Cardboard clock

An outrageous project with educational uses

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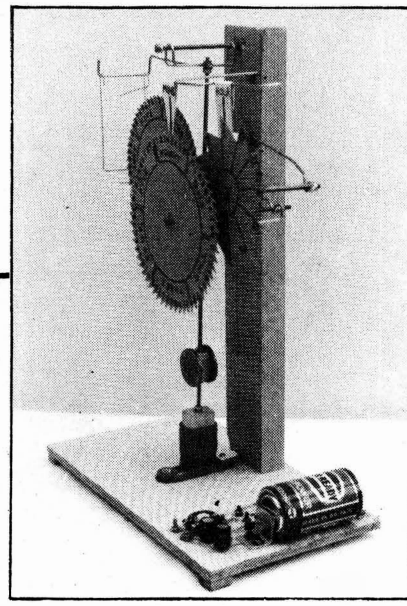


This clock keeps time to a few seconds a day and can be readily constructed with home tools. It can be made by one individual, or will serve as a holiday project for a small group. It illustrates much of electricity and mechanics, and has been found of interest at a variety of educational levels. The clock runs for about a year on an HP2 battery and has all the fascination of a little engine. The larger moving parts are cut from cardboard and this gives the device a slightly outrageous character, guaranteeing interest from anyone who sees it working.

To maximize fascination the working of the clock should be very visible, and this suggests the use of a pendulum. The latter carries a magnet, which receives drive from a stationary coil. Thus the gear train transmits no power, and the wheels only need to turn each other to record the time. This is such a light duty that the wheels can be cut from cardboard. To help overcome errors in construction these wheels are large, and many adjustments can be made to the clock after assembly. Fig. 1 is a drawing of the general arrangement.

Magnetic drive to the pendulum is quite an old idea, with the pendulum operating a mechanical switch to control the coil. When transistors became available a simpler system was devised, whereby the pulse induced by the magnet as it passes the coil is itself used to switch a short power pulse. An early system had two magnets on a balance wheel, with a stationary coil for each. One coil picked up a signal pulse, which was amplified and then fed to the other coil as a power pulse, and each winding had perhaps a thousand turns. More recently the two coils have been placed together and operated by a single magnet assembly, as in the widely used German movement shown in Fig. 2. By comparing coil resistance with coil volume in that movement, it may be estimated that the two coils contain together some 4,500 turns.

Such a figure completely excludes amateur construction. The difficulty was tackled head on by combining the two coils into a single coil of 100 turns, although this only yields some 20mV as the magnet passes over it. So the sensitive trigger circuit of Fig. 3 was developed to fire on this small pulse. The increased sensitivity found in that circuit is largely due to the relatively low value of the 10 kΩ resistor. This ensures that the first transistor is not saturated in the stable state of the circuit, and thus it is able to amplify even small input signals.

We leave further explanation of this circuit to the reader, and offer now some constructional suggestions. The reader who wishes primarily to evaluate the ideas involved is invited to proceed at once to the heading "Practical Points".

The construction will be described in its simplest form, leaving the reader to make such adaptations as he wishes. Caution is advised, however, in making changes on the mechanical side, as these tend to have knock-on effects.

The baseboard

The materials listed in Table 1 should first be assembled. To make the baseboard, cut out a rectangle of centimetric graph paper 23 × 13 cm, and copy on to it the points on Fig. 4. (Alternatively, use a tracing of Fig. 4 itself.) Stick the graph paper on to the chipboard base. The 10 mm cube blocks are feet for the baseboard: stick one under the front edge at the centre and one at each end under the rear edge. Then make, drill and bend the aluminium brackets shown in Fig. 4. Finally, drill the board as there suggested.

To mount components use 6 BA screws of about 13 mm thread length, inserting them from under the board. But do not wrap component leads round the screws. Instead, fix as suggested in the next paragraph.

To fix a lead, first load the relevant screw with a 4 BA washer. Then pass the lead close to the screw and tighten, so that the lead is trapped between washer and baseboard.

