Chapman Conservation
◊ preserving the past ◊

Condition and Treatment Report

Job no: 0001	**Date received:** 4/12/2020
Object: Electric master clock	**Version:** 2 12/01/2022
Client Ref: [redacted]	**Client accession no:**

Date assessed: 13/04/2021	**Conservator:** John Chapman
Treatment start date: 19/04/2021	**Treatment completion date:** 27/06/21

Images of object as received:


Figure 1: Front view


Figure 2: Rear view

Dimensions (mm):			
Case:	H: 760	W: 270	D: 154
Dial:	163 diameter over bezel (6” dial)		
Movement (casting):	H: 190	W: 95	D: 20

1 Contents

2 Description

2.1 General

Electric, wall mounted, half-seconds master-clock by the Silent Electric Clock Company. The clock has provenance dating it to the early 1920s (see *Section 8*).

The polished mahogany case with six inch dial behind bevelled glass with hinged bezel, mounted on hinged, glazed opening front door with lock and original key.

Described by the manufacturer as "The neatest and most compact electric "Master" clock ever manufactured".[1] George Bennett Bowell formed The Synchronome Syndicate Ltd in 1897 with Frank Hope-Jones which was wound up in 1901. Around 1909, Bowell formed The Silent Electric Clock Company.[2]

Figure 3: Silent Electric Clock Company factory at 192 Goswell Road, London

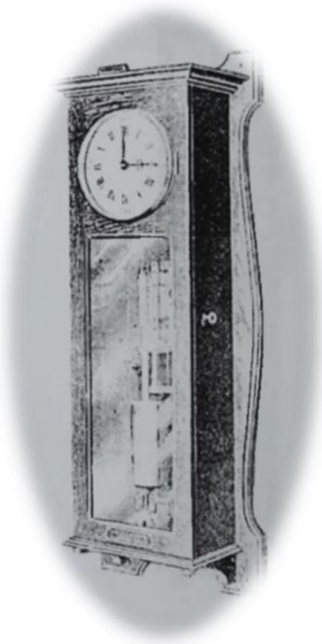

Figure 4: Half-second master clock (from 1919 catalogue of the Silent Electric Clock Company)

The clock consists of two main parts; the master clock movement and the pilot dial. Further external slave dials can be driven from the master clock.

[1] Silent Electric Clock Co. (1919), sales catalogue.
[2] Nye J. (2016), 'Time to reconsider–The life and work of George Bennett Bowell (1875-1942)', *AHS Journal*, March 2016, pp. 55-72.

2.2 Master Clock

Rectangular cast iron backplate carrying the movement consisting of master clock, switch for half-minute impulse to pilot dial (and further slave dials). Half-seconds pendulum suspended from same cast iron backplate. Electrical terminals for batteries and dials to bottom rear of case with cable exit holes.

Steel pendulum rod with lead filled, brass cased bob with knurled brass rating nut.

The master clock movement operating on the Hipp-toggle principle whereby the pendulum is magnetically impulsed when its amplitude falls below a certain level. See *Section 5.1* for a detailed description of operation.

Figure 5: Master clock movement 'as found'

2.3 Pilot Dial

The six inch enamelled dial with Roman numerals, traditional black painted minute hand and spade hour hand behind hinged glazed door with bevelled glass. The dial is impulsed every half-minute by the master clock movement.

The pilot dial working on the 'Silectock' system, patented by G. B. Bowell in 1905, 1909 and 1911. A small rotary armature operating within two magnetic fields, advances in 90° increments, with wheelwork to advance the minute hand in half-minute steps. See *Section 5.2* for a detailed description of operation. The hour hand driven from the centre arbor by motion work mounted on the front plate.

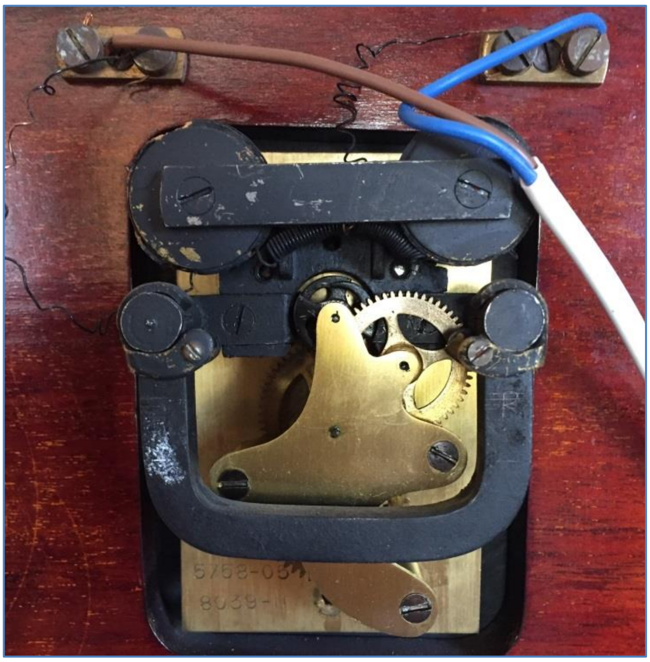

Figure 6: Pilot dial movement 'as found'

3 Condition

3.1 General

The cast iron backplate now with gloss black paint, showing scant regard for the original matt finish, see *Figure 16*. The gloss black clearly applied while the movement was fully assembled.

The repolished mahogany case in generally good condition with minor paint deposits to sides and rear. Door lock broken, but retaining original key.

3.2 Master Clock

General lack of maintenance and cleaning evidenced by thick oil deposits to all pivots. Hipp-toggle is sticky and reluctant to hang vertical. Count wheel is very sticky, as is the pendulum crutch.

Count wheel advance pawl and click are both badly worn to their active faces. Advance pawl pivots, arbors and all locking nuts with black over-paint, see *Figure 7*.

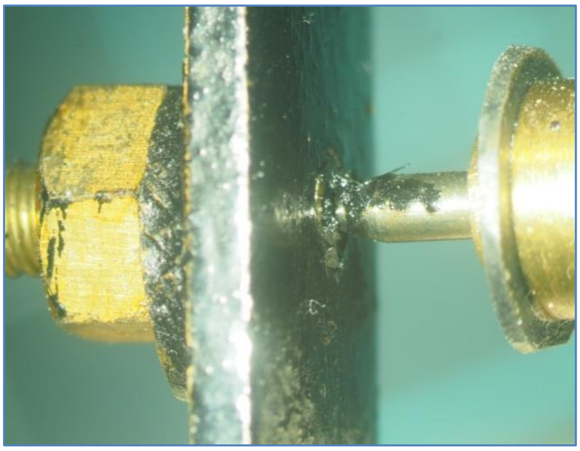

Figure 7: Advance pawl rear bearing is typical of dirt and over-paint found throughout the clock

Front crutch arbor pivot and corresponding pivot hole in plate are worn, see *Figure 18* and *Figure 20* respectively.

The Hipp-toggle vane and the advance pawl (both mounted on the crutch) have excessive side and end play, see *Figure 27*.

The actuating link has excessive side play, see *Figure 42*.

Sub-assembly carrying main coil spark quench resistor has wrong screw in lower position which is loose and the wrong thread (6BA, should be 5BA).

3.2.1 Electrical Contacts

Hipp-toggle spring (moving) contact has a deep hole worn into it, see *Figure 48*.

Hipp-toggle adjustable (screw) contact has entirely worn away, exposing the brass screw, now with soft solder added, see *Figure 45*.

The pilot dial switch contact has been modified and is now worn away completely, see *Figure 34*.

3.3 Pilot Dial

Minor chips and scratches to enamelled dial. Large chip to rear of bevelled glass, see *Figure 8*. Previous repair to hinge. Hinged door loose due to fixing screws.

Figure 8: Chip to dial glass

Minute hand collet epoxied onto hand and centre arbor, see *Figure 52*.

Movement set back from the dial on a single white plastic spacer to prevent the centre arbor clashing with the dial glass. This fixing method is not sufficiently robust.

Lower mounting screw to dial is loose, having no retaining nut.

Dial wired with mains flex (see *Figure 6)* which, as well as being aesthetically unsuitable, presents a considerable safety risk should someone acquire the clock and assume that it needs to be plugged into the mains.

Spark quench resistor (located on wooden case backboard) is a functional replacement of correct value (100 Ω) but without regard to the aesthetic form of the original part, see *Figure 63*.

Adjustable magnetic keeper is missing. The keeper must be present as it allows the strength of the permanent magnet to be varied.

Excessive side play to the pivots of the rotor, intermediate wheel and centre wheel.

4 Treatment Proposal

The aim of this proposed treatment is to return the clock to safe working order, whilst ensuring the longevity of any interventions and replacements and being mindful of basic conservation principles such as minimum removal of original material and the use of non-aggressive cleaning techniques.

To:

- Dismantle and clean master clock movement.
- Dismantle and clean pilot dial movement.
- Repair pivots and rebush plates to both movements where necessary.
- Repair/replace damaged and worn platinum contacts.
- Fabricate a replica magnet keeper/clamp assembly for pilot dial movement.
- Fabricate a replica dummy spark quench resistor for the pilot dial.
- Clean all electrical connections to remove any oxide deposits, including wiring harness and all connector blocks inside case.
- Remove gloss paint from cast iron backplate and overpaint from other components.
- Replace modern PVC wiring with more aesthetically suitable cotton-covered flex.
- Replace perished rubber sleeving.
- Replace or repair various incorrect, corroded or damaged screws with correct types.
- Effect a proper repair to the minute hand which is currently permanently attached to the centre arbor with epoxy resin.
- Remove all active corrosion deposits.
- Establish the correct operating voltages and currents for both the main master clock and the pilot dial.
- Design and supply a suitable, safe power supply to run the clock with its pilot dial.
- Clean dial and case and remove glued-in label.
- Repair door lock.
- Reassemble, lubricate, setup and test.

5 Description of Operation and Adjustments

The project has involved a considerable amount of research, investigation and measurements to determine correct operating conditions and setup. This section describes the outcome of this investigation, prior to describing the conservation treatment undertaken in *Section 6*. A suitable power supply design is presented in *Section 7*.

The master clock (pendulum) movement and the dial operate independently, each requiring different supply voltages.

A circuit diagram of the clock is shown in *Figure 9*.

