Program for a Dead-Beat Escapement

G M Smith shows how to use a computer to cut out the guessing and produce one that works

IN VIEW OF Ted Wale's article discussing the dead-beat escapement[1] and Dick Stephen's detailed description of making the escapement for his six-month movement[2] (*HJ* March 2005) I would like to present a different approach to some of the problems involved. The difficulty of making a dead-beat escapement that actually ends up with the intended and required characteristics is quite considerable. When this is attempted by the traditional method of 'cut-and-try' I think it is almost impossible. Obviously people make dead-beat escapements that work but I would question whether the design objectives are actually achieved. I certainly have found the traditional process extremely tedious and not totally successful in producing the design parameters for which I was aiming.

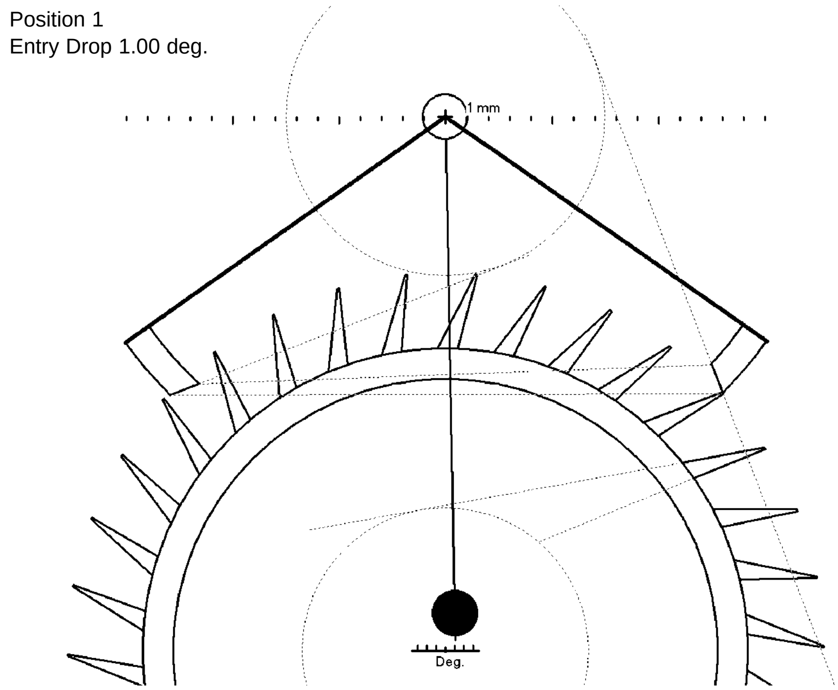
My approach is to calculate the escapement dimensions required to achieve the design and to make as near as possible to these dimensions. One thing that jumps out from these calculations is the very small tolerance that must be achieved to realise the expected performance. Dick Stephen[2] has shown the care with which the escape wheel must be finished to correct errors which have occurred in the initial cutting when one is aiming for small values of drop.

In view of this, and the consequent difficulty of making the wheel to an absolute size, I think the best approach is to first make the wheel to the best possible accuracy of tooth pitch and concentricity and then measure its diameter. Provided that the wheel has an even number of teeth, as is usual, this is not difficult. This diameter is then used for the calculations that will arrive at the dimensions to which the pallets must be made.

The only writer I have seen on this subject who has calculated dimensions for the escapement is Derwent Mercer, whose articles, first published in 1979, were repeated in *HJ* in 2003.[3] Having done this he then advocated cut-and-try when making and adjusting the escapement, not using the dimension produced. He is also the only writer I have come across to consider and calculate the clearance resulting from the design and he points out how small this is. Unfortunately he makes a mistake in this and the correct value is even smaller; it should be about one third of his value.

The clearances I calculate are the shortest distances between tooth and pallet, and these occur as the other pallet starts its impulse. Clearance is ***the*** critical factor, as errors in all other parameters, if not too large, will still allow the escapement to run – albeit with reduced efficiency. Negative clearance means a non-runner.

