

NOTES ON H. R. PLAYTNER'S LEVER ESCAPEMENT

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These are my revised notes on H. R. Playtner's 1910 paper, "An Analysis of the Lever Escapement", hereafter cited as [P]. It can easily be found on the internet. The paper is very careful and thorough, but is a bit difficult to read for an amateur horologist like myself, as it assumes some familiarity with the horology literature of the era. I have undertaken to explain the overall function of the lever escapement, introduce all of the components involved, and define the many quantities used in its construction, following [P]. Hopefully these notes are detailed enough to draft the mechanism in a modern CAD program. (Playtner carefully describes the procedure for drafting it with a ruler, compass, and protractor). Playtner gives multiple designs for most of the components involved, and discusses the advantages and disadvantages of each; I will only include his recommended choices.

1. COMPONENTS AND FUNCTION

1.1. The escapement is the assembly which transfers power from the wheel train to the balance wheel. It is absolutely critical to the functioning of the movement from the standpoint of timekeeping and reliability; as such it must be carefully designed and manufactured with extreme precision. This is complicated by the fact that the escape lever in an average-sized movement is under a centimeter long. To my knowledge, the primary considerations in the design of the escapement are as follows:

- (1) Mass. A lighter escape lever has less angular inertia; hence less energy is wasted in moving it back and forth.
- (2) Reliability. A shock to the movement can occur at any moment, and must not interrupt the functioning of the escapement.
- (3) Manufacturing. It must be possible to actually produce an escapement to within acceptable tolerances.

1.2. Components. The components of the escapement are labeled in Figure 1.

- A. The *escape wheel* provides torque in a clockwise direction.
- B. A *tooth* on the escape wheel. The shape is called a *club tooth*.
- C. The *lever*.
- D. The *engaging pallet*.
- E. The *disengaging pallet*. Both pallets are jewels.
- F. The *fork* is the top section of the lever.
- G. The *slot* is the space in the middle of the fork into which the impulse pin fits.
- H. The *horn* is the part of the fork that curves away from the rest of the lever.
- I. The *dart* is attached to the lever but is underneath the rest of the lever, on the level of the safety roller.
- J. The *impulse roller*, outlined in gray, is attached to the balance wheel and carries the impulse pin. It is above the lever.

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- K. The *impulse pin* or *ruby pin* is a jewel which sits on bottom of the impulse roller and fits in the slot of the fork.
- L. The *safety roller* is below the main part of the lever, on the same level as the dart.
- M. The *crescent* is an arc cut out of the safety roller.
- N. The *banking pins* or *banks* restrict the side-to-side motion of the lever.

1.3. Overall function. In Figure 2A, the lever is *locked*: the tooth of the escape wheel is pushing against the left face, or *locking face*, of the engaging pallet, which prevents the escape wheel and lever from moving. The balance wheel is rotating counterclockwise, and the impulse pin has just struck the right face of the slot. The momentum of the balance causes the impulse pin to exert a clockwise force on the fork, indicated by the green arrow.

In Figure 2B, the impulse pin has moved the lever far enough to unlock it: as the tooth is no longer resting against the locking face of the engaging pallet, the escape wheel is free to turn. As it does so, the tooth pushes up on the bottom face, or *impulse face*, of the engaging pallet; the clockwise torque of the escape wheel thus induces a clockwise torque on the lever. The left face of the slot now pushes the impulse pin, imparting a counterclockwise force to the balance. These forces are indicated by the green arrows in Figure 2C.

In Figure 2D the tooth has just passed the impulse face of the engaging pallet. The escape wheel no longer imparts any torque to the lever, the impulse pin leaves the left face of the slot, and the balance spins free of the escapement. With no resistance, the escape wheel turns freely until the tooth just to the left of the disengaging pallet strikes the left (locking) face of the latter, in Figure 2E. This rotation is so slight and quick that the lever is not assumed to have moved between D and E of Figure 2. In Figure 2E the lever is locked but has not yet come to rest against the right banking pin; in Figure 2F it has.

Eventually the balance spring will cause the balance to reverse direction, turning clockwise. When the impulse pin strikes the left face of the slot the above mechanism repeats in reverse, with the roles of the engaging and disengaging pallets reversed. The reverse action is illustrated in Figure 2(G–L). In many modern movements this tick-tock action happens four times per second.

2. ESCAPE WHEEL AND PALLETS

In this section we define and describe the parameters that must be specified when designing the escape wheel teeth and the pallets. We will touch on the considerations that go into these choices, referring the reader to the full discussion in [P], and we will give Playtner’s recommended values for a typical movement.

We assume that the escape wheel has 15 identical teeth, evenly spaced at 24° . Other configurations are possible and are not uncommon in practice; Playtner discusses the issue on p.7.

2.1. Primitive circle and locking circle. The point in the plane where the tooth touches the pallet just at the moment of unlocking is called an *unlocking point*. There are two unlocking points, one for the engaging pallet and one for the disengaging pallet; these can be seen in Figure 2(B,H) and in Figure 3. The unlocking points are necessarily equidistant from the escape wheel pivot B , as they lie on the same corner of the tooth. The distance between B and an unlocking point is called the *primitive radius* of the escape wheel; the circle centered at B and passing through the unlocking points is the *primitive circle*. The unlocking points span an arc subtending 60° on the primitive circle. This is equal to the angle subtended by