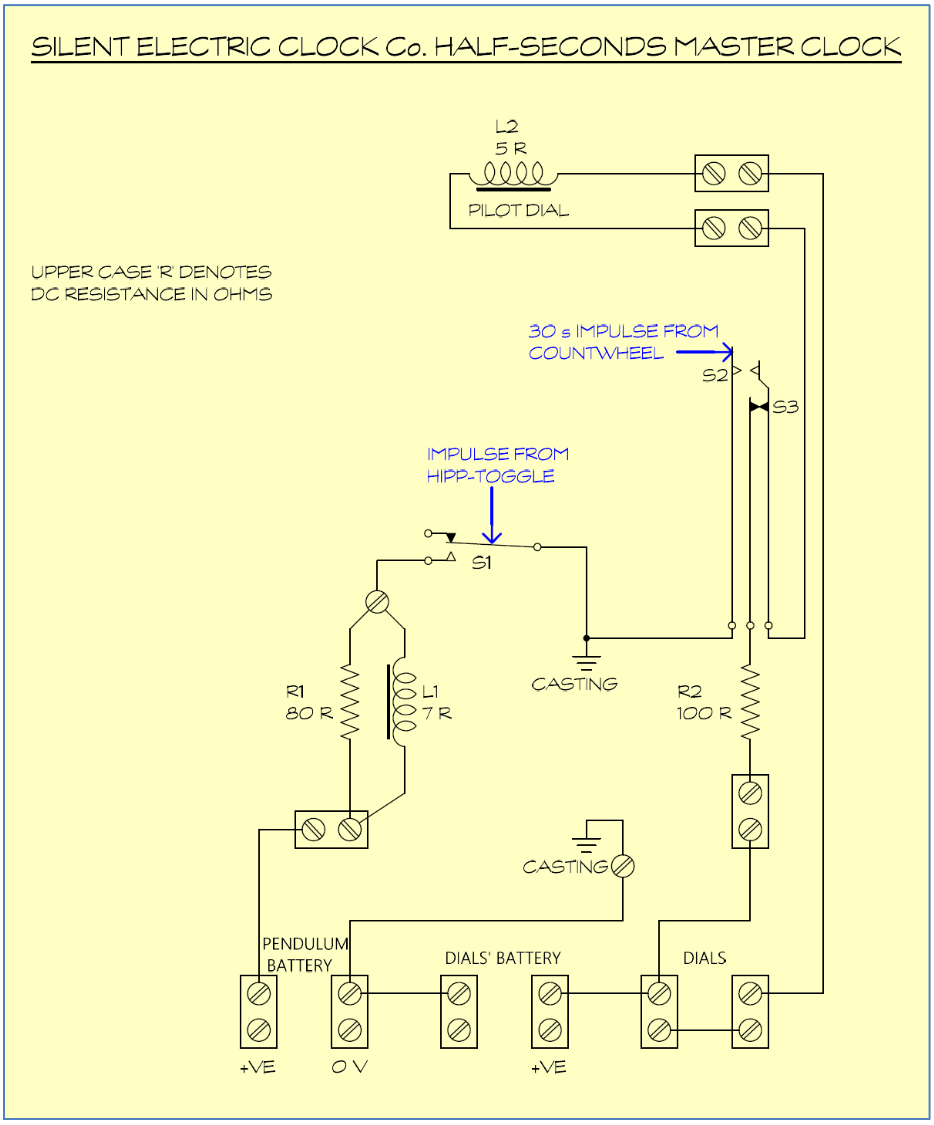

Figure 9: Circuit diagram of Silent Electric Company half-seconds master clock

Modifications have been made to the spark quench devices and dial pulse length (not shown in *Figure 9*) to improve longevity and reliability of the clock, which are described in this section.

5.1 Master Clock (Pendulum) Movement

The master clock movement consists of the Hipp-toggle movement with half-seconds pendulum, a 30-tooth count wheel, and switch contacts to generate a half-minute pulse to the pilot dial and further slave dials if required. The main component parts are illustrated in *Figure 10.*

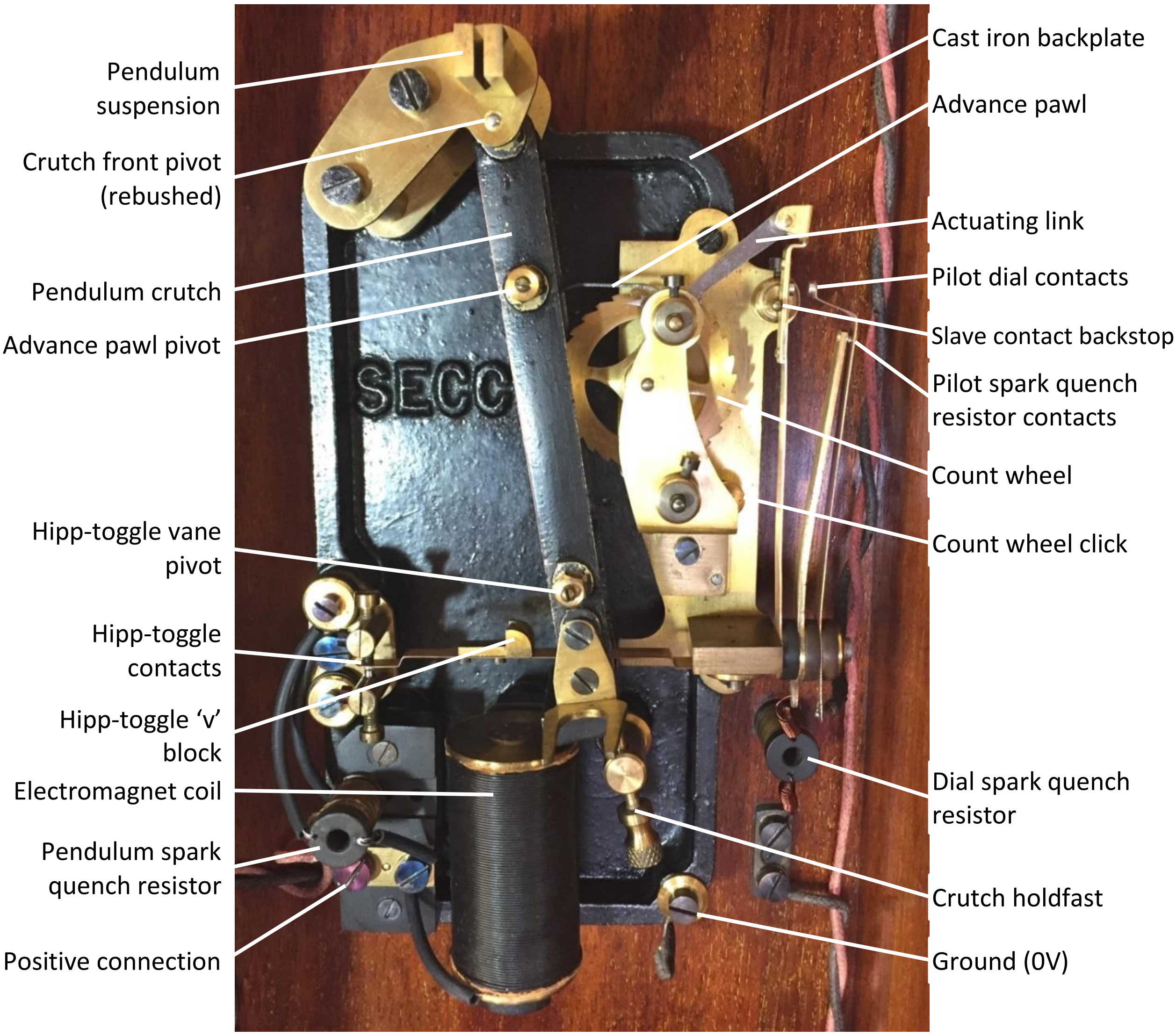

Figure 10: Annotated diagram of master clock movement (pendulum removed for clarity)

A phosphor bronze contact strip carries a grooved agate jewel (the Hipp-toggle 'v' block in *Figure 10*) that catches a hardened steel Hipp-toggle vane when the pendulum amplitude falls below a certain amplitude (for further details see *Section 5.1.5*). This actuates the switch contacts momentarily to energise the electromagnet coil which attracts an iron armature attached to the bottom of the brass pendulum crutch. The geometry of the Hipp-toggle ensures the electromagnet is energised with the crutch near bottom dead centre, at maximum pendulum velocity. The agate 'v' block is shaped so the Hipp-toggle vane only engages when the pendulum swings from right to left. The iron armature is wedge-shaped to ensure the magnetic attraction diminishes rapidly after the pendulum passes the centre point as the pendulum swings from left to right.

A 30-tooth count wheel, impulsed by the pendulum once per second, rotates twice per minute. A slot in the wheel lowers the advance pawl to engage the actuating link, providing an impulse to the pilot and slave dials as described in *Section 5.1.4*.

5.1.1 Pendulum Electrical Impulse

No published data has been found relating to operating parameters for this particular build standard. Earlier master clock movements used a 12 Ω coil with a published supply voltage[3] of 4 V (very early clocks, c.1910, used a 22 Ω coil). This clock is a later version, with a lower power coil (although with the same operating current as the 12 Ω coil). The parameters have been estimated and empirically determined as follows:

- Nominal coil DC resistance (DCR): 7 Ω
- Nominal coil current: 300 mA
- Nominal operating voltage: 2.1 V
- Nominal pulse length: 170 ms (to give 22 seconds per impulse at 300 mA)

The requirements for the electrical impulse are not critical since the Hipp-toggle is a self-regulating system. Nevertheless, the number of pendulum cycles per impulse provides a good indication of the well-being of the movement (see *Section 5.1.5*). If a pulse is missed (a Hipp-toggle misfire), then the pendulum will impulse on its next cycle.

Oscilloscope traces of the voltage and current waveforms for the pendulum pulse are shown in *Figure 11* and *Figure 12* respectively for the completed clock after treatment.

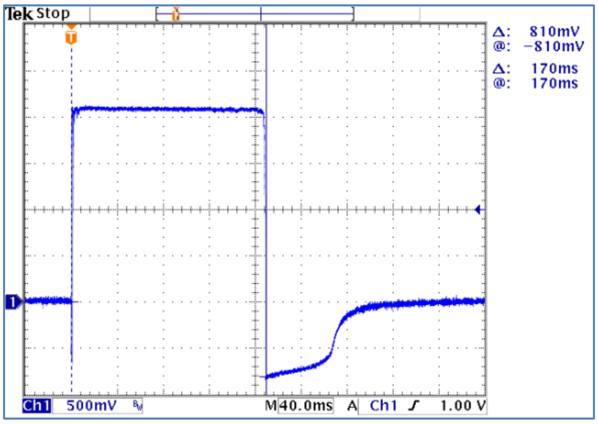

Figure 11: Voltage pulse applied to pendulum coil.

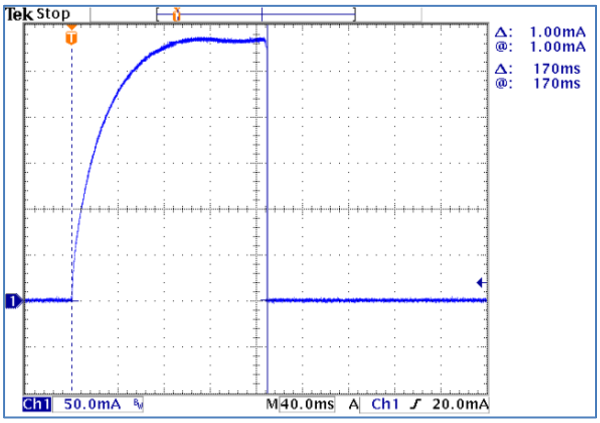

Figure 12: Waveform of current in pendulum coil. Note risetime of 100 ms due to coil inductance.

There is a small back-emf of -0.8 V across the coil when the switch contacts open, due to the clamping action of the spark quench diode (see *Section 5.1.2*).

[3] Silent Electric Clock Co. (1919), *Notes upon the installation & maintenance of "Silectock" electric clocks*.

The current waveform shown is the total current to the coil in parallel with the quench diode, hence the current appears to stop instantly. In practice current continues to flow from the coil through the diode until all the energy is dissipated.

5.1.2 Spark Quenching

Energy is stored in an inductor as a magnetic field. When current flow in a coil is stopped, the collapsing magnetic field generates a voltage across it (a back-emf). The voltage generated by the pendulum coil is around -100 V with no suppression (quenching). Large voltages such as this cause sparking at the switch contacts, leading to premature wear. The back-emf can be reduced by allowing coil current to flow until the energy stored in the magnetic field is dissipated as heat.

In this clock, resistive quenching was used, consisting of an 80 Ω wire-wound resistor connected across the pendulum coil. This reduces the back-emf to around -20 V. Replacing the resistor with a silicon diode, however, clamps the back-emf to -0.8 V which can be seen in *Figure 11*. This was done to prevent damage to the power supply regulator IC[4] (*Section 7*), but also reduces contact sparking to a negligible amount. The original 80 Ω resistor is disconnected but left in situ.

