MATHEMATICS OF A **COAXIAL** ESCAPEMENT

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1. Subject

   This article is a continuation of the preceding one named " Mathematics of a watch escapement", (www.hsn161.com/HSN/Petrangeli2.pdf) whose introduction has been published on HSN Newsletter, Issue 2017-3, July 2017. This previous article was devoted to the mathematical model of the well known Swiss Lever Watch Escapement.

   The subject here is a similar study of the Coaxial Escapement, patented by George Daniels (see Appendix 1). Reference will be frequently made to the previous article as well as to the text of the patent request (Appendix 1). Main References are those of the previous article. Numerical data, if not taken from Appendix 1, are the same as those of the previous article.

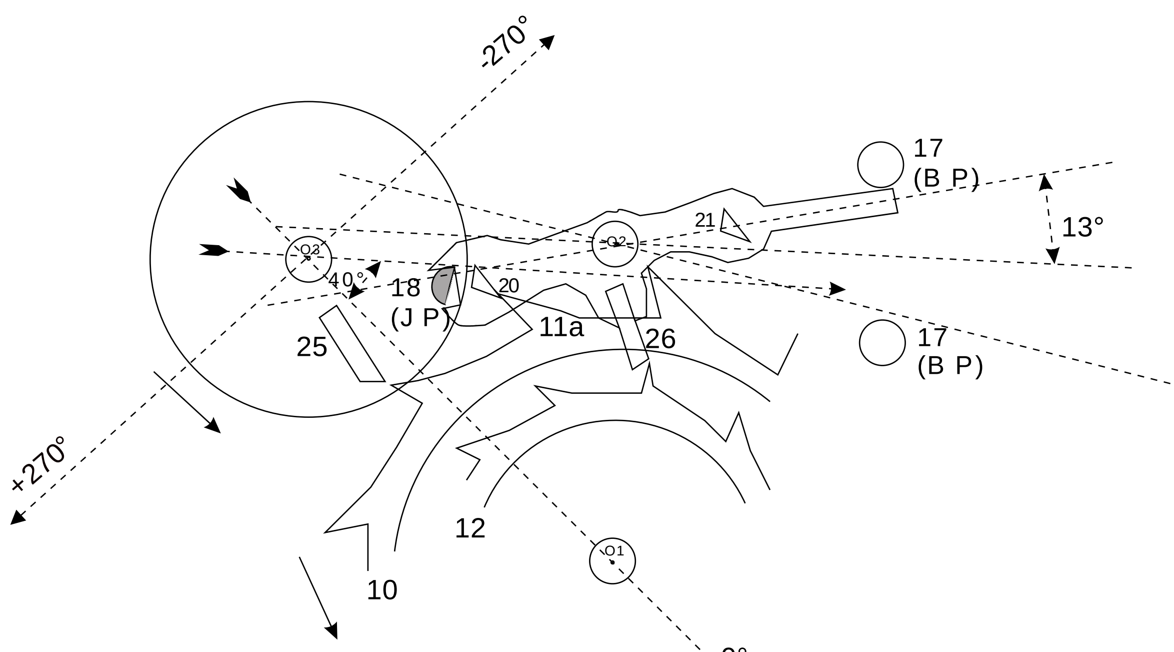


Figure 1. Scheme of the escapement (from Fig. 1 of Appendix 1)

2. <u>Method used</u>

The method proposed here is the same as in the previous article and consists in arbitrarily, yet with justification, splitting the mathematical model into two parts:

- The first part studies the movement of the three main parts of the escapement (Balance, Anchor and Escape Wheel) neglecting any friction loss and also the impulses received by the Balance from the Anchor. This first part can be named “basic model”.
- The second part studies energy losses (due to friction and other main effects) and energy gains (due ultimately to the action of the power spring) of the balance, as small perturbations of the basic model.

This procedure is justified by the very small entity of the Balance energy losses and gains as compared with the energy (kinetic plus spiral spring stored energy) of the Balance itself; the results of the “basic model” give a good approximation of the escapement motion, while the study of energy gains and losses of the Balance (second part of the model) serves to refine the overall result and, in particular, to determine the exact value of the amplitude of the Balance oscillation. An approximate value of this amplitude has to be initially “assumed” in the “basic model” on the basis of normally used values in the watch design practice.
This method, I believe, makes the treatment of the problem rather simple and versatile, yet sufficiently accurate for practical uses.

3. Balance movement

Under the assumptions listed in Section 2, the equation of the Balance movement is, simply:

$$\ddot{\boldsymbol{\theta}} + \boldsymbol{\omega_0^2} \ \boldsymbol{\theta} = \mathbf{0} \qquad \textbf{(1)}$$

Where:

$\boldsymbol{\vartheta}$ is the Balance angle measured counter-clockwise from $\overrightarrow{O3O1}$

ω_0 is the own rotational speed of the Balance $(= 2\pi/T), 15.708\ rad/s$

T is the own oscillation period of the Balance (=$2\pi\sqrt{J_b/K}$), 0.4 [s]

The solutions of equation (1) for θ and $\dot{\theta}$ are:

$$\theta=\theta_0 \sin(\omega_0 t) \qquad (2)$$

$$\dot{\theta}= \omega_0\, \theta_0 \cos(\omega_0 t) \qquad (3)$$

Where:

θ_0 is the amplitude of the oscillation of the Balance which is initially assumed equal to 270° (= 3/2 π [rad] = 4.7124 [rad] t is the time [s]

The spreadsheet results for equations (2) and (3) are shown in Fig. 2. The first and the second columns show the time t[s] with two different starting points: in the first column the time runs from 0 at the position θ=0 of the balance, while in the second column the time assumes the 0 value at the impact of the Jewel Pin against the Anchor fork towards left, 40° (Fig.1). The second column is the one used to draw the graph of the Balance oscillation.

