Restoration of Shortt - Synchronome Clock # 23
For the Lick Observatory©

A Cooperation between the University of California Observatories and

National Association of Watch and Clock Collectors Chapter 107

2016 – 2023

Compiled by

G. Price Russ III

Contents

1. Introduction

In early 2016 D. H. Mayeron brought it to the attention of National Association of Watch and Clock Collectors (NAWCC) Chapter 107 that the Lick Observatory owned a Shortt-Synchronome clock and suggested that chapter members might want to see it. This led to his arranging through Tony Misch a trip to Lick to see the clock.

As explained below, Shortt-Synchronomes, hereafter referred to as Shortts, are unique in their use of two pendulums in a master/slave configuration. The master unit was located in storage in the basement of the 3-meter Shane Reflector Building. The slave unit was not found. Subsequent searches including inquiries throughout the horological community failed to locate it. A group of chapter members headed by Price Russ thought it worthwhile to try to restore the master and recreate a slave. This led to an agreement to let Chapter 107 borrow the master for restoration and to recreated a slave with the intent that the restored clock be publicly displayed. It was agreed that at such time as the University no longer desired to display the clock it would be offered to the West Coast Clock and Watch Museum. This agreement was formalized in the Memorandum of Understanding between Chapter 107 and the University of California Observatories – see Chapter 17.

The main goal of this project was to restore the clock to operational condition but not necessarily to optimal performance. Optimal performance would have required operating it under tightly controlled conditions that were not practical for a museum display. It would also have required authentic replacement of certain critical parts, including the master pendulum suspension spring. When components were replaced, an effort was made to preserve at least a sample of the original material.

The purposes of this document are to describe the significance of Shortt clocks in general and this one (serial #23) in particular, their operational principles, the condition of #23 as found, what was done to bring it back into operation, how to operate and maintain it, provide a variety of documents relating to these clocks, and acknowledge those who contributed to the project. In order to document as closely as possible what was done, no effort was made to limit the length of this report. Additional photographs and an animation of the how the clock operates will be provided to the interested parties in electronic form. It is hoped that a separate document will be produced for publication in the NAWCC's "Watch and Clock Bulletin".

While the clock was brought into operation in 2020, its return to the observatory was delayed until 2023 largely because of the COVID-19 pandemic.

2. Importance of Shortt – Synchronomes (John Koepke)

The Shortt – Synchronome free pendulum clocks were the most accurate pendulum clocks ever commercially produced. They were invented about 1921 by a British civil engineer William Hamilton Shortt in collaboration with horologist Frank Hope-Jones and manufactured by the Synchronome Co., Ltd. of London[1]. The first prototype Shortt Clock No. 0 was installed January 1922 at the Royal Observatory, Edinburgh. The final Shortt Clock No. 100 was constructed from stock components by G. Richman in 1972 of Brooklyn, New York. The second Shortt Clock No. X with the others made a total of 102 clocks manufactured. Fifty-five of the clocks kept Sidereal Time while 47 of the clocks recorded Mean Solar Time[2]. The clocks were used worldwide in astronomical observatories, naval observatories, in scientific research, and as a primary standard for national time dissemination services. Most of the Shortt clocks were produced from 1922 to 1956 and were thought to have an accuracy of around one second per year.

Using his personally owned Shortt (No. 6), shown on the right, Admiral C. A. Fountaine in 1924 identified and recorded a small six-monthly digression and insisted that it was due to nutation (a periodic variation in the precession of the equinoxes caused by the moon's gravitational pull). This was confirmed in 1928 by clocks 3 and 11 at Greenwich. From then the nutation correction was included in the *Nautical Almanac*. [3]

In August of 1928 Alfred L. Loomis started an investigation at his laboratory on the precise measurement of time. He had purchased Shortt clocks No. 20, No. 21, and No. 22 all installed at Tuxedo Park, New York. He made extremely accurate time comparisons against the Marrison crystal clocks in Bell Telephone Laboratories. All four clocks were compared on a continuously recording chronograph that was designed and built in the Loomis laboratory in 1928.This enabled the lunar variation of gravity to be detected[4,5]. The Shortt clock was the first clock to be a more accurate timekeeper than the Earth itself. Differences of time between the Shortt clocks and star observations could no longer be faulted to the clocks. It is interesting to note that both of these important measurements were made in private laboratories.

In 1984 Pierre Boucheron studied the accuracy of a Shortt clock preserved at the US Naval Observatory using modern optical sensors. He compared its rate to an atomic clock for a month. He found that it was stable to 200 microseconds per day (2.31 ppb), equivalent to an error rate of one second in 12 years[6].

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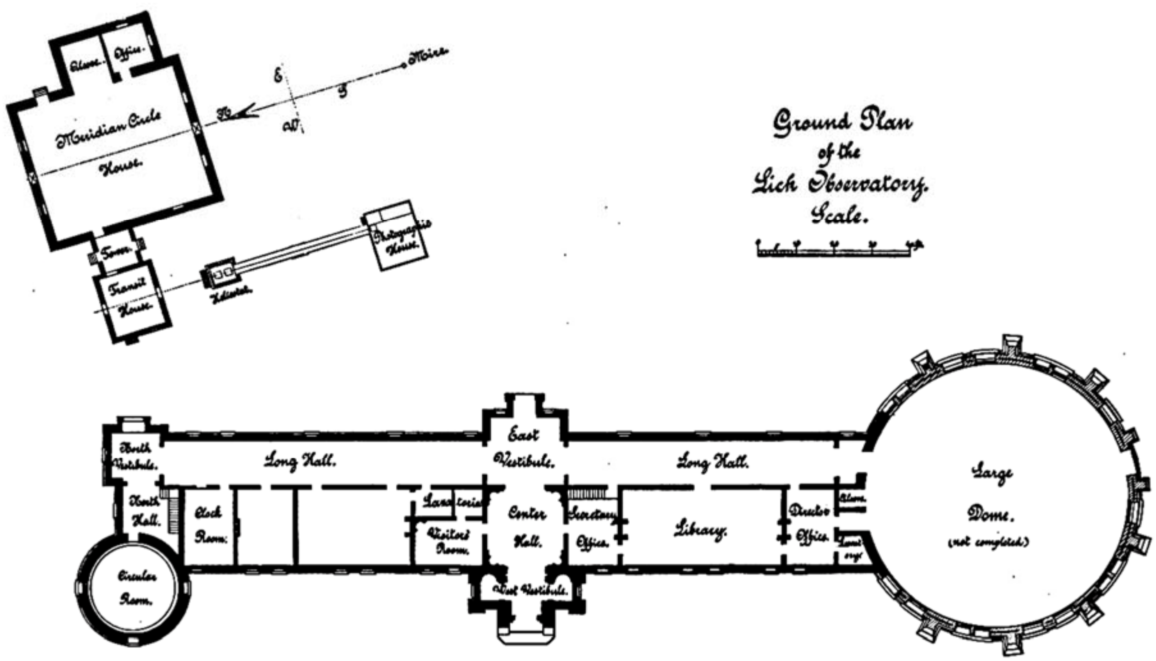
[1] Wikipedia
[2] Miles, Robert H. A. *Synchronome Masters of Electrical Timekeeping*, The Antiquarian Horological Society (2019) 250- 256.
[3] F. Hope-Jones, "Electrical Timekeeping", N.A G. Press (1940) 208-210.
[4] Loomis, Alfred L., "The Precise Measurement of Time", *Monthly Notices of the Royal Astronomical Society*, V. 91 (March 1931) 569-575
[5] Brown, Ernest W. and Brouwer, Dirk, "Analysis of Records made on the Loomis Chronograph by Three Shortt Clocks and a Crystal Oscillator" *Monthly Notices of the Royal Astronomical Society*, V. 91 (March 1931) 575-591.
[6] Boucheron, Pierre H., "Just How Good Was the Shortt Clock?" *Bulletin of the National Association of Watch and Clock Collectors* Number 235 (April 1985) 165-173.

3. Timekeeping at the Lick Observatory (John Koepke)

Pendulum clocks were very important to astronomers. They could determine time by an observation but could not preserve it accurately without a precision clock. It was originally intended at Lick Observatory to have a precision clock in each observing room. Five clocks were obtained for this purpose. Three clocks were sidereal time[7], two by Hohwu and one by Dent, one was either sidereal or mean solar time (used as a mean time clock) by Frodsham, and a mean solar time by Howard for time service work. The floor plan of the buildings in 1887 is shown below[8]. The observatory was still under construction and had not been completed at this time.



The small dome is located on the north side of the main building while the large dome is on the south side. Hohwu #35 was mounted in the Transit House on a sandstone pier. The Transit House was one of the first buildings completed on the site. The time service that Lick provided to the area was dependent on the instruments in the Transit House. The development of the Gardner's system for using a master clock to control a set of slave clocks replaced the precision clocks being located in the same room as the astronomical instruments. The Dent clock cost $550 while the Hohwu were $447 each. Gardner slave clocks were $25 each. The slave clocks had dials that were easier to read than the precision timekeepers. The Dent clock was used as a master for the Gardner Sidereal clocks located next to the astronomical instruments. The Howard

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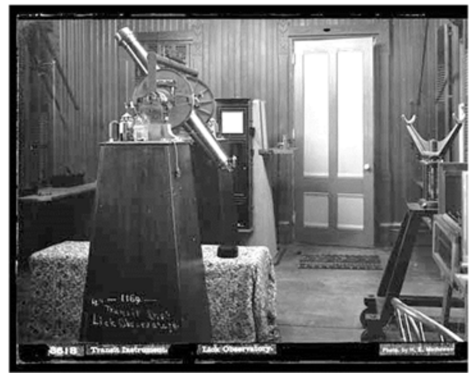
[7] The difference between a mean solar day and a sidereal day is about 3 minutes and 56 seconds. The sidereal day, based on Earth's rate of rotation measured relative to the fixed stars, is the shorter of the two. Although there are 365 days in a solar year, the earth will rotate on its axis 366 times. This is because the earth orbits the sun as well as rotating on its axis. After one mean solar year for a spot to be pointing at the sun again requires one extra rotation. Imagine an observer looking straight down at the earth's North Pole. Imagine also an arrow from the center of the earth to a fixed point on the equator. The time it takes for the observer to see that arrow return to the same angle is a sidereal day. The use of sidereal time in an astronomical observatory makes it easy to locate celestial objects.

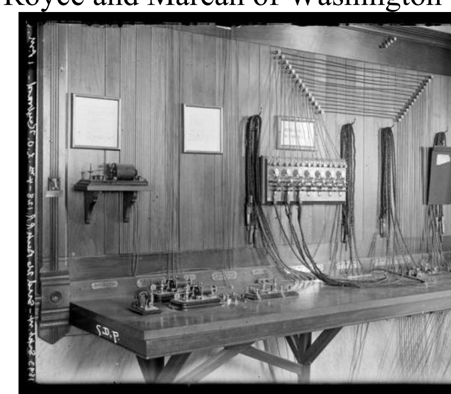
[8] Holden, Edward S.," Publications of the Lick Observatory of the University of California", V. 1 (1887) facing 34.

mean solar clock served the same function for the Gardner mean time clocks located throughout the other observatory buildings.

The photo at right[9] shows the interior of the Transit House with the four-inch transit telescope made by Fauth & Company. Mounted on the pier in the background is the sidereal Hohwu No. 35. Photos of the same room a short time later show the clock replaced with a sidereal Gardner slave clock, controlled by the Dent clock originally installed in the Meridian Circle House but now relocated to the clock room next to the small dome in the main building. By pushing a button by the Dent clock, all minute and second hands on the slave clocks on the same circuit would spring to zero. This is necessary only every few days as the slave clocks will only vary a second or two in that time period. Lick acquired two other precision clocks, a Riefler #97 in 1906 and the Shortt Clock in 1929.


Courtesy Special Collections, UC Santa Cruz

The photo at right[9] shows the electric switchboard made by Royce and Marean of Washington in 1884. It was located in the main hall at the north end next to the door to the clock room. This was the location were clocks, chronographs or instrument keys could be connected together to compare clocks to each other or record observations with a clock on a chronograph. The time signals that the observatory sent to San Jose, California came from this location. The Howard mean time clock was connected to a 20-mile telegraph line at this point. This clock was kept 6 minutes 34.29 seconds fast of the local mean time of the transit instrument and therefore indicates the time of the 120th meridian from Greenwich, or Pacific Standard Time.


Courtesy Special Collections, UC Santa Cruz.

In the 1880s the distribution of time by electric signals to railroads, telegraph companies, cities, private business firms and others for commercial purposes was a regular function of many observatories in the United States. The Lick time service started in January 1887 and lasted until at least 1902 and possibly as late as 1923. The time signal was sent to the Southern Pacific Company, San Jose Telephone Office and W. D. Allison Jeweler of San Jose, California.

The photo at right[9] shows an early image of the Transit House (small building on left) and the Meridian Circle Building (larger building on right). Riefler clock #97 was first mounted in November 1906 in the clock


Courtesy Special Collections, UC Santa Cruz

[9]Lick Observatory Records: Glass Negatives UA 36 Ser. 6.

chamber in the basement of the Meridian Circle Building. The Riefler kept sidereal time.

Shortt Clock No. 23 was a sidereal clock ordered with a type A slave (No. 156) in October 1928[10]. The account below is from "The Shortt Clock of the Lick Observatory" by Hamilton M. Jeffers[11] The Shortt was installed in the clock chamber in the basement of the Meridian Circle Building next to the Riefler No. 97. Jeffers reports that from early 1929 to July 1931 "the conditions under which it operated were unfavorable, and air leaks caused considerable difficulty." In a foot note he also states "There were several difficulties with this location, the most serious of which was the mechanical interference between the two clocks." After July 1931, the Shortt was installed in a new clock room in the basement of the main building at the north end. The Shortt slave clock was not relocated and remained in the clock room beneath the Meridian Circle Building. The Shortt ran from July 1931 to the middle of January 1935 at the new location with little disturbance. At the end of this period, the clock stopped. The cause was a sticking of a pivot in the resetting mechanism of the free pendulum caused by the deterioration of the lubricating oil. This period from 1931 to January 1935 is called run 1 and lasted for about 3 ½ years.

Run 1 allowed the first analyses of the running of the Shortt clock. The main disturbances to the clock for this period were earthquakes and temperature variations. During these years, the clock did not stop. However, three earthquakes during this period did disturb the pendulums to such an extent that the synchronizers failed to function. The apparent effect of such an occurrence is that the system loses about 2 seconds before the pendulums are again in step. There were also no air leaks in the case of the free pendulum clock; the pressure during the 3 ½ year period had diminished nearly 4 mm to 19mm. This effect has been noted in other Shortt clocks. In May 1932 there was an abrupt 12-hour power failure to the clock room heater that caused a change in the clock's rate. The rate change indicated a lengthening of the pendulum that was abnormally large. The normal formulas to correct the clock rate no longer applied. At this stage it was decided that not much more could be done with the examination of the performance of the clock without knowledge of the arc of swing of the pendulum. Jeffers considered the means for measuring the pendulum arc that came with the clock as quite inadequate as the arc could only be measured to an accuracy of 0.2 mm. A change of 0.2 mm in the semi-arc of the pendulum corresponds to a variation of 0.032 seconds in the daily rate.

Jeffers had a device built in the Observatory shop (shown at right) by James Cosh (the instrument maker) that was put into service in June 1933. A small concave mirror was attached to the bottom of the pendulum rod. The Jeffers' device projected a light to a 45° plane mirror under the glass bottom of the Shortt clock. The light was reflected to the concave mirror on the pendulum and back down to the 45° mirror under the clock case and then back to the Jeffers' device which contained a glass photographic plate. Each exposure was for 30 seconds after which time the plate would move 1/20 of an inch. One 6 ½ x 8 ½ inch plate at four records per day would last for 40 days. The Jeffers' device was found next to the Shortt clock in the Shane storage room.

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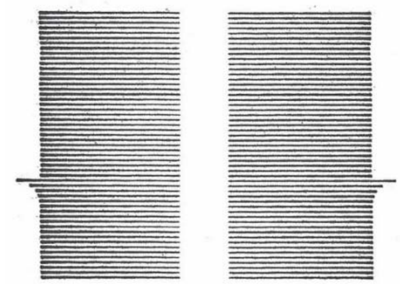
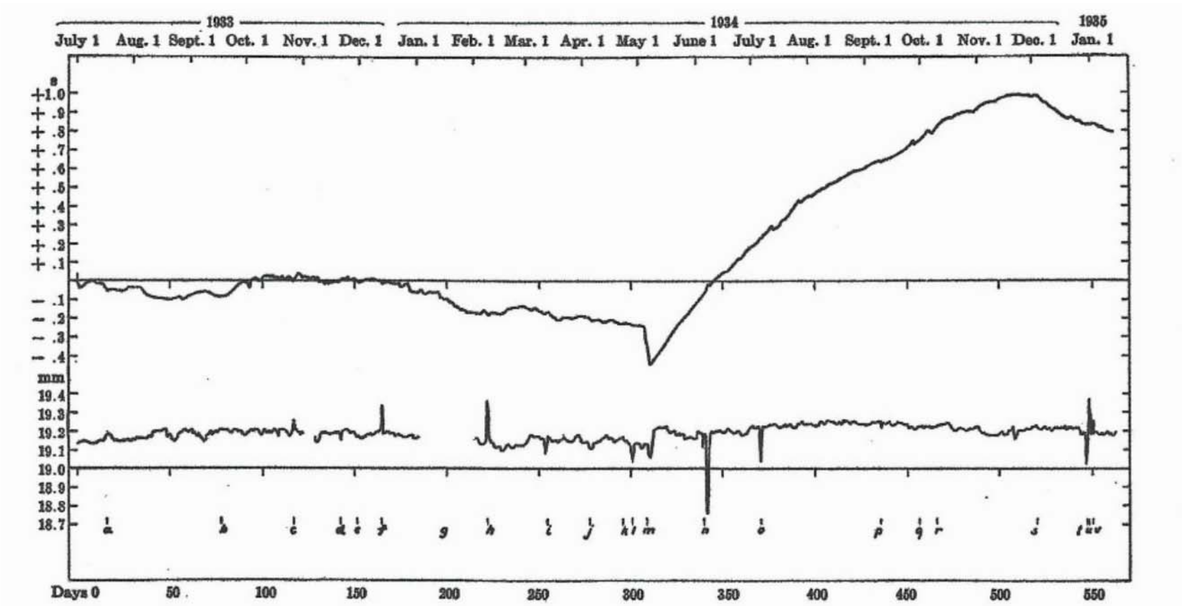
[10] Miles, *Synchronome*, 251.

[11]. Jeffers, Hamilton M., "The Shortt Clock of the Lick Observatory*", Lick Observatory Bull.*, V. 17, No. 468 (1935).

The photo at right shows a Shortt pendulum arc record. The reproduction has a portion of the middle of the record omitted. The original length of the line is about 14.5 cm. A sharp nearby earthquake occurred at noon June 25, 1933, and the record which first shows the effect was made at 4 p. m. The interval covered by this illustration is from June 17 to June 30, 1933, and an exposure was made every six hours.



The chart below shows a sudden change of clock correction and rate beginning May 5, 1934 which is very striking. The change corresponds to an abrupt change in clock rate of 0.07 seconds per day commencing at the time when the heat supply to the clock room failed. The rate change would indicate a shorting of the Invar rod and Elinvar suspension spring. On May 8, 1934 after the adjustment of the heat control relay the temperature



Upper curve: Comparison of the observed clock corrections minus those computed from the formula that includes correction for the changes in arc. ***The coefficients of the formula depend upon a solution covering the interval 0-185 days only.*** **Lower curve: The measured semi-arcs, on the same time scale as the upper curve.**

returned quickly to normal. On this date the clock made another sudden change corresponding to a lengthening of the pendulum.

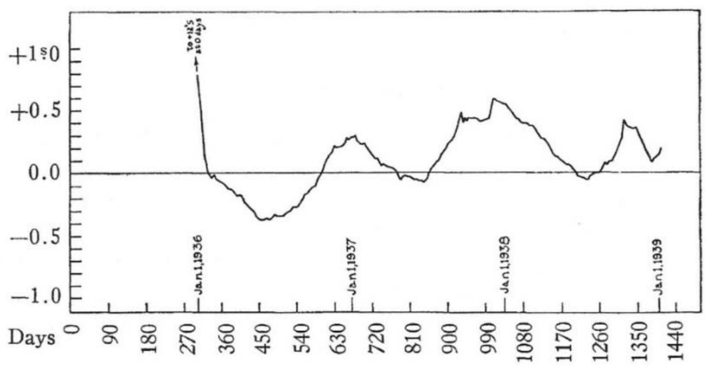
Jeffers conclusion of Run 1 was that after variations in the pendulum arc have been allowed for, the clock keeps time as accurately as the length of the pendulum rod. He thought that the temperature changes were causing serious time keeping problems by affecting the length of the pendulum. Invar while having a low coefficient of expansion was known to get longer over time, and he thought this growth rate was being affected by the temperature changes.

Run 2 of the Shortt No. 23 was published by Betty Adams[12]. The clock was started in March 1935. For this run, the case was filled with nitrogen at a pressure of 20 mm. During this run there

[12] Adams,Betty, "The Rate of the Shortt Clock of the Lick Observatory", *Astronomical Society of the Pacific* V. 52 (1940) 395-397.

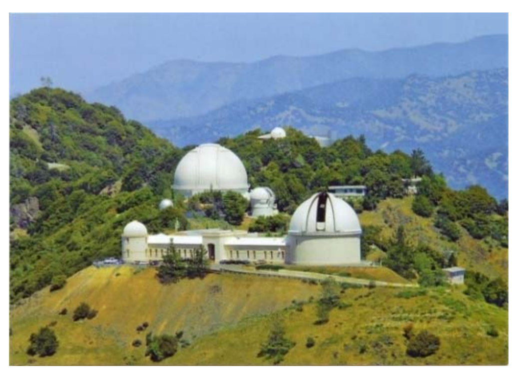
were no air leaks and like the first run the pressure decreased by about 2.5 mm in four years. The arc as in the previous run has been recorded four times a day with the Jeffers' device. Earthquakes as well as the shock caused by the digging of a trench 20 feet from the clock all affected the arc of the pendulum. These mechanical disturbances seem to only have temporary effects on the rate.

During Run 2 in January 1936 there was a sharp change in the rate again without any change to the pendulum arc. On that date, meteorological equipment was moved to a location in the hall above the clock room. It is thought that due to an electrical change when wiring the new equipment, the thermostat in the clock room was disconnected. The chart on the right shows the striking effect of the disturbance of January 24, 1936. The chart which is corrected for all known effects including nutation also showed what seemed to be an oscillation or periodic change, with amplitude of about ½ second and a period of about 1 year. Data for Shortt No. 48 at the United States Naval Observatory showed a similar pattern with about the same phase but half the amplitude. No other precision time data were available for comparison to try to explain the data.



Run 2 of Shortt No. 23 ended January 9, 1939 when the lubricating oil on one of the pivots of the resetting mechanism of the free pendulum thickened causing it to operate erratically. At this time, I've found no other information on the use of the Shortt clock at Lick after 1939 or the further study of the data from Run 2.

The photo to the right is a current view of Lick Observatory. In the foreground is the original observatory building with the small dome to the north and the large dome to the south. The large dome behind the main building houses the 120-inch Shane reflector telescope. Shortt No. 23 and the Jeffers device were stored in this building in later years. The Meridian Circle Building was demolished about 1956 to make room for the new northeast wing of the main building. This would have destroyed the clock chamber in the basement and required the removal of the Shortt slave clock and the Riefler. Construction of the Shane dome began in the early 1950's. It may well be that the Shortt clock was put into storage about this time[13].



4. How Shortt – Synchronomes Work

[13] "What's Where at Lick Observatory on Mt. Hamilton". www.ucolick.org/~sla/mtham/mtham.html

A "free" pendulum swinging with a constant arc under constant gravitational force and with no interference from other variable conditions would be an ideal timekeeper. In practice a pendulum- based timekeeper will be subjected a variety of factors impacting its performance. These include variations in the power source used to keep it swinging at a constant arc, the system used to count the swings, temperature, barometric pressure, vibration, wind currents, and humidity. For precision clocks, even variations in gravity, such as caused by the moon, must be accounted for. Variations in temperature affect the length and hence the pendulum's period. The use of materials with low expansion coefficients, temperature regulation, and compensation using special materials will largely control variations in length. Enclosing the pendulum in a sealed tank operated at low pressure will control variations in pressure and humidity and eliminate wind currents. Operating the case at a constant reduced pressure will reduce the input energy required to keep the pendulum swinging. One of the best ways to deliver constant energy to a pendulum is through a "gravity escapement" which drops a weight onto an arm that gives the pendulum a slight push. This leaves the problem of how to know when to drop the weight and how to record the number of swings.

In a Synchronome, there is an arm attached to the pendulum. The arm pulls a 15-tooth count wheel one tooth on each swing to the right. Given that the pendulum period is two seconds for a full cycle (left to right and back to left), the count wheel rotates with a 30 second period. A rod on the count wheel releases a gravity arm every 30 seconds and a roller on the gravity arm travels down the curved end of another arm on the pendulum thereby providing impulse. The falling gravity arm makes an electrical contact that activates a solenoid (coil) that resets the arm. The electrical pulse is also used to advance a dial that indicates the time. In this arrangement the only activity the pendulum performs is to pull the count wheel. Synchronomes are not housed in sealed tanks and are subject to many of the variations listed above.

A schematic of the system taken from *Synchronome*[14] and four screen captures from a computer automation[15] (Windows) showing the operation of the Shortt clock are reproduced at the end of this section. Referring to them while reading this section may be helpful for understanding the interaction of the parts. A copy of the animation program will be supplied along with this report.

In a Shortt clock there are two pendulums. One, the master, is housed in a tank kept at constant low pressure and in a temperature-controlled environment. Its pendulum rod is also made from Invar an alloy with a very low thermal expansion coefficient. The other, the slave, is basically a conventional Synchronome to which a "hit-and-miss" synchronizer has been added. When the Synchronome gravity arm drops advancing the slave's dial and activating its reset solenoid, it also activates a solenoid in the master which releases an impulse arm in the master that gently transfers energy to the pendulum. This is the only contact ever made with the otherwise free pendulum. As the master's impulse arm drops it closes another contact that that activates a solenoid that resets the arm, advances the master dial, and activates the synchronizer.

Synchronization is maintained by having the slave adjusted to run slightly slow (about 6 seconds per day) and having the synchronizer bringing the slave back into synchronization with the master. The synchronizer consists of a horizontal arm that rides above the top of a leaf spring

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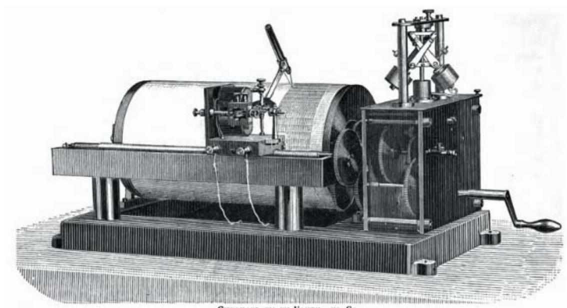
[14] Miles, *Synchronome*, 184

[15] Ted Bosschieter, personal communication

fitted to the slave pendulum. Each time the master reset arm is activated it also activates a solenoid on the synchronizer that causes its arm to drop. If the slave has slowed sufficiently, the arm will hit the spring and speed the slave. If the slave is not sufficiently slow, the arm drops on top of the spring, a "miss", and have negligible effect on its rate.

The two circuits and their dials activate approximately 0.8 seconds apart. The instant of activation of the master reset solenoid (coil) is the reference or "true" time. This event could also be recorded on a chronograph, such as shown here, or a strip chart recorder. Events of interest could also be recorded on the chronograph and the time of the event determined by interpolating between two activations of the master's reset solenoid.



CHRONOGRAPH BY FAUTH AND CO.

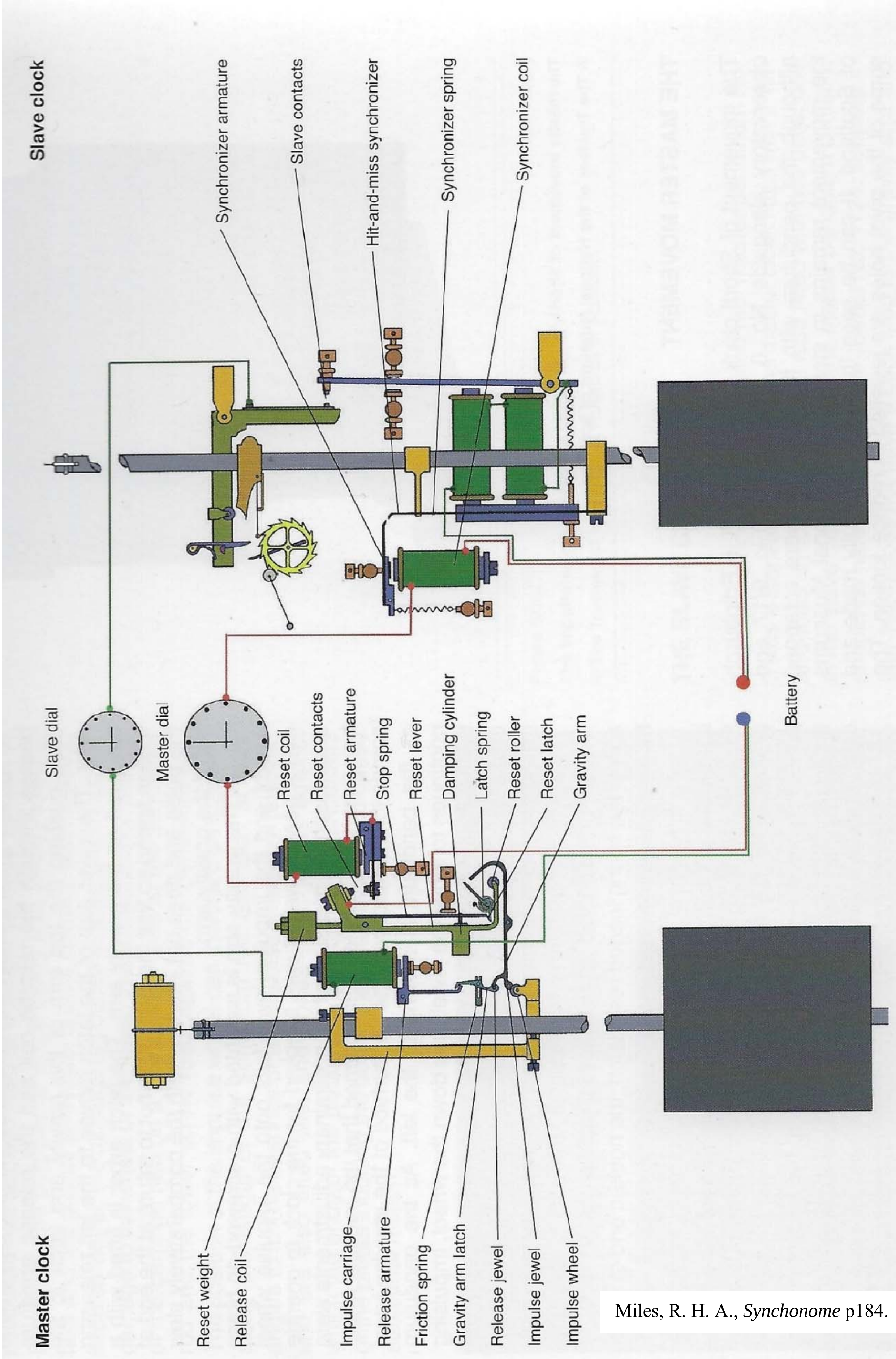
The amount of impulse given to the master pendulum is controlled by a weight on the gravity arm. Two weights were provided with each Shortt clock. One was for use during normal operation when the tank was at low pressure. The other (heavier) was for use during testing when the tank was at atmospheric pressure. It was judged to be impractical to operate #23 at reduced pressure, so the heavier weight was installed during the restoration.

In that the number of dials on the circuits was variable depending on the installation, the circuits should be set to provide a current flow of 1/3 amp[16]. This was achieved by variable resistors in the slave case.

When discussing clocks made by the Synchronome Company, the terms "master" and "slave" are used in two senses. When discussing normal Synchronomes, master refers to the pendulum movement and slave refers to a dial connected to the movement. There could be many slaves operated from one master. For Shortt clocks, the master is the unit in the tank and the slave is the Synchronome movement with its synchronizer. In this document the term "dial" will be used to refer to the physical dial displaying the time, its hands, and the mechanism that controls the hands.

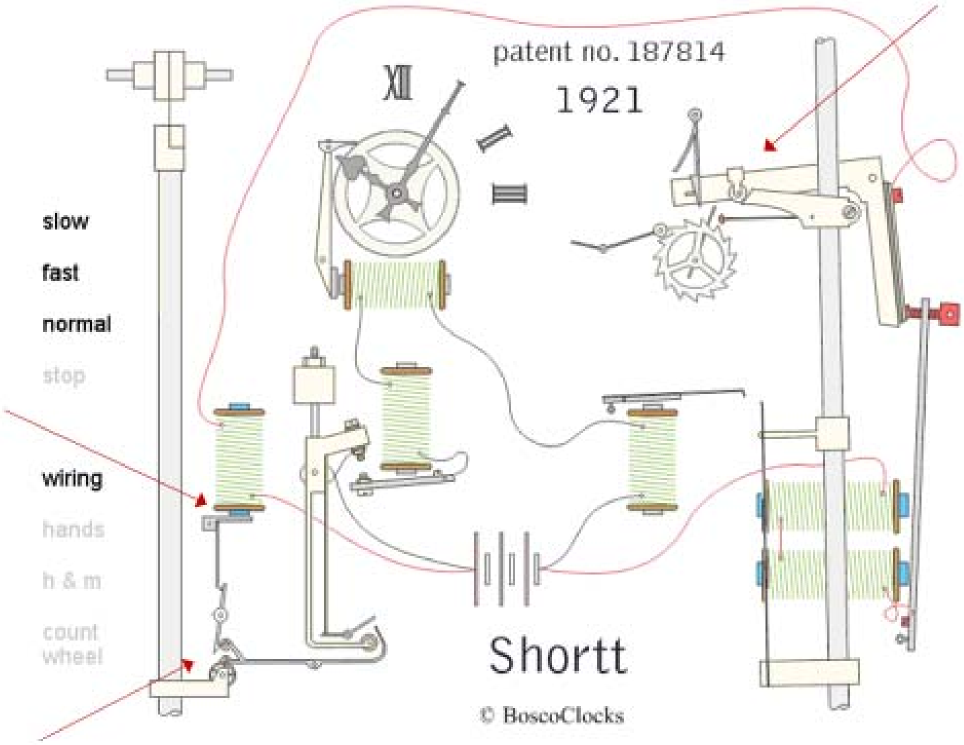
These issues are discussed in more detail in several of the articles listed in Section 16.

[16] Synchronome Co., *Instructions for the Erection of the Free Pendulum, Master, and Slave Clocks*, 9.

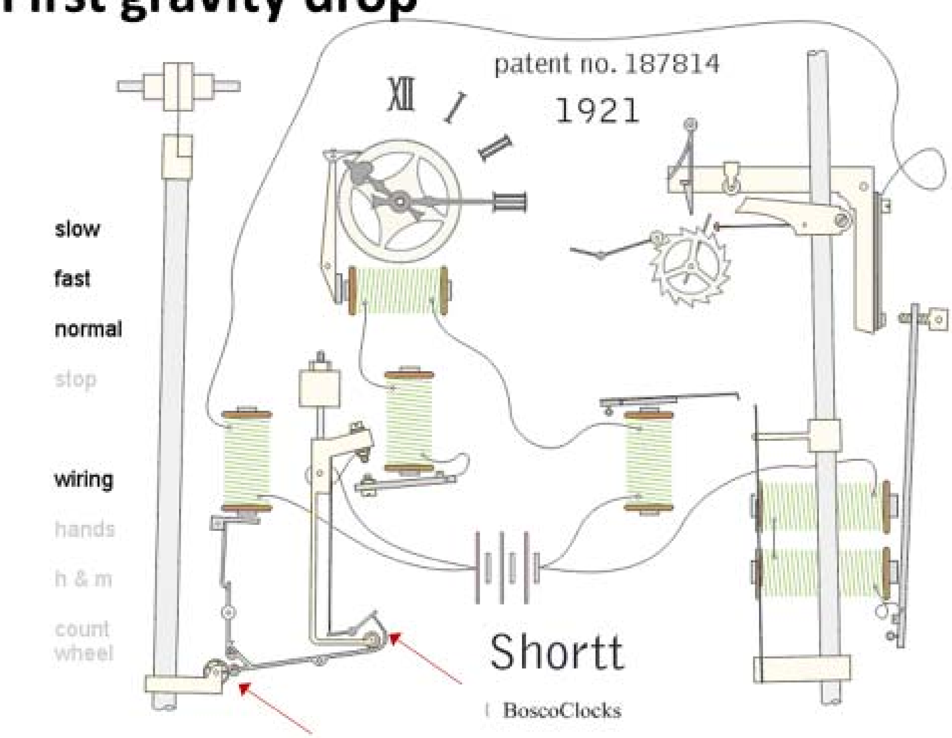


Miles, R. H. A., *Synchonome* p184.

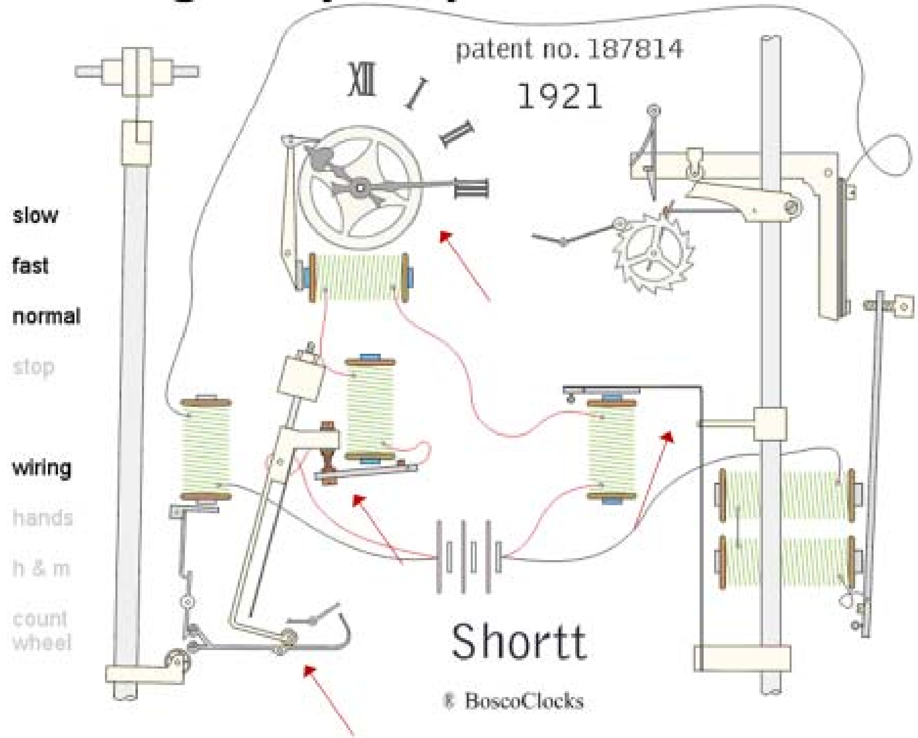
Release of gravity arm



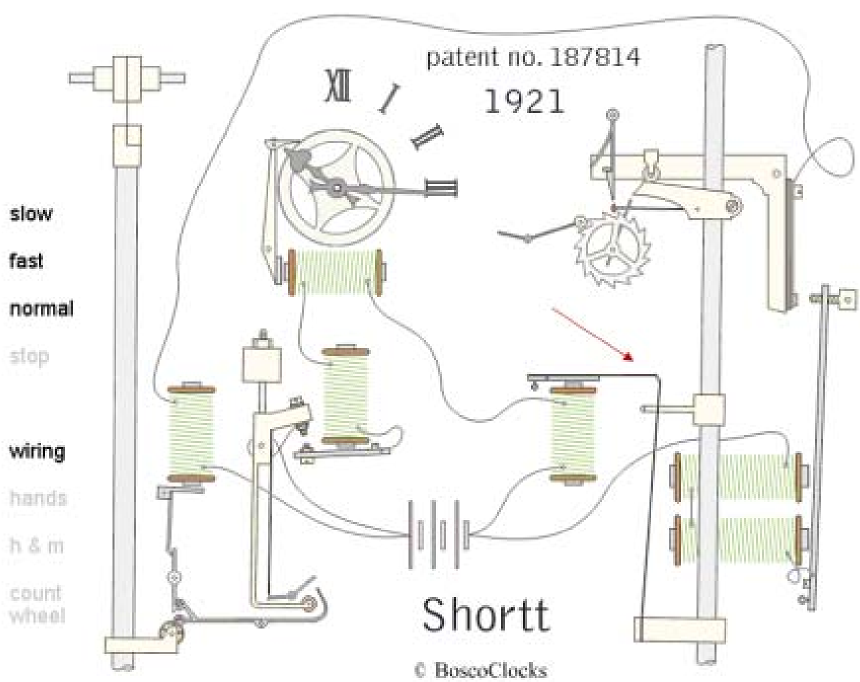
First gravity drop



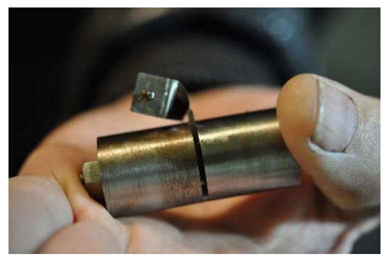
Second gravity drop & clock advance



Hit and Miss



5. Condition of #23 Master when Found



The above photographs show the master unit in the storage area of the Shane Reflector Building. The tank with its movement and bell jar was bolted to a wall. The bottom glass and its holder were on the floor. The pendulum with its impulse carriage was leaning against an electrical box. Amazingly the impulse carriage and wheel were intact. While the tank and glassware were extremely greasy (vacuum grease) and dirty, the only obviously damaged item was the pendulum suspension spring which was irreparably twisted. It was probably damaged when the pendulum was removed. The two internal vacuum gauges were missing, but these are known to have been removed when the clock was in service. The object on the floor left in the above picture showing the tank is the device made by Hamilton Jeffers to monitor the amplitude of the swing of the pendulum. A better photograph of this device appears in Section 3.

Tony Misch located several other items stored elsewhere. These included the beat plate and mirror for the master pendulum, the reticle used in connection with the beat plate to monitor the pendulum's arc, the gravity arm weight for use when the tank is operated at atmospheric pressure, a partial set of weights for adjusting the period of the pendulum, and several spare parts for the missing slave unit.

6. Restoration of Master

It was agreed that Price Russ, who had already prepared the slave (see next section), would take the lead in the restoration of the master. Due to the remote location of the observatory, the only practical way to restore and test the clock was to set everything up in his home. On November 5, 2018, John Koepke, Tony Misch, and Price Russ removed and boxed everything from the tank and then unbolted the tank from the wall. All the components were transported to Russ's garage in Koepke's van. This section is arranged in the order operations were performed. The general sequence of cleaning and repair was tank, beat plate, impulse arm, movement, and finally suspension springs. Following warning given by James Nye and Jan Wright, that the finish (lacquer?) on the brass parts had never been successfully duplicated, throughout the cleaning process attention was given to preserving the finish. This eliminated the possibility of soaking the parts in solutions normally used for cleaning clocks.

The first task undertaken was to degrease the glassware. Simple Green was found to do a good job of removing the vacuum grease from the glassware. It was then used to clean the triangular bottom bracket. A sample of the yellow-orange vacuum grease was saved for future reference.

The walls (interior and exterior) of the tank were sticky with vacuum grease. There was also a more viscous black compound on and around the vacuum feedthroughs. A sample of the black material was saved. Three feedthroughs were for the electrical connections and one for the evacuation valve and pressure gauge. All of the feedthroughs were removed and the tank cleaned in the laundry sink with Simple Green and water. No attempt was made to polish the tank. It seemed better to leave the finish alone. The two brass nameplates were polished and waxed.

Carriage bolts were installed into two pieces of 2x4 and the boards were bolted to an interior stud wall. The cleaned tank was then hung on the carriage bolts.

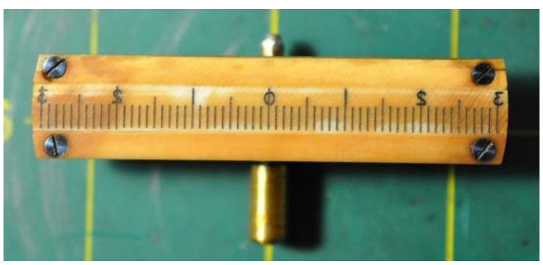
The electrical feedthroughs consisted of threaded steel rods whose middle sections were wrapped in vacuum grease-coated "string". Washers and nuts on each side of the tank served to compress the string-wrapped region and make the vacuum seal. When the feedthroughs were removed, the string tended to unwrap. For the "B" (common) and "S" (slave) feedthroughs was possible to reinstall them with the original packing. For "F" (master) number 30 linen thread coated with Dow Corning vacuum grease was used instead. As shown wrapping the thread was facilitated by mounting the rods in a lathe. On reinstallation one of the interior washers cracked and was discarded. The F feedthrough did not feel like it

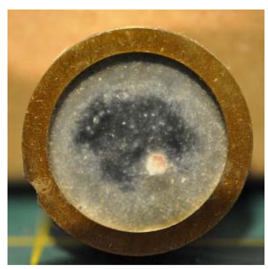
was seating properly, so original yellow grease which is more viscous than the Dow Corning was used to hopefully get a better seal. There was no plan to use or even test the tank under reduced pressure but an attempt was made to make the seals tight.

At the bottom of the tank, the pump-out feedthrough was coated with Dow Corning grease before reinstallation. New leather pads for cut for the screws that push the glass disk against the bottom of the tank. The glass was then mounted using the triangular bracket. No vacuum grease was applied to the glass. For temporary protection of the glass, padding material was put on top of it and left in place until all the other components were installed in the tank.

