The First Correct Drawing of the Grasshopper Escapement Ever Published

Peter Hastings reports.

The title for this article was written by Rupert Gould in 1929[1]. The phrase was used to describe a diagram in the Report to the RAS[2] by E T Cottingham[3] on his examination of, and repair work to, the late regulator by John Harrison.

I have scanned this diagram from the original printed volume. **Figure 1** shows the diagram scaled so that the OD of the escape wheel is five and five-eighths inches and then overlaid with a CAD 'tracing' in red. All the dimensions are stated in inches.

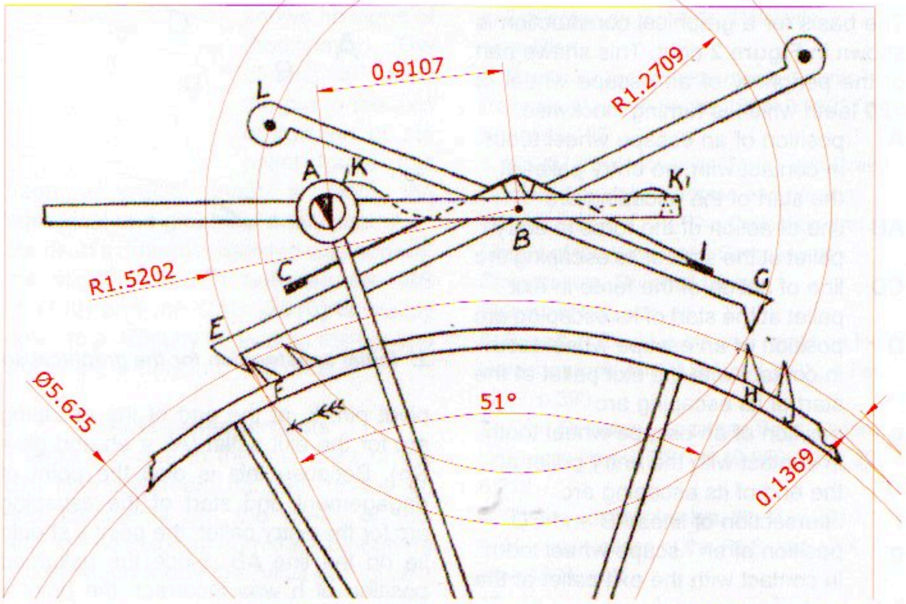
In Figure 1 the pendulum is swinging clockwise about A (the crutch arbor) and is being impulsed through the exit pallet EB. Eventually the entry pallet BG will contact tooth J on the escape wheel and the momentum of the pendulum will push the escape wheel backwards. This will release the exit pallet which will rise out of the path of tooth F and come to rest against stop C. The pendulum will then swing anti-clockwise until the exit pallet engages the escape wheel again, drives it backwards and releases the entry pallet. A more detailed description and explanation of grasshopper escapements can be found in Chapter 9 of *Practical Clock Escapements* by Laurie Penman[4].

Figure 1 is made a little hard to follow because the pivot pin for the pallets is shown directly above the centre of the escape wheel with the crutch arbor to the left. In reality, of course, the crutch arbor is directly above the centre of the escape wheel and the pivot pin would be to its right. The confusion is compounded by the escapement being drawn as seen from behind, as it might be on the bench, with the escape wheel shown turning anti-clockwise.

All other diagrams in this article show the escape wheel turning clockwise and the crutch arbor directly above the centre of the escape wheel.

Allowing for the fact that Figure 1 is an illustration which has been printed and then scanned rather than a working drawing, the good correlation between the details shown above and Harrison's own drawing suggests that the escapement as it was in 1909 conformed to Harrison's intentions and was probably original.

It is reasonable to conclude that the diagram published in 1909 in the Monthly Notices of the RAS was prepared from careful measurements of the escapement.



1. Dimensioned scan of the first diagram in Cottingham's report of 1909 to the RAS. Dimension in inches.

Notable points of agreement are:

the length of the entry pallet	+ 5%
the length of the exit pallet	- 3.5%
distance from the crutch axis to the escape wheel axis	- 0.6%
the number of escape wheel teeth spanned	identical
the distance from the axis of the crutch to the pallet pivot	+ 0.5%
the length of the escape wheel teeth	+ 1.2%

the line of action of the force transmitted by each pallet at the start of its escaping arc is tangential to the periphery of the escape wheel.