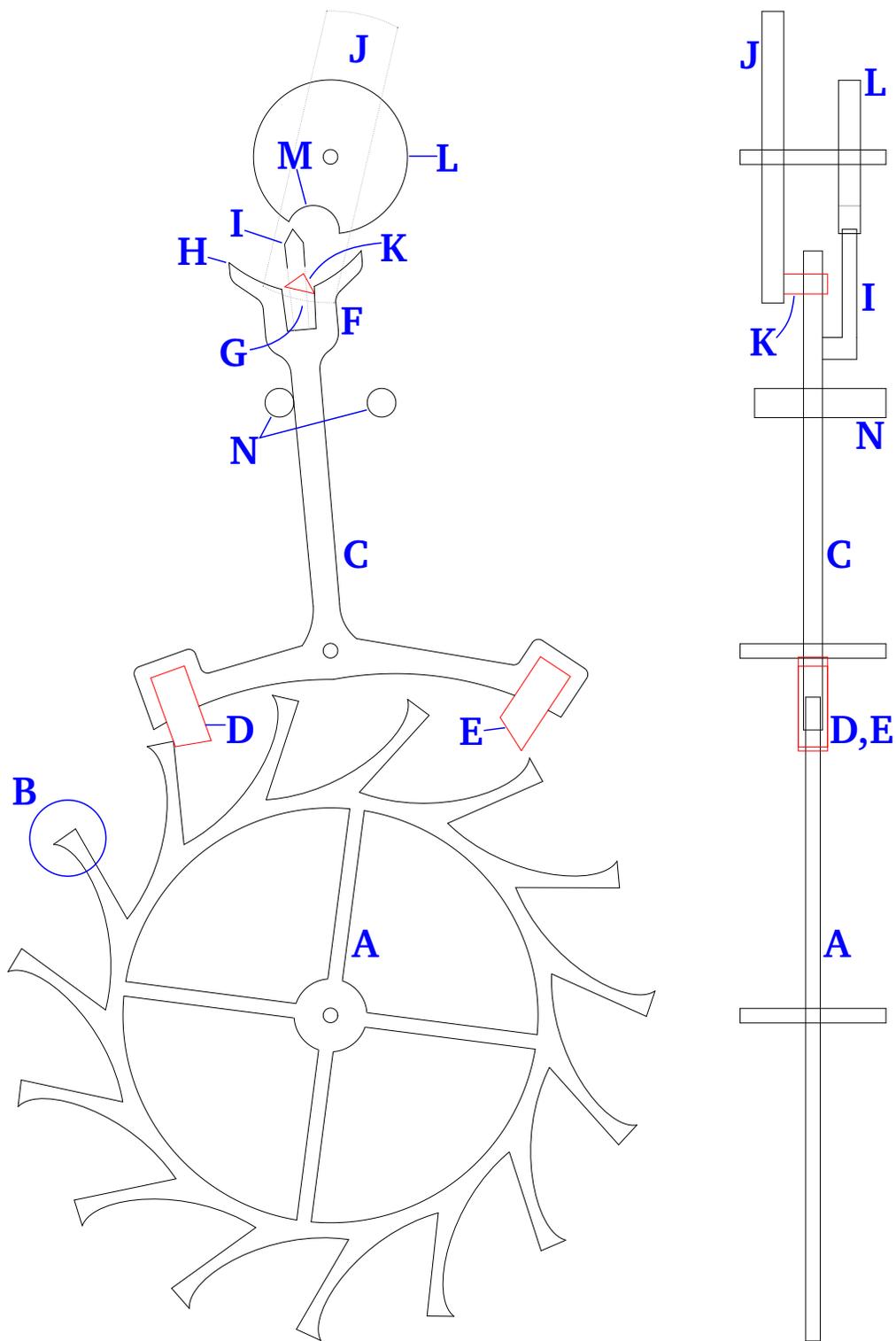


FIGURE 1. The main components of the lever escapement. In the side view on the right, the right-hand side is toward the “bottom” of the movement.

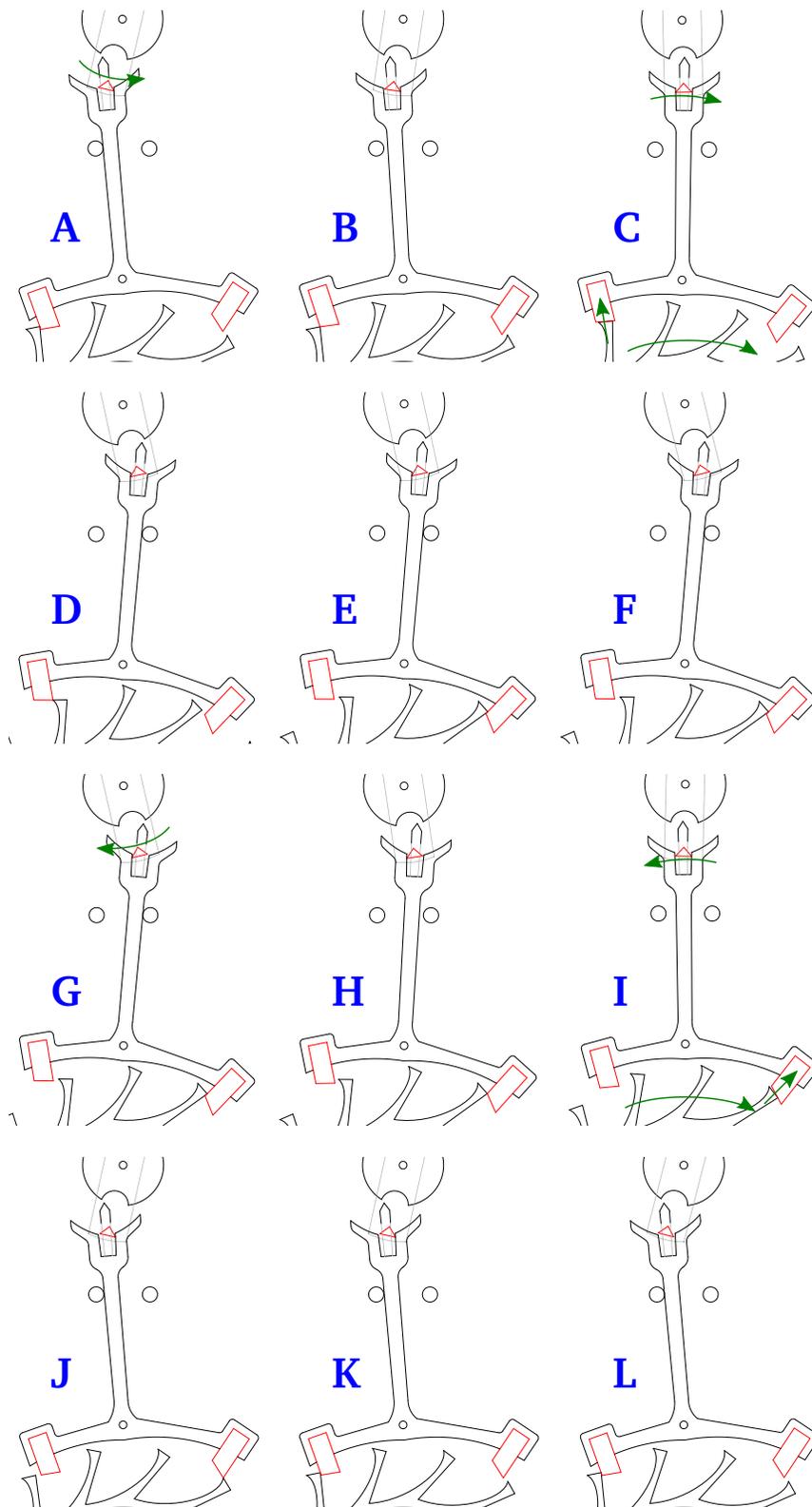


FIGURE 2

two and a half teeth: $60 = 24 \times 2\frac{1}{2}$. The reason for this will be explained in (2.6). See Figure 3 for an illustration.

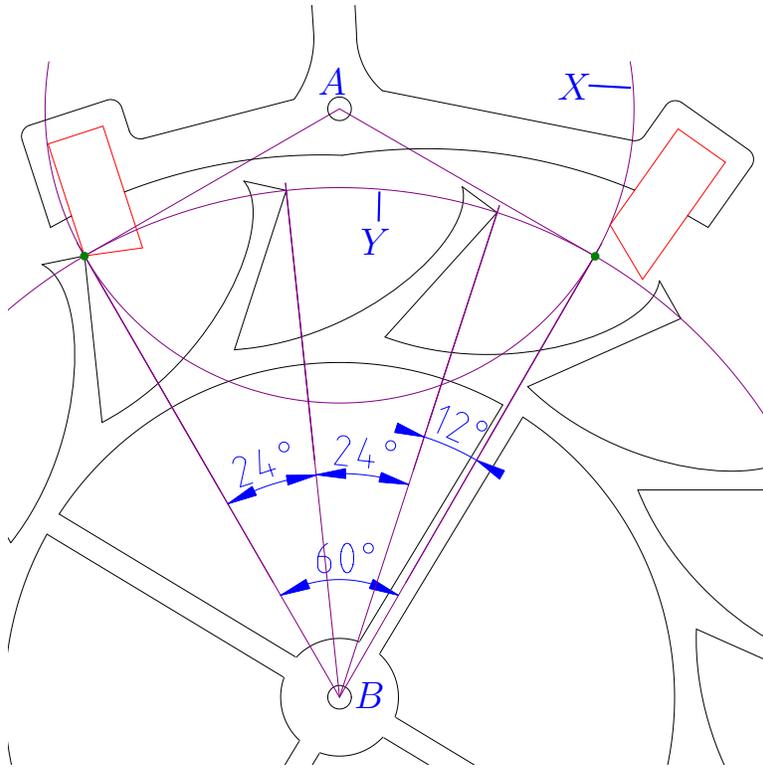


FIGURE 3. Close-up of Figure 2B. The green vertices are the unlocking points, A is the lever pivot, B is the escape wheel pivot, X is the locking circle, and Y is the primitive circle of the escape wheel.