The graph in Fig. 2 would be very slightly altered (and in a measure which could be drawn with difficulty in one sheet of paper) if the impulses originated by the Wheel and Anchor were considered.

t[s]	t[s]fin	teta[rad]	t[s]	t[s]fin	teta °	teta'
0,009467	0,000000	0,698188	0,009467	0,000000	40,003242	73,205422
0,012458	0,002991	0,916294	0,012458	0,002991	52,499791	72,609565
0,015478	0,006011	1,134461	0,015478	0,006011	64,999858	71,845351
0,020000	0,010533	1,456211	0,020000	0,010533	83,434777	70,399449
0,040000	0,030533	2,769877	0,040000	0,030533	158,702339	59,885299
0,060000	0,050533	3,812408	0,060000	0,050533	218,434938	43,509131
0,080000	0,070533	4,481751	0,080000	0,070533	256,785505	22,873966
0,100000	0,090533	4,712387	0,100000	0,090533	270,000000	-0,000272
0,120000	0,110533	4,481740	0,120000	0,110533	256,784892	-22,874483
0,140000	0,130533	3,812387	0,140000	0,130533	218,433772	-43,509571
0,160000	0,150533	2,769849	0,160000	0,150533	158,700734	-59,885618
0,180000	0,170533	1,456178	0,180000	0,170533	83,432891	-70,399617
0,185730	0,176263	1,047439	0,185730	0,176263	60,013879	-72,170659
0,188721	0,179254	0,830501	0,188721	0,179254	47,584226	-72,863752
0,191712	0,182245	0,611730	0,191712	0,182245	35,049557	-73,396037
0,200000	0,190533	-0,000035	0,200000	0,190533	-0,001984	-74,022379
0,220000	0,210533	-1,456244	0,220000	0,210533	-83,436664	-70,399281
0,240000	0,230533	-2,769905	0,240000	0,230533	-158,703944	-59,884979
0,260000	0,250533	-3,812428	0,260000	0,250533	-218,436104	-43,508691
0,280000	0,270533	-4,481762	0,280000	0,270533	-256,786118	-22,873449
0,300000	0,290533	-4,712387	0,300000	0,290533	-270,000000	0,000816
0,320000	0,310533	-4,481730	0,320000	0,310533	-256,784279	22,875001
0,340000	0,330533	-3,812367	0,340000	0,330533	-218,432606	43,510001
0,360000	0,350533	-2,769821	0,360000	0,350533	-158,699130	59,885938
0,380000	0,370533	-1,456145	0,380000	0,370533	-83,431004	70,399785
0,400000	0,390533	0,000069	0,400000	0,390533	0,003967	74,022379

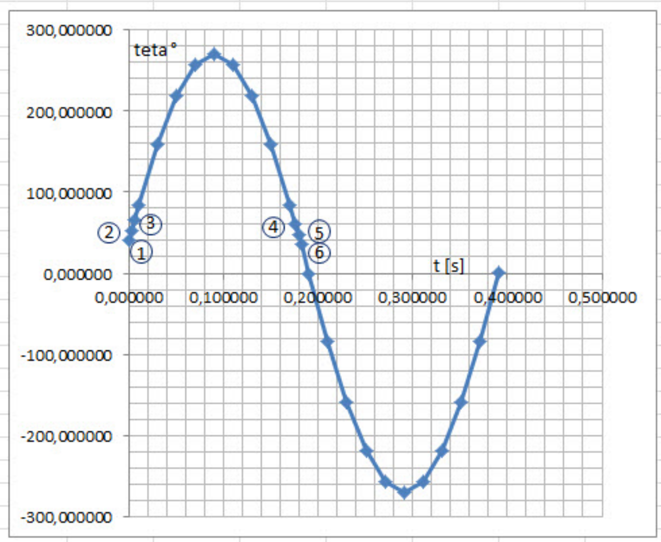


Fig. 2 – Balance movement as calculated in the "basic Model"

The points marked by a number in a circle in Fig.2 have the following meaning:

1- Start unlocking from left tooth of the Wheel
2- Contact with the Anchor central pallet
3- Start of free anticlockwise balance run

4- Start unlocking from right tooth of the Wheel
5- Contact with the balance pallet
6- Start of free clockwise balance run

The results (spreadsheet) of this section are one of the basis for calculation of the Wheel movement in the next Section.

4 -Wheel movement

The Wheel movement starts with the unlocking of its blocked tooth at left from the left locking anchor pallet (20 in Fig.1). The unlocking superposition between tooth and pallet is measured from drawings equal to 0.3 mm; the radius of rotation of the Anchor around O_2 is measured equal to 16.8mm. The angle of rotation of the Anchor during unlocking is, then,

$$\propto_{u\,A}= \frac{0.3}{16.8} = 0.018\,rad = 1.023°$$

The corresponding rotation of the Balance is then

$$\theta_{uB} = 1.29 * 0.018 = 0.023\,rad = 1.33°$$

Since the ratio between Balance and Anchor rotation angles is 1.29 when the Jewel Pin (JP 18) and the Anchor fork are in contact.
Since the rotational speed of the Balance is, at the same time, equal to 73.2 rad/s, the duration of the unlocking is

$$\Delta t_u = \frac{0.023}{73.2} = 0.0003\,s$$

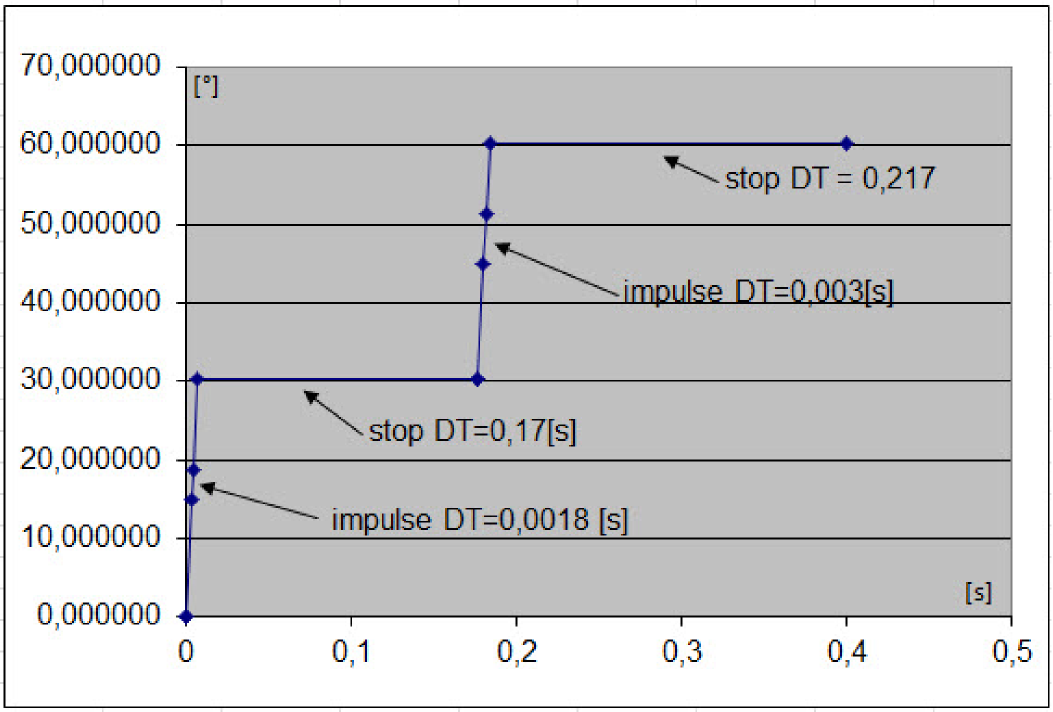
The rotation of the Wheel during unlocking is with a good approximation, equal to 0 (no recoil in this escapement).
After unlocking of a Wheel tooth, the following Small Wheel tooth "falls" on the Anchor pallet in a time step which can be calculated by the constant acceleration motion of the Wheel under the action of the power spring of the escapement.
The angle between two adjacent Wheel teeth is equal to 360/12=30°=0.5236 rad. The "fall" angle on the Anchor pallet is about one half of 30°.
The Wheel motion equation during this "fall" is, then:

$$90.48 \times 10^3 \times \frac{\Delta t_f^2}{2} = 0.5236/2$$

Since the rotational speed at the start of the movement is 0.
$90.8x10^3$ is the value of C_w/J_{gt} (see symbols and Reference Petrangeli 2)
This equation gives, for the duration of the "fall" the figure of 0.0024 s.
The impulse (time and angle) from the Anchor pallet can be calculated on the basis of data taken from drawings: impulse angle of the Anchor pallet (Wheel) is measured equal to 5.8° = 0.1 [r] (Fig. 2 of the Appendix at the end of this article); the corresponding Balance angle is equal to 5.8° x 1.29 = 7.5 °; from Fig.2 the corresponding rotation speed is 72.6 [r/s] and, therefore, the impulse time is Δt_{up}= 0.13[r]/72.6[r/s] = 0.0018 [s]; the time at the end of this unlock phase is t_{up}= 0.0027+0.0018=0.0045 [s] .
The subsequent fall on the right Anchor pallet has a duration of 0.0018 [s] (a little less than 0.0024 [s] of the previous fall, due to the already made 5.8° during impulse) and the final time at contact and stop of Wheel is 0.0063 [s].
The stop of the Wheel on the right Anchor pallet lasts (by approximation from table in Fig. 2) 0.17 [s]. The time at which the unlock from the right Anchor pallet starts is, then, 0.1763 [s].
The duration of the unlock is assumed equal (assumption of symmetry) to that from the left Anchor pallet (= 0.0003 [s]); the overall elapsed time is, then, t_{ur}= 0.1766 [s].
The Wheel now rotates by 15° until a tooth of the large Wheel falls on the Balance pallet; this rotation time is again Δt=0.0024 [s]; overall time is then $t_{b,p}$=0.179[s].

The impulse angle for the Balance is roughly 0.218 [r] = 12.5° and theimpulse time is, with the speed taken from Fig. 2, $\Delta_{u,b}$=0.218/73.11=0.003 [s]; $t_{u,b}$= 0.182 [s]. The Wheel rotates 6.3° during impulse.The subsequent (15-6.3)=8.7 [°] fall on the left Anchor pallet takes 0.0014 [s] and $t_{l,p}$=0.1834[s].
The Wheel then stops until the time of 0.4 [s] is reached (end of the oscillation period).
Figure 3 shows the table and the graph of the above described Wheel movement.

t[s]	alfa [°]
0	0,000000
0,0003	0,000000
0,0027	15,000000
0,004500	18,700000
0,006300	30,200000
0,176300	30,200000
0,176600	30,200000
0,179000	45,000000
0,182000	51,300000
0,183400	60,200000
0,400000	60,200000



(the abscissa of the horizontal lines of the graph has been increased by 0,2° for sake of visibility)

Fig.3 Movement of the Wheel

5- Balance Energy considerations

5.1 - Energy of the Balance
This quantity is equal to the maximum Kinetic energy of the Balance at zero amplitude angle (= 0°):

$$E_{cbmax} = \frac{1}{2} J_b \omega_{bmax}^2 = 0.5 * 2\ 10^{-6}\ 74.0224^2 =$$

$$=5*10^{-1}*2*10^{-6}*5.48*10^{3}=54.8*10^{-4}=5.48*10^{-3} \text{ [N mm]}$$

This quantity is reproduced here as a reference for energy losses and gains of the Balance.

The same approach as in [Petrangeli2] is here used. Some parts are omitted because of small importance in the energy balance.

5.1 Energy lost during left unlock (friction)

This energy is calculated by the friction work done by Wheel tooth – left pallet, which is essentially equal to the work done by the Jewel Pin on the fork face.

$$E_{l,lu} = \frac{C_w}{R_1} \times f \times lock(from\ drawing) = \frac{2.287 \times 10^{-3}}{2.728} \times 2 \times 10^{-1} \times 2 \times 10^{-2} = 3.36 \times 10^{-6}\ [N\ mm]$$

For one period, then (assuming symmetry for sake of simplicity):

$$E_{l,lu} = 2*3.36*10^{-6} = 6.72*10^{-6}\ [\text{Nmm}]$$

$$E_{l,lu}/E_{cbmax} = 0.123\%$$

The force exerted by the Wheel on the Anchor is equilibrated (because of the geometry of the escapement) by the reaction force of the staff in O_2 and essentially no force is exerted by the Anchor fork on the Balance Jewel Pin because of the Wheel push; consequently, no friction loss exists in the Balance staff O_3 in this phase (except for the Balance weight which is a function of the watch position with respect to a vertical axis and of possible accelerations). Anchor inertia is considered practically zero.

5.2- Energy gained during impulse to Anchor central pallet

The angle of rotation of the Wheel during this phase (α_{cp}) is (from drawings): 0.1 [r] =5.8°.

The energy gain is equal to the work done by the Wheel during this impulse:

$E_{g,cp}= C_w* \alpha_{cp}= 2.287*10^{-3} * 0.1 = 2.287*10^{-3} * 1*10^{-1} = 2.287 *10^{-4}$ [N mm] = 4.2% of the total Balance energy, E_{cbmax}

No Balance energy is lost because the friction force at contact is equilibratred by the reaction in O_2.

5.3- Energy gained during impulse to Balance pallet

$E_{g,bp} = C_r*(1.28/2.728) *\theta_{bp}= 2.287*10^{-3} * 0.47*0.218$ (from drawings) $=2.287*10^{-3}*4.7*10^{-1} *2.18*10^{-1}= 2.3*10^{-4}$ [N mm] =4.28% of the total Balance energy, E_{cbmax}

5.4- Energy lost by friction in the Balance staff

This energy is in part due to the force acting on the Balance staff during impulse to Balance pallet (Sec.5.3) and in part to the weight of the balance (supposed in a vertical position for one half of the time, as in [Petrangeli2], although a more realistic value has normally to be chosen according to the specific use and movements of the watch).