The photographs which accompany Cottingham's report show that the pallets were not straight, as shown in Figure 1, but were in a shallow S-shape which was convex upwards next to the working end of the pallet. The counterweights for the pallets were formed as an elegant scroll. Sadly, both pallets were broken in an accident in 1910 and had to be replaced by Rupert Gould in the late 1920s. Gould used an enlarged model of an escapement to determine the angles and lengths of the replacement pallets.

Cottingham describes the pallets as being made of lignum vitae. Gould states[6], however, that the pallets he replaced were made of mahogany and the ones that he made were of lignum vitae. Both Jonathan Betts[7] and Martin Burgess[8] have stated that mahogany would be a more appropriate material for the pallets. So there is no certainty as to what material Harrison actually used.

Cottingham reported the working arc as 12½ degrees. The supplementary 1.1 degrees at each end of the action causes a clearance of only 0.005 inch at the entry pallet and 0.007 inch at the exit pallet. This underlines the need to make the working faces of the pallets of such a shape (true arc or otherwise) that there is no possibility of them dragging across the escape wheel tooth after release.

Cottingham comments[9] on the very small size of the recoil: 'Although there is a very slight recoil of the escape-wheel, it would be a great injustice to Harrison to compare it with that commonly known as the recoil escapement, for the working conditions are so different...'

The above examination further strengthens the conclusions drawn by Johnson et al, concerning the geometry of the escapement in the RAS clock, which were reported last year[10] in the pages of ***HJ***. Although their analysis to derive the geometry of the escapement was numerical, it is possible to use graphical methods to reach identical conclusions from the same two basic premises. These were :

The escapement spans 17 teeth, or 18 when the action of the pallets interchanges.

The basis for a graphical construction is shown in **Figure 2** right. This shows part of the periphery of an escape wheel of 120 teeth which is turning clockwise.

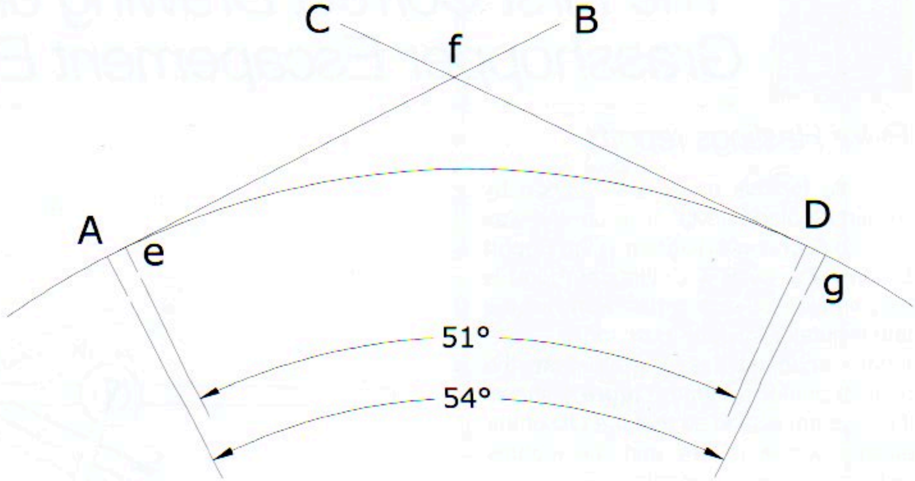
- **A** position of an escape wheel tooth in contact with the entry pallet at the start of the escaping arc
- **AB** line of action of the force in entry pallet at the start of its escaping arc
- **CD** line of action of the force in exit pallet at the start of its escaping arc
- **D** position of an escape wheel tooth in contact with the exit pallet at the start of its escaping arc
- **e** position of an escape wheel tooth in contact with the entry pallet at the end of its escaping arc
- **f** intersection of lines AB and CD
- **g** position of an escape wheel tooth in contact with the exit pallet at the end of its escaping arc

AB and **CD** are tangential to the periphery of the escape wheel but the following method of construction will still work perfectly well even if they are not.

The construction is as follows :

The common pivot pin for the pallets lies somewhere along the line CD at the end of the escaping arc for the entry pallet (which is also the start of the escaping arc for the exit pallet). This point lies slightly to the left of the point f. Assume a position, h, for the pallet pin and therefore a provisional length, hD, for the exit pallet, **2a.**

The red circles show the lengths of both pallets based on the assumed position, h, of the pivot pin at the end of impulse by the entry pallet. The length of the entry pallet is the radius eh. With the length of both pallets determined it is possible to determine the position of the pivot pin, k, at the end of the escaping arc for the exit pallet (Ak = eh and gk = Dh). Because this is also the point of engagement and start of the escaping arc for the entry pallet, the point k should lie on the line AB. Since the assumed position of h was incorrect, the point k lies to one side of AB. Assume a new position h' for the pivot such that the resultant position, k', of the pivot pin at the end of the escaping arc for the exit pallet is on the other side of line AB from point k.