The unlocking points are also assumed to be equidistant from the lever pivot A . In this case the locking is said to be *equidistant*, as opposed to *circular*; see [p.9, P] for a comparison of the two designs. The circle centered at A which passes through the unlocking points is called the *locking circle*. The corners of the pallets coincident with the locking and impulse faces lie on the locking circle at all times.

2.2. The drop. The term “drop” refers to an action as well as a quantity. The *drop* as an action is the sudden free movement of the escape wheel starting when it ceases imparting impulse to one pallet and ending when the next tooth locks with the other pallet, i.e. from D–E and from J–K in Figure 2. We call the motion from D–E the *engaging drop* and the motion from J–K the *disengaging drop*. The *drop* as a quantity is the angle that the escape wheel rotates during the drop; this applies to both the engaging and disengaging drop. See Figure 4.

The drop is a loss of energy: if there were no drop then the escape wheel would transfer energy to the lever during its entire motion. In fact, in Playtner’s reference escapement, the escape wheel is turning freely for $\approx 55^\circ$ out of 360° . However, the drop is necessary in order to allow the lever and pallets to move freely. Playtner specifies an angle of $1\frac{1}{2}^\circ$ for both the engaging drop and the disengaging drop. This quantity is purely notional, and is used only as a basis for specifying the width of the teeth (2.4) and the pallets (2.5). In Playtner’s escapement the actual engaging drop is $\approx 1.8^\circ$ and the actual disengaging drop is $\approx 1.9^\circ$. For

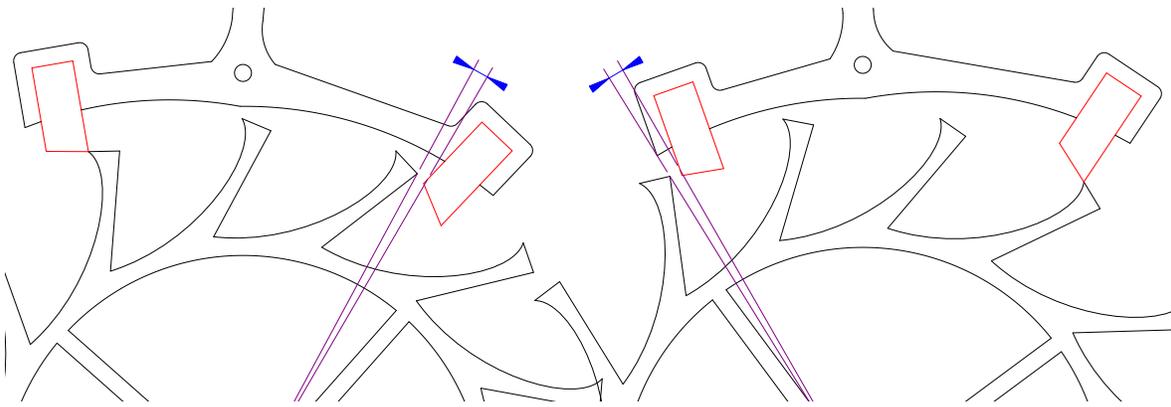


FIGURE 4. The angle indicated in blue is the engaging drop (left) and the disengaging drop (right).

this reason we distinguish between the *theoretical drop* or *specified drop* and the actual drop. Playtner glosses over this point entirely. See (2.6) for further discussion.

2.3. The lift, lock, and run. The *lift* or *total lift* is the angle that the lever rotates from its locked position to the drop, i.e. from A–D and from G–J in Figure 2. See Figure 5. In theory these two angles need not be equal, but the pallets are designed to enforce this important symmetry. Playtner specifies 10° of total lift.

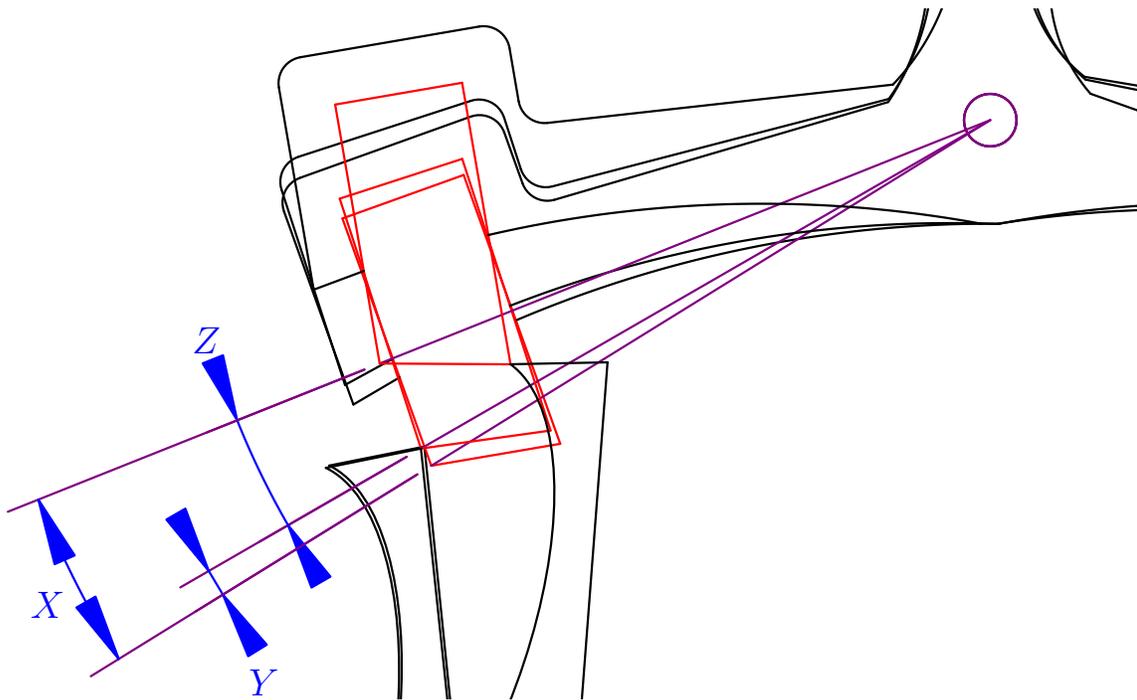


FIGURE 5. The angle X is the total lift, Y is the total lock, and Z is the actual lift. The run is not pictured.