The spark quench diode has a reverse voltage across it equal to the supply voltage, *i.e.* 2.1 V. The forward voltage is clamped, by its characteristic, to 0.8 V. The maximum forward current that can flow in the diode is the coil current of 300 mA, but only for about 100 ms (from *Figure 11*). The 1N4001 diode has a continuous forward current rating of 1 A, so is quite suitable for this purpose.

5.1.3 Count Wheel Adjustment

This adjustment sets only the angular position of the count wheel. The amount of angular rotation per pendulum swing is governed by the pendulum's amplitude, therefore it is important to set the minimum pendulum amplitude first, as described in *Section 5.1.5*.

The angular position of the count wheel is set by adjusting the position of the click which is mounted on an eccentric arbor. The advance pawl should push the count wheel just past the click so that the wheel recoils slightly to lock the tooth securely against the click. If the active faces of either the click or the advance pawl are worn, it is advisable to grind them both back by a similar amount, otherwise there may be insufficient adjustment.

5.1.4 Actuating Link Adjustment

The 30-tooth count wheel is advanced by the pendulum on every other beat. Once per revolution (every half-minute), a slot in the count wheel allows the advance pawl to drop into the actuating link. The actuating link, also known as the 'bird's mouth link'[5] or the

[4] Integrated circuit
[5] Wright, T. D. (1920) 'Electric Clocks', *The Horological Journal*, August 1920, p. 171.

‘peculiar shaped member’[6], operates the switch contacts that generate the pilot dial pulse. It can be seen in *Figure 10* and in more detail in *Figure 41*.

The actuating link is adjusted horizontally with the slave contact backstop (see *Figure 10*), so that the advance pawl drops reliably onto the link at minimum and maximum pendulum amplitudes.

The actuating link rests on an eccentric post that is adjusted so the advance pawl normally just clears the link, but aligns safely into the ‘beak’ when the count wheel slot arrives.

The length of the pilot dial pulse (*i.e.* the time for which the contacts are closed) is adjusted as described in *Section 5.2.3.1*.

5.1.5 Hipp-Toggle Adjustments (Pendulum Amplitude)

Given that the supply voltage to the coil is stabilised and the magnetic pole gap between the electromagnet core and the armature is fixed, there are only two variables affecting the pendulum amplitude. The minimum amplitude required to advance the count wheel is set by the Hipp-toggle depthing and the maximum amplitude is set by the electromagnet pulse length.

The minimum and maximum amplitudes of the pendulum are set using the Hipp-toggle contact screws (see *Figure 10*).

5.1.5.1 Minimum Pendulum Amplitude

The pendulum amplitude dictates the amount of angular rotation of the count wheel for each cycle. The count wheel has 30 teeth, so each tooth represents 12° of angular rotation. To ensure each tooth engages properly with the click at each pendulum cycle, its minimum amplitude should be sufficient that the advance pawl rotates the wheel by more than 12° (say 14°). The count wheel should recoil slightly until it is arrested by the click around its whole circumference (it will rarely be precisely concentric).

Set the minimum pendulum amplitude first with the top (insulated) screw which adjusts the relative depth of engagement of the Hipp-toggle vane into the agate block (the position of the vane itself is not adjustable). Raising the agate block requires increased pendulum amplitude for the Hipp-toggle vane to drop into its groove. Therefore, undoing (raising) the screw deepens the engagement which increases the minimum amplitude. Lowering the screw reduces the engagement which reduces the minimum amplitude.

Note that adjusting the minimum amplitude also affects the pulse length.

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[6] Langman H. R. (1935) *Electrical horology*. London: The Technical Press Ltd, p. 80.

5.1.5.2 Maximum Pendulum Amplitude

Maximum amplitude determines how long the pendulum will free-run before the next impulse. The impulse should not be too large – the requirement is to impart only enough energy to free-run the pendulum for 20 to 25 seconds. If the impulse is made unnecessarily large, there will be a large difference between maximum and minimum pendulum amplitude which is undesirable, particularly because of the adverse effect on the pilot dial pulse length (see *Section 5.2.1*).

The maximum amplitude is set by the bottom contact screw which adjusts the pulse length. Lowering the screw reduces the pulse length and raising the screw increases the pulse length. When raising the screw, ensure the phosphor bronze strip is not forced down too far as this imposes a considerable load on the pendulum which can cause the number of pendulum cycles per impulse to decrease rather than increase. Correct adjustment for this clock is when the pendulum makes between 20 and 25 cycles (seconds) per impulse[7]. After treatment on this clock, the 170 ms pulse length with a supply voltage of 2.1 V (see *Figure 11*), drives the pendulum for approximately 22 cycles per impulse.

Adjustment of the bottom contact screw on its own does not affect the Hipp-toggle trip point (*i.e.* pendulum minimum amplitude).

[7] Silent Electric Clock Co. (1919), *Notes upon the installation & maintenance of "Silectock" electric clocks*.

5.2 Pilot Dial

Refer to *Figure 13* for an annotated picture of the pilot dial movement.

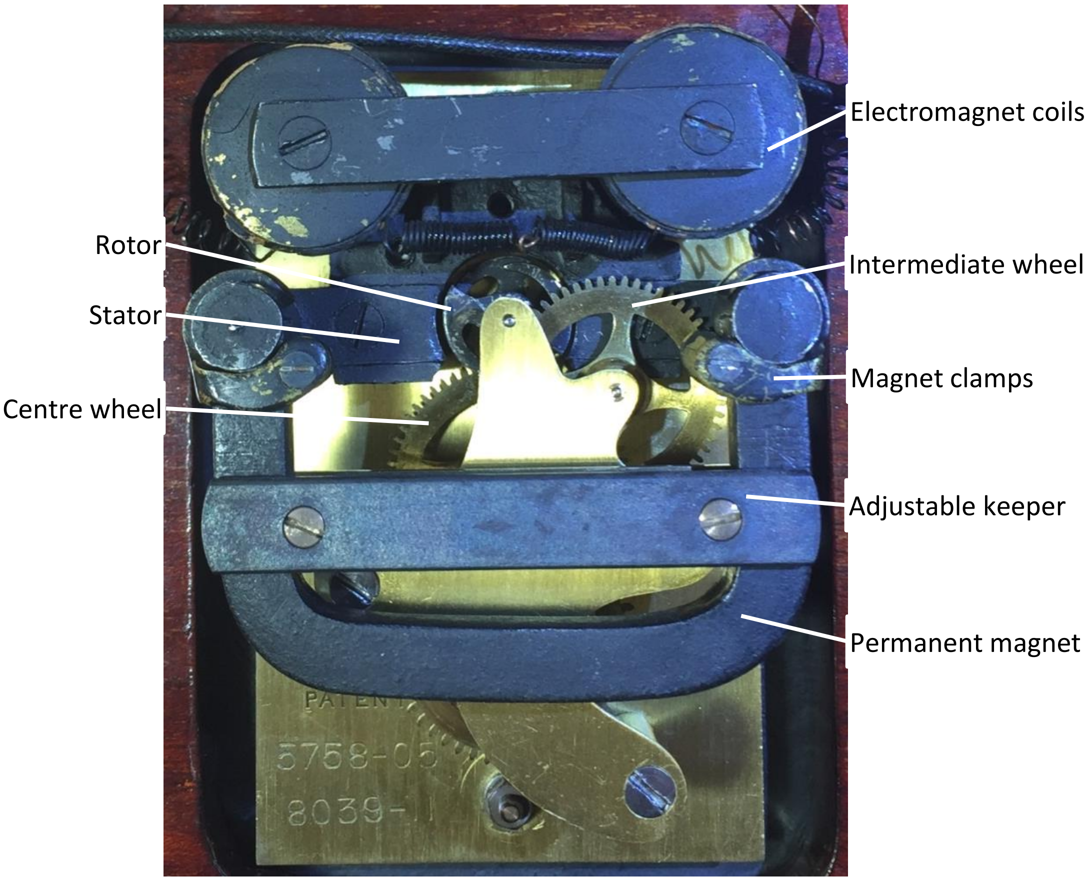

Figure 13: Annotated diagram of pilot dial movement

The pilot dial is a single polarity type (*i.e.* uni-directional pulses) using the 'Silectock' system[8]. A small rotary armature lies in the path of two magnetic circuits. A permanent magnetic circuit is formed by a 'U' shaped magnet and a second circuit is produced 'on demand' by two series connected electromagnet coils. The iron rotor normally rests east-west as shown in *Figure 13,* held by the field of the permanent magnet. When current flows in the electromagnet, the rotor turns 90° anticlockwise (as viewed from the rear in *Figure 13*), specially shaped rotor vanes ensuring rotation in only one direction. When the current pulse stops, the rotor is pulled round a further 90°, where it remains locked again by the permanent magnet's field.

All the arbors, pivots and pinions are brass (apart from the rotary armature itself) to avoid adverse interaction with the magnetic circuits.

The field due to the electromagnet is stronger than the permanent magnet's field, so that the rotor can be pulled away. To overcome production tolerances in manufacturing, the strength of the permanent magnet is adjustable by a variable magnetic keeper. This

[8] Patented by G. B. Bowell

ensures the sensitivity of slave dials can be adjusted to operate at the same minimum current which is essential when several slave dials are to be used in one system, especially when run from a battery supply.

Correct electrical polarity of the dial is important. The dial will impulse with reversed polarity, but with much impaired operation (the magnet of this clock had been assembled the wrong way round).

5.2.1 Dial Electrical Impulse

Operating parameters for the pilot dial are as follows[9]:

- Nominal coil DC resistance (DCR): 5 Ω
- Nominal coil current: 250 mA
- Nominal operating voltage: 1.25 V
- Nominal (published) pulse length: 200 ms
- Operating pulse length (minimum): 250 ms

The nominal (published) strength of the dial electromagnet's field is defined by the specified coil current of 250 mA for 200 ms. Since the supply voltage for the electromagnet is stabilised at 1.25 V, pulse length is the only variable used to adjust the energy imparted to the electromagnet. It must generate sufficient flux to pull the rotor away from the permanent magnet's field at the minimum pulse length and when the opposing torque due to the weight of the unbalanced hands is maximum (*i.e.* a quarter to nine).

Once the Hipp-toggle has been set up (*Section 5.1.5*), the pilot dial pulse length depends on the pendulum amplitude, being a maximum immediately after the pendulum has been impulsed. This is because the pilot dial switch (S2 in *Figure 9*) is driven from the pendulum crutch so the larger the pendulum amplitude, the longer the switch remains closed.

The rotor movement is undamped, therefore when the electromagnet is impulsed, the rotor overshoots and undershoots before coming to rest, due to inertia of the wheelwork and the unbalanced hands. This may be exacerbated due to slightly increased backlash in the wheel train, compared to when it was new. The total settling time is approximately 240 ms, *i.e.* similar to the pulse length. If the pulse stops at the instant the rotor is undershooting, it can be attracted *back* by 90° to its previous position. Since the pulse length varies with Hipp-toggle cycle time, this can be a cause of apparently random skipped pulses. To reduce the problem in this clock, the pulse length has been extended from 200 ms to 250 ms (minimum), which ensures adequate settling time for the rotor prior to the end of the electromagnet pulse. The increased energy consumption of the longer pulse is of little concern with a mains operated power source.

[9] Silent Electric Clock Co. (1919), *Notes upon the installation & maintenance of "Silectock" electric clocks*.

Settling time of the rotor is determined by the energy in each magnetic impulse, and also by the position of the hands, *i.e.* whether the hand torque is opposing or aiding the rotor.

Oscilloscope traces of the voltage and current waveforms for the dial pulse are shown in *Figure 14* and *Figure 15* respectively for the completed clock after treatment.