Two components can readily be trapped in this manner under a single washer, provided that their leads pass on opposite sides of the screw. On the two occasions where a second nut is recommended, the lead may be fixed by bending it. Where two washers are suggested, this is to deal with several connections, or to protect the thin coil winding wire.

Two BC108 transistors (or similar) are fitted into the 5mm diameter holes from beneath. But first bend the leads on each transistor radially outwards from the centre of its underside, taking care not to short to the can. Trap both emitter leads at e_1; e_2, and the remaining leads will point to their correct fixtures. Before fixing the 1 kΩ potentiometer, bend outwards at right angles the thin extremities of its three legs.

Acquire if possible two of the small T-style caps that close containers of detergent or washing-up liquid, as shown in Fig. 1. If the vertical height is excessive, shave small pieces off the base very carefully, to arrive at the dimensions shown. The 4mm dimension is the critical one, as it affects pendulum length. These T pieces are the coil formers, and after drilling should be fitted (T upright) as shown under washers. The 100 turn coil can now be wound tightly anticlockwise as shown, using wire of diameter about ¼mm (33 s.w.g.).

Pendulum post

This is prepared from softwood as in Fig. 1. The sawcut which defines the bottom of this post must be made with maximum care. The bottom face must be at right angles to the length of the post, and must tilt neither front-to-back nor left-to-right. Now cut from one of the lengths of studding sections of 70mm, 80mm, 90mm, using pliers or junior hacksaw. Clean the ends so that nuts will run on and off, by filing briskly at right angles to the rod. This task is made easier if a nut is already on each section when it is cut off. Bolt the 80mm length into the top of the pendulum post to give the pendulum bearing. The pendulum rolls on this rod, abolishing bearing friction.

Then screw two nuts against each other on the free forward end of this rod. Finally, screw the completed post to the baseboard as in Fig. 4. The only critical dimension in Fig. 1 is marked 284mm, and it affects pendulum length.

The pendulum

Form the bracket No. 2 (Fig. 1) from 16 s.w.g. copper wire or similar. A regular half circle loop may be obtained by bending with the fingers round a 7mm diameter screwdriver, for example. When a right angle bend is required, grip the wire in pliers so that the desired point of bending lies 2mm clear. Then push the wire round firmly with the fingers against the side of the pliers. The third loop is formed round pliers to embrace 6 BA rod. The first attempt at this bracket can be treated as a training run and discarded. The second attempt will be almost perfect!

The pendulum can now be assembled from Fig. 1. The largest faces
rites will be the magnetically active surfaces, and the North seeking face can read-