Calculation of escapement dimensions is not difficult but can be tedious, particularly if revisions have to be made to the design in the light of first results. Because of this I have written a computer program[4] to do all the sums. This allows all mechanical and design data to be entered and then calculates all dimensions to give the required design parameters. Since this is virtually instantaneous all sorts of 'what if' variations can be tried if the input data results in an unworkable mechanism, or if the necessary tolerances are too tight or can be tightened. This can



ESCAPEMENT INPUT DATA and RESULTS for File GMS1.DBT 16/03/2005

Escapement Wheel Diameter 35.00 mm. Tooth Tip Witness 0.30 deg.
Number of Teeth 34 Drop 1.00 deg.
Tooth Span 9 Lock 0.30 deg.
Impulse Angle 2.00 deg. Included Tooth Angle 12.00 deg.

Pallet-to-Wheel Centres 24.75 mm.
Incident Angle of Pallet and Wheel 90.00 deg.

Pallet Inside Radius 16.84 mm. Pallet Outside Radius 18.16 mm. Pallet Thickness 1.31 mm.

Entry Locking Corner to Exit Release Corner 25.59 mm.
Entry Release Corner to Exit Locking Corner 23.74 mm.

Pallet Generating Circle Radius 7.38 mm.

Tooth Generating Circle Radius - Front 6.64 mm. Back 3.04 mm.

Pallet Incline Angles Entry 24.94 deg. Exit 24.94 deg.

Actual Pallet Impulse Angles Entry 1.997 deg. Exit 2.003 deg.

Pallet Clearances Entry 0.160 mm. Exit 0.157 mm. G.M.Smith.

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1. Wale, Ted. 'Deadbeat Discussion' *HJ* **147** (3) p.81.
2. Stephen, Dick. 'A 6-Month Weight Driven Movement'. *HJ* **147** (3) p.89 March, 2005.
3. Mercer, Derwent. 'Studies in the Dead-Beat Escapement'. (*HJ* Jan/Feb 1979) reprinted *HJ* **145** (8) p.273, (9) p.331, (10) p.366. (August, September, October 2003).
4. To obtain a copy of the program contact: gsmith12@toucansurf.com

give a better understanding of how the escapement works. To demonstrate this I have used a typical 'square' configuration with a 34-tooth wheel and pallets spanning 8 tooth spaces. I have allowed the program to calculate the best escape wheel/pallet centre spacing, but a specific spacing can be entered to allow existing escapement arrangements to be calculated. After the first calculation is done, this spacing can be modified in steps of 0.01 mm. to show the effect of errors in depthing.

The input and output data is displayed on the screen together with a diagram, **1**, which serves to confirm that the layout is as expected. This diagram can be stepped round manually or run automatically, and at each step the value of the relevant parameter is displayed. These are entry and exit locks, drops and clearances. Enlarged views of the individual pallets can also be shown. Also calculated are the pallet dimensions, the internal and external radii and the pallet thickness, and the distances between the tips of the pallet impulse faces. These latter two distances are the primary dimensions to which the pallet assembly must be made as these determine the clearances, locks and drops and their symmetry.

These dimensions are not too easy to measure and I use a microscope attached to the knee of my milling machine, with the pallet assembly on the table. I focus the microscope using the traversing feed as this removes the necessity for mounting the microscope exactly at right angles to the longitudinal feed. The measurement is then made using the longitudinal feed, which is fitted with a digital read-out. If possible the measurements should be made within 0.01 mm, particularly if small values of drop are aimed for.

The other important dimension is the pallet thickness as this also controls the drop, but this is easily measured. The drop I define as the free rotation of the wheel (in degrees) between the end of one pallet's impulse and locking on the other. By this definition, the tooth tip witness is included in the drop and is not additional to it.

This defines the thickness of the pallets to be one half of the tooth pitch minus the drop, which Derwent Mercer categorically states to be incorrect. His example however, demonstrates it to be true. It seems to me logical to include the tooth tip witness in the drop as this gives the total free rotation of the wheel, and this is where the effect of inertia of the escape wheel shows up. The rotation of the wheel must be fast enough so that, even with no supplementary pendulum arc, the wheel locks securely and does not land on the impulse plane. Provided that this condition is satisfied there is no point in reducing inertia further as the momentum of the wheel is constant.