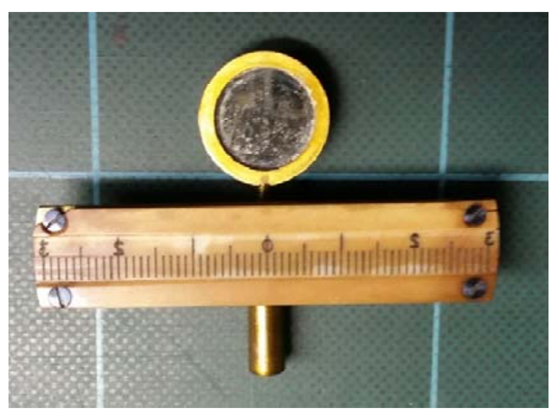
The four-legged head bracket was given a light cleaning with Simple Green solution and reinstalled. To avoid damaging the existing finish, more extensive cleaning was not attempted or needed. Likewise, the bracket that originally held the pressure gauges was only lightly polished with Flitz. Using a digital capacitance meter, the 2µF spark-suppression capacitor the mounts in the tank tested as 3µF. The capacitor was remounted in the tank.

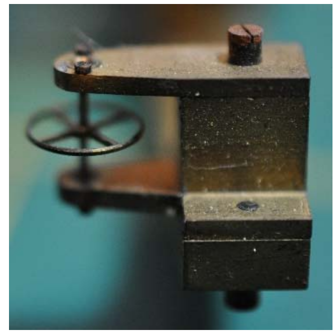
The beat plate appears to be ivory mounted on brass. It is ruled in millimeters. The numbers are reversed because it was meant to be read through a now-missing inverting microscope. The





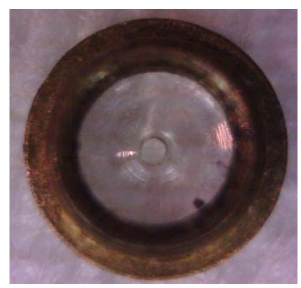
mirror intended for use with the Jeffers device for measuring arc was dirty and disconnected. Attempts to clean the ivory with water, ethanol, and Simple Green had no effect. An attempt to clean the mirror, which is second surface, with lens cleaner resulted in the reflective coating wrinkling. Fortunately, the wrinkles largely disappeared. The rod intended to connect the mirror to the plate had only one turn of good thread (3x48). The rod was replaced with a new length of rod with the same thread. The fact that an American rather than a BA thread had been used to mount the mirror suggests it was a post-installation modification.



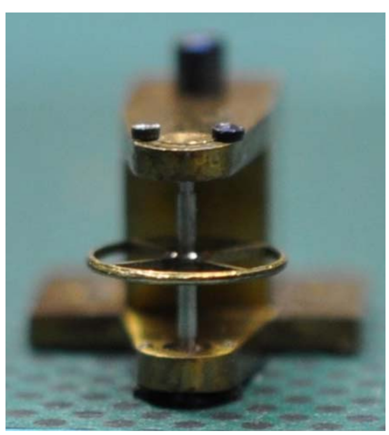
Having been stored outside the tank with no protection, the impulse arm and wheel were dirty and had surficial rust. For example, rust can be seen on the head of the screws in the impulse wheel holder. The impulse wheel and its carriage were visibly dirty. The impulse wheel is mounted in hole and cap jewels on each end. The condition of one of the jewels is also shown. The depths of the arm's mounting and adjusting screws were carefully measured before the arm and wheel carriage were disassembled. Rust was removed from the screw heads including those for the jewel settings by turning them in a lathe while holding polishing paper against the screw heads. One jewel screw was lost, but a replacement with a slightly larger head was found. The larger screws were "toothbrushed" with Simple Green, rinsed, and dried. The screws were then blued in a kitchen oven at 500°F. The brass arm was dunked in Simple Green, rinsed, and dried.

The wheel arbor was not completely straight. This would have made it difficult to polish the pivots. Examination of the pivots under a microscope showed they were not scored and did not need polishing. The wheel and arbor were brushed with Simple Green and rinsed in alcohol. The outer rim had some sort of deposit, possibly grease. The wheel was chucked in a lathe with the idea of cutting of the deposit. The metal in the wheel was found to be soft and turning with a graver was judged to be too risky. The edge was then wiped with polishing paper. After that the wheel was "ultrasoniced" in toluene. At that point the wheel was judged to be sufficiently clean.

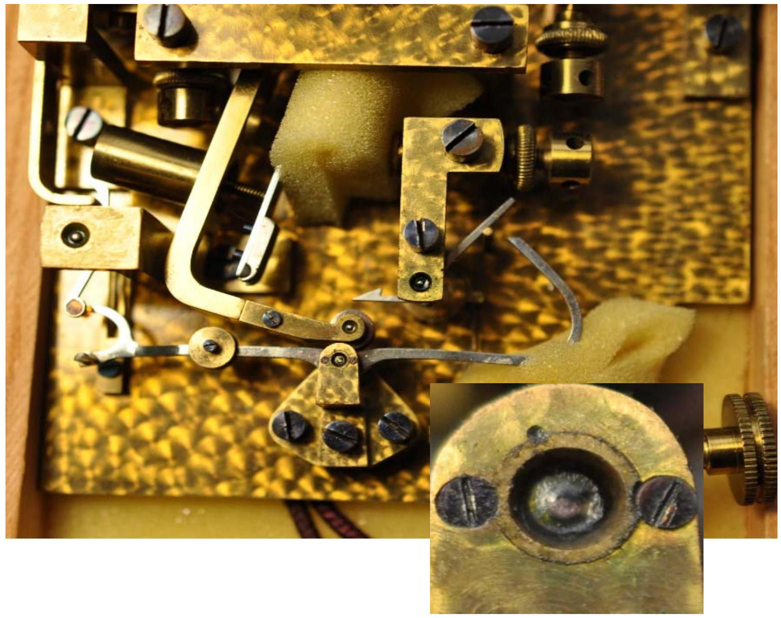


The jewels were cleaned one pair at a time. Each pair was cleaned over a period of two days by repeated soaking in toluene with intermittent ultrasonic agitation and rubbing with toothpicks to remove deposits while being viewed under a microscope. A cleaned jewel is shown on the right. Emphasis was placed on the cleanliness of the surfaces that would be in contact with the wheel pivots. Little effort was placed into brightening the setting. While these jewels are no smaller than would be encountered, not losing one was a serious concern.

The wheel carriage was then reassembled. Based on discussions with others who have serviced Shortt clocks, it was decided not to lubricate the pivots. <u>No lubrication was used on any part of the master movement.</u> Two views of the cleaned and reassembled wheel carriage are shown on the right. In the right photograph, one jewel setting screw has a visibly larger head than the other. The larger one is the replacement.

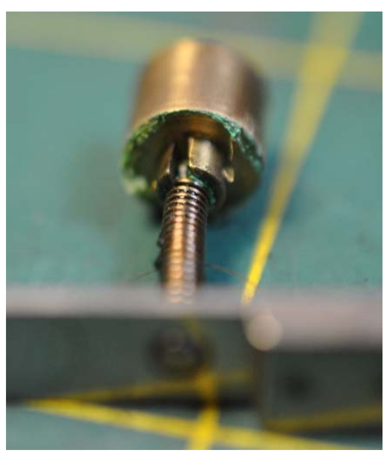



Having been inside the tank with the bell jar in place, the master movement; i. e., the plate and mechanism that controls the gravity arm; was considerably cleaner than the impulse carriage, but the individual components required cleaning and rust removal. Emphasis was put on cleaning pivots and the holes they ride in while maintaining the finish on the brass parts. Rather than describe the cleaning of each element, specific examples will be discussed. The other elements were cleaned similarly.



The photograph of the lower part of the movement including the release arm, gravity arm, and lower portion of the reset lever is representative of the movement as a whole. (The foam pieces were used to block the arms during transport.) The magnified insert is of the upper jewel on the gravity arm cock. The lower end of the spring stop and the damping piston, normally housed in the damping cylinder and rusty screws on the back of the plate are also shown. Note the green goo on the piston. As found the piston was stuck inside the damping cylinder, but came out with minimal force. The green goo is consistent with the movement having been oiled in the past.

Rather than take the whole movement apart before starting to clean the parts, it was disassembled is sections starting with the gravity arm. Work then proceeded upward.

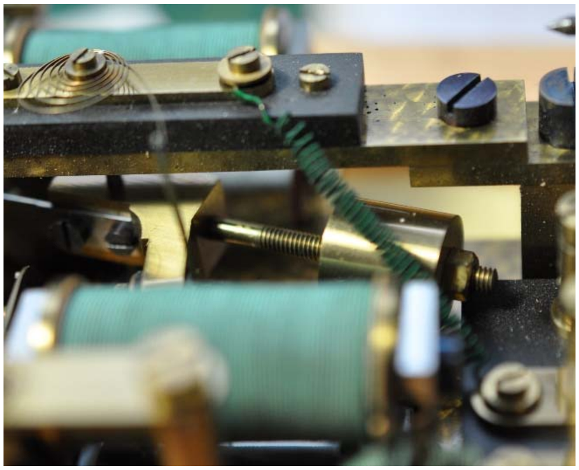


Parts were soaked in concentrated Simple Green, toluene, and/or alcohol with or without ultrasonic agitation. Mechanical action was applied with toothpicks, peg wood, and brushes. Polishing paper was used to remove rust from screw heads as they were turned in a lathe. Screws were then re-blued as described above for the impulse carriage. Jewels in settings were removed from the plates and cleaned individually.

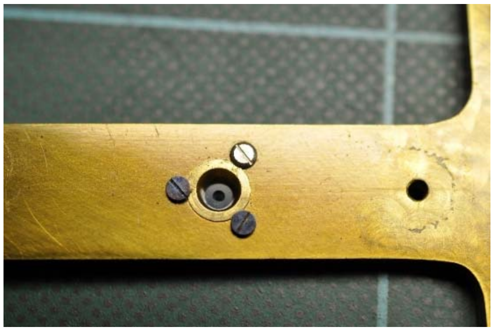
As received the coil spring providing the electrical connection to the reset contact on the reset lever was out of round with the outer coil pulled under the rest of the spring. On reassembly the arm on the contact was repositioned to flatten the spring. It was deemed too risky to make the coils evenly spaced.

Before reinstalling the gravity arm the heavier weight for operation at atmospheric pressure was installed. The two weights were not photographed together but the difference in their sizes can be inferred from the fact that they are the same diameter and the slot is identical.

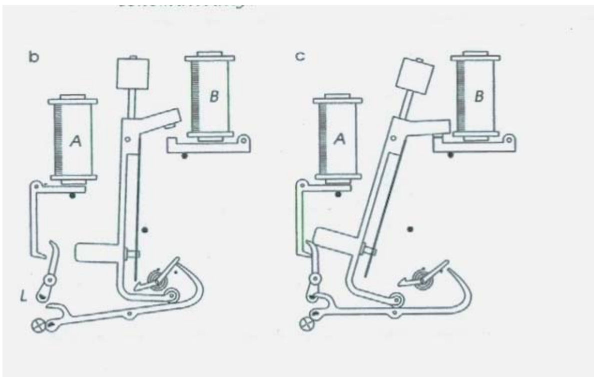
Once the movement was judged to be clean, it and the impulse arm were installed in the tank. After adjusting alignment and clearances, functional tests were conducted using D cell batteries, resistors, and current meters. These tests were performed with the slave. Because of the transient nature of the circuit closures, it was difficult to get meaningful current measurements. (One wonders how this was done in the 1920s.) Contacts were manually held closed to get current readings. The reset latch was not operating properly, so it was removed and recleaned. The reset contacts were found to be pitted, so the upper contact was rotated to a new position and the surfaces burnished. The effect of the reset weight's position on the action of the operation of the reset arm and the current needed for proper resetting was tested by moving the weight along the threaded rod. Initially the bottom of the weight was 0.661" from the top of the bracket. Lowering the weight to 0.384" above the bracket along with raising the reset contact by one turn gave consistent closure at 360 mA. Each time the reset weight was adjusted the arm pivots were removed from their hole jewels rather than risk torque during adjustment cracking a jewel. This of course had to be balanced against the risk of damage taking the mechanism apart and reassembling it. The photo shows the weight in its original position.

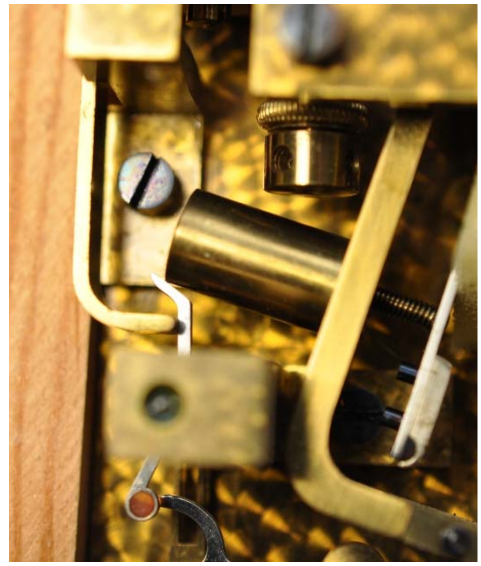


The upper jewel for the reset lever and its mounting is shown in the next photograph. One screw holding the setting on place is different from the other two. Notes taken contemporaneously with the picture do not mention this fact. This document is being written a year later and the author does not recall whether he replaced the screw or it was that way when he worked on the movement. As discussed in Section 3, Run 2 terminated when the oil on this or the corresponding jewel thickened. It is possible the screw was replaced when the jewel was cleaned.



The Bosschieter animations and the screen captures from them shown in Section 4 omit the damping cylinder and misrepresent the action of the gravity arm latch. The latch is released when it is pushed by the arm on the release armature. As shown below[17], the latch remains in the released position until the cylinder physically pushes it back into its locked position. The photograph on the right shows the cylinder just as it completes relocking the latch.





Perhaps the most serious concern in undertaking the restoration of Shortt #23 was how to fabricate a replacement for the master-pendulum suspension spring, which as discussed in Section 5 was irreparable. As supplied these springs were formed from a single piece of elinvar, a steel alloy with a very low expansion coefficient and excellent spring qualities. The central section was thinned to 0.005" to provide the flexible portion. While the team was aware of two successful attempts to reproduce such springs, doing so was considered problematic. Among other issues, elinvar or modern equivalents are not readily available and require heat treatment after cutting or grinding. Harvard University was willing to lend a spring from its collection of scientific instruments, but their spring had rust spots. The team was concerned that the rust might have weaken it, so the offer was declined.

After a great deal of discussion with among others Jan Wright and Robert Matthys, two people who have successfully made single piece springs, it was decided to take two approaches.

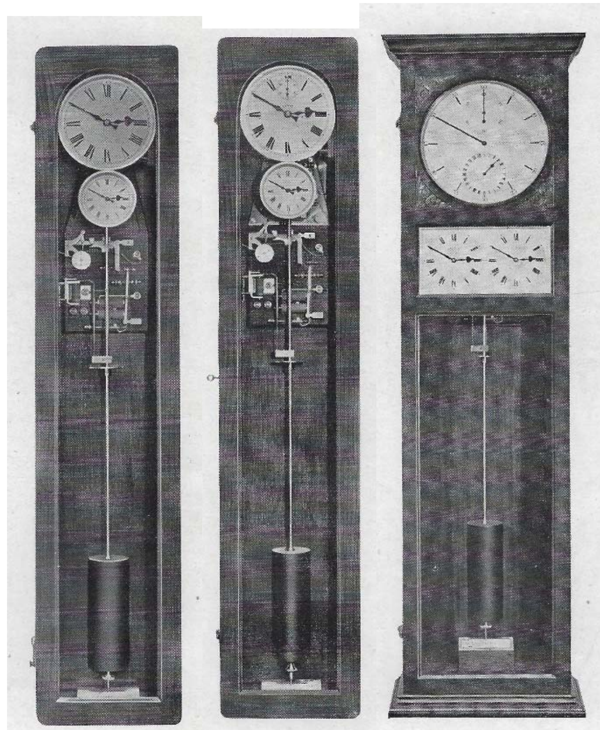
The first approach involved modification of a pair of springs made and donated by Matthys. D. H. Mayeron was able to make the necessary modifications to one of the springs. It is shown on the right in its mounting bracket and in a closeup. This spring was installed and used for initial testing, but the irregularities visible in the closeup photograph lead to concerns that it might tear in use. The mass on the weight required to bring the pendulum close to sidereal time was 14.8 grams.

[17] Woodward, Philip, *My Own Right Time*, Oxford (1995) 87.

It should be noted that the cylinders holding the spring are reproductions. Suffice it to say the original spring and cylinders were misplaced. The replacement cylinder diameter and length were shown in available drawings. The center holes in the cylinders and the corresponding hole in the spring were drilled for BA 4 rod.

Based on conversations with Wright and information in *Accurate Clock Pendulums* by R. Matthys, it was decided to make a batch of four suspension springs from phosphor bronze. Rather than being one piece, they were made from 0.005" sheet material sandwiched/soldered between 0.025" thick chops. Three drawings of Shortt suspension springs are shown in Section 14.5. The third, a factory drawing, was not available when the springs were made. (More accurately, it may have been available but not recognized among the stack of documents and emails.) It should be noted that there are significant differences among the drawings. For example, the radius of the curve on the ends of the thin section is 0.5" in the factory drawing and approximately 0.25" in the others. While the details affect the arc and the weight required to bring the clock to time, they are not critical to being able to get the clock to operate. One dimension that was more important than realized was the distance between the mounting holes in the suspension spring. As built this distance is approximately 1.001". The original specification was 26.5 mm (1.043") and the intended dimension was 1.030". It is not known how the error occurred, perhaps inexperience. As discussed in Section 10, this led to a minor problem installing the springs. Details of how the springs were fabricated are in Section 13.

7. Recreating the Slave



The three types of slaves were available for Shortt clocks – A, AS, and B, left to right respectively in the photos[18].

Type A had two dials stepped at 30 second increments. The larger gave the master time. The smaller one gave the time from the slave pendulum. There was also a third dial mounted on the count wheel that indicated seconds in two second increments.

Type AS was similar to Type A but with the addition of a seconds hand below the 12 on the master dial. A seconds switch on the slave pendulum advanced the seconds hand with each swing of the pendulum.

Type B had a large "astronomical dial" and two smaller dials. The smaller dials were functionally the same as the two major dials of the Types A and AS. The astronomical dial was driven by the seconds switch on the slave pendulum.

According to Miles[19], Shortt 23 was delivered with a Type A slave. After much discussion about the problems associated with making a reliable seconds switch for the needed replacement slave and given the fact that #23 was believed to have had a Type A slave, it was decided recreate the slave unit without seconds indications. The small two-second dial was also omitted.

A case with dial suitable for the slave was donated by Nile Godfrey of Classical Clocks and Antiques (Livermore, CA). The case included a Synchronome kit movement[20]. This movement was not used because it just didn't look "right" for the clock. However, some parts were used in making the synchronizer.

Jude Hill of San Francisco donated a movement for parts, but because it looked more correct it was used for the slave. The count wheel as received had been deformed into an oval shape. It was stretched back to round using a self-centering four-jaw lathe chuck. There was a tendency for the gathering pallet to ride over the tops of the teeth, so the teeth were recut to catch the pallet stone better. (Synchronome count wheel teeth seem to have been cut in a variety of shapes.)

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[18] Synchronome Co., *Astronomical Regulators and Observatory Time Installations*, undated catalog, 12-14.
[19] Miles, *Synchronome*, 251.
[20] On the back of the movement, there was a label stating "Mr. R. H. Bailey, 'The Mount', Victoria Road, Rushden, Northants NN10 0AS".

Price Russ made the hit-and-miss synchronizer (right). It was modeled after the one shown in Figure 9/4 of *Synchronome*[21]. This design has two arms. The lower one, made of steel, is pulled down by the solenoid. The upper, made of brass, falls by gravity when the lower one is pulled down. Some Shortt-Synchronomes have only one arm with a steel lower part and brass upper. (Jan Wright stated that he had never seen the two-arm version.) The two-arm version was picked because it was thought that it would put less compression on the top of the synchronizer spring during a "miss"; i. e., when the arm came down on the top of the spring. The solenoid for the synchronizer was taken from a conventional Synchronome dial movement provided by Price Russ. Pivots for the arms were made by turning down the ends of steel bolts. For the steel arm, the pivot holes were lined with brass to avoid steel-on-steel friction. The series of holes in the upper brass arm to the left of the mounting bracket arose from the need to correctly position the arm with respect to the pendulum. The extension of the arm to the left of the pivot while not planned reduces the force exerted by the arm on the top of the spring.

The synchronizer spring and mounting bracket were made by Richard Hatch. The arm to restrict the spring's movement to the left was made by Price Russ. The synchronizer springs supplied with Shortt clocks were made from relatively thick steel thinned over part of its length to achieve the desired flexibility As pointed out by Hope-Jones[22] in, this is not necessary. In this case, the synchronizer spring was made from 0.25" wide 0.015" thick wear-resistant 1095 spring steel. The length from the top of the holder to the bend at the top is approximately 5¼".

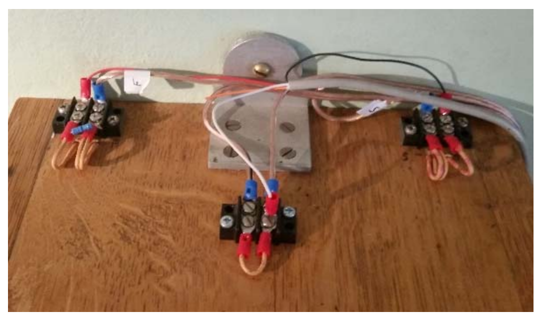
The pendulum rod, rating nut, impulse arm, and suspension spring were donated by The Clockworks (London). The lead-filled bob[23] and weight tray were fabricated by Price Russ.

[21] Miles, *Synchronome*, 172

[22] Hope-Jones, F., *Electric Clocks and How to Make Them*, Argus (1949) 57.

[23] Approximately 14 pounds of lead cast in brass cylinder.


The larger dial came with the case and is advanced by the master reset solenoid. The smaller dial advanced by the slave solenoid was assembled from a typical Synchronome dial movement contributed by Price Russ, a dial plate provided by Dorian Clair (San Francisco), and hands made by Russ. To fit behind the smaller dial a corner of the movement was cut off. The slave dial was mounted in a metal plate bolted to the upper dial. The dials were mounted on a plate that can be swung out to expose the backs of the dials, the slave movement, and the slave pendulum. There is a diode for spark suppression on the back of the slave movement, so the polarity of the connections is important. (Jan Wright argues against using diodes. He says it affects the circuit response times.) Elsewhere resistors have been used for spark suppression as was done originally. Authentic maroon wrapped Synchronome wire was not available, so available wire from roughly the same time period was used.



Terminal blocks for connection to the power supply and master tank were mounted externally on the top. They are marked "F" (master), "S" (slave), and "B" (common) to be consistent with the markings on the tank feedthroughs. F is on the left. S is on the right, and B is in the middle. B is negative. The 22 ohm resistor on the F side connector block is in parallel with the synchronizer and dial to bring the resistance of that part of the circuit closer to that of the solenoid in the tank and reduce the voltage required for the desired current.

DO NOT try to turn the hands in either direction. They are operated by a ratchet system.

Either dial can be set forward in 30 second increments by pressing on the ratchet arm on its movement. Two second forward-adjustments can be made by turning the slave's count wheel. Switches have been provided in the upper left corner of the slave case to bypass the dials. This allows one to stop the dials without disturbing either clock movement until the time catches up to that indicated by the hands. The upper switch controls the master dial. The lower one controls the slave dial. Each by-pass has been provided with a resistor to simulate the resistance of the dial solenoid.

If it is necessary to make large adjustments to the hand positions, swing the dials out, manually disengage the ratchets and turn the large wheel until you get close to the desired position.

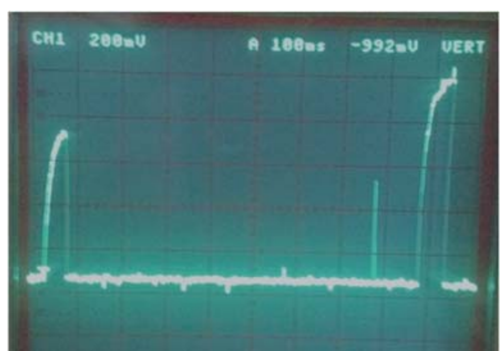
The lower, slave, dial is not quite centered on the hands, so the agreement between the hands on the two dials may seem to be off by 30 seconds on some positions of the hands.

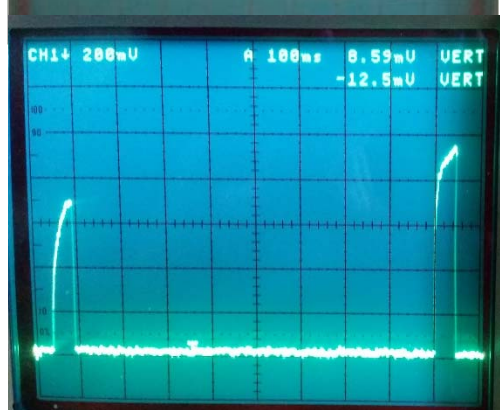
After cleaning the slave and dial movement pivots were lubricated with Mobil 1 (5W-30) synthetic motor oil.

8. Power Supply

An uninterruptable constant-current power-supply and box were provided by Lick. Price Russ mounted the components. He added external voltage test points and a hole to see the charger status light. There are separate circuits for the master and slave. As noted earlier, the nominal operating current is 1/3 amp in each circuit. Based on performance with the clock, the master was set to 410 mA. The slave was set to 360 mA. Because current is delivered in pulses too short to be read by a multimeter, contacts were manually held closed for current readings. It is not clear how readings were made when this type of clock was originally set up. A schematic diagram for the power supply is shown on the next page.

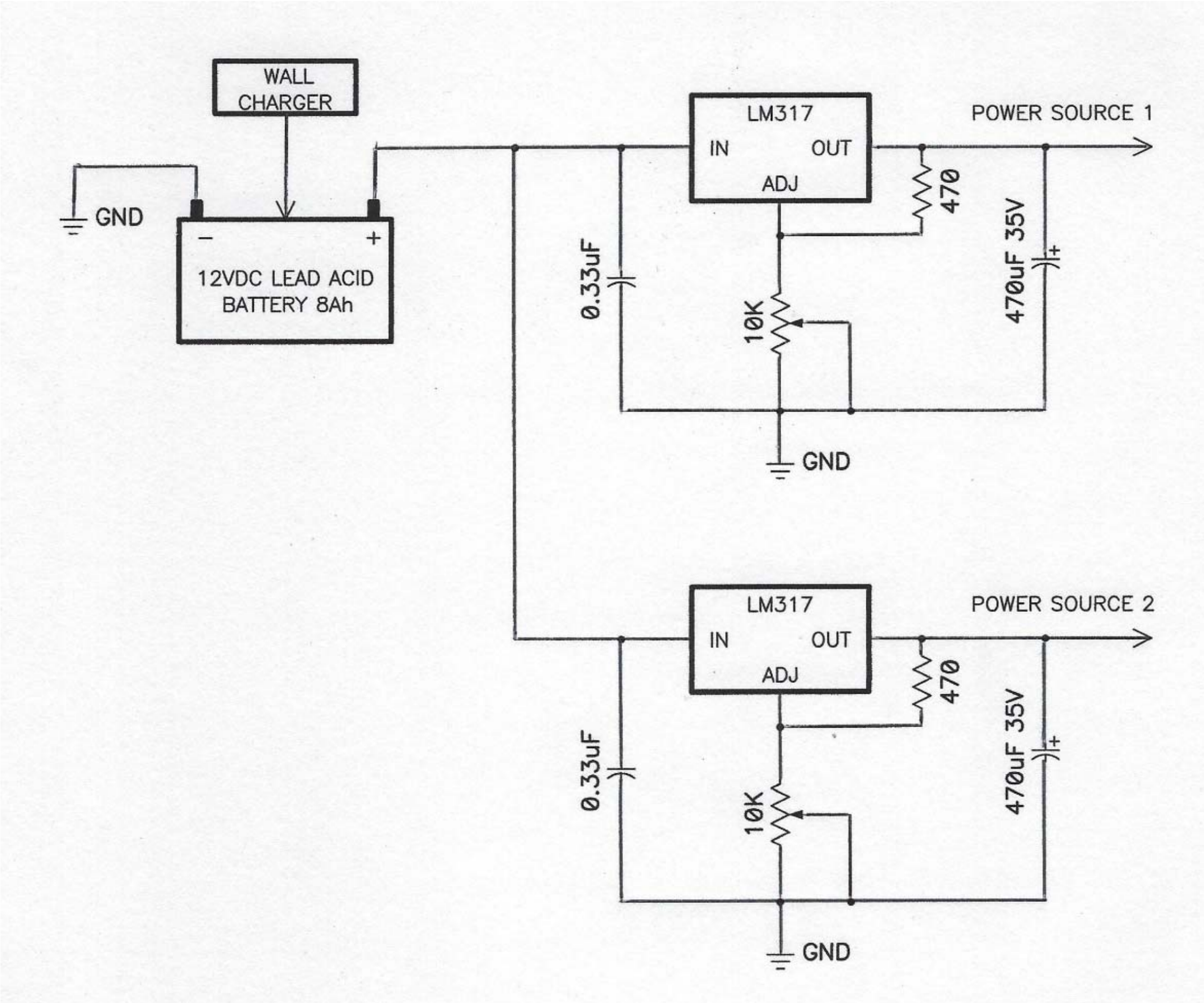
The resistances of the various solenoids are worth noting. The gravity arm reset coil and dial are both 8 ohms. The release coil in the tank is 4 ohms. The synchronizer coil is 9 ohms. The master dial coil is 16 ohms, and the reset coil in the tank is 4 ohms. It was found that the master synchronizer and dial could be operated with less current than the reset coil. To avoid putting more current than necessary through the synchronizer and dial, a 22 ohm resister was put in parallel with them. This resister is located on the terminal block on the top of the slave case.





Well after initial set up, a memory oscilloscope became available to track the current flow under operating conditions. The current was measured from the voltage drop across a 2.2 ohm resistor placed in the common line. In the screen image on the right, the vertical scale is 200 mV per graticule line. The horizontal scale is 100 msec. per graticule line. The first peak (left) is the voltage drop when the slave circuit is active. The large peak on the right is the drop when the master circuit is active. Slow motion video showed that the spike at ~700 msec, was caused by the arm bouncing. A one-eighth turn advancement of the reset-armature rest stop caused the bounce to go away – lower trace. It also lengthened the time between the pulses.

The plots allow one to determine the width of the pulse, their separation, and the current flow. The peak currents are then ~340 mA and ~480 mA for the slave and master, respectively. The durations are ~50 and ~45 msec. The separation between their starts is ~860 msec[24]. For such measurements, it is convenient to have two parallel commons, so the resistor can be introduced or removed without stopping the clock.



[24] A separation of ~800 msec. is nominally expected.

9. General Instructions for the Erection of Shortt-Synchronomes

There are at least two versions of the "Instructions for the Erection of Free Pendulum, Master and Slave Clocks". They appear to be identical except for one being retyped. The version in Section 14.1 came from the NAWCC library. Notes generated by P. Boucheron in Nov. 1987 and files he copied from the Royal Observatory in Oct. 1985 are reproduced in Sections 14.2 and 14.3. A personal communication from Boucheron to Art Bjornestad concerning lubrication is copied included as Section 14.4. These documents provide fundamental information for anyone attempting to set up or operate a Shortt clock. They should be studied before setting up, altering, or disassembling one.

10. Specific Instructions for Erecting and Operating #23

The information/instructions in this section are supplemental to those discussed in Section 9. They are intended to help with both the set up and operation of the clock and to consolidate operating parameters in one place.

10.1. Master

Installation of master pendulum: Correctly position the three electrical leads. (If the tank has been moved these will have been removed or hung upside down in the tank. This is a good way to keep them in the correct order.) If the resister/capacitor arc suppression unit has been removed, install it.

Place a small table or other stable platform below the tank. Put several layers of padding on surface of the platform. Remove the mirror from the beat plate and secure the beat plate into position on the bottom of the pendulum. There is a dimple in the rod that correctly positions the beat plate. Lower the pendulum into the tank. Letting it rest on the padding, have someone keep it upright to avoid side stresses on the beat plate. The safety pin should be aligned parallel to the wall. Install the four-legged casting without the suspension spring and mounting cylinder. The pendulum rod needs to protrude through the safety plate when the casting is put in place. Then holding the pendulum by the weight tray lift it so that the safety pin goes through the slot in the safety plate and turn a quarter turn so that the pin is perpendicular to the wall and the hooks on the top of the rod face you. Let the pendulum rest on the safety plate. Once the safety pin is resting on the plate, remove the platform and padding and install the mirror. If the rest of the components that go into the tank are not going to be fitted at this time, reinstall the bottom glass (see below) and the bell jar to preserve cleanliness and avoid accidents. It is suggested that provision be made to prevent casual removal of the bell jar by idle hands. If the rest of the components are to be installed at this time, leave the padding and platform in place.

Fitting of suspension spring: Because the suspension springs made for this project are slightly short, the pendulum hook can not be raised enough by the safely plate to clear the pin on the bottom of the spring using the factory set up. On the right side of the safety plate, a spacer has been added between the bottom of the plate and the head of the screw that holds it. This allows the safety plate to be raised enough for the hook to clear the pin. The pendulum supported by the safety plate is raised to full height. The suspension spring and cylinder are then put in place with the lower portion of the spring in the slot in the top of the rod. The safety plate can then be CAREFULLY lowered to capture the pin on the spring in the hooks on the end of the rod. Once the spring is in place, lower the safety plate using the thumb screw on the left side just enough to free the pendulum. If may be necessary to loosen the crew on the left side a little bit to free the pendulum. Be sure the pendulum is free before swinging it. You do not want it swinging on the safety pin. That could destroy the spring. In the final position the safety plate should be roughly parallel to the floor and just low enough to clear the safety pin. The mounting cylinder is then centered, squared and secured in its housing using the six adjusting screws. There is a brass rectangular damping-plate that sits on top of the mounting cylinder. This plate has two slots that slide into the top of the assembly holding the mounting cylinder and rests on the top thereof.

The movement can then be hung and connected following the factory instructions. Next position and adjust the impulse arm following the factory instructions. Finally install the bracket holding the thermometer and put the bell jar in place.

Installing bottom glass: At this point the lower glass can be installed. (Actually, it can be installed earlier, but leaving it out allows for easy recovery of anything that should happen to fall into the tank during setup.) Install the three threaded rods into the bottom of the tank. Place the glass into the triangular frame. The triangle is positioned so that the leg with the screw on the side faces the front. (The screw was part of the setup for the microscope that was removed by Jeffers.) lift the triangle and glass into position on the rods and secure with the brass nuts. Before doing this be sure the three pads that lift the glass with the triangle are in place and that the glass raising screws are partially withdrawn so that the triangle can be raised fully before the glass hits the tank bottom. Finally raise the glass into position. When installing the triangular plate, it tends to go into position easily, but care should be taken to lift it evenly so that it doesn’t get “cocked” and bind. This is particularly true if it has to be lowered. The reticle can then be installed and centered under the beat plate.

In this “restoration, vacuum grease was applied to the feedthroughs but not either the bottom glass or the bell jar. No attempt was made to check for vacuum tightness.

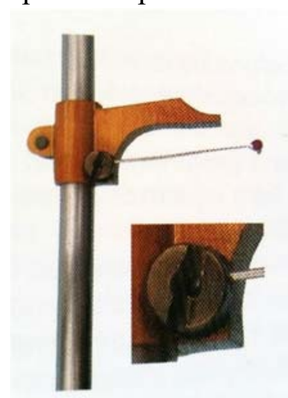
It is recommended that a swiveling mirror be placed on the floor below the pendulum, so its motion can be easily observed.

Starting the master: When starting the master pendulum, it is important to note that the arc is small and that one wants to move the pendulum with minimal force applied below the weight tray. A feather or a wire tie such as found on loaves of bread work nicely. Give the rod a series of light pushes until the impulse wheel travels under the impulse jewel. In operation, the impulse wheel should ride just below the impulse jewel and the left edge of the impulse jewel just be directly above the center of the wheel at the end of the pendulum’s swing to the right. This is the point at which the impulse jewel should drop. Height can be adjusted with the two screws from which the movement is suspended. Point of impulse can be adjusted by moving the pendulum suspension or by the position adjusting screw on the impulse carriage. At equilibrium the arc of the master as measured on the beat plate should be about 16-18 mm to each side.

10.2. Slave

Section 7 covers most of the issues concerning the slave unit including the electrical set up and ways to set the dials.

Case: The case mounts to the wall with two bolts. One is through a bracket on the top of the case. The other through the case behind the pendulum bob. The distance between them is 42¼ inches. During the restoration project, it was mounted on the opposite wall of the workroom. For permanent display the location of the case can be determined by available space and aesthetics. The case can be locked and the key removed. Locking is counter clockwise. The case door is slightly distorted and does not open immediately when the latch is turned. To open, at a spot near the lock push the wood panel on the door to your left while pulling gently on the door. The reverse action may be needed to close it. The dials are mounted on a swingout panel. If the panel is not pushed in fully, the door can block the hands of the master dial. A small block of wood has been added to the door to push the panel in.



Take down and setup: Any time it is necessary to remove the pendulum, two things must be done. First, observe the position of the at rest pendulum, gathering pallet, and impulse arm with respect to the count wheel, and gravity arm and determine the location of the support trunnion with respect to the movement frame, particularly the distance from the back of the frame. Second, the gathering pallet and wire should be removed. The gathering wire is removed by raising to vertical and sliding the wire to the back and out of the impulse arm. To reinstall it, stick the wire fully into the hole in the impulse arm and lower the pallet to your left. It should be captured in the slot at the back of the impulse arm[25]. More precisely the slot is in a press fit bushing on the back of the arm. If it is necessary to adjust how far the pallet drops onto the count wheel teeth, the bushing can be rotated. If properly packed and the gathering pallet removed, the pendulum can be transported as one unit. Care should be taken to protect the synchronizer spring and the pendulum support structure with its suspension spring. The movement can be transported in the case if care is taken to brace the gravity arm. If the movement needs to be removed from the case, remove the top screw first and replace it with a piece of threaded rod. This will help stabilize the movement while the other bolt is removed. The movement can then be slid out being careful not to damage the backstop arm. When reinstalling the pendulum, the step on the trunnion diameter will determine the correct left-right position. There are no physical guides for forward-rear positioning and squaring of the trunnion with respect to the movement. This is why it is important to establish one's own alignment aids.

Starting the slave: The slave pendulum suspension is less delicate than the master's. With the impulse arm in the reset position, one can simply swing the pendulum enough for the gathering pallet to engage the count wheel. When the arm behind the count wheel reaches the impulse arm release, the arm should drop onto the impulse face on the pendulum, push the pendulum, and reset.

[25] Miles, *Synchronome*, 83.

Amplitude of swing: There is some overshoot when the gathering pallet advances the count wheel. If the amplitude of the pendulum's swing is too great, it is possible for the pallet to pull two teeth instead of one. This is avoided by adjusting the amplitude such that the pallet does not travel more than about ¾ of the way along the length of the tooth beyond the one to be pulled. The amplitude is controlled by the impulse given to the pendulum by the gravity arm as it travels down the face of the impulse arm. The amount of travel of the gravity arm before is makes contact with the reset mechanism will determine the amount of impulse. The travel of the gravity arm is determined by the position of the reset arm electrical contact at rest. This can be adjusted by its stop or by the position of the electrical contact on the arm. Should the amplitude be too great, one of these adjustments can be made.

10.3. Rate Adjustment

Both pendulums are equipped with weight trays for regulating the rate. Two sets of weights have been provided. They are in blue cases inside the slave case. To avoid dropping weights, particularly in the master, care should be taken to handle them with quality tweezers. (Avoiding touching the weights also prevents their becoming corroded.)

For the master, the weight tray was factory positioned such that adding one gram increases the rate by one second per day. While using the single piece spring, 14.9 g. gave a roughly correct rate. With the spring described in Section 13, the value was 64.5 g when the clock was in Walnut Creek. The difference probably arises from the two springs flexing at different points along their length. The amplitude in either case was approximately 18 mm in each direction. On initial installation at the observatory, 83 g were needed.

For the slave, the rate change per gram added to the weight tray is also about one second per day.

Before trying to synchronize the two pendulums it is helpful to set them to roughly the desired rates. For a clock, such as this, that keeps sidereal time, one needs to know that a sidereal second is 0.9972696 of a mean solar time second. This is the target rate for the master pendulum. The slave is meant to run six seconds per day slower than the master, so its target rate is 0.997339 mean solar seconds per beat. The slave must run slower than the master but the exact difference can be adjusted later. For this project, a Microset timer was used to measure rates. Other timers probably could be used.

Measuring the rate of the master without the slave in operation requires a motion sensor and timer. In most clocks a motion sensor can be placed near the end of the pendulum rod and sense each time the rod interrupts the sensor beam. Shortt clocks have beat plates on the end of the rod and nothing extending below it. This precludes the use of the standard Microset optical sensor, which requires the item being sensed to move between a light source and detector that are in a fixed arrangement. If the optional laser sensor is available the laser beam can be bounced off the mirror and the beam swept past the conveniently placed detector as shown on the right. Because of the multiple reflections off the bottom glass and parts of the pendulum, obtaining good readings can be challenging. An alternative approach would be to remove the bottom glass and attach a wire to the bottom of the pendulum and let it protrude beyond the beat plate for some arbitrary distance. The standard optical sensor could then be used to measure the rate. This should be adequate for initial set up. Finer adjustments to the rate could be made later based on longer-term performance.

The initial rate of the slave can be set using the Microset and the standard optical sensor. Once the approximate rates have been set the pendulums can be put in motion and synchronized. They should bring themselves into synchronization, but the process can be speeded up by manually advancing or retarding the slave.

Local sidereal time can be obtained from a variety of internet sites. Cell phones are handy for this. For Android operating systems, *MySiderealTime* was found to work well and not use up a lot of resources. It gives local sidereal time, local mean time, GMT, latitude and longitude. Setting the dials was discussed in Section 7.

Ideally the synchronizer will hit every other 30-second interval. In reality this is difficult to achieve under the best of circumstances. It is however possible to achieve an average of equal hits and misses. This will be discussed in more detail in Section 11. Once the master pendulum is operating at an acceptable rate, then the slave can be adjusted to average out the hits and misses.

10.4. Synchronization of Pendulums:

When the slave impulse arm drops and activates its reset circuit, it advances the slave dial and activates a solenoid in the master that drops its impulse arm. When the master impulse arm drops it activates another solenoid that rests it and advances the master dial and activates the hit-and-miss synchronizer. When the two pendulums are synchronized, the master impulse jewel will fall on the top of the master impulse wheel which will be at the end of its travel to the right. The synchronizer blade will either fall on top of the spring attached to the slave pendulum or catch the spring and push it backwards. When the two pendulums are started, this almost certainly won't be the case. Given enough time, the pendulums should bring themselves into synchronization. If the synchronizer blade is pulled down when the spring is far from making contact with it, the slave pendulum can be manually retarded or advanced a small amount (fraction of a second) to help synchronize the two pendulums. If the synchronizer blade falls on the top of the spring, that is close enough. Likewise if it "hits"; i.e., catches the spring.

10.5. Routine Operation:

As noted in Section 8, the power supply is equipped with battery backup in case of interruption of the mains supply. The total operating time under battery power has not been tested. In that a normal Synchronome will operate for about two years on 4 D cell batteries in series, the battery should power the clock for a considerable period. From time-to-time the indicator light should be checked to see that it is green. A protocol should be established for battery replacement.

The time indication should be checked against correct sidereal time and the dials adjusted as appropriate. As the indicated time drifts from correct, the weights on the master can be adjusted to correct the rate. It should not be necessary to change the weights on the slave unless the hit miss cycle is far from one to one. Having a Microset or similar timer available would be helpful for making adjustments.

No other routine maintenance should be necessary for several years. The things most likely to interfere with operation are earthquakes, electrical contact failures, or aging of the oil on the pivots and count wheel of the slave. If the clock stops because of an earthquake and there is no obvious damage, the clock can simply be restarted. Other failures should occur only after multiple years of operation. Should the clock become unreliable outside help may be called for.

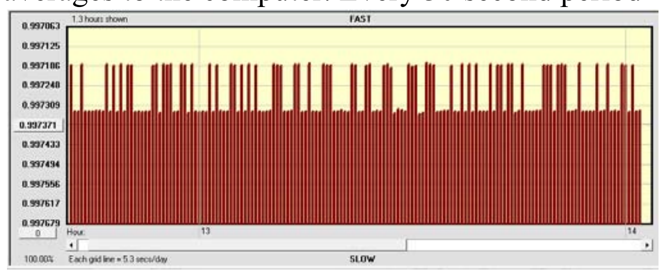
If personnel are available to make periodic, perhaps weekly, comparisons with correct time, it would be interesting to keep a log or plot of fluctuations over an extended time period. Such data would be of interest for publication in the *Watch and Clock Bulletin* or a similar horological publication.

11. Performance Testing

The simplest way to test the performance of the clock over an extended time is to compare its readings to those of a sidereal time cell phone app. The sensitivity of these apps is typically 1 second. This is adequate for a museum display. The ratio of synchronizer hits to misses can be determined by watching the slave for a period of minutes.

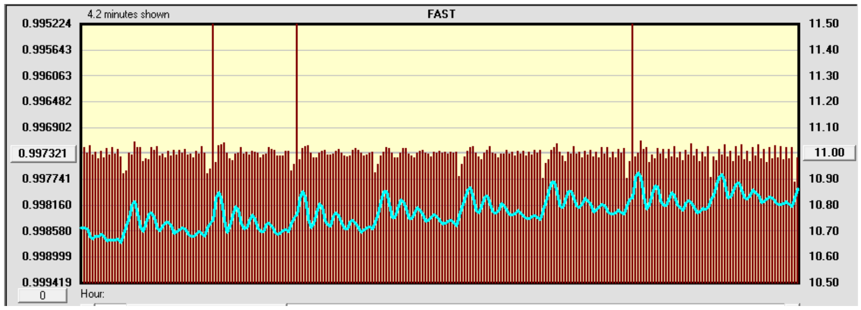
A much better understanding of the clock's operation and more accurate adjustment can be achieved with a timer such as the Microset with the standard optical sensor shown in Section 10.3. With the timer, its software, and a computer, it is easy to adjust the rate and the hit to miss ratio.

The most straightforward measurement is to set the timer to average the time per pendulum swing in 30 second intervals and output those averages to the computer. Every 30 second period will include one activation of the synchronizer. If it is a hit, the average rate for that interval will be slightly faster than if it was a miss. As shown in the Microset screen capture to the right, the data can be plotted as bars where their heights are the rates. The distribution of fast and slow bars provides a visual indication of the hit to miss ratio. The average of all the readings is the rate of the master pendulum. The rate of the misses is the unsynchronized rate of the slave. The Microset also has the capability of recording and displaying amplitude, temperature, barometric pressure, and humidity measurements. Such data can be useful when trying to analyze for rate changes. The averaging functions included in the software are also useful. For further analysis, the data files can be imported into Excel.