$E_{l,\ bs}= (C_r/R_1 *\theta_{bp}+5.95*10^{-4}*(270*2/57.2958)) * f * R= ((2.287 *10^{-3}/2.728)*.218+ 5.95*10^{-4}*9.42)*0.15*0.1=$

$=(1.8*10^{-4}+5.6*10^{-3})*1.5*10^{-1}*10^{-1}= 8.7*10^{-5}$ =1.6% of E_{cbmax}

6. Summary of energy balance (for one period) and consequences

Energy loss or gain in one balance oscillation period (0.4 s) [N mm]	Loss	Gain	Percentage of Balance energy
Energy lost during left unlock (friction)	$6.72*10^{-6}$		$= 6.72*10^{-6}/5.48\ 10^{-3}=$ 0.123%
Energy gained during impulse to Anchor central pallet Energy gained during impulse to Balance pallet		$2.287 *10^{-4}$ $2.3*10^{-4}$	4.2% 4.28%
Energy lost by friction in the Balance staff	$8.7*10^{-5}$		1.69%
TOTAL	$9.37*10^{-5}$	$4.52 *10^{-4}$	
ΔE=Difference = $3.66*10^{-4}$			6.7%

$\Delta E =1/2\ J_b(\omega^2_{w2}-\omega^2_{w1})$; $\omega^2_{w2}= 2*3.66*10^{-4}/2\ 10^{-6}+74.0224^2=365+5479=5844$ [/s²] ; $\omega_{w2}=76.45$ [/s]

$d\theta_0=d\omega_{wmax}/\omega_0=(76.45-74.0224)/15.708= 0.15$ [r] =8.84°

It can be concluded, with the possibility to perform more precise calculations as indicated above, that the Balance will adjust, in this case, to a maximum angle of oscillation different from the initially assumed one.

For clarity, the change of Balance amplitude of oscillation can compensate moderate unbalances in energy losses and gains. The energy loss is, in fact, essentially proportional to Balance amplitude, while energy gain is not (fixed position of Banking Pins). Similarly, any moderate change in the power couple C_w can be compensated by a change of Balance oscillation amplitude. Moreover, any moderate change in oscillation amplitude does not affect oscillation period. This escapement too, then, is self-adjusting in front of energy unbalances (which can be originated by unbalances between Balance energy losses and gains or by insufficient watch motive power).

7. Quality factor

$$Q = \pi \frac{stored\ vibration\ energy(Balance)}{vibration\ energy\ lost\ by\ half\ cycle} = \pi \frac{5.48 * 10^{-3}}{4.685 * 10^{-5}} = 367$$

8. Final Considerations emerging from the preceding treatment

The escapement here studied has some advantages over the one (Swiss Lever Escapement) examined in [Petrangeli2]. In particular, the impulse transmitted to the Balance through the Anchor and the Balance pallet, entails no (significant)simultaneous Balance energy loss: almost all the lost energy during impulses is supplied here by the main spring power. One consequence of this fact is that almost no lubrication is needed in the interacting impulse surfaces. Lubrication, however, appears to be needed in the staff of the Balance and Anchor. The total Balance energy loss in one period is also lower than in the Swiss lever escapement for the same total Balance oscillation amplitude.
The advantages of the Swiss lever escapement are preserved in the coaxial escapement.

SYMBOLS USED AND DATA

BP, Banking Pins
C_h, viscous hydrodynamic couple on Balance staff
C_w, Couple transmitted to the Wheel by the Gear Train, $2.287*10^{-3}$ [N mm] [form [Vermot] CD, Data]
$E_{g,bp}$ energy gained during unlock from Balance pallet
$E_{l,bs}$ energy lost by friction in the Balance staff
$E_{g,cp}$ energy gained during unlock from Anchor central pallet
E_i , energy transmitted from Wheel to Anchor and to Balance during the impulse phase
$E_{l,f}$ energy lost in the Balance and Anchor staffs for each Balance oscillation period

$E_{l,lu}$ energy lost during left unlock (friction)
f, friction coefficient between Wheel tooth and Anchor pallet during unlocking (= 0.2)
F_t, tangential force transmitted from the Wheel to the Anchor pallet [N]
JP, Balance Jewel Pin, Fig. 1
J_a, moment of inertia (mass) of Anchor , 1.02 10^{-8} [N mm s^2]
J_b , moment of inertia (mass) of Balance, 2 10^{-6} [N mm s^2]
J_{gt}, moment of inertia (mass) of the Wheel plus Gear Train, 2.53 10^{-8} [N mm s^2]
Jewel Pin D: pin of the balance which impacts on the anchor fork, Fig. 1
K, rotational elastic constant of the Balance spiral spring, 5.03 10^{-4} [N mm /rad]
Lock: term used by horologists for the penetration, in a lever escapement, of the escape-wheel tooth on the pallet-stone [mm]
M_b, Weight of the Balance, (59.5 mg)
O1, O2, O3, Centers of rotation of Wheel, Anchor and Balance (Fig. 1)
O_1O_2, segment of length 3 [mm]
O_2O_3, segment of length 2.7 [mm]
$\overrightarrow{O3\ O1}$ Oriented vector for the reference abscissa of equation (1)
R, radius of the Balance staff tip, 0.1 mm
R_a , distance between O_2 and left unlock contact point, 0.683 [mm]
R_{bp},radius of Balance at contact of its pallet=1.28 [mm]
R_1, radius of the contact point of large Wheel and Anchor pallets with center O_1, 2.728 [mm]
T, own period of Balance oscillation, 0.4 [s]
α, angle of rotation of Wheel starting anticlockwise from the block left position, (Fig. 1)
α_c , angle (as seen from O_1 of the impulse to the Anchor pallet (3.7° from drawing, Fig.2 App.1)
θ, oscillation angle of the Balance, positive in counter-clockwise direction
θ_{bp}, impulse angle of the Balance pallet =0.218 [r]=12.5°
θ_{lu}, rotation of balance during left unlock, 0.021 [r]
θ_0 , maximum oscillation angle of the Balance (initial tentative value for "basic model" = 270°=(3/2)π [rad] =4.7124 [rad])
ρ, density (mass)
ω_{bmax}= maximum real rotational speed of the Balance 74.0224 [rad/s]
ω_0, own rotational speed of the Balance $(=2\pi/T)$, 15.858 [rad/s]
ω_w, rotational speed of wheel [rad/s]

APPENDIX 1: Text of the Patent (EPO) for the Coaxial Escapement (George Davies)

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 018 796
A2

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 80301358.0

(22) Date of filing: 25.04.80

(51) Int. Cl.³: G 04 B 15/08

(30) Priority: 30.04.79 GB 7915006

(43) Date of publication of application: 12.11.80 Bulletin 80/23

(84) Designated Contracting States: CH FR GB IT LI

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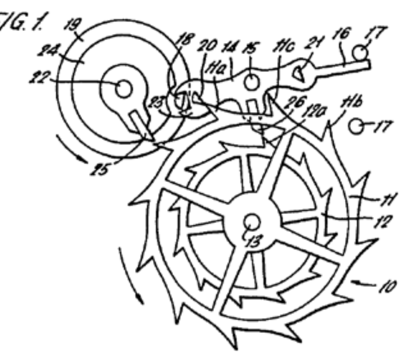
(54) **Watches, clocks and chronometers and escapements therefor.**

(57) The invention relates to a detached escapement which preferably does not require oil to be applied to the escape wheel.