The radius of the circle defining the pallet faces is calculated and this is used as described by Dick Stephen[3] and many others[5] to grind the pallet impulse faces to the correct angles. The general method is to pivot the pallet assembly on a pin, which is offset on either side of the grinding wheel plane in turn, to grind each pallet face. The two offsets do not have to be set up with enormous accuracy to equal the circle radius, provided that the offsets are equal.

If they are not set to the circle radius there will be a minor error in the impulse angles but so long as they are equal the entry and exit impulse angles will be equal, and this I feel that this is more important than the actual angle. I prefer to use two pins so that once set up they do not have to be moved.

My program only uses the case where the entry and exit pallets have equal radii, and can be formed by simple turning. This means that the entry and exit locking radii are not equal, as one is internal and the other external. While there may be some slight advantage in making them equal it introduces a difficulty of manufacture that I feel is not justified.

Other calculations made are of the tooth generating circles, which define the slopes of the front and back of the teeth. The slope of the front of the teeth is set by the program to be 10° to the radial, and the tooth angle as set by the input data is that of the actual tooth itself. The Pallet Incline Angles are the angles made by the pallet impulse faces and the radii from the wheel centre to the mid-point of the impulse faces when the tooth tip is at the face midpoint.

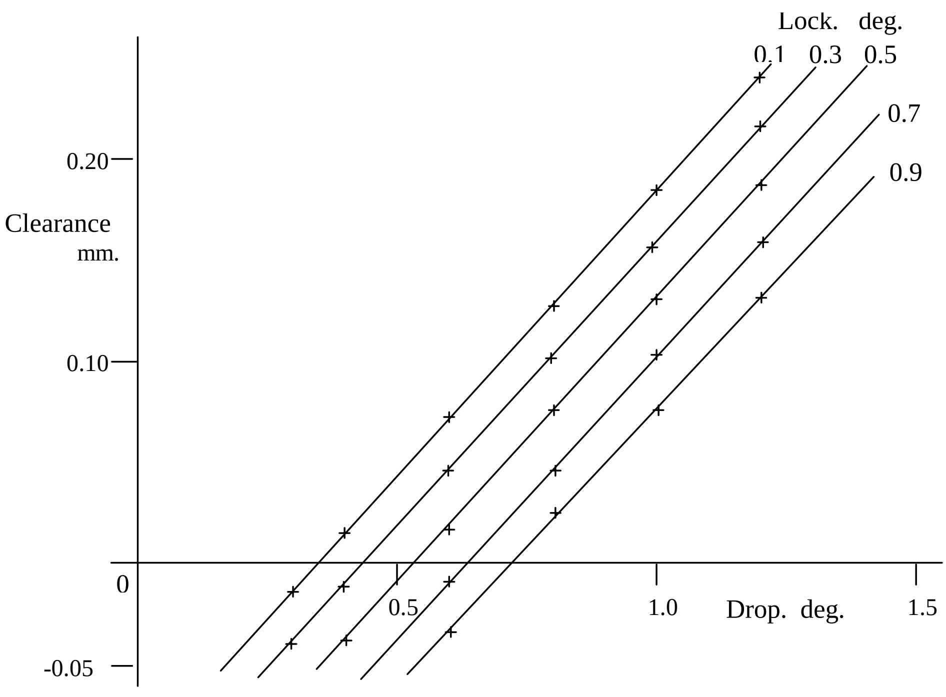
For a 'square' configuration these angles will be equal but will of course be increasing on the entry pallet and decreasing on the exit pallet during the impulse. The angles give the 'gearing' between the escape wheel and the pallet assembly; that is, the rate of change of pallet angle as the wheel gives the impulse. The actual angles moved by the pallet assembly during the impulses are very slightly different, due to the curvature of the tooth tip path. They can be made equal by a very small reduction in the wheel-to-pallet centre spacing and this was advocated by G D Aydlett.[6]

It can be seen from **1**, that the difference between the angles is extremely small. The spacing reduction to correct them is about 0.01 mm. and I feel that few of us will achieve that sort of accuracy in our depthing.