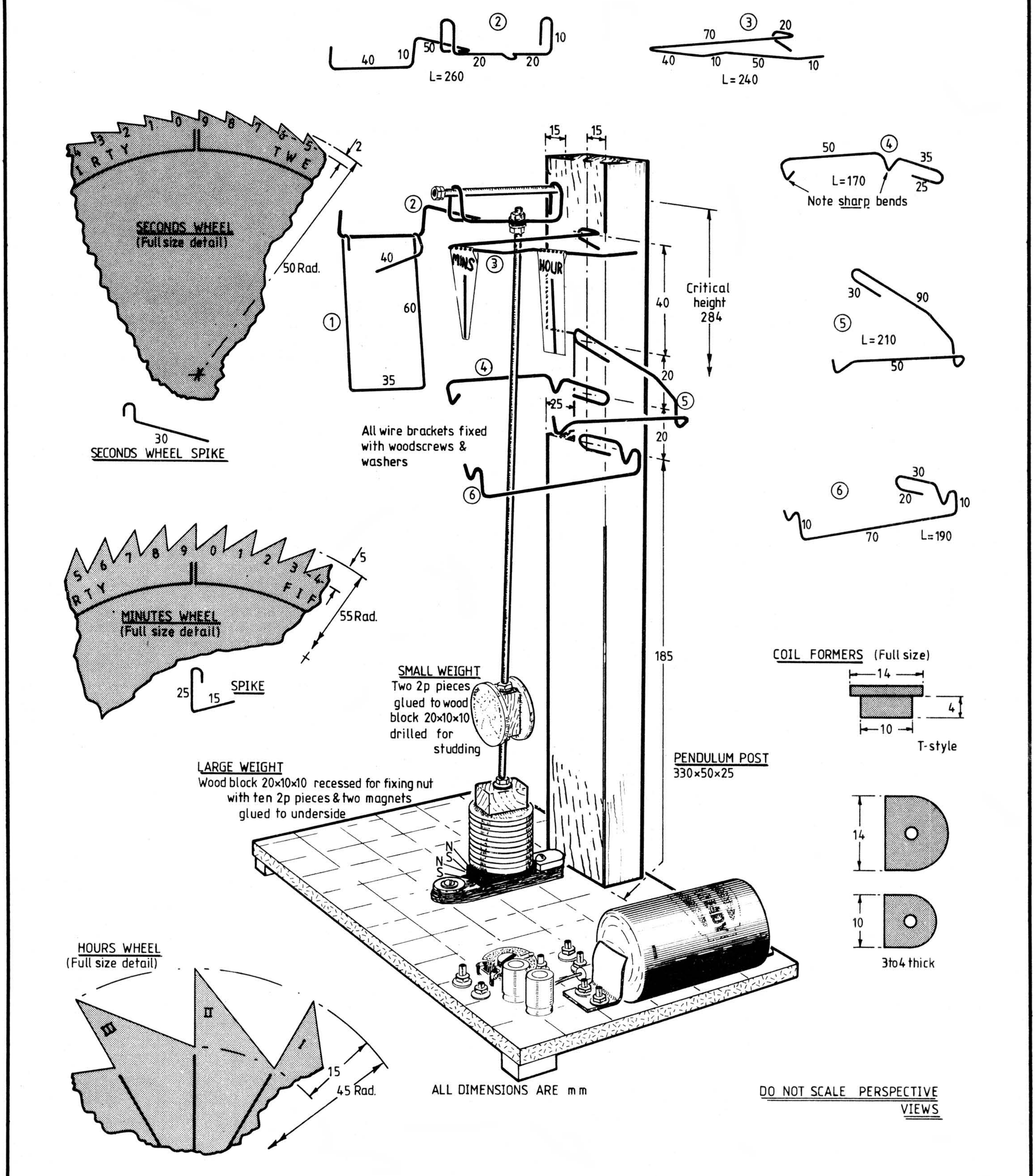


Fig. 1. Essential mechanism of the cardboard clock, showing parts of the three wheels and the axle support system. The pendulum has a period of 1Hz and so it cranks the seconds wheel directly. The offset spike at the centre of the seconds wheel drives the minutes wheel. Wire brackets are also shown. For the coil formers, if T-style caps from detergent containers are not available, use two pieces of material 3-4mm thick as shown.

ily be identified by hanging a ferrite from thread. Fine adjustment of timekeeping is made by varying the position of the small weight indicated. It should be trapped on the rod between nuts and washers, and set initially some 40mm clear of the coin stack. All the coins can be recovered undamaged at any time by shearing the stack in a vice, to break the bonds of the glue.

Adjust the position of the upper bracket on the rod so that the semicircles made in it roll on the pendulum bearing, while the magnets at the bottom clear the coil by 1mm. This task is slightly easier if the washer below the bracket is of the non-slip variety. Install the battery, adjust the pot to about mid range, and set the bob swinging with a travel of 50mm or so. It should continue to swing indefinitely, with the amplitude adjustable on the pot. This success will encourage completion of the count wheel system.

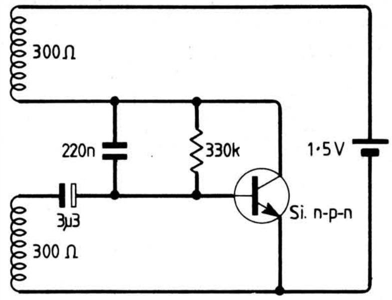
Seconds wheel

Bend the bracket No. 4 as shown in Fig. 1. The V bends as indicated must be tight, and just over a right angle. For these V bearings, the important point is to provide a gap beneath the 6 BA rod. Even the smallest gap is perfectly satisfactory. This feature removes any tendency for a wheel to roll back after being moved. The same care must also be used in constructing the V bearings on the later brackets.