The weight on the slave's tray will control the unsynchronized rate of the slave and on average how often the synchronizer will hit. As illustrated by the screen capture above, the hit and miss cycle can show considerable variation. In the test environment on a wood stud wall, this variation is at least in part due to vibrations. The target rate for the slave is six seconds per day slow. To regulate the rate, it is helpful to know the effect weights on the tray have on the slave rate. The change in rate for a given added weight depends on the position of the weight tray along the rod. The slave's dependence was determined to be 1.3 seconds per day per gram for the current position of the tray.

The clock will operate within a considerable range of unsynchronized slave rates and a range of hit to miss ratios. Although in practice the hits and misses may not occur in a highly reproducible pattern, the average can be obtained quickly by comparing the number of hits to the number of misses. If there are significantly more hits than misses, the slave pendulum's rate is too slow. By chance when tested in Walnut Creek the synchronizer spring was found to have the proper strength (length) for the hit to miss ratio to be very close to unity for the target loss rate of six seconds per day with no weight on the tray. It would be preferable to need a little weight to allow for adjustments. As initially installed at the observatory 24 grams were needed on the weight tray to achieve the desired slave pendulum rate.



More detailed information about the behavior of the system can be obtained by recording the period of every swing of the slave pendulum; i. e., every second. The plot to the right for 4.2 minutes of time shows the rate of each swing, red bars and the "relative amplitude" of the swings, teal line. Relative amplitude is calculated from the length of time it takes the pendulum to pass through the sensor. The larger the amplitude the less time the pendulum spends blocking the light beam.

Every 30 seconds (bars) the rate drops as the gathering pallet and count wheel releases the gravity arm. It the synchronizer hits, the rate shows a one-swing large rate increase. The rate for the single release swing is about 33 seconds per day slow. The rate during synchronization swing (off scale) is about 353 seconds per day fast. The rate drops back to "normal" within one swing. From the cycles where the synchronizer misses one can see that the rate is not affected by the dropping of the gravity arm but the amplitude increases and then gradually decreases until the next impulse. The cause of the ringing in the amplitude is not clear. It may have to do with vibrations in the rod caused by the impact of the gravity roller on the arm. For this set of data, the amplitude is rising throughout. This indicates that the pendulum has been disturbed and not reestablished its steady state.

12. Installation at the Lick Observatory

After a long delay largely due to the COVID-19 pandemic, the clock was returned to the observatory on February 14, 2023. Over the next four days, it was mounted in the long hall of the main building. Specifically, it was positioned near the north end of the hall outside what was originally the clock room in the location that once housed the electrical switchboard which connected the various clocks, chronographs, and so forth. (The Shortt clock was never located in the clock room.)

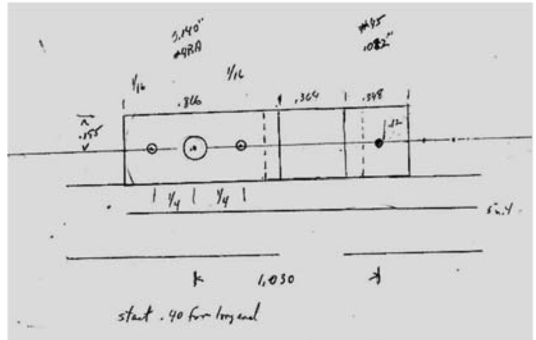
On February 17, 2023 the clock with the pendulum periods approximately set was put into operation.

As of February 20, 2023, the following tasks still need to be addressed. This assumes the clock is running

- Purchase a swivel mirror for observing master pendulum
- Complete display
- Assign responsibility for maintenance and provide basic training
- Set maintenance schedule
- Establish storage place for spares
- Establish storage place for key to slave case
- Create operational log
  - Weights on trays
  - Rate of master
  - Rate of unsynchronized slave

13. Fabrication of Suspension Springs

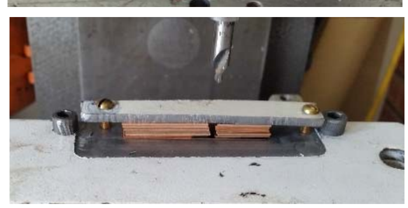
This section is to document in detail the steps and techniques used by Price Russ to fabricate suspension springs for the master pendulum. His working diagram is shown on the right. Making several simultaneously did not require much more effort than one and meant they would be as nearly identical as possible. If successful, spares would be available. If errors occurred during machining, one or more could be sacrificed. A batch size of four was picked as not too large to handle during machining.



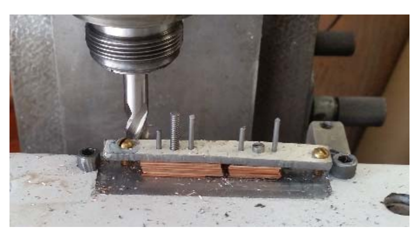
As discussed in Section 6, phosphor-bronze was the material of choice. The specific material used was 510 spring tempered (ASTM-B-103, ASM-4510) in 0.005" and 0.025" thicknesses. The thinner material was for the flexible portion. The thicker was for the "chops". Richard Hatch sheared enough 0.5" wide pieces of each thickness to make a dozen springs. The thinner strips were sheared into 2" lengths. The thicker ones were cut into two lengths – 0.75" and 1".

Three dimensions are of particular significance. One is the diameter of the hole for the pendulum support pin. The second is the diameter of the hole used to secure the spring in the upper mounting cylinder. The third is the distance between the holes. The third dimension is important not only because it affects the stiffness of the spring but also it is important for mounting the pendulum. As noted elsewhere, in the as built springs this dimension turned out about 0.02" short which complicated hanging the pendulum.

A sacrificial steel plate was bolted to the bed of a mill and an area machined flat. A second "top" strip of steel about 4" long was bolted the flat area. The only requirement for the top strip was that it be longer than the spring stock and that the bolt holes be parallel to the mill table's "X" axis and near the middle of the strip in terms of "Y". The Y setting was then locked.



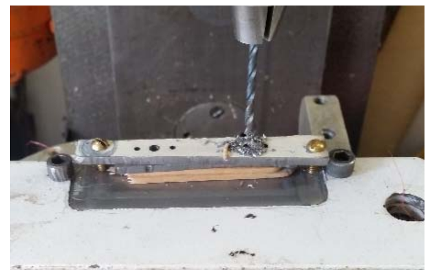
Enough material for 4 springs, positioned roughly as they would be in the final springs, was sandwiched between the two pieces of steel. The longer pieces of the 0.025" stock were placed to the left. The shorter ones went on the right, and the thin stock, not visible in the photograph, went across both. Keeping the Y fixed, a series of holes was then drilled through the sandwich.



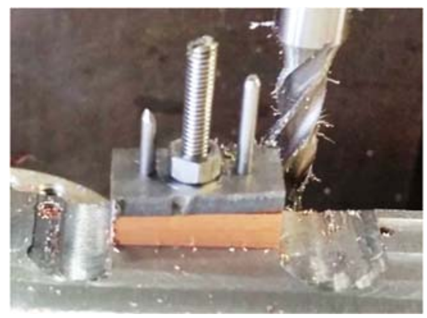
From left to right, the first, third, and sixth holes (1/16" dia.) were for alignment pins. The second (#28) was for the 4BA rod used to hold the spring mounting cylinders together. The fourth hole had two functions – alignment and for the pendulum mounting pin. For these springs, #45 drill rod (0.082") was used for the pendulum support. For convenience at this phase, holes

1, 3, 4, and 6 were made the same diameter and the four pins were cut from an appropriate diameter length of wire. The fifth hole was to anchor the lower chop pieces when they are machined. Its diameter and exact placement are not important as long as it was beyond the end of the final spring.

A side cutter was installed in the mill and the head was positioned such that the edge of the sandwich could be trimmed to 0.195" from the line of holes. The top plate was removed, the spring pieces turned over, and the second edge milled to 0.195" from the center. Maintaining their relative positioning, the spring pieces were removed from the sandwich and holes 2 and 5 tapped. Another length of steel was placed in the sandwich and drilled using the holes in the top plate as a guide. This piece served to clamp the chops for later steps. This piece would not be necessary if one was willing to sacrifice the top bar of the sandwich. With better planning, it could also have been made in the previous step. After drilling this piece was cut in two between holes 3 and 4.

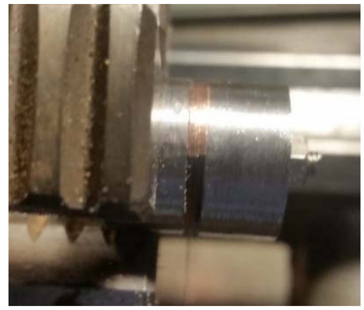


The pieces destined to be the chops for the upper end of the springs (left in discussion above) were returned to the base plate, the appropriate end of the newly cut steel piece was placed on top and the assembly bolted together. The left end was squared off 10 mm from the center of the 4BA hole. The right end was cut to give and overall length of 0.866". The stack of chops was then separated.

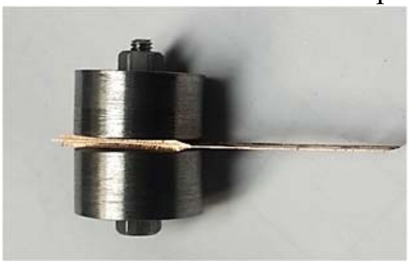


One at a time, the chops were clamped back in the previous orientation. A 0.25" radius ball mill was then used to taper the edge of each chop. After cutting the first piece the X and Z positioning were fixed so that all the tapers would be the same. Note that the pin in hole #3 had to be removed for the taper cuts.

For the lower chops (those on the right), the right ends were to be cut off at a later stage so there was no need to cut the right ends to the same length. With the pieces aligned and sandwiched, the left ends were cut to 0.187" from the center of pin 4, the pendulum mounting point. It can be seen in the photograph to the right that the hole for the pin is close to the edge of the tapered portion.

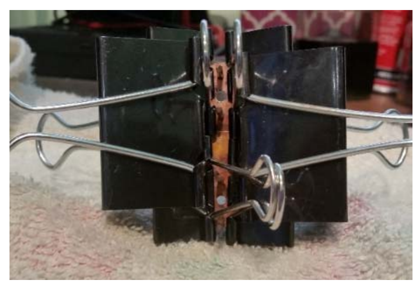


The top end of the upper chops and the spring material needed to be rounded to the radius of the spring mounting cylinder. For this a



cylinder was turned to 20 mm diameter, center drilled for 4BA, split into two parts, and faced. A channel to accommodate the alignment pins was cut into one of the cylinders. Upper chops were placed on each side of the flexible pieces. These assemblies including alignment pins were one at a time secured between the cylinders and bolted together. One side of the cylinder was held in a lathe chuck. The back gears of the lathe were used to prevent the spindle from rotating while the tops of the bronze parts were filed to the diameter of the steel cylinder.

A pair of lower chops was positioned on each spring/upper chop assembly and held together lengthwise with a spring clamp along one edge. The exposed part was then coated with Tix Anti-Flux. After the anti-flux dried, the coated side was clamped and the original clamp removed. This allowed the rest of the assembly to be coated with the anti-flux. The assemblies were individually dissembled, and the inner, uncoated, side of each chop was tinned in preparation for soldering with Alpha Fry 2% silver 98% tin solder. Each chop was heated on a hot-plate. The flux that came with the solder was spread over the surface with a small brush, and then about 1½ mm of solder was placed on the surface. The chop was held in place with an ice pick while a thin layer of solder was spread over the surface with a knife blade.



Each spring unit was reassembled and aligned. Four small spring clamps, two on each side of each pair of chops were used to hold the assemblies together. For added compression, a large spring clamp was added on each side. These large clamps were positioned outside the smaller clamps pressing on them.

The clamped spring assemblies were one at a time placed in a toaster oven at 450° F. After about 10 minutes, they were removed and allowed to cool. Once cool the clamps and alignment pins were removed. The excess anti-flux was wiped off with alcohol. Scale was removed with a fiberglass brush followed by Flitz polish. No attempt was made to achieve a high polish.

The lower ends were then cut off. The first one cut (right in the photograph) was improperly positioned and cut shorter than intended. It was, however, kept and could be used. Number 45 drill-rod pins were press fit into the lower end of the other three.

Careful examination of the spring shown above resting on a towel shows the upper chop protruding slightly beyond the edge of the flexible portion. The edges were smoothed with a flat diamond file. (This suggests the edges of the chops may not be perfectly parallel.) The springs were then boiled in tap water to remove any residual flux. After drying they were polished again with Flitz polish, and boiled a second time in fresh water. (East Bay Municipal Utility District has a very low salt content, so it was not considered necessary to use distilled water.) The springs were then coated with Renaissance Wax. One was selected for use and clamped between the mounting cylinders.

14. Factory Drawings and Personal Communications

14.1. Factory Instructions for Erection

INSTRUCTIONS FOR THE ERECTION OF
FREE PENDULUM, MASTER AND SLAVE CLOCKS

Introduction. These clocks are operated from a common battery and arranged so that the half-minute impulses of the Master firmly hold the Slave in absolute synchronisation with the Master. The half-minute impulses of the Slave release the impulse mechanism of the Master and so relieve it of all work.

In order that the energy required to be supplied to the Master Pendulum to keep it moving may be as small as possible, the air pressure in the case is reduced to about 2 c.m.

The Master Clock, or Free Pendulum, is accordingly mounted in a cylindrical copper case closed at the top by a glass jar and at the bottom by a plate glass disc.

The ends of the cylinder are terminated by flanging the copper tube to form wide flat surfaces which enable grease joints to be made with the glasses. Each gunmetal ring is provided with a pair of lugs, or feet, which enable the case to be firmly bolted on the wall of the clock chamber or room.

For the best results, the Free Pendulum should be bolted to solid rock. In practice, it is rigidly fixed to a foundation wall in a clock chamber in a cellar.

Although every care is taken to make the temperature compensation as perfect as possible, it is undoubtedly desirable, if the very highest order of timekeeping is required, that the temperature of the clock chamber should be kept constant by means of an electric heater controlled by a thermostat. It is also desirable to instal a fan to operate when the heater is cut-out, in order to prevent stratification of the air.

If the Master Clock is mounted in a small cell, it is only necessary to control the temperature of this cell. A chamber of the following dimensions is sufficient:-

4 ft. x 4 ft. x 8 ft. high

As the Slave Clock is controlled by the Master, there is no need to mount the former in the constant temperature cell: in fact, it is better to keep it outside, and it may be erected wherever its dial can be most conveniently seen.

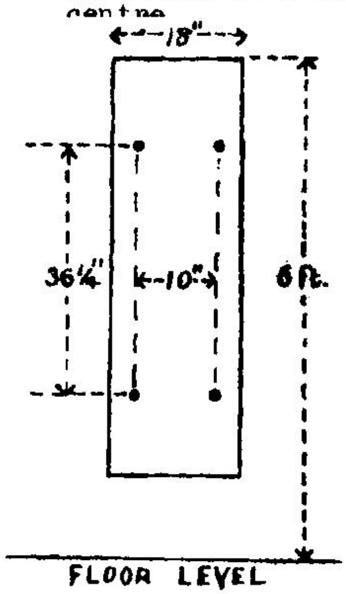
The Erection of the Master Clock Case.
The clock case should be fixed on the wall of the clock room or chamber by four half-inch diameter steel bolts.

It is desirable to have a section of the wall 18 inches wide floated with cement from 12 inches up to 6 ft. above floor level, in order to ensure that it is quite flat and vertical.

The four half-inch steel bolts should be set into the wall and grouted up so as to project 2 inches from the face of the rendering, and they should be threaded half-inch Whitworth to within 1 inch of the wall.

The two bottom bolts should be set 10 inches apart centre to centre and 20 inches above floor level.

The two top bolts must be set vertically above the bottom bolts and at a distance of 36¼" from them, measuring from centre to centre.



The marginal sketch indicates the positions, also the cement rendering required.

The clock may be mounted at a greater height if desired, but this will put the movement more than 5 ft. above the floor.

When unpacking the cylindrical copper case, great care must be taken not to damage the surfaced ends.

It must be mounted so that the ring with the three projecting terminals is at the top. Proceed to fit up the case fittings as follows:-

Unpack the valve, remove the nut, steel washer and thick copper washer from the thread on the valve, leaving the thin copper washer on. See that the valve thread and seating, also the washers, are clean and free from dust. Put some of the special grease round the thread of the valve and the thin copper washer and insert thread into the hole provided for it on the left hand side of the bottom ring of the Free Pendulum case; having greased the remaining copper washer, place it in position on the projecting thread inside the case. Now place on the steel washer and nut and tighten up with the nozzle pointing downwards.

Unpack the glass base plate and bell jar, also the triangular frame and fixing screws necessary to hold it in place.

It will be found convenient to make the joint between the glass disc and the bottom of the case before fixing the case to the wall; for this purpose, the case should be inverted (a soft pad being placed on the ground to protect the surfaced end) and the bottom surfaced end carefully cleaned and rubbed over with a uniform layer of the special jointing grease, a tin of which is supplied.

The plate glass disc, after being cleaned, should then be carefully placed in position and gently squeezed, with a slight rotary motion, into contact with the copper flange, seeing that glass is correctly centred, and the joint free of air bubbles.

A fillet of grease should finally be formed round the glass disc where it joins the copper flange by rubbing the junction round with the special grease with the aid of the finger.

If the triangle casting is fitted with a mirror, bowline, etc., these should now be assembled as shown on Drawing 24124. When a microscope is supplied, this is already in position on the triangle as shown on Drawing 18138.

Place the triangle in position over the glass, fix it in position with the three fixing screws, after which the three padded screws in the corners of the triangle may be gently turned until they press firmly upon the glass and prevent any possibility of it moving.

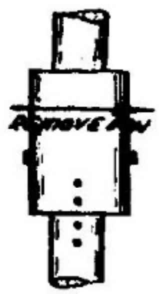
The cylinder is now ready to be bolted to the wall. This should be done as follows:-

Remove the nuts from the bolts built into the wall, lift the cylinder into position, sliding the feet of the two end castings over the bolts. Place a flat washer on each of the two top bolts and spring washers on the two bottom bolts. Replace the nuts and tighten up the two top ones. If the wall is not absolutely flat, there will be a space between one of the bottom lugs and the wall.

Erection of Master Movement and Pendulum.

The erection of the movement and pendulum can now be proceeded with.

The first thing required is the pendulum. The pendulum rod has a hook formed at its top end and when mounted up this hook will face the front, a little lower down is a cross pin called the safety pin, used in conjunction with the safety plate on the head-casting (see Drawing No.14124). Near the bottom will be seen the brass compensating collar; remove the steel pin holding the compensator and slide it off the rod.



Insert the end of the pendulum rod through the small hole in the top of the bob.

After making sure that the seating, at the point where the large hole joins it which will rest on the top of the compensator, is quite clean, slide on the compensator and replace the steel pin, seeing that the compensator is not reversed; the double dot (:) on it and the rod indicate the correct way.

Then put the beat plate on at the bottom of the rod making sure that it is parallel to the plane of swing.

Then slide the ring magnet on to the rod and temporarily fix it by tightening it's screw at about two inches from the bottom of the pendulum rod.

Next put the beat plate on to the bottom of the rod as far as it will go. The beat plate should then be pinned to the rod by first lining up the dot on the collar of the beat plate holder with a corresponding dot on the front of the rod, and then inserting the pin, from the right, through the hole provided for it.

Adjusting screws A.A., Drawing No.10720, are fitted to the beat plate holder to enable the scale to be swivelled round, one way or the other, should the scale not be travelling straight when the pendulum is suspended and in motion. This adjustment cannot be made until the pendulum is fitted in position, set in motion and observed through the microscope.

It will be necessary for the plate glass circle to be removed whilst this operation is being tested and dealt with.

Having fitted the beat scale, lower the magnet on to it until it is resting on it and fasten the ring magnet by means of the screw in the collar; this screw should be facing the front.

NOTE. Great care must be taken not to touch or rub the stainless steel scale as the diamond engraving is very finely cut and may easily be damaged and affect its reflecting properties adversely.

The pendulum may now be lifted and carefully placed in the cylindrical case, the beat plate resting on the plate glass bottom.

Erection of Head Casting and other Fittings at top of case.

The three specially bent connecting wires should be connected to the inner ends of the three terminals passing through the top ring casting of the case.

Slacken the hexagonal nuts and hook the appropriately labelled ends of the wires into the corresponding terminals, behind the washers and re-tighten the nuts, taking care that the rising portions of the wires are vertical.

Now screw the small shaped brass bracket to the right hand side of the top ring where a hole is provided, with the countersunk headed screw, the upwards pointing arm being towards the pendulum. Fit the spark condenser at the back of the top ring.

Unpack the four-legged casting, clean it and place it in position on the top ring of the case, so that the two legs which carry the projections are on the right hand side. The Print No. 14124 will be helpful.

It will be found that the pendulum rod is just too long to enable the top of it to be inserted in the elongated hole in the safety plate attached to the underside of the body of the head casting; therefore lift the casting carefully to a sufficient height to enable this to be done and then lower it again into position, rotating the pendulum so as to get the safety pin through the slot in the safety plate.

The head casting may now be screwed down with the aid of the four cheese headed brass screws to the top ring of the case, the four holes in the finished surface for the reception of these screws will have already been noticed.

Finally adjust the milled screw holding the left hand end of the safety plate until this plate is level, place the fingers underneath the weight tray and lift the pendulum until the safety pin is just clear of the safety plate, rotate the pendulum rod through about 90° so as to bring the safety pin squarely across the elongated hole in the plate and then lower gently until the safety pin rests on the safety plate and the latter takes the whole weight of the pendulum.

Pendulum Suspension.

The next thing to be done is to carefully unpack the pendulum suspension from its small box. The greatest care must be taken in unpacking this piece of apparatus to ensure that the special spring is not damaged in any way.

The cross pin attached to the lower end of the suspension is provided to take hooks at the top of the pendulum rod and before placing the suspension in position, care should be taken to see that the hooks on the pendulum are facing the front and the rod is central in the round hole.

When the position of the pendulum has been satisfactorily adjusted, the suspension may be carefully lowered into position between the six adjusting screws, which must be withdrawn sufficiently to allow the cylindrical portions to set down on the top of the steel blocks.

The cross pin should pass in front of the hooks on the pendulum and if these hooks are not high enough to enable the cross pin afterwards to pass under it into its proper position, the milled screw supporting the left hand side of the safety plate should be turned and the plate and pendulum raised until the suspension cross pin will pass under the hooks.

When this has been done, the safety plate may be gently lowered until the suspension cross pin takes the whole weight of the pendulum and it swings freely.

It is again necessary to emphasise that every care must be taken to prevent tortional vibration of the pendulum and the buckling of the spring.

The safety plate should not be lowered clear of the safety pin more than is sufficient to ensure that there is no possible danger of their touching one another.

Assembling and Erection of Movement.

The movement itself may now be carefully unpacked from the box containing it. In order to ensure that it should not be damaged in any way during transit, the heavy re-setting lever, marked X on the accompanying Drawing No. 181229 of the movement, has been removed and also the light impulse lever marked Y.

Before replacing these levers in the movement, it should be tried in position on the right hand side of the head casting, so as to make sure that it can be readily inserted and removed subsequently, also that the connecting wires come in their right position etc.

This having been done, the insertion of the heavy re-setting lever may be proceeded with. For this purpose, remove the screws indicated by the letters A.B.C. and D. on Drawing No. 181229 and lift off the inverted 'T' shaped front plate of the movement. See that the pivots of the heavy lever are quite clean and carefully insert the proper pivot into the jewelled hole in the back plate of the movement and, whilst holding the lever in its proper position carefully place the jewelled hole in the front 'T' shaped plate of the movement over the other pivot of the heavy lever and replace the fixing screws A.B. and C. The utmost care must be taken in this operation that the jewels in the holes are not in any way damaged or strained by the pivots.

The screw D may now be replaced through the centre of the continuity hairspring and the electrical connection from terminal B to the contact screws at the end of the contact arm of the heavy lever completed.

It will be noticed that there are two cylindrical weights in the box with the impulse lever, the heavier one is for use in normal air pressure and the smaller weight for the reduced air pressure. Fit the heavier weight on the impulse lever exactly midway between the impulse corner of the jewel and the pivot.

When this has been done the insertion of the impulse lever may be dealt with on similar lines. Remove the cock piece by taking out the screw E, place the impulse lever into position with its lower pivot in its pivot hole, then replace the cock piece and screw, being careful to gently guide the top pivot into its bearing hole, great care must be taken not to damage the pivots or the jewels.

The movement may now be placed in its proper position on the head casting and the connecting wires fixed to terminals on the movement. The flex from the movement to be connected to the spark condenser.

Fitting of Impulse Wheel Carriage.

The next stage in the erection of the Master clock may now be completed by unpacking the impulse wheel carriage. This carriage carries the small impulse wheel at its lower end and only requires to be hung in position on the pendulum. The two pointed steel screws go into the two holes already mentioned in the brass block fixed to the pendulum just below the safety plate.

When hung in position, the impulse wheel should only just clear the underside of the 'D' shaped impulse jewel and unless the adjustments of the various parts have altered in transit, this should be found to be the case when the pendulum suspension has been placed with the aid of the six adjusting screws so that the pendulum hangs in the centre of the case.

The plane of the impulse wheel when the pendulum is swinging to and fro should pass through the centre of the 'D' shaped portion of the impulse jewel.

The position of this jewel relative to the position of the impulse wheel when the pendulum is at rest is defined on the accompanying enlarged print No.2423D of the impulse wheel and lever. From this print it will be seen that the left-hand edge of the impulse jewel should be exactly 1¾ millimetres on the right-hand side of a vertical line passing through the pivot of the impulse wheel.

The necessary adjustment to effect this may be made in two ways: one by shifting the pendulum bodily to the right or left by means of the two adjusting screws at the top of the head casting, or by adjusting the milled screw at the bottom right-hand corner of the movement plate, which rests against the small bracket attached to the top of the case.

Measurement of Arc.

It only remains to adjust the bowline at the outside of the bottom of the case to enable the arc of vibration to be measured from time to time.

The bowline should be carefully adjusted to coincide with the zero of the beat plate scale, but this, of course, must be done after the pendulum has been finally adjusted for position.

The normal total arc of vibration should be 110 minutes approx. The minimum arc on which the clock will work is 60 minutes, which is represented by a movement of the beat plate of 20 mm: or from 1cm. to 1cm. on the beat plate scale which is divided into millimetres.

If a microscope is provided with your Free Pendulum, the reference to the working arc above mentioned does not apply, and a memorandum will be found attached, illustrating the scale on the special beat plate and the method of reading it.

The Free Pendulum may now be left for the moment, with the bell jar placed in position to protect the movement from dust or damage.

Erection of Slave Clock & Wiring of Circuit.

The slave clock should be unpacked and erected and the electrical wiring and battery arranged.

As already explained, the position of the slave clock does not require the same care in selection as that of the Master, but a good wall and sound fixing are essential.

The accompanying print shows the electrical wiring required and as the terminals of both the slave and Master are lettered S.B.F. respectively, there should be no difficulty in correctly starting them up.

As the Master movement has not yet been set going, connect together temporarily the two terminals on the Master's case marked S and B so that the slave may be started going, without the Free Pendulum.

INSTRUCTIONS FOR THE ERECTION OF THE SLAVE CLOCK.

Unpack the clock and its parts contained in the small boxes, the case keys will be found in one of the boxes, open the case and remove the tissue paper, unpack the pendulum rod and bob.

It is necessary to fix the clock on a substantial wall free from vibration if the best results in timekeeping are to be obtained.

The clock should be erected so that the top of the case is about 6 ft. above the floor level, this will bring the clock movement to a convenient height for fitting up now and attention in the future.

A hanging plate will be noticed on the back of the clock case. Plug the wall and fix screw in plug so that the clock may be hung by its hanging plate on the wall at the recommended height.

A set of wood screws will be found in one of the small boxes, one screw 1½" long to hang the clock on and four 2½" screws for fixing the clock firmly to the wall.

As the clock is hanging on its one screw, open the door and hang a plumb line from the top of the case and down the left hand side of the clock, bring the clock to an upright position and mark off wall through the 4 - ¼" diameter holes in the back board of the case. Remove the clock and plug the wall in the four marked off positions.

Replace clock and screw back through the 4 holes firmly to the wall using the $2\frac{1}{2}$" screws for this purpose.

Ascertain with the plumb line that the clock is not leaning out or inwards i.e. that the face of the wall is upright. If the clock is not upright in this respect, the fixing screws should be slackened off and hard wood packing of the right thickness placed behind the top or bottom batten to make it so, and the screws tightened up again.

Having got the clock firmly fixed to the wall, remove the wire ties from the seconds switch lever and the half minute gravity lever.

Proceed now to complete the assembly of the pendulum. Drawing No.20638 should be referred to.

Fit the top chops in which is fitted the suspension spring and cross bar or trunnion, remove screw from the suspension spring chop at the top end of the pendulum rod and insert spring into the slot until the holes in the spring and chop line up taking care to see that the clamping screws in both chops will be the same way round. Replace screw in the pendulum chop and tighten up until the spring is gripped firmly but not dead tight.

The bob should now be fitted having the rounded brass collar at the top and the flat shouldered collar let in at the bottom. Screw the rating nut on until the top of the rounded collar at the top of the bob is level with the line marked on the pendulum rod.

If the clock has a magnetic corrector fit the ring magnet on the plain part of the rod below the rating thread having the grub screw at the front, fit the beat ring at the bottom of the rod so that the black beat line is at the front - Drawing No. 20638 shows this.

Fit the jewelled click B into the special slotted screw at the back of the pallet so that the arm of the click comes to rest at the bottom of the circular slot.

Hang the pendulum in position and check for the right to left position whilst the pendulum is hanging stationary. Sketch 5 on Drawing No. 20638 shows the correct position with the gravity lever off its catch and the roller R resting on the pallet J.

If the clock is mounted upright the pendulum should be correct for position. If a slight adjustment is required use the trunnion traverse screws. (See Drawing No.9542).

When the pendulum is settled for position check the adjustments of the toggle, pallet and synchronising spring and re-adjust if necessary.

First adjust the seconds switch toggle for correct height on the rod which should be so that the rocking toggle piece just lifts the steel catch lever supporting the heavy switch lever just sufficient to release it, plus $\frac{1}{4}$ millimetre to spare as the pendulum is swinging from left to right and vice-versa.

Now adjust pallet J for position relative to roller 12 on gravity lever G. The top corner of the impulse curve of the pallet should swing under roller R with 1/100 inch clearance when gravity lever G is supported on its catch K. The pallet should also be adjusted so that its length is parallel to the plane of swing or to the back of the clock.

The jewelled click B should now be in the correct position for gathering one tooth only of the fifteen toothed wheel for each complete swing of the pendulum however large the arc. The clock was sent out with this adjustment correct but should it need further adjustment the click wire may be slightly bent.

Next come the synchroniser fittings. Adjust the wire support ring so that the spring support wire is ½" below the lip of the synchroniser blade and adjust the synchroniser block holding the spring so that the top hook end of the spring is free to pass under the tip of the synchroniser blade with 1/100 inch to spare, see also that the spring is resting against its support wire and that the block and support wire are in a parallel plane to the swing of the pendulum. The position of the synchroniser fittings are shown on Drawing No. 191229.

Finally see that the weight tray is about ⅜" below the synchroniser block.

Magnetic Corrector. (See memorandum attached)

The battery may now be wired up to the clocks as shown on Drawing No.   , but as stated before, terminals S and B on the Free Pendulum should be temporarily connected together so that the slave may be started going.   volts is sufficient for all purposes.

Start the pendulum on a small arc, just large enough to ensure the 15 toothed wheel being rotated and the electrical beating of the seconds switch operating.

After about 1 hour the arc should have increased to 4 plus 4 centimetres on the beat scale.

On the right hand side of the case will be seen a panel with two adjustable resistances, one for the F.P. and the other for the slave. Providing the wiring resistance is negligible the F.P. resistance should be set at   ohms when the Atmosphere test is in progress i.e. when the heavy weight is being used on the F.P. gravity lever, and at   ohms when the F.P. is working at the reduced pressure of 20 millimetres of air i.e., when the light weight is being used. The slave resistance should be set at   ohms. In the latter case of the Free Pendulum and in the case of the slave clock these adjustments allow for the current flow to be 1/3 amp which is correct working value.

When the heavy weight is being used on the Free Pendulum gravity lever more current is required to operate the switch, adjusting the resistance to   ohms ensures this.

On the left hand side of the case are a similar pair of resistances mounted on a calibrated panel which, as will be seen by Drawing No.   , are for use in the seconds circuits. The top resistance is in series with the seconds switch and regulator dial coil and should be adjusted to   ohms to ensure a working current of 75 milliamps. The lower resistance provides a further seconds beat electrical circuit if required and the dotted line wiring on Drawing No.   shows how this may be used. It is advisable not to pass more than .25 amp through this circuit which may be used for operating relays or chronograph pen or additional dials of seconds beat.

The Seconds Beat Regulator Dial.

The propelling of the dial wheel work is by means of a reciprocating brass lever having an armature plate at its top end which is attracted at each impulse by the magnet, and at the bottom end is fitted a steel click engaging with a wheel with 60 rectangular teeth.

As the armature is attracted the click steps back and down one tooth of the wheel and the spring resting on the heel of the click drives the armature brass lever forward on cessation of the impulse. Whilst this operation is taking place the wheel is held steady by a backstop i.e., a brass lever terminating in a steel square which fits into the teeth of the wheel.

To set this dial to time the minute hand must be turned in a forward direction by means of the set button on the back end of its arbor, the hour hand will follow the minute hand.

The seconds hand may be set by pressing on the left hand end of the back stop lever i.e., that part which overhangs its pivot, the wheel is then free to be revolved forwards to the correct second. If the seconds hand is some seconds slow the armature may be tapped on in between impulses.

The F.P. and Slave Dials.

The action of these movements is similar to the seconds beat dial excepting that they only move half-minute at each impulse.

To Set to Time.

Depress left hand end of backstop lever which will free the wheel work of the click and backstop and turn large wheel until the correct time is indicated. If a little slow these movements can also be tapped on in between impulses.

The above Slave Clock's normal rate when uncontrolled must be a losing one of six seconds per day, relative to the time to be measured (Sidereal or Mean as the case may be) and the rating of the Slave should be attended to before bringing it under the control of the Free Pendulum.

Starting up and Rating of Master Clock.

Two sets of regulating weights will be found among the accessories and the position of the weight tray and the weight of the pendulum bob have been so arranged that the placing of a one gramme weight on the tray will accelerate the pendulum by one second per day. The tray should be 5.5/16" below the safety pin, which will be found to be about ¼" below the surface on which the bell jar rests.

The compensator supporting the bob has been pinned to the pendulum in such a position that the clock will lose a few seconds per day on   time at   in vacuum, so that if a gramme weight is placed on the weight tray, the rate should be found to approximate closely to   time, during the preliminary rating at ordinary atmospheric pressure.

The time has come to start up both the Free Pendulum and Slave, but before doing this replace the appropriate wires on the S and B terminals on the Free Pendulum case which were connected together during the trial run and rating of the Slave clock, also stop the slave pendulum.

Now start up the Free Pendulum taking care that it swings in a true plane and not with a circular motion, work it up gently until the arc is about 18 mm. plus 18 mm. on the ivory beat plate or 100 minutes on the diamond engraved beat plate. Replace the bell jar whilst attention is now given to the Slave clock. Start the slave pendulum in motion to a little under its normal arc. It will be found that when its switch action occurs, the release magnet on the Master will operate, i.e., every half-minute.

The operation of the releasing magnet will allow the impulse lever to drop, and when this lever reaches the limit of its movement, it will release the catch holding the re-setting lever which, in its turn, will gently re-set the impulse lever upon its catch and finally close the Master remontoire circuit by means of the screw mounted on the contact arm. This energises the re-setting magnet and causes its armature to throw the re-setting lever back on its catch once more.

The closing of the Master remontoire circuit causes an impulse to return to the synchroniser on the Slave clock.

The action of the synchroniser should occur just as the slave pendulum is passing through zero on its excursion from right to left but owing to both pendulums most likely not being in a relative phase on starting up, the phase of the Slave pendulum should be gently retarded or quickened, whichever is nearer to synchronisation, by hand until a synchroniser HIT occurs i.e., when the spring on the pendulum is caught and bent back by the synchroniser blade.

The synchroniser action can be tried more frequently than its normal half-minute spaces by waiting until the Slave pendulum is over to the extreme left when catch K can be pushed aside by the finger thus releasing the gravity lever. Each time this is done the cycle of operations will be repeated.

Having got the Slave clock into a position where it is being synchronised it now remains to leave the clocks to work normally and watch the action of the synchroniser.

Owing to the slowing rate of the Slave of approximately six (6) seconds per day relative to the Master, the interval between the release of the impulse lever and the operation of its remontoire will gradually decrease, until the time arrives when the synchronising spring on the Slave just fails to get under the end of the synchronising magnet armature before this armature moves, that is to say, the armature will come down before the spring reaches it, with the result that the spring will engage with the end of the armature and be deflected as the pendulum continues its swing to the left.

This engagement and flexing of the spring naturally results in a shortening of the time of the particular swing of the slave pendulum by an amount dependent on the strength of the spring. The spring has been adjusted so that each time it is flexed that particular period of the slave is decreased by 1/240th of a second. As 6 seconds per day equal 1/480th of a second per half-minute, it follows that the slave will only drop back this amount between successive contacts and that it will not have dropped back sufficient for engagement to take place at the next contact and a miss will occur. At the end of another half-minute, however, it will drop back where it was before, and an engagement should take place. Thus engagements and misses should follow one another alternatively for an indefinite period, if the rate of the clocks does not change.

If the engagements and misses do not occur alternatively, or approximately so, the rating of the slave should be altered by adding or removing weights from its weight tray in order to bring this about. If more misses occur than engagements, the slave is obviously going too fast and weights should be removed from the tray. On the other hand, if the engagements preponderate, the clock is going too slow and weights should be added to the tray.

As soon as the synchronising of the slave is in satisfactory operation, the rate of the Master Clock can be determined. When the rate is definitely known to 1/10th of a second per day, arrangements for sealing the case and pumping out the air may be made. Before doing so, it is necessary to remove 12.25 grammes from the weight tray of the Master Clock, in addition it will be necessary to lighten the impulse lever by removing the weight and substituting it with a smaller weight. In ordinary air pressure the current rate is somewhat more than normal, owing to the use of the heavy cylindrical weight which, when being replaced by the lighter weight will bring the current to normal. Therefore it will be necessary to re-adjust the Free Pendulum resistance in order to obtain the standard current rate of .33 amp.

These alterations should not be made while the movement is in place. It should be removed from the case for this purpose. When the lever has been lightened the movement can be replaced.

Next, the mercury and oil gauge should be unpacked and set up on the top ring of the case on the left hand side. The fixing screws will be found with the gauge. Take care to see that the mercury is to the top of the tube side of the gauge with the scale reading. Now remove the oil gauge bulb with its opal scale and put into its container pump oil to the depth of about 10 millimetres, then replace the bulb so that the end of its tube is immersed almost the complete depth of the oil. The object of the oil gauge is to give a pressure reading of about ten times greater than the mercury gauge.

It must be remembered that the impulses are now insufficient to maintain the arc of the pendulum under ordinary air pressure. It is therefore necessary to gently increase the arc by hand at least 50% above its normal amount and to proceed with the sealing and exhaustion of the case immediately, otherwise it may be found that by the time the case has been exhausted, the arc of the pendulum has got below the minimum value at which the mechanism will operate.

Now clean the bell jar, and carefully grease the ground edge with the special grease. Clean the surface of the top ring of the case, place the bell jar in position and gently squeeze it into close contact with the copper with a slightly rotary motion.

The pump should now be prepared. Cut the rubber tube into two convenient lengths, attach one piece to the valve inlet of the Free Pendulum case, and its other end to one side of the glass drying tube. Fit the other piece of rubber tube to the remaining end of the drying tube and its other end to the pump. Now put about one third of the bottle of drying salts, supplied for the purpose, into the drying tube. The clock case is now ready to be pumped out.

Open the valve by withdrawing the screw plunger about two turns and start pumping. Pumping should be continued until the mercury gauge shows 1.8 c.m. from a vacuum. Now let sufficient air into the case to send the oil up the tube and until the mercury reaches 2 centimetres.

When this value has been reached, close the valve by screwing the plunger home and note the position of the mercury and oil. After allowing the case to remain undisturbed for an hour or so, again carefully note the position of the mercury and oil, repeat two or three times at intervals of twelve hours. The oil will probably move a little for the first two or three observations owing to the settling down of the temperature, in fact, the oil will continue to fluctuate if the clock is not kept in a constant temperature.

If the oil and mercury has remained steady, the test may be considered satisfactory. On the other hand, should a movement be disclosed a leak is indicated and all joints and connections must be carefully examined. The order of probable leakage is as follows:-

1. Joint between bell jar and copper flange.
2. Joint between glass disc and bottom flange.
3. Joint between valve and socket and bottom casting.
4. Joints between terminals and top casting.

The whole case was carefully tested as above before despatch and proved to be able to hold 74 cm. of vacuum indefinitely.

If it should happen that while pumping out the air, the arc of the pendulum has got below the minimum value at which the mechanism will operate, shut the valve up and remove the rubber tube. Now place a finger over the valve inlet and unscrew the valve plunger about two turns, watch the pendulum and as it commences to swing away from the valve, let a spurt of air in for a duration of about half a second. Repeat this until the pendulum has regained a reasonable arc. These air impulses will rapidly restore the pendulum to the required arc. The valve may now be closed, the rubber tube replaced and pumping re-commenced when the valve is opened again.

Assuming that the case has been satisfactorily sealed, the pressure should be reduced until the mercury gauge reads 2 cm. or thereabouts, and the rate of the clock under this pressure can then be accurately determined.

As the effect of the reduction of the air pressure is not known to within 1/10th of a second per day, it is probable that the rate of the clock when exhausted may be so far from time it cannot be corrected by increasing or further reducing the air pressure. Under these circumstances, there will be no alternative but to open the case and adjust the regulating weights on the weight tray accordingly, in the proportion of 1 gramme to one second per day. This alteration should not, of course, be made until the rate of the clock is known to the nearest 1/100th of a second.

The amount of the arc is a valuable indication of the satisfactory going of the clock and once this arc has settled down it should remain absolutely constant, so long as the density of the air within the case is unchanged.

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14.2. Boucheron Notes on Erection

NOTES ADDED NOVEMBER 1987

The prior pages of these instructions were transcribed from a copy of the original instructions provided with Shortt No. 20. Shortt No. 20 was originally despatched to Alfred L. Loomis, Tuxedo Park, New York, ca. 1928.

The following additional notes may be found to be helpful to one interested in re-starting a Shortt Master Pendulum:

1. The "special grease" referred to on page 2, and throughout the instructions, is silicone vacuum grease.
2. The ability to maintain a good vacuum is greatly enhanced by applying a strip of some nonhardening silicone based sealing material around the outside of the glass to metal joints at both the top and bottom of the Master Clock case. STRIP-CALK manufactured by the 3M Company, and available at automotive supply stores, has been found to be quite satisfactory for this application.
3. In some installations it has been found desirable NOT to attempt to bolt the lower bracket of the Master Clock case to the support wall. Securing the lower bracket may have a tendency to warp the case thereby increasing the probability of vacuum leaks. (Page 3)
4. Four or five Volts should be sufficient to run the Master and Slave Clocks (page 9). An uninterruptable supply of five Volts may be readily obtained by placing a "regulator" integrated circuit in series with a 12 Volt automotive battery which, in turn, is held at full charge with a "floating" type battery charger. Such an elaborate supply is not really required, and the clock may be operated quite satisfactorily for several months using three "D" size alkaline flashlight cells in series.
5. Note especially that there is no mention of oiling the mechanisms anywhere in the instructions. Both the Master and the Slave Clock mechanisms should be run dry.

Pierre Boucheron
November 1987

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14.3. Drawings Accompanying Boucheron's Erection Notes

SYNCHRONOME C° LTD

WOODSIDE PLACE

ALPERTON • MIDDX.