Figure **2** shows the variation of clearance as other parameters change. This illustrates that with this basic escapement it is not possible to achieve a drop smaller than about 0.3°, even with a lock of as little as 0.1° as the clearance goes negative. With a set of graphs like this it is easy to choose parameters, depending on how optimistic one is of ones machining capability.

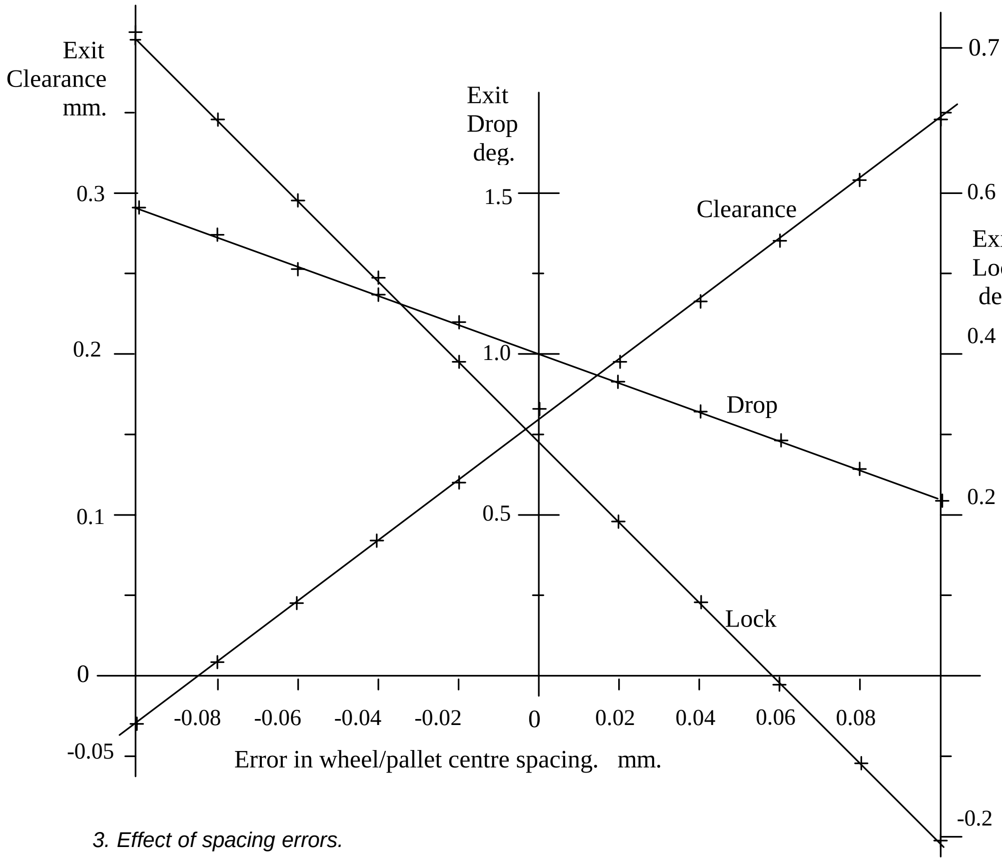
Figure **3** shows how dependent the drop, lock and clearance are on correct

5. Timmins, Alan A. 'Watchmakers Workshop Regulator' *HJ* **123** (9) p.16 (March 1981).
6. Aydlett, G D. A Review of George Graham's Classic Escapement. NAWCC *Bulletin* No. 8.



2. Variation of clearance with Drop and Lock.

Illustrations by the author



3. Effect of spacing errors.

depthing of the escapement. The values shown are for the exit pallet. The values for the entry pallet are very similar, except the drop and clearance graphs have the inverse slopes. Both locks increase and decrease together. These graphs suggest that the wheel/pallet centre spacing should be within about 0.02 mm of the correct value. This accuracy is probably not achievable, at least not by me, unless a jig-borer is available and so some means of adjustment of the spacing is necessary.

