The electromechanical clock of the city hall in Cluses and its restoration

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This document is an introduction to the electromechanical clock installed around 1912 at the city hall of Cluses (France) and constructed at the Cluses horology school under the direction of Charles Poncet. Besides describing how the clock works, I am also analyzing the outcome of the restoration that took place in 2017-2018, and I am drawing a number of conclusions on the issues related to a good patrimonial intervention.

1 Introduction

The clock described here was made when Charles Poncet was director of the Cluses horology school, and for practical reasons, I will call it "Poncet's clock." Poncet (1868-1942) is in fact a very little known French clockmaker and professor of horology but who deserves to be better known. From 1883 to 1886, he was a student at the Cluses horology school [3, 4], a school founded in 1848 and first opened to pupils in 1849. He returned to the school in 1892 and in 1905 he became its new director and remained at that position until 1934. He was the author of several books.

In his book on clock strikings, published in 1938, certainly one of the most detailed book on the subject and a book every clockmaker should own, Poncet described a very interesting tower clock [6, pp. 149-157]. Although the whereabouts and fate of this clock were not given, it was recently found that it had been constructed around 1910 and installed at the city hall in Cluses, France, that is, very close to the Cluses horology school where the clock has been constructed. Before its installation in the city hall, it was also exhibited at the Turin International in 1911. It seems that this exhibition was instrumental in Poncet's obtaining the *Légion d'honneur* in November 1912.[1]

The clock was restored in 2017-2018. In what follows, I will first describe Poncet's clock, then I will tell more about the restoration and the conservation of the clock.

2 Poncet's description

Poncet did not give all the details of his clock, but he gave enough to reach a good understanding of the workings of the clock, and also to draw a clear picture of what was needed in the restoration and further scientific development of the clock.

[1]Journal officiel de la République française, 2 and 3 November 1912, page 9351.

In this section, I am therefore loosely translating Poncet's description, adding useful information when necessary and available. I have tried to include everything that Poncet wrote, so that it is normally no longer necessary to access Poncet's original text.[2] Obvious typos in Poncet's text have been silently corrected. Some information was also drawn from the restoration report and I am usually making it clear. For reasons explained later, I am not giving any photograph of the clock. Some photographs can easily be found on the web by googling "horloge monumentale Cluses."

Figure 1 shows a front view of the clock. The clock is fixed to a wooden frame which, according to the restoration report, is 96.5 cm wide and has a depth of 76.2 cm. The height of the clock, from this base to the end of the remaining transmission, is 122.2 cm. According to François Simon-Fustier, the restorer, it is made up of a total of 1910 parts, this number including the screws and various small parts. It weighs about 265 kg, this value probably including the base.

The clock used to strike two bells and show the time on the dial on the front of the city hall.

2.1 A master or slave clock

Poncet's clock is one of many clocks illustrating the application of electricity to clocks. The main ideas used in Poncet's clock, namely the use of an electric motor both for striking and for rewinding the going work, were already embodied in a clock exhibited by the Cluses horology school at the 1900 Universal Exhibition in Paris [1].

The clock made for the city hall of Cluses, probably by the Cluses horology school under the supervision of Poncet, went a little bit further. First, it was a tower clock, and second it was aimed at being a slave clock, controlled by a master clock at the Cluses horology school. An example of a master clock also designed by Poncet survives at the Cluses museum and was described in 1909 [5] (figure 2). This master clock delivered an electrical impulse every minute. However, the clock at the city hall is built in such a way that it requires an impulse every 30 seconds. It is therefore not clear if the master clock really delivered an impulse every minute, or if it was modified, or if another master clock was used at some point. In any case, when such an impulse came to the city hall, a wheel would make exactly half a turn. This was obtained by an electromagnet which is not described by Poncet, and also not described here, but on which some ele-

[2] Poncet's entire book is available at
https://gallica.bnf.fr/ark:/12148/bpt6k318860k.

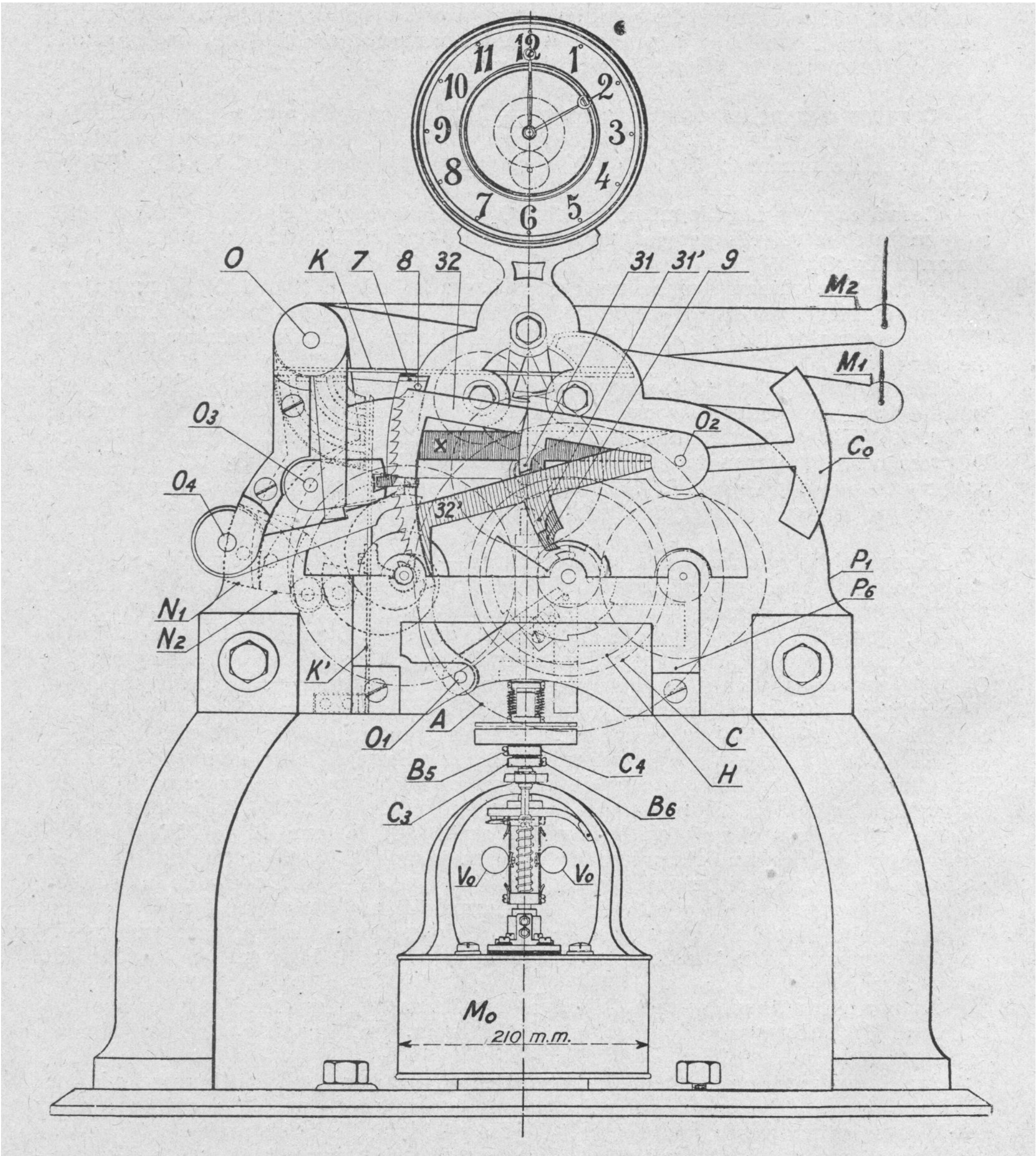


Fig. 100. — Face principale de l'horloge.

Figure 1: Front view of the clock.

ments can be found in the 3D animations made by Sébastien Lucchetti for François Simon-Fustier.

However, Poncet's clock described here could also have worked independently, although it probably never did. The clock could have been fitted with a pendulum and the going work would have been controlled by the pace of this pendulum. When the clock was used as a slave clock, the going work was only triggered every 30 seconds and the gears merely advanced immediately by the same amount they would have advanced in 30 seconds with a more conventional escapement. In order to ease this switch, which could have been useful in case of a power outage or a failure of the master clock, Poncet's clock was fitted with two escapements so that it was easy to move manually from one to the other. The 3D animations show that the two escape wheels are next to each other and could easily be shifted, so that one is in mesh when the other one isn't.

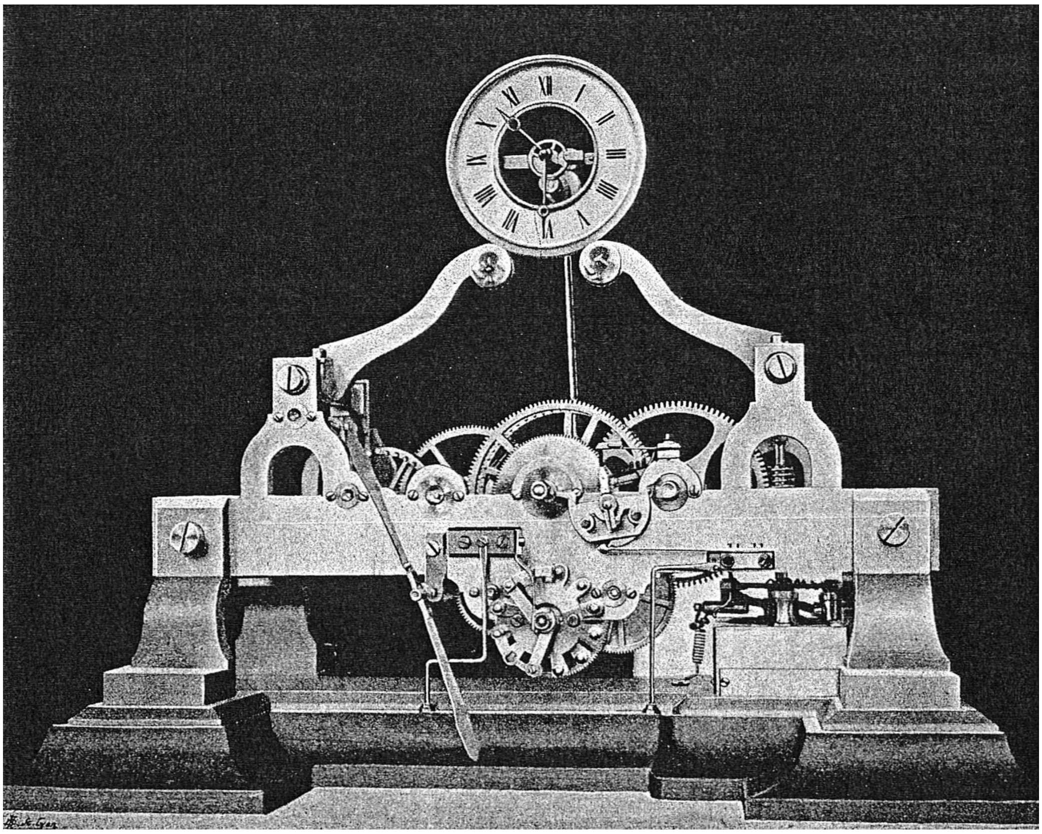


Figure 2: Poncet's master clock from 1909 [5].