Using an 18mm No. 6 woodscrew with a washer under the head, clamp the bracket to the pendulum post at the hole in Fig. 1. The woodscrew should pass through the loop of the bracket, half way along the 25mm part of it.

To cut the teeth on the wheel it is worth preparing a 6° template. Draw a circle of 60mm radius on a sheet of paper, using a sharp pencil. Prick accurately through the centre. Draw any one diameter of this circle. Using a protractor draw the other diameters that make angles of 6°, 12°, 18° with the first, and so on at 6° intervals. When drawing these diameters it is more accurate not to rely on the centre.

Now the seconds wheel can be made. Take the back of a school exercise book or other similar card, and check that when cut with scissors a clean edge is left, free from granulation. Draw on the card a circle of 48mm radius. Mark the centre with a cross of arms 10mm, and prick through. With the same centre draw a circle of 50mm radius, and carefully cut it out.



◀ *Fig. 2. Circuit of Kienzle clock movement. Five times a second a semi-sinusoidal induced voltage of 500mV peak tends to raise the upper ends of both coils. Then a current pulse of 3mA lasting 10ms does work against the induced voltage in the upper coil. Thus each pulse transmits some 15μJ of energy to the movement. Tuning fork oscillators are powered in a rather similar way.*

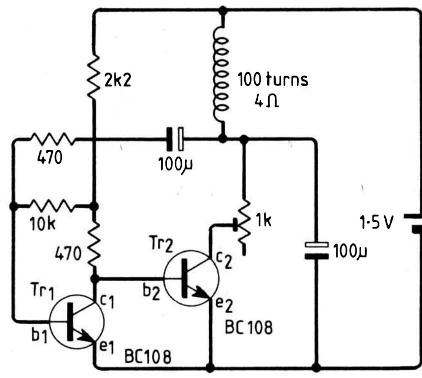


Fig. 3. The "millivolt monostable". The single coil is connected to this very sensitive form of the monostable circuit. When the hot end of the coil produces a 5mV negative trigger, a 100ms current pulse of about 3mA is provided.

Fig. 4. Full size plan of baseboard. But note the broken baseline: total length is 230mm. Do not drill the baseboard until the upper bracket is fixed. Prepare the lower bracket and position it with the aid of the battery. Then mark hole positions on the baseboard, and drill.