Performance

Having finished the clock and got it ticking, the next question is how well is it achieving the design specification? While it can be argued that so long as it goes, the only criterion is the time-keeping, it is still of interest to know if it performs to specification. The only way I have thought of is to look at it in operation, preferably with a magnifying glass, but it is not easy to see the detail, particularly if it is a fast ticker.

A way that I have tried is to harness the amazing technology built into a digital still camera. If one takes a movie sequence, as almost all cameras can, and displays it on a television screen it is possible, with my camera at least, to stop the replay and click through individual frames. With my camera the movie frame rate is about 15 frames/sec., which is fast enough to catch any required part of the escapement cycle. The problem is to get a sufficiently clear and close-up view.

As my present clock under construction is a skeleton, the clear view was not difficult but the close-up view was. As the camera resolution in movie mode is much lower than the resolution for stills, closeness is important. While my camera has a macro focus setting, allowing focusing down to about 8 cm, the zoom facility does not work in this mode, defeating the object somewhat. So I tried using a supplementary lens. This is a simple lens held with sticky tape into a cardboard tube that fits over the camera lens mount. I was able to find one that gave a suitable magnification and a satisfactory optical performance. In addition the zoom and automatic focusing still work.

With this I have found it fairly easy to look at and check each part of the cycle. Clearance is the best parameter to check when adjusting the depthing as, using the dimensions given, **1**, clearance varies by about 23% as the spacing is varied by 0.02 mm, while the drop only varies by about 9%. However clearance is difficult to see and another possibility is to check the lock. Both entry and exit locks will be equal and increase together as the wheel/pallet centre spacing is reduced and so the depthing has to be adjusted until either lock is at the design value. At this point the clearances and drops will be equalised, provided that all dimensions are correct.

As a further demonstration of the program I have used the dimensions given by Dick Stephen for his six-month movement, as this could be helpful to those who are making it. This clock has an escape wheel 28 mm in diameter, with 30 teeth each having a tooth-tip witness of 0.15 mm. The pallets span 10 teeth, have internal and external radii of 23 and 24.3 mm. The escape wheel-pallet centre distance is 28 mm. It is not clear from the description whether these dimensions are considered final or whether they will all be adjusted during the cut-and-try procedure. The design aim is a drop of 0.1°. but to this must be added the tooth-tip witness of 0.15 mm (equivalent to about 0.6°) to suit my program.

Using these figures, with a total drop of 0.8°, a lock of 0.1°, a tooth angle of 13° (estimated from his diagram) and an impulse angle chosen to give a pallet generating circle of 15 mm radius, gives the results shown, **4**

This looks acceptable, if a little unbalanced, but in fact it will lead to an exit lock of –0.23° as the escapement is stepped round. The entry lock is 0.1°, as specified, and this does not agree with my earlier point; that the two locks will be equal. This is due to the constraint of the

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ESCAPEMENT INPUT DATA and RESULTS for File Stephen.dbt 17/03/2005

Escapement Wheel Diameter 28.00 mm. Tooth Tip Witness 0.61 deg.
Number of Teeth 30 Drop 0.80 deg.
Tooth Span 10 Lock 0.10 deg.
Impulse Angle 2.55 deg. Included Tooth Angle 13.00 deg.

Pallet-to-Wheel Centres 28.00 mm.
Incident Angle of Pallet and Wheel 93.05 deg.

Pallet Inside Radius 22.88 mm. Pallet Outside Radius 24.15 mm. Pallet Thickness 1.27 mm.

Entry Locking Corner to Exit Release Corner 24.11 mm.
Entry Release Corner to Exit Locking Corner 22.85 mm.

Pallet Generating Circle Radius 14.95 mm.

Tooth Generating Circle Radius - Front 5.61 mm. Back 2.43 mm.

Pallet Incline Angles Entry 36.45 deg. Exit 42.55 deg.

Actual Pallet Impulse Angles Entry 2.384 deg. Exit 2.716 deg.

Pallet Clearances Entry 0.088 mm. Exit 0.026 mm. G.M.Smith.

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