2. Initial construction for the graphical solution.

The correct position of the pivot point at the end of the escaping arc for the exit pallet is found by drawing a straight line between k and k'. Where this line, kk', crosses the line AB is the correct position, K, for the pivot pin when the exit pallet hands over to the entry pallet. The correct length of the entry pallet is AK and the correct length of the exit pallet is KP. These lengths can then be used to determine the correct position, H, of the pivot pin at the end of the action of the entry pallet. As required, this lies on the line CD, **2b.**

This settles the two positions, H and K, of the pivot pin when one pallet hands over to the other. The remaining geometry concerns the position, L, of the crutch arbor. L will lie somewhere to the right of HK. The distances HL and KL are the same. In the case of the RAS regulator, the distance HL is known. It is 29/32 of an inch. Striking arcs of this radius from K and H gives the location of L. If HL were not known, or it were desired to use a specific escaping arc, then L can be found by noting that :

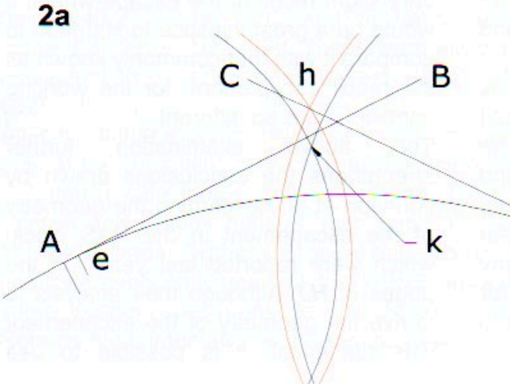
the angle HLK is the escaping arc.

L lies on a line perpendicular to line HK which crosses HK at its mid-point (the perpendicular bisector of HK).

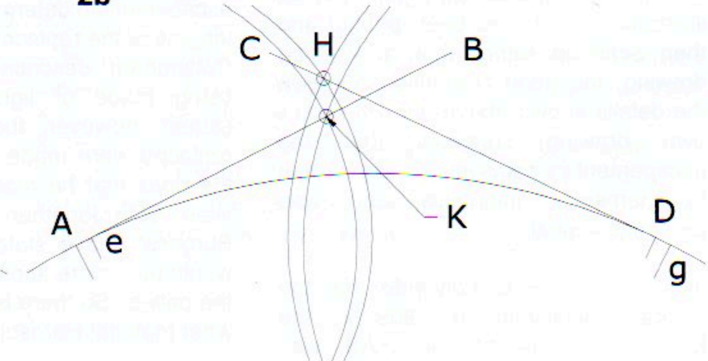
There is not infinite freedom to reduce the escaping arc by increasing HL, however. When the point L moves to the right of the perpendicular bisector of line Dg the escapement will cease to work at all. Well before that, however, the distance that the exit pallet lifts onto its composer when it releases will be too small, and the pallet face too short, to make a reliable escapement. For those who prefer to use computer-based methods, a spreadsheet has been prepared which is derived from, and analogous to, this graphical analysis **2c**. It will be available in due course on the BHI website.

The various dimensions from this drawing have been measured and are

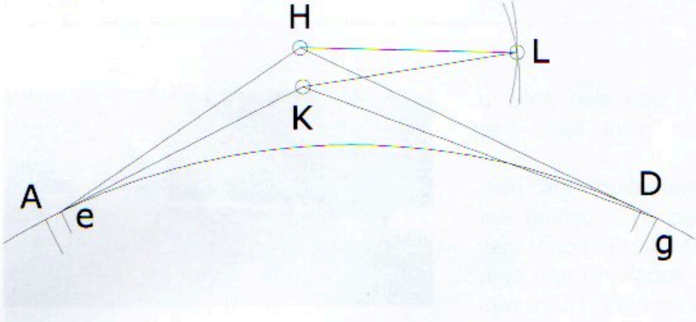
2a



2b



2c



compared in **Table 1** (see below) with the results reported by Johnson[11].

This is a comforting cross-check, suggesting that each method is valid and the results are sound. The acid test is to compare these results, not against each other, but against a 'Higher Authority'. The results of doing this are shown in **Figure 3** below.

A number of conclusions may safely be drawn from Figure 3:

Harrison intended that the line of action of the force in both pallets at the start of their escaping arc should be tangential to the periphery of the escape wheel.