2.2 Going work

Poncet does not describe the going work and mainly focuses on the striking work, which is understandable since his book is on striking works. But a description of the going work can be given based on the 3D model and on the informations found in the restoration report. The first wheel of the going work, called C by Poncet, has 128 teeth and makes one turn in one hour (figures 3 and 5). It meshes with a 16 leaves pinion whose arbor carries a 120 teeth wheel, which itself meshes with a 16 leaves pinion whose arbor carries the 30 pin escape wheel. From this we deduce easily that the escape wheel makes one turn in one minute and, if a pendulum were used, it would have a half-period of one second.

On the arbor of the first wheel is a 24 leaves pinion meshing with another similar pinion. The arbor of this pinion carries a 42 teeth bevel gear which meshes with a similar bevel gear with a vertical axis. This leads to two 74 teeth bevel gears leading to the horizontal arbor behind the minute hand of the control dial. Note that some of these informations can be checked either on the actual clock, or on a 3D interactive application of the clock, which can be seen next to the clock, and is available online, or on 3D animations put online by the restorer.[3] But the 3D model itself (made with SolidWorks) is not freely available.

The dial work uses a 28 teeth pinion meshing with a 56 teeth wheel on which arbor a 12-leaves pinion meshes with a 72 teeth wheel conducting the hour hand.

2.3 General organization of the electric engine

This clock strikes the quarters on two bells and the hours on only one bell. These strokes are not obtained by the fall of a weight, but by the direct action of an electric motor. The motor does at the same time rewind the going work spring. This mechanism is quite rare, because almost every tower clock works with weights. However, there have been a few other experiments of tower clocks using springs before Poncet's clock, although I am unable to name a surviving example of such a clock. Poncet does not give any other example and may have thought that his construction was the first of that kind.

On figure 1 (page 5), the lower part is the electric motor and the upper part shows the control dial. There are two levers M_1 and M_2 for the striking hammers. The lever at the front is for the smallest hammer, whereas

[3] https://www.youtube.com/channel/UCSB9wpPKBw2S3DLPbH_SHhg

the lever at the back is for the largest hammer, which is also used for striking the hours.

We can also guess the form of the snails and racks. This clock normally did not work with a pendulum, but could easily be fitted with one, if necessary. It was normally a slave clock which could receive impulses from a master clock, such as the one constructed by Poncet and which is still exhibited in the former horology school (now high school) of Cluses. At each impulse, the escape wheel would make half a turn. But if equipped with a pendulum, it would only make a 60th of a turn at each half-oscillation. The clock therefore contains two escapements, only one of which is used at a given time.

Weights could be dispensed with because the going spring is rewound very often and because the electric motor acts directly on the striking work, and not as a means to lift a weight. One of the advantages of using an electric motor is that the clock takes up much less space.

The spring is on the central axis (figure 5) which is also the axis of the two snails.

Figure 3 shows a left side view of the clock, and figures 4a, 4b and 5 show some components which will be described later.

Figure 6 shows the electric circuit of the clock. *Ro* is the rotor of the electric motor, *Ex* are the stator coils and B_3 and B_4 are its brushes.

The DC electric motor used to be driven by six lead batteries, here shown on the right, hence a voltage of $6 \times 2{,}1$ Volts. These batteries were apparently at some time replaced by the mains AC power supply and a transformer.

There is an electromagnetic clutch made of a circular shielded electromagnet E_c, which is attached to the upper (free) trunnion of the rotor. The rotor and E_c always move together.

The lifting mechanism for the striking work is made of the endless screw V_i (3 threads) (on the axis of the rotor) and the wheel R_v (132 teeth). The lifting mechanism for the going work is made of the two previous elements, the pinion a (16 leaves) and the wheel A (264 teeth).[4] Consequently, the screw V_i needs to turn $132/3 = 44$ times for each turn of the wheel R_v.

Each time the screw V_i rotates, there is both a stroke (through the rotation of R_v) and a rewinding of the going spring (through the rotation of A).

g and g' are two cams raising the striking levers and one turn of R_v corresponds to one stroke. This is very similar to many modern electric

[4] In his description, Poncet did not give the tooth counts for a and A, and wrote that R_v has 100 teeth. Perhaps this was initially the case.

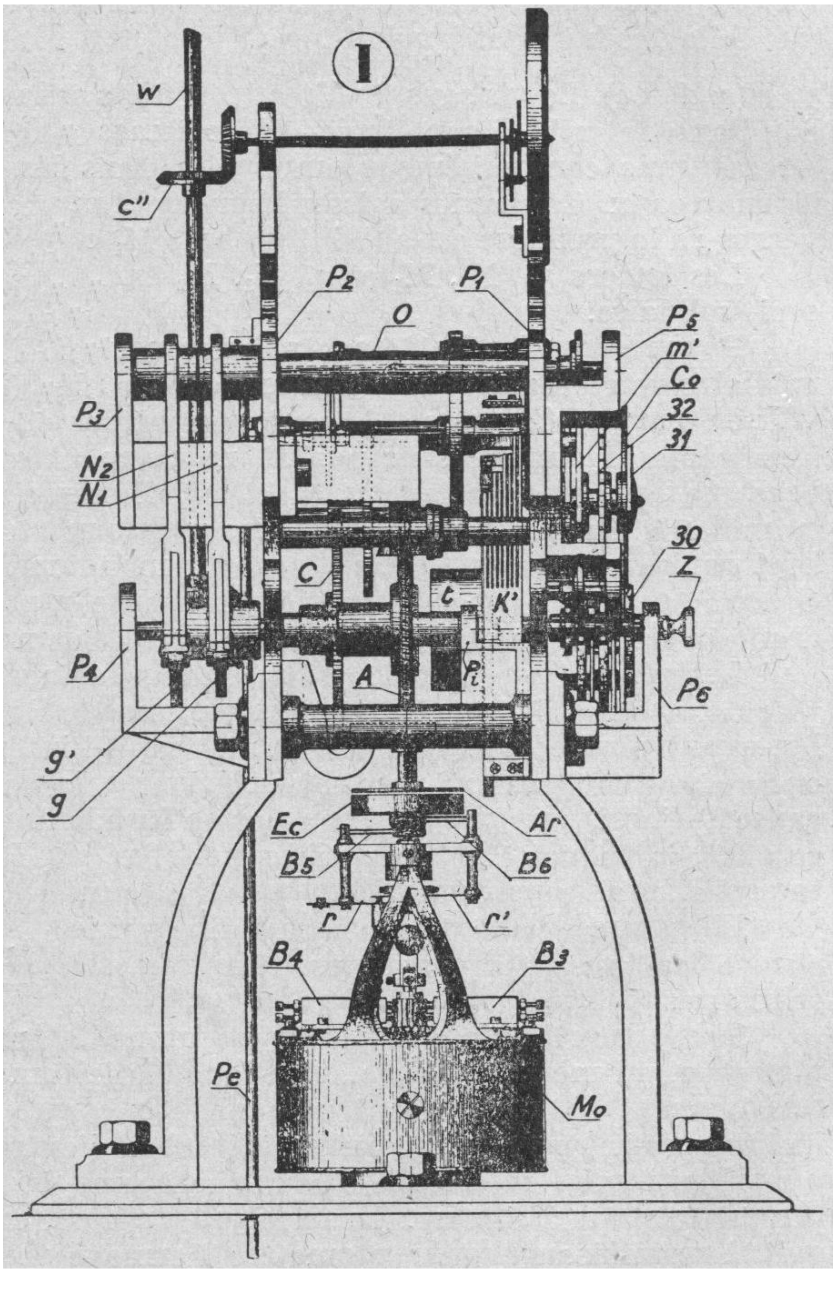
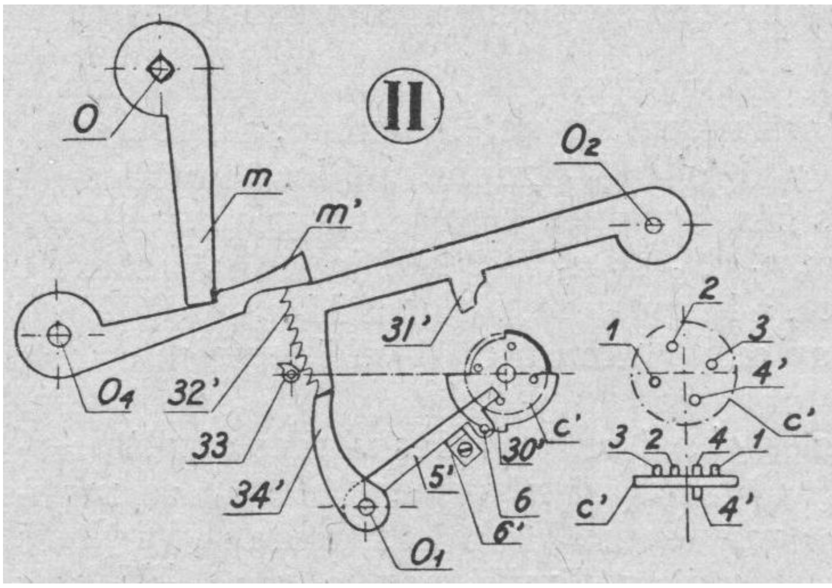
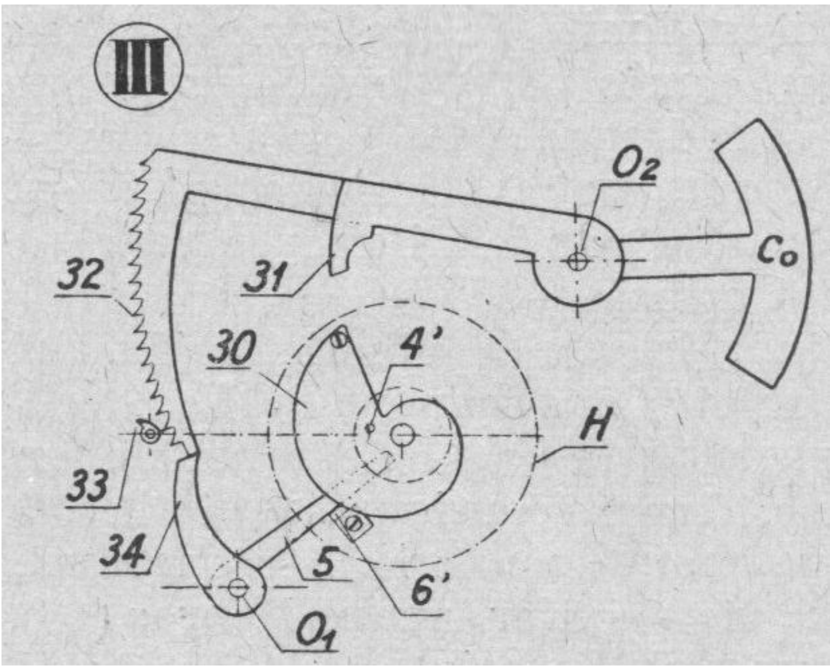


Figure 3: Left side view of Poncet's clock.