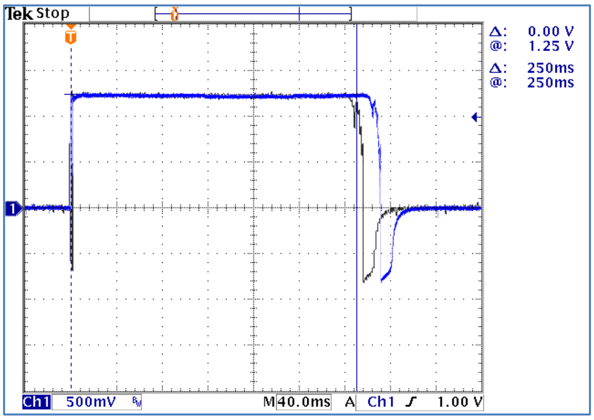

Figure 14: Voltage pulse applied to dial

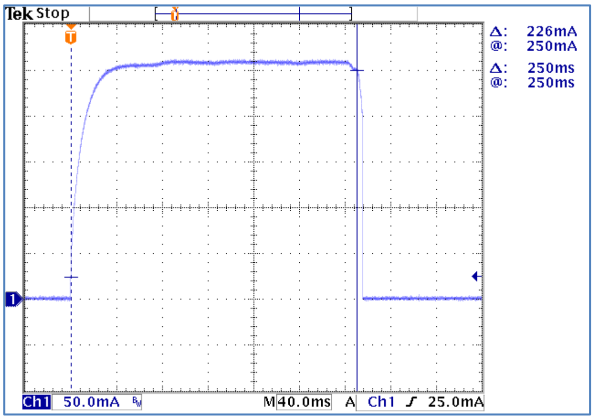

Figure 15: Current waveform in dial coil. Note risetime of 40 ms due to coil inductance.

Two voltage traces are shown in *Figure 14*, which indicate the minimum and maximum pulse lengths generated as the pendulum arc varies from minimum to maximum amplitude. In the voltage plot note the negative pulse clamped at -0.8 V by the spark quench diode (see *Section 5.2.2*).

The current waveform is measured as a parallel combination of the coil with its quench diode fitted hence the current appears to stop instantaneously. In practice, there is a fast exponential decay at the end of the pulse as the diode conducts.

5.2.2 Spark Quenching

A slot in the count wheel enables the actuating link that disconnects the pilot dial spark quench resistor momentarily before closing the pilot dial switch contacts.

This make-before-break switching configuration disconnects the quench resistor to save power while the pilot/slave dials are being impulsed, but reconnects the resistor just before the main pilot dial contacts are broken, in order to suppress the spark that would otherwise occur at the contacts. On large installations operated from batteries, disconnecting the resistor prior to enabling the coil provides increased voltage to the coil and reduced current consumption. It is, however, a compromise.

Good engineering practice is to perform spark quenching at source, *i.e.* as close as possible to the electromagnet coil, which minimises the 'loop area' between the coil and spark quench device to avoid radiated electrical interference. (The spark generates wideband radio-frequency noise, the wire running between the two components acting as a radiating antenna.) Hence the arrangement of switched resistive spark suppressor has been modified in this clock.

A new functional spark quench diode has been added directly across the pilot dial coil, where it has maximum effect and will not be switched. This ensures minimal sparking, no wear to the original resistor switching contacts (because they are not being used), reduces radiated electromagnetic emissions and protects the output of the electronic regulator IC from damage. The same type of diode is used as for the pendulum coil (1N4001).

The shunt resistor switch contacts now serve no purpose, although they are still mechanically operational.

5.2.3 Pilot Dial Adjustments

There are several variables associated with the dial, which may lead to a skipped pulse (where the minute hand fails to advance in response to a pulse from the master clock):

- Torque load on rotor varies with hand position
- Undamped wheel train causes long settling time of the rotor
- Strength of the electromagnet:
  - Pulse length varies with pendulum amplitude
  - Pulse amplitude varies with supply voltage (not a problem with stabilised supply)
  - Pulse amplitude reduces if switch contact resistance increases due to contamination (design of contact geometry can minimise this)
- Strength of the permanent magnet

The following sections deal with the only two adjustments that can be made to optimise dial reliability.

5.2.3.1 Electromagnet Adjustment (Pulse Length)

The magnetic flux generated by the electromagnets is well-defined by the current flowing through the coils, *i.e.* 250 mA, so is not adjustable (other than by changing the supply voltage). The *length* of the pulse (total energy), however, can be varied.

Section 5.2 describes operation of the dial and how the minute hand moves in a two-step motion as the actuating pulse is applied, then released. The two steps should be clearly defined and apparently of equal strength. In addition, the minute hand should momentarily reach a steady-state condition between the two steps, or half-pulses. To achieve this condition, it may be necessary to increase the electromagnet pulse length (see *Section 5.2.1* regarding rotor overshoot).

Since the pendulum amplitude varies, the length of the electromagnet pulse varies over time as shown in the oscilloscope plot in *Figure 14*. In this clock it was found necessary to increase the pulse length from 200 ms to 250 ms, at minimum pendulum amplitude, to ensure adequate rotor settling time. This has the added advantage of reducing the percentage change in pulse length applied to the dial (which is approximately 15 ms, from *Figure 14*).

The length of the pulse is adjusted by cold-forming the centre (thicker) contact piece to the left to lengthen the pulse and to the right to shorten it.

5.2.3.2 Permanent Magnet Adjustment (Keeper)

The strength of the permanent magnet was originally factory set, using the adjustable keeper, to ensure that all dials operate reliably at the lowest current level of 210 mA, when the electromagnet strength is weakest.

The magnet has to produce a flux in the stator that is weaker than the flux produced by the electromagnet, yet it has to be strong enough to lift the hands and lock the rotor at maximum torque (*i.e.* a quarter to nine) at the end of the electromagnet's pulse.

If the magnet is too strong, the electromagnet's field will not be able to reliably pull the rotor away from the fixed field (see test defined below). This results in a sluggish movement of the minute hand for the first half-pulse[10] (when the electromagnet is energised).

If the magnet is too weak, it will fail to hold the rotor in position (there should be a discernable detent every half-minute when the minute hand is moved slowly by hand). The minute hand will appear sluggish for the second half-pulse, especially at maximum opposing torque when the hands are pulled against gravity.

The magnet's strength is altered by the adjustable keeper/clamp assembly, see *Figure 13* and *Figure 60*. Move the keeper up to reduce the strength and down to increase it.

The strength of permanent magnets can diminish over time; the following test can be used to determine whether the magnet is sufficiently strong:

- Ensure the pilot/slave pulse from the pendulum is generating the correct current of 250 mA.
- Maximise the magnet's strength by setting the keeper to its lowest position (the effect of the keeper can be further reduced by spacing it away from the magnet).
- Let the master pendulum send a pulse to the pilot dial.
- The pulse should *not* be able to pull the rotor around by 90°. If it can, then the magnet is too weak and needs to be recharged.

[10] But note this is also symptomatic of insufficient energy in the electromagnet pulse.

6 Detailed Condition and Treatment Undertaken

This clock provides evidence that the original manufacture was not of the high quality implied by the manufacturer in its sales literature. There is evidence of inaccurate drilling, non-parallel pivots and arbors and the crutch clashes with the count wheel plate when the holdfast is in use. There is also evidence of a cost-cutting exercise due to the lack of jewelled bearings, plain glass to front door (earlier models had bevelled glass). The count wheel cock was secured with two screws in earlier models but this clock has only one, albeit with steady pins fitted.

6.1 Treatment of Master Clock Movement

6.1.1 Backplate Casting

Section 3.2 describes initial observations, the treatments of which are described here.

The movement was removed from the case and completely dismantled to reveal the backplate had been over-painted with gloss black paint. The casting was originally painted matt black, so paint stripper could not be used to remove the newer paint without destroying the original finish. The casting was rubbed down with fine wire wool which cut back the gloss finish sufficiently to blend with the original finish still present on the back and sides.

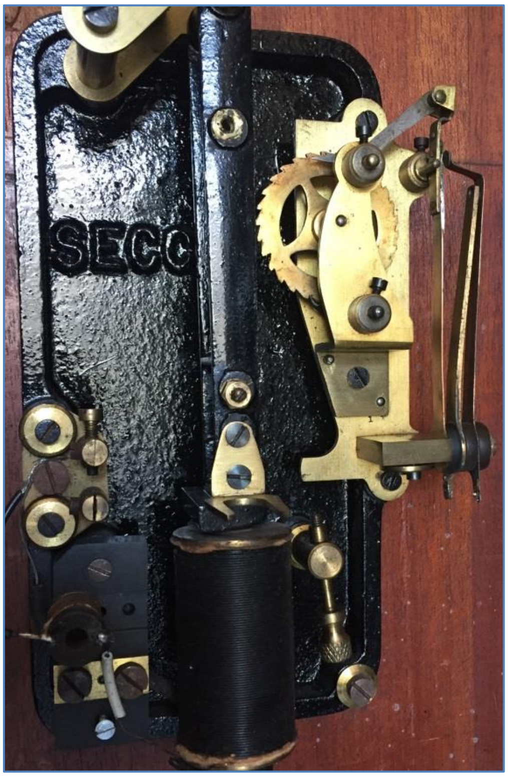

Figure 16: Movement 'as found' with gloss paint (pendulum not fitted)

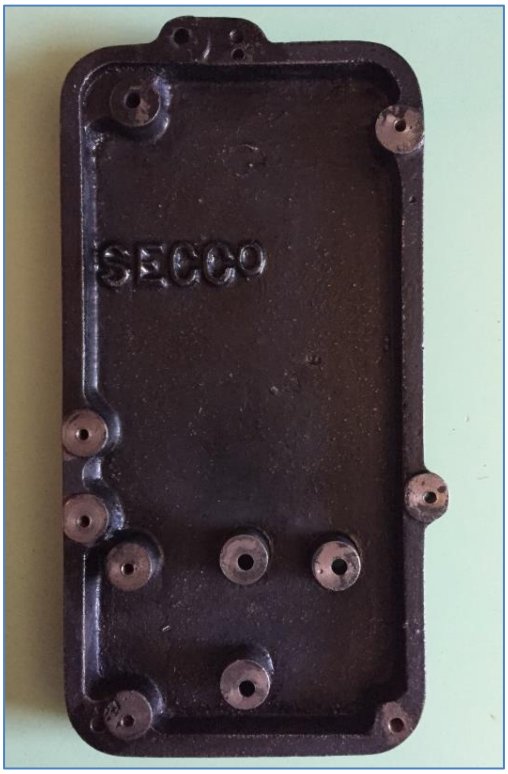

Figure 17: Backplate after treatment

6.1.2 Pendulum

The pendulum and its suspension spring are unmodified. The spring is 0.2 mm thick and in good condition.

6.1.3 Crutch Assembly

The crutch assembly consists of a sturdy brass casting, to which is screwed the steel armature and pendulum fork at the bottom, see *Figure 16*. The crutch also carries the Hipp-toggle vane as well as the advance pawl to drive the count wheel.

6.1.3.1 Crutch Suspension

The crutch is suspended from an arbor terminated in pivots that run in a pair of sub-plates also carrying the pendulum suspension bracket. The arbor is secured to the crutch casting with a lock-screw, but was almost seized up, preventing the crutch from being adjusted front to back. The arbor was also damaged by previous attempts to release it with pliers. Evidence suggests that the arbor had previously been rotated to present an unworn section of pivot. The arbor was eased out and after deburring and cleaning, the arbor now moves easily on the crutch and can be secured with the lock-screw as intended. It was found necessary to increase the arbor end-shake. The weight of the pendulum exerts a turning moments on the bracket that tends to reduce crutch arbor end-shake.