The lifting motion has two stages: first the momentum of the balance wheel causes the impulse pin to turn the lever (A–B and G–H in Figure 2); once unlocked, the escape wheel

lifts the lever (B–D and H–J in Figure 2). The angle that the lever rotates during the unlocking stage is called the *total lock*, and the angle that the lever rotates during the lifting stage is called the *actual lift*. The total lift is by definition the total lock plus the actual lift. Playtner specifies a total lock of $1\frac{3}{4}^\circ$ and an actual lift of $8\frac{1}{4}^\circ$.

After the drop the lever is not yet at rest against the banking pin. The remaining angle that the lever rotates to reach the banking pin (E–F and K–L in Figure 2) is called the *run*. Playtner specifies $\frac{1}{4}^\circ$ of run. Confusingly, Playtner also defines a quantity called the *lock* as the total lock minus the run. This is the amount that the locking face of the pallet lies below the primitive circle at the moment the tooth drops onto it. We will not make use of this term. The *acting angle* is the angle that the lever rotates from bank to bank; it is equal to the total lift plus the run, in our case $10\frac{1}{4}^\circ$.

2.4. The teeth. The acting face of a club tooth has two corners. The *heel* is the corner that contacts the locking face of the pallet when the escapement is locked, and the *toe* is the corner that contacts the impulse face of the pallet in the final part of the lift. The heel is clockwise of the toe, and is slightly closer to the escape wheel pivot B . The angle between the rays from B to the heel and toe of a tooth is called the *width* of the tooth. Playtner specifies a tooth width of $4\frac{1}{2}^\circ$. The distance from B to the toe of a tooth is the *real radius* of the escape wheel (as opposed to the primitive radius, the distance from B to the heel, defined in (2.1)), and the circle centered at B which passes through the toes of the teeth is its *real circle*. The primitive and real circles intersect the locking circle in two pairs of points. The angle subtended by the arc spanned by either of these pairs of points, measured with respect to the lever pivot A is the *height* of the tooth. Playtner specifies a tooth height of 3° . The width and height of the tooth constitute enough data to draft the acting face of the tooth. See Figure 6.

The face connecting the heel of the tooth to the wheel is straight, and is drawn at a 24° angle. This is angle Z in Figure 6. Angle Z must be steep enough that only the heel of the tooth contacts the pallet while locked; see (2.5). The face of the tooth connecting the toe to the wheel is drawn concave so that it also cannot touch the pallets.

2.5. The pallets. The face of the pallet opposite the locking face is called the *discharging face*. The impulse face of the pallet has two corners: the *locking corner* is incident to the locking face, and the *discharging corner* is incident to the discharging face. The discharging corner is the last part of the pallet to touch the tooth before the drop (Figure 2(D,J)). The locking corners of the pallets lie on the locking circle; the locking circle and the primitive circle of the escape wheel intersect in the unlocking points. The *width* of a pallet is the angle subtended by the arc spanned by its unlocking point and the point at which the discharging corner crosses the primitive circle. Playton specifies a width of 6° for both pallets. See Figure 7.

The angle of the impulse face of a pallet is determined by the actual lift and the height of the teeth, as can be seen in Figure 7. Hence these data suffice to draft the impulse faces of the pallets.

The locking face of each pallet is inclined clockwise. This is so that, if the movement were to be jarred while locked, the escape wheel would draw the lever back against the banking pin. Said differently, the unlocking motion turns the escape wheel *counterclockwise* by a small amount. This can be seen in Figure 5. The angle of inclination of the pallet is called the *draw* or the *draft angle*. More precisely, the draw is the angle between the locking face and the ray from the escape wheel pivot through the locking corner of the pallet, when the pallet is fully

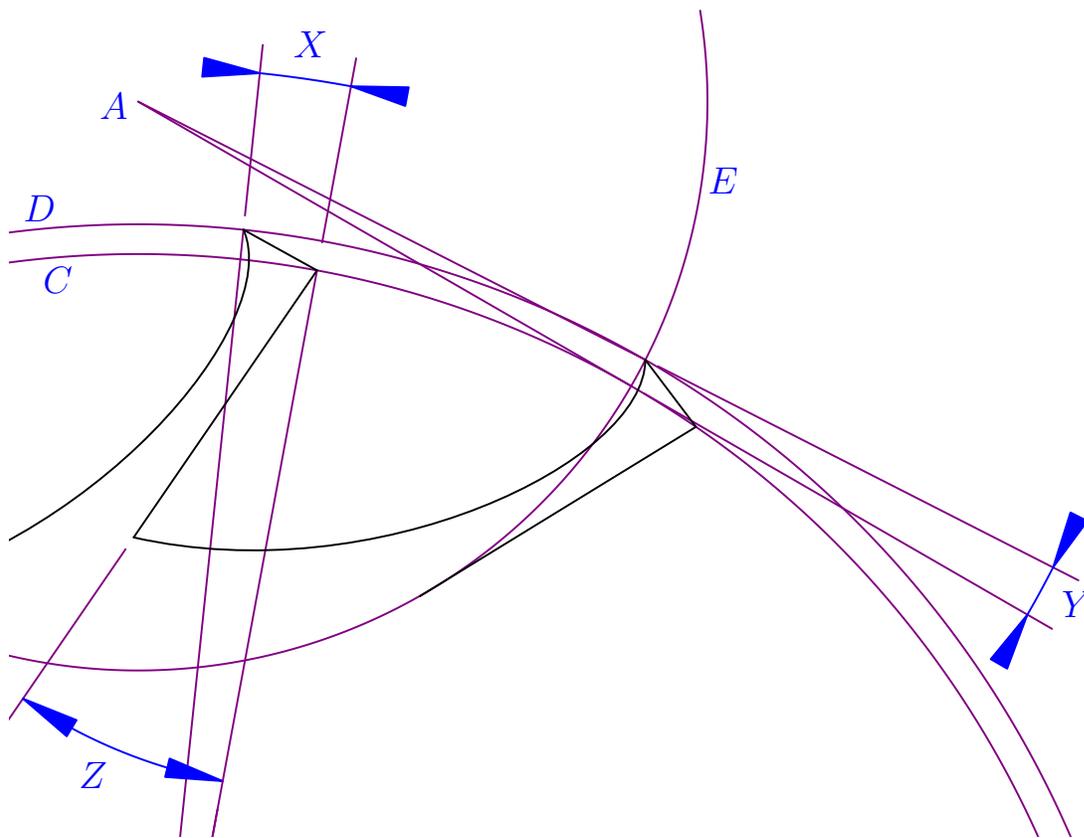


FIGURE 6. This figure illustrates the specification of the tooth. The point A is the lever pivot, C is the primitive radius of the escape wheel, D is its real radius, and E is the locking circle. The angle X is the width of the tooth and Y is its height.

locked (i.e. the lever is resting against the banking pin).¹ Playtner specifies a draw of 12° . See Figure 8. The angle Z of Figure 6 is chosen to be twice the draft angle.

As the unlocking motion exerts a drag on the balance wheel, the total lock and the draw should be as slight as possible. Playtner discusses this issue beginning on p.13.

The discharging face of the pallet does not play a functional role in the escapement. It is generally drawn parallel to the locking face. Once both pallets have been drafted, the angle between them must be determined. To do so, starting in Figure 8, rotate either pallet around the lever pivot by the acting angle, in our case $10\frac{1}{4}^\circ$.

