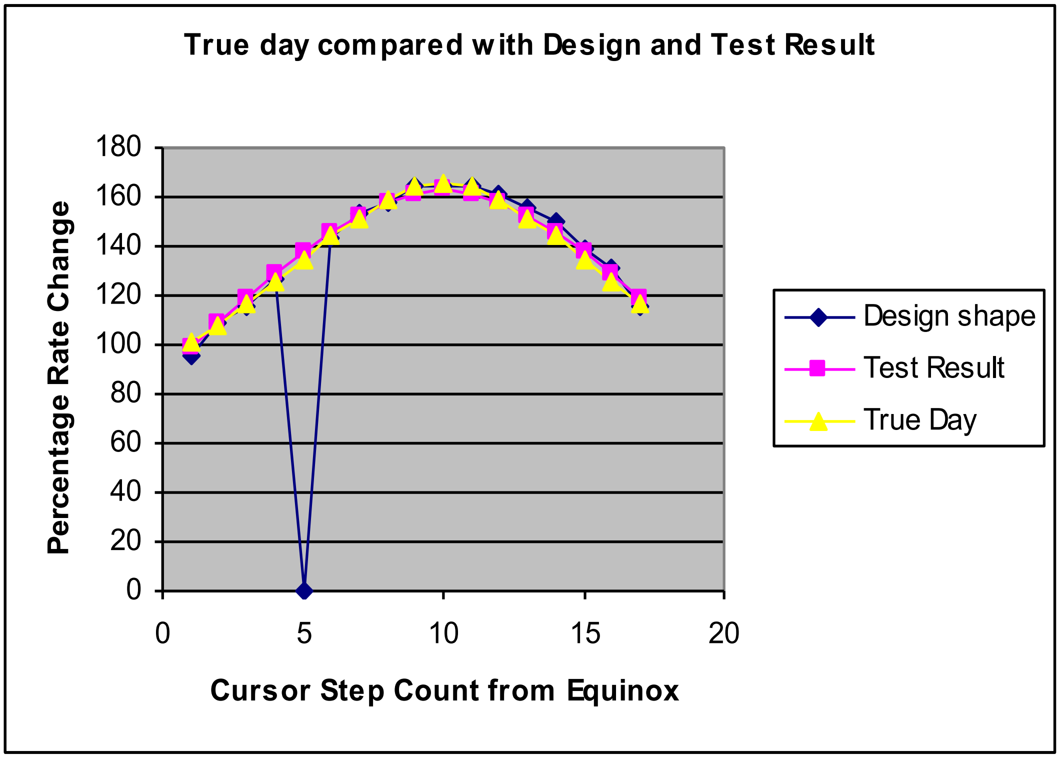

Fig 14 *Summary graph of the required and actual showing close fit of real data (dark line) with true daylight time (pink line). It must be noted, the data from the test runs was scaled by a single constant to align with the co-ordinates of the graphs of the real day and calculations because the clock was not regulated to be the exact rate but that does not change the shape of the curve which the key issue: the intention was to show that the rate of change of the rate matched the rate of change of real time with the season. The strange "blip" is because of a data recording error and instead of correcting it I have shown it as a negative number so that there can be no question of manipulation.*

Moving the cursors on these clocks gives a match to the unequal hours of the sinusoidal summer but what about the winter? If they are to match the winter with similar simplicity then they should also have a curved shape at their inner ends too. But they don't. So, if these two pieces of hard physical evidence are valid and representative of clocks of their period in summer then how are they to be interpreted for the winter?

By way of a question and not any kind of conclusion perhaps the following thought might be a clue? Opinions on this question would be very welcome.

I have already mentioned the improbability of spending sixteen hours in bed in midwinter that the conventional unequal hours model requires and that the more practical view of winter workable day including twilight gives a better model. Add to that also that two weeks of every month has a half moon or better then even more of the dark time is available for useful or leisure activity. Did they use it in a way that is not currently considered?

Would it not be practical to suppose that in the medieval period they did not shorten the day between, say, the autumn equinox and the vernal equinox, or maybe the beginning of November to the end of February? This would give six or four winter months of equal hours as we have today. A twelve hour working day with some challenges in late December to mid January with the extra darkness for the first and last hour but not impossible for those used to it. This gives a completely new way to look at antique time keeping: equal hours in winter and extending unequal hours in summer to maximise the daylight available. A similar but in many ways better method, certainly for an artisan and canonical society, than our "daylight saving" system used today.

This testing of the sinous foliots induces a completely new way of looking at medieval timekeeping – they may not have used either perfect unequal hours or perfect equal hours but a rational hybrid to suite real working practise. This new insight to the medieval winter is not completely to be unexpected; the Republican Romans did not even have names for the two winter months; Julius Caesar had to invent names for the two new months inserted into his re-organised calendar because winter was thought of as a single event to be survived as best as possible. Getting the day length precisely right in order to stay in bed as long as possible is utterly nonsensical in that context, we have to rethink our approach and I suggest that the intarsia clocks give is a very broad hint indeed.

Let me emphasise, this last section is a question – did the medieval world live in asymmetric time – lengthening summer days between the equinoxes and with fixed days in winter? This seems a practical and workable solution and it does not have the problems we have with "summer time". Is there anything in the texts, now that we know what to look for, that might support this hypothesis? It is nothing more than an Engineering suggestion derived from visual inspection of the physical evidence at this stage.

It does raise the question: what did the Japanese do? So far I have been unable to discover: this information seems to have been lost in Japan although it is being researched for me. However, they are at longitude 36 north compared with say, central Italy at around 43 north and England around 53 north. In Japan the change in day length is not so great and so the issue of the very short winter day does not arise so much.

Summary

What this testing has achieved is to prove, subject to confirmation by other practitioners: -

1.0 A well maintained Verge and Foliot clock has the capability to keep reliable time to within two minutes in an apparent twelve hour day.
2.0 That the movement of the cursors on the foliot gives an exactly linear rate change regardless of the starting point on the foliot.
3.0 That one step on even a relatively finely divided foliot is too big for rate adjustment to achieve precision time keeping.
4.0 That temperature effects are negligible and the much repeated needed rate change to compensate for cold at night is not sustainable.
5.0 That it is easy to make a sinous foliot with equal steps to match the summer variable hours similar to those in the famous intarsia panels.

All of these raise the question; “were fixed or equal hours used in the winter months and extended unequal hours in the summer” during the middle ages”? It has been clearly proved by demonstration that this would be completely within the capability of contemporary Verge and Foliot clocks. There is much more to learn about medieval Verge and Foliot clocks that will educate us about the brilliance of the minds of people in the medieval world.

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