The front pivot was very worn, as shown in *Figure 18*, the rear pivot less so, which only required burnishing.

Figure 18: Front crutch pivot

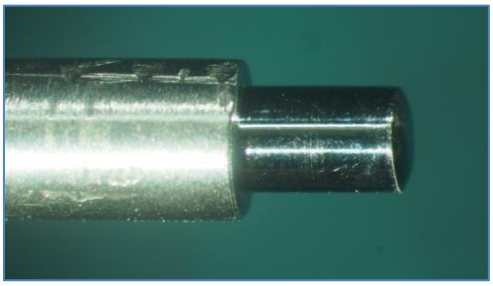

Figure 19: Repaired front crutch pivot

Both front and rear crutch arbor pivot holes were rebushed, see *Figure 20* and *Figure 21*.

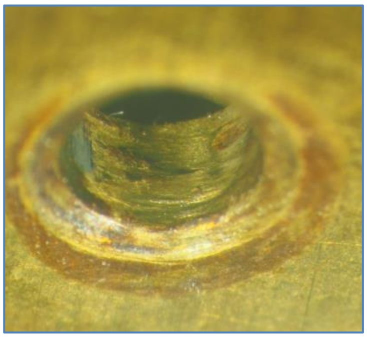

Figure 20: Wear to front crutch pivot hole

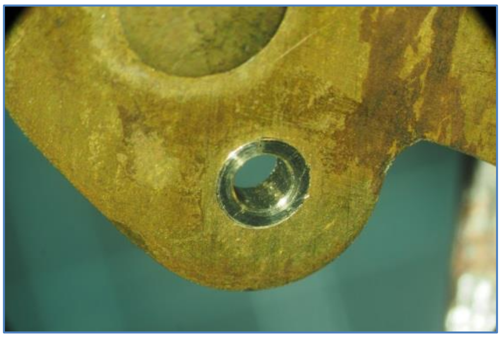

Figure 21: Bushed front crutch pivot hole

6.1.3.2 Advance Pawl

The advance pawl acts on the top of the count wheel to advance it by one tooth per pendulum cycle on the left to right swing (*i.e.* once per second). It was very worn, as shown in *Figure 22*. The hardened pawl was ground back and polished to provide a new surface, see *Figure 23*.

Both the advance pawl arbor and the Hipp-toggle vane arbor have coned pivots running in adjustable brass screws with end-holes. Early Silent Electric Master Clocks used jewelled bearing in these positions, but there is no evidence they were used in this clock. The screw pivot bearings were poorly set up, exhibiting excessive side-shake and end-shake, causing wear on both the hardened pivots and the brass screw bearings, as shown in *Figure 27*.

Figure 22: Advance pawl 'as found'

Figure 23: Advance pawl after repair

The 5BA bearing screws were re-faced, drilled out to 1.0 mm and lightly countersunk to the same angle as the cone pivot to provide a new bearing surface that sits slightly higher up the pivots than previously, *Figure 24*.

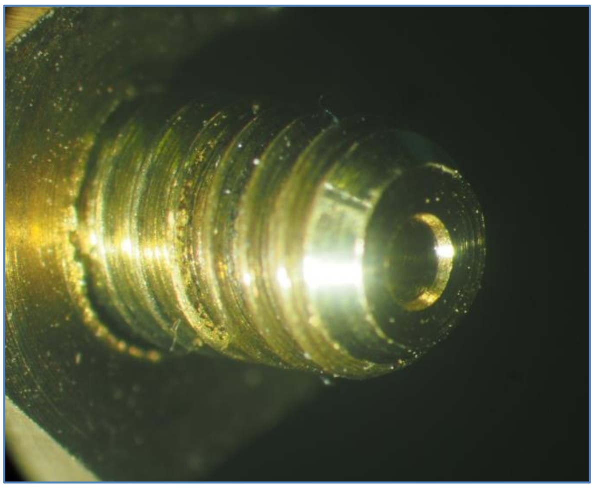

Figure 24: Recut coned pivot bearing (one of four)

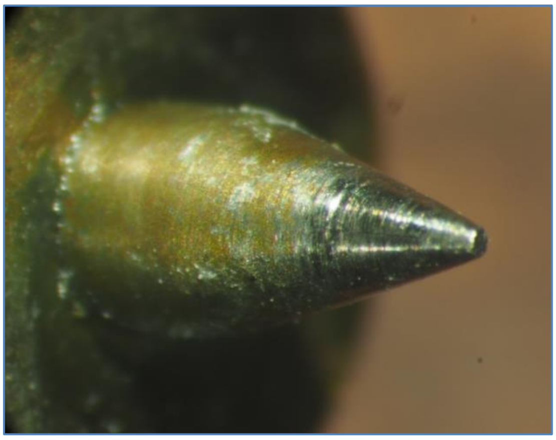

Figure 25: Advance pawl front pivot

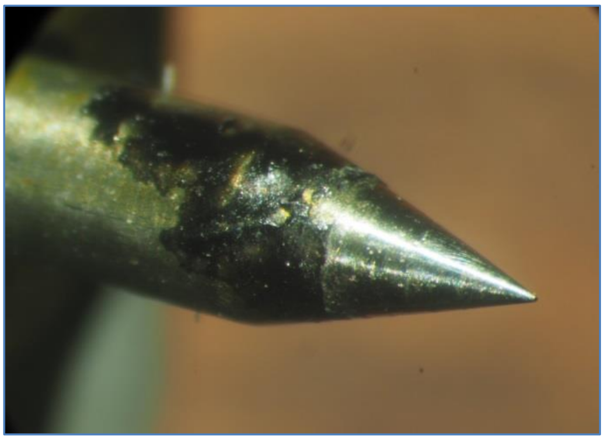

Figure 26: Advance pawl rear pivot showing paint deposit

6.1.3.3 Hipp-Toggle Vane

The Hipp-toggle bearings are of the same type as the advance pawl bearings and also mounted in the crutch casting. Again, the bearings were poorly adjusted and caked in thick old oil and with black paint deposits, see *Figure 27*.

Figure 27: Hipp-toggle rear pivot and bearing as found

6.1.4 Count Wheel Assembly

The count wheel assembly is mounted on a brass plate screwed to the main casting. The count wheel itself is retained by a cock mounted on the plate with one screw and two steady pins. The plate has had its mounting holes hand filed at manufacture to allow alignment with the corresponding holes in the casting. It is not mounted to the casting with steady-pins, so cannot be replaced with accuracy in the same position.

The count wheel was sticky as supplied and would not spin on its pivots. The bearings were clogged with hardened old oil deposits as shown in *Figure 28*. The pivots, however, were not badly worn and only required burnishing, see *Figure 29*. All components were removed from the count wheel plate and cleaned in paraffin before inspection and repair.

Figure 28: Count wheel rear pivot 'as found'

Figure 29: Count wheel rear pivot after treatment

Count wheel end shake was increased slightly by cold forming the cock. The cock steady pins were relocated as they had become loose and one was inserted backwards.

The count wheel click, which prevents the wheel from rotating backwards, was badly worn as shown in *Figure 30*. The hardened click was ground back and polished to provide a new surface, see *Figure 31*.

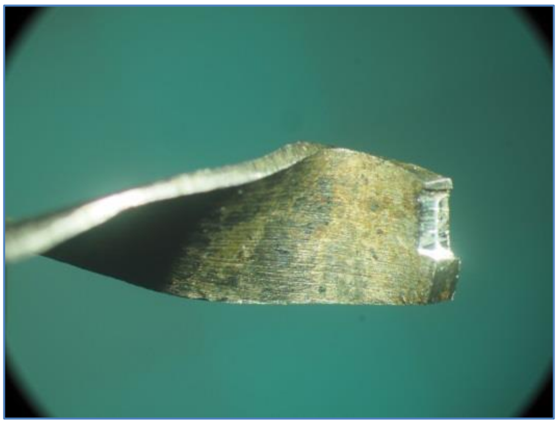

Figure 30: Wear to working surface of click

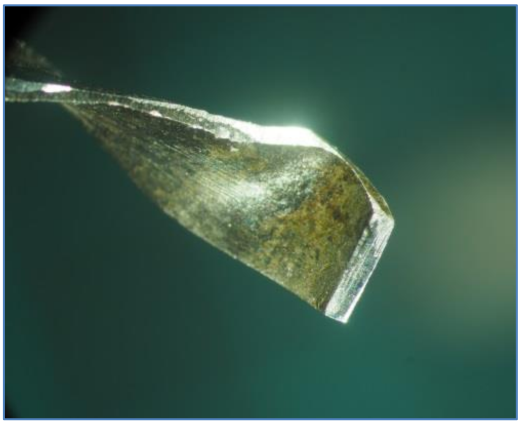

Figure 31: Click after treatment

6.1.5 Pilot Dial Switch Contacts

The spark quench resistor had been previously replaced by a late 20th century high power mains dropper resistor, presumably because the original part was open-circuit. The effect of this can be seen on the coil contacts (upper pair) which are practically non-existent and will be replaced, see *Figure 32*. Details of repairs to the contact spring assembly follow, with the finished assembly shown in *Figure 33*.

Figure 32: Dial contact spring assembly before treatment

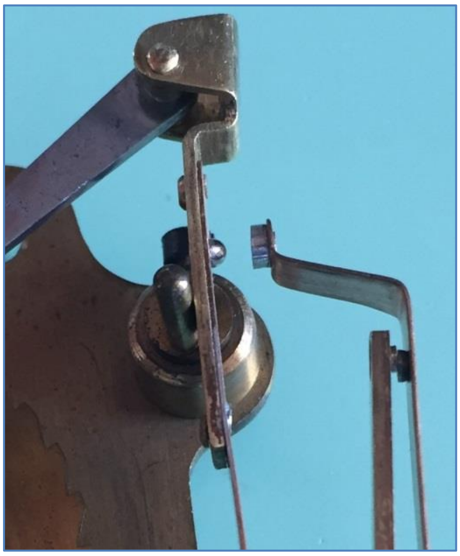

Figure 33: Dial contact spring assembly after repair, with new platinum contacts

A piece of relay contact had been soldered over the left hand contact, see *Figure 34*. This was removed to reveal another replaced contact underneath, made of steel, see *Figure 35*. This was drilled out and replaced with a platinum contact, as fitted originally, see *Figure 36* and *Figure 37*. A domed contact was found to be essential. This gives a small contact area, providing a high mechanical pressure to maintain a low DC resistance. A slight wiping action also helps to keep the contact clean.

Figure 34: Dial contact before treatment, with added contact spring

Figure 35: Soldered contact removed to reveal a steel contact (arrowed)

Figure 36: New platinum contact

Figure 37: Contact riveted in place

The mating (right hand) pilot dial contact was thin and spark eroded in the centre and filled with black paint which also surrounded the contact, see *Figure 38*. This contact was also drilled out and replaced with a new platinum part, see *Figure 39* and *Figure 40*.