SHORTT CLOCK

MASTER & SLAVE DETAILS

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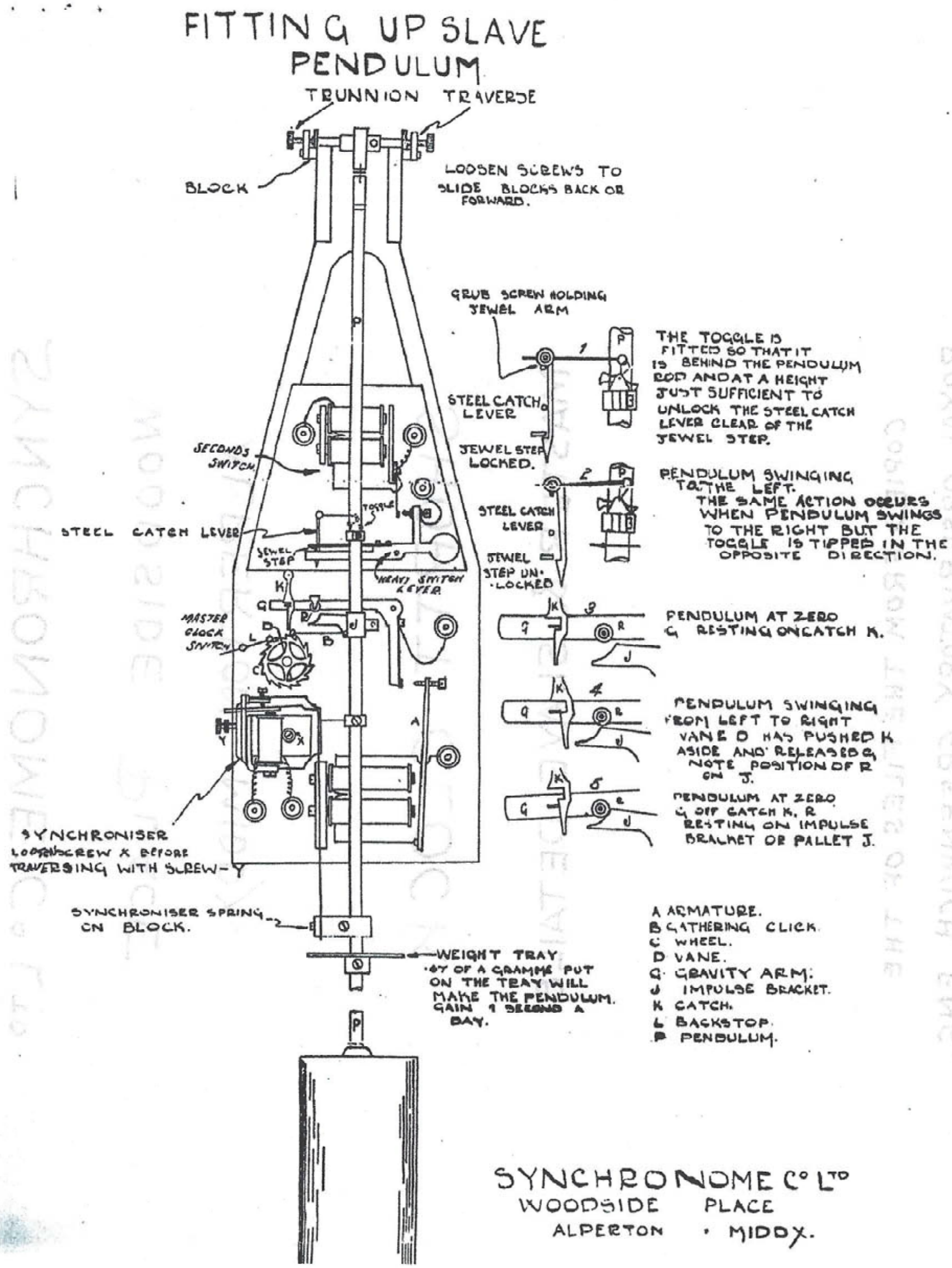
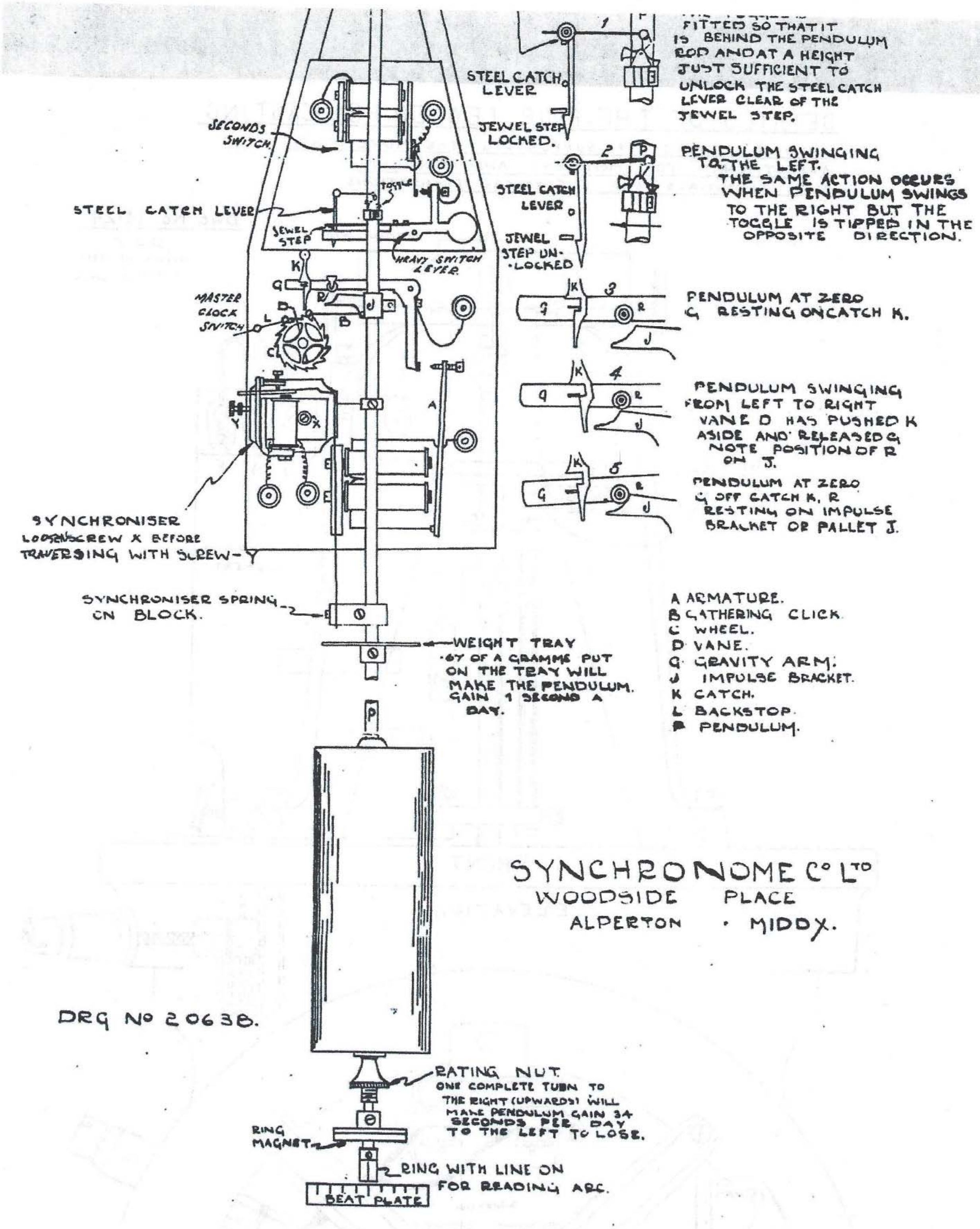
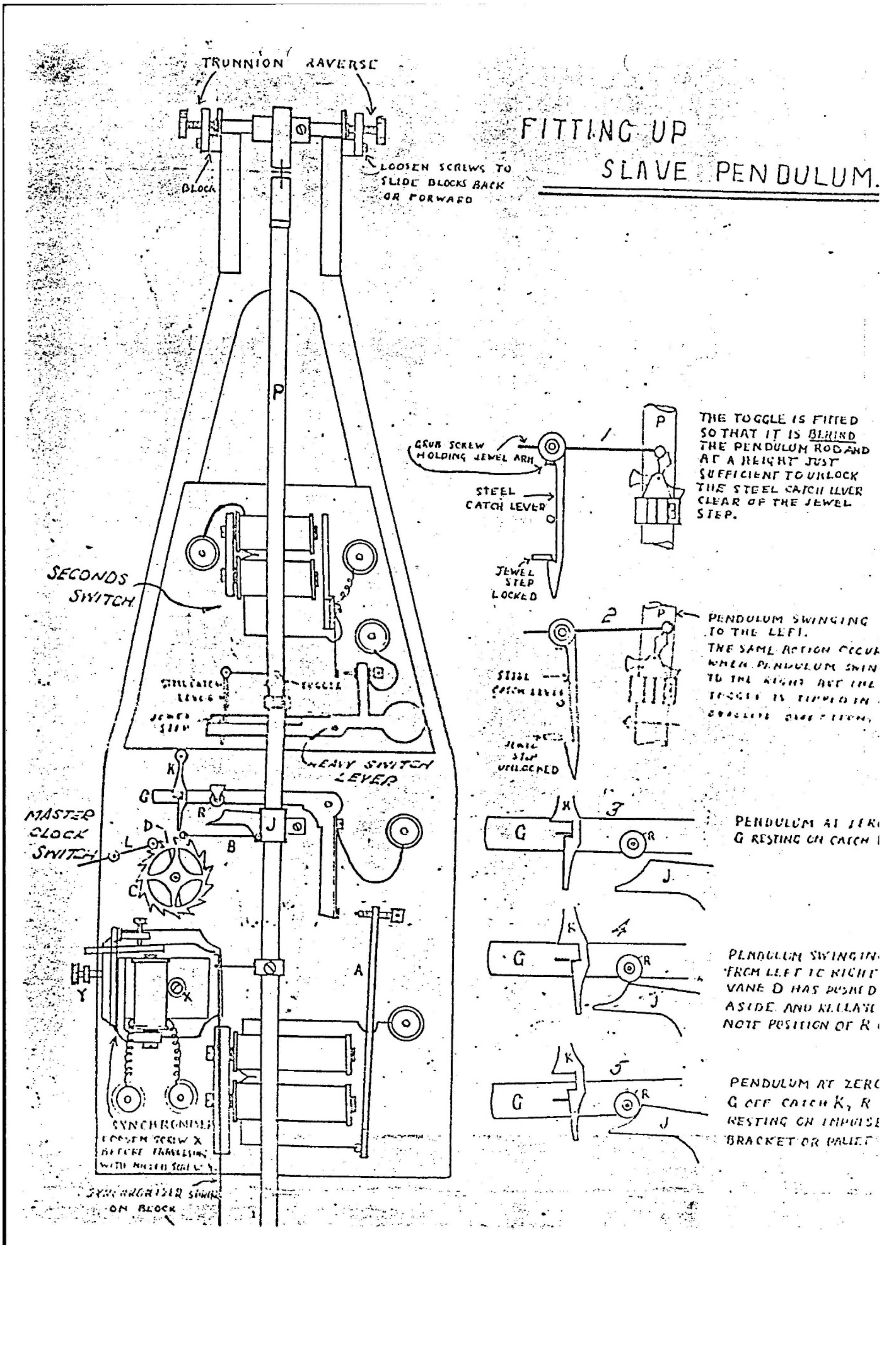
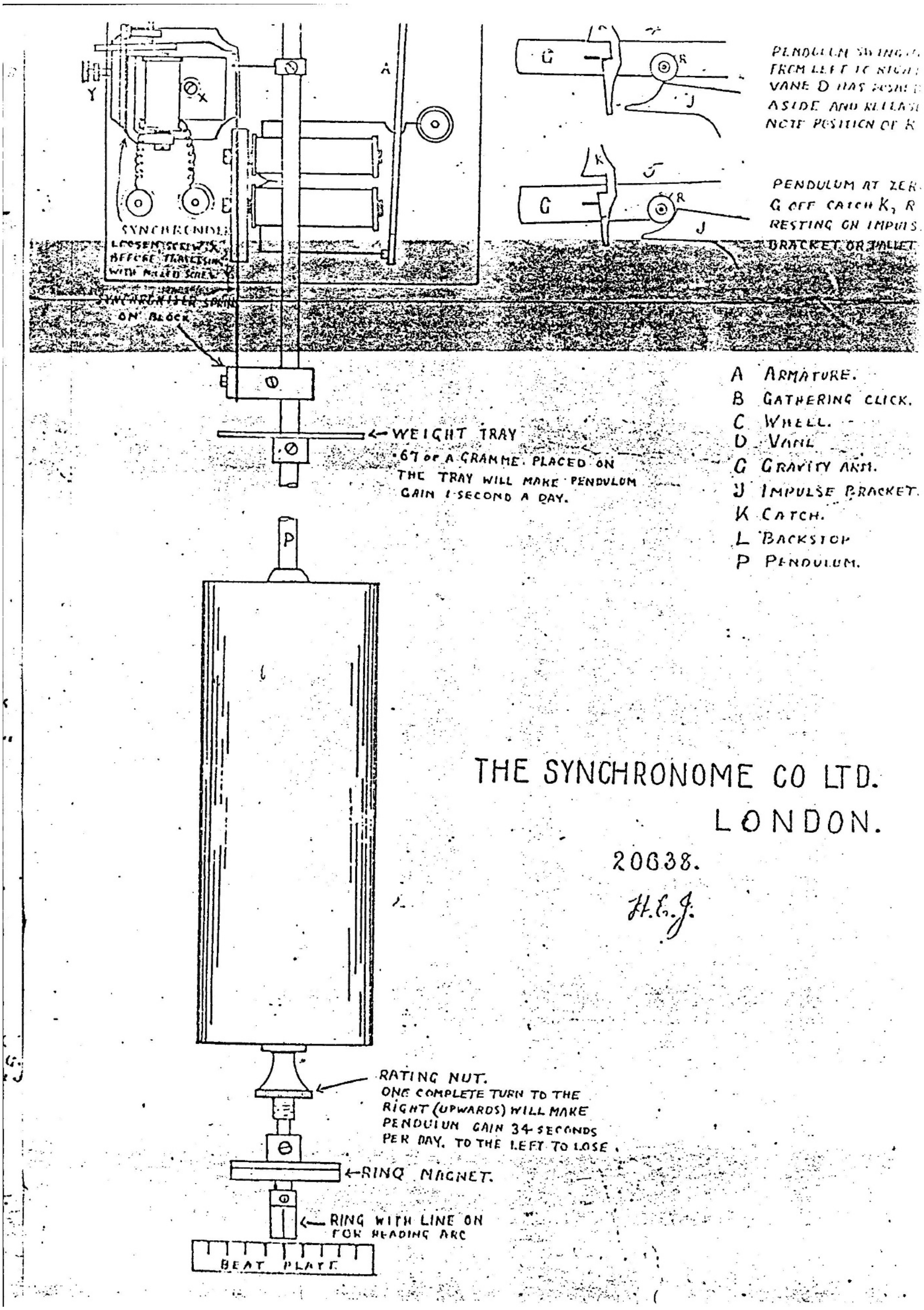
OCTOBER 1985 – PIERRE H. BOUCHERON

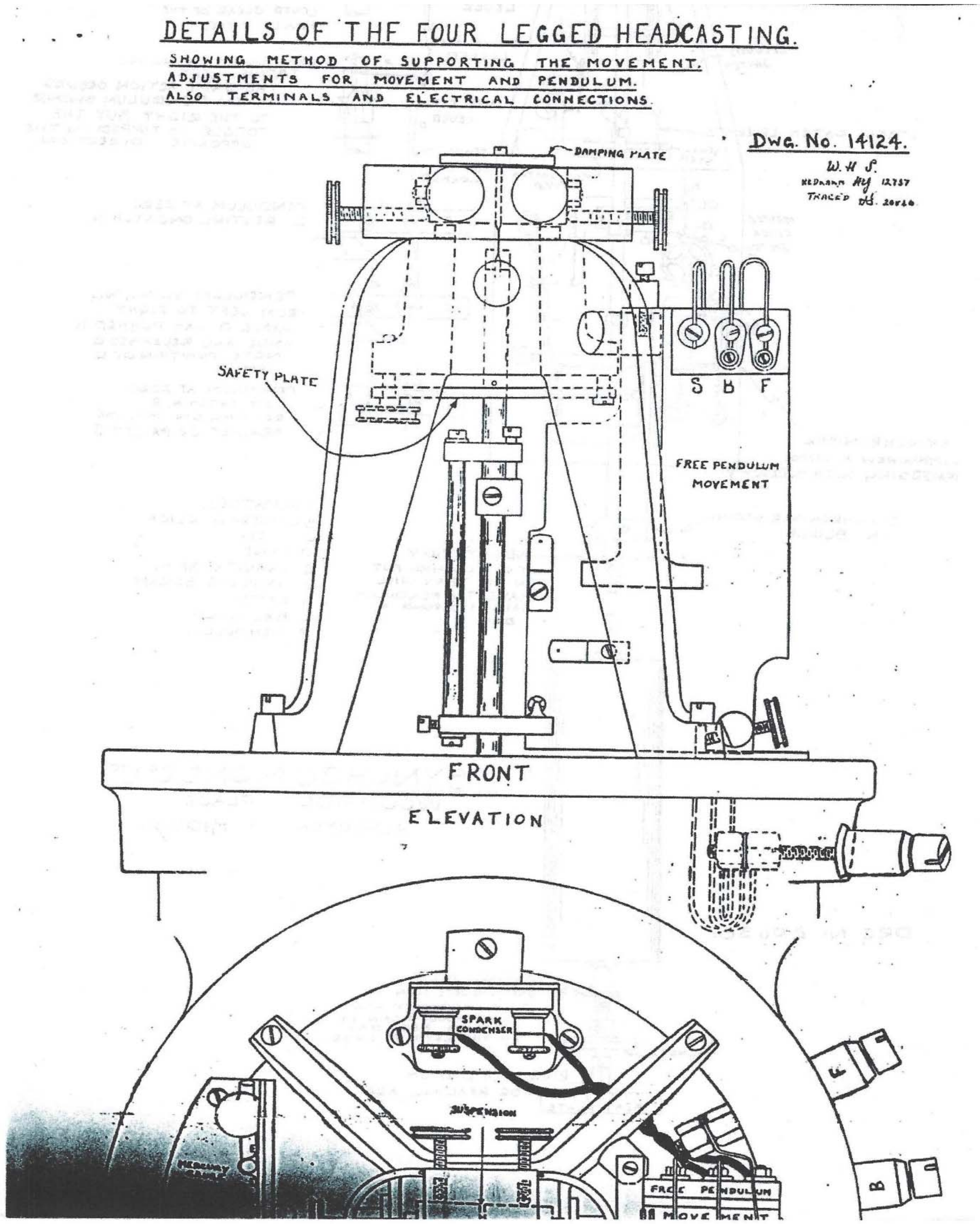

FITTING UP SLAVE PENDULUM
TRUNNION
TRAVERSE
BLOCK
LOOSEN SCREWS TO SLIDE BLOCKS BACK OR FORWARD.
GRUB SCREW HOLDING JEWEL ARM
THE TOGGLE IS FITTED SO THAT IT IS BEHIND THE PENDULUM ROD AND AT A HEIGHT JUST SUFFICIENT TO UNLOCK THE STEEL CATCH LEVER CLEAR OF THE JEWEL STEP.
STEEL CATCH LEVER
JEWEL STEP LOCKED.
SECONDS SWITCH
TOGGLE
PENDULUM SWINGING TO THE LEFT. THE SAME ACTION OCCURS WHEN PENDULUM SWINGS TO THE RIGHT BUT THE TOGGLE IS TIPPED IN THE OPPOSITE DIRECTION.
STEEL CATCH LEVER
STEEL CATCH LEVER
JEWEL STEP
HEAVY SWITCH LEVER
JEWEL STEP UN-LOCKED
MASTER CLOCK SWITCH
PENDULUM AT ZERO G RESTING ON CATCH K.
PENDULUM SWINGING FROM LEFT TO RIGHT VANE D HAS PUSHED K ASIDE AND RELEASED G NOTE POSITION OF R ON J.
PENDULUM AT ZERO G OFF CATCH K. R RESTING ON IMPULSE BRACKET OR PALLET J.
SYNCHRONISER
LOOSEN SCREW X BEFORE TRAVERSING WITH SCREW-
SYNCHRONISER SPRING ON BLOCK.
WEIGHT TRAY
·07 OF A GRAMME PUT ON THE TRAY WILL MAKE THE PENDULUM GAIN 1 SECOND A DAY.
A ARMATURE.
B GATHERING CLICK.
C WHEEL.
D VANE.
G GRAVITY ARM.
J IMPULSE BRACKET.
K CATCH.
L BACKSTOP.
P PENDULUM.
SYNCHRONOME C° LTD
WOODSIDE PLACE
ALPERTON · MIDDX.

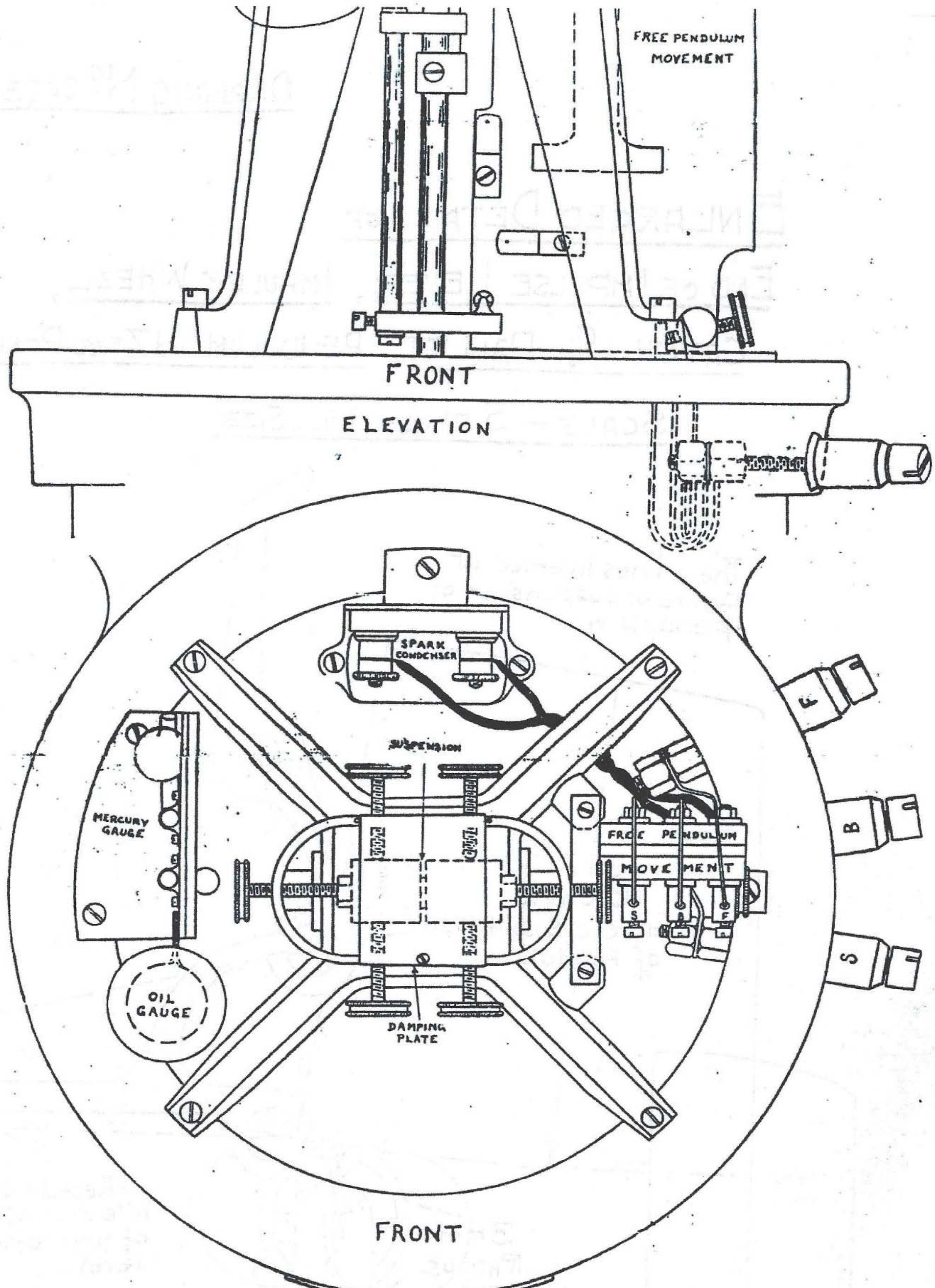

FITTED SO THAT IT IS BEHIND THE PENDULUM ROD AND AT A HEIGHT JUST SUFFICIENT TO UNLOCK THE STEEL CATCH LEVER CLEAR OF THE JEWEL STEP.
1
STEEL CATCH LEVER
JEWEL STEP LOCKED.
2
PENDULUM SWINGING TO THE LEFT. THE SAME ACTION OCCURS WHEN PENDULUM SWINGS TO THE RIGHT BUT THE TOGGLE IS TIPPED IN THE OPPOSITE DIRECTION.
STEEL CATCH LEVER
JEWEL STEP UN-LOCKED
SECONDS SWITCH
TOGGLE
STEEL CATCH LEVER
JEWEL STEP
HEAVY SWITCH LEVER
MASTER CLOCK SWITCH
3
PENDULUM AT ZERO G RESTING ON CATCH K.
4
PENDULUM SWINGING FROM LEFT TO RIGHT VANE D HAS PUSHED K ASIDE AND RELEASED G. NOTE POSITION OF R ON J.
5
PENDULUM AT ZERO G OFF CATCH K, R RESTING ON IMPULSE BRACKET OR PALLET J.
SYNCHRONISER
LOOSEN SCREW X BEFORE TRAVERSING WITH SCREW-Y
SYNCHRONISER SPRING ON BLOCK.
WEIGHT TRAY
·67 OF A GRAMME PUT ON THE TRAY WILL MAKE THE PENDULUM GAIN 1 SECOND A DAY.
A ARMATURE.
B GATHERING CLICK.
C WHEEL.
D VANE.
G GRAVITY ARM.
J IMPULSE BRACKET.
K CATCH.
L BACKSTOP.
P PENDULUM.
SYNCHRONOME C° L^TD
WOODSIDE PLACE
ALPERTON · MIDDX.
DRG N° 20638.
RATING NUT
ONE COMPLETE TURN TO THE RIGHT (UPWARDS) WILL MAKE PENDULUM GAIN 34 SECONDS PER DAY TO THE LEFT TO LOSE.
RING MAGNET
RING WITH LINE ON FOR READING ARC.
BEAT PLATE


TRUNNION
FITTING UP
SLAVE PENDULUM.
LOOSEN SCREWS TO SLIDE BLOCKS BACK OR FORWARD
BLOCK
P
GRUB SCREW HOLDING JEWEL ARM
STEEL CATCH LEVER
JEWEL STEP LOCKED
THE TOGGLE IS FITTED SO THAT IT IS BEHIND THE PENDULUM ROD AND AT A HEIGHT JUST SUFFICIENT TO UNLOCK THE STEEL CATCH LEVER CLEAR OF THE JEWEL STEP.
SECONDS SWITCH
PENDULUM SWINGING TO THE LEFT.
STEEL CATCH LEVER
JEWEL STEP
TOGGLE
HEAVY SWITCH LEVER
MASTER CLOCK SWITCH
PENDULUM AT ZERO G RESTING ON CATCH
VANE D HAS PUSHED ASIDE
PENDULUM AT ZERO G OFF CATCH K, R RESTING ON IMPULSE BRACKET OR PALLET
SYNCHRONISER
LOOSEN SCREW X BEFORE TRAVERSING
SYNCHRONISER SPRING ON BLOCK



A
Y
X
SYNCHRONISER
LOOSEN SCREW X BEFORE TRAVELLING WITH NAILED SCREW
SYNCHRONISER SPRING ON BLOCK
A ARMATURE.
B GATHERING CLICK.
C WHEEL.
D VANE
G GRAVITY ARM.
J IMPULSE BRACKET.
K CATCH.
L BACKSTOP
P PENDULUM.
WEIGHT TRAY
·67 OF A GRAMME PLACED ON THE TRAY WILL MAKE PENDULUM GAIN 1 SECOND A DAY.
P
THE SYNCHRONOME CO LTD.
LONDON.
20638.
H.E.J.
RATING NUT.
ONE COMPLETE TURN TO THE RIGHT (UPWARDS) WILL MAKE PENDULUM GAIN 34 SECONDS PER DAY. TO THE LEFT TO LOSE.
RING MAGNET.
RING WITH LINE ON FOR READING ARC
BEAT PLATE

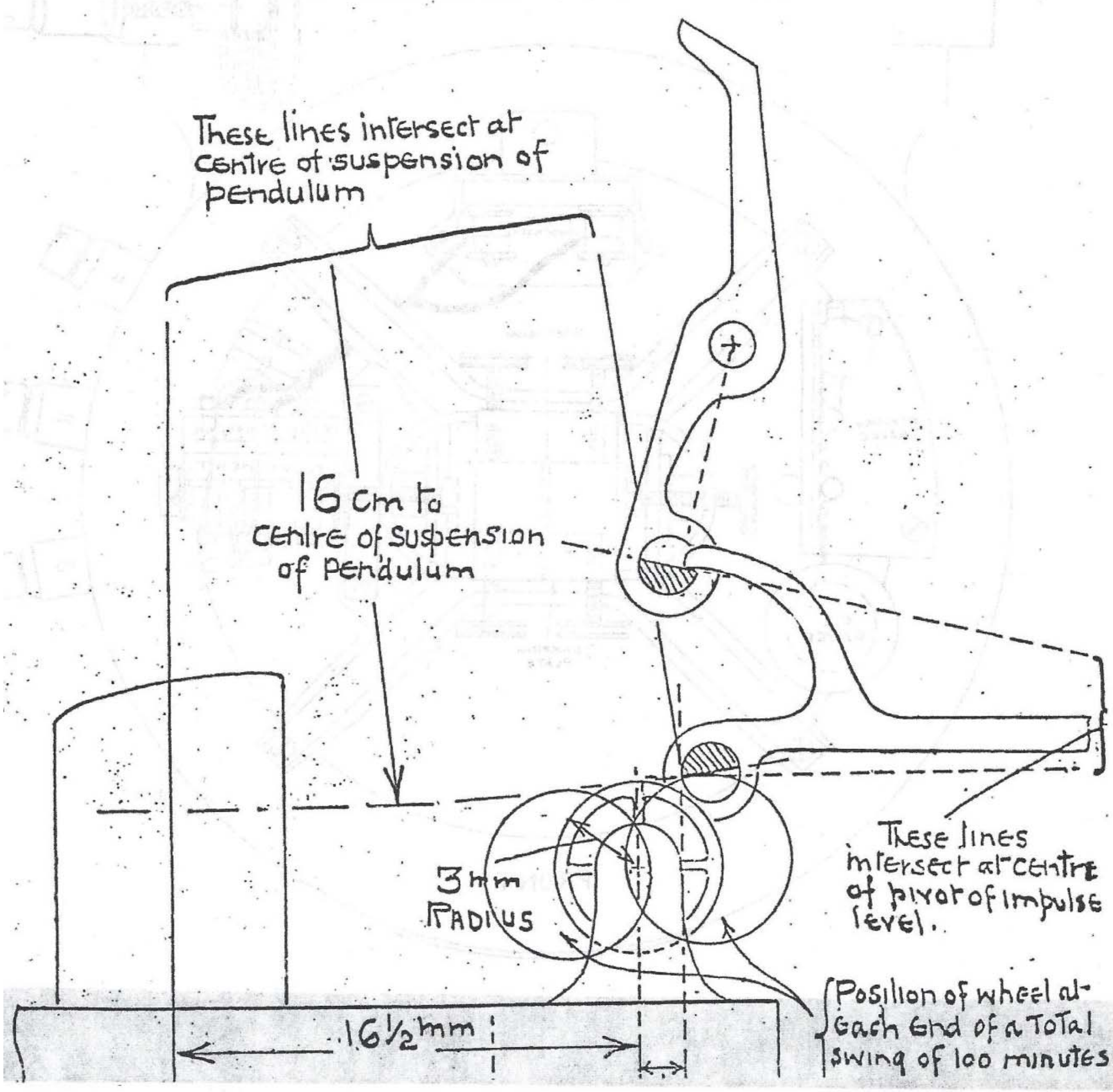

DETAILS OF THF FOUR LEGGED HEADCASTING.
SHOWING METHOD OF SUPPORTING THE MOVEMENT.
ADJUSTMENTS FOR MOVEMENT AND PENDULUM.
ALSO TERMINALS AND ELECTRICAL CONNECTIONS.
DWG. No. 14124.
DAMPING PLATE
SAFETY PLATE
S B F
FREE PENDULUM MOVEMENT
FRONT
ELEVATION
SPARK CONDENSER
SUSPENSION
FREE PENDULUM MOVEMENT
F
B

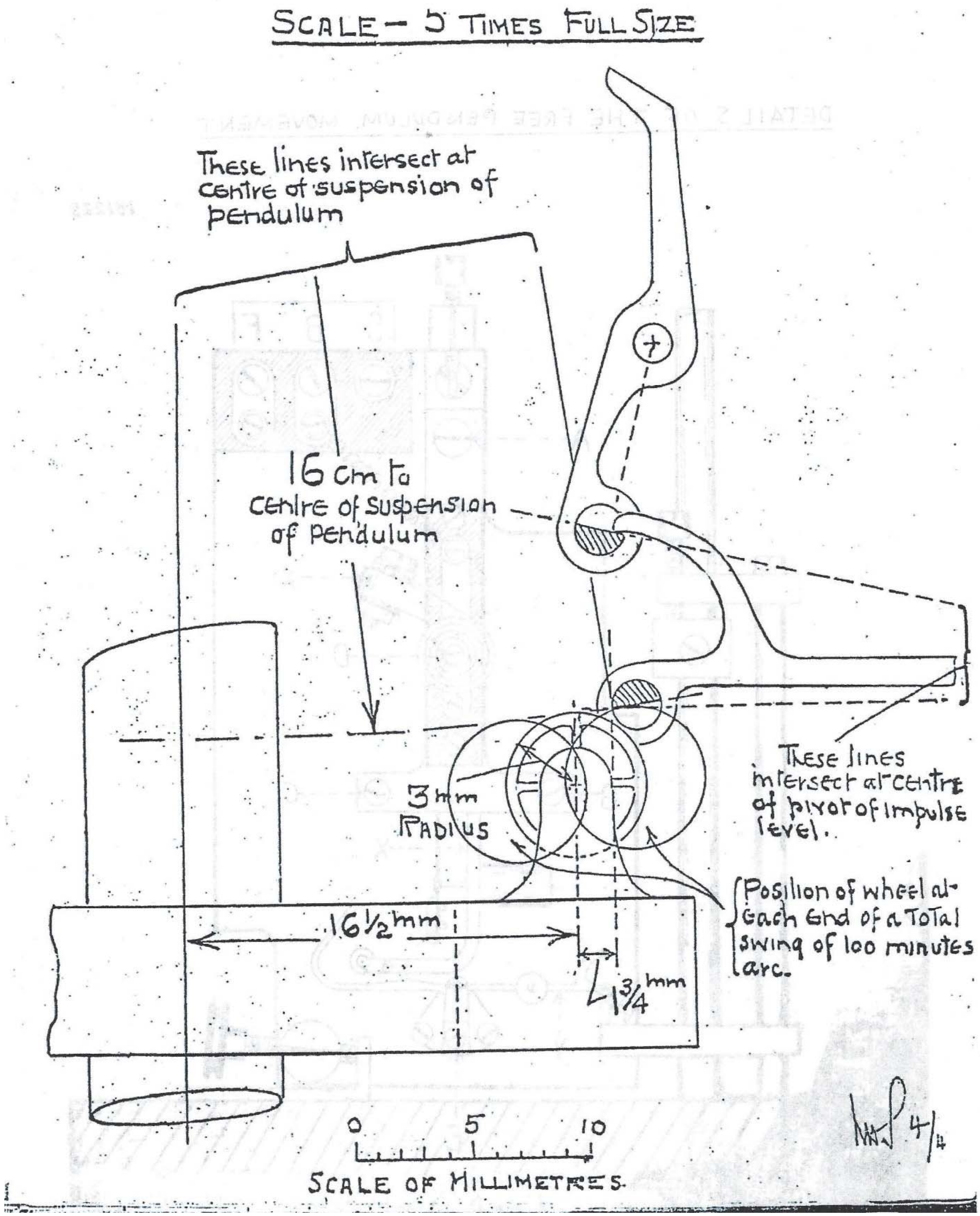

FREE PENDULUM MOVEMENT
FRONT
ELEVATION
SPARK CONDENSER
SUSPENSION
MERCURY GAUGE
FREE PENDULUM MOVEMENT
S
B
F
OIL GAUGE
DAMPING PLATE
FRONT

DRAWING No. 2423D

ENLARGED DETAIL OF END OF IMPULSE LEVER, IMPULSE WHEEL, CATCH & PALLET PENDULUM IN ZERO POSITION

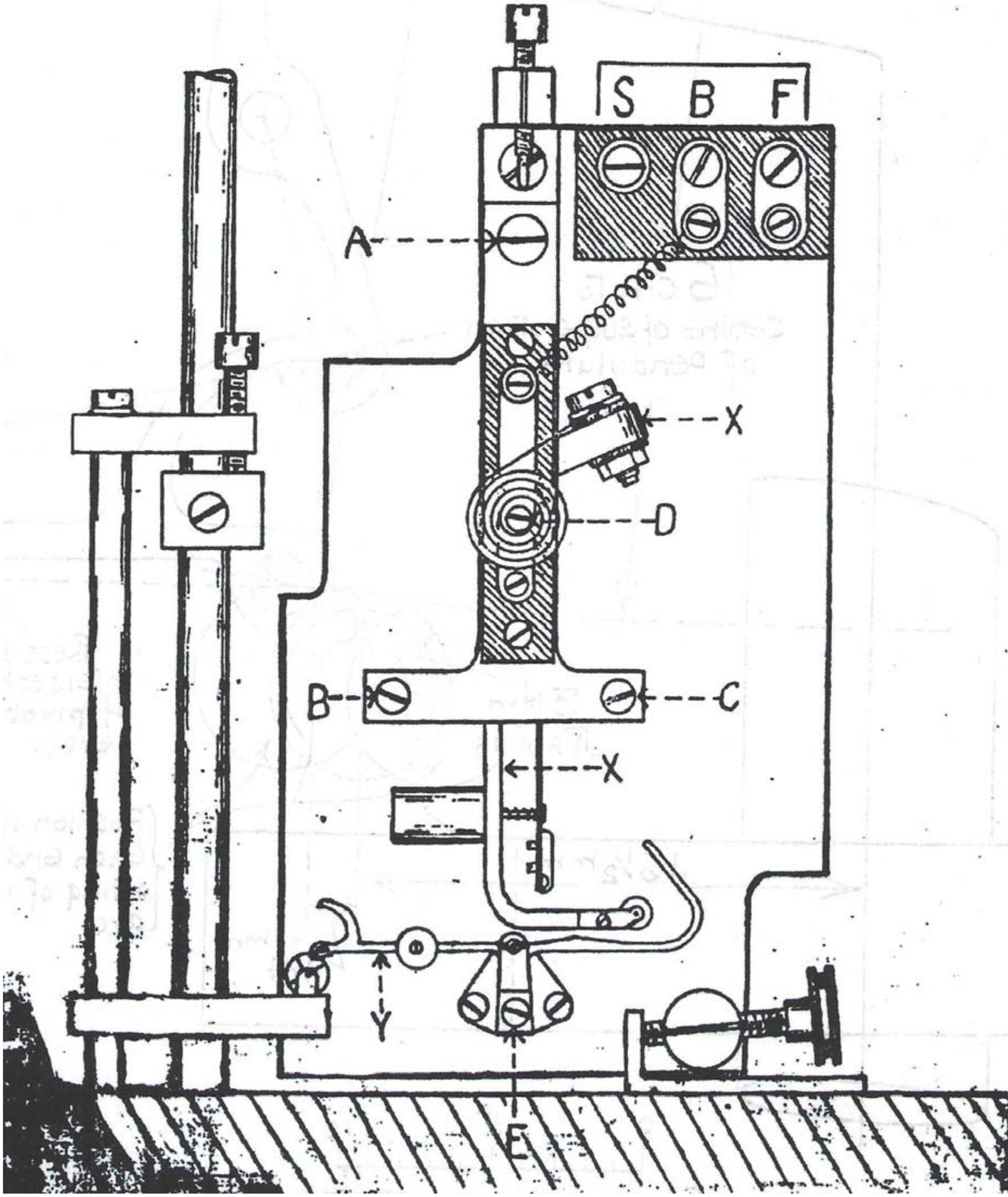
SCALE – 5 TIMES FULL SIZE




SCALE – 5 TIMES FULL SIZE
These lines intersect at centre of suspension of pendulum
16 cm to centre of suspension of pendulum
3 mm RADIUS
These lines intersect at centre of pivot of impulse level.
Position of wheel at each end of a total swing of 100 minutes arc.
16½ mm
1¾ mm
0
5
10
SCALE OF MILLIMETRES.

DETAILS OF THE FREE PENDULUM MOVEMENT

181229



14.4. Boucheron Letter about Lubrication

Art, 23/12/87, p2

detective work) that the reset contacts for the reset arm (marked in red on the enclosed diagram) had failed to make contact. The whole operation of the mechanism is quite delicate, and these contacts are supposed to be adjusted so that they just make, with the arm at rest in its uncocked position. The problem was that, in operation, the reset arm slightly overshoots its rest position, hence the contacts will make even though they be set a bit too far open. Somehow, through wear, or something, they had worked themselves open, and the clock had been running anyway for goodness only knows how long; 50 weeks anyway. It has been a couple of years now, so I am not positive, but I believe I have marked the correct adjustment screw on the drawing.

I have not been able to find an authoritative reference to the proper operating voltage. I ran #41 on approximately 4.5 Volts, but I am reasonably confident that 6 Volts would not be injurious. However, I don't believe that I would go much higher than that. You might save some wear on the contacts by installing small silicon *diodes across the coils as I have shown on the diagram. This is* a bit of finesse that you may not wish to bother with.

If you plan to run the master at low pressure, a couple more notes are in order. The US Naval Observatory, and others, have found it undesirable to bolt down the bottom mounting bracket. Seems it tends to warp the case thereby promoting vacuum leaks. The "special grease" used on the vacuum joints at the bottom plate and the top bell jar, is nothing more than silicone grease. It is available from scientific supply houses, or perhaps more readily, from your friendly local Radio Shack store in the form of "Heat Sink Grease" used with power transistors to promote good thermal conductivity. You will probably also find it necessary to apply a complete ring of silicone putty around the outside of the vacuum joints after assembly. A handy form of this putty is a product called Strip Caulk, made by the 3M Company, and available from your local auto *parts store. It is used to seal auto body joints against wind and* weather. (Spelled STRIP-CALK...)

Don't know whether I have been of any help or not. Probably told you everything you already know, and NOT what you wanted to learn. Please do let me know how you make out, or if there are any questions I can take a stab at confusing answers for.

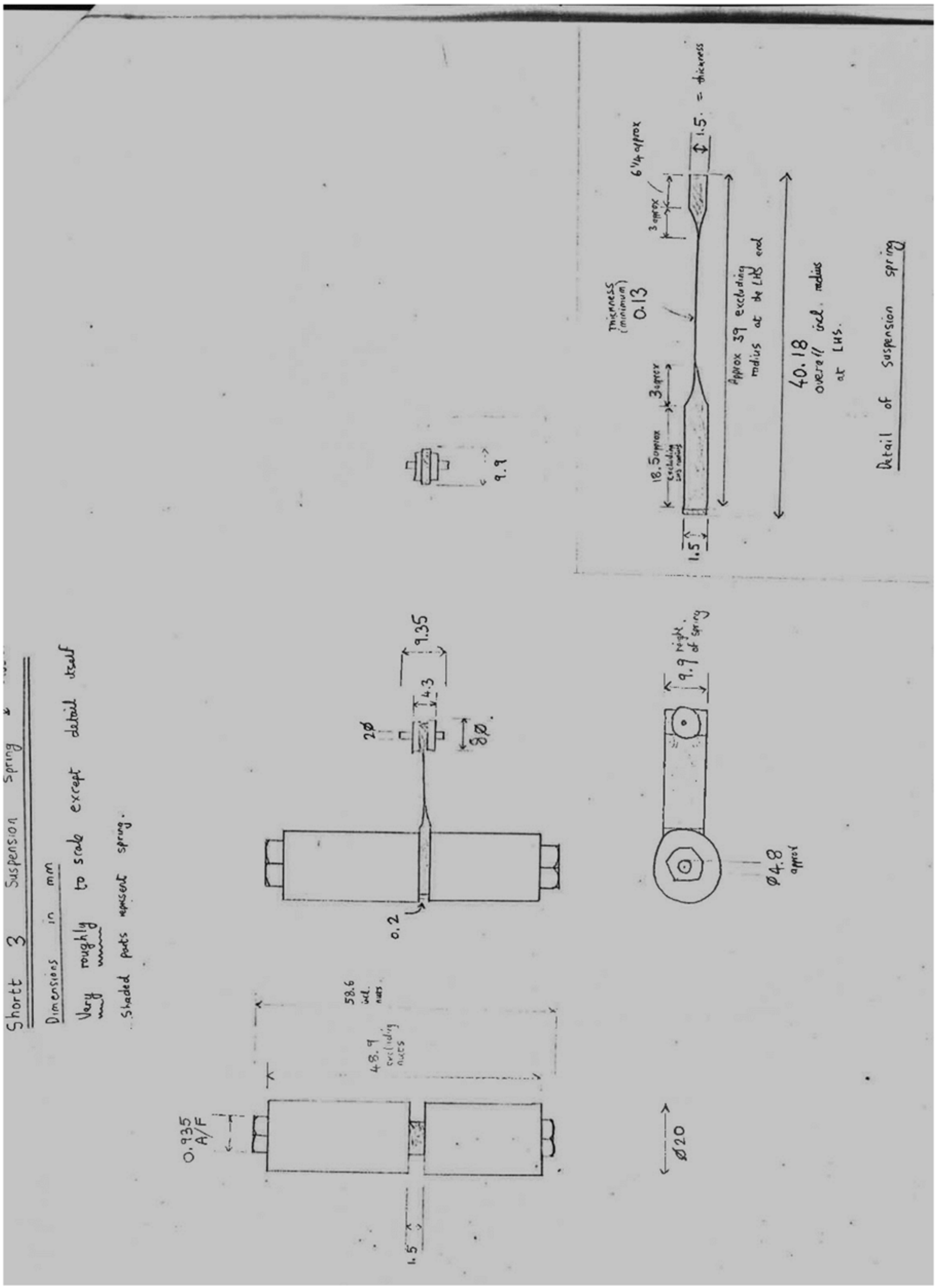
Hope that you had a Very Merry Christmas, and that you will have a Happy New Year.