2.6. Remarks. The escape wheel rotates by half a tooth from drop to drop, e.g. from E to K in Figure 2. Since it has 15 teeth, this amounts to 12° . In order for this to happen, the unlocking points have to span a half-integral number of teeth on the primitive circle of the escape wheel; this explains why the arc between them subtends an angle of $2\frac{1}{2} \times 24 = 60$

¹When drafting the escapement in the figures, I measured the draw when the locking corner of the pallet is on the primitive circle. The error in the draft angle in the figures is approximately equal to the total lock of $1\frac{3}{4}^\circ$ — that is, I have illustrated a draft angle of about $10\frac{1}{4}^\circ$ on the engaging pallet and about $13\frac{3}{4}^\circ$ on the disengaging pallet.

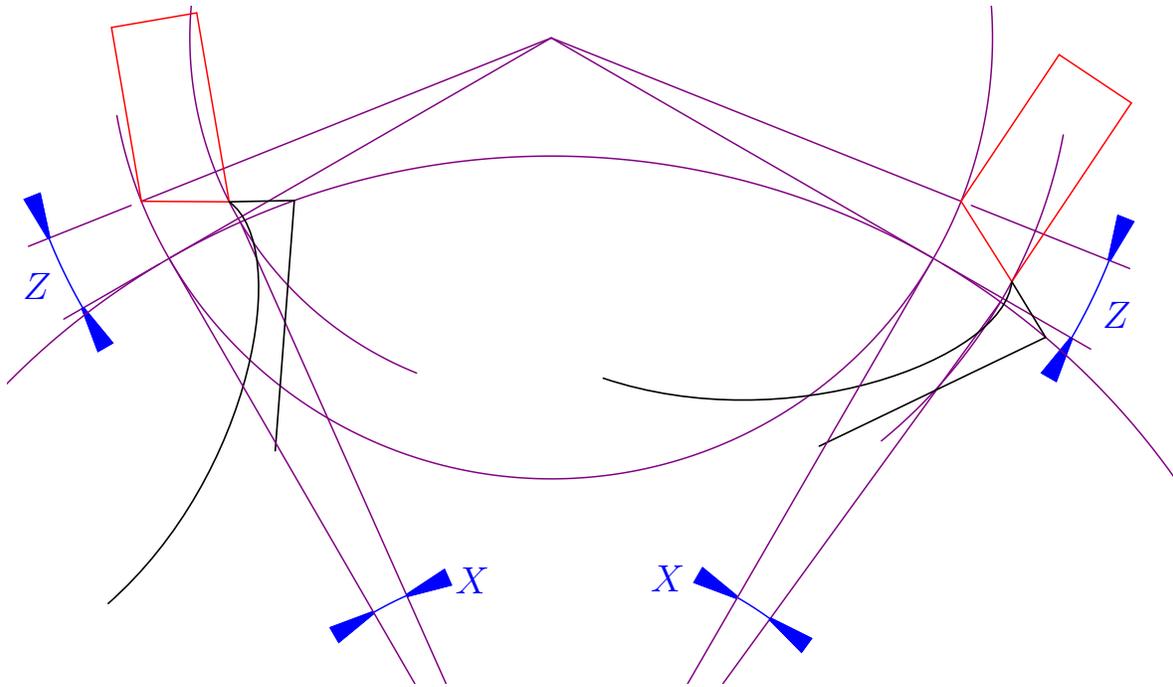


FIGURE 7. This figure illustrates the specification of the impulse face of the pallets. The angle X is the width of the pallets, and Z is the actual lift (cf. Figure 5). Both pallets are drawn just before the drop happens: that is, the engaging pallet appears as in Figure 2D, and the disengaging pallet appears as in Figure 2J.

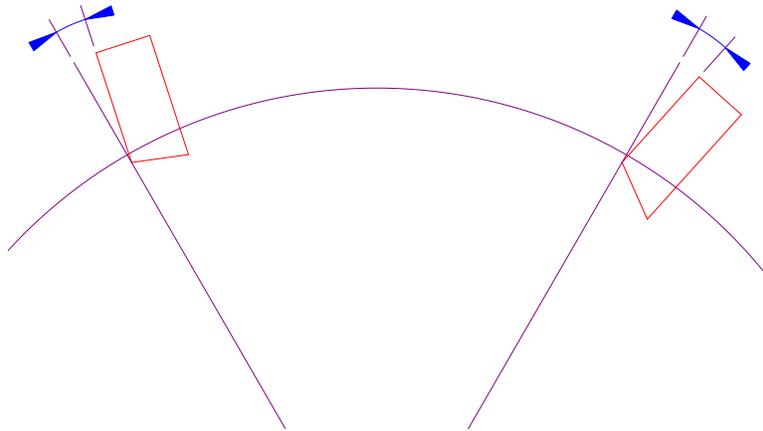


FIGURE 8. The angles indicated in blue are the draft angle. Both pallets are in the locked position: that is, the engaging pallet appears as in Figure 2A, and the disengaging pallet appears as in Figure 2G.

degrees. By definition, the width of the pallet plus the width of the tooth plus the (theoretical) drop equals 12° , i.e. $6 + 4\frac{1}{2} + 1\frac{1}{2} = 12$. This is the relation Playtner uses to choose the pallet and tooth width. It is a reasonable rule of thumb: the escape wheel rotates approximately

$10\frac{1}{2}^\circ = 6^\circ + 4\frac{1}{2}^\circ$ from locked to just before the drop (B–D and H–J in Figure 2), as the tooth has to move all the way across the impulse face of the pallet. However, since the point of contact between the tooth and pallet does not always lie on the primitive circle, the actual drop will not be equal to the theoretical drop, as mentioned in (2.2).

The escapement can be designed with any given value for the ratio between the widths of the lever and the tooth. Playtner discusses the issue in depth starting on p.17.

Similarly, to first approximation the actual lift is equal to the height of the tooth plus the height of the impulse face of the pallet, the latter being defined as the angle between the rays from the lever pivot to the corners of the pallet. The height of the pallet would then be $8\frac{1}{4}^\circ - 3^\circ = 5\frac{1}{4}^\circ$. Again, since the point of contact between the tooth and the pallet is always changing, this value is not exact; the actual height of the impulse face is $\approx 5.24^\circ$ on the engaging pallet and $\approx 6.15^\circ$ on the disengaging pallet. In any case, Playtner uses this relation when choosing the height of the tooth; he discusses this choice starting on p.16.

The discrepancy between the actual height of the impulse face of the pallet and its theoretical height is somewhat subtle and is one of the more difficult points to understand in [P]. In fact, if I understand them correctly, Playtner’s instructions for drafting the angle of the impulse face on the engaging pallet are incorrect (admittedly, the error is $\approx .01^\circ$), although he seems to understand this when he says that there is “no appreciable loss of lift on the engaging pallet” (p.46). To avoid these difficulties, I prefer to ignore the height of the impulse face entirely, as the angle of the impulse face is determined by the height of the teeth and the actual lift, as discussed in (2.5).

3. FORK AND BALANCE

In this section we describe the design of the fork of the lever and the components attached to the balance wheel. As the parameters defining each component depends on the previous components, we will present them in the order they must be drafted.

3.1. Acting length and impulse radius. The *acting length* of the lever is the nominal distance between its pivot A and the point of contact with the impulse pin. Of course the actual distance from A to the point of contact varies a bit as the lever and balance wheel turn. The circle centered on A with radius equal to the acting length is the *acting circle*. Playtner specifies an acting length equal to the distance from A to the escape wheel pivot B — in other words, B lies on the acting circle. See Figure 9.

The *theoretical impulse radius* is the nominal distance between the balance wheel pivot A' and the acting corners of the impulse pin. The *theoretical impulse circle* is the circle centered at A' with radius equal to the theoretical impulse radius. The theoretical impulse radius is used in making design choices and in construction, but is only an approximation to the slightly larger *real impulse radius*, i.e. the actual distance from A' to the acting corners of the impulse pin, which we will construct later (3.3).

In Playtner’s reference escapement, the axes of rotation B , A , and A' are collinear; the line containing these points is called the *line of centers*. This condition is somewhat arbitrary, and many movements are designed differently. The theoretical impulse circle intersects the acting circle in two points; we require that the arc on the acting circle spanned by these points subtends an angle equal to the acting angle, i.e. the total angular motion of the lever, in our case $10\frac{1}{4}^\circ$. This requirement is explained as follows. Ignoring the total lock and the run, in theory the lever acts on the impulse pin throughout its motion, i.e. through an angle of $10\frac{1}{4}^\circ$. As the nominal distance from A to the acting edge of the lever is equal to the acting length,

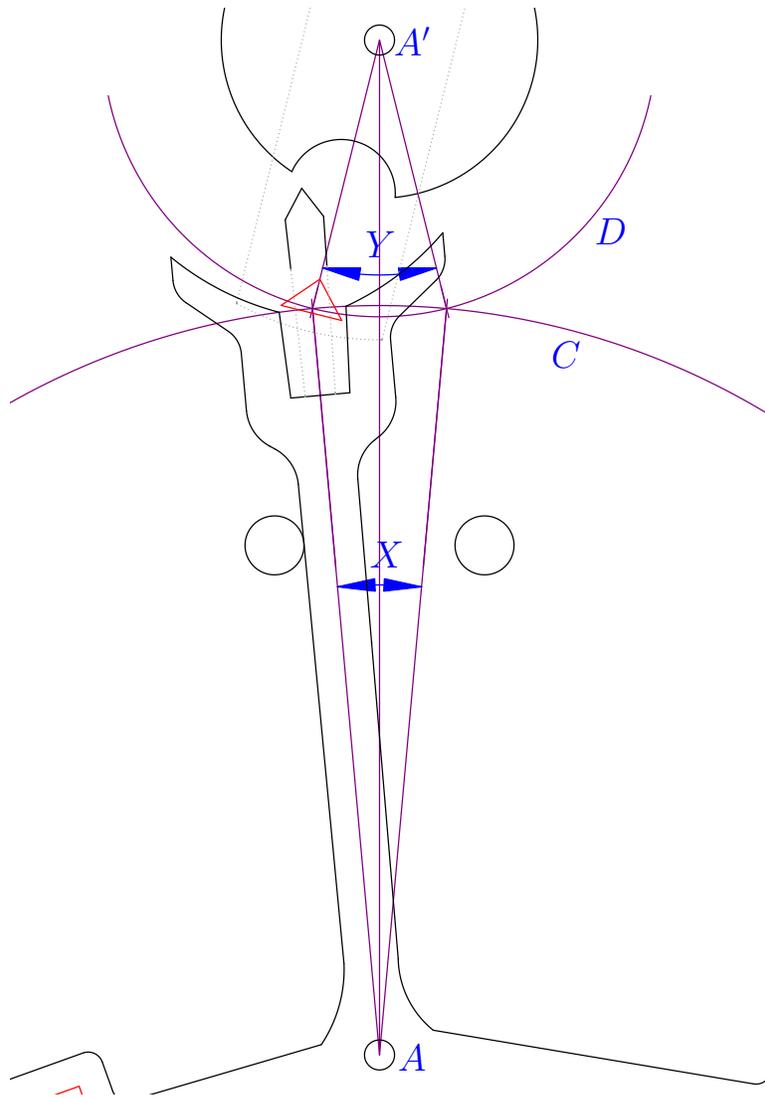


FIGURE 9. An illustration of the acting circle and the theoretical impulse circle. The point A is lever pivot, A' is the balance wheel pivot, C is the acting circle, D is the theoretical impulse circle, X is the acting angle, and Y is the impulse angle. Note that the values of X and Y , the radius of C , and the requirement that the line from A to A' be vertical, determine the location of A' and the radius of D .

and the nominal distance from A' to the acting corners of the impulse pin is equal to the theoretical impulse radius, the pin will first make contact with the lever at one intersection point, and will leave the lever at the other. Hence the angle on the acting circle subtended by the arc spanned by these points must be the acting angle. The *impulse angle* is defined to be the angle subtended by the arc on the theoretical impulse circle spanned by the same intersection points. For the reasons just discussed, the impulse angle is the nominal amount that the lever turns the balance wheel.

Playtner's recommended value for the impulse angle is 28° . This value, along with the other requirements imposed on the design, fully determine the theoretical impulse radius and the location of the balance wheel pivot. See Figure 9.

The ratio between the acting angle and the impulse angle, or between the acting length and the theoretical impulse radius, is an important design decision. Playtner discusses it beginning on p.26.

3.2. The slot. The outer corners of the slot lie on the acting circle. The sides of the slot are radial, i.e. they lie on the rays from the lever pivot to the corners of the slot. The angle between these line segments is called the *width* of the slot. The depth of the slot does not need to be precisely specified, as long as it is deep enough to accommodate the impulse pin. Playtner specifies a slot width equal to half the acting angle, in our case $5\frac{1}{8}^\circ$. See Figure 10.

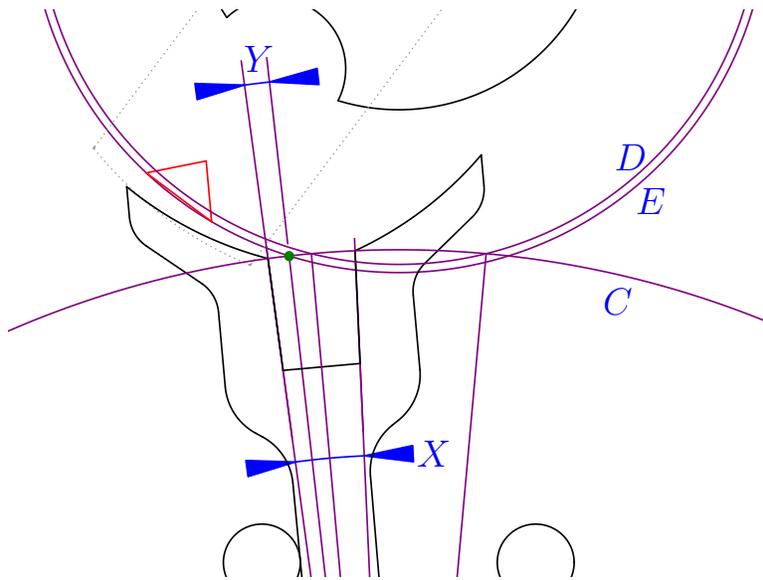


FIGURE 10. This figure illustrates the construction of the slot and real impulse circle. The circle C is the acting circle, D is the theoretical impulse circle, and E is the real impulse circle. The angle X is the width of the slot and Y is the freedom between the corner of the slot and the impulse pin.

3.3. The real impulse radius. Assume for the moment that the outside face of the impulse pin lay entirely on the theoretical impulse circle. With the lever resting against the left bank, suppose that the movement were to receive a jar just as the impulse pin passes over the left corner of the slot. The lever is free to rotate clockwise until the left corner of the slot strikes the outside face of the impulse pin; the point of contact lies on the intersection of the acting circle and the theoretical impulse circle. This point lies in the center of the slot when the lever is resting against the bank; hence the lever has rotated by an amount equal to half the width of the slot, in our case just over $2\frac{1}{2}^\circ$. This is enough rotation to unlock the lever; as the impulse pin is not entirely within the slot, this can stop the balance.

We have just described the reason for the difference between the real and theoretical impulse radii. We specify an angle of freedom Y for the lever to rotate from its resting position against the bank until the corner of the slot strikes the impulse pin in the above situation, now under the assumption that the outside face of the impulse pin lies along the

real impulse circle, i.e. the circle coradial with the theoretical impulse circle of radius equal to the real impulse radius. More precisely, with the lever resting against the left bank, rotate the lever clockwise through an angle of Y ; the left corner of the slot by definition now lies on the real impulse circle. The position of the left corner of the slot after this rotation is indicated in green in Figure 10.

Note that Y must be less than the total lock. The impulse pin in Playtner's reference movement in fact has a flat outside face, but if the difference between the total lock and Y is large enough then this will not cause problems. Playtner specifies a value of $1\frac{1}{4}^\circ$ for Y , which is $\frac{1}{2}^\circ$ less than the total lock.

3.4. The impulse pin. The impulse pin is drafted in the “down” position, i.e. when its center lies on the line of centers. It is symmetric with respect to the line of centers. The impulse pin can have many shapes, but in Playtner's reference movement it is a triangle.² The acting corners of the impulse pin lie on the real impulse circle, and the third corner lies on the line of centers, closer to the balance wheel pivot. The *width* of the impulse pin is the angle between the lines from the lever pivot through the acting corners of the impulse pin. The impulse pin must have some freedom of movement inside the slot, so the width of the impulse pin is less the width of the slot. The difference between the two widths is called the *shake*. Playtner recommends a shake of $\frac{1}{4}^\circ$, so the width of the impulse pin is $5\frac{1}{8}^\circ - \frac{1}{4}^\circ = 4\frac{7}{8}^\circ$. The third (non-acting) corner does not need to be specified exactly; the impulse pin should be large enough that it does not break, but it should also be as light as possible. See Figure 11.

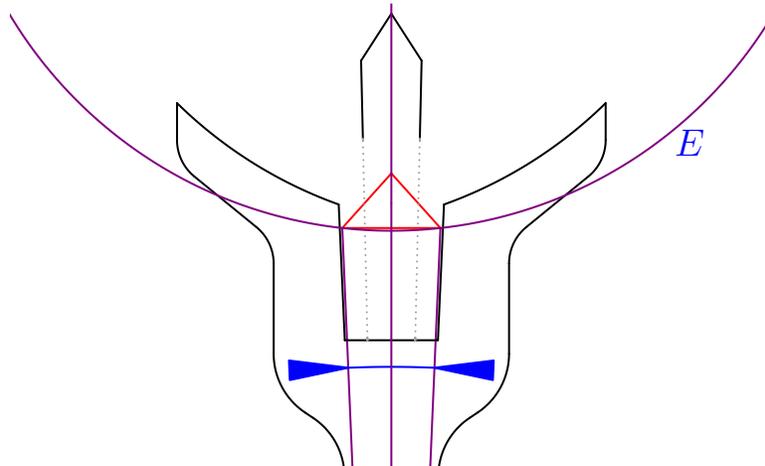


FIGURE 11. This figure illustrates the specification of the impulse pin. The circle E is the real impulse circle and the angle indicated in blue is the width of the pin.

3.5. The safety roller and dart. The safety roller and the dart are below the level of the rest of the lever and the impulse pin. Their purpose is to prevent the lever from unlocking while the balance wheel is spinning freely and the impulse pin is nowhere near the fork. The safety roller is a circle which is coradial with the impulse circles. Playtner recommends a safety roller radius equal to $\frac{4}{7}$ of the theoretical impulse radius. See [p.47, P] for a brief discussion of this choice.

²Actually it is not clear to me whether Playtner means for the outside face of the pin to be straight or an arc of the real impulse circle. I don't think it makes any practical difference.

The dart is attached to the lever. When the lever is resting against the banking pin and the impulse pin is far from the fork, if the movement receives a jar then the lever can only turn until the dart contacts the safety roller. The angular freedom of movement Y of the lever in this situation, along with the radius of the safety roller, determine the position of the point of the dart. This construction is similar to the determination of the real impulse radius in (3.3) and is illustrated in Figure 12. As in (3.3) the angle Y should be less than the total lock so that the lever cannot accidentally unlock. Playtner recommends a value of $1\frac{1}{4}^\circ$ for Y .

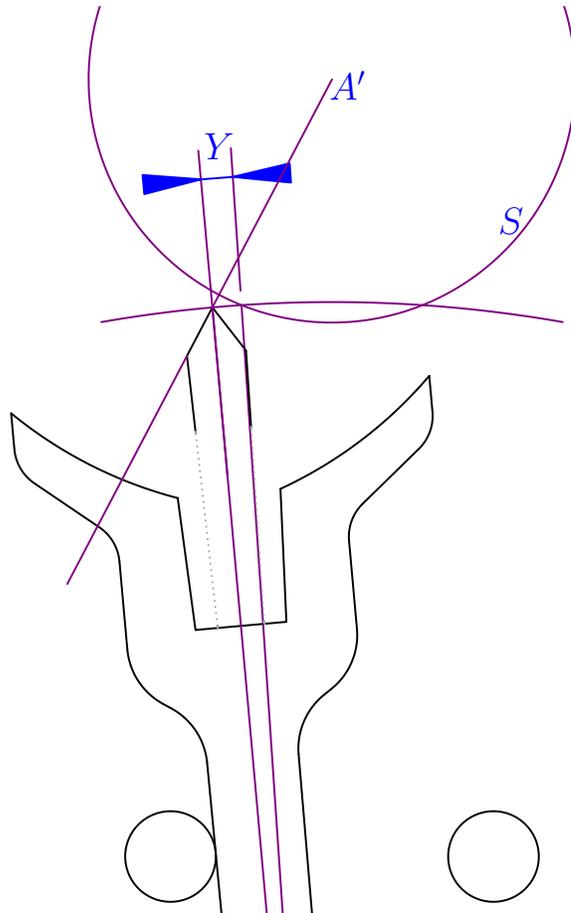


FIGURE 12. This figure illustrates the specification of the dart. The point A' is the balance wheel pivot, S is the safety roller, and Y is the angular freedom of motion of the lever from the banking pin until the dart contacts the safety roller.

The rest of the dart does not need to be specified precisely, as the point of the dart is the only part that contacts the safety roller. The leading edges of the dart should form an acute enough angle that they will not touch the safety roller at any time. In Playtner's reference escapement, the leading edge of the dart points toward the balance wheel pivot when the lever is resting against the bank, as in Figure 12.

3.6. The crescent. As the lever should actually unlock when struck by the impulse pin, there must be a section cut out of the safety roller for the dart to pass through. This section is called the crescent. It is an arc whose center is incident to the safety roller circle and the

ray from the balance wheel pivot A' through the center of the impulse pin. The center of the crescent is indicated in green in Figure 13. The radius of the crescent is constructed as follows. We put ourselves in the situation of Figure 2A: the lever is resting against the left banking pin and the impulse pin has just struck the right face of the slot. We draw a ray from A' to the point of the dart, then we draw a second ray at a specified clockwise angle X from this first ray. The crescent passes through the intersection of this second ray and the safety roller circle. The angle X determines the clearance for the dart when entering the crescent; Playtner recommends a value of 5° . See Figure 13.

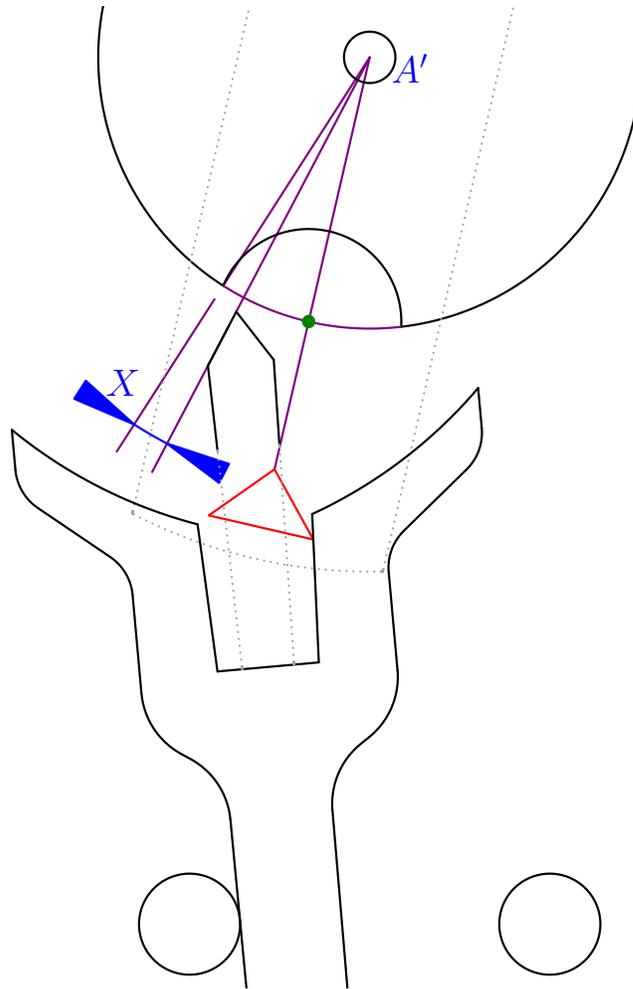


FIGURE 13. This figure illustrates the specification of the crescent. The point A' is the balance wheel pivot. The angle X is the clearance for the dart when entering the crescent. The green point is the center of the crescent.

3.7. The horn. The purpose of the horn is to prevent the lever from accidentally unlocking when the impulse pin is in the vicinity of the fork, when the dart would enter the crescent instead of contacting the safety roller if the movement were to receive a jar. The corner of the horn is constructed as follows. With the lever resting against the left banking pin, we rotate the impulse pin and crescent to the orientation such that the dart would contact the right-hand corner of the crescent if we were to rotate the lever clockwise. Said differently,

the impulse pin and crescent are rotated counterclockwise as far as possible such that the dart would contact the safety roller and not the crescent if the lever were rotated clockwise. See Figure 14. We mark the point P incident to the real impulse circle and the ray from the balance wheel pivot through the center of the impulse pin. The point P is indicated in green in Figure 14. We now rotate P counterclockwise through a specified angle Y with respect to the lever pivot. This new point is the corner of the horn. The angle Y is the nominal angular freedom of movement of the lever from the banking pin until the horn contacts the impulse pin; as before, Y must be less than the total lock. The acting face of the horn is the arc passing through the corner of the horn and the corner of the slot, with radius equal to the real impulse radius.

Playtner specifies a value of $1\frac{1}{2}^\circ$ for Y . I am not certain why this freedom of movement is not also $1\frac{1}{4}^\circ$ as in (3.3) and (3.5). My best guess is that the actual freedom of movement between the horn and the impulse pin is always somewhat less than the nominal freedom of movement.

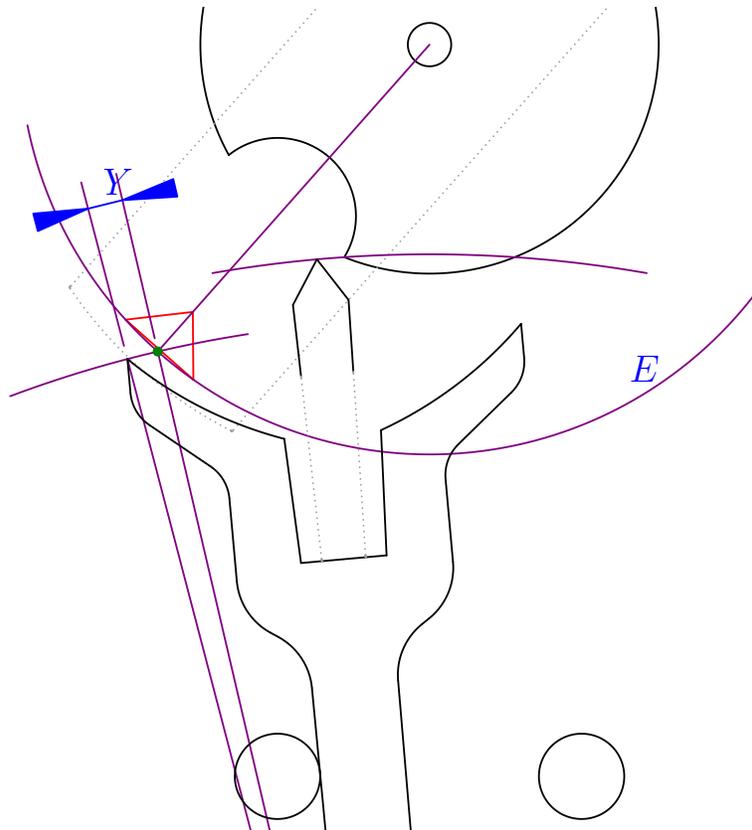


FIGURE 14. This figure illustrates the specification of the horn. The circle E is the real impulse circle. The angle Y is the angular freedom of movement of the lever from the banking pin until the horn contacts the impulse pin.

3.8. Final considerations. All of the functional components of the escape wheel, lever, impulse pin, and safety roller have now been specified. The actual form of the lever should be designed by compromising strength and weight. The impulse roller has not been mentioned since (1.2). It is attached to the balance wheel above the level of the lever, and it carries the

impulse pin on its bottom face. Usually the impulse roller is in fact round, but it need not be, as its only function is to carry the impulse pin.

3.9. Remarks. The components of the fork, safety roller, and crescent are carefully designed in order to prevent the lever from unlocking at *any* orientation of the balance wheel, except of course when the impulse pin is inside the slot and the escapement is supposed to be unlocked. During most of the rotation of the balance, the dart and safety roller prevent unlocking, and when the impulse pin nears the slot, the horn and pin prevent unlocking. These details are crucial to the reliability of the movement.