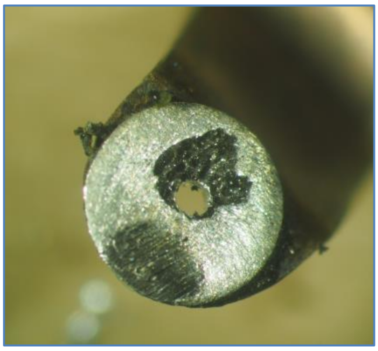

Figure 38: Original worn contact with pilot-hole drilled for removal

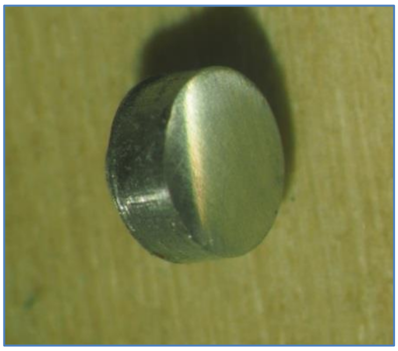

Figure 39: New domed and polished platinum contact

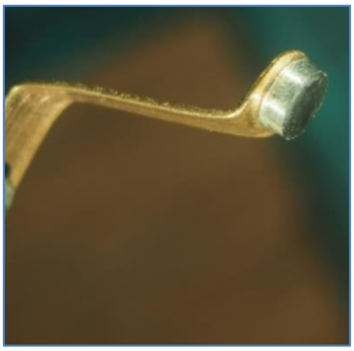

Figure 40: New contact fitted to contact spring

Contacts for the pilot dial spark quench resistor are roughly filed but serviceable. The resistive load has resulted in little wear, and this switch is now unused (see *Section 5.2.2*).

6.1.5.1 Actuating Link

The pilot dial pulse actuating link, (see *Figure 41*), suffered from excessive side-shake and end-shake, see *Figure 42*. The long rivet was removed and replaced with a new one of slightly larger diameter. End-shake was significantly reduced by closing the 'U' bracket slightly before the rivet was replaced.

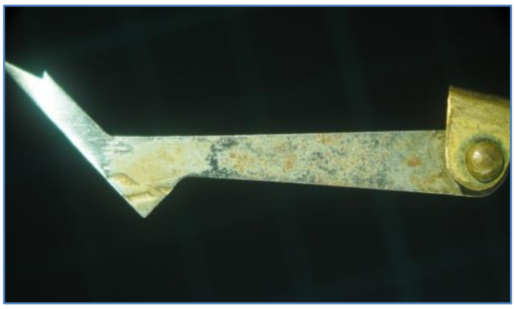

Figure 41: Actuating link before treatment

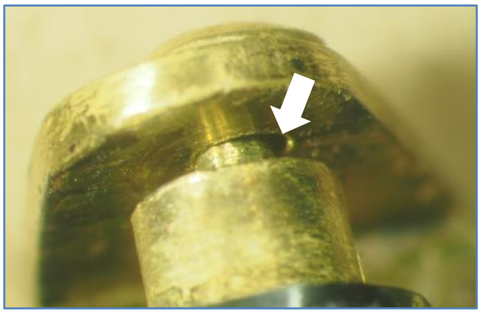

Figure 42: Detail showing end and side-shakes

6.1.6 Hipp-Toggle Switch Contacts

6.1.6.1 Hipp-Toggle Fixed Contact Sub-Assembly

Most of the steel screws in this assembly were corroded. The top contact lockscrew was seized up, but released with penetrating oil and the application of localised heat. After disassembly, the screws were derusted using 'Restore'[11], then polished and blued.

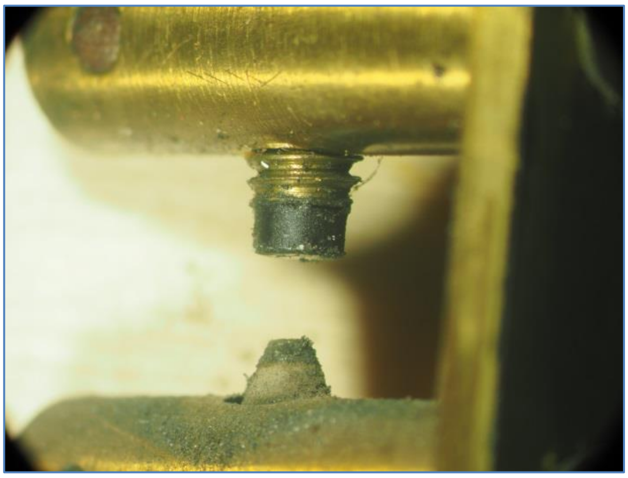

Figure 43: Pendulum switch contacts before treatment

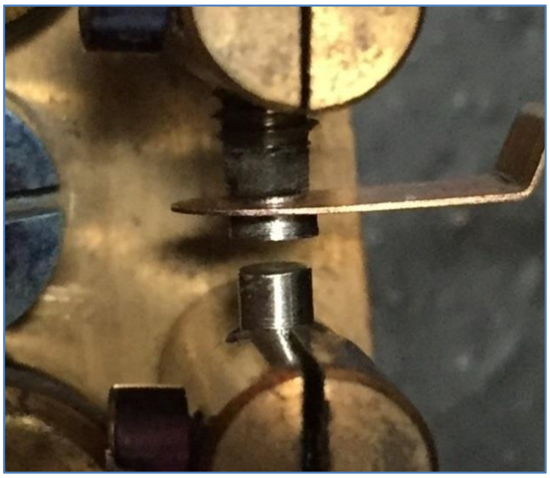

Figure 44: Pendulum contacts after treatment

Dust on the lower surface in *Figure 43* is composed largely of metal from the lower contact which is formed from soft solder and brass.

The sub-assembly plate is insulated from the cast iron frame with a hard black insulating material, similar to Ebonite. The top (resting) contact is again isolated, the screw having an insulated tip. The bottom contact screw closes the circuit to the Hipp-toggle electromagnet. This originally had a platinum tip, but now consists only of the end of the brass adjusting screw, surrounded by a cone of soft solder, see *Figure 45*. The soft solder was turned off to reveal the brass screw spigot, see *Figure 46*. A new platinum contact was turned and press fitted onto the screw spigot, see *Figure 47*.

Figure 45: Lower contact screw with brass spigot protruding through soft solder

Figure 46: Solder turned off to reveal spigot

Figure 47: New platinum contact fitted

[11] A non-acidic chelating agent manufactured by Shield Technology Ltd.

6.1.6.2 Hipp-Toggle Moving Contacts

The moving contact, fixed to a phosphor bronze spring, is severely worn with a round hole spark eroded deep into it, see *Figure 48*. This contact was drilled out and a new platinum contact turned and riveted in place as shown in *Figure 49*.

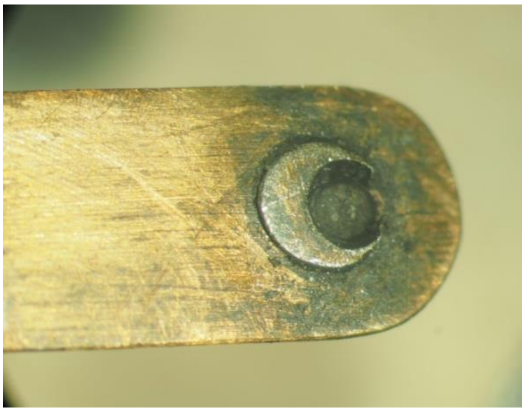

Figure 48: Badly worn moving contact

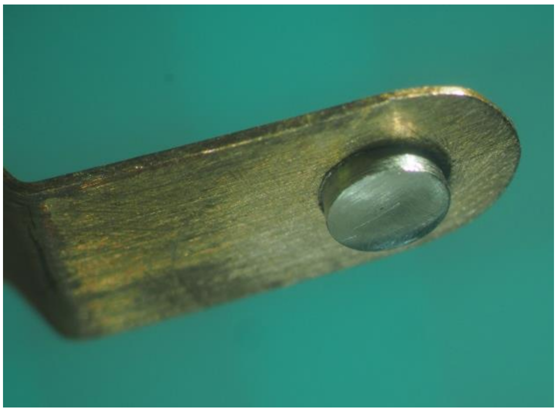

Figure 49: Worn contact replaced

6.2 Treatment of Pilot Dial and its Movement

Section 3.3 describes initial observations, the treatments of which are described here. The whole pilot dial was removed from the front of the case to enable easier separation and reassembly of the movement and dial.

6.2.1 Dial Treatment

The dial was removed from the movement and lightly cleaned with a non-ionic surfactant in aqueous solution, see *Figure 50* and *Figure 51*. Chips to the enamel at the edge of the dial were not treated and are largely concealed behind the bezel.

Figure 50: Dial before treatment

Figure 51: Dial after cleaning

The top 5BA dial fixing screw is probably original, but is damaged. It screws into a threaded dial post riveted to the movement front plate. The bottom screw was a later, 6BA brass replacement. This screw passes through a clearance hole in the bottom dial post and is secured at the back with a nut which was missing. The top screw was deburred, cleaned, polished and blued, together with a replacement matching 5BA steel screw for the bottom fixing. The bottom screw is longer as it has to pass right through the dial post. Also, a pair of distance-pieces were turned from Ebonite[12] and secured to the dial posts with cyanoacrylate adhesive to set the movement back from the dial by 3.2 mm to avoid the centre arbor clashing with the dial glass.

6.2.2 Hands

6.2.2.1 Minute Hand

The minute hand had been permanently secured to the centre arbor with epoxy resin, see *Figure 52*. The hand was carefully removed with most of the epoxy remaining on the hand. The resin was softened with dichloromethane to reveal that the hand collet (originally soft soldered) had also been secured with epoxy.

[12] Vulcanised rubber commonly used in the early 20th century

After cleaning, it could be seen that the centre of the collet had been drilled out too large for the centre arbor. Also revealed was a cross-drilled hole in the end of the centre arbor, where a taper pin once secured the hand. There is no step on the centre arbor for a boat washer, so the hand must have been a friction-fit on the arbor. Around the taper pin hole, the arbor had 'mushroomed' slightly. This was turned down with a slight taper, see *Figure 57*, then a new hand collet was turned with a matching reverse taper. The new collet was tinned and sweated onto the hand, see *Figure 54* to *Figure 56*. The hand was repainted matt black to match existing. A flat brass hand-collet now ensures the taper pin pushes the hand against its new taper, as shown in *Figure 53*.

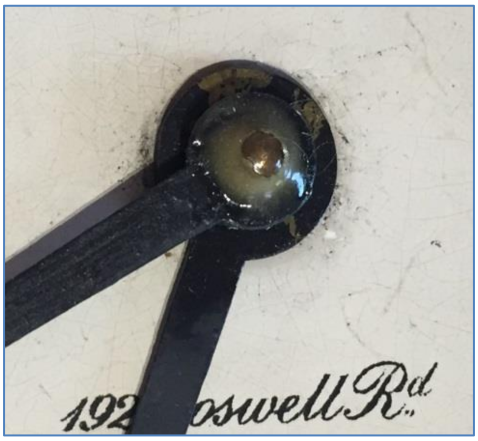

Figure 52: Hands before treatment

Figure 53: Hands after treatment

Figure 54: Minute hand with new collet

Figure 55: Front view with new collet soldered

Figure 56: Rear view with new collet soldered

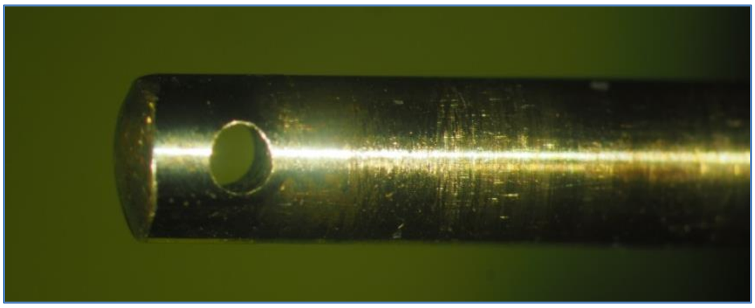

Figure 57: Repaired and tapered centre arbor

6.2.2.2 Hour Hand

The hour hand collet had been cut down, as shown in *Figure 58*, although the reason for this cannot be determined. The collet would have originally come to rest on the step on the outside of the hour pipe.