Cheers,

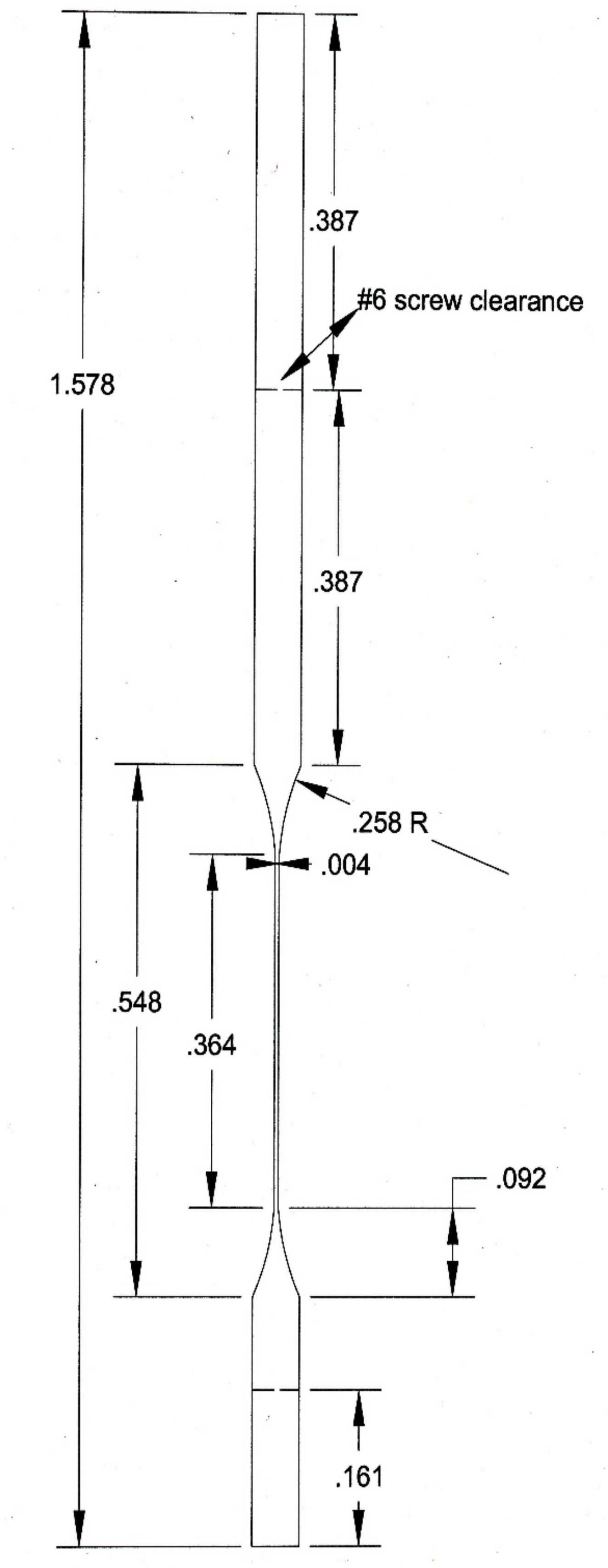
Pierre

Pierre H. Boucheron
Friendly Woods
Route 1 Box 124
Barboursville, VA 22923

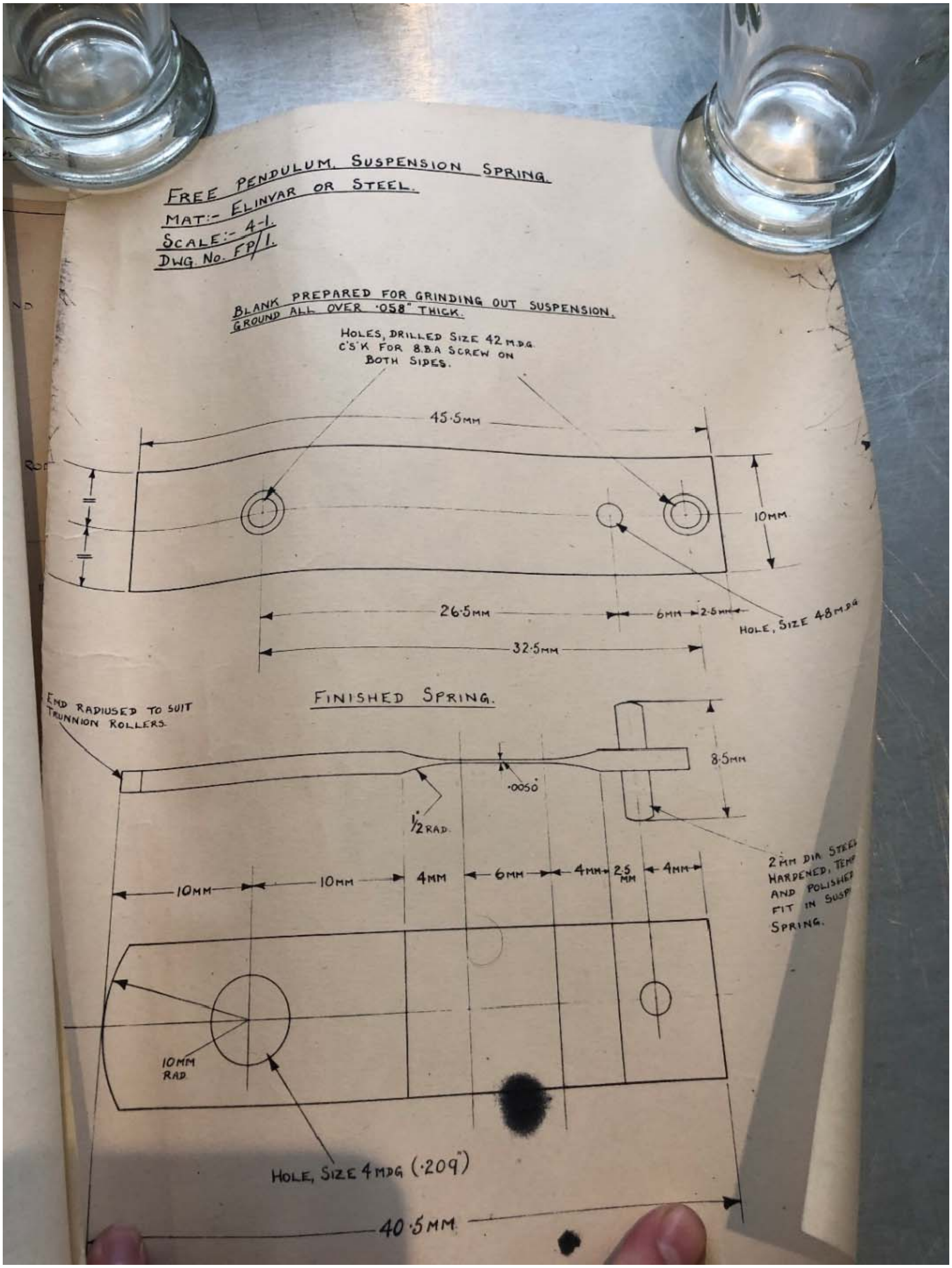
14.5. Suspension Spring Drawings



Provided by Rory McEvoy



Provided by Bob Holmstrom



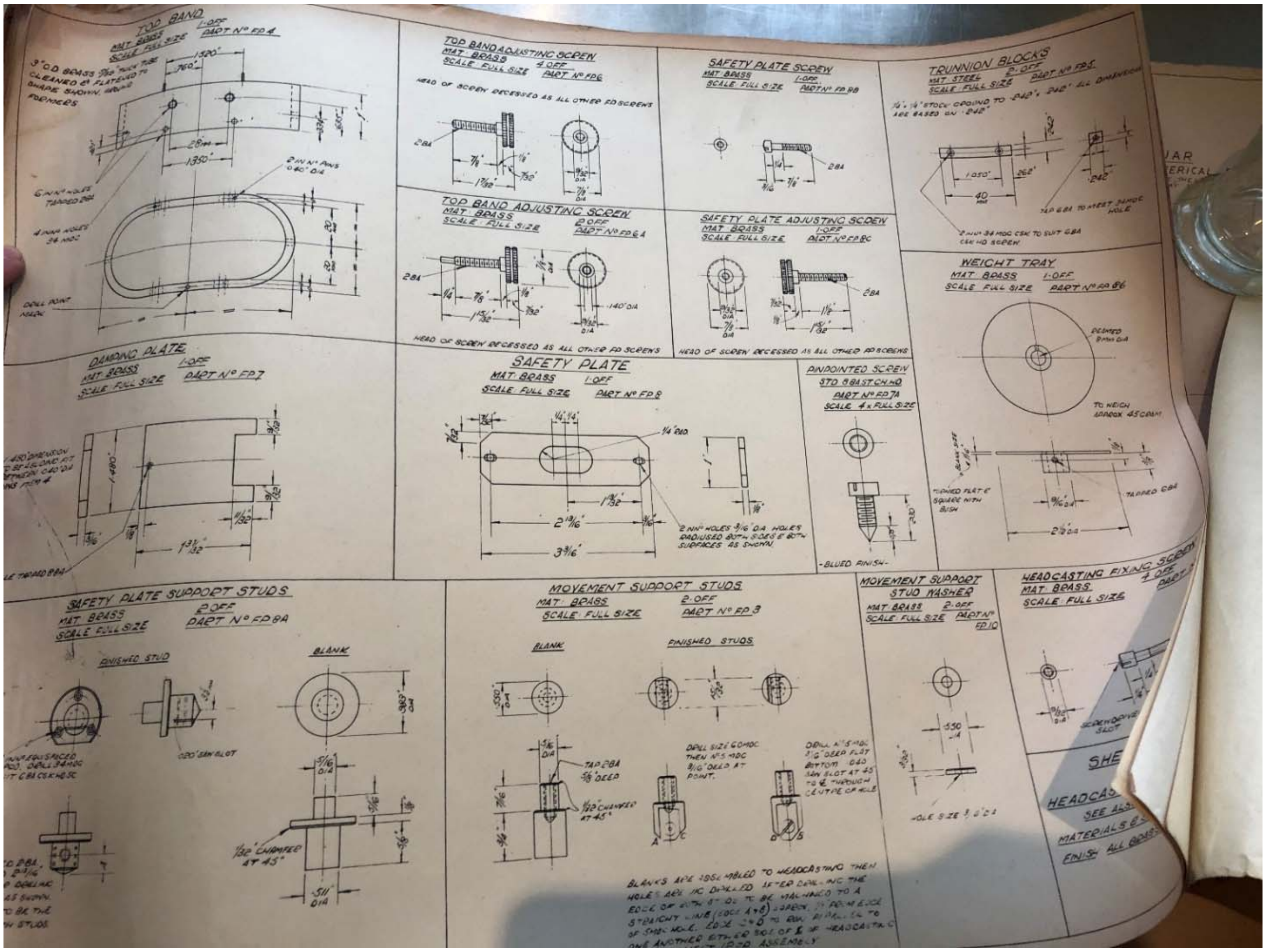
Provided by James Nye

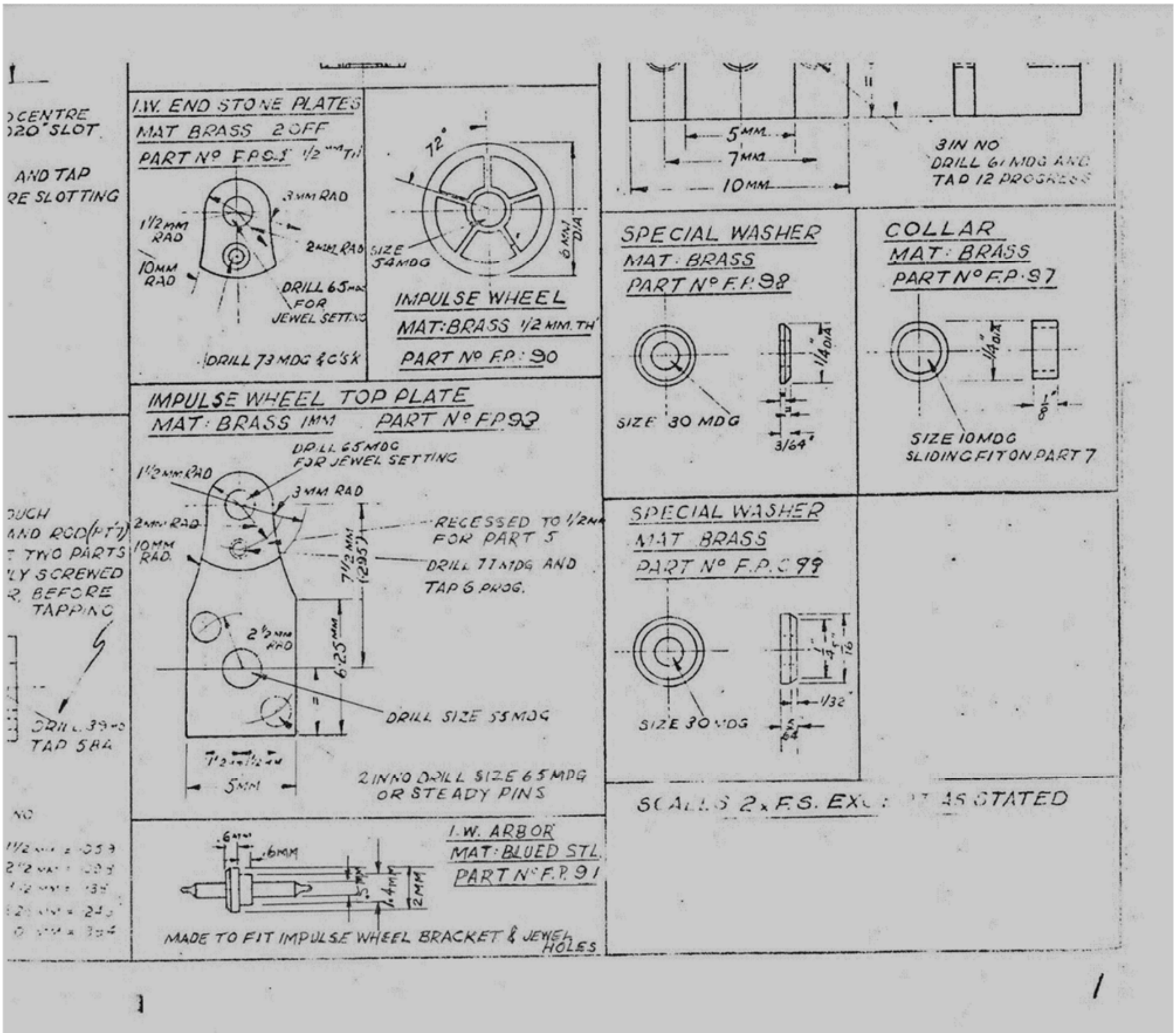
14.6. Mechanical Drawings

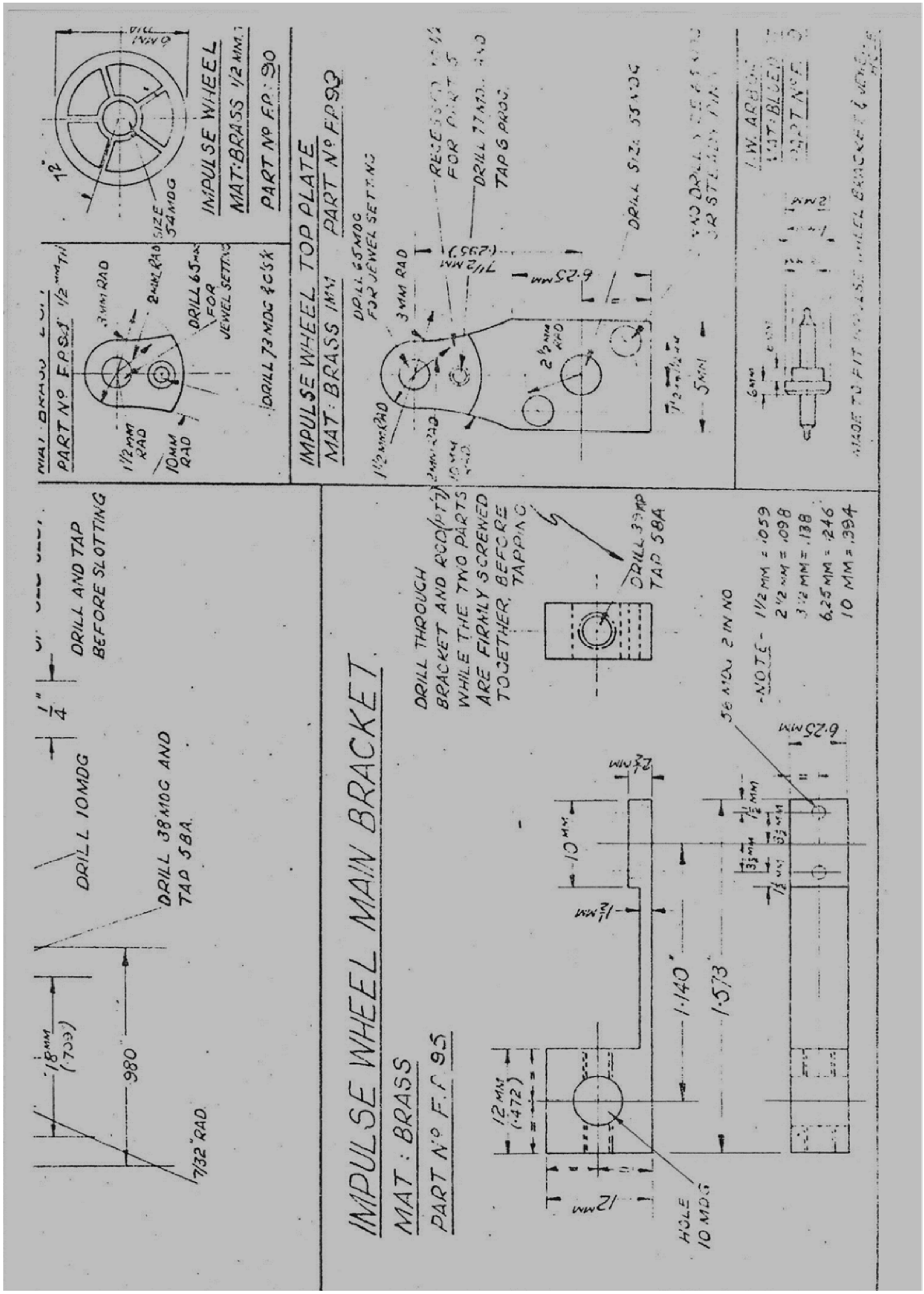
Some nominally duplicate drawings are included that were obtained from multiple sources and have slight differences.

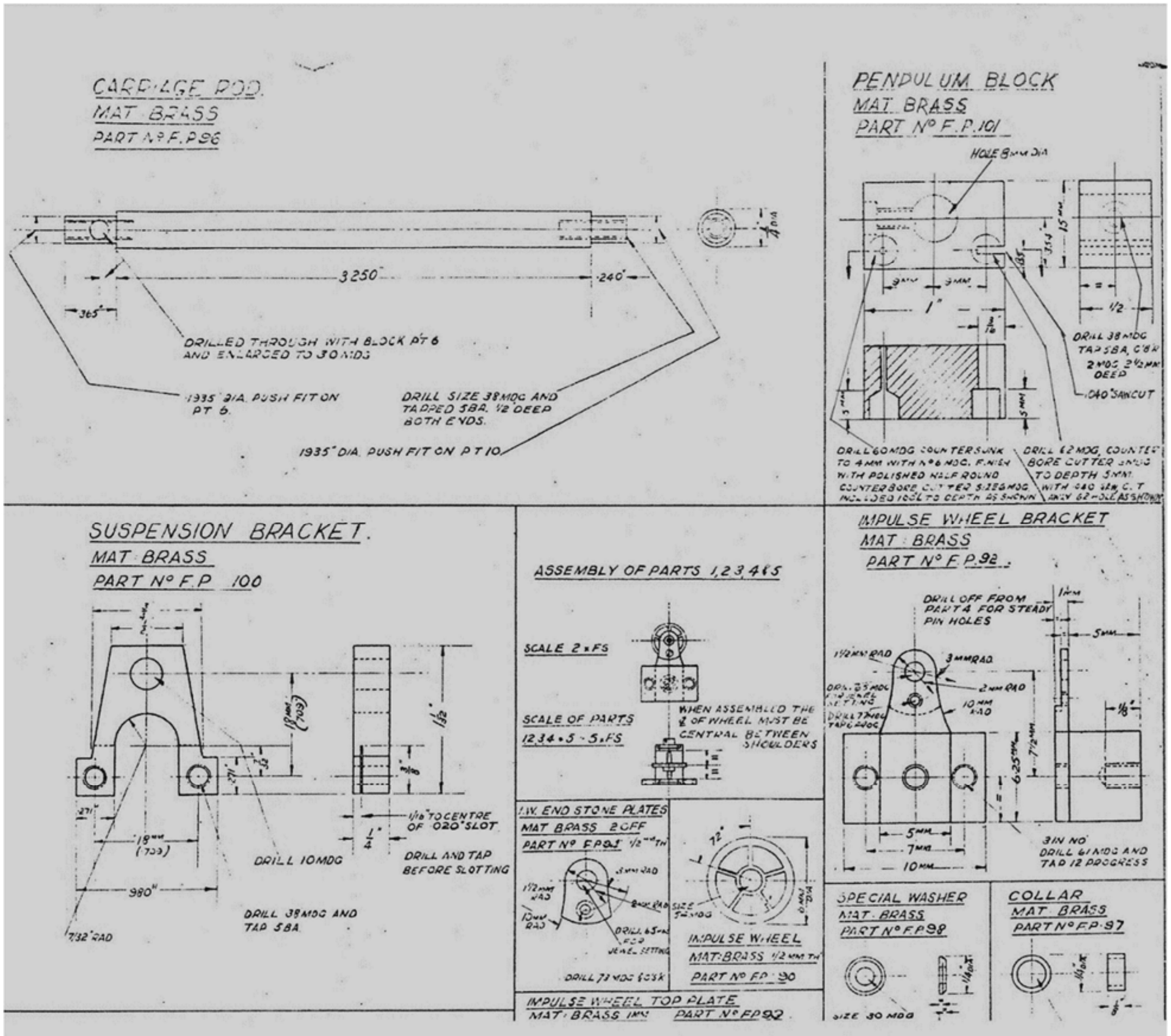
SHORTT-SYNCHRONOME DRAWINGS

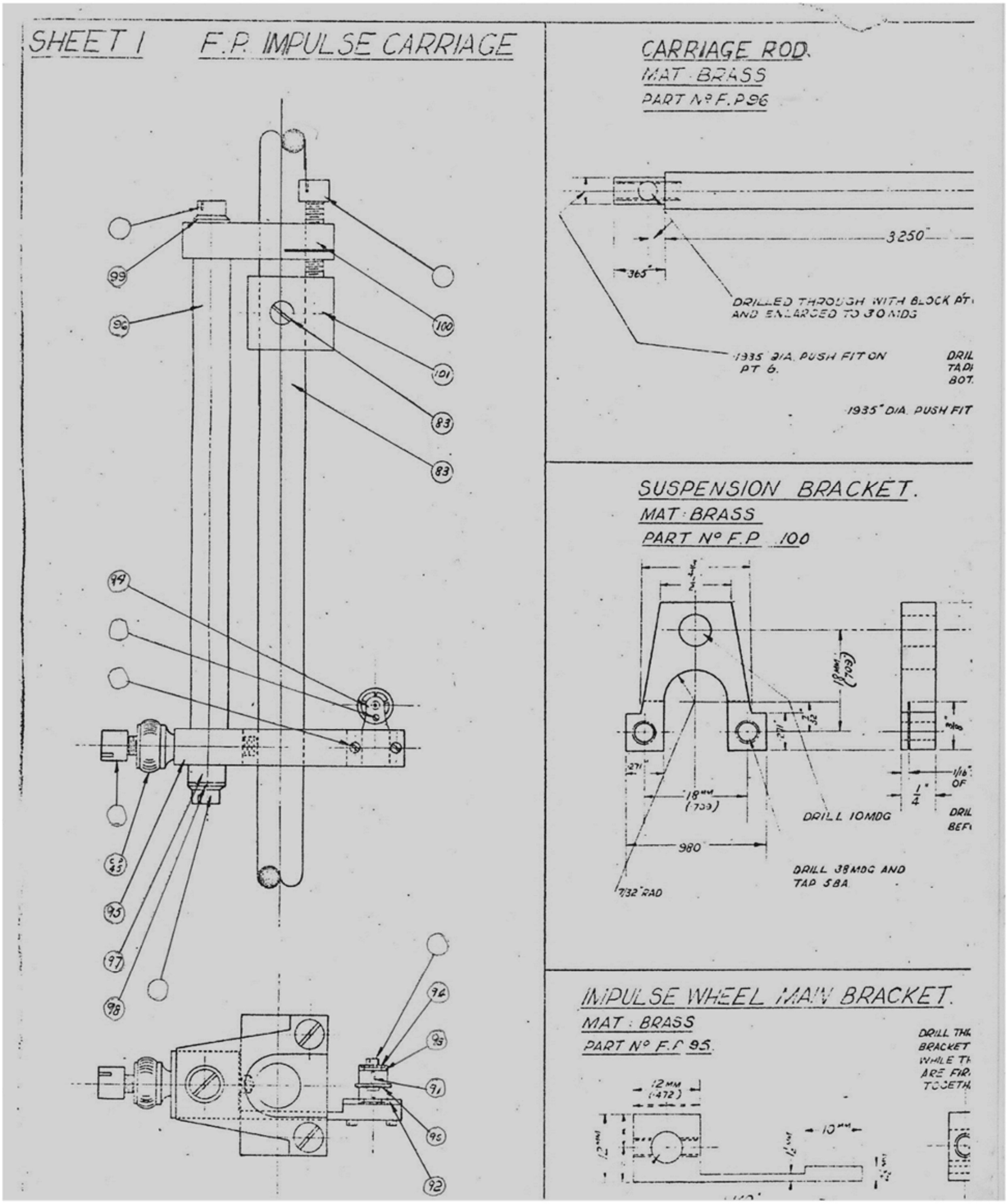
Drawing No.	Title	Notes
FP/1	Free Pendulum Suspension Spring	
Sheet 1	F.P. Impulse Carriage	
Sheet 2	F.P. Case Fittings	
Sheet 3	F.P. Electrical Parts	
Sheet 7	F.P. Inertia Lever Details	
Sheet 10	F.P. Valve & Mercury & Oil Gauge	
Sheet 12	F.P. Pendulum Parts	
Sheet 13	F.P. Headcasting Parts Detail	
Sheet 14	F.P. Assembly of Terminal Block	
A/0959/A	Pendulum Assembly & Details, Master Clock 2CP	Synchronome
1.7.55	Motion of Seconds Pendulum	
2423	General View	Arrangement top of FP
2423D	Enlarged Detail of Impulse Lever, Impulse Wheel, Catch & Pallet	
9412	Free Pendulum & Slave Connections	Supersedes 171229
11252	External Wiring of Circuit, Sidereal Installation	
14124	Details of the Four Legged Headcasting	
20638	Fitting Up Slave Pendulum	
181229	FP Impulse Mechanism	
191229	Slave Synchronizer & Back Board	

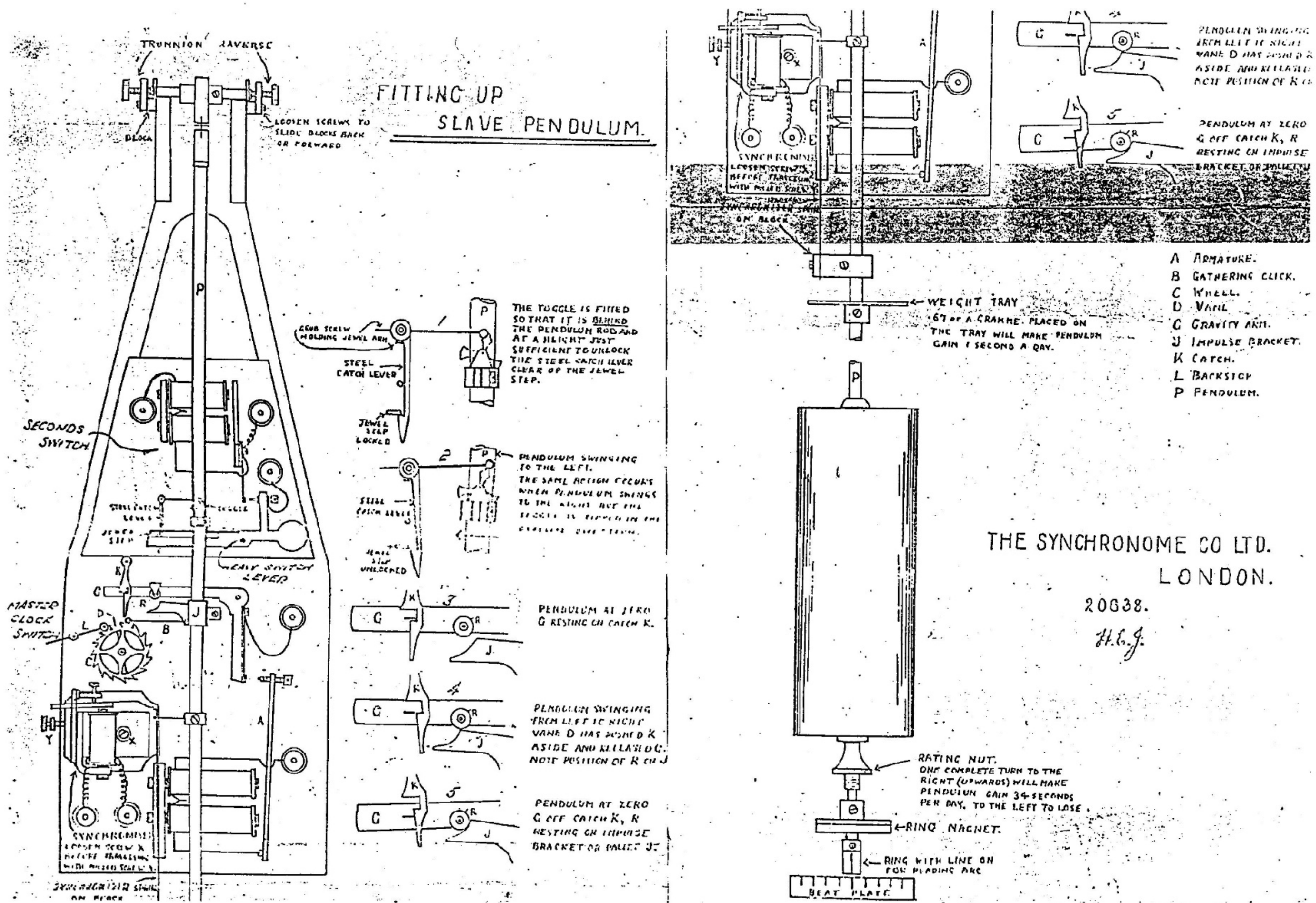

TOP BAND
MAT: BRASS 1-OFF
SCALE: FULL SIZE PART Nº FP4
TOP BAND ADJUSTING SCREW
MAT: BRASS 4-OFF
SCALE: FULL SIZE PART Nº FP6
SAFETY PLATE SCREW
TRUNNION BLOCKS
MAT: STEEL 2-OFF
SCALE: FULL SIZE
TOP BAND ADJUSTING SCREW
SAFETY PLATE ADJUSTING SCREW
WEIGHT TRAY
MAT: BRASS 1-OFF
DAMPING PLATE
MAT: BRASS 1-OFF
SCALE: FULL SIZE PART Nº FP7
SAFETY PLATE
MAT: BRASS 1-OFF
SCALE: FULL SIZE
PINPOINTED SCREW
BLUED FINISH
SAFETY PLATE SUPPORT STUDS
MAT: BRASS 2-OFF
SCALE: FULL SIZE PART Nº FP8A
FINISHED STUD
BLANK
MOVEMENT SUPPORT STUDS
MAT: BRASS 2-OFF
SCALE: FULL SIZE PART Nº FP3
BLANK
FINISHED STUDS
MOVEMENT SUPPORT STUD WASHER
MAT: BRASS 2-OFF
SCALE: FULL SIZE
HEADCASTING FIXING SCREW
MAT: BRASS
SCALE: FULL SIZE

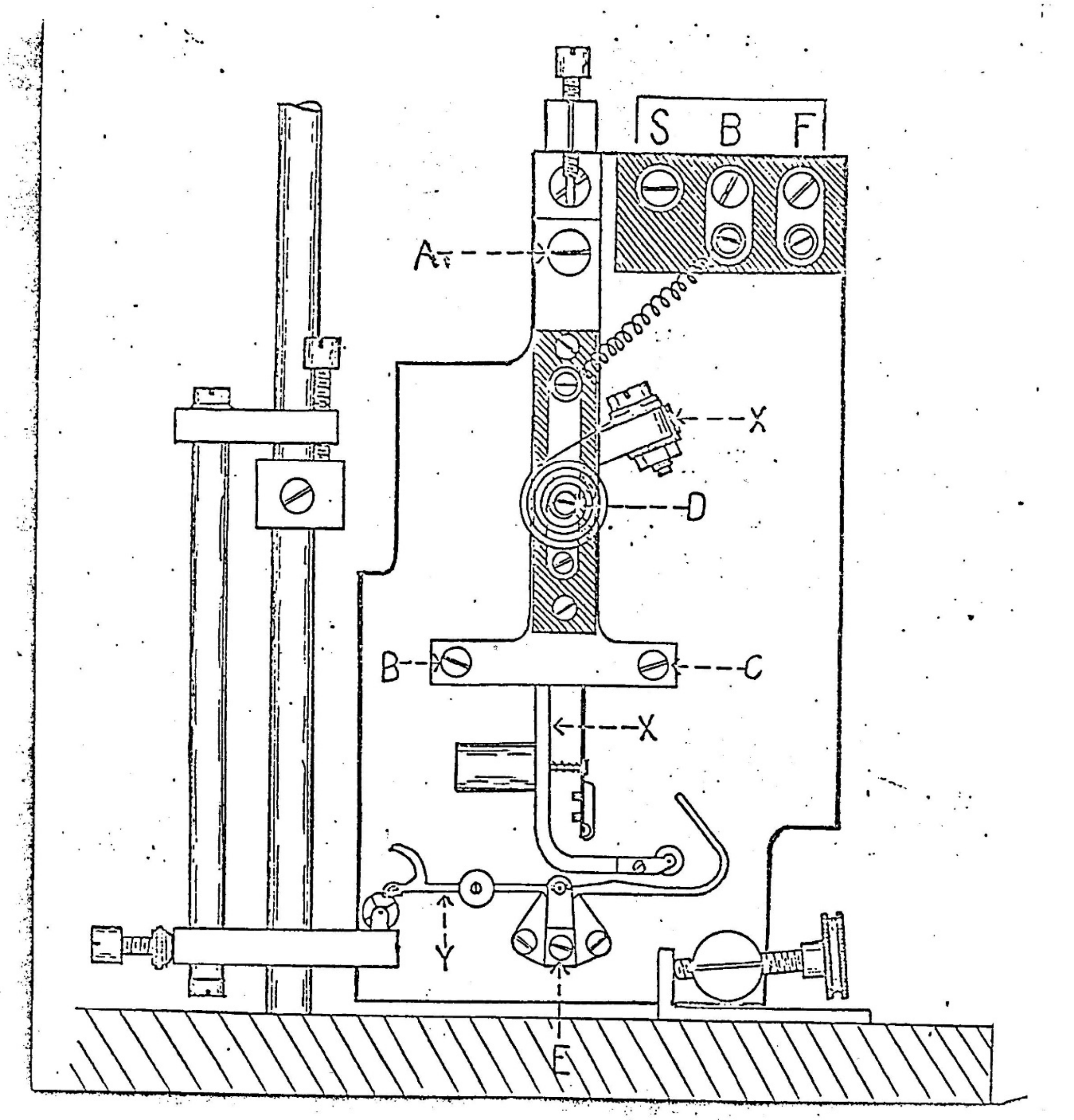

I.W. END STONE PLATES
MAT BRASS 2 OFF
IMPULSE WHEEL
MAT: BRASS 1/2 MM. TH
PART Nº F.P: 90
SPECIAL WASHER
MAT: BRASS
PART Nº F.P. 98
COLLAR
MAT: BRASS
PART Nº F.P. 97
SIZE 10 MDG
SLIDING FIT ON PART 7
IMPULSE WHEEL TOP PLATE
MAT: BRASS 1MM PART Nº F.P. 93
DRILL 65 MDG FOR JEWEL SETTING
RECESSED TO 1/2MM FOR PART 5
DRILL 77 MDG AND TAP 6 PROG.
DRILL SIZE 55 MDG
2 IN NO DRILL SIZE 65 MDG OR STEADY PINS
SPECIAL WASHER
MAT BRASS
I.W. ARBOR
MAT: BLUED STL.
PART Nº F.P. 91
MADE TO FIT IMPULSE WHEEL BRACKET & JEWEL HOLES
3 IN NO DRILL 61 MDG AND TAP 12 PROGRESS

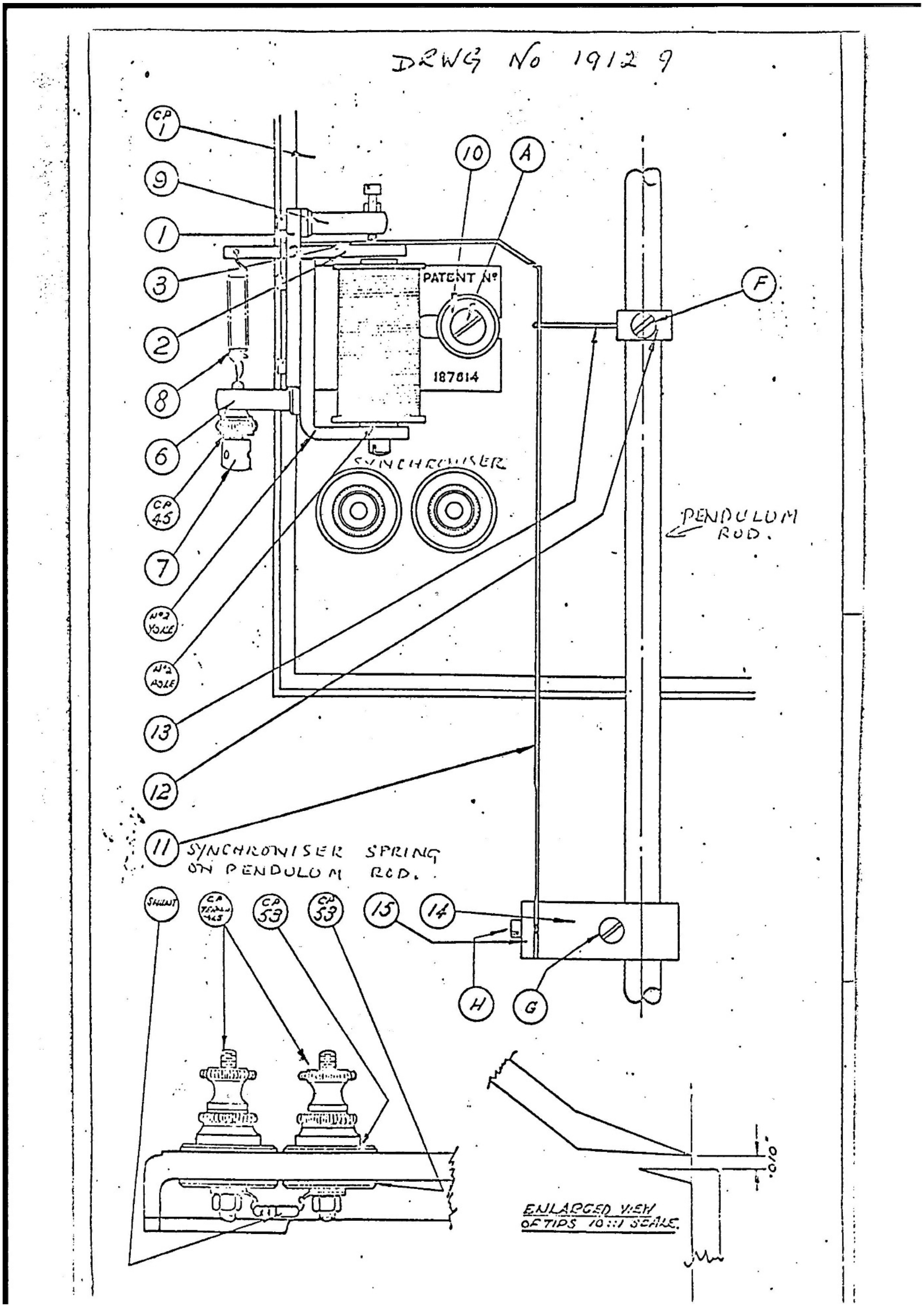

IMPULSE WHEEL MAIN BRACKET.
MAT : BRASS
PART Nº F.P. 95
DRILL 10MDG
DRILL AND TAP BEFORE SLOTTING
DRILL 38 MDG AND TAP 5BA.
18MM (.703)
.980
7/32" RAD
12MM (.472)
12MM
HOLE 10 MDG
1.140"
1.573
10MM
1½MM
DRILL THROUGH BRACKET AND ROD (PT7) WHILE THE TWO PARTS ARE FIRMLY SCREWED TOGETHER, BEFORE TAPPING
DRILL 39 TAP 5BA
58 MDG 2 IN NO
6.25MM
-NOTE- 1½MM = .059
2½MM = .098
3½MM = .138
6.25MM = .246
10 MM = .394
IMPULSE WHEEL TOP PLATE
MAT: BRASS 1MM
PART Nº F.P.93
DRILL 65 MDG FOR JEWEL SETTING
3MM RAD
1½MM RAD
2½MM RAD
6.25MM
7½MM (.295)
5MM
DRILL 77 MDG TAP 6 PROG.
PART Nº F.P.91 ½MM
3MM RAD
2MM RAD
1½MM RAD
10MM RAD
DRILL 65 FOR JEWEL SETTING
DRILL 73 MDG & CSK
SIZE 54MDG
IMPULSE WHEEL
MAT: BRASS ½MM
PART Nº F.P. 90
MADE TO FIT IMPULSE WHEEL BRACKET & WHEEL

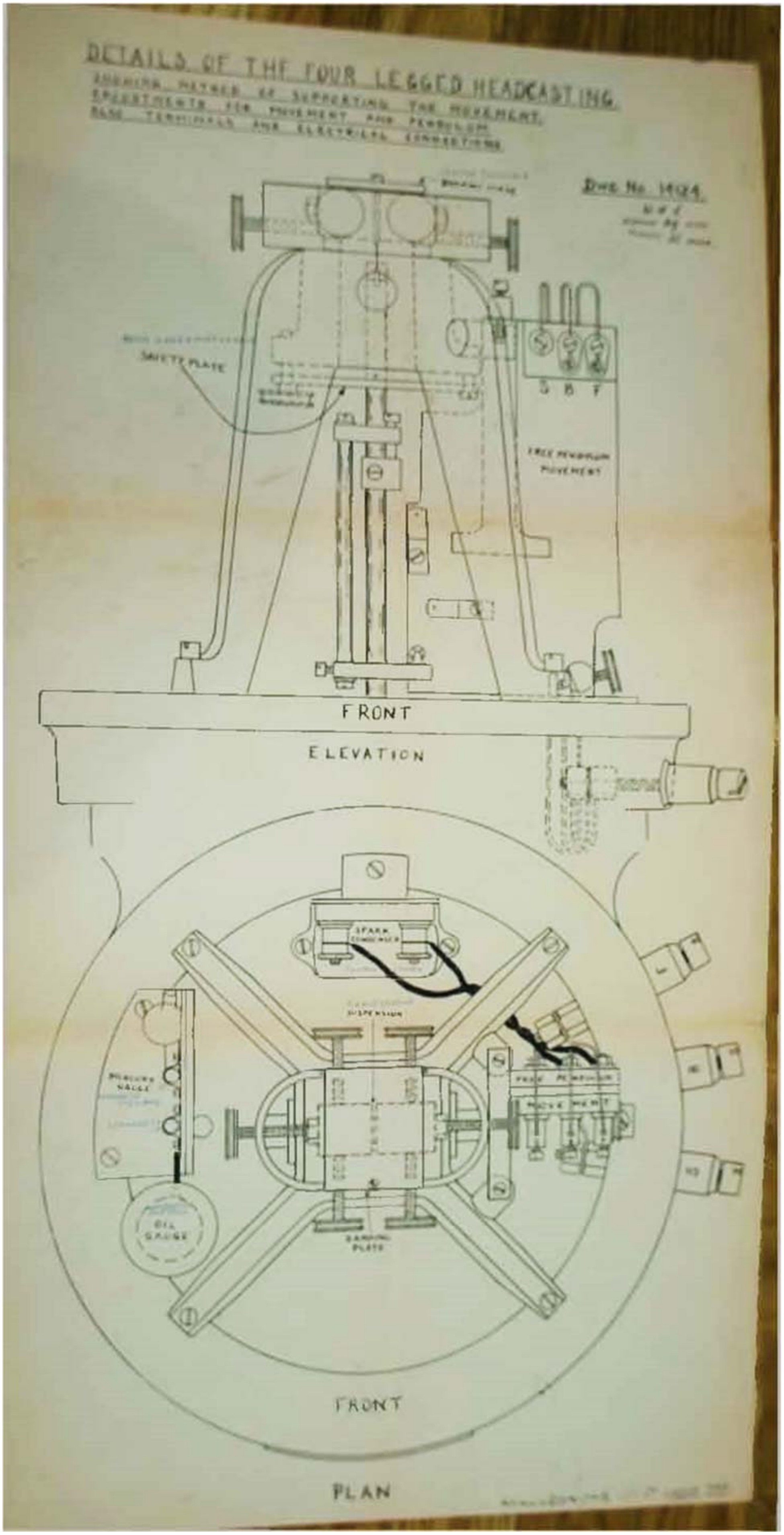

CARRIAGE ROD.
MAT BRASS
PART Nº F.P.96
3.250"
.240"
.365"
DRILLED THROUGH WITH BLOCK PT 6 AND ENLARGED TO 30 MDG
.1935" DIA. PUSH FIT ON PT 6.
DRILL SIZE 38 MDG AND TAPPED 5BA. 1/2" DEEP BOTH ENDS.
.1935" DIA. PUSH FIT ON P T 10.
PENDULUM BLOCK
MAT BRASS
PART Nº F.P.101
HOLE 8MM DIA
1"
1/2
.040" SAWCUT
SUSPENSION BRACKET.
MAT BRASS
PART Nº F.P 100
DRILL 10MDG
DRILL 38MDG AND TAP 5BA.
7/32" RAD
.980"
1/16" TO CENTRE OF .020" SLOT
DRILL AND TAP BEFORE SLOTTING
ASSEMBLY OF PARTS 1,2,3,4 & 5
SCALE 2 x FS
SCALE OF PARTS
1,2,3,4 • 5 - 5 x FS
WHEN ASSEMBLED THE ℄ OF WHEEL MUST BE CENTRAL BETWEEN SHOULDERS
I.W. END STONE PLATES
MAT BRASS 2 OFF
PART Nº F.P.91
IMPULSE WHEEL
MAT BRASS
PART Nº FP 90
IMPULSE WHEEL TOP PLATE
MAT BRASS
PART Nº FP 92
IMPULSE WHEEL BRACKET
MAT BRASS
PART Nº F P.92
DRILL OFF FROM PART 4 FOR STEADY PIN HOLES
3MM RAD
2MM RAD
10MM RAD
5MM
7MM
10MM
DRILL 61 MDG AND TAP 12 PROGRESS
SPECIAL WASHER
MAT BRASS
PART Nº F.P.98
SIZE 30 MDG
COLLAR
MAT BRASS
PART Nº F.P.97