Harrison intended this layout to be used on what is now known as the RAS regulator and he actually made the hardware to these dimensions.

Although neither of the original pallets survives, the position of the pivot pin in the pallet frame shows no signs of modification. The dimension[12] from the pin to the axis of rotation of the pallet frame has been a crucial input to both the numerical and graphical analyses.

Harrison's draughtsmanship was superb; the slight mismatch between the MS (c.1740) and the CAD (2010) is mainly down to a difficulty in dividing the escape wheel accurately into 120 parts.

Acknowledgements

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References

1. *The Society's Harrison clock;* Monthly Notices of the RAS, Vol. LXXIX, 4 Feb 1929, pp.398-401.

2. *A Description of the Society's Harrison Clock;* Monthly Notices of the RAS, Vol. LXX, 1 Nov. 1909, pp.25-28.

3. Edwin Turner Cottingham FRAS, assistant to Eddington on the 1919 'Relativity' expedition.

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5. MS3972/3; *Mechanical Notes and Drawing Compiled by John Harrison and his son William c.1726-1772;* The Collection and Library of the Worshipful Company of Clockmakers, Guildhall Library, Aldermanbury, London.

6. Rupert T. Gould in his own report on the Harrison clock; MNRAS, Vol. LXXIX, 4 Feb 1929, p.399.

7. *Time Restored*, Jonathan Betts, Oxford University Press, ISBN 0-19-856802-9, 2006, p.212.

8. Private communication, 8th May 2010.

9. Monthly Notices of the RAS, Vol. LXX, 1 Nov. 1909, p.27.

10. *Horological Journal*; Vol. 152, No.4; April 2010; pp.170-176.

11. *Horological Journal*; Vol. 152, No.5; May 2010; p.197.

12. This has been measured both by Cottingham in 1909 and, more recently, by Jonathan Betts.

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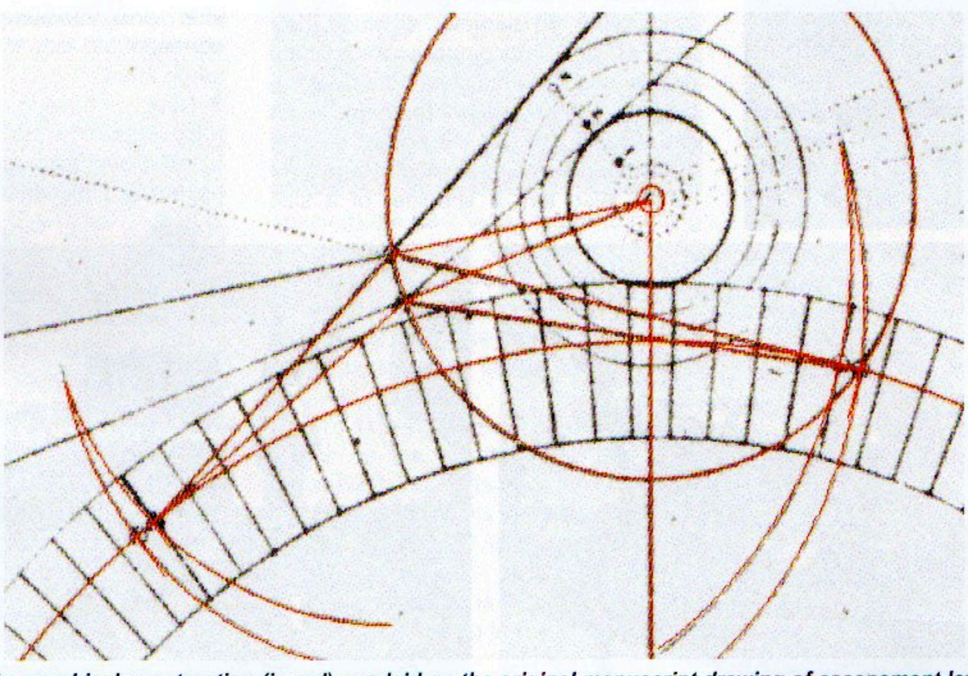
Table 1 : comparison of results from the numerical and graphical constructions for the escapement of the RAS regulator

	Graphical Construction		Johnson et al
Escape angle in degrees	10.329		10.328
	inch	mm	mm
Crutch pivot above escape teeth	0.4582	11.638	11.640
Entry pallet arm length	1.2077	30.676	30.676
Exit pallet arm length	1.5761	40.033	40.032



3. CAD drawing of the graphical construction (in red) overlaid on the original manuscript drawing of escapement layouts[5] by John Harrison.