(a) The quarter rack.



(b) The hour rack.

Figure 4: The quarter and hour racks.

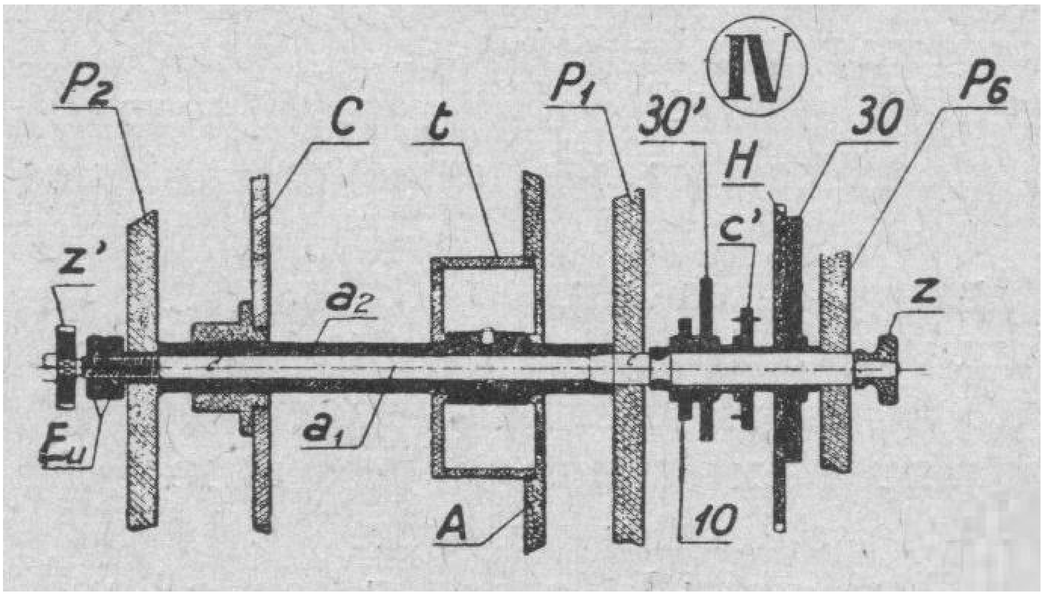


Figure 5: The main arbor of the going work.

striking works in church towers and elsewhere. But in older mechanical clocks, there is a wheel with a number of pins or rollers, for instance 10, and each pin or roller raises the striking lever. Here the striking levers are raised through two rollers which are rolling on the cams and which push the intermediate levers n_1 and n_2. (In the actual clock, these levers are of course less stylicized, but the principles remain the same.) This reduces friction with the two cams. The two hammers are raised by strings fixed to the ends of the levers M_1 and M_2.

In fact, things are a bit more complex in that the arms carrying the rollers can pivot around o and o'. When a hammer is raised, the roller tends to pivot clockwise around o or o', but the arm which carries it is stopped at p or p_1. Once a roller goes past its heighest point, the roller arms quickly move counterclockwise and the hammer is released. Poncet writes that this system makes it possible to use the entire span between the lowest and heighest point on the cam. This may require some more investigations, and I assume first that the tip of the heighest point of the cams is basically flat, and second that this is meant to ensure a precise fall, in spite of the non-zero dimensions of the rollers.

The pin 16 fixed on wheel R_v is used to stop this wheel when it encounters the arm 15. This does only occur when that lever is in its lowest position, which depends on arm X, as we will see later. The position of the arm X does in turn depend on the cam 10.

The horizontal blade K, together with the contacts s_0, s_1, s_2 and s_3 is a progressive circuit switch whose purpose is to avoid sparks. A safety switch is made of the vertical blade K' and the other ends of the contacts s_0, s_1, s_2 and s_3 and its purpose will be explained shortly.

The rotor R_o and the screw V_i should have the same axis.

Facing the electromagnet E_c, and as close as possible, there is a circular armature A_r. This armature is fixed on a piece x' which rotates with the lower trunnion of the screw, but which can slide vertically. That way, the armature may be attracted by the electromagnet but in normal conditions this armature is maintained in an upper position by two coilsprings whose upper ends are fixed to a piece x which is entirely attached to the endless screw.

The electromagnet E_c has a coil whose ends are linked to two insulated rings C_3 and C_4, on which the two brushes B_5 and B_6 are rubbing. These two brushes are mounted in derivation on B_4 and B_3. Both the rotor and the electromagnet are simultaneously subject to a current when the electric circuit of the battery is closed.

Poncet observed that in an earlier configuration the circuit of the electromagnet was closed not with a pair of special brushes, but merely by the use of the centrifugal force which when the rotor rotates would bring the armature near the electromagnet. This construction was replaced by the current one.

All these parts are located on the rear of the clock (see figure 3 which shows a side view and where N_1 and N_2 are on the left). The trunnions of the arbor of R_v pivot in the bridges P_4 (back of the clock), P_i (inside of the clock) and P_6 (front of the clock). These precautions are useful because of the sudden stoppage caused by the wheel R_v at the end of each striking. This stoppage is caused by the pin 16 meeting the arm 15.

The wheel R_v hence serves three functions: it is part of the lifting mechanism and driven by the electric motor, it is used for raising the hammers, and it is used to stop the striking. In an ordinary tower clock, there is a wheel for lifting the weight, there is another wheel for raising the hammers, and there is yet another wheel to stop the striking.

On the front trunnion of R_v, and immediately behind the bridge P_i, there is a pinion a meshing with the wheel A. This wheel is part of the going spring case (barrel) t (see figure 5), and the rotation of A will rewind the spring in t. Inside this case there is a thick strip making only one turn and carrying a hook for the spring. The spring is therefore not attached to the outside wall of the barrel t, but to this strip, and an excessive winding will cause the strip to slip inside the barrel, thus preventing a spring break.

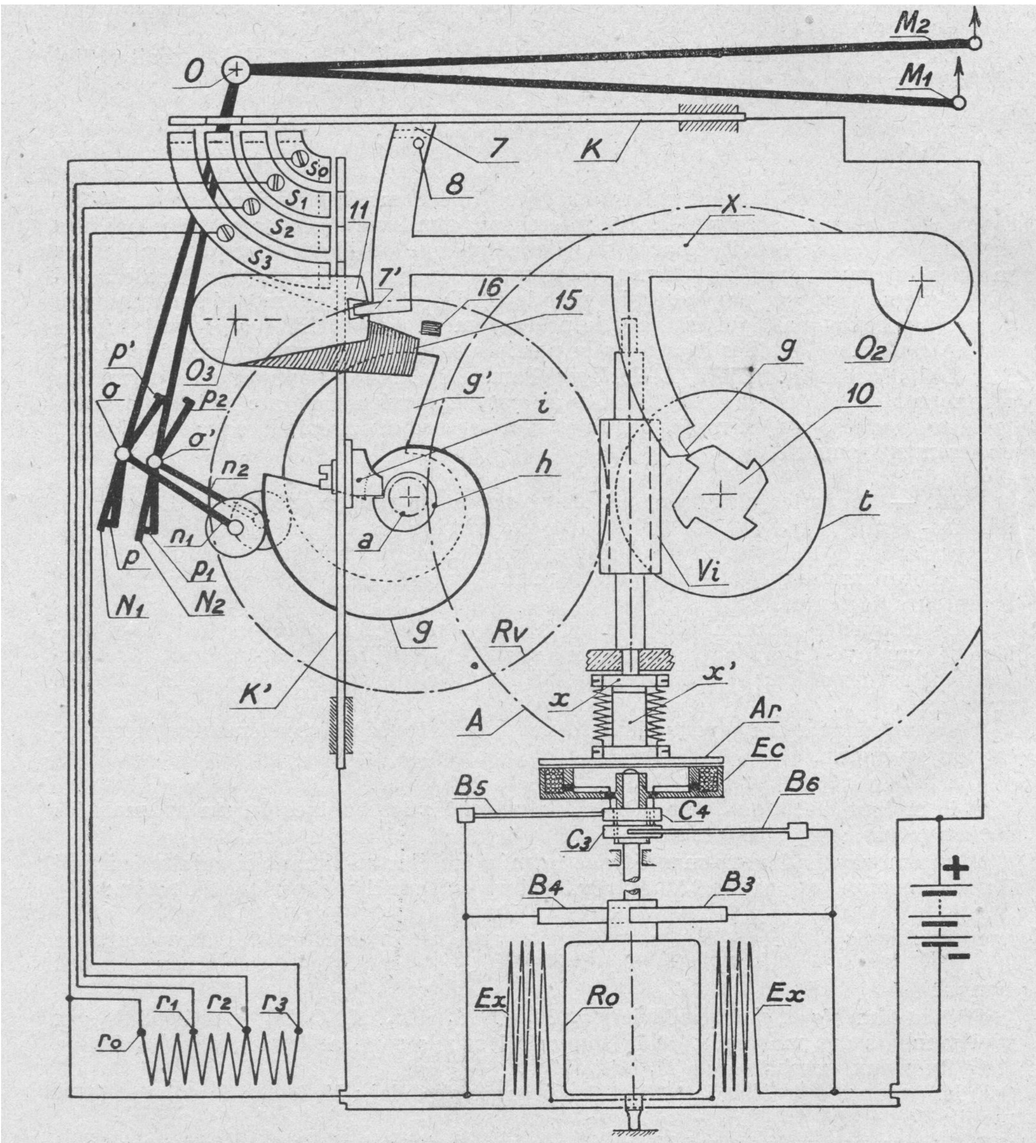


Fig. 98. — Schéma d'une horloge d'édifice munie d'un moteur électrique à courant continu excité en dérivation.

Figure 6: The original wiring of the clock and the striking functions.