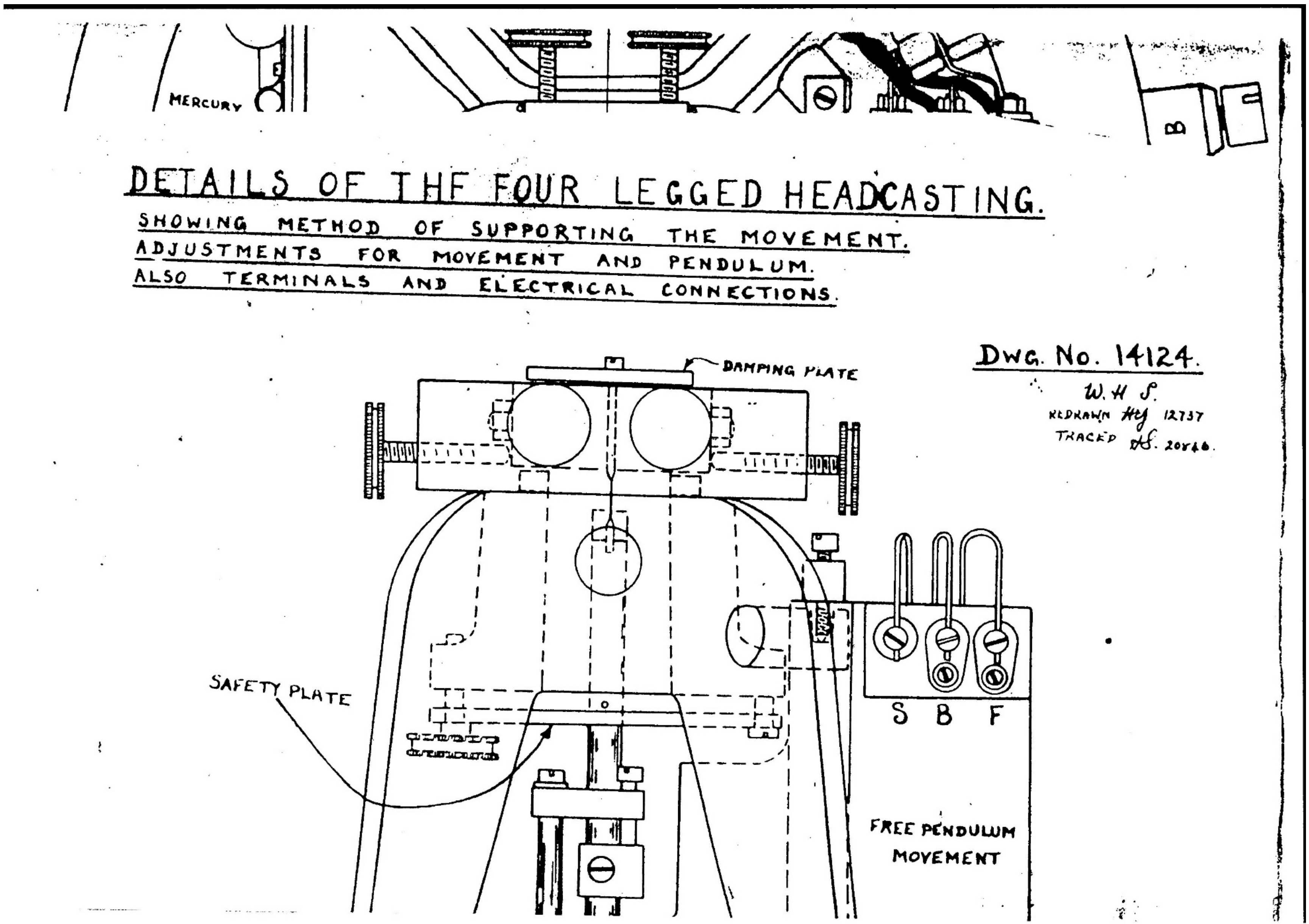

SHEET I F.P. IMPULSE CARRIAGE
CARRIAGE ROD.
MAT BRASS
PART Nº F.P.96
3250"
365"
DRILLED THROUGH WITH BLOCK PT
AND ENLARGED TO 30 MDG
1935 DIA. PUSH FIT ON PT 6.
1935" DIA. PUSH FIT
SUSPENSION BRACKET.
MAT BRASS
PART Nº F.P 100
18 MM (709)
980
DRILL 10MDG
DRILL 38MDG AND TAP 5BA
7/32" RAD
IMPULSE WHEEL MAIN BRACKET.
MAT: BRASS
PART Nº F.P 95.
12 MM (472)
10 MM
99
96
100
101
83
94
95
97
98
91
92

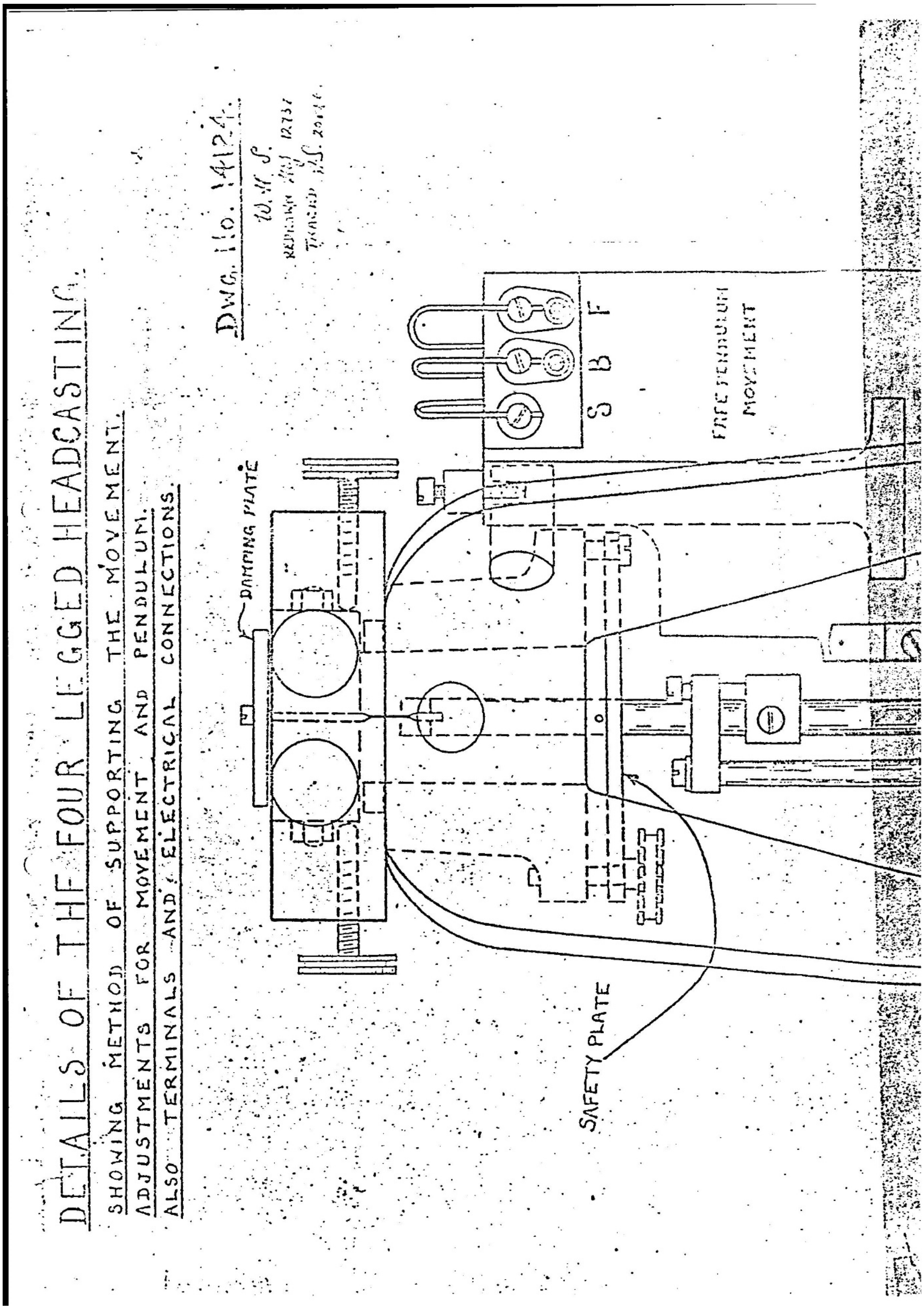

FITTING UP
SLAVE PENDULUM.
TRUNNION
BLOCK
LOOSEN SCREWS TO SLIDE BLOCKS BACK OR FORWARD
P
SECONDS SWITCH
MASTER CLOCK SWITCH
K
R
B
J
C
D
L
A
Y
THE TOGGLE IS FITTED SO THAT IT IS BEHIND THE PENDULUM ROD AND AT A HEIGHT JUST SUFFICIENT TO UNLOCK THE STEEL CATCH LEVER CLEAR OF THE JEWEL STEP.
STEEL CATCH LEVER
JEWEL STEP LOCKED
PENDULUM SWINGING TO THE LEFT.
JEWEL STEP UNLOCKED
PENDULUM AT ZERO G RESTING ON CATCH K.
PENDULUM SWINGING FROM LEFT TO RIGHT VANE D HAS PUSHED K ASIDE AND RELEASED G. NOTE POSITION OF R ON J
PENDULUM AT ZERO G OFF CATCH K, R RESTING ON IMPULSE BRACKET OR PALLET J.
WEIGHT TRAY
THE TRAY WILL MAKE PENDULUM GAIN 1 SECOND A DAY.
A ARMATURE.
B GATHERING CLICK.
C WHEEL.
D VANE.
G GRAVITY ARM.
J IMPULSE BRACKET.
K CATCH.
L BACKSTOP
P PENDULUM.
THE SYNCHRONOME CO LTD.
LONDON.
20638.
H.G.J.
RATING NUT.
ONE COMPLETE TURN TO THE RIGHT (UPWARDS) WILL MAKE PENDULUM GAIN 34 SECONDS PER DAY, TO THE LEFT TO LOSE.
RING MAGNET.
BEAT PLATE

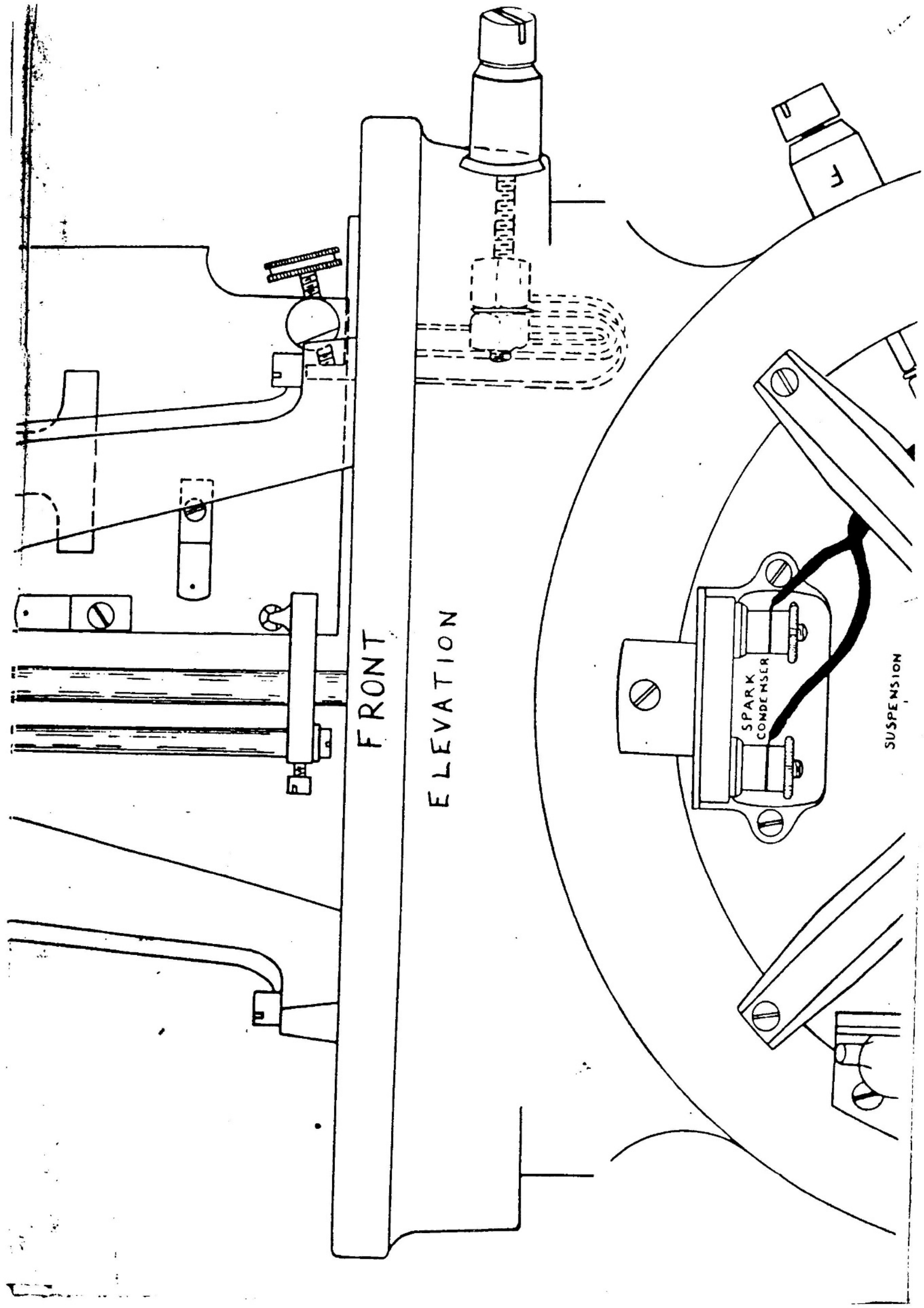

S B F
A
X
D
B
C
X
Y
E

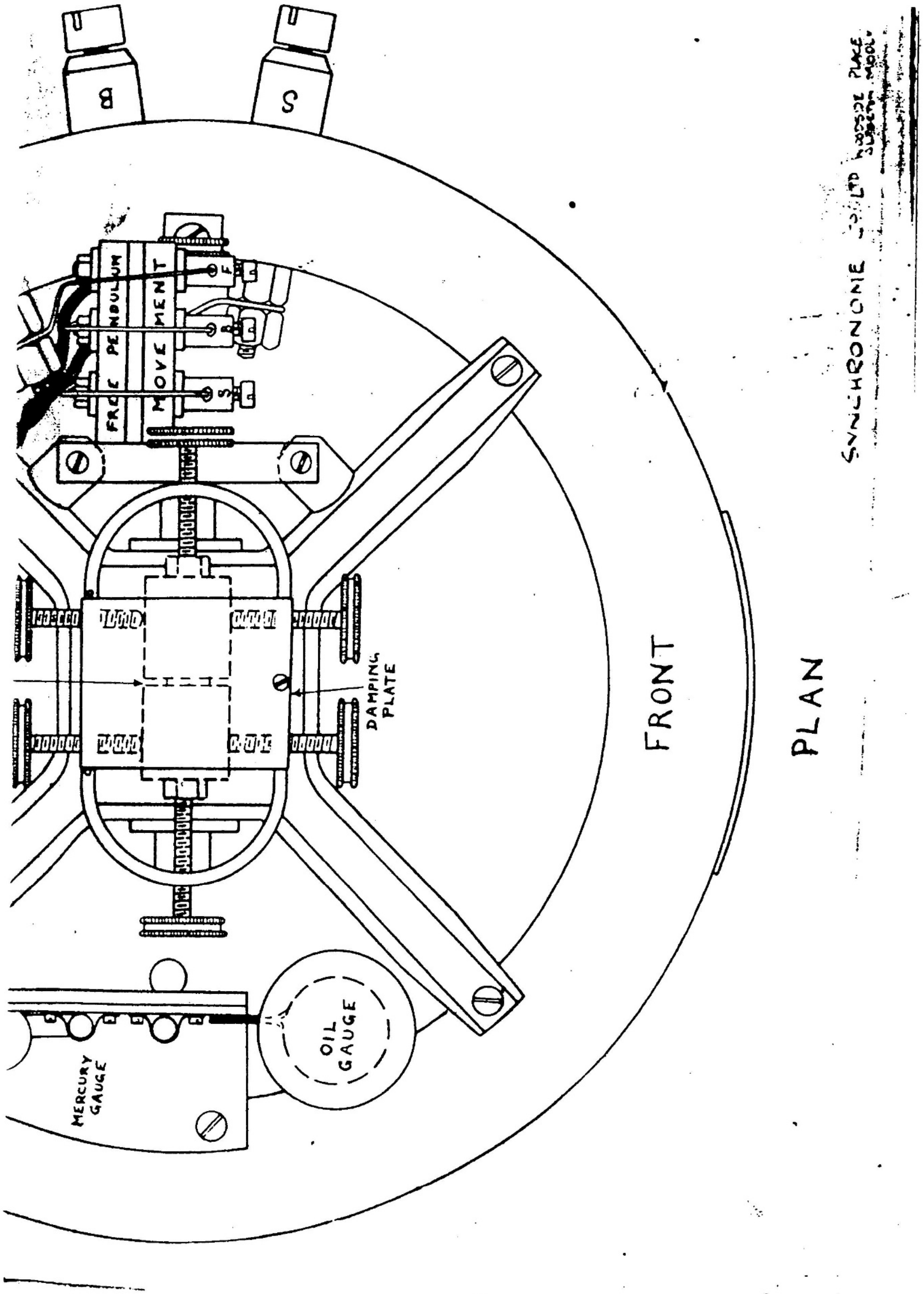

DRWG No 1912 9
CP 1
9
1
3
2
8
6
CP 45
7
No 2 YOKE
No 2 POLE
13
12
11
SYNCHRONISER SPRING ON PENDULUM ROD.
10
A
PATENT No
187614
SYNCHRONISER
F
PENDULUM ROD.
SHUNT
CP 53
CP 53
15
14
H
G
ENLARGED VIEW OF TIPS 10:1 SCALE.
.010"

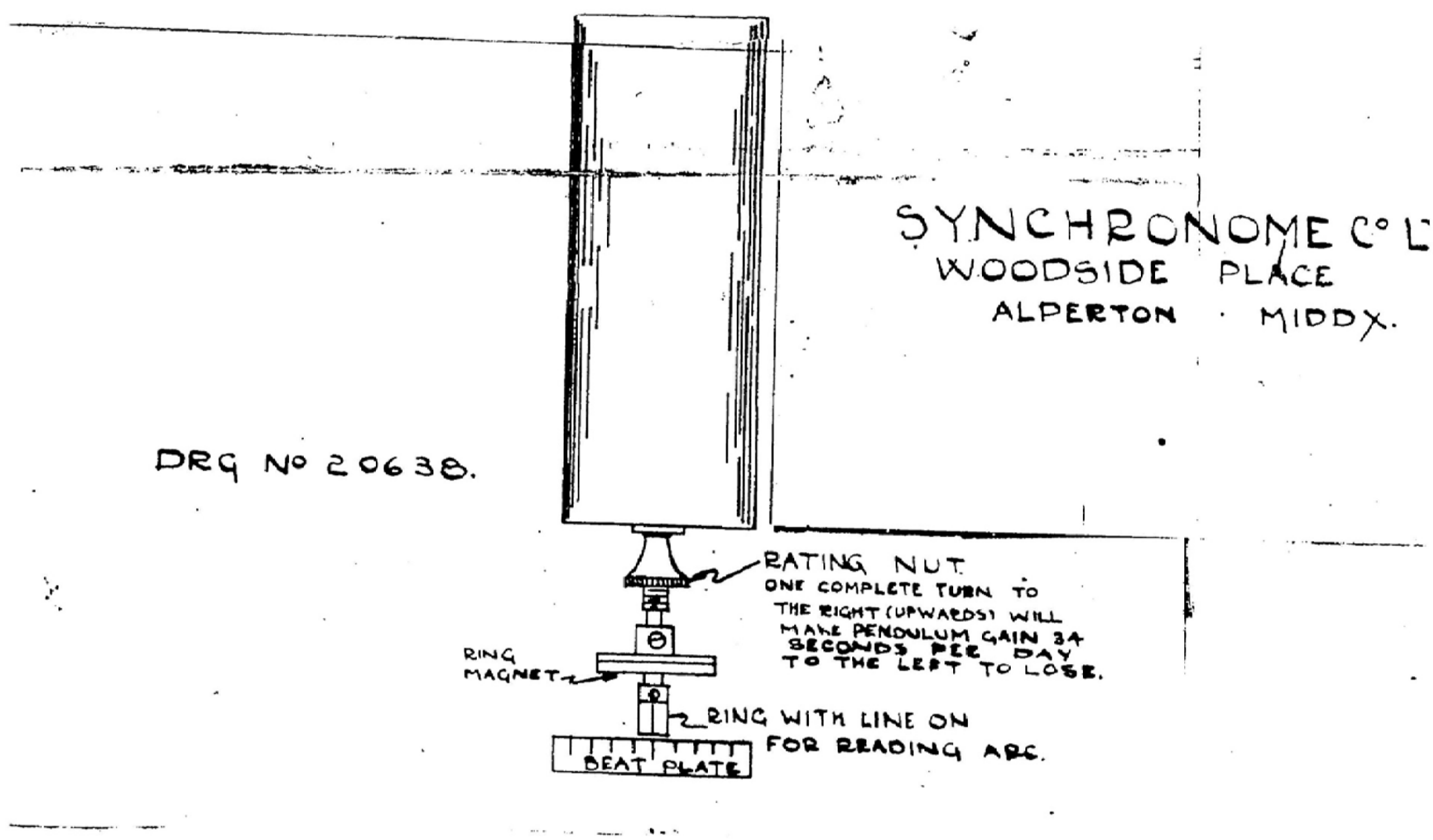

DETAILS OF THE FOUR LEGGED HEADCASTING
SAFETY PLATE
S B F
FREE PENDULUM MOVEMENT
FRONT
ELEVATION
SPARK CONDENSER
SUSPENSION
OIL GAUGE
FRONT
PLAN

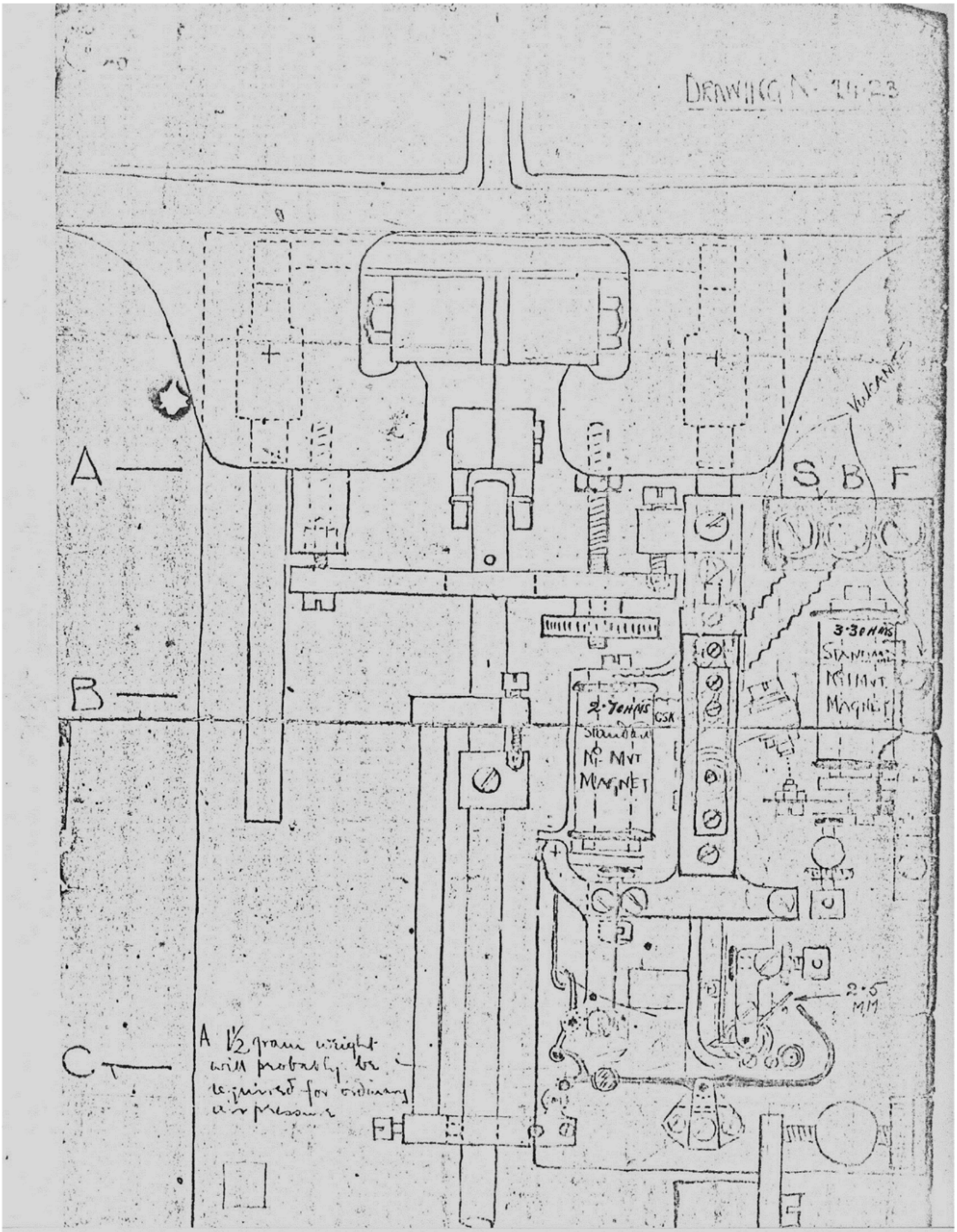

MERCURY
B
DETAILS OF THF FOUR LEGGED HEADCASTING.
SHOWING METHOD OF SUPPORTING THE MOVEMENT.
ADJUSTMENTS FOR MOVEMENT AND PENDULUM.
ALSO TERMINALS AND ELECTRICAL CONNECTIONS.
DWG. No. 14124.
W. H. S.
REDRAWN 12737
TRACED 20x46.
DAMPING PLATE
SAFETY PLATE
S B F
FREE PENDULUM
MOVEMENT

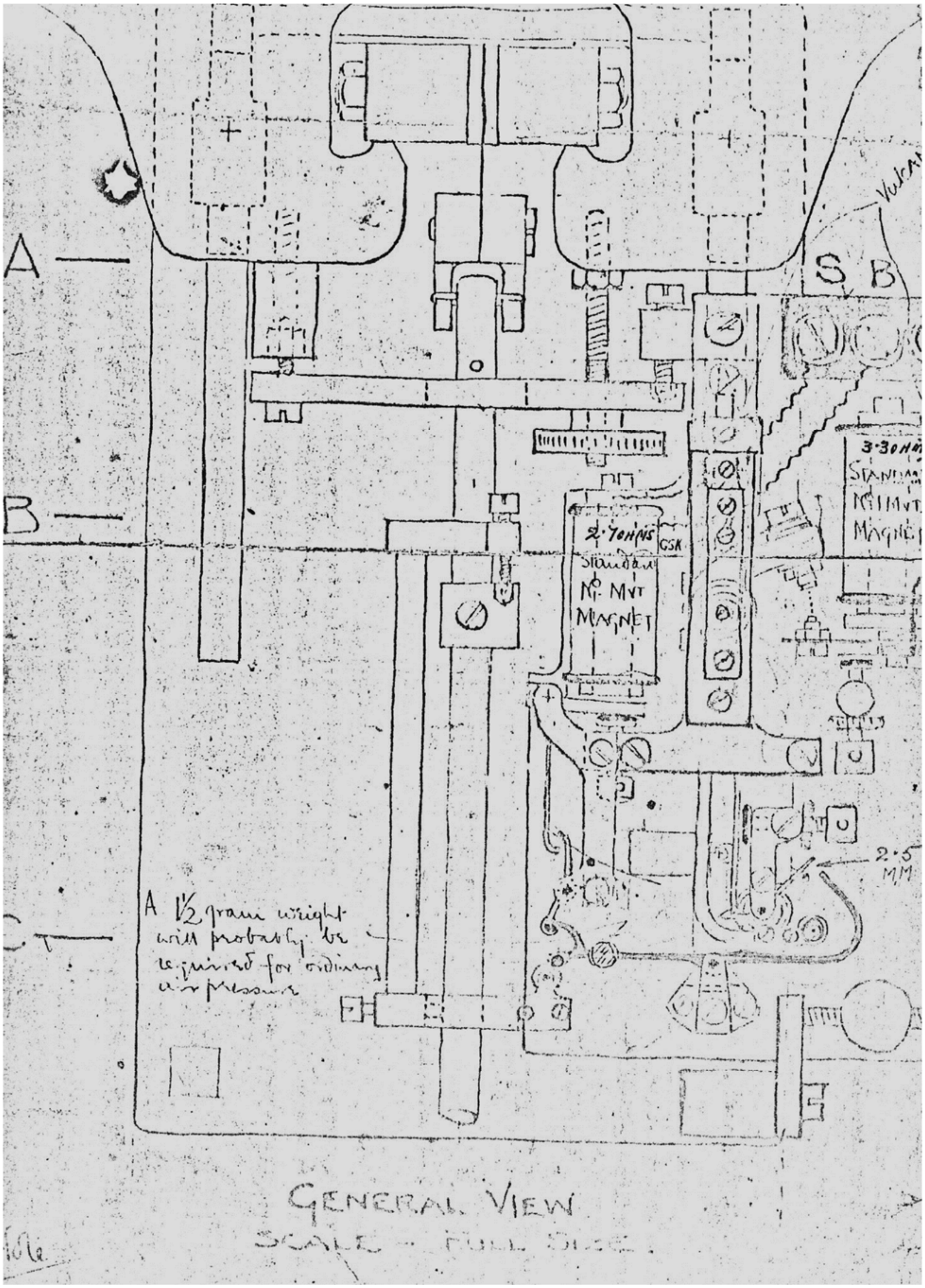

DETAILS OF THE FOUR LEGGED HEADCASTING.
SHOWING METHOD OF SUPPORTING THE MOVEMENT.
ADJUSTMENTS FOR MOVEMENT AND PENDULUM.
ALSO TERMINALS AND ELECTRICAL CONNECTIONS.
DWG. No. 1412A.
DAMPING PLATE
SAFETY PLATE
S B F
FREE PENDULUM MOVEMENT


FRONT
ELEVATION
SPARK
CONDENSER
SUSPENSION
F


B
S
FREE PENDULUM
MOVEMENT
DAMPING PLATE
FRONT
PLAN
MERCURY GAUGE
OIL GAUGE
SYNCHRONOME


SYNCHRONOME C° L
WOODSIDE PLACE
ALPERTON · MIDDX.
DRG N° 20638.
RATING NUT
ONE COMPLETE TURN TO THE RIGHT (UPWARDS) WILL MAKE PENDULUM GAIN 34 SECONDS PER DAY TO THE LEFT TO LOSE.
RING MAGNET
RING WITH LINE ON FOR READING ARC.
BEAT PLATE


DRAWING N. 14.23
VULCANITE
S B F
A
B
C
3.3 OHMS
STANDARD
M.M.V.T.
MAGNET
2.7 OHMS
Standard
M.MVT
MAGNET
CSK
2.5
MM
A 1½ gram weight will probably be required for ordinary air pressure

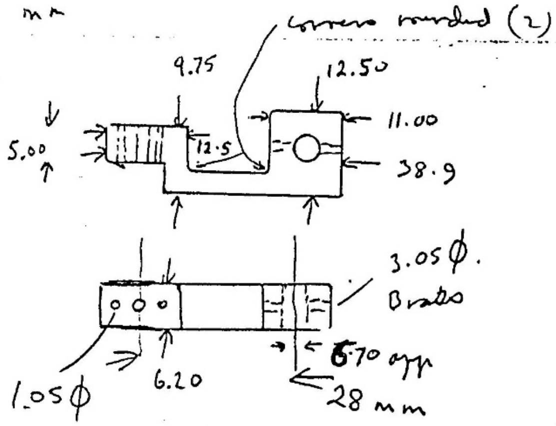

A
B
C
S B
VULCAN
3·3 OHMS
STANDARD
No. MVT
MAGNET
2·7 OHMS
GSK
Standard
No. MVT
MAGNET
2·5 MM
A 1½ gram weight will probably be required for ordinary air pressure
GENERAL VIEW
SCALE – FULL SIZE

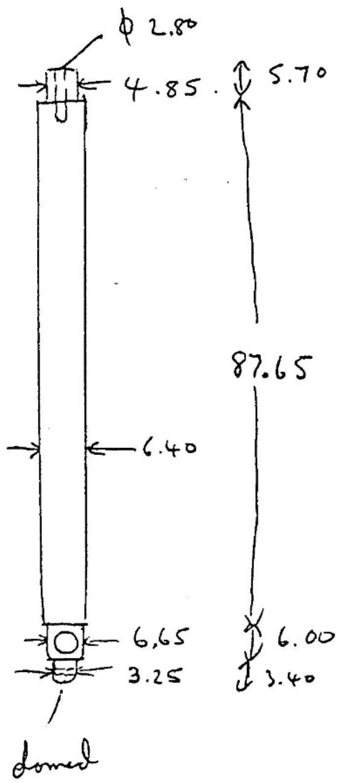
This is a photostat copy of Mr Shortt's original drawing, from which we made the first Free Pendulum which was fitted in a glass tube.
I have slightly altered the small gravity lever to bring it up to the shape we found was necessary.
The general suspension parts & top fitting is very much different to when we fitted everything in the copper cylinder.

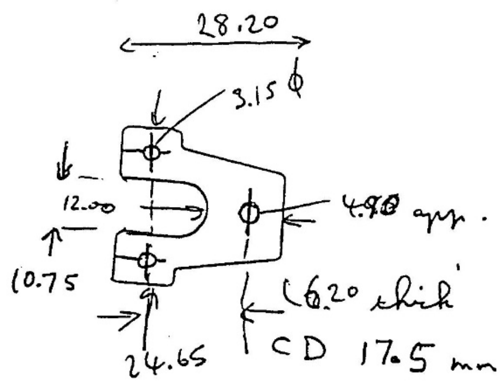
WHR

I found this drawing rather tattered just by chance.

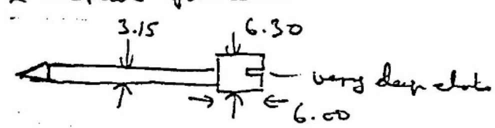
Carrier Impulse roller.



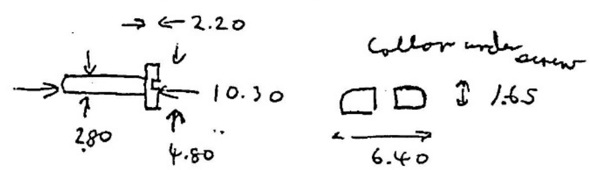




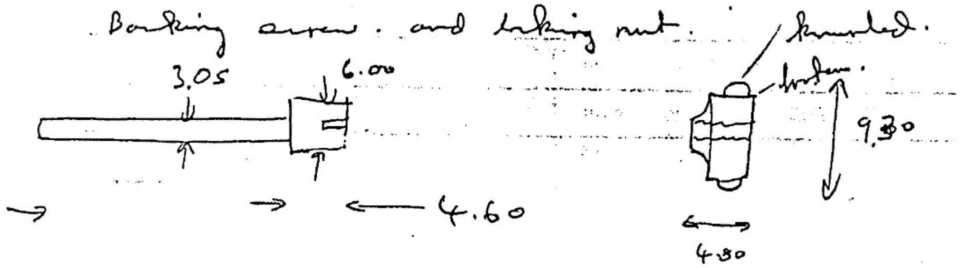
2 screws for above.



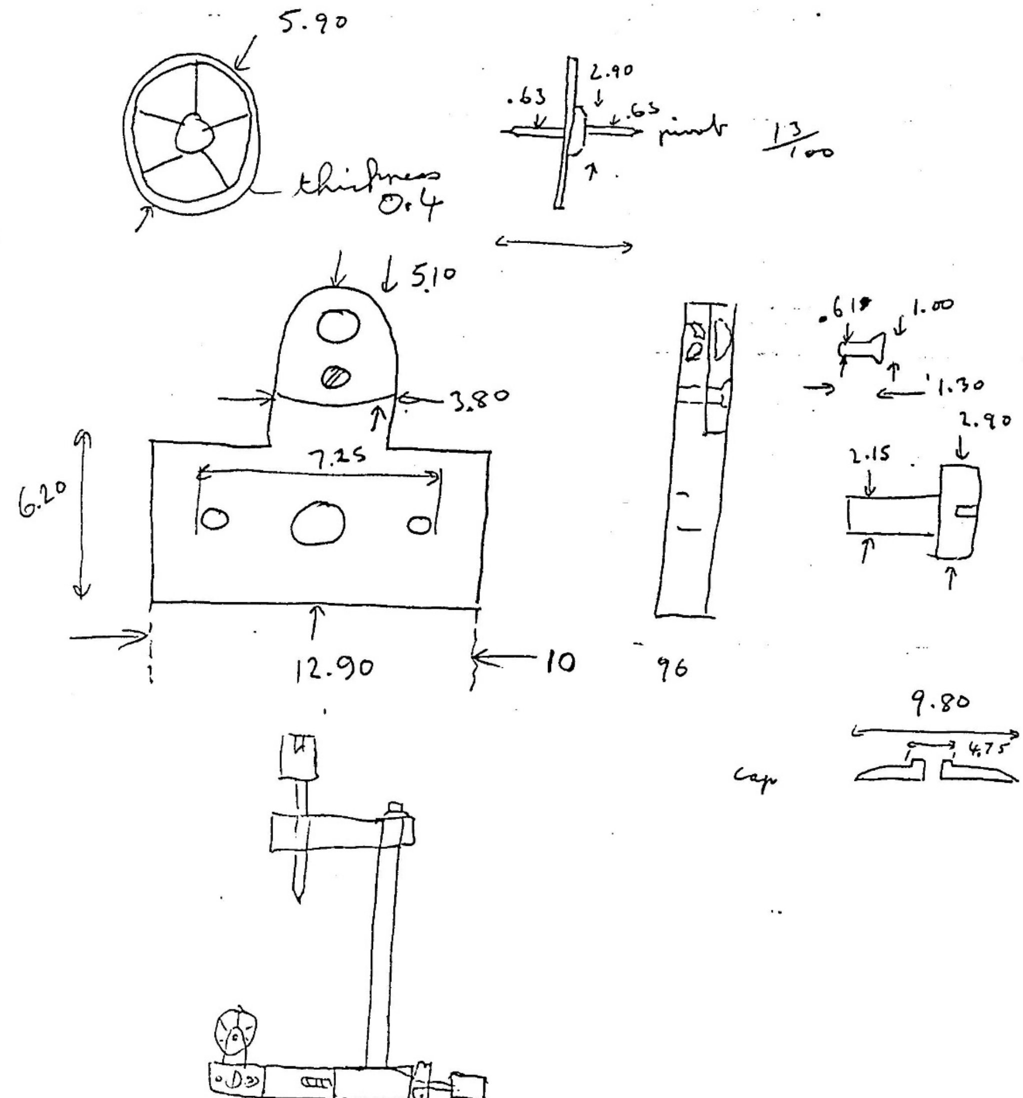
securing screw for above.



Backing screw and locking nut.

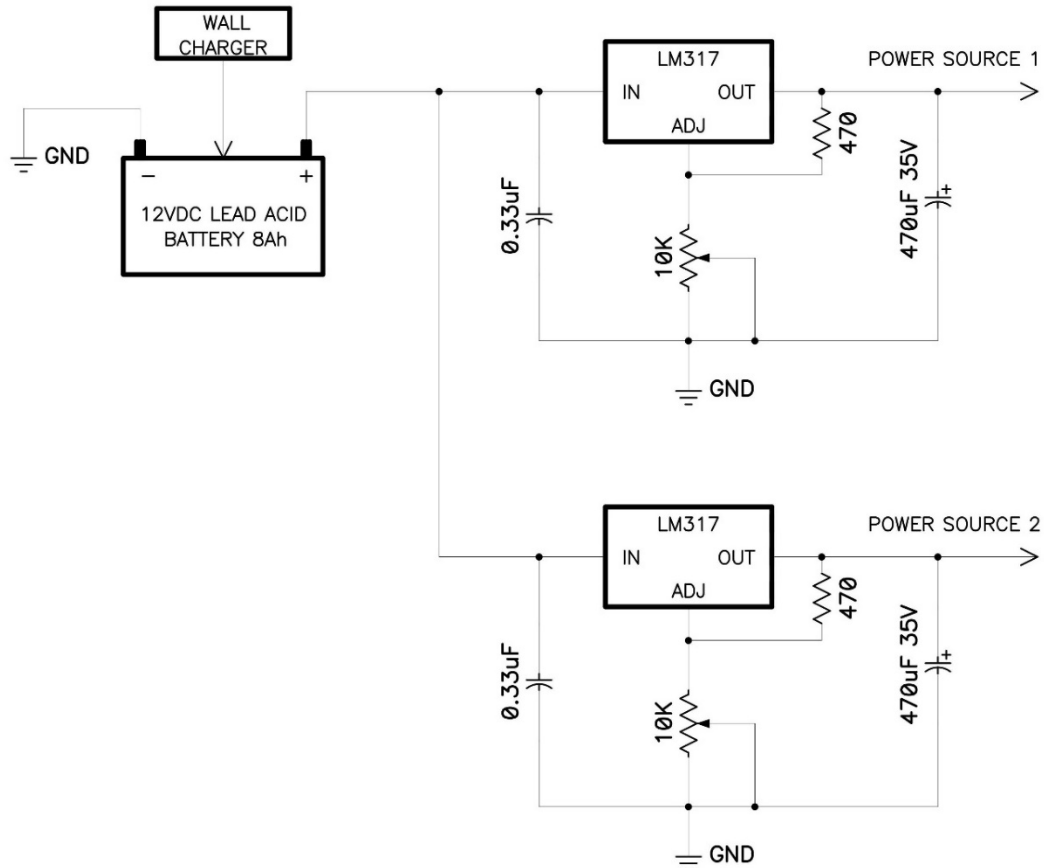


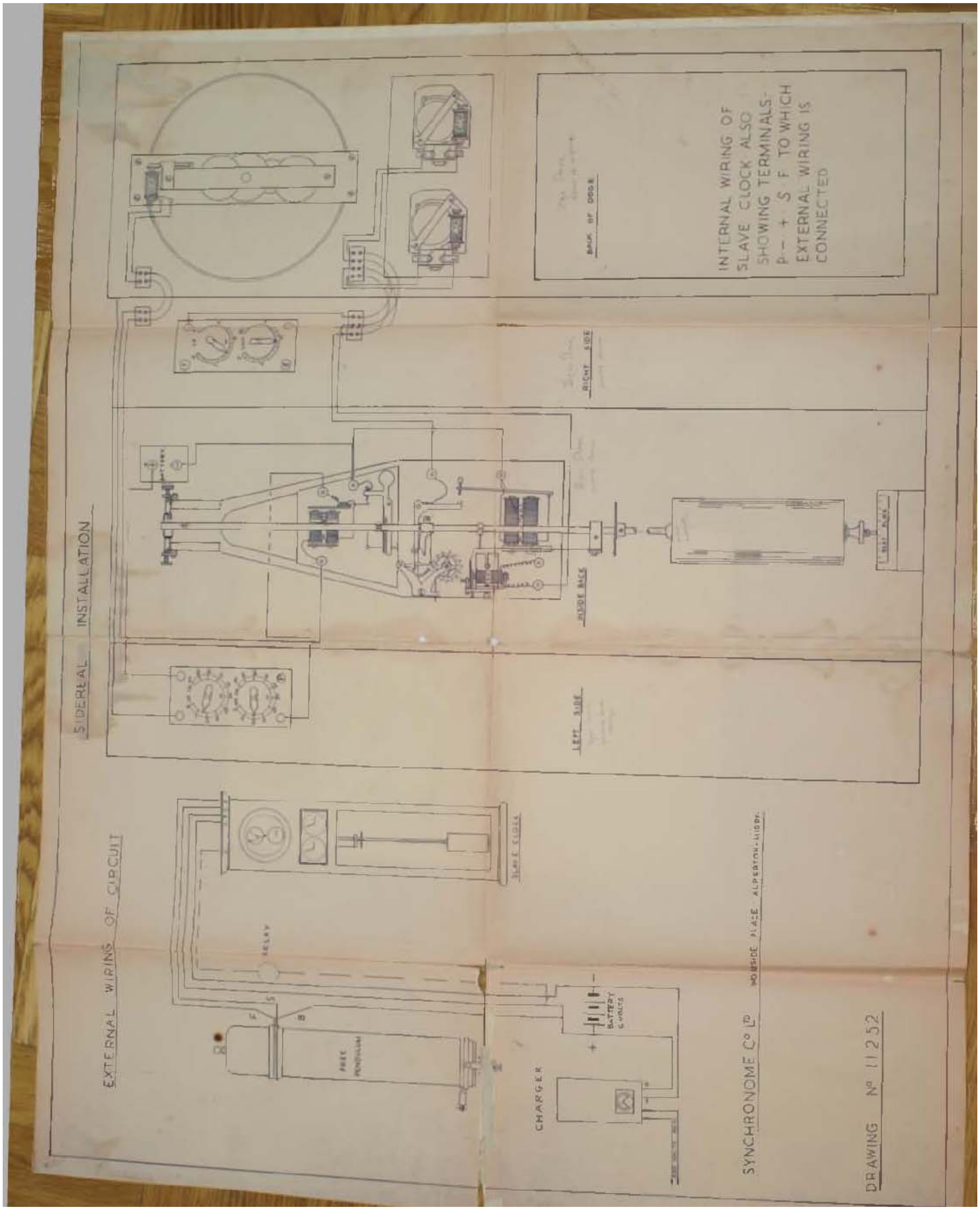
wheel and carriers.