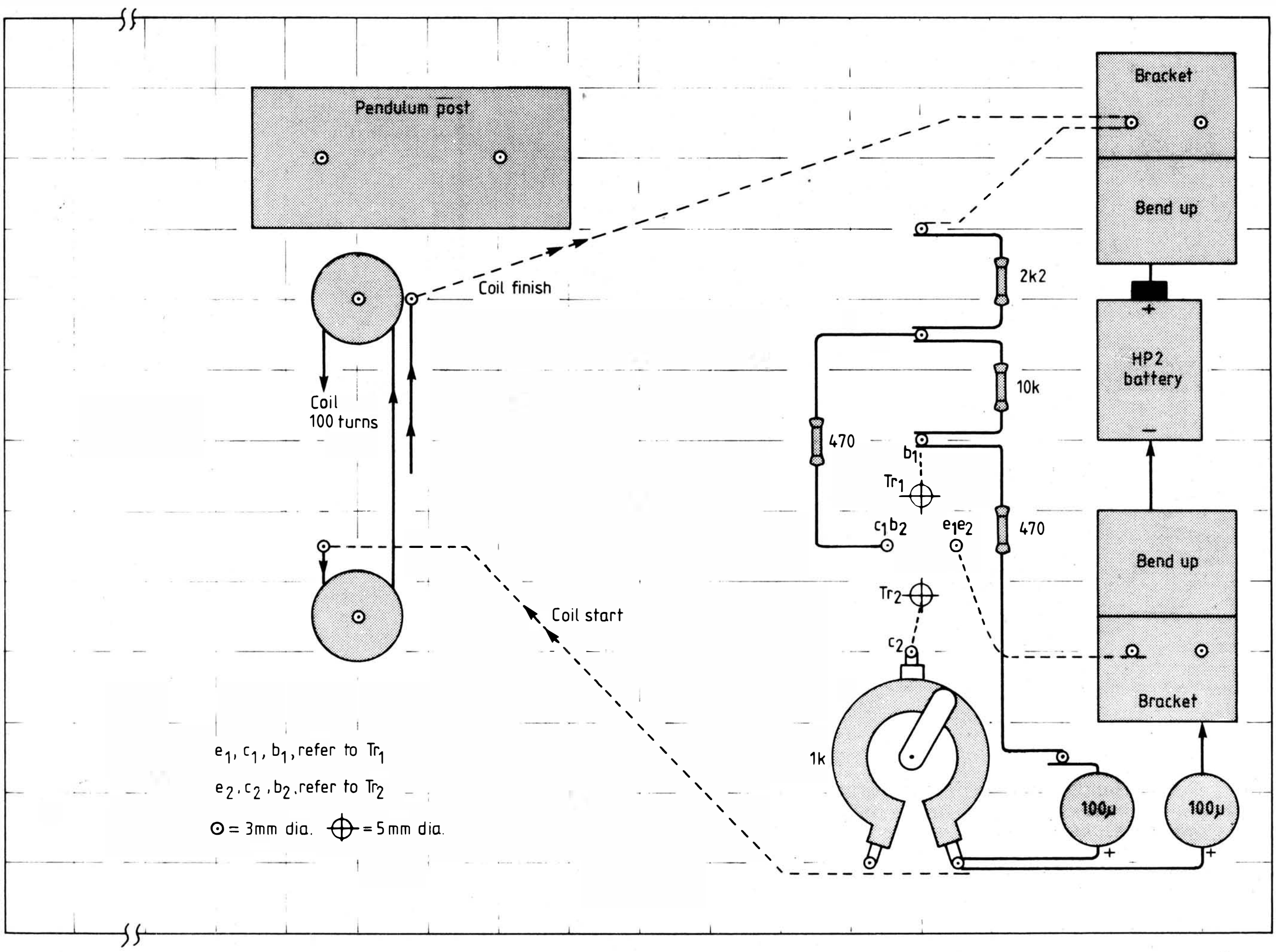


Table 1: parts for the clock

MECHANICAL MATERIALS (dimensions in mm)
2 aluminium pieces 38 × 19 of 16 s.w.g.
2 No. 10 screws 38 mm; 4 No. 6 screws 19mm
Chipboard 230 × 130 × 6, with centimetric graph paper to cover
Softwood 330 × 50 × 25
3 wood blocks 10 mm cube; 2 wood blocks 20 × 10 × 10
2 off 300 mm length 6 BA studding (threaded rod) from model/tool/hardware shop
15 screws 6 BA of 13 mm thread length or so, with 37 nuts
39 washers 4 BA (not 6 BA), ideally with one non-slip
2 detergent container caps T-style
12 coins 2p
Cover from one school exercise book, or similar card

ELECTRICAL PARTS
2 ferrite magnets 25.0 × 7.7 × 6 or so (Magnet Applications Ltd, 323 City Rd EC1V have waived their small order charge in favour of WW readers, and for 24p in stamps will supply both ferrites, if a 26p s.a.e. is also enclosed.)
1 foot connecting wire, say 24 s.w.g.
1½ metre 16 s.w.g. bare/tinned copper wire (or strip 1 metre 13A cable, and use the thicker wire)
12½ metres enamelled copper wire about ¼mm diameter = 33 s.w.g.
1 horizontal p.c.b. preset 1k (larger size: 20 mm diameter)
2 resistors 470Ω, one 2.2k and one 10k, all ½W
2 capacitors p.c.b. type 100 μF (not to be varied!)
1 HP2 battery

Place this disc centrally over the template, and mark off two points 180° apart. Then make the intermediary marks. Using the inner circle as a guide, make by eye 2mm radial cuts inwards from the points just marked on the circumference. Choose which side is to be the front of the wheel, and complete the teeth with slanting cuts, as shown in Fig. 1, top diagram. Do not use a mirror image, but follow the slants as shown. Keep the slant angle constant, and this will compensate for errors in the radial cut. The precise length and direction of these cuts is not too critical, but the radial cuts must start at the correct point.