The escapement has an escape wheel (10;30), a balance wheel and a pivoted lever (14;37) arranged so that during each movement of the balance wheel in one direction of rotation an impulse is applied direct to an element (25;33) attached to the balance wheel. During each movement of the balance wheel in the other direction of rotation it is preferred that an impulse is applied to the balance wheel via the pivoted lever.

The escapement may be used in a watch, clock or chronometer.

FIG. 1.



EP 0 018 796 A2

WATCHES, CLOCKS AND CHRONOMETERS AND ESCAPEMENTS THEREFOR

The invention relates to watches, clocks and chronometers and escapements therefor.

It is known to provide a detached escapement comprising a toothed escape wheel urged to rotate in a single direction by a mainspring via a gear train and intermittently held against rotation by a pivoted lever, and a pin forming part of a balance wheel which is arranged to be oscillated by a balance spring. During each movement of the balance wheel the pin moves the lever in the opposite direction which releases the escape wheel to move through half a tooth, and the balance wheel receives an impulse from a tooth of the escape wheel via the pivoted lever.

According to the invention there is provided a detached escapement comprising a toothed escape wheel urged to rotate in a single direction by a mainspring and intermittently held against rotation by a pivoted oil is not required.

According to the invention there is provided a detached escapement which requires no oil comprising a toothed escape wheel, pivoted lever and balance wheel as described above except that during each osillation of the balance wheel in one direction the impulse from the escape wheel to the balance wheel is transmitted via the pivotal lever and during each oscillation of the balance wheel in the other direction the impulse from the escape wheel to the balance wheel is transmitted direct to the balance wheel or an element attached thereto. This difference has the advantage that the direction of rotation of the escape wheel may be opposite to the direction of pivotal movement of the lever when the balance wheel oscillates in said one direction and opposite to the direction of rotation of the balance wheel when the balance wheel oscillates in the other direction. In this case, the secure intersection of the impulse transmitting components may be achieved during each oscillation of the balance wheel.

Preferably the impulse transmitted to the balance wheel each time it oscillates in said other direction is transmitted from a tooth of the escape wheel to a pallet attached to the balance wheel.

each movement of the balance wheel.

Preferably the pivoted lever carries an impulse pallet for engagement by a tooth of the escape wheel during each movement of the balance wheel in said other direction of rotation.

The surface of the or each impulse pallet when engaged by a tooth of the escape wheel is preferably radial of the escape wheel.

The pivoted lever is preferably arranged so that it is mid-way between banking pins during the application of each impulse to the balance wheel.

The pivoted lever also preferably carries entry and exit locking pallets for alternate engagement with a tooth of the escape wheel.

Preferably the area of surface contact of the escape wheel teeth is sufficiently small that oil is not required to be applied to the escape wheel.

The escape wheel may have two concentric rings of teeth of different radii disposed in parallel planes Alternatively, the escape wheel may have a single ring of teeth.

Preferably the interengaging means between the balance wheel and the lever are a pin associated with the balance wheel which engages in a fork in the lever. The pin may be mounted on the balance arm.

The invention also provides a watch, clock or chronometer having an escapement as defined above.

By way of example, specific embodiments in accordance with the invention will be described with reference to the accompanying diagrammatic drawings in which:-

Figure 1 is a plan view of an escapement for a watch, clock or chronometer, the balance wheel shown rotating in an anti-clockwise direction and about to unlock the escape wheel;

Figure 2 shows the escapement of Figure 1 at mid-impulse;

Figure 3 shows the condition of the escapement of Figure 1 in which the balance wheel is rotating in the opposite direction and about to unlock the escape wheel;

Figure 4 shows the escapement in the condition of Figure 3 but at mid-impulse;

Figure 5 is a perspective view of the escapement in the condition of Figure 3;

Figure 6 is a plan view of another escapement in a condition similar to Figure 4; and

Figure 7 is a perspective view of a further escapement in a condition similar to Figure 3.

This example relates to a watch, clock or chronometer escapement having a toothed escape wheel urged to rotate in a single direction by a mainspring via a gear train and intermittently held against rotation by a pivoted lever. The escapement also has a balance wheel arranged to be oscillated by a balance spring. The invention is concerned only with the escape wheel, the pivoted lever and the balance wheel and so only these parts will be described.

Referring to Figures 1 to 5, the escape wheel 10, has two concentric rings of teeth 11, 12 disposed in parallel planes, one above the other. In this embodiment the teeth are provided by two wheels of different radii mounted for rotation together on the same arbor 13 but may readily be provided by a single wheel, for example a wheel of which the inner ring of teeth project downwardly into a plane beneath the outer ring of teeth.

The lever 14 is mounted for pivotal movement about an arbor 15 and at one end has a tail 16 which extends between two banking pins 17 which limit the extreme positions of the lever. The other end of the lever 14 is formed at 23 for reception of the balance roller pin 18. In this embodiment the balance roller pin is carried by the balance roller 19 which is itself attached to the balance wheel (not shown). The lever 14 carries exit and entry locking pallets 20, 21 respectively for alternate engagement with an outer tooth 11 of the escape wheel when the lever is in its respective extreme position, the escape wheel thereby being held against rotation (Figures 1, 3 and 5).

The balance roller 19 is mounted for oscillation about a staff 22 and carries a conventional safety roller 24 which prevents the lever 14 from pivoting when the balance roller pin 18 is not engaged within the fork 23 of the lever, and also a pallet 25 for engagement by an outer tooth 11a of the escape wheel (see Figure 4) when the balance wheel is moving in the appropriate direction of rotation, i.e. clockwise as viewed in Figure 4. An impulse is thereby applied by the escape wheel to the balance wheel. When the balance wheel is moving in the opposite direction of rotation an impulse is applied to the balance wheel through engagement of an inner tooth 12 of the escape wheel and another pallet 26 carried by the lever 14 (Figure 2).