It was decided to keep the original collet, since it is still a secure push-fit onto the hour pipe despite having been reduced in length.

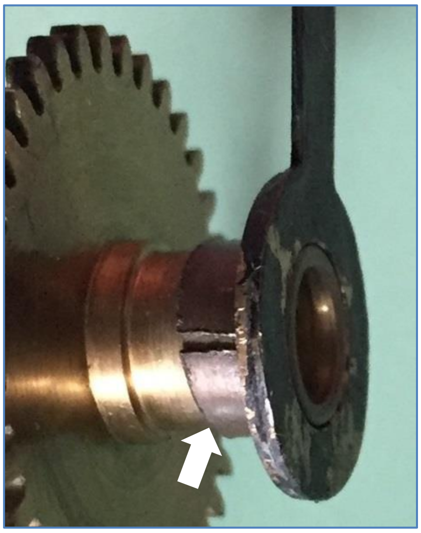

Figure 58: Cut-down hour hand collet

Figure 59: Close-up of collet showing saw marks

6.2.3 Keeper/Clamp Assembly

In this clock, the adjustable keeper was missing from the pilot dial magnet. It is conjectured that the dial was run for some considerable time at a high voltage/current, without the keeper fitted, which has no doubt contributed to wear on the pivots and pivot holes of the movement, as well as causing damage to the electrical contacts.

Figure 60: Replica functional keeper/clamp assembly

A new keeper and clamp was fabricated to replace the missing part. This component is essential to the operation of the dial, to adjust the strength of magnetic flux applied to the rotor. The adjustment is a one-off setup, described in more detail in *Section 5.2.3.2*. The completed assembly is shown in *Figure 60*. The screws are 7BA to match the original part.

6.2.4 The Wheel Train

The movement was dismantled for cleaning and inspection. Excessive side-shake compromised meshing between the rotor and the intermediate wheel that no doubt would have led to unreliable indexing of the rotor.

Most of the pivots were not badly worn, only requiring light burnishing in the Rollimat pivot polisher since they are brass (apart from the rotor itself). The rear pivot of the intermediate wheel, however, was badly worn to a barrel shape, see *Figure 61*. This was repaired on the Rollimat as shown in *Figure 62*. The following four pivot holes were worn and required bushing:

- Rotary armature, front pivot hole
- Intermediate wheel, front and rear pivot holes
- Centre wheel, rear pivot hole

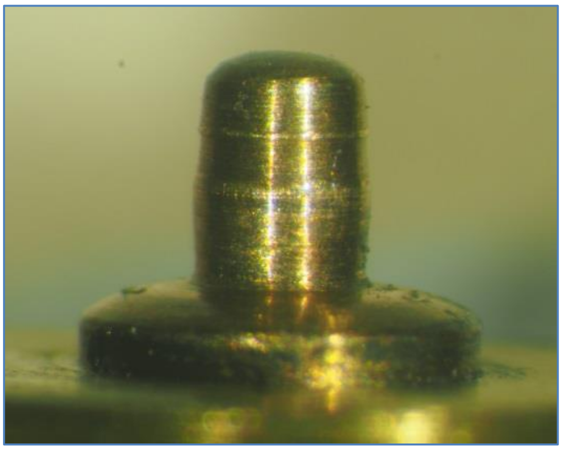

Figure 61: Intermediate wheel rear pivot – before treatment

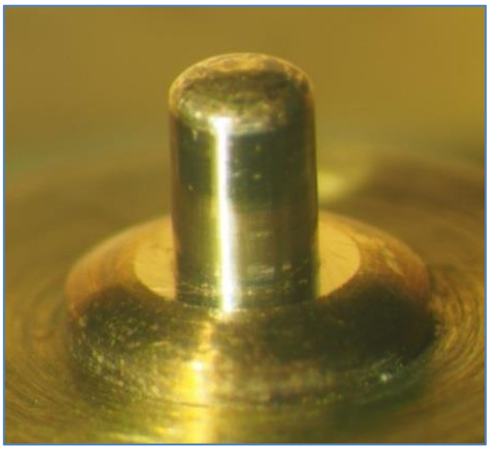

Figure 62: Intermediate wheel rear pivot – after repair

6.2.5 Spark Quenching

The pilot dial spark quench resistor is located on the main wooden backboard, and is switched by the pilot dial contacts as described in *Section 5.2.2*.

The resistor had been previously replaced with a late 20th century, high-wattage, ceramic resistor, as shown in *Figure 63,* and the original part had been removed. In order to conserve the aesthetic appeal of the clock, the resistor was replaced with a replica part in the correct location.

A spark quench diode was connected directly across the electromagnet coil as described in *Section 5.2.2*. The original resistor switch contacts are retained in their original form, although they are not used.

The replica part, therefore, did not need to be functional. An Ebonite former/bobbin was turned to match the quench resistor of the Hipp-toggle resistor and wound with a single layer of silk-covered copper wire of the same diameter, see *Figure 64* and *Figure 65*.

Figure 63: Dial spark quench resistor 'as found'

Figure 64: Replica quench resistor

Figure 65: Replica part fitted

6.3 Treatment of Case and Wiring

6.3.1 General Cleaning

The dial glass and front door glass were cleaned on both sides.

Emulsion paint was removed from the side mouldings with white spirit and fine wire wool.

6.3.2 Wiring

The wiring loom was removed for cleaning and all terminal blocks were cleaned. Several of the 5BA terminal screws had rusted, some seized in their brass terminal blocks. These were relieved with penetrating fluid and the threads recut to remove rust and other debris. The terminal block threads were retapped to clear the threads of embedded rust from the steel screws.

A new copper shorting link was made for the DIALS terminals to replace the modern PVC cable wire link.

The four terminal screws at the top of the case serving the pilot dial were particularly corroded. These screws were treated with Restore rust removing fluid before being reblued by heat treating.

The screws of the bottom left hand terminal block were also badly corroded and it was removed from the case. The fixing screw had rusted away almost completely. A replacement screw was fitted after being chemically blacked to aesthetically match the others.

The replica dummy pilot dial spark quench resistor, described in *Section 6.2.5*, was fitted.

Braided cotton-covered flex was procured for the dial wiring to replace the modern PVC mains flex that had been fitted. The cable clamp for this flex had been 'repurposed' within the clock to hold the replacement dial spark quench resistor, so this was replaced in its correct position in the top left hand corner of the case, see *Figure 66*.

Figure 66: New wiring to pilot dial, using the original flex clamp

6.3.3 Door Lock

The lock return spring was broken and operation of the mechanism was rough.

The lock was dismantled to find the return spring in two pieces and the moving parts poorly finished with many burrs.

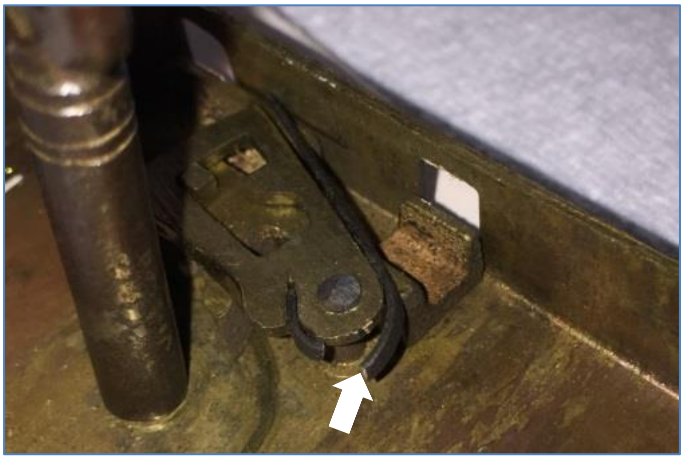

Figure 67: Dismantled lock showing broken spring

Figure 68: Broken spring (top) and new replacement part (below)

A new return spring was made, as shown in *Figure 68* alongside the original spring. The internal components of the lock were deburred and reassembled, see Figure 69. The key was derusted by burnishing only, to preserve the black patina.

Figure 69: Repaired and reassembled lock

7 Power Supply Design

The use of a stabilised power supply is advantageous in reducing the number of variables associated with the operation of the dial (see *Section 5.2.3*). Whilst battery operation is possible, running both the dial and pendulum from constant voltage regulated supplies will enhance the reliability of the clock.

7.1 Design Philosophy

Mains power supplies require design, testing and certification to onerous safety and EMC[13] standards. A pragmatic solution is to use an off-the-shelf mains power unit, followed by low power regulators for the voltages required by the clock in a separate enclosure that can reside inside the clock case. A non-latching RCD[14] ensures that any mains power interruption will permanently disconnect the power, requiring a manual reset. A block system diagram for the proposed mains power supply is shown in *Figure 70*.

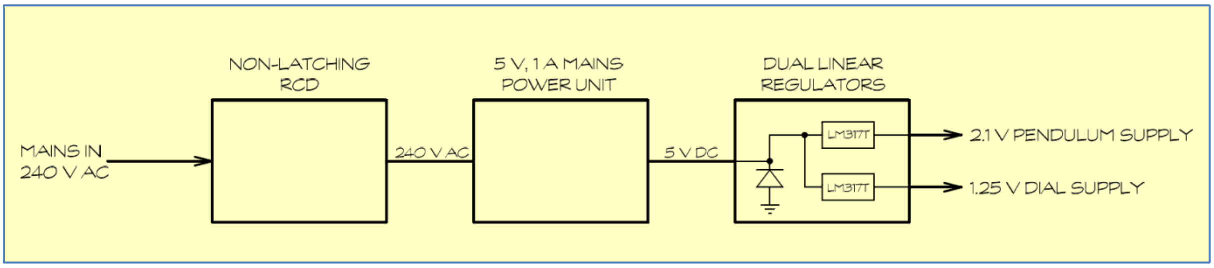

Figure 70: Block diagram of mains power supply

7.1.1 Mains Power Unit

A suitable off-the-shelf power supply is a self-contained mains adaptor, not much larger than a 13 A fused plug with the plug pins moulded into the casing, commonly referred to as a wallwart. The output voltage needs to be high enough to supply the linear regulators for the clock supplies. The output current must be capable of supplying both dial and pendulum, even if they demand current simultaneously (0.55 A).

A brief specification for a suitable commonly available off-the-shelf adaptor is given below:

- Mains input: (230 V AC, 50 Hz)
- Output voltage: 5 V DC
- Output current: 1 A current limited
- Thermal overload protection
- Over-voltage protection
- Output connector: In-line DC connector, 5.5 mm Ø, centre positive

The power supply should be approved to all relevant mains safety and EMC regulations.

13 Electromagnetic Compatibility
14 Residual-Current Device

7.1.2 Non-latching Residual Current Device (RCD)

There are two main problems associated with a failure of the mains supply.

Firstly, since the clock is not self-starting, when power is reconnected, the Hipp-toggle pendulum switch (and possibly the dial impulse switch) will be engaged, hence the electromagnets will draw current continuously. This will not only heat up the coils, but also the linear regulators supplying them.

Secondly, if power is interrupted momentarily, say for a few seconds, it is possible a dial impulse will occur during the outage period, thereby causing a skipped pulse. If the interruption lasts for less than about 30 seconds the clock will continue to run but the cause of the skipped pulse will remain unknown.

A solution to both of these problems is to ensure that power is permanently removed from the clock in the event of a mains interruption. This can be achieved using a non-latching RCD to run the mains adaptor. The RCD will require a manual reset when the clock is reset and started. A suitable off-the-shelf RCD is readily available as a plug-in part, see *Figure 71*.