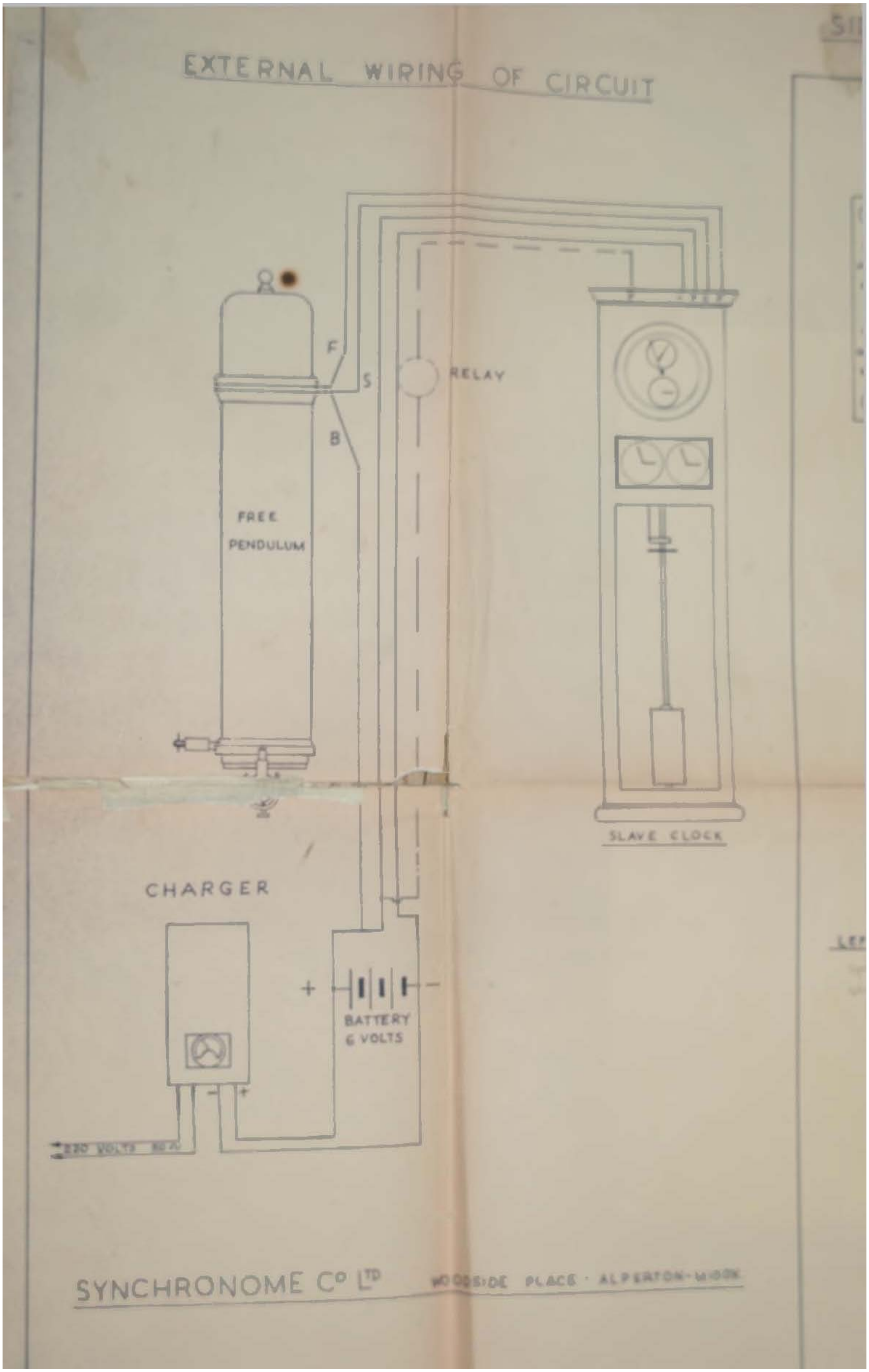


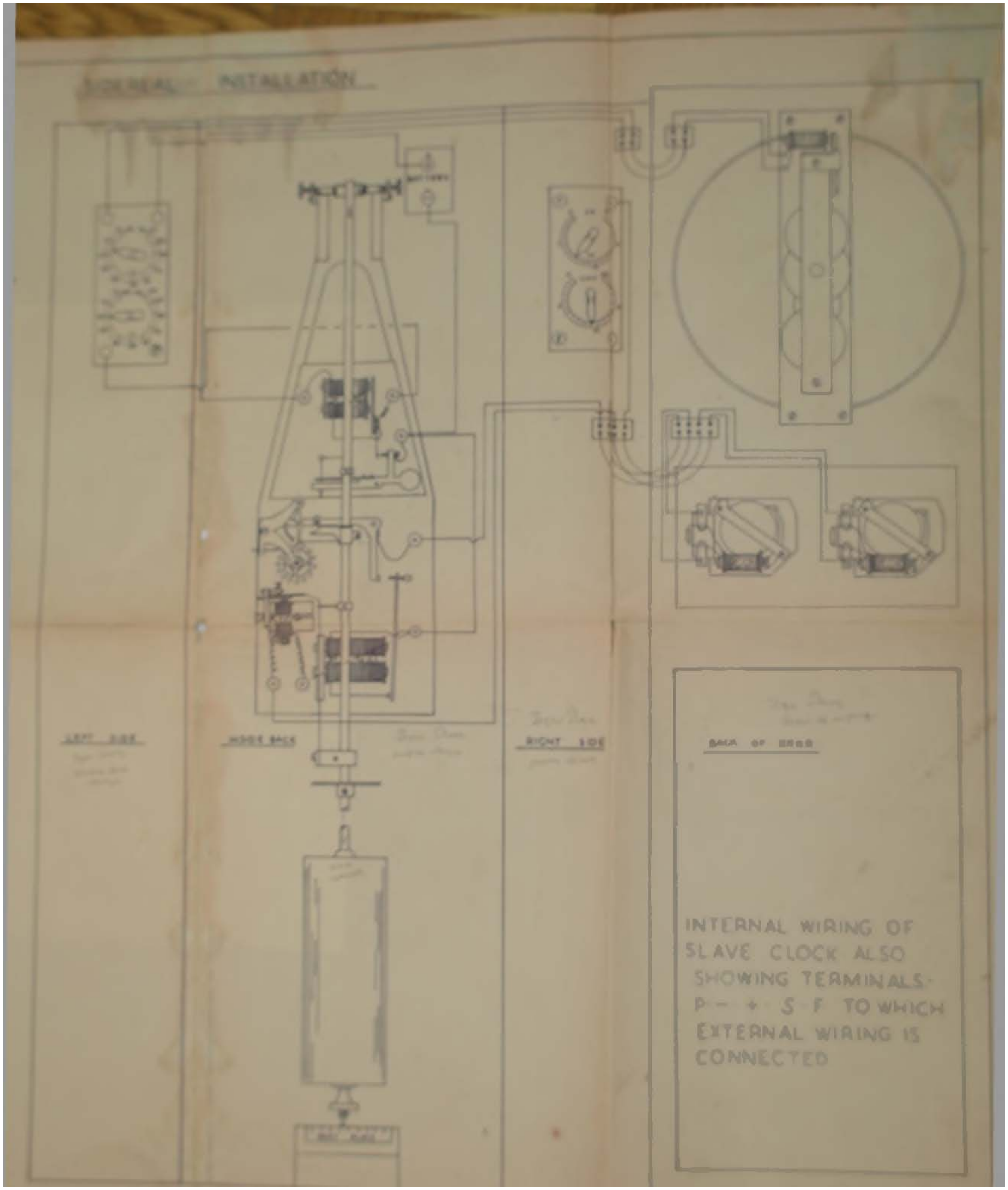
14.7. Wiring Diagrams

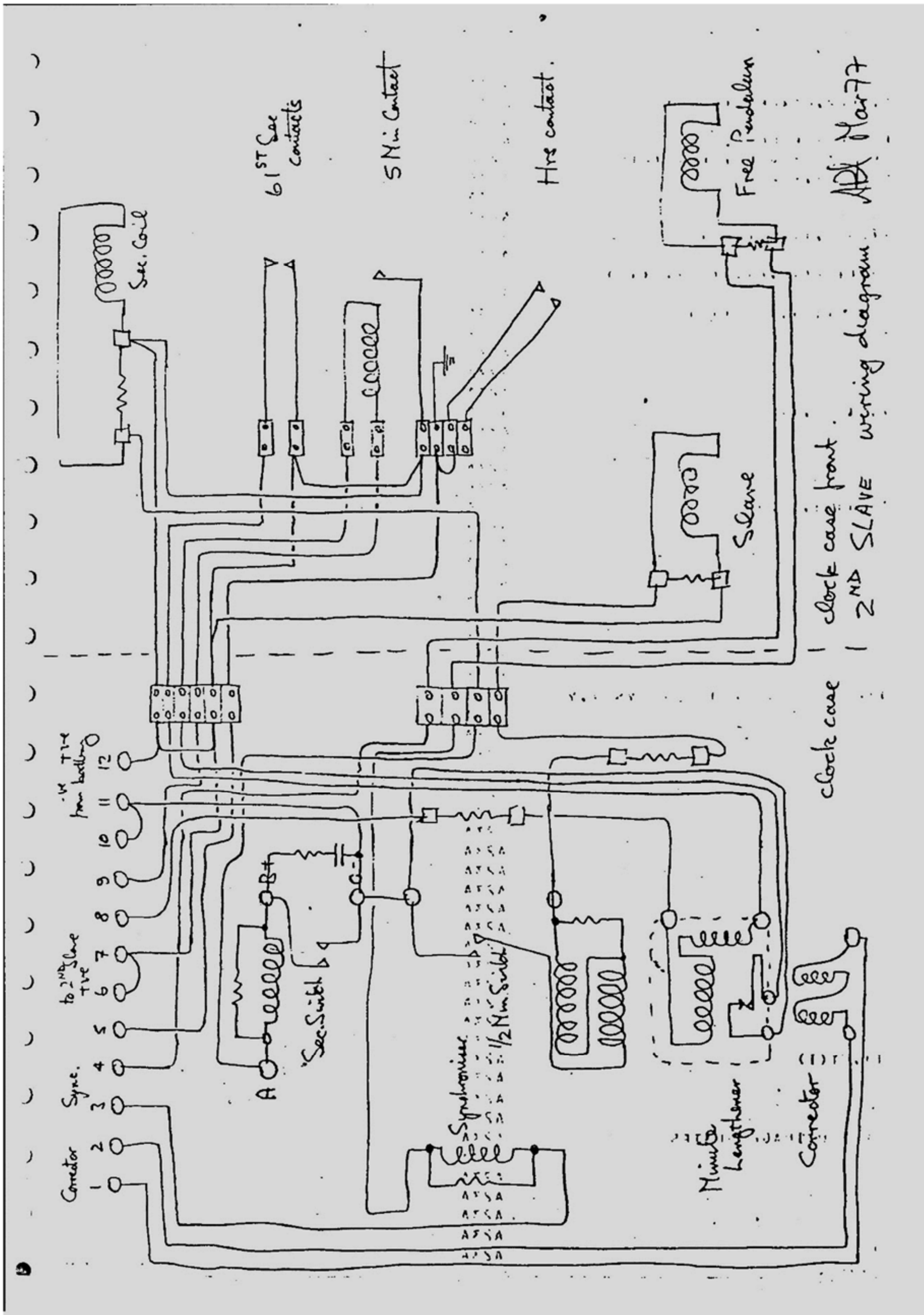
Power Supply (This is the same drawing as shown in Section 8.)

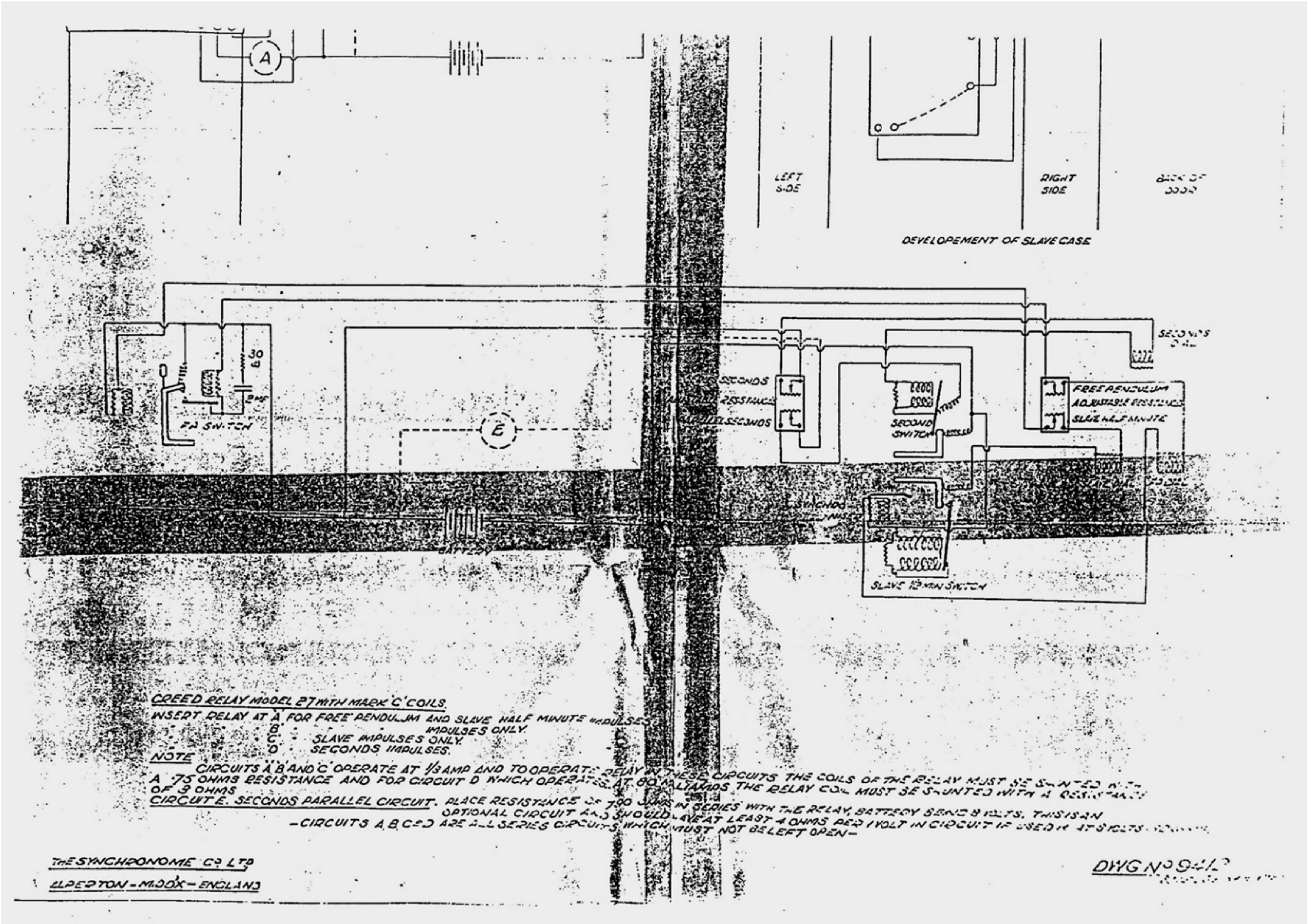


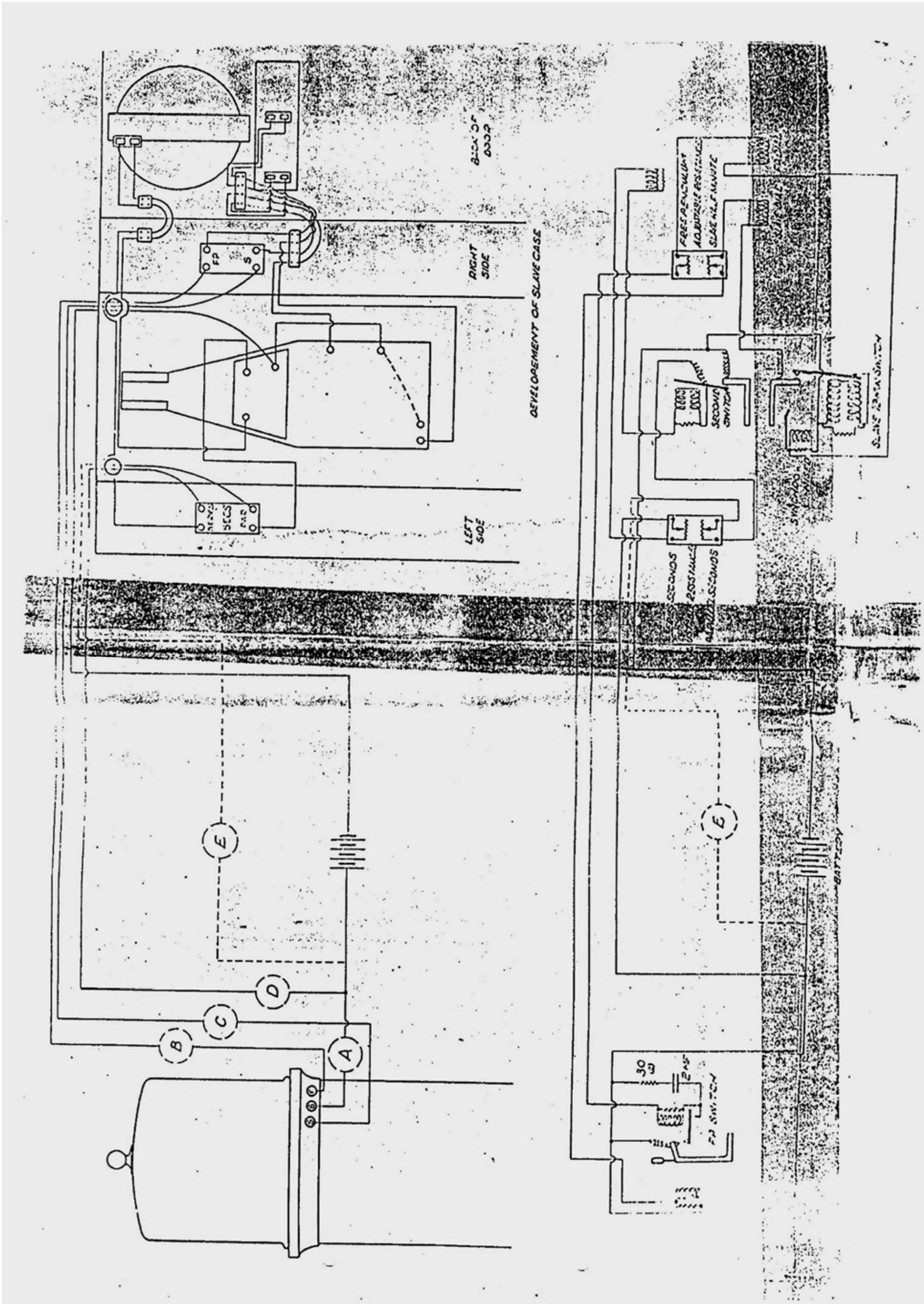

EXTERNAL WIRING OF CIRCUIT
SIDEREAL INSTALLATION
INTERNAL WIRING OF SLAVE CLOCK ALSO SHOWING TERMINALS- B- + S F TO WHICH EXTERNAL WIRING IS CONNECTED
LEFT SIDE
RIGHT SIDE
INSIDE BACK
BACK OF DOOR
SLAVE CLOCK
RELAY
FREE PENDULUM
BATTERY 6 VOLTS
CHARGER
SYNCHRONOME Co Ltd
DRAWING No 11252

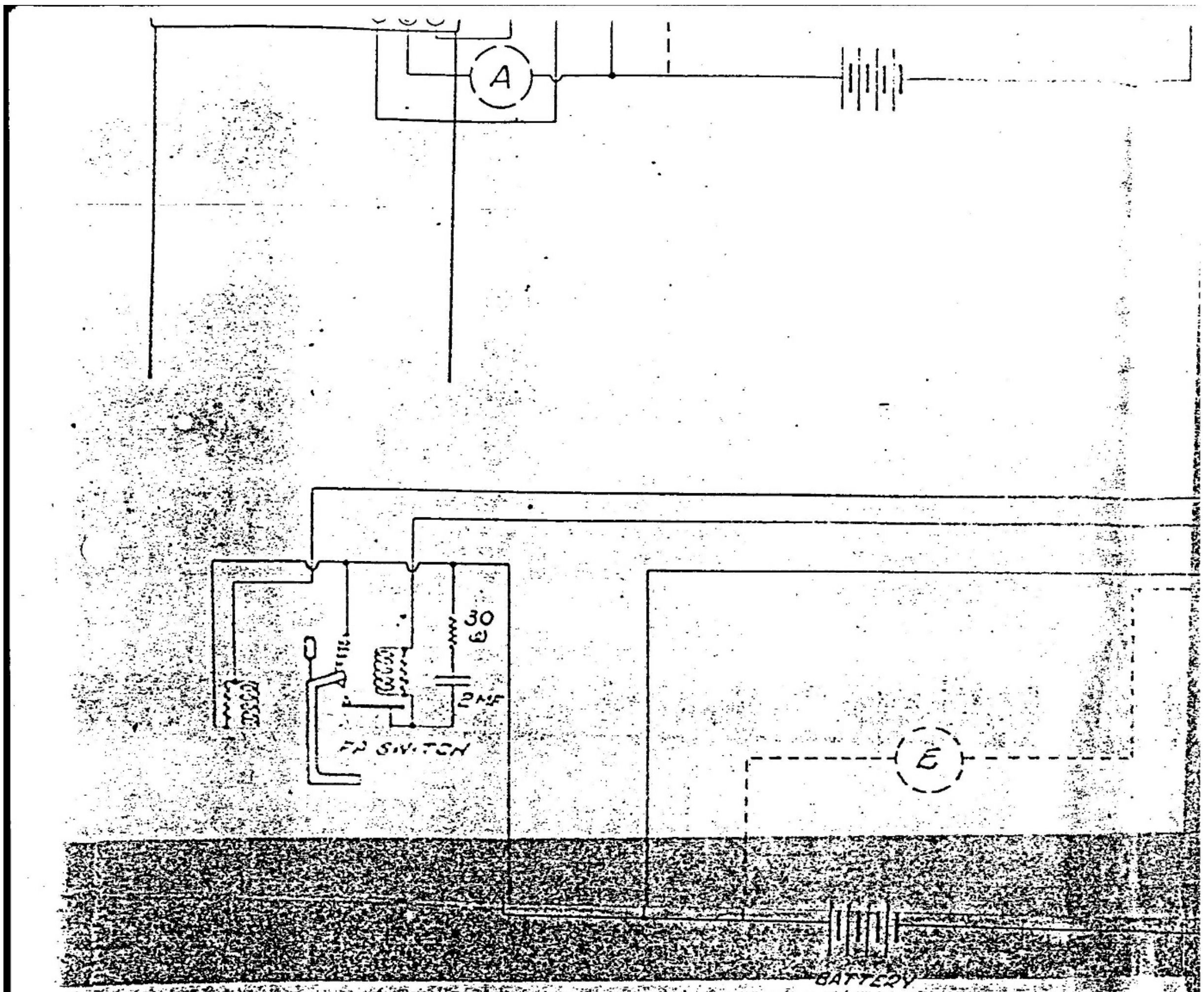

EXTERNAL WIRING OF CIRCUIT
F
S
B
RELAY
FREE
PENDULUM
SLAVE CLOCK
CHARGER
+
-
BATTERY
6 VOLTS
230 VOLTS
SYNCHRONOME Co LTD
WOODSIDE PLACE · ALPERTON · MIDDX


SIDEREAL INSTALLATION
LEFT SIDE
RIGHT SIDE
BACK OF DOOR
INTERNAL WIRING OF SLAVE CLOCK ALSO SHOWING TERMINALS P — + S F TO WHICH EXTERNAL WIRING IS CONNECTED


Sec. Coil
61ST Sec contacts
5 Min Contact
Hrs contact
Free Pendulum
ADL Mar 77
Slave
clock case front
2ND SLAVE wiring diagram
clock case
Sec. Switch
Synchroniser
1/2 Min Switch
Minute Lengthener
Corrector
Sync.
1 2 3 4 5 6 7 8 9 10 11 12
A
B+
G-


LEFT SIDE
RIGHT SIDE
DEVELOPEMENT OF SLAVE CASE
SECONDS DIAL
SECONDS
RESISTANCE
SECONDS
SECOND SWITCH
FREE PENDULUM
SLAVE HALF MINUTE
F.P. SWITCH
30
2MF
BATTERY
SLAVE ½ MIN SWITCH
CREED RELAY MODEL 27 WITH MARK 'C' COILS.
INSERT RELAY AT A FOR FREE PENDULUM AND SLAVE HALF MINUTE IMPULSES
B IMPULSES ONLY.
C SLAVE IMPULSES ONLY.
D SECONDS IMPULSES.
NOTE
CIRCUITS A B AND C OPERATE AT 1/3 AMP AND TO OPERATE RELAY IN THESE CIRCUITS THE COILS OF THE RELAY MUST BE SHUNTED WITH
A ·75 OHMS RESISTANCE AND FOR CIRCUIT D WHICH OPERATES AT 80 MILLIAMPS THE RELAY COIL MUST BE SHUNTED WITH A RESISTANCE
OF 3 OHMS
CIRCUIT E. SECONDS PARALLEL CIRCUIT.
OPTIONAL CIRCUIT AND SHOULD HAVE AT LEAST 4 OHMS PER 1 VOLT IN CIRCUIT
-CIRCUITS A B C & D ARE ALL SERIES CIRCUITS WHICH MUST NOT BE LEFT OPEN-
THE SYNCHRONOME CO LTD
ALPERTON - MIDDX - ENGLAND
DWG No


DEVELOPEMENT OF SLAVE CASE
RIGHT SIDE
LEFT SIDE
SECOND SWITCH
BATTERY
A
B
C
D
E
E



CREED RELAY MODEL 27 WITH MARK 'C' COILS.

INSERT RELAY AT A FOR FREE PENDULUM AND SLAVE HALF MINUTE IMPULSES
" " " B " " " IMPULSES ONLY.
" " " C " SLAVE IMPULSES ONLY.
" " " D " SECONDS IMPULSES.

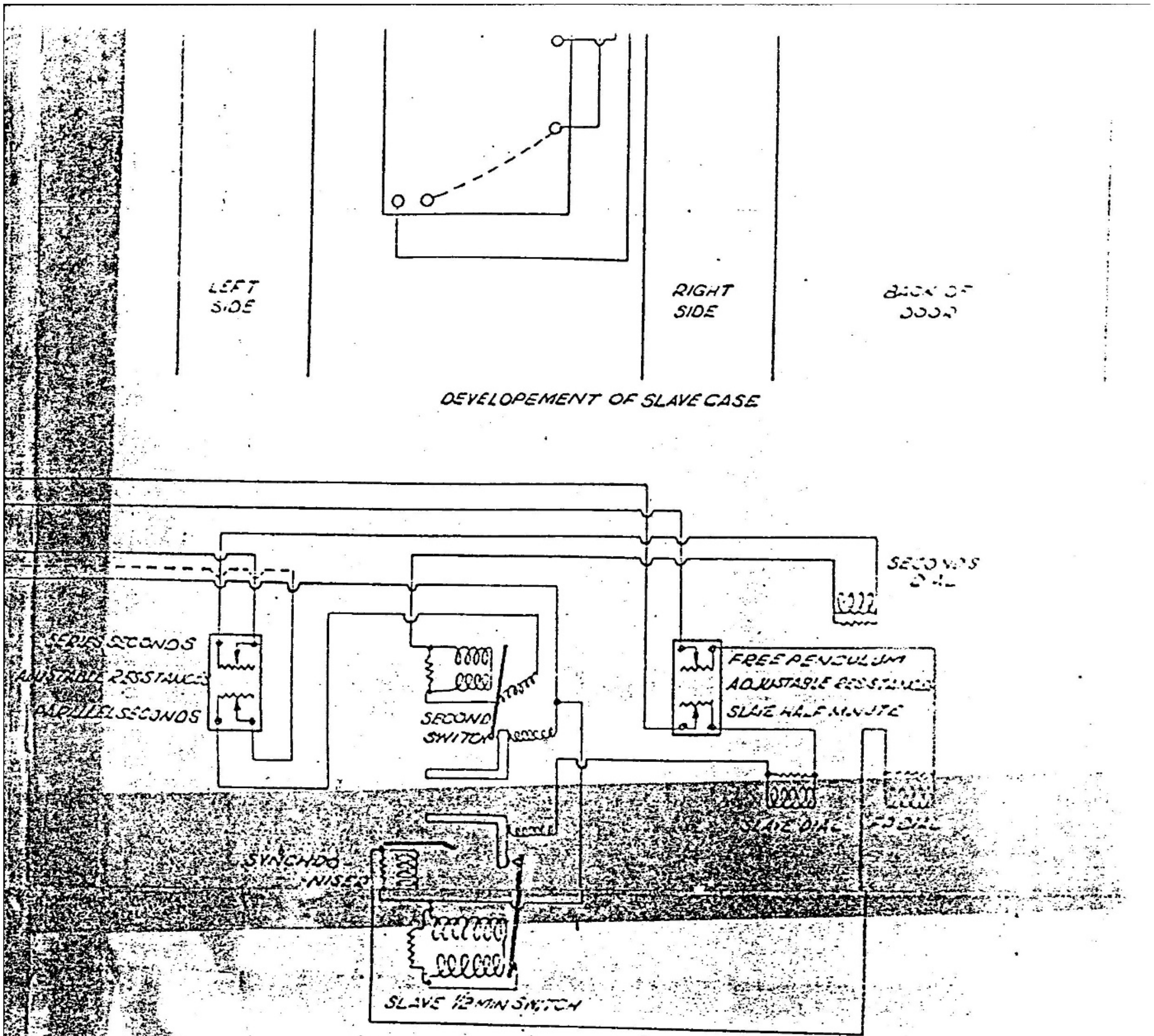
NOTE

CIRCUITS A B AND C OPERATE AT 1/3 AMP AND TO OPERATE RELAY
A ·75 OHMS RESISTANCE AND FOR CIRCUIT D WHICH OPERATES AT 8
OF 3 OHMS

CIRCUIT E. SECONDS PARALLEL CIRCUIT. PLACE RESISTANCE OF 790
OPTIONAL CIRCUIT AND SHOU
—CIRCUITS A B C & D ARE ALL SERIES CIRCUITS WHI

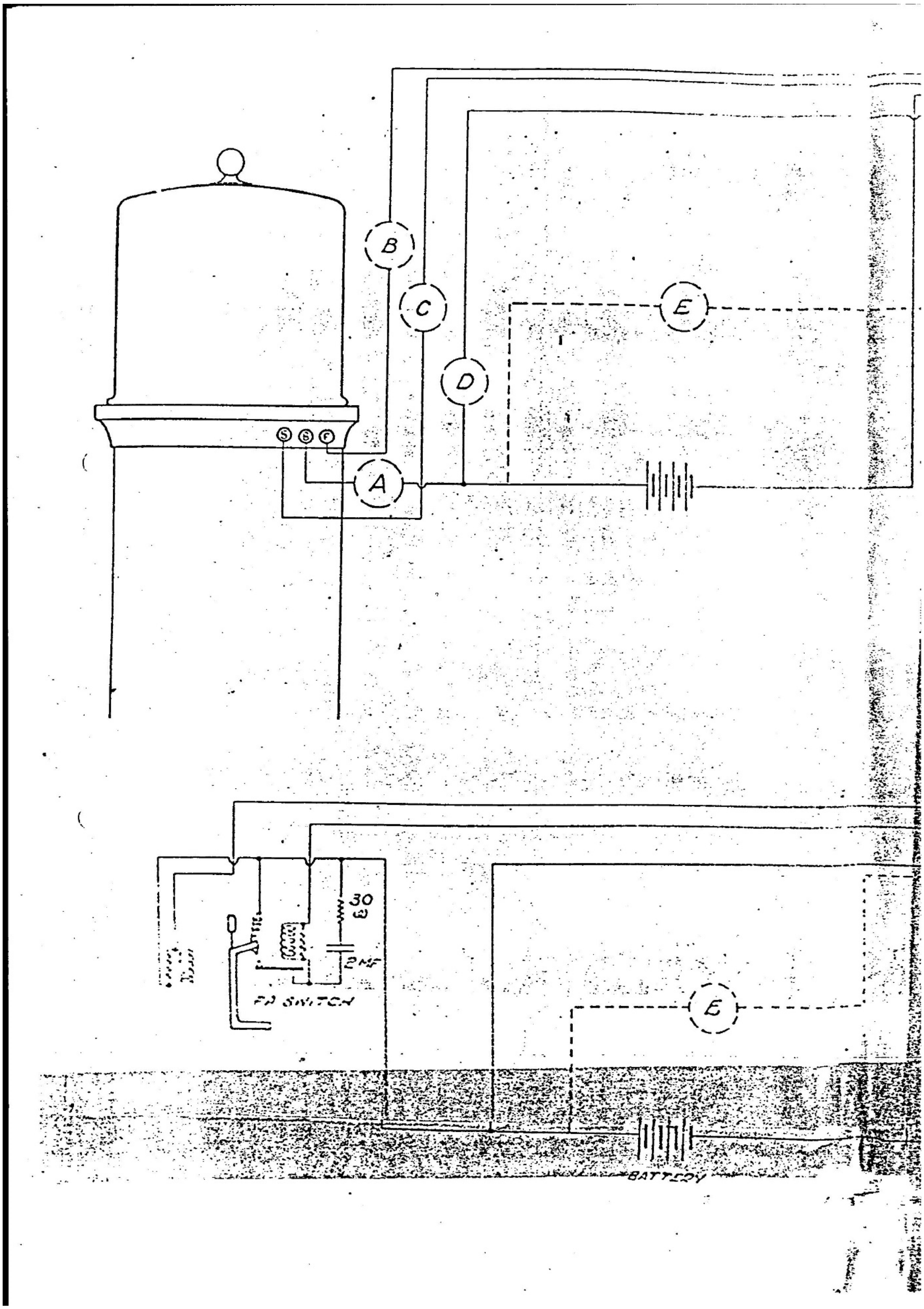
THE SYNCHRONOME Cº LTD

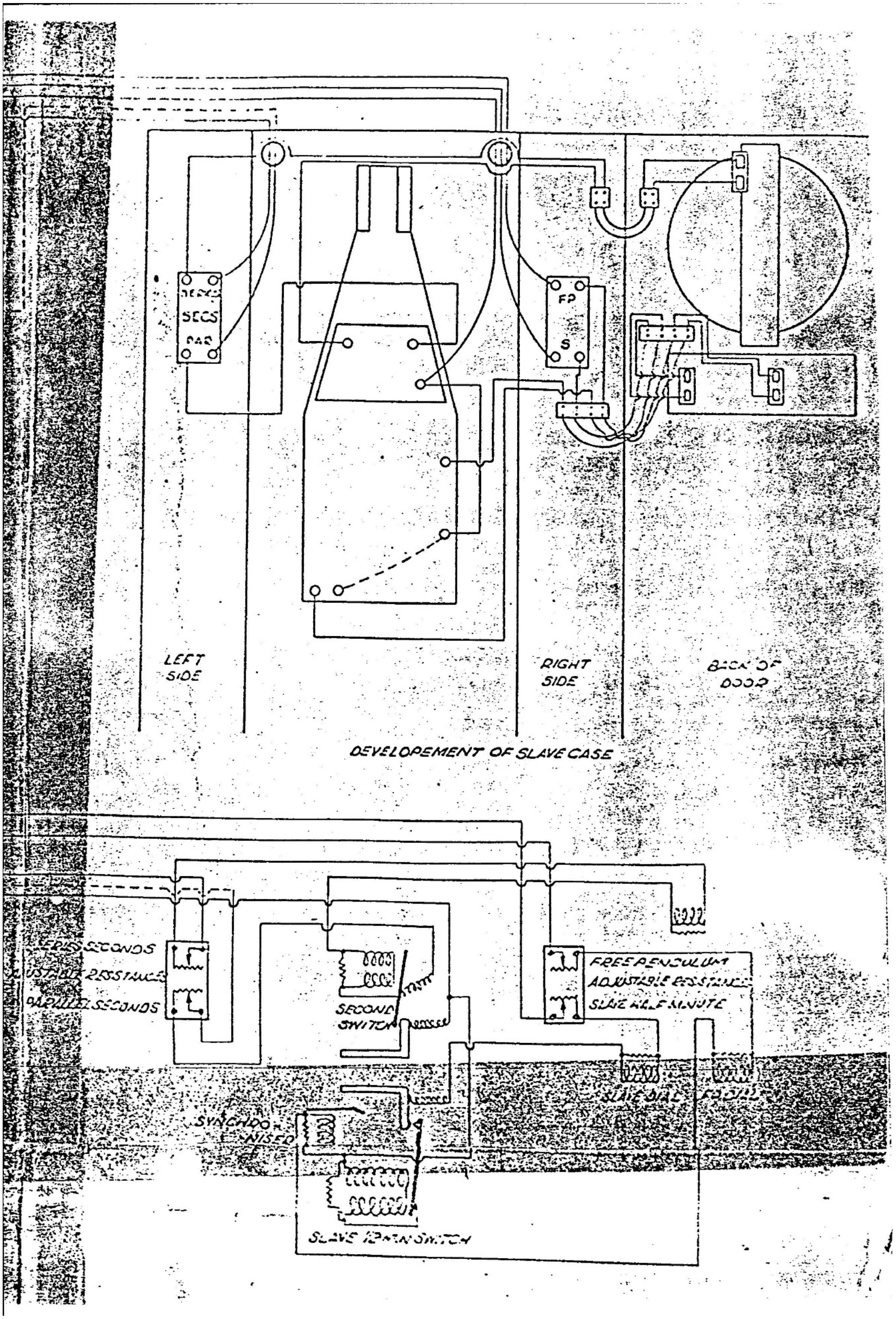
ALPERTON - MIDDX - ENGLAND

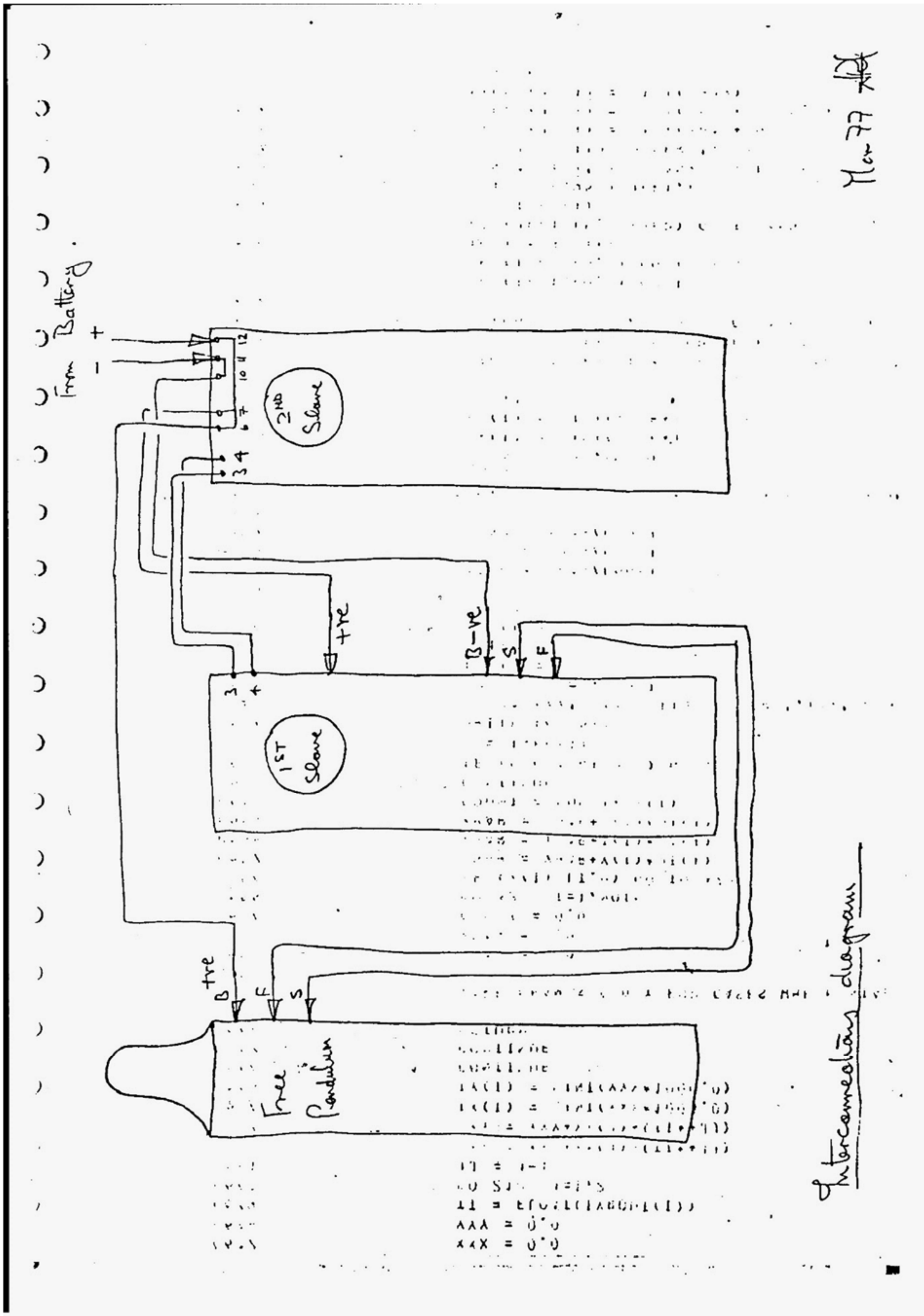


THESE CIRCUITS THE COILS OF THE RELAY MUST BE SHUNTED WITH
MILLIAMPS THE RELAY COIL MUST BE SHUNTED WITH A RESISTANCE
IS IN SERIES WITH THE RELAY, BATTERY BEING 8 VOLTS. THIS IS AN
D HAVE AT LEAST 4 OHMS PER 1 VOLT IN CIRCUIT IF USED AT 8 VOLTS
H MUST NOT BE LEFT OPEN—

DWG Nº 94[illegible]


B
C
E
D
S
S
F
A
30
ω
2 MF
FA SWITCH
E
BATTERY


SECS
FP
S
LEFT SIDE
RIGHT SIDE
DEVELOPEMENT OF SLAVE CASE
PARALLEL SECONDS
SECOND SWITCH
FREE PENDULUM
SLAVE DIAL
SYNCHRONISED


From Battery
+
-
2ND Slave
3 4 6 7 10 11 12
1ST Slave
3 +
+ve
B-ve
S
F
Free Pendulum
B +ve
F
S
Intermediary diagram
Nov 77

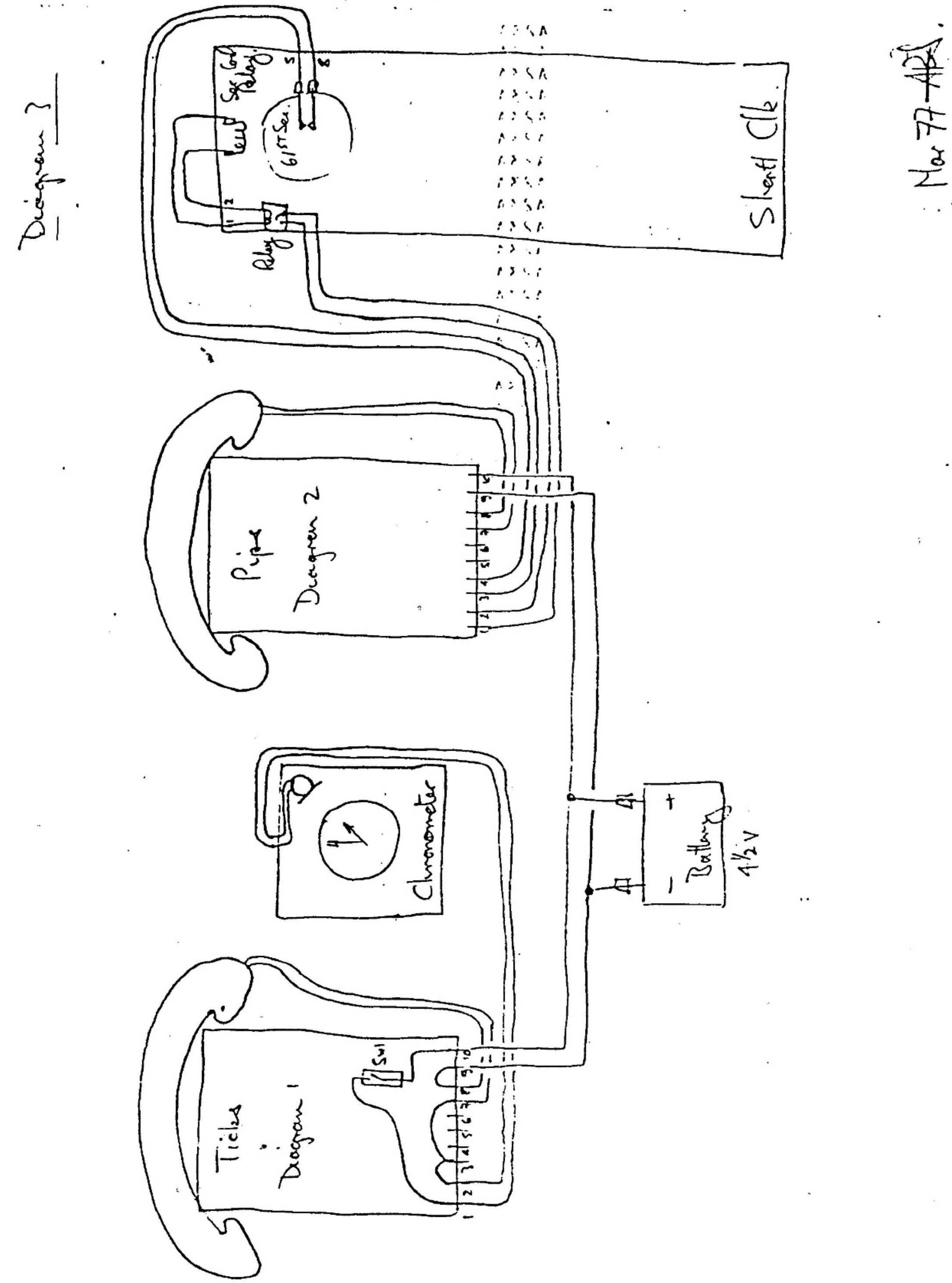


Diagram 3
Relay
Slave Clk
Pipe
Diagram 2
Chronometer
Battery
1½ V
Ticks
Diagram 1
SW1
Mar 77

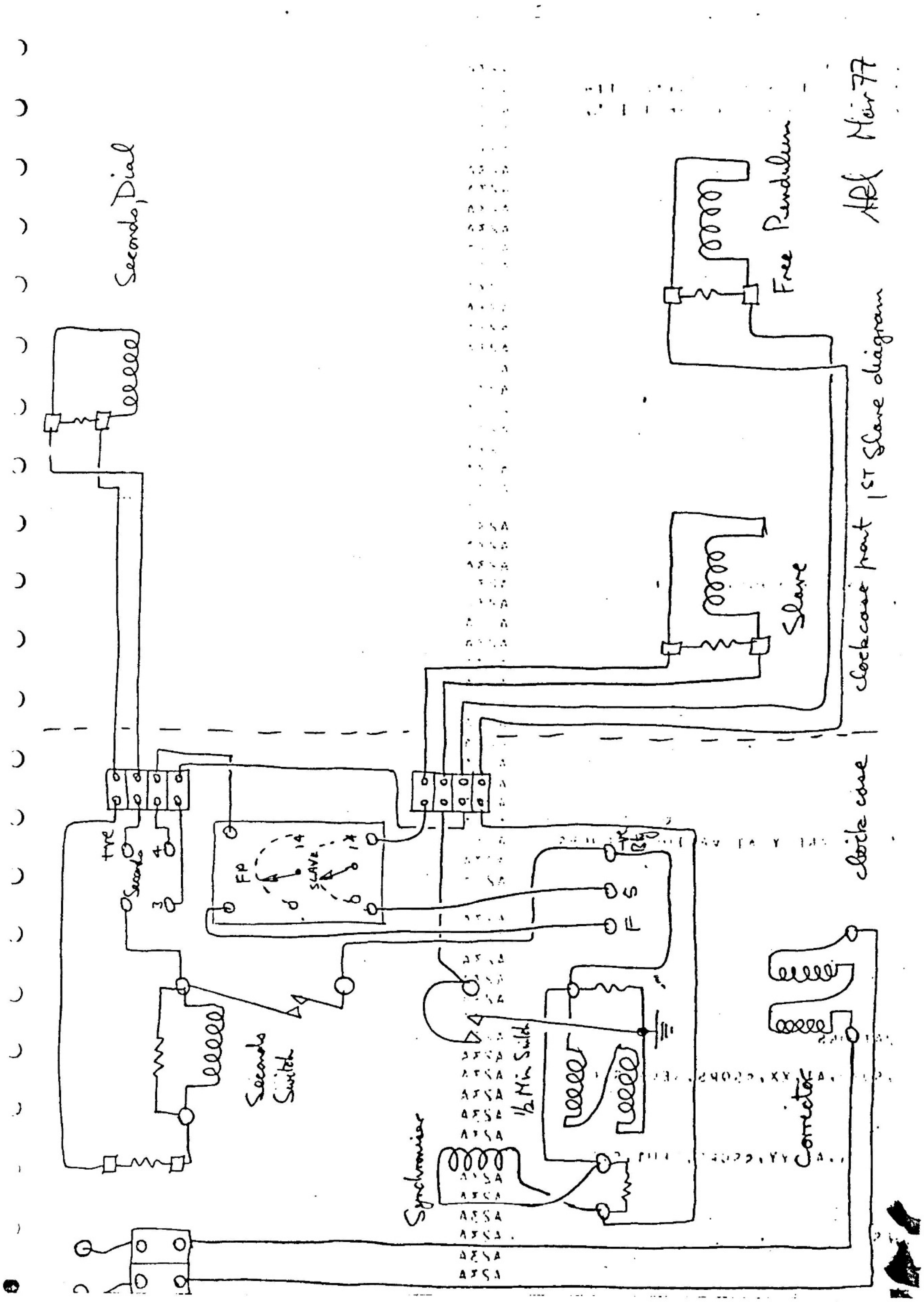
Circuit Description

A single 4½V battery provides the power for the complete system.