In this embodiment the areas of contact between the locking pallets 20, 21 and the teeth of the escape wheel, and also between the impulse pallets 25, 26 and the teeth of the escape wheel, are sufficiently small that no oil is required. Also, in this embodiment, the position of the balance impulse pallet 25 relative to the balance staff 22 and the outer teeth 11 of the escape wheel, and similarly the position of the lever impulse pallet 26 relative to the arbor 15 and the inner teeth 12 of the escape wheel, is chosen so that the impulse applied to the balance wheel through each pallet is of the same strength. Moreover, both impulses are applied radially of the escape wheel, i.e. the teeth of the escape wheel engage the pallets 25, 26 when the surfaces of the pallets engaged by the teeth of the escape wheel are radial of the escape wheel (see Figures 2 and 4).

The operation of the escapement will now be described. In the condition shown in Figure 1, the escape wheel 10 is held against rotation by engagement of tooth 11a with the exit locking pallet 20. Rotation of the balance wheel and hence the balance roller 19 in an anti-clockwise direction causes engagement of the balance roller pin 18 with the fork 23 of the lever 14 and thereby pivotal movement of the lever to release the escape wheel. The escape wheel then rotates through half a tooth until it is stopped by the entry locking pallet 21 engaging tooth 11b (Figure 3). In the meantime the tooth 12a has engaged the pallet 26 to apply an impulse via the lever 14 to the balance wheel 19 (Figure 2). The balance wheel will continue to rotate in the anti-clockwise direction until the energy is exhausted.

The energy stored in the balance spring will then reverse the direction of rotation of the balance wheel and the balance roller pin 18 will again engage the fork 23 of the lever 14 (Figure 3). The lever 14 will pivot to release tooth 11b from the entry locking pallet 21 and the escape wheel will again rotate until tooth 11c engages the exit locking pallet 20. In the meantime tooth 11a has engaged the pallet 25 to apply an impulse to the balance wheel (Figure 4). The direction of rotation of the balance wheel will then again be reversed and the above cycle repeated.

The fact that when the balance wheel is moving in a clockwise direction the impulse is applied via the balance impulse pallet 25, and that during movement in the other direction of rotation the impulse is applied via the lever impulse pallet 26 and the lever 14 means that during each oscillation secure intersection of the impulse components is achieved.

It will also be appreciated that in the embodiment described above, one impulse is applied by an outer tooth 11 of the escape wheel and the next impulse is applied by an inner tooth 12 of the escape wheel. In another embodiment of escapement shown in Figure 6, both impulses are applied by an inner tooth 12 of the escape wheel. Otherwise the escapement operates in the same manner as before and the same reference numerals are employed.

Figure 7 illustrates a further embodiment in which the escape wheel 30 is a single wheel in which the same teeth engage the entry and exit locking pallets 31, 32 and the impulse pallets 33, 34. A further difference is that the balance roller is omitted and the balance roller pin 35 is mounted on the balance arm 36 which forms a part of the balance wheel (not shown). Consequently, the pivoted lever 37 has its forked end 38 cranked for engagement with the pin 35, the escapement thereby taking up considerably less space vertically compared with the escapements of Figures 1 to 5 and Figure 6. This may be important when it is desired to incorporate the escapement in a watch. However, the manner of operation of the escapement is entirely similar to the embodiments previously described.

In the case of the embodiment of Figures 1 to 5, the escape wheel 10 as viewed in the drawings is driven by the mainspring in an anti-clockwise direction, whereas in the embodiments of Figures 6 and 7 the escape wheel is shown as being driven in a clockwise direction. However, in the case of each embodiment, the escape wheel 10 can be arranged to rotate in either direction, whichever is desired. Similarly, the lever 14 may be pivotally mounted on either side of the line joining the axes of the balance and escape wheels. There is thus provision for considerable flexibility of design layout.

In each embodiment, when the balance wheel and balance spring are quiescent because the mainspring is run down, the lever 14 or 37 will be positioned with its tail mid-way between the banking pins. Hence, in this condition, the escape wheel will always be unlocked and one tooth of the escape wheel will be in engagement with one of the impulse pallets, whereby the application of power to the escape wheel, i.e. by winding the mainspring, will cause that tooth to impulse the respective pallet and the escapement will start the balance wheel oscillating without it being necessary to shake or agitate the watch, clock or chronometer. Thus the escapement is self-starting from the unwound condition.

Additionally if the escapement is stopped accidentally, the escapement will still be self-starting even though a tooth of the escape wheel may be locked by one of the locking pallets. This is because the energy stored in the balance spring when the balance spring is not quiescent or mid-way through its oscillating cycle, is sufficient to unlock the escape wheel from the locking pallet.

CLAIMS

1. A detached escapement comprising a toothed escape wheel (10;30) urged to rotate in a single direction by a mainspring and intermittently held against rotation by a pivoted lever (14;37), and a balance wheel arranged to be oscillated by a balance spring, interengaging means (18,25;35,38) between the balance wheel and the lever whereby during each movement of the balance wheel the lever is pivoted to release the escape wheel to move through half a tooth, during which movement of the escape wheel the balance wheel receives an impulse from the escape wheel, characterised in that during each movement of the balance wheel in one direction of rotation the impulse is appled direct to an element (25;33) attached to the balance wheel.

2. An escapement as claimed in claim 1, wherein an impulse pallet (25;33) is attached to the balance wheel for oscillation therewith, the pallet being engaged by a tooth (11;12) of the escape wheel during each movement of the balance wheel in said one direction of rotation.

3. An escapement as claimed in claim 1 or claim 2, wherein during each movement of the balance wheel in the

other direction of rotation the impulse is applied to the balance wheel via the pivoted lever (14;37).

4. An escapement as claimed in claim 3, wherein the pivoted lever (14;37) carries an impulse pallet (26;34) for engagement by a tooth (12;11) of the escape wheel during each movement of the balance wheel in said other direction of rotation.

5. An escapement as claimed in any one of claims 2 to 4, wherein the surface of the or each impulse pallet (25, 26; 33, 34) when engaged by a tooth (11;12) of the escape wheel (10;30) is radial of the escape wheel.

6. An escapement as claimed in any one of the preceding claims, wherein the pivoted lever (14;37) is mid-way between banking pins (17) during the application of each impulse to the balance wheel.