Number the teeth in the direction shown, using a felt-tip pen. Teeth 25-34 are illustrated. To control warp, cut a second disc of half the radius, and glue it to the back of the first. Form the spike, using the thin connecting wire. Now trap the seconds wheels between washers at the front end of the 70mm length of studding. Then slip on an extra washer to trap the spike. This must point out ahead of the wheel, parallel to its axle, but 4mm off centre in the direction of tooth 15. This spike will then provide the correct drive for the minute wheel.

Place the completed seconds wheel in its bearing. Make the claw No. 1 in Fig. 1, but again using the finer connecting wire. The 40mm tail is an adjustable counterweight, which varies the pressure exerted by this claw on the seconds wheel. The diameter of the curves of the claw should be 4mm or more, to ensure that rolling takes place on 2. Hang the claw there, and loosen the screw holding bracket No. 4. This bracket can now be moved horizontally, to allow the claw to hang vertical, touching the wheel at about the level of its axle. The pendulum should now drive the seconds wheel. If at any time this wheel starts to squeak, place a little lard on the front bearing.

Minute and hour wheels

Make the minute wheel bearing 6 in Fig. 1, constructing the V bends once more as explained above. Clamp the bearing to the pendulum post as shown. Now draw on

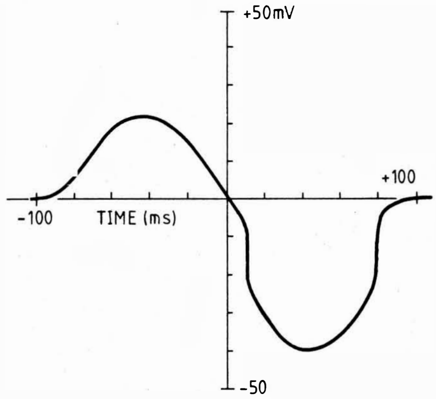


Fig. 5. *Trace of the potential of the hot end of the coil in Fig. 3 as the magnet passes in either direction. Triggering occurs when the induced volts reach some 5mV negative. The negative pulse should occur as the magnet is leaving the coil, so that a long pulse has no ill effects.*

card a circle of 50mm radius, and mark the centre with a cross. Prick it through. Draw a concentric circle of 55mm radius, and cut it out carefully. Mark the periphery from the template as before, and make 5mm radial cuts as in Fig. 1, middle diagram. Choose which side is to be the front, and complete the teeth and numbering as shown, noting that slanting cuts and numbers now proceed in the other direction. Back the new wheel with a 25mm radius disc, and mount it at the front end of the 90mm length of studding. Make the spike shown and trap it behind an extra washer, but this time at the rear of the wheel below tooth 07. This spike will then drive the hour wheel correctly. Now mount the minute wheel in its bearing, and terminate the axle at the rear with two nuts screwed together, so that the axle has little freedom of movement backwards and forwards. Ultimately both other axles may be so terminated.

Imagine the seconds wheel axle to extend forward indefinitely. Now adjust horizontally the bearing of the minute wheel, so that its teeth would just scrape the extended axle. As the seconds wheel rotates, its spike will now mesh with the minute wheel teeth, but it should only penetrate some two thirds of the available distance. Also when the seconds spike leaves the minute wheel it should next enter it near the centre of the next tooth. If the spike does not meet these two requirements, its radius can be adjusted.

Make the hour wheel bearing 5 in Fig. 1 without bends, and fix at the hole 2 on the post. Draw on card a 30mm radius circle, marking the cross at the centre and pricking through. Draw a concentric circle of 45mm radius, and cut it out. Mark the perimeter from the template, but only every 30°. Make 15mm radial cuts and choose the front. The slanting cuts are large, and they and the numbering follow the direction of the seconds wheel. Number the teeth I-XII. Mount the wheel at the front end of the 65mm or so length of studding remaining. Adjust the position of the bearing so that the hour wheel is correctly driven. This will include making two bends to bring the wheel forward somewhat. When the hour wheel is correctly driven each operation by the minute wheel leaves a radial side of an hour tooth vertical.