In normal working conditions, the strip and the barrel behave as if they were only one piece. The other end of the spring is of course attached to the arbor which does one rotation per hour.

The warning lever X moves around the fixed axis O_2. It has three functions. First, through its appendix $7'$ which loosely fits a notch in the arm 11 pivoting around the axis O_3, it raises the arm 15 and can stop the rotation of wheel R_v. Second, through its bent appendix 7 which goes inside the cage, it prevents the insulated blade K from closing the electric circuit. One of the poles of the battery is linked to this blade K (see figure 6). This appendix 7 is covered by an insulated plate to avoid a short-circuit. Third, when the arm 9 falls on a notch after one of the teeth of the cam 10, it allows the blade K to come in contact with the insulated pieces s_0, s_1, s_2, s_3, that is to close the circuit, and this must coincide with the minute hand reaching 0, 15, 30, or 60 minutes on the dial.

Note that the cam 10 makes one turn per hour, but that it is fixed to the arbor, not to the wheel A.

The four insulated pieces s_0, s_1, s_2, s_3, together with the blade K' (also insulated), make up the safety switch which will be explained later. These pieces s_0, s_1, s_2, s_3 are visible towards the right of figure 3, over the label K'.

These blades are positioned in such a way that when the arm X moves down, there is first a contact with s_3, then with s_2, then with s_1, and finally with s_0. Each of these contacts closes the electric circuit, but in each case the electric current takes a different path. When the contact with s_3 is established, the current goes through the resistors r_3, r_2 and r_1. When the second contact is established, the current goes only through r_2 and r_1. When the third contact is established, it goes only through r_1. And finally, when the last contact is established, all the current goes directly towards the electric motor (see figure 6).

It would have been nice to be shown how the resistors are implemented and what are their numerical values, but this information is nowhere to be found. Poncet did not give them and neither does the restoration report give any details. Even if there are no separate resistors, there are numerical values which could have been measured, and which seem not to have been measured.

The way the circuit is closed ensures that the current increases gradually and that there are no (big) sparks. The remaining sparks do not damage the contacts. Poncet suggests in addition to add a condensator of 7 to 8 μF, but I do not know if this was ever done. The restoration report is totally silent on this matter and no condensator is visible in the 3D animations. I also do not know if the contacts had been worn.

When the circuit is again opened, exactly the opposite takes place and the contacts are opened in the opposite order: first s_0, then s_1, then s_2 and finally s_3. At the very moment the circuit is opened, all three resistances are involved and the current is very low.

2.4 Striking parts

There are two racks, the hour rack 32 and the quarter rack $32'$ (see figures 1, 4a and 4b). The

These racks are made of several parts and the teeth are separate parts which could easily be replaced if needed. The hour rack has an arm 31 which falls on the hour snail 30. Similarly, the quarter rack has an arm $31'$ which falls on the quarter snail $30'$. Both snails are on the same axis, as shown in figure 1.

The quarter snail makes one turn in one hour and the hour snail makes one turn in 12 hours. There are four wheels which are used to transform the hourly rotation of the quarter snail to the 12 hour rotation of the hour snail. On the arbor of the quarter snail, there is a 50 teeth wheel which meshes with a 150 teeth wheel. On its arbor is a 40 teeth wheel which meshes with a 160 teeth wheel moving together with the hour snail. This gives the sought ratio 12.

The two racks are also on the same axis O_2 as lever X. These two racks are normally (that is, when no striking occurs) maintained in a raised position by the two pawls 34 and $34'$ which are pivoting on a common fixed axis O_1. This is very similar to what is found in common tower clocks using rack striking.

Each rack has a toothed part which can be raised by the use of the two small pawls 33 (one behind the other) which are located on the axis of the wheel R_v. These pawls perform one turn for every stroke. In its default (inactive) position, the pawls are not in contact with the teeth (figures 4a and 4b).

The hour rack also has a counterweight C_o, in order to ease its great falls.

When the hour rack 32 is entirely raised, it also keeps the lever X raised through the pin 8 which is fixed on the lever X (figure 6). There is actually a notch on the top of the hour rack for this pin, as can be seen on the 3D model. In any case, it is consequently the hour rack which opens the circuit and stops the striking when it is completely raised.

The two pawls 34 and $34'$ also carry the arms 5 and $5'$ (see figures 4a and 4b). The end of the arm 5 is in the path of the pin $4'$ (figure 4b), so that this pin can cause the pawl to release the hour rack. Similarly, the end of arm $5'$ is in the path of the pins 1, 2, 3 and 4 and the quarter rack can be released that way. These pins are located on either side of the disk c' (figure 4a).

Two coil springs normally maintain the arms 5 and $5'$ on the $6'$ abutment.

Finally, the arm $5'$ also carries a pin 6. This pin causes the hour rack to be released whenever the quarter rack is released.

2.5 The four-quarter and hour striking

As an example, Poncet considers what happens a few minutes before and during the 10 o'clock striking. The pins 4 and $4'$ move the arms $5'$ and 5 and cause the falls of the quarter and hour racks on the quarter and hour snails.

Shortly after these falls, the two pins are leaving the arms 5 and $5'$ and the two pawls 34 and $34'$ then rest on the teeth of the racks.

When the hour rack falls, it also causes the lever X to fall. However, this fall is interrupted by the contact between the arm 9 and the upper part of one of the teeth of the cam 10 (figure 6), because we are not yet exactly at 10 o'clock. The racks are ready, but the circuit is not yet closed.

At that point, however, the arm 15 has already released the pin 16, and the blade K has come closer to the contacts s_3, s_2, s_1 and s_0, but still without touching them. It is only two or three minutes later that the arm 9 falls between two teeth of the cam 10. The circuit is then closed and the electric motor is put in motion. The armature A_r is then attracted by the electromagnet E_c and rotates together with the rotor. This causes the rotation of the screw V_i and of the wheel R_v.

And each time the wheel R_v makes one turn, the two cams g and g' cause the two hammers to be raised for one quarter. Each rotation of R_v causes a double stroke and at the same time the pawls 33 raise the racks by one tooth. (As mentioned before, there are in fact two separate 33 pawls, one next to each other, both moving together.) The pawls 34 and $34'$ which are gliding on the teeth serve to maintain the racks in the positions attained by the pawls 33. At each double stroke, the small hammer strikes first.

When the quarter rack has entirely been raised, the pawl $34'$ has moved under the rack and the arm $5'$ abutts on the bridge $6'$. But each rotation of the pawls 33 still raises the quarter rack by one tooth, although it immediately falls back to its rest position.

After the four double strokes for the four quarters, the hour rack continues to be raised for the remaining strokes. Since it is 10 o'clock in our example, the hour rack is actually raised ten more times. This means that it was actually raised 14 times. I presume that there is no *empty stroke* between the quarters and the hours. Poncet doesn't mention it, and I do not see how it would be implemented.[5] Moreover, there is no real need for an empty stroke, because there is a natural gap between the fourth stroke of the second hammer of the quarters, and the first stroke of the hours (figure 7).

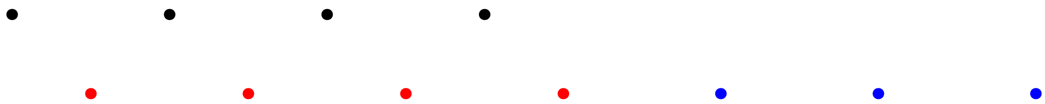


Figure 7: The strokes for 3 o'clock. The black dots represent the first (quarter) hammer, the red dots represent the second (quarter) hammer, and the blue dots represent the same hammer used for the hours. There is a natural gap between the last red dot and the first blue dot.

During the hour strokes, only one of the two hammers is lifted. As mentioned above, the first stroke of the quarters is by the smallest of the two hammers. This hammer is maintained lifted during the hour striking, so that only the largest hammer strikes from then on. This is done as follows. On this hammer's arbor O is another lever m (figure 4a) which moves with the lifting lever of the hammer. During each quarter stroke, this lever has a clockwise and then an anticlockwise motion. But when the quarter rack is raised for the last time, actually the fifth time, the small hammer is raised just before the rack $32'$ reaches its heighest position, and when the rack reaches the heighest position, the rack pushes the lever m' up, which then blocks the lever m. Consequently, the small hammer can no longer fall and only the other hammer falls. This shows that the quarter rack is really lifted five times, the first four times for the quarter strokes, and the fifth time for the first hour stroke. After that, the quarter rack is still lifted a little bit, but its small fall (on the pawl $34'$) is not sufficient to unlock the lever m. Of course, when the racks are released, the lever m' also falls and the lever m is also released, but the small hammer does not immediately fall, being prevented from it by the roller gliding on its cam.

Finally, the last lift of the hour rack causes the lever X to be raised and therefore the circuit to be opened, as mentioned above. At the same time,

[5] This is one of several questions I asked to the restorer, but got no answer. The restorer refuses to answer any technical question or discuss his work with people who do not have the same diplomas and titles as he has.

the lever X raises the arm 15 and this stops the wheel R_v after a very short time.

At that moment, the circuit is open, R_v does no longer rotate, but the rotor still moves a little bit, without carrying the armature A_r. And the armature itself may also still rotate, being merely mounted on its canon by friction.

Poncet remarks that the endless screw V_i should have a sufficient slope in order to avoid being stuck with the wheel R_v. In the actual construction, an anti-backlash device was added on the arbor of wheel R_v, in order to prevent this wheel from going backwards after each turn. This was briefly mentioned in the restoration report, and is visible in the animations.

2.6 The first three quarter strikings

The hour rack plays an essential role in that it is this rack which opens and closes the electric circuit. Consequently, this rack has to be released, even during the first three quarters. This is where the pin 6 comes into play. Poncet takes the example of the third quarter. A little before the minute hand reaches the 45 minutes mark, the pin 3 moves the arm $5'$ (figure 4a), and a short time afterwards the pin 6 moves the arm 5, causing therefore both rack falls.

More precisely, we have the following steps:

1. the quarter rack falls three teeth on the third sector of the quarter snail $30'$;
2. the arm m' also falls and releases the arm m; both hammer can therefore strike;
3. the lower end of the hour rack is missing one tooth (compare figures 4a and 4b), so that it possible for the hour rack to move only slightly when the pin 6 moves the arm 5; consequently, the hour rack does not do a complete fall, but only falls one tooth;
4. this causes the fall of the lever X as well as the arm 15, but the circuit is not yet closed;
5. the pin 3 then goes beyond the arm $5'$ and the pawl $34'$ meshes in the teeth of the quarter rack, while the pawl 34 remains under the last tooth of the hour rack;
6. at that point also, the pin 16 is no longer blocked, and we are merely awaiting the start of the electric motor;

7. finally, the closing of the circuit occurs when the arm 9 falls after a tooth of the cam 10.