7. An escapement as claimed in any one of the preceding claims, wherein the pivoted lever (14;37) carries entry and exit locking pallets (21, 20; 31, 32) for alternate engagement with a tooth (11) of the escape wheel (10;30).

8. An escapement as claimed in any one of the preceding claims, wherein the area of surface contact of the wheel teeth (11) is sufficiently small that oil is not required to be applied to the escape wheel (10;30).

9. An escapement as claimed in claim 3, wherein the escape wheel (10) has two concentric rings of teeth (11;12) of different radii disposed in parallel planes.

10. An escapement as claimed in claim 9, wherein the outer ring of teeth (11) of the escape wheel (10) are engaged by the pivoted lever (14) to lock the escape wheel intermittently and to apply each said impulse which is applied direct to an element (25) attached to the balance wheel, whilst the inner ring of teeth (12) of the escape wheel apply each said impulse which is applied to the balance wheel via the pivoted lever.

11. An escapement as claimed in claim 9, wherein the outer ring of teeth (11) of the escape wheel are engaged by the pivoted lever (14) to lock the escape wheel intermittently, and the inner ring of teeth (12) apply said impulses to the balance wheel.

12. An escapement as claimed in any one of claims 1 to 8, wherein the escape wheel (30) has a single ring of teeth (11) which are both engaged by the pivoted lever (37) to lock the escape wheel intermittently and to apply said impulses to the balance wheel.

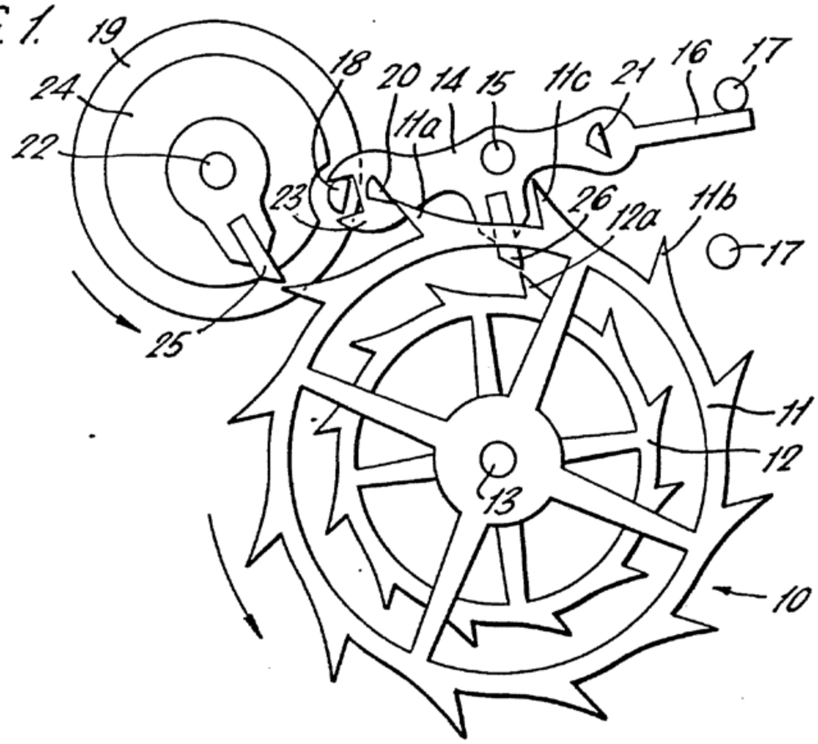
13. An escapement as claimed in any one of the preceding claims, wherein the interengaging means between the balance wheel and the lever are a pin (18;35) associated with the balance wheel which engages in a fork (23;38) in the lever (14;37).

14. An escapement as claimed in Claim 13, wherein the pin (35) is mounted on the balance arm (36).

15. A watch, clock or chronometer having an escapement as claimed in any one of the preceding claims.

RESH/KS

FIG. 1.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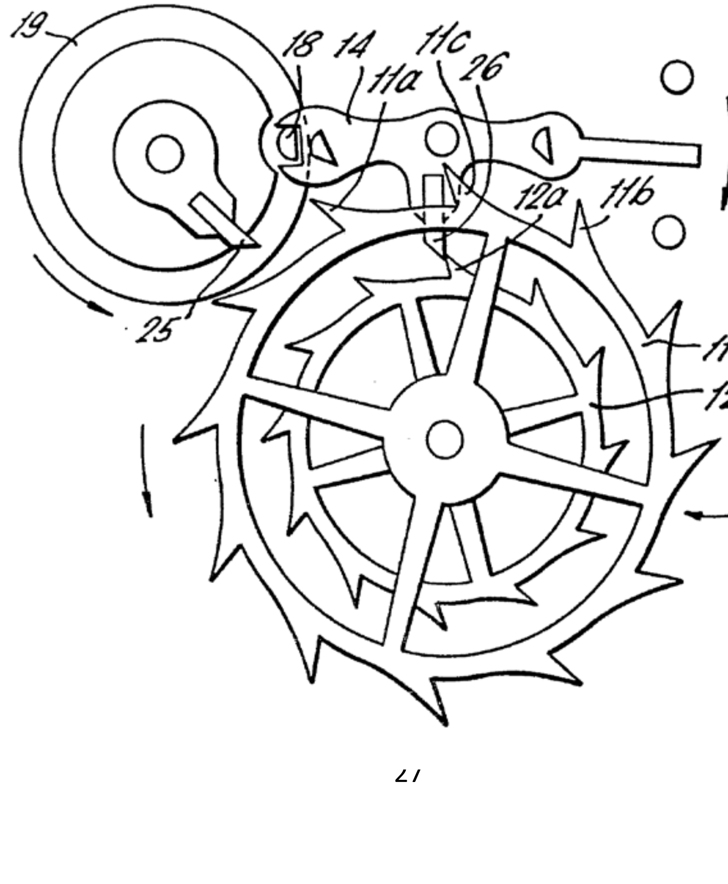
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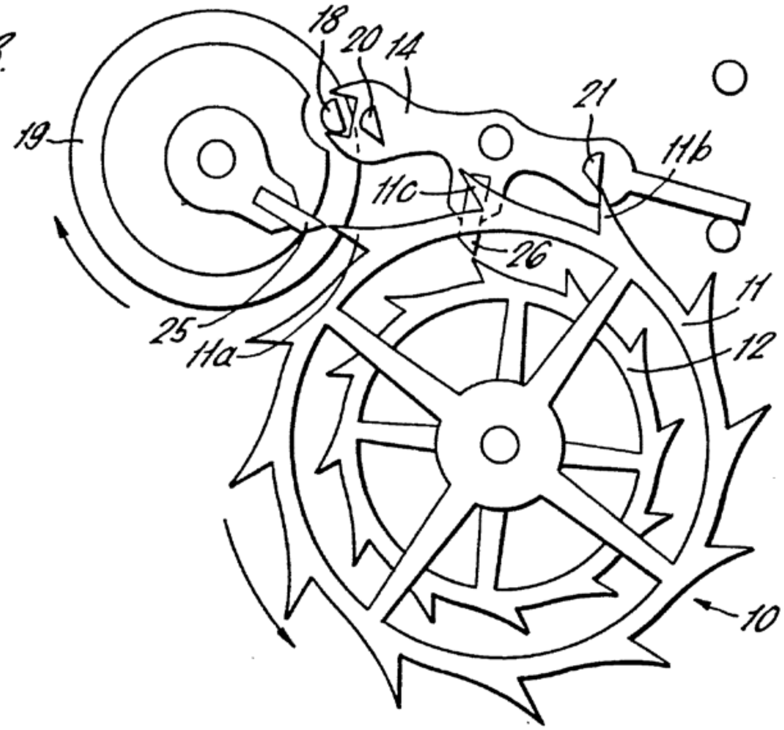
FIG. 2.