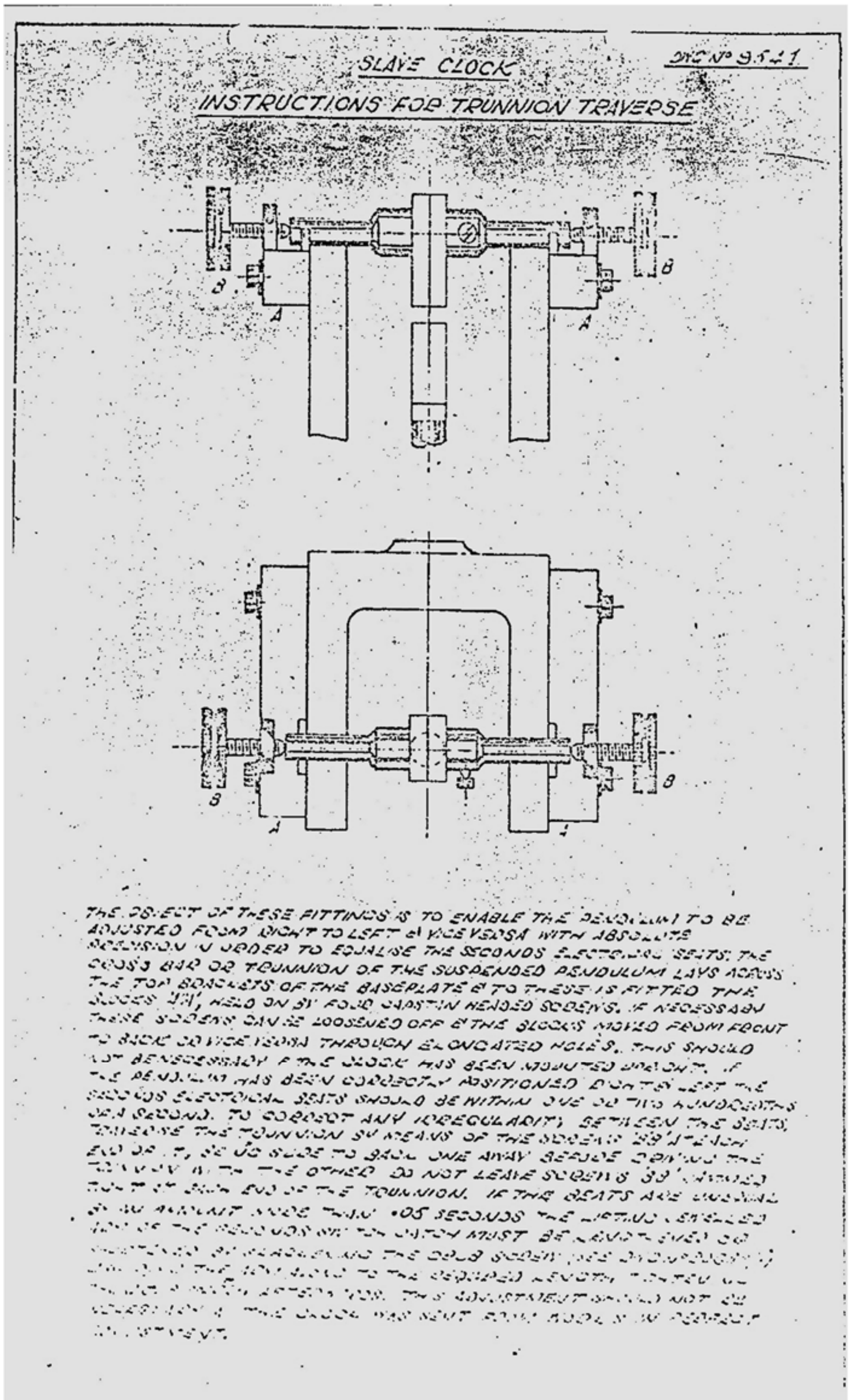
The ticks circuit is very simple and is shown in diagram 1. An ordinary carbon microphone is placed in the chronometer case and feeds a standard teleph ear piece in the handset. When the handset is raised from the cradle power is applied to the circuit and the ticks should be clearly heard.

The pips circuit is shown in diagram 2 and consists of a simple pulse shaping circuit followed by a multi-vibrator tone oscillator.
RLA is operated by the seconds pulse to the second slave dial, thus triggering the pulse shaper off and it produces a pulse approx. 100 m Sec long this allows power to flow into the tone oscillator and a short pip will be heard in the ear piece. When the 61ST second contact is made the next seconds pulse is lengthened to approx 400 m Sec by the addition of the 16 μF capacitor. When the handset is lifted from its cradle the pulses will be heard

Setting up of the 61ST second lengthening circuit is fairly straight forward. The operating cam to the 61 sec contacts must be made for the 61ST sec and encompass it completely.


Seconds Dial
Free Pendulum
Slave
clockcase part
1st Slave diagram
clock case
+ve
Seconds
FP
SLAVE
Seconds Switch
½ Min Switch
Synchroniser
Corrector

15. **Other Documentation not Directly Applicable to #23**

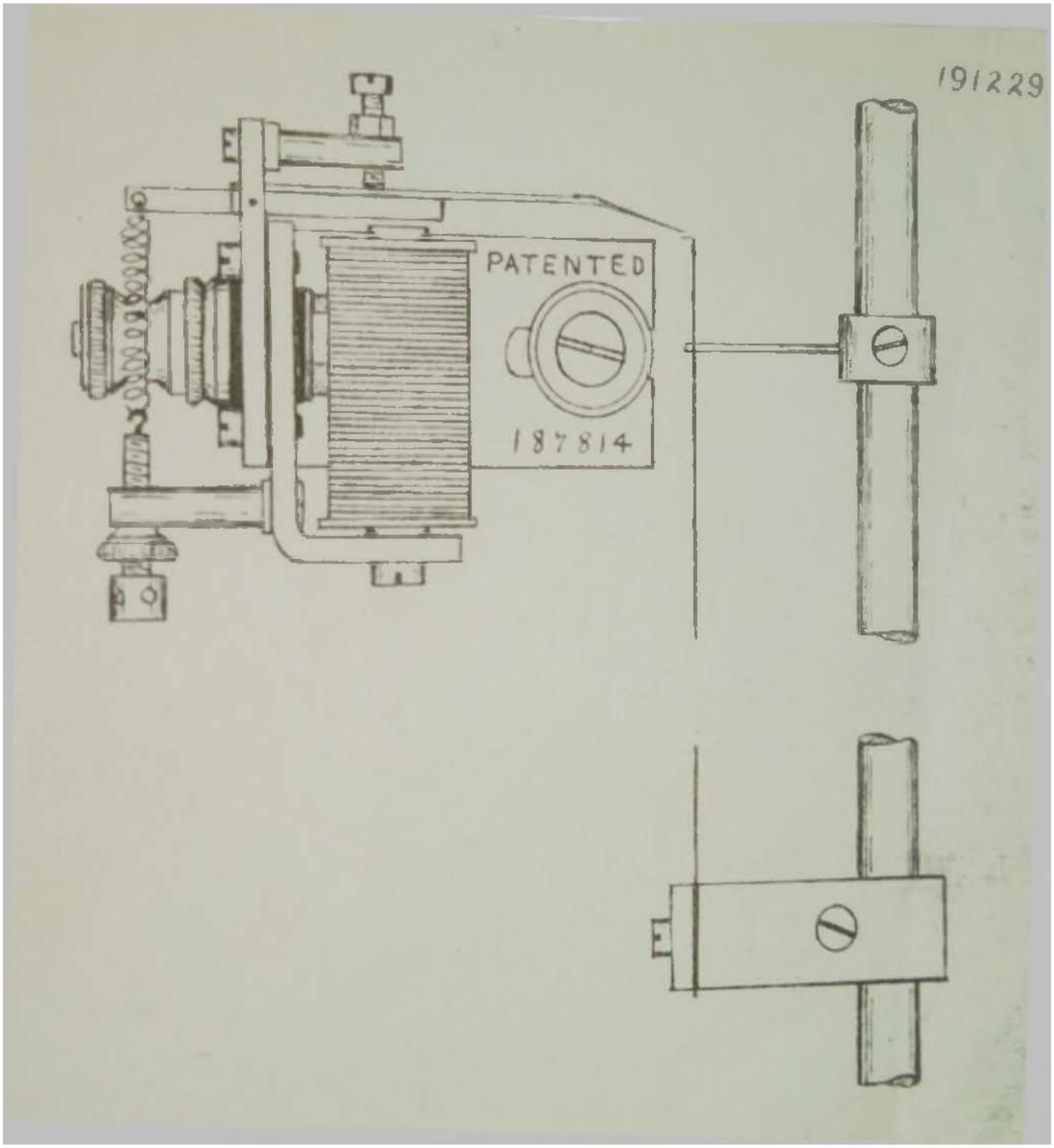


SLAVE CLOCK

INSTRUCTIONS FOR TRUNNION TRAVERSE

DWG Nº 9541

THE OBJECT OF THESE FITTINGS IS TO ENABLE THE PENDULUM TO BE ADJUSTED FROM RIGHT TO LEFT & VICE VERSA WITH ABSOLUTE PRECISION IN ORDER TO EQUALISE THE SECONDS ELECTRICAL BEATS. THE CROSS BAR OR TRUNNION OF THE SUSPENDED PENDULUM LAYS ACROSS THE TOP BRACKETS OF THE BASEPLATE & TO THESE IS FITTED THE BLOCKS "A", HELD ON BY FOUR CAPSTAN HEADED SCREWS. IF NECESSARY THESE SCREWS CAN BE LOOSENED OFF & THE BLOCKS MOVED FROM FRONT TO BACK OR VICE VERSA THROUGH ELONGATED HOLES. THIS SHOULD NOT BE NECESSARY IF THE CLOCK HAS BEEN MOUNTED UPRIGHT. IF THE PENDULUM HAS BEEN CORRECTLY POSITIONED RIGHT & LEFT THE SECONDS ELECTRICAL BEATS SHOULD BE WITHIN ONE OR TWO HUNDREDTHS OF A SECOND. TO CORRECT ANY IRREGULARITY BETWEEN THE BEATS, TRAVERSE THE TRUNNION BY MEANS OF THE SCREWS "B" AT EACH END OF IT, BE SURE TO BACK ONE AWAY BEFORE DRIVING THE TRUNNION WITH THE OTHER. DO NOT LEAVE SCREWS "B" [illegible] [illegible] END OF THE TRUNNION. IF THE BEATS ARE UNEQUAL BY AN AMOUNT MORE THAN •05 SECONDS THE [illegible] MUST BE [illegible] THE [illegible] SCREW [illegible] TO THE REQUIRED LENGTH [illegible]. THIS ADJUSTMENT SHOULD NOT BE [illegible] THE CLOCK WAS SENT [illegible] IN PERFECT [illegible].


191229
PATENTED
187814

ANGLO DAL LTD. (VARIDEX)

Consignment of Sidereal Clock No. 98 and B type slave clock and other accessories

---

Case No. 5

46" x 22" x 82"
Gross weight - 1cwt. 2qrs. 20lbs.
Nett weight - 2qrs. 22lbs.

1 - copper cylinder Free Pendulum case.

Case No. 6

63" x 26" x 19"
Gross weight - 1cwt. 3qrs. 3lbs.
Nett weight - 2qrs. 14lbs.

1 - B type slave clock
1 - box containing free pendulum rod with parts fitted on.
1 - box containing slave pendulum rod with parts fitted on.

Case No. 7

46" x 40" x 26"
Gross weight - 2cwt. 2qrs. 14lbs.
Nett weight - 3qrs. 18lbs.

1 Box containing:
1 - Free Pendulum movement.

1 Box containing:
1 - heavy resetting lever
1 - gravity lever with heavy weight fitted.
1 - gravity lever light weight.

1 Box containing:
1 - Free Pendulum carriage
1 - Free Pendulum suspension spring.

1 Box containing:
1 - Condenser Unit
1 - Special beat plate
2 - boxes of regulating weights.
1 - movement support bracket.
1 - case valve
1 - set of 3 wires S.B. & F.

1 Box containing:
Mercury and oil gauge on bracket with fixing screws

1 Box containing:
Triangle frame with microscope fitted, also fixing screws.
1 - plate glass circle.

1 Box containing:
1 - Four legged casting with fixing screws and damping plate.

1 Box containing:
1 - Glass bell jar

Number 23 does not have this beat plate. Its microscope was replaced by the Jeffers device.

MEMORANDUM ON THE MICROSCOPE AND SPECIAL BEAT PLATE.

Adjusting screws are fitted to the special beat plate in order to enable the scale to be adjusted so that the image is seen in the microscope as passing from left to right or vice-versa, without any back to front motion, in other words, the engraved scale must be exactly in line with the plane of swing of the pendulum.

The microscope will be found already fitted to the triangle casting, and only needs to be placed in position, focussing and adjusting may then be done as follows:-

1. The pendulum should be in a stationary position.

2. Place an electric light about 3 inches below the glass plate about 3 inches to the right or left of the microscope and in line with the beat plate.

3. Turn the traversing screw at the back end of the microscope either way until the engraved lines on the beat plate come centrally into view, move the light about and focus the object lens until the best result is obtained, which should be when the lines on the beat plate show up clear and bright.

4. Now move the microscope from right to left or vice-versa by means of the traversing screw provided for that purpose, until the zero line of the beat scale is on the centre line of the eye-piece scale.

Having now exactly located the position of the microscope relative to the beat plate, tighten up the three milled head screws on the front ring through which the microscope tube passes, and tighten up the milled nut on the cross traverse.

The arc can now be measured by reference to the print 211229.

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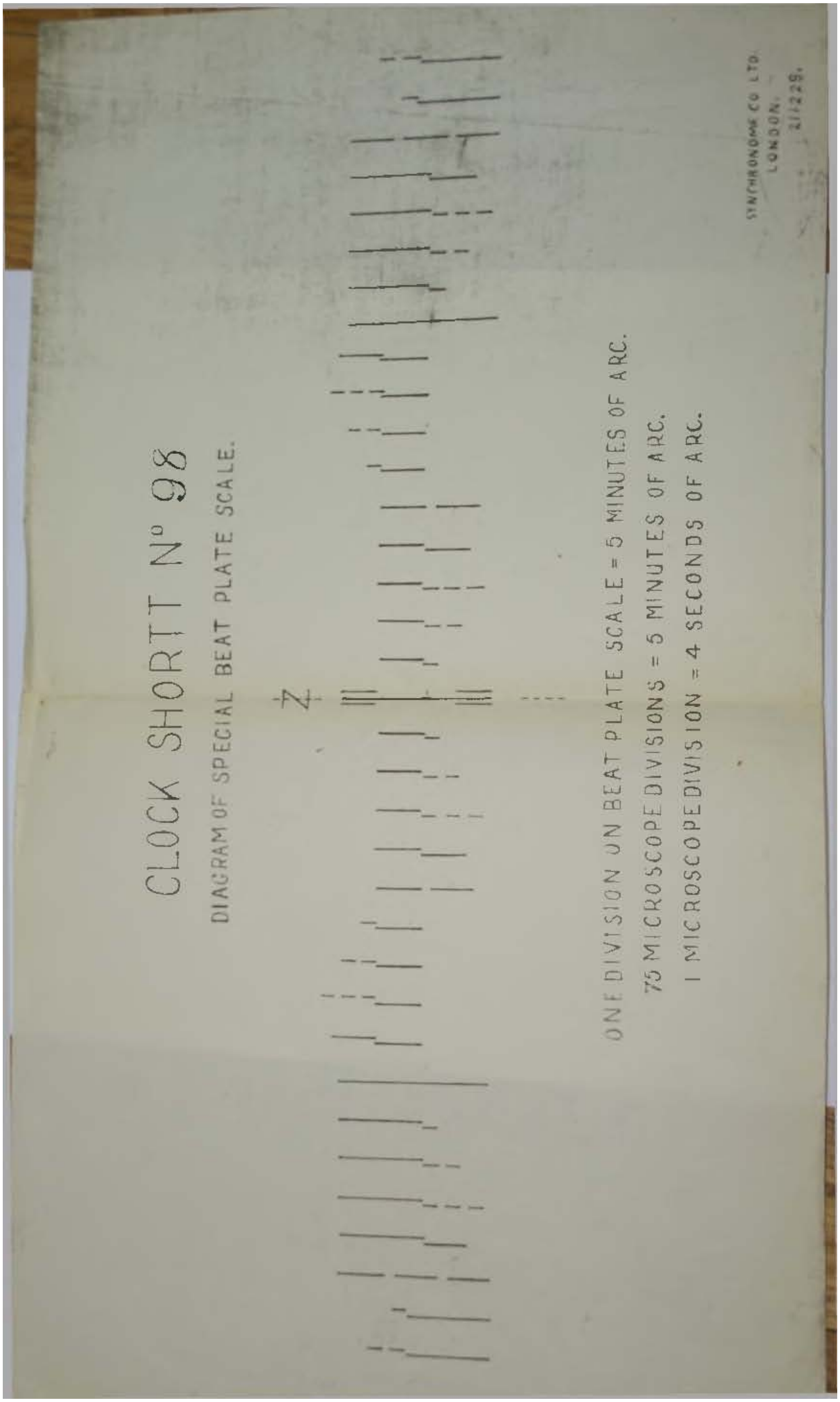
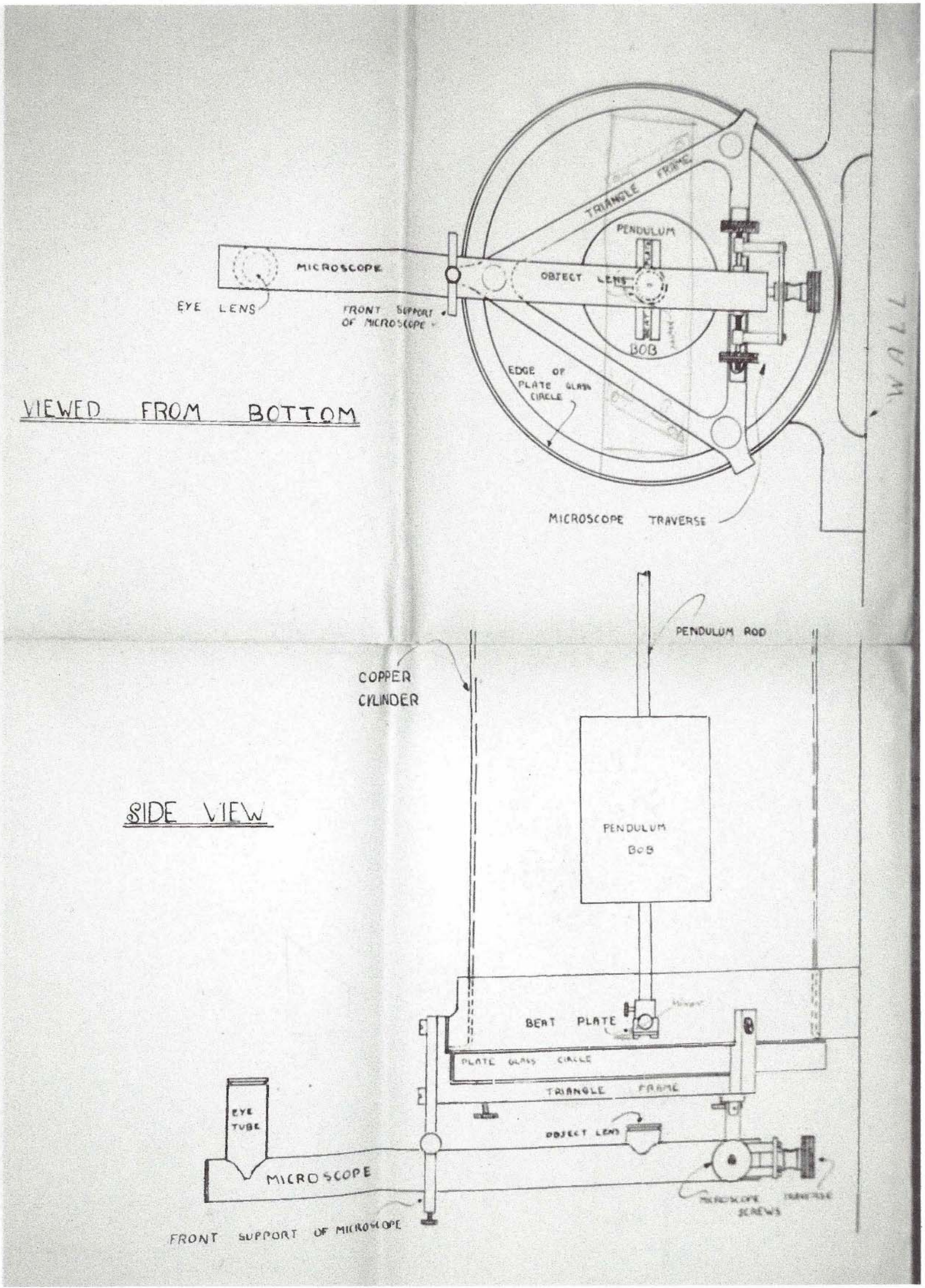
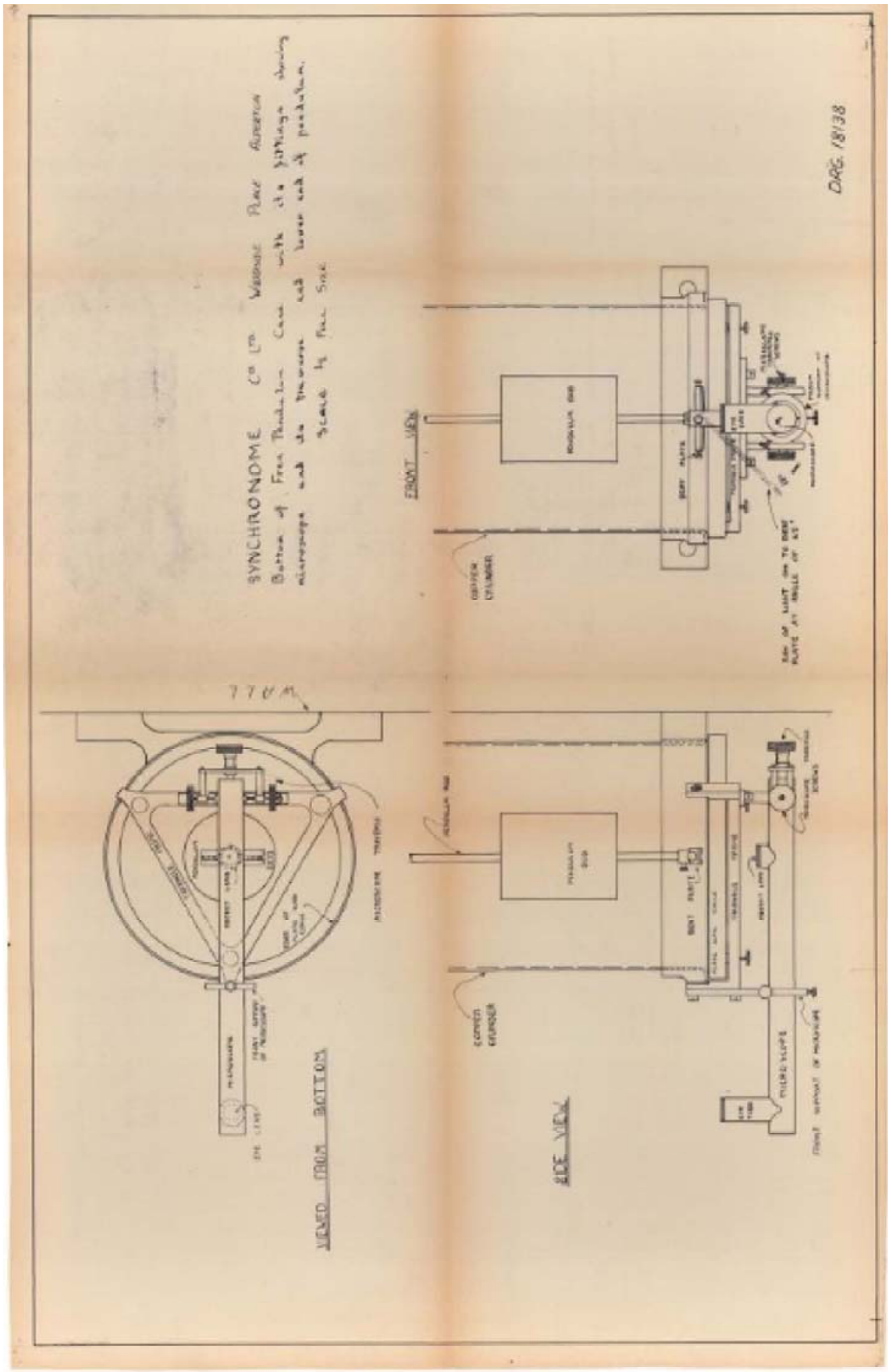
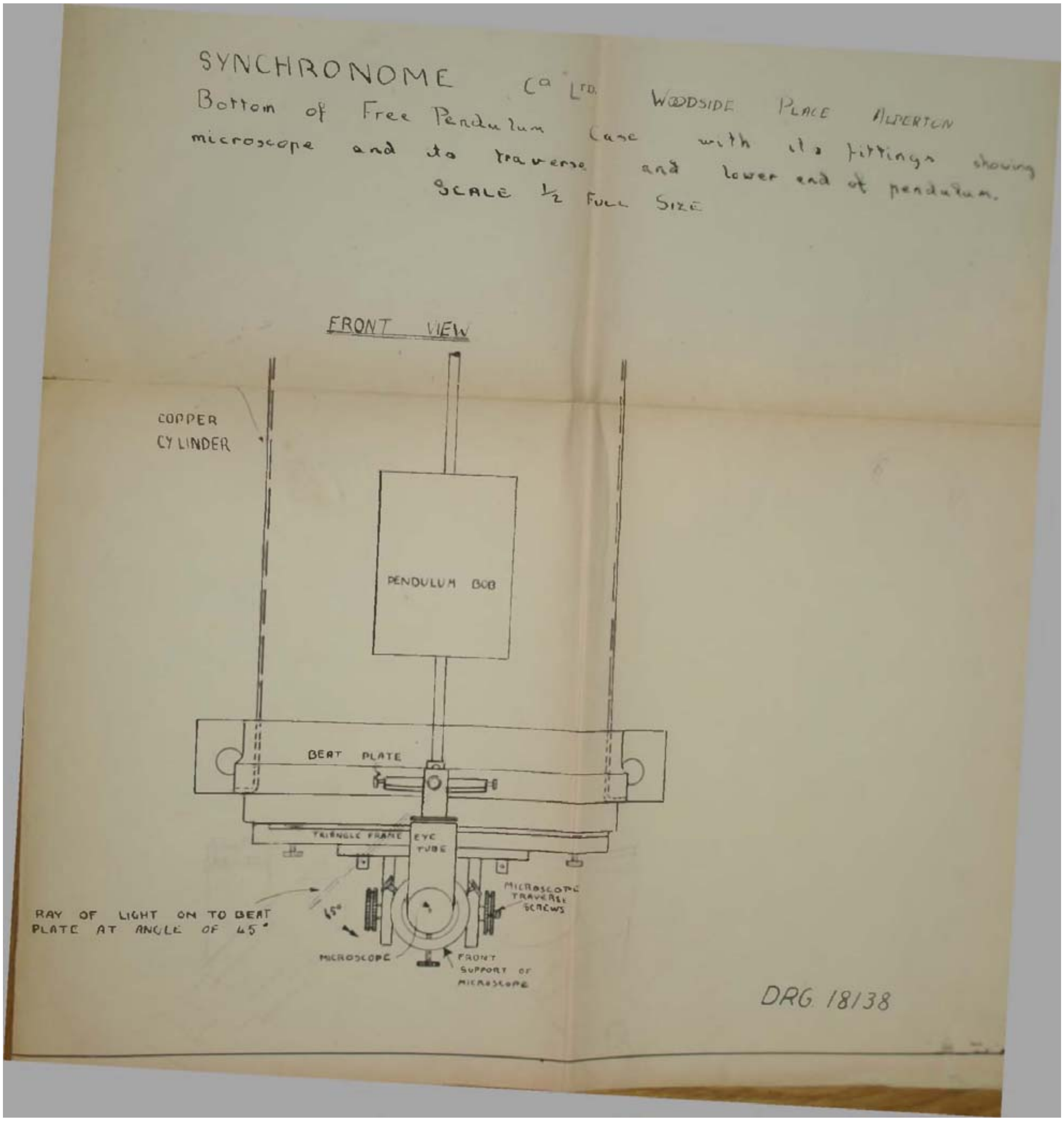

CLOCK SHORTT Nº 98
DIAGRAM OF SPECIAL BEAT PLATE SCALE.
Z
ONE DIVISION ON BEAT PLATE SCALE = 5 MINUTES OF ARC.
75 MICROSCOPE DIVISIONS = 5 MINUTES OF ARC.
I MICROSCOPE DIVISION = 4 SECONDS OF ARC.
SYNCHRONOME CO LTD.
LONDON.


VIEWED FROM BOTTOM
MICROSCOPE
EYE LENS
FRONT SUPPORT OF MICROSCOPE
TRIANGLE FRAME
PENDULUM
OBJECT LENS
BOB
EDGE OF PLATE GLASS CIRCLE
MICROSCOPE TRAVERSE
WALL
PENDULUM ROD
COPPER CYLINDER
SIDE VIEW
PENDULUM BOB
BEAT PLATE
PLATE GLASS CIRCLE
TRIANGLE FRAME
EYE TUBE
OBJECT LENS
MICROSCOPE
MICROSCOPE TRAVERSE SCREWS
FRONT SUPPORT OF MICROSCOPE

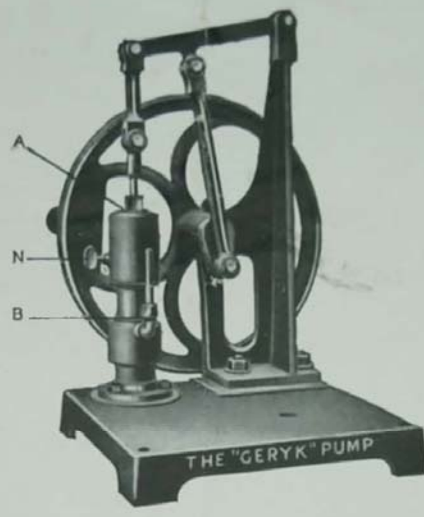

SYNCHRONOME
Bottom of Free Pendulum Case with its fittings showing microscope and its traverse and lower end of pendulum.
Scale ¼ Full Size
FRONT VIEW
COPPER CYLINDER
WALL
VIEWED FROM BOTTOM
SIDE VIEW
COPPER CYLINDER
DRG. 18138


SYNCHRONOME Co LTD. WOODSIDE PLACE ALPERTON
Bottom of Free Pendulum Case with its fittings showing microscope and its traverse and lower end of pendulum.
SCALE ½ FULL SIZE
FRONT VIEW
COPPER CYLINDER
PENDULUM BOB
BEAT PLATE
TRIANGLE FRAME
EYE TUBE
MICROSCOPE TRAVERSE SCREWS
RAY OF LIGHT ON TO BEAT PLATE AT ANGLE OF 45°
45°
MICROSCOPE
FRONT SUPPORT OF MICROSCOPE
DRG. 18/38

INSTRUCTIONS FOR USING

"GERYK" VACUUM PUMPS

(SINGLE CYLINDER TYPE)



IN these Pumps the friction is reduced to a minimum. All working joints are liquid sealed and self-adjusting, and all valves are mechanically moved so that the air meets with no resistance whatever. There is no clearance space, and therefore there is a cent-per-cent efficiency of piston displacement. The liquid used is a special oil.

There must always be sufficient oil in the pump to reach to the level of the screw plug " N " when a vacuum has been formed, and the piston is at half-stroke. To determine whether there is a proper charge of oil in the pump, unscrew plug " N " after pumping up a partial vacuum. If the chamber is not full to the point of overflow, add more oil at " A," making sure that any excess of oil is drained off at " N " before replacing the plug. The pump will then be charged for good. When once this proper charge of oil is in the pump it will last for an indefinite time. The pump is fully charged with oil before being despatched, and the above instructions are given in case any of the oil has run out by the machine being inverted in transit.

Never let any water or vapour get into the pump, and a hygroscopic substance should always be used in the vacuum receiver to dry the air.

IMPORTANT

Speed of working should not exceed 100 revolutions per minute. If worked faster the best results cannot be obtained. Should the pump oil get dirty after long use, or thick and milky on account of water or water vapour having got into the pump, it can readily be changed as follows:—Remove the suction pipe and pour oil into the socket " B," then unscrew the plug " N " and work the pump slowly. The dirty oil will overflow at the plug hole and more clean oil can be poured into the socket " B " and the pump again worked as before, until the oil which overflows at " N " is no longer dirty.

These single-cylinder pumps are capable of giving a vacuum of 1/50th of a millimetre off perfect on a closed dry circuit.

16. Supplemental Reading – in no particular order

Miles, R. H. A.; *Synchronome*, Antiquarian Horological Society 2nd ed.) 2019.

Matthys, R. J.; *Accurate Clock Pendulums*, Oxford University Press 2004.

Hope-Jones, F.; *Electric Clocks and How to Make Them*, Argus Books 1977 (reprint).

Hope-Jones, F.; *Electric Clocks*, N.A.G. Press 1931.

Hope-Jones, F.; *Electrical Timekeeping* (2nd ed.), N.A.G. Press 1949.

Hunter, A; *Astronomy*, Science Progress V. 33, No. 131 (Jan. 1939) pp. 509-517.

Loomis, A. L.; *The Precise Measurement of Time*, Monthly Notices of the Royal Astronomical Society, V. 91 (March 1931) pp. 569-575.

Jeffers, H. M.; *The Shortt Clock of the Lick Observatory*, Lick Observatory Bulletin V. 17, No. 468 (1935) pp.75-79.

Adams, Betty; *The Rate of the Shortt Clock of the Lick Observatory*, Publications of the Astronomical Society of the Pacific, V. 52, No. 310 (Dec. 1940) pp. 395-399.

Hope-Jones, F.; *The Free Pendulum*, British Horological Institute (lecture) April 19, 1923.

Hope-Jones, F.; *The Free Pendulum*, Journal of the Royal Society of Arts, V. 72 No. 3731 (May 23, 1924, pp. 446-460.

Boucheron, P. H.; *Just How Good was the Shortt Clock?,* V. 27 No. 2 (April 1985) pp 165-173.

Jackson, J. and Bowyer, W.; *The Accuracy of the Shortt Free Pendulum Clocks*, Nature, V. 121 Issue 3057 (June 2, 1928) pp. 868-870.

Jackson, J.; *Shortt Clocks and the Earth's Rotation*, Royal Astronomical Society, LXXXIX. 3 (Jan. 1929) 239- 250.

Holden, Edward S.; *Publications of the Lick Observatory of the University of California*, V. 1 (1887) pp. 59-76,

Keeler, James E.; *The Time Service of the Lick Observatory*, Sidereal Messenger, V. 6 (09/1887) pp. 233-250.

Bulletin of the National Association of Watch and Clock Collectors – numerous articles. See online index.

Some Hope-Jones US patents: US610539, US628325, US871407, US1047810

Some Hope-Jones UK patents: GB463087 (A), GB189707868

Some Shortt UK patents: GB190704092, GB191509527, GB187814

17. Timeline for the Project

Early 2016: Initial contact by D. H. Mayeron
April 10, 2016: Presentation on Shortt to Ch 107 by P. Russ
May 14, 2016: First trip to Lick
Rest of 2016: Search for original slave
August 2016: Russ visit to Art Bjornstad
Dec. 2016: Russ visit to Clockworks and Science Museum
2017: Collect information on suspension springs and drawings
April 23, 2017: Second Lick visit
Late 2017: Case donated by Nile Godfrey
Nov 2017: Mayeron visit to Matthys received example suspension springs
Feb. 26, 2018: First input for MOU
March 10, 2018: Third Lick visit
March 13, 2018: Slave movement donated by Jude Hill
March 19, 2018: Slave parts received from Clockworks
March/April 2018: Discussions on seconds switch
July/Aug. 2018: Construct synchronizer and assemble small dial
Nov. 5, 2018: Moved master clock from Lick to home of Price Russ
Jan. 4, 2019: Russ second visit to Clockworks (met with Jan Wright)
Feb. 16, 2019: Installed master pendulum using single piece spring
March 6, 2019: First operation (with Matthys's suspension spring)
May 17, 2019: Power supply from Lick installed
April 30, 2019: MOU signed
May/July 2019: Construct new suspension springs for master
July 4, 2019: Changed suspension spring to new one
July 2019 – Feb. 2023: Allowed to operate with no major changes
Oct. 2022 – Feb. 2023: Intermittent problem with master dial falling behind slave dial. Tightened shim in pipe of hour hand.
Feb. 10, 2023: Dissemble and prepare for transport
Feb. 14, 2023: Transport to Lick

18. Contributors to the Project

Organization:

D. H. Mayeron - initiated the project
Price Russ - managed the project for Chapter 107
Tony Misch and Kostas Chloros - were the principal contacts for the Observatory
John Koepke – researched the history of observatory timekeeping and Shortt clocks including #23

Hardware: The following people and institutions contributed hardware and fabrication

Nile Godfrey – Case for slave, dial unit, and kit Synchronome clock movement used for parts
Jude Hill – Synchronome movement used for slave
The Clockworks (James Nye & Johan ten Hoeve) – Pendulum rod and fittings for slave
Henryk Halberda – Gathering Pallet
Robert Matthys – Suspension Springs
D. H. Mayeron – Modification of master suspension-spring provided by Matthys
Richard Hatch – Synchronizer Spring and mounting bracket
Dorian Claire – Dial for slave
Donnie Redel (Lick) – Uninterruptable Power Supply
Rocky Francisco (Lick) – Mounting on wall
Price Russ – Synchronizer, pendulum bob (slave), weight tray (slave), smaller dial assembly and hands, master suspension-springs, cleaning, assembly, and testing

Display:

Tony Misch

Drawings:

David Walter, James Nye, Rory McEvoy, Bob Holmstrom
Ted Bosschieter – Animation

Understanding/Advice:

Many people generously shared their knowledge and provided guidance on the repair and operation on Shortt clocks. The project would not have succeeded without the help of Jan Wright and James Nye. Others who provided invaluable help include Rory McEvoy, Jonathan Betts, David Walter, Johan ten Hoeve, Tom Van Baak, Alan Bloore, David Rooney, Peter Torry, and Richard Parker – in no particular order.

19. Memorandum of Understanding

MOU for the restoration and disposition of Lick's Shortt-Synchronome clock system.
Drafted by Price Russ, 26 Feb, 2018, amended by Tony Misch, including input from Claire Max, 8 August 2018. Additional input by Price Russ 9 August 2018. Amended and finalized March 2019.

1. Parties:
    Diablo Valley Chapter (#107) of the National Association of Watch and Clock Collectors ("Chapter 107")
    University of California Observatories ("UCO")
2. Objectives:
    a. Return Shortt-Synchronome (serial #23) to operation
    b. Display in a public area at Lick or site specified by UCO, and at UCO's expense (see 20180622 Mt Hamilton Antique Clock Project, Internal Project Form, cost projection)
    c. Incorporate explanatory information about the clock in the display
    d. Provide for disposition of the clock at such time as Lick (or the alternative site as specified by UCO) no longer wishes to maintain and display it.

3. Background:

Shortt-Synchronome clocks were until the introduction of quartz clocks the most precise clocks ever constructed. They were used in most major observatories. They consisted of a master pendulum (free) housed in an atmospherically controlled tank and a slave unit based on the standard Synchronome clock but with the addition of a synchronizer to keep the slave coupled to the master pendulum.

Currently the master tank and components normally fitted therein are located in a storage room at Lick. The suspension spring for the master pendulum has been damaged beyond repair. The slave unit is missing. A search lasting over a year for an authentic slave unit has not located one. We continue to look.

Chapter 107 has located a Synchronome and modified it to serve as the slave unit. This unit including a custom-built synchronizer is now undergoing performance testing using an electronic slave driver to simulate the free pendulum. Chapter 107 will donate this unit with a fair-market value of $500 to the UC.

4. Tasks for Lick:
    a. Make the master unit available to Chapter 107 for repair, mating to slave, and testing at a chapter member's facility.
    b. Determine where the repaired clock will be displayed and prepare the exhibition space
    c. In consultation with Chapter 107, mount the clock in a public place.
    d. In consultation with Chapter 107, develop explanatory material for the display
    e. Consider incorporating a recording chronograph and the Jeffers's pendulum arc device into the display.
    f. Display shall include acknowledgement of those who have contributed materials/components.
    g. With assistance from Chapter 107, maintain the clock

h. Provide appropriate, uninterruptable DC power to operate the clock
i. Resurface the mirror used to measure arc of pendulum swing as needed
j. Assist with other mechanical and electrical support as needed
k. Provide lodging for Chapter 107 member for enough nights to be reasonably sure the installed clock is operating properly.
l. Should Lick decide to no longer exhibit the clock in a public area at Lick or other site specified by UCO, offer it to the West Coast Clock & Watch Museum (Vista, CA), on loan and for display. (Lick retains ownership and right of return in accordance with the terms of the loan.)

5. Tasks for Chapter 107:
   a. Relocate master unit to a member's facility and set up for testing
   b. Mate replacement suspension spring to master pendulum
   c. Clean and test operational components in master unit
   d. Provide a Synchronome modified as necessary for use as the slave unit
   f. Electrically connect the master and slave units
   g. Bring the combined unit into operation
   h. Performance test and adjust combined unit
      Note: The master will be operated under atmospheric conditions
      The test period should last several months.
   i. Relocate the clock to Lick or location designated by UCO and install.
   j. Perform on-site oversight for enough nights to be reasonably sure the installed clock is operating properly.
   k. Train Lick personnel in operation of the clock
   l. Provide written operational "manual"
   m. Assist in maintaining the clock

6. Joint Tasks:
   Should an authentic slave become available, consider jointly contributing to its acquisition.

7. Liability:
   Chapter 107 will use due caution to protect the master unit while on loan to the chapter and in the possession of the chapter and/or its members. Lick and UCO, recognizing that this is entirely a volunteer effort, agree not to hold Chapter 107 or any of its members liable for any damage that might occur to the master unit. Notwithstanding this, Lick, UCO and/or the UC shall have no liability to Chapter 107, its members, or any third parties related to Chapter 107's use, transport, or other operations related to the master unit while on loan to the chapter.

8. Termination:
   Either party can terminate this project at any time upon written notice to the other party. If this project is terminated prior to the time that the combined unit is relocated to Lick,

Chapter 107 will promptly return the master unit to Lick. Once the clock is installed, the agreement concerning its disposition at such time as Lick or UCO no longer wants to display it is binding (see section 4.1. above).

For: DIABLO VALLEY CHAPTER (#107) OF THE NATIONAL ASSOCIATION OF WATCH AND CLOCK COLLECTORS

By: G. Price Russ
Its: Vice President Chapter 107
Date: ~~March , 2019~~ April 30, 2019

For: UNIVERSITY OF CALIFORNIA OBSERVATORIES

Claire Max

By: Claire E. Max
Its: Director, UC Observatories
Date: April 29, 2019