Figure 71: A typical proprietary plug-in RCD

7.1.3 Linear Regulators

Two linear regulator circuits are used, employing LM317T IC regulators which have their output voltages set by fixed resistors and employ internal current limit and thermal overload protection, see *Figure 72*. Diode D1 protects the ICs in the event that an external power supply is connected with reversed polarity.

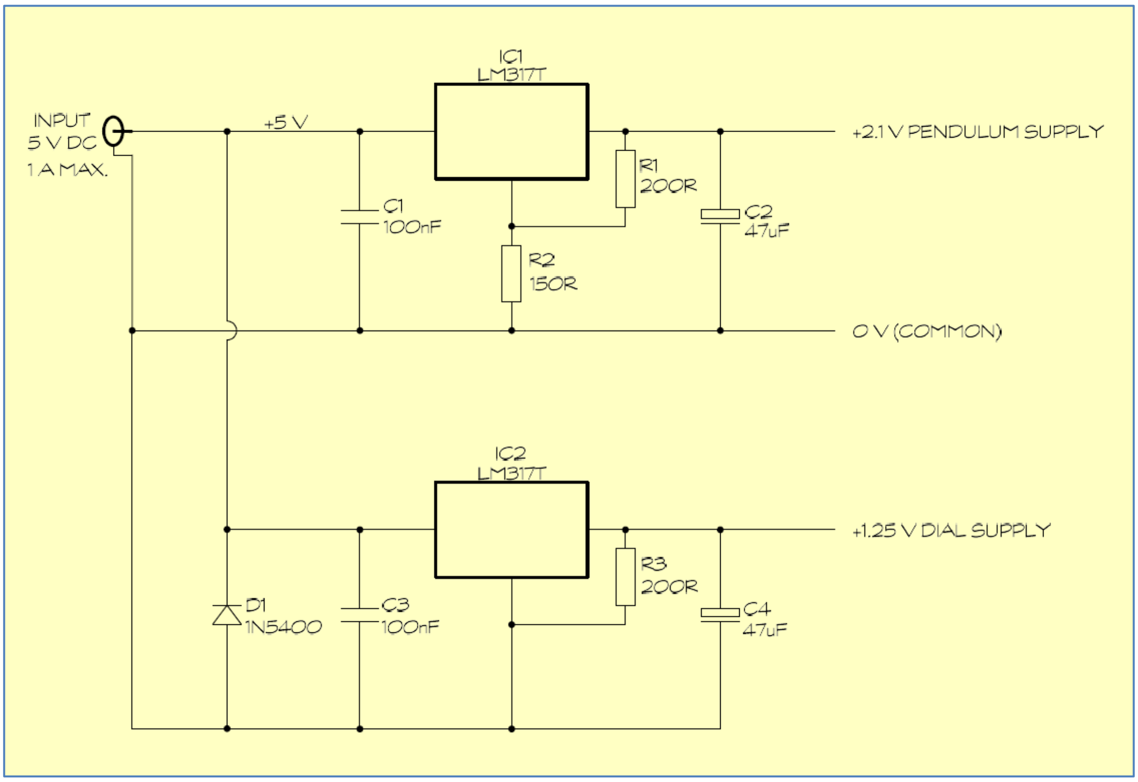

Figure 72: Circuit diagram of dual regulator

The regulators are mounted in a small plastic enclosure that can be placed inside the clock case, thereby minimising lead length on the stabilised output, see *Figure 73* and *Figure 74*. Due to the very low duty cycle of current pulses drawn by the clock, negligible heat is generated by the circuit.

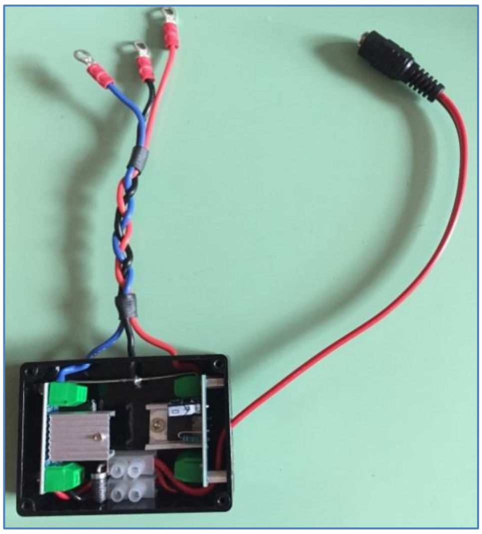

Figure 73: Circuit diagram of dual regulator

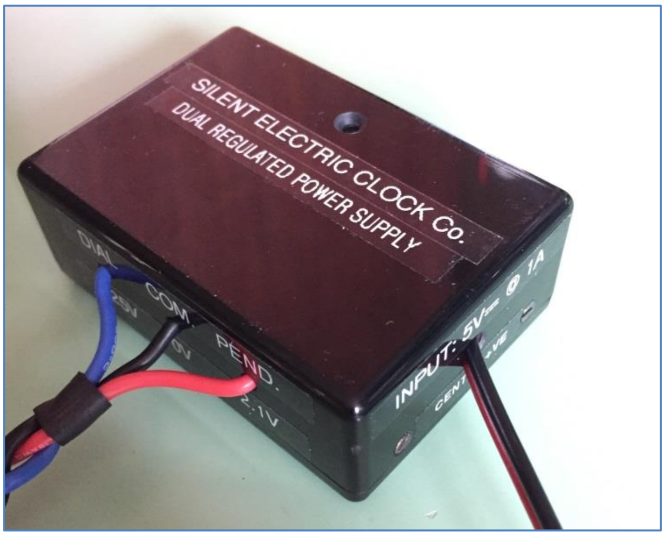

Figure 74: Circuit diagram of dual regulator

7.1.3.1 Master Clock Power Supply

From *Section 5.1.1*, the pendulum electromagnet coil parameters are summarised below:

- Nominal coil DC resistance (DCR): 7 Ω
- Nominal coil current: 300 mA
- Nominal operating voltage: 2.1 V

The regulator output voltage is given approximately by[15]:

$$Vout = 1.25\left(1 + \frac{R2}{R1}\right)$$

The bought-in regulator module is fitted with R1=200 Ω. Using a preferred value of 150 Ω for R2 gives:

$$Vout = 1.25\left(1 + \frac{150}{200}\right)$$

$$Vout = 2.19\ V$$

In practice, the on-load voltage at the coil is exactly 2.1 V (see oscilloscope trace in *Figure 11*).

7.1.3.2 Pilot Dial Power Supply

This power supply design is only relevant for the internal pilot dial. If further slave dials are to be driven from the master clock, the power supply requirements will be different.

From *Section 5.2.1*, the pilot dial electromagnet coil parameters are summarised below:

- Nominal coil DC resistance (DCR): 5 Ω
- Nominal coil current: 250 mA
- Nominal operating voltage: 1.25 V

From the data sheet equation in *Section 7.1.3.1*, it can be seen that when R2 is set to zero, the output voltage is 1.25 V, which is the voltage required.

[15] ON Semiconductor (2019), *LM317 data sheet*, October 2019 – Rev. 16.

8 Provenance

A label affixed to inside of case describes this clock was purchased (second-hand) by the firm of Ricardo in Shoreham-by-Sea (West Sussex) in 1924, see *Figure 75*. Slave dials used in this installation have since become disassociated from the clock. No extant source documentation has been found to verify this provenance.

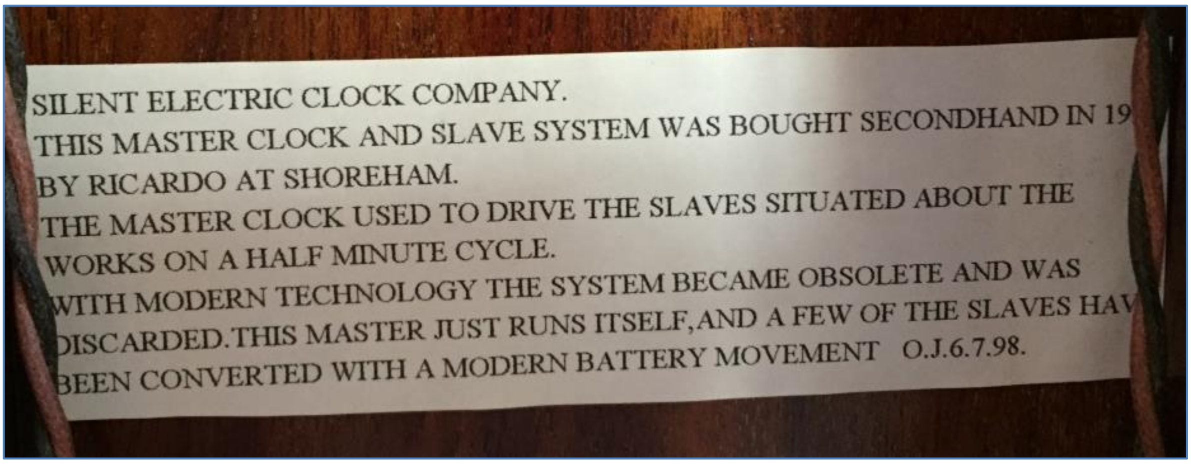

Figure 75: Label fixed inside case in 1998

Ricardo's headquarters have been at Shoreham-by-Sea since 1919 and the Company still operates there today developing engines, transmissions and other vehicle sub-systems.

9 Installation, Operation and Maintenance

The clock must be firmly fixed to the wall using all four corner fixings. Do not position the clock above a radiator or in direct sunlight. Initially, use the rear mounted mirror plate to hang the clock. Then temporarily fit the pendulum and use it as a plumb line against the fixed reference pointer, then mark and drill the four corner holes.

Nominal voltages and currents are given in *Table 1*, which can be useful if the clock is being tested using a bench power supply unit.

	Clock label	Nominal operating current	Nominal operating voltage
Main movement	PENDULUM BATTERY	300 mA	2.1 V
Pilot dial	DIALS' BATTERY	250 mA	1.25 V

Table 1: Nominal coil voltages and currents

The clock should be oiled sparingly, taking care not to allow any oil onto the electrical contacts. The advance pawl and Hipp-toggle cone pivots are not oiled. The clock should be fully overhauled every 5 years, depending on the environment. A hot dry location will dry out clock oil more quickly than a cooler position.

The platinum switch contacts for the coils should be cleaned every few months, with a piece of thick paper moistened with isopropyl alcohol (IPA).

Pendulum impulses should occur approximately once every 22 seconds.

If the clock requires rating, the rating nut at the bottom of the pendulum bob is very sensitive. It may be found more convenient to add or remove small weights from the top of the pendulum bob to raise or lower its centre of gravity.

If the clock is moved, the pendulum must be removed first. Having removed the pendulum, secure the crutch with the holdfast on the backplate (see *Figure 76*).

Figure 76: Crutch holdfast (arrowed)

10 Appendix 1 – Train Count

Clock: Silent Electric Company Half-Seconds Master-Clock

Arbor name	Wheel: No. of teeth			Pinion: No. of leaves	No. of rotations
Pilot dial:					
Rotary armature		7			1 per minute (90° per ½ pulse)
Intermediate wheel arbor		56	8		1 per 8 minutes
Centre wheel arbor			60	10	1 per hour = 1 per 60 minutes
Master clock:					
Count wheel	30				2 per minute (driven by pendulum)

Arbor name			No. of rotations
Motion work:			
Canon (minute wheel)	10		1 per hour
Reverse minute wheel	50	15	1 per 5 hours
Hour wheel		36	1 per 12 hours

One count wheel tooth is gathered for each pendulum cycle (*i.e.* 2 beats)
Therefore (effectively) half a tooth is gathered for each beat
No. beats per minute = 2 x 30 x 2 = 120, therefore a half seconds pendulum
No. beats per hour = 120 x 60 = 7200