FIG. 3.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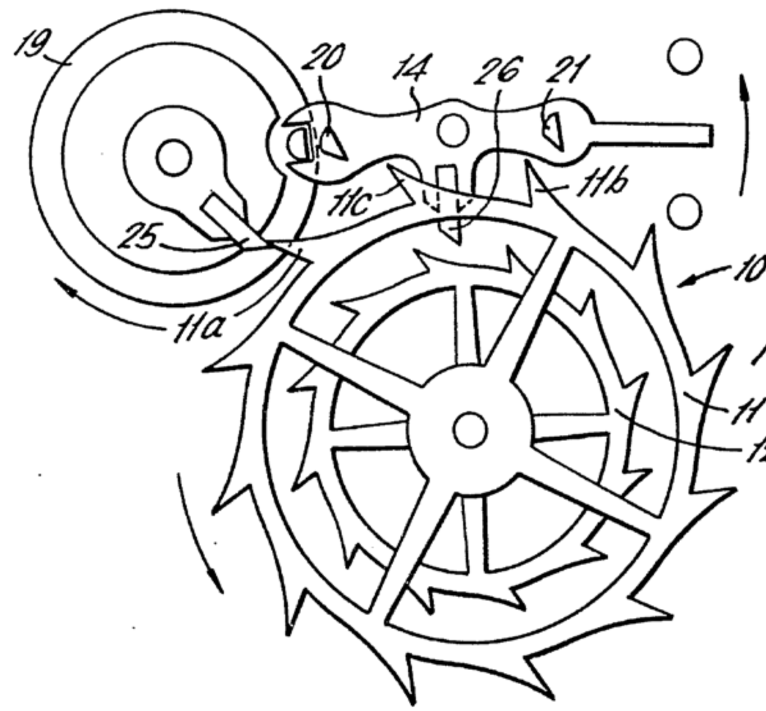
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FIG. 4.

FIG. 5.

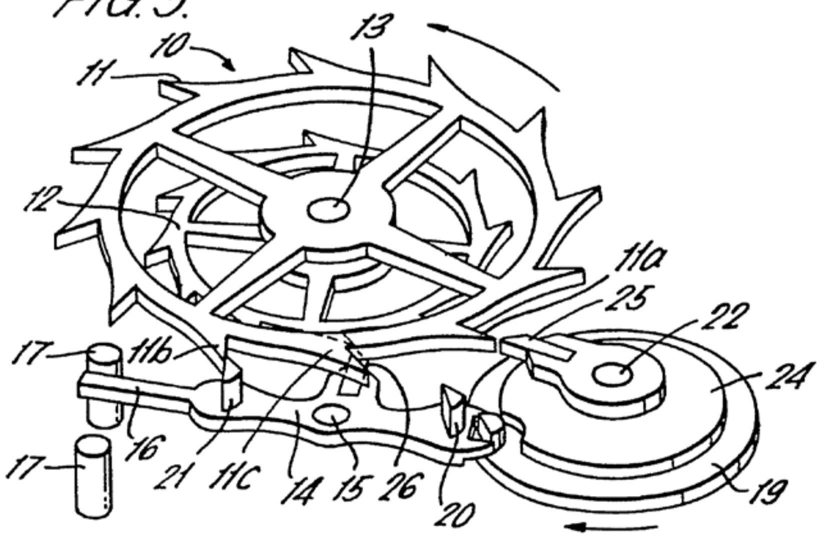
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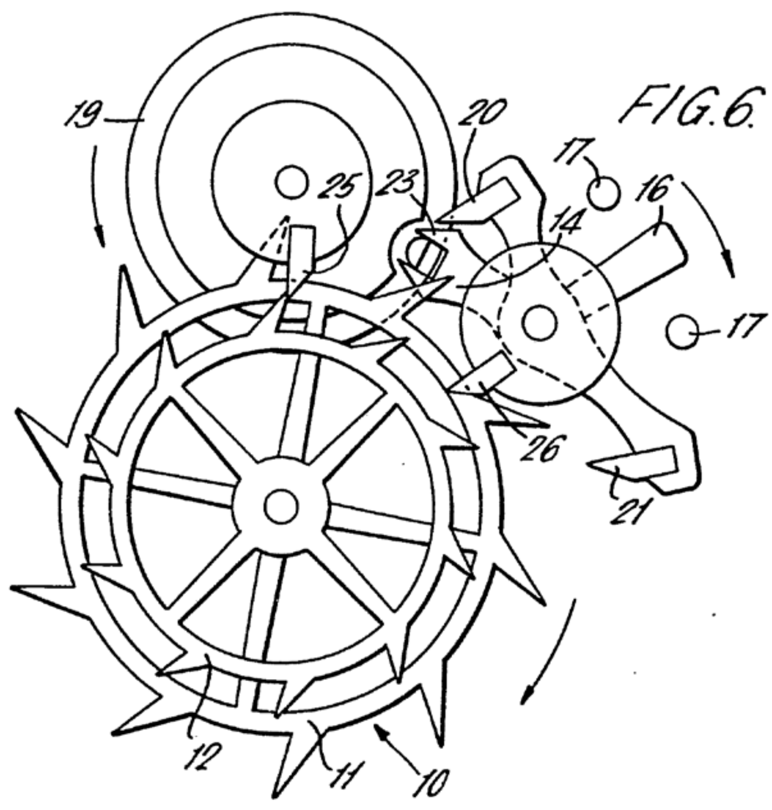
FIG. 6.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