During each rotation of the wheel R_v, both hammers strike their bells. After each double stroke, when the quarter rack is lifted by one tooth, the hour rack is also lifted but comes back to its initial position (just before the closing of the circuit), and this closes again the circuit. So, at the end of each double stroke, if nothing else were done, the circuit would be briefly opened, and closed again, or merely would stop working. This, however, is prevented by a "safety switch." On the arbor of the wheel R_v, there is a cam h (figure 6) which pushes the blade K' towards the contacts s_3, s_2, s_1 and s_0 exactly when the circuit was going to be opened, and this blade is released a few moments afterwards, so that it does not prevent the electric motor from stopping when the striking is really completed.

The pawl 34 does not return to the position under the rack, because the arm 5 is still pushed by the pin 6. It is only at the end of the third quarter, that is after three rotations of the wheel R_v, that the pawl $34'$ returns to its rest position, and that the pawl 34 can also do the same when the hour rack is lifted. This then opens the circuit and ends the third quarter striking.

2.7 Rewinding of the going work

The spring barrel tA is supported by the axis a_2 of the wheel C which does one turn per hour. The internal end of the spring is fixed to this arbor, and the outside end to a strip inside the barrel, as described above.

This spring is only rewound at each striking, that is, every 15 minutes. However, since the strikings are not all identical, the spring is rewound more at certain times than at others, and it is necessary to ensure that after 12 hours (the striking period) the spring is exactly rewound as much as it was unwound. Figure 8 shows how much the spring is loaded on a period of 12 jours. The spring starts with three coils ("3 tours"), and it continuously loses some of its tension. (Poncet put curved segments, but these should actually be straight lines.) And at each quarter, some of the amount lost is gained again. At each hour, more is gained, and eventually we return to the initial situation. The minimum spring load occurs just before 7 o'clock. These considerations constrain the features of the gears, but it is easy to find out what are these constraints.

Since C does one turn in one hour, it does 12 turns in twelve hours and so the wheel A must do exactly 12 turns in twelve hours. And since the pinion a makes one turn per double/single stroke(s), we must have $N = 12 \times \frac{A}{a}$ where N is the number of double/single strokes in 12 hours.

This number is $N = (1+2+3+4) \times 12 + (1+2+\cdots+12) = 198$. In other words, we must have $A/a = 16.5$. Poncet writes that one solution is to take $a = 12$ and $A = 198$ and that another is to take $a = 8$ and $A = 132$. In fact, according to the restoration report obtained in 2019, we have $a = 16$ and $A = 264$. In any case, a has to be an even number.

These considerations are not new and they were used on the first tower clocks that had periodical rewindings, before Poncet's clock, and they are common on all the tower clocks which were electrified in the 1940s or 1950s. There may however be different configurations, for instance with clocks that strike only the hours, or only the hours and the half hours, and so on, leading to different gear ratios.

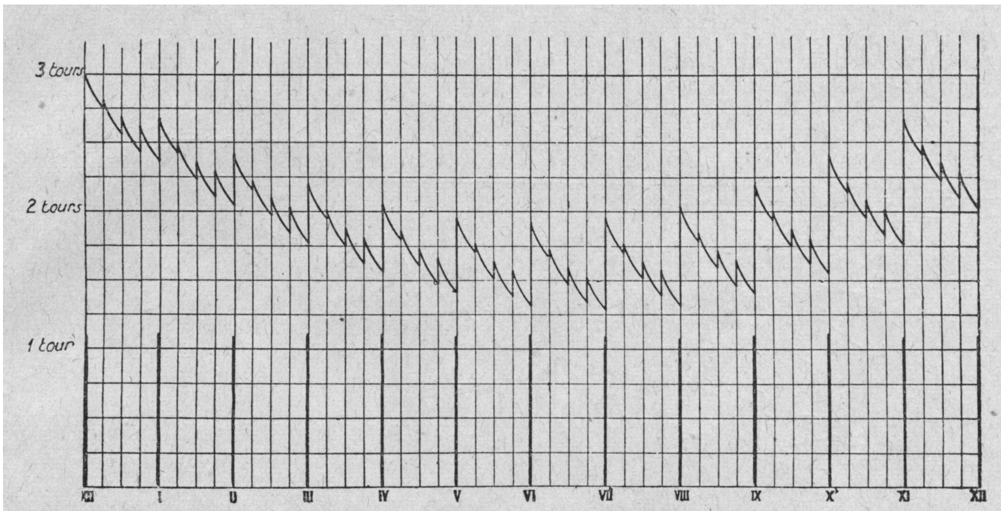


Fig. 101. — Horloge à sonnerie des quarts et des quatre quarts. Graphique des différentes phases de désarmage et d'armage du ressort de barillet en douze heures — le ressort étant armé de huit tours.

Figure 8: The evolution of the going barrel spring load over a period of 12 hours.

In fact, given that the outside end of the spring is fixed to a strip, it is probably possible that the spring is not always identically rewound at 12 hour intervals, but that there is some average rewinding.

Poncet also observes that even though a spring working on such a small number of coils should hold quite long, he made it possible to replace this spring easily. I do not know if the spring was changed during the recent restoration, and, if so, if the old spring was kept, which it should have been.

2.8 DC and AC currents

Poncet observed that this clock was designed at a time when only direct current (DC) was distributed, and power outages were frequent. He suggested that for alternating current (AC) a 3-phase motor were used as well as a centrifugal clutch.

According to the restorer, the clock can only work without current for 15 minutes, but this does not seem true. If there is no current (no battery or power outage), the clock will not strike, although the racks will fall, but this will not prevent the going spring from unwinding. Depending how much the going spring was wound, the clock could still work for about two hours and perhaps more in certain cases.

3 The restoration and transformation

Poncet's clock was restored in 2017-2018 and came to my attention at the beginning of 2019. I had actually seen Poncet's description many years before, and immediately recognized that the clock which was restored is the one described in Poncet's book. I contacted the city of Cluses for further details in January 2019, but neither the Mayor of Cluses, nor the persons who had supervised the restoration were able to adequately answer my questions about some specifics of the current situation, as well as about the conservation of historical parts of the clock. After many painful exchanges, it was only in November 2019 that I have been able to obtain a copy of the restoration report [9] (which can be obtained through the city hall by any person interested), of the teeth counts and a copy of Poncet's 1909 article on the master clock mentioned above, for which I thank the city archivist and museum director, Florence Poirier. But the municipality did not provide any detailed photographs of the clock (although it certainly has them), except for those found in the restoration report, whose resolution was reduced. The restorer himself, François Simon-Fustier, has refused to answer any technical question.[6]

It appears in fact that the restoration was scientifically unsupervised, and that the needs of scientists and scholars have not at all been taken into

[6]In fact, François Simon-Fustier (30 Chemin de Crépieux, 69300 Caluire-et-Cuire, France, hcrlyon@gmail.com, fsf@fsf-lyon.com) has even sued me for asking repeatedly questions and for questioning his work. I have had to testify before a police officer who did not believe that I was a scholar in horology and viewed me as a delinquent because I dared question someone's work without having any diploma in horology (something of which I am in fact proud).

account. A lot of information seems to have been lost, and no one knows if the historical elements of the clock have been kept and/or documented.

For these reasons, I am not including any pictures found on the web, but I am directing the interested persons to the 3D videos which are online,[7] as well as to the interactive application (which does not work on all platforms).[8] The restoration report is freely available by request to the Cluses archives.[9]

3.1 The fundamental patrimonial issues

Any intervention on a patrimonial (or heritage) object, that is an object having some scientific or historical interest for some community, should be conducted with great care, having in mind the reasons why an object is restored (or merely studied), and for whom an object is kept. A patrimonial intervention is in fact much more than cleaning an object and making a 3D model. Restorers and curators have duties towards the community, and they are unfortunately often unaware of these duties.

What should be done depends therefore on many factors, and cannot merely be decided by a restorer and/or by the owner of the object, whatever their qualifications, titles or experiences may be. The scientific background of the object, the work that other historians or scientists have done on that object, or related objects, the needs expressed by various scholars, and also any issue that might arise from the study of the present object should be part of a broaded investigation. This is true in architecture, in painting, sculpture, in fact in any art and craft, also in literature, but in the case of machines, such as clocks, this may even be more acute because of the dynamic nature of these objects. The patrimonial principles imply that the restorers, but also the curators and scholars have duties, and that none of these groups should work in isolation. The first priority of a restorer, for instance, should not be to foster his/her own business, but to do everything possible for the historical object, and to make everything available to all. It is also important that everyone communicates, and not that one person believes that he/she alone can handle the case. Each person can bring something to the study and should not be discarded for unfounded reasons.

[7] `https://www.youtube.com/c/HorlogerdelaCroixRousse/videos`

[8] The interactive application used to be available at `https://cluse-app.horlogerie-ancienne.fr`, but this address does no longer seem to work.

[9] Mairie de Cluses, 1 Place Charles de Gaulle, 74300 Cluses, France, `mairie@cluses.fr`.

For instance, in the case of a clock, other scholars may have already worked on it, or may have expressed some needs, some scholars may want to conduct broader investigations of which this clock is only an element, research on this clock may shed light on others of which neither the restorer nor the owner are aware, etc. These are some of the research issues, but there are also issues related to the means used to explain the object, that is not only the means to simplify its understanding, but also the means to make all of its workings understandable to all. Everything scientists and restorers know about a patrimonial object should be made accessible to all and no information should be withheld by the owner, by the restorer or by scientists. And of course, no part of the clock should vanish or be kept by a party, even if replaced.

There is moreover a general need for documentation, so that every decision concerning a clock, every piece of knowledge, every choice, are archived, and so that historians, or anybody interested in the workings and history of that clock (and its restoration) is able to obtain these informations and to understand them fully in the future, without having the need to request additional information from a curator or a restorer, who might well no longer be involved. A fundamental principle of documentation is that it should be as self-contained and complete as possible. It is the duty of those who supervise patrimonial interventions, and in particular of curators, to ensure that these issues are met and that all the needs of scholars are taken into consideration, not merely sampled.

In what follows, I will go in more detail over the following issues related to Poncet's clock:

- how was the clock documented and how should it have been documented?
- how was the restoration documented and how should it have been documented?
- the 3D model and its requirements;
- the animations and interactive application;
- the on-demand working and its documentation;
- the conservation of the clock.

These are six different issues, which are all important, and which all raise questions in the case of this clock.

3.2 The documentation of the clock

Whenever there is an intervention on an object, that object should be documented as much as possible, as far as dimensions, photographs, function, history, condition, etc., are concerned. Everything that can be acquired should be acquired, and especially everything that can only be acquired during the intervention. This is in particular important for mechanisms, or other objects where some parts are not visible to all. In the case of an object which will be disassembled, it is moreover essentiel to document the object as much as possible before the disassembly. Unfortunately, very few restorers and craftsmen do this and documentation is often not a priority.

The documentation should also meet the needs of scholars, should take into account other documentations made elsewhere, and should try to improve them, whenever possible. The documentation should anticipate future needs and future usages of the collected informations. In the case of a mechanism, it is of utmost importance that drawings are made, that measurements are taken, that relevant dimensions are obtained, that teeth numbers are counted, and that the kinematics is scientifically analyzed, not just quantitatively. And the documentation produced should not be for a restricted usage, it should be available to all, not merely to the owner or curator.[10]

In fact, a good documentation should among other things give all the information that everyone may want to have. This may include videos, but it should at least provide photographs of every part, with all the technical features. The documentation should contain more than just dimensions, it should be possible to correlate the collected information with the elements of the mechanism. It would therefore not be sufficient to provide only drawings, or even 3D models, but it is essential to provide also the actual photographs (or perhaps even 3D photographs, not to confuse with 3D models) and that the link between photographs, drawings and other information be possible.

In particular, the collected information should be sufficient to understand all the details of the clock, and it should also be sufficient to reconstruct the clock, if that need were to arise.

In Cluses, the documentation written by the restorer is unfortunately very far from that ideal. The restoration report does not explain how the

[10]Interestingly, the city hall of Cluses initially was reluctant to provide a copy of the restoration report, and then tried to set an illegal price for the copy of each page. Eventually, after several months of pressure, it provided the report at no cost. This should be the norm. The city hall should actually put the report online, which would be much simpler for all.

clock works. It contains only three pages of explanations summarizing Poncet's description and thus tells a lot less about the workings than Poncet's book. It does not contain any drawing of the organization of the gears, it does not answer a number of questions raised by Poncet's description, it does not contain detailed photographs of the parts, nor plans of each part. And it contains some errors. For instance, the restorer writes that the striking work starts without a warning phase, which is wrong, and this makes us wonder if the restorer really understands all the intricacies of clocks. A separate document gives teeth counts, but with no figures, and not everyone will be able to correlate the photographs or the 3D model with the teeth counts, especially since the restorer didn't use Poncet's names for the parts. The animations themselves are not sufficient and do only give a vague idea that things are working, but even if one has read Poncet's description, many questions remain unanswered. Some parts are not at all detailed, for instance the structure of the escapement electromagnet. The original frequency of impulses (presumably every 30 seconds) is not given.

And the report produced by the restorer totally omits any archeological analysis. It fails to compare the clock as it was before the restoration with the clock as described by Poncet. It does not analyze the differences, it does not try to provide a possible chronology of the changes. In summary, the restoration report is not a scientific report and it doesn't meet the standard that one would expect for a report on a patrimonial object.

3.3 The documentation of the restoration

A restoration report is often only that, it describes (some of) the work done by the restorer, it shows pictures prior to cleaning and afterwards. In the case of paintings and other surface restorations, the restorers often isolate some part of the work and show on one side the unrestored surface and next to it the restored surface. And it is a common practice to describe the chemicals and other materials used.

But a restoration report should also be more than merely a documentation of the restoration. A restoration report should also describe the object, independently of the restoration. A restoration often provides the opportunity to reach some inaccessible parts of an object, and to document something that has never been documented.

A restoration report should be more than merely a report showing that *something* has been done. What is essential is that the restoration report describes in detail the initial condition of the object, the rationale behind the intervention, how it is scientifically organized, how the needs of scholars are taken into account (for instance, the minimum is to ensure that the restoration tries to answer the obvious questions raised by Poncet's description), all the restoration steps, and the final result.

In the case of Cluses, the work can be summarized as a disassembly, a cleaning, an attempt to understand how the clock worked, a replacement of the electrical wiring by a new system, the creation of a 3D model, and of an interactive application for the visitors. The restoration report only sketches each of these aspects. The report (which is titled "rapport d'expertise", that is "expertise report") [9] does in fact give very little rationale, there is no description of the initial condition, and there is very little information on the restoration itself and products and materials used are not described in detail. Instead, the focus is on the 3D model (which is not made available and probably never will), and on the on-demand animation of the clock, although even those parts are only superficially described. And the report does not tell what became of the former control panel.

3.4 The 3D model

In the case of Poncet's clock, Sébastien Lucchetti, François Simon-Fustier's employee, made a 3D model using the SolidWorks CAD (Computer Aided Design) software. This is one of many CAD softwares, and it is by no means the only one or the best one for the task. In fact, one has to distinguish the creation of a model and its uses, and it is for instance possible to construct a model with a certain tool and then to use another tool for the animation or rendering, thanks to exchange formats. Creating a 3D model is basically constructing a series of shapes based on measurements. Many CAD softwares make this very easy, and in some cases they are equipped with tools to construct gears, screws and other common parts. It is not much more difficult to use such a software than to use a text processor.

But 3D models are like cars: there are good models and there are less good models. There may also be good models which are not polished, and there may be bad models which are polished. They may look good, but when you look at the details, you may realize that not everything is right. People looking at 3D models are often unaware of this, and CAD is not a binary world. We don't merely have things that have been modelled and others that haven't and the reality is much more something in between. Moreover, in some cases, the manufacturing process is itself important, that is how the elements of the model have been constructed, and the flexibility of the construction.

In fact CAD is like a theory. A CAD model is a conceptualization of a reality (or sometimes a virtual reality), and being a model, it can be close, it can be distant, it can be right, or it can be wrong. These features of a model can often only be appreciated by comparison with what served as the model. If we don't have the original object, or if we do not have sufficient information on the original object, it can be difficult to judge the quality of a model, even if the model looks very polished and professional.

The CAD software should therefore not be confused with the product. There are many good CAD softwares, but even with a good software it is possible to construct models which are not optimal, for the same reason as a good hammer and a good nail are not sufficient for getting the nail right and in the right place. There is also a matter of know-how and of knowing how the tools are made, what they do, how things could be done differently, how things should be done, etc. Using an expensive professional software is not a sufficient guarantee for a work to be done right.

In other words, constructing a 3D model is not the same as being a CAD expert. A CAD expert knows the underlying concepts of CAD, a CAD expert knows how objects are stored and rendered, he/she knows about surfaces, about the mathematics of splines, NURBS, Bézier patches, and so on. Very few users of CAD software know about these issues, and most CAD software users are like (sometimes experienced) car drivers, but a car driver is not the same as a car mechanic.

Moreover, a given model can be constructed in a variety of ways. There is not only one way to build a model, even with a particular CAD software. For instance, if a model contains several parts, one way to construct the model may be to construct part A first, then part B, but the converse might also be possible. There may be dependencies between parts, which were or were not taken into account during the construction. This parallels somewhat the construction of actual parts, which can be machined in different ways. A gear can be cast, or it can be cut. Some parts can be in one piece or assembled, and the assembly may be seamless at the end.

In his restoration report, François Simon-Fustier gives some details about the modelling process, and in particular he writes that some "planeity" defects had to be corrected, in order to avoid parts to interpenetrate themselves. This problem may have arisen because various parts have been measured and some incompatible dimensions were collected. This really looks like a beginner's mistake. What the restorer should have done is to compute some of the dimensions from other dimensions, so that there are no such problems. For instance, if the distance between two wheel centers is known, this distance should be used to compute the teeth shapes, and the teeth shapes should not be designed independently from the distance of centers. Poncet's clock may contain many parts, but most of them are very simple. Almost all of them are prismatic and can be designed by extrusion along the same axis. This makes it very easy to position these parts.

Constructing a 3D model is in fact making a mathematical model. It is not merely a matter of measuring dimensions and creating shapes, it is also a matter of organizing the data in an optimal way, and of making these data available to all. In Cluses, for instance, we don't know what is the mathematical model underlying Poncet's clock. For instance, we don't know if the racks have been computed from the snails, or if the snails have been computed from the racks, or if the various parts were merely adjusted by hand. This is one of the technical issues which should not be kept secret, for the same reason as the manufacture of an object comes with its plans. A 3D model is a new object, and it should also come with all its information, not be a new opportunity to hide information.

Whenever a 3D model is made, this model can be used in several ways. It can be used to construct animations, interactive tools, etc., parts can be shown in isolation, and so on. It can be rendered in different ways. But if we want the model to be fully exploited, it should be made available so that others can use it in their own CAD software. This is not the case if all we have are animations or interactive displays, without a total control over the 3D model.

In the case of Poncet's clock, the model made by Sébastien Lucchetti seems to be very nicely made, but all we have is an interactive model and a few animations showing how some parts are working and how some parts are assembled. There is no detailed explanation of the working of the clock which would contain everything that Poncet wrote, and the user cannot examine parts separately. The user of the interface cannot use the model of the clock for his/her own purposes, because the model itself was not made available, neither as it was made for SolidWorks, nor as files using a standard exchange format such as STEP. This model, like many others made by other persons, is therefore basically a dead end.

Finally, some issues lead to other ones. For instance, if one makes a 3D model available to all, as individual parts, it is essential that each part be located with respect to its own reference frame (for instance its rotation axis), and that the locations of all the parts are given, both as translations and rotations. That way, another person may be able to create other animations, or replace some parts by others, etc. In other words, the 3D model can be a step towards further scientific developments. Such developments are currently not possible with Poncet's clock model. One would practically have to make a new model. Another issue is the naming of the files. If portability is at stake, it is rather inadequate to use a simple numerical scheme, and the use of long filenames containing spaces is the worst possible configuration, because it makes it then very difficult to automate the processing of the 3D parts. Better solutions should be used.

3.5 The animations and interactive application

The 3D model was used to produce a number of videos which have been put on youtube,[11] as well as an interactive application. I have only located a dozen of videos, only half of them really useful. Five of the videos show how some of the modules are assembled, using some automatic assembly features of SolidWorks. But what was really needed was absent. There was a need to have videos corresponding to Poncet's drawings and descriptions, so that Poncet's explanations could easily be followed. For instance, there was a need to show clearly which hammer is inhibited for the hours, and how it is inhibited. There was a need to show exactly the flow of electricity before the restoration, and this is nowhere to be found. There was also a need to show how the switches K and K' work, how the going spring is rewound, how the electromagnetic clutch works, etc. All these things which are in fact essential are totally non existant. And even if some of these things may appear in the future (the restorer has still been adding videos of the clock in 2021), it is unlikely that all the required explanations will be given, merely because there has not been any will to exchange with scientists and to listen to their demands.

The second offshoot of the 3D model is an interactive application which was made by Sébastien Lucchetti for François Simon-Fustier. It is available in Cluses both at the city hall and in the museum. It used to be also available online, but it has apparently been removed.[12] It does however not work in all computer environments, and I did not find it very practical when I tried it. The screen was cluttered by menus which took up too much space and navigating through the clock was difficult. It was impossible to reach some of the viewpoints I wished to reach. The explanations provided by the animation were insufficient and it was impossible to see some parts in isolation. This interactive application was produced in WEBGL (three.js), probably with an addon of SolidWorks. An introduction to this animation is available online, but I cannot say that I learned much

[11] https://www.youtube.com/channel/UCSB9wpPKBw2S3DLPbH_SHhg

[12] This may be in part due to the fact that François Simon-Fustier is in the process of rebranding himself, and perhaps relocating his web site. The interactive application might be available again at some point.

on the clock with it, and someone who spends only two minutes on the animation will learn next to nothing. It takes more than two minutes to understand how Poncet's clock works.

3.6 The documentation of the on-demand working

According to François Simon-Fustier's restoration report, meetings between him and the people involved in the Cluses city hall led to the set-up of an on-demand working of the clock. If I have understood correctly, the clock is normally not working and it was decided to leave it in that condition, rather than having it work permanently. (I may be wrong, but this is what I understood.) So, in normal conditions the visitor will find the clock stopped at some random time just after a striking. The minute hand should therefore be on 15, 30, 45 or 60 minutes. But if the visitor presses a button in front of the clock, the clock will advance 15 minutes, in 30 steps, strike, and then stop again.

This scheme was probably agreed upon as a way to show how the clock works, and also to allow the visitor to trigger the clock several times in order to get a better understanding of what is going on. I doubt, however, that this configuration is really useful to understand how the clock works. It may help the visitor (who usually came for other reasons) to correlate some of the material in the animation with the clock itself (assuming therefore the possibility to switch back and forth from the application to the clock, and that the application doesn't restart for lack of screen activity), it may help him/her to see where some parts are moving, but it will probably not replace a proper explanation, which is not present in the animation.

It would certainly have been much more pedagogical to let the clock work, as it did for many years, to connect it with a master clock, or even to add a pendulum, and to provide separately real explanations, so that the visitor can really learn something, and can also leave the city hall with something in hand. A document such as this article might be more useful to a visitor than the animation currently provided, but of course the city of Cluses will never give my article to visitors!

In any case, I consider that whatever was done should be documented, whether it is good or bad. In the following sections, I will try to give a clearer view of the new command system of the clock.

3.6.1 Introduction

I have first to stress that there is no clear description of how the on-demand working and striking works. I have not seen the clock myself (and perhaps never will) and the city of Cluses has not answered my requests for explanations. Everything I write here is drawn from the restoration report, from Poncet's original description, and from my attempts to fill the details with industrial automation technical documents.

In normal conditions, when Poncet's clock was connected to a master clock, it must have received an impulse every 30 seconds, or rather one change of voltage at some point and the opposite change 30 seconds later, that is some kind of square wave.

The new button put in front of the clock simulates this behavior in that it delivers 15 periods of a square wave in 30 seconds, corresponding to 30 actual impulses. In other words, when the button is pressed, the escape wheel advances 30 times and makes 15 turns, corresponding to 15 minutes. And the quarter (and sometimes hour) striking is then triggered.

I had initially thought that the dial was still showing the right time, but that the button made it possible to obtain some kind of striking repetition. This, however, would not be easy without some extensive transformation of the clock. I had asked the city hall for some clarifications, which of course I never obtained. The truth is that it seems that no one at Cluses really understands how this clock works, and that is not normal. The Mayor, and every person involved in this restoration, as well as everyone in the Cluses museum, should have an intimate knowledge of this clock, and should know much more than what I have painfully gathered here.

3.6.2 A new control panel

Now, how did the restorer obtain the effect of a fast string of impulses? Jean Thomas,[13] who seems to be the person behind the new system, made use of a new regulated power supply PSU100M from Siemens[14] and several new components, in particular a Zelio 2 smart relay SR2B121B from Schneider Electric.[15]

This relay can be programmed [7, 8] and the restoration report contains some elements of how the work was done, including a list of logical

[13] `jthomas2@wanadoo.fr`, probably Jean Thomas, 27 rue Varichon, 69008 Lyon. Thomas was probably born September 11, 1946 and died in Azé on September 21, 2020.

[14] Such a power supply costs between 300 and 400 euros. Incidentally, the model shown on page 47 of the report (6EP1336-3BA00) is not the one one used in the control panel, which is the model 6EP1337-3BA00.

[15] This smart relay costs between 100 and 200 euros.

Figure 9: The new Siemens SITOP PSU100M power supply (6EP1337-3BA00). (source: `https://fr.wiautomation.com/siemens`)

connections written in Boolean logic (for instance $\texttt{Q2} = \texttt{I2} + \overline{\texttt{M2}}$, meaning that Q2 is the logical disjunction between I2 and the negation of M2). The restoration report also contains graphical programs written in Zelio logic 2 (actually so-called "ladder diagrams") as well as other figures on timers which are not described in detail. The report also mentions [9, p. 43] a program written by Sébastien Lucchetti, so that presumably he too was involved, at least in part, in writing the programming logic.

Programming such a smart relay is not very difficult, especially because there is a graphical interface, but unfortunately the restoration report leaves us essentially helpless, with information aimed at showing that something was done, but without any real description.

3.6.3 Some elements on programmable logic controllers

In order for others to make it easier to go further in the (scant) documentation of the new electronic control panel of the clock, I am therefore giving here some elements of the logic of industrial automata. The Zelio 2 smart relay SR2B121B is a programmable logic controller for industrial automation and such a device can be controlled in various ways, in particular in a graphical way with diagrams called Ladder Diagrams (LD), because they resemble ladders. These diagrams are defined in part 3 of the IEC 61131 standard for programmable logic controllers (PLC) and they are used by many manufacturer [2].

A PLC has inputs and outputs. The SR2B121B from Schneider Electric is shown in figure 10. It can also be seen in the lower right of figure 11 which shows the new control block for the clock.

It has 8 inputs (top, named I1 to I8) and 4 outputs (bottom, named Q1 to Q4). The purpose of the PLC is to establish a relation between the inputs and the outputs. This can be done with a ladder diagram of which a simple one (unrelated to Poncet's clock) is shown in figure 12. The representation of these ladders can slightly vary from one software to the other. The LD program designed by Jean Thomas contains 37 lines, not counting spacing lines and the beginning of his program is shown in figure 13. A LD program is written with a separate software on a computer, then transferred to the PLC.

The left and right vertical lines of a ladder diagram are power lines. The horizontal lines are the "rungs." The LD is a program and the PLC processes the code from left to right and top to bottom.

A rung contains inputs which are either written

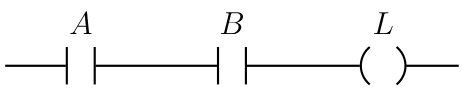
—| |—

Figure 10: The SR2B121B PLC from Schneider Electric. (sources: `https://www.amazon.fr/Schneider-Electric-Sr2b121b-intelligent-thermique/dp/B003A6ABAU` and `https://fr.farnell.com/productimages/large/fr_FR/2835258-40.jpg`)

or

The first is a normally open contact (NO), and the second is a normally closed contact (NC). As the names imply, current does not flow through a NO contact and it flows through a NC contact. A contact can be connected to an input and if that input changes its state, the contact will go from NO to NC, and conversely.

A rung such as



where A and B are normally open switches and L is a lamp will turn the lamp on only when the two switches are closed. This rung therefore corresponds to an AND gate. A, B and L are connected in series.

If instead we connect inputs in parallel, we may have something like this:

Figure 11: The new control block, with the SR2B121B PLC at the lower right and the Siemens PSU100M at the upper left (excerpt from the restoration report [9]). **(Image not shown for copyright reasons.)**

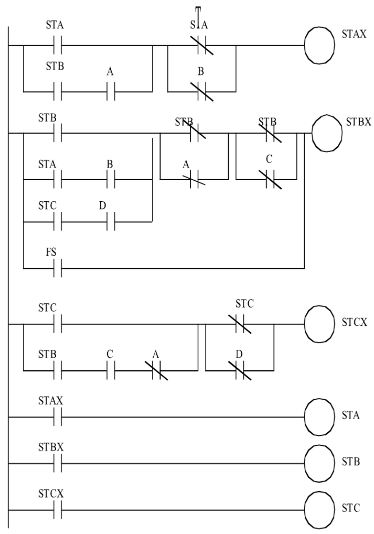
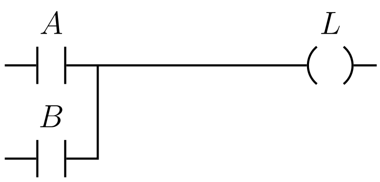


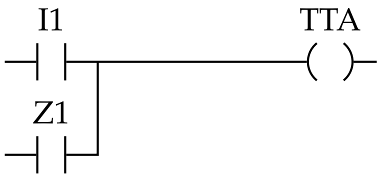
Figure 12: A simple ladder logic example (Hugh jack at English Wikibooks, file `Trial_ladder_logic.svg`).



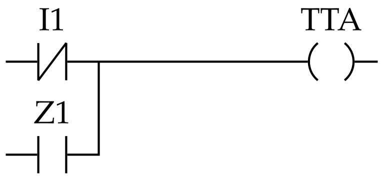
and this represents an OR gate between $AandB$. The lamp L is on whenever at least one of A or B is closed.

3.6.4 The ladder logic for the clock

If we write the previous example as follows, we obtain the beginning of Jean Thomas's LD program (figure 13).

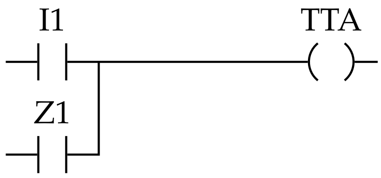


I1 corresponds to the first input, the one for the visitor's button. It is normally not pressed. When it is pressed, the contact NO becomes NC:



Z1 is apparently some switch inside the control panel which makes it possible to do the same as pressing the visitor's button, but from the inside. Z1 and I1 have the same effect. In other words, we have here an OR gate between I1 and Z1. And TTA is connected to a timer of 500 ms.

Each of these rungs can be expressed with simple relations. For instance,



can be expressed as `TTA=I1·Z1` and the restoration report contains the list of all these equations, equivalent to the ladder diagram. They were presumably output by the Zelio software.

Figure 14 shows all the logical relations from Thomas's LD program in a more compact way. Only the four inputs I1, I2, I3 and I4 are used.

The Zelio logic (and IEC 61131 standard) also includes timers. The timers are of different types. The types used by Thomas are A, B, L, and W. Their meaning is as follows:

- A: work, command maintained;
- B: passage to the activation of a command; the impulse is calibrated on the ascending front of the input;
- W: passage to the unactivation of a command; the impulse is calibrated on the descending front of the input;
- L: blinker (cyclic impulses).

The ten timers used by Thomas are called T1 to T8, TA and TB. Each timer is associated to a coil and it can be manipulated within the LD program. For instance, the main timer of interest to us is T1 (figure 15, top) which is of type blinker (L), and actually produces a cyclic square wave. This timer has two parts, the coil TT1 which commands the timer, and a contact T1 associated to the timer. TT1 normally goes on forever, but will be limited either at 30 seconds or at 2 seconds, depending whether 15 periods or only 1 period are produced. During these intervals, T1 has a square

Figure 13: The beginning of Thomas's LD program (excerpt from the restoration report [9]). **(Image not shown for copyright reasons.)**

$$\mathtt{TTA = I1 \ . \ Z1 \ ; \ TTB = I2 \ . \ Z2}$$
$$\mathtt{M3 = TA + \overline{T3} + \overline{T5} \ ; \ M4 = TB + \overline{T5} + \overline{T3}}$$
$$\mathtt{TT2 = M3 + \overline{M2} + \overline{I3} + \overline{T7} \ ; \ TT3 = TT2 \ ; \ TT4 = M4 + \overline{M2} + \overline{I3} + \overline{T7}}$$
$$\mathtt{TT5 = TT4 \ ; \ TT1 = T2 \ . \ T4 \ ; \ Q1 = T1 \ ; \ CC1 = Q1 \ ; \ CC2 = CC1}$$
$$\mathtt{RC1 = (\overline{T5} + C1) \ . \ (\overline{T3} + C2) \ . \ I4 \ ; \ RC2 = RC1}$$
$$\mathtt{RT1 = I4 \ . \ (T6 + V1) \ ; \ RT2 = RT1 \ ; \ RT3 = RT1 \ ; \ RT4 = RT1 \ ; \ RT5 = RT1}$$
$$\mathtt{RM1 = RT1 \ ; \ Q2 = I3 + \overline{M2} \ ; \ fM1 = Q2 \ ; \ TT7 = Q2 \ ; \ CC3 = Q2}$$
$$\mathtt{TT8 = Q2 \ ; \ SM2 = T8 \ ; \ SQ3 = SM2 \ ; \ RM2 = I4 \ ; \ RQ3 = RM2}$$
$$\mathtt{TT6 = M1 \ ; \ RC3 = C3 \ ; CC4 = RC3}$$

Figure 14: Logical relations corresponding to the ladder diagram (reformated from the restoration report [9]).

shape with an upper part lasting 1 second and a lower part lasting also 1 second. If TT1 lasts 30 seconds, this does produce 15 square periods.

T2 is a different type of timer, and once TT2 is initialized, T2 produces an impulse of 30 seconds. T3, T4, T5 and T7 are similar, but with the periods 35 seconds, 2 seconds, 5 seconds and 5 seconds.

T2 and T4 are the timers used to limit the cyclic square wave produced by timer T1. This is expressed by the equation `TT1=T2.T4`.

T6, TA and TB are of type B and last 0.8 second, 0.5 second and 0.5 second at the start of TT6, TTA and TTB (and not at their completion as in the case of T2, etc.).

Now, the two main outputs of the PLC are Q1 (escapement electromagnet) and Q2 (electric motor). Q1 is connected to the timer T1, so that it will receive 15 ascending and 15 descending impulses, causing the escape wheel to make 30 half turns, hence 15 turns, corresponding to an advance of 15 minutes.

The electric motor was initially started when the switches K and K' were closed. These switches are connected to the input I3 of the PLC, so that the LD program can know about them. Basically, Q2 is connected to I3. But since the motor should not work for too long, Thomas has set a limit of 20 seconds to its working. The timer T8 is used for this purpose. This timer starts an impulse only 20 seconds after TT8 (which it itself started when the motor is started), and this is used to ensure that the electric motor does not work more than 20 seconds. Once 20 seconds have elapsed, T8 becomes true, and M2 is set: `SM2=T8`. This in turn turns the motor off with $\mathtt{Q2=I3+\overline{M2}}$.

These are the main ideas behind the control of the clock. There are a number of other equations which I am not describing, and which are not entirely clear, but which might be clarified in a future version of this document. It is however unfortunate that the restoration report does not fully describe all these functions. It is unfortunate that it does not show a detailed map of the components and the wiring (several components are not described, and figures are not related to the actual wiring), and that there is no introduction to the LD diagrams, nor to the timers. The figures included in the report are almost always of insufficient resolution, and sometimes barely legible. Therefore, one may doubt whether anyone in Cluses has taken the time to understand Poncet's clock properly, and this of course should not be so for a historical work which is exhibited.

Anybody who wishes to get a better understanding of this clock should first obtain a copy of the restoration report,[16] try to obtain photographs of the clock, of its restoration, and of the new electrical wiring, as well as of the remains of the initial control panel (if the city of Cluses still has them, which I do not know), and perhaps go to Cluses and examine the control panel, assuming the municipality of Cluses will let you access it. You will have to get a minimal understanding of PLC, in particular through the technical documentation of the Zelio system, and of course you should get in touch with the restorers, François Simon-Fustier and Jean Thomas (who died in 2020), who have never answered even one of my technical questions. Finally, the videos of the 3D model of the clock should also be studied, although they will be of no help for the new electronic controls.

Figure 15: Two of the timers in Thomas's LD program (excerpt from the restoration report [9]). **(Image not shown for copyright reasons.)**

[16] It can be obtained from the city hall of Cluses: Mairie de Cluses, 1 Place Charles de Gaulle, 74300 Cluses, France.

3.6.5 Conclusion

From the above analysis, it seems that the wiring of the clock has been entirely changed and that the current does no longer go through the various contacts s_3, s_2, s_1, and s_0. The new control panel is connected to the various elements of the clock and controls them separately.

This is unfortunately not at all visible in the 3D model which hides all the electrical changes. Neither the initial wiring, nor the new wiring were modelled by the restorer, and this represents a great loss in the documentation of this clock. It is also symptomatic of the idea that a restoration of a clock, or perhaps a 3D model, should represent the initial state of the clock, which is in my opinion a very naïve view of what a restoration and documentation should be.

It is unfortunate that the new electrical system was not documented more thoroughly, because the new digital logic component is now part of the clock, and of its history, and should have been described with the same level of detail as the mechanical parts of the clock (which, as I have shown, have also not been described in sufficient detail). All is probably not lost, though, as the Zelio components are well documented and a better understanding can probably still be achieved, even without the cooperation of the restorers and of the city hall of Cluses. But the person who could have described the work the best has not done so. And at this point, I don't have the time to read all the technical documentation to clarify the restoration report. I hope that others can work that out better than me, or perhaps are able to have scientific exchanges with the restorer, which has not been possible in my case.

3.7 The conservation of the clock

The conservation of an object should not be limited to its cleaning or repairing. Conserving an object means that its condition should be stabilized, that it should perhaps be cleaned and put in working condition, but also that all its history and components are preserved, and the history includes both the initial condition of the object, everything that happened with it until the intervention, the condition at the time of the intervention, all the details of the transformations during the intervention, and the final condition. The history and the elements of the object are part of the object. If some electrical wire is replaced, the old wire should be kept, not by the restorer, but in some adequate place, so that future archaeologists may use these elements for their own study of the transformations.

Prior to the restoration of Poncet's clock, there was a control panel under the mechanical part and this panel made it possible to vary the intensity of the current with a rheostat. Two photographs appear in the restoration report (front of the panel, and back of the panel, with the rheostat), but these elements have not been described in detail and it is even possible that they are no longer part of the clock. They have perhaps been kept by the restorers. The electrical part was reworked by Jean Thomas who unfortunately did not return our questions. I have suggested to the Mayor of Cluses that the ancient parts should be recovered by the city, in case they have been kept by the restorers, but no one answered my demand. The city of Cluses actually seems happy with getting rid of me as quickly as possible.

The restoration report also briefly describes a collaboration between Jean Thomas and François Simon-Fustier. It contains a schematic figure of the original wiring, but also another figure, given without explanations, and which seems to be a replacement wiring using a miniature snap-action switch (micro switch). But these informations are not given as complete explanations, they are merely given to narrate the restoration and are highly insufficient as a documentation of the work done. It is not clear if such a snap-action switch was used in the new system.

The description of the analysis of the electrical system is totally insufficient. For instance, François Simon-Fustier writes [9, p. 15] that he decided to replace the old electrical connections, but we do not see any detailed pictures of the old connections and we do not know what they became. During the function tests, before the restoration, a regulated power supply was used, but it is not clear if this power supply was made up by Jean Thomas, or if some standard power supply was used.

Finally, François Simon-Fustier mentions the existence of a lubrificator for the electric motor, but it is not clearly described. According to him, it was added at a later time.

4 Conclusion

Poncet's clock at the city hall of Cluses is a very interesting clock, with an unusual use of the electric power, both to command the clock from a master clock, but also to strike the bells and rewind the going spring at the same time. It therefore totally dispenses with weights.

This clock was restored in 2017-2018 by François Simon-Fustier with the collaboration of Jean Thomas for the electrical part and of Simon-Fustier's employee Sébastien Lucchetti for the 3D modelling and animation.

It is unquestionable that some of the work was done very professionnally. I trust that the clock was well cleaned and that the new electrical system was well designed and works well. The 3D model also seems to be nicely done, even if it probably has some defects and approximations here and there, as all 3D models do.

But this is only the tip of the iceberg. Working on an historical clock is more than just cleaning it and making a 3D model. It's also about conservation, about documentation, and about making everything accessible and understandable to all. And in these respects, what has been done is a failure. Not only did the restorers and the city of Cluses refuse to answer any technical questions (the city of Cluses because it doesn't know how the clock works, and the restorer because you need to have many diplomas in horology to be allowed to ask a question), but the restoration report only sketches the work done. It does not describe in detail how the clock worked, it does not describe the electrical wiring before the intervention, it does not properly describe the restoration, it does not describe in detail how the new control panel was made, it does not make the 3D model openly accessible, and it fails to answer basic questions about the conservation of the clock.

If the restoration report misses so much of what it should contain, it is mainly because the restoration of this clock was not scientifically supervised and that the work was not done in close collaboration with scholars and curators, and consequently that the needs of the scientific world have not been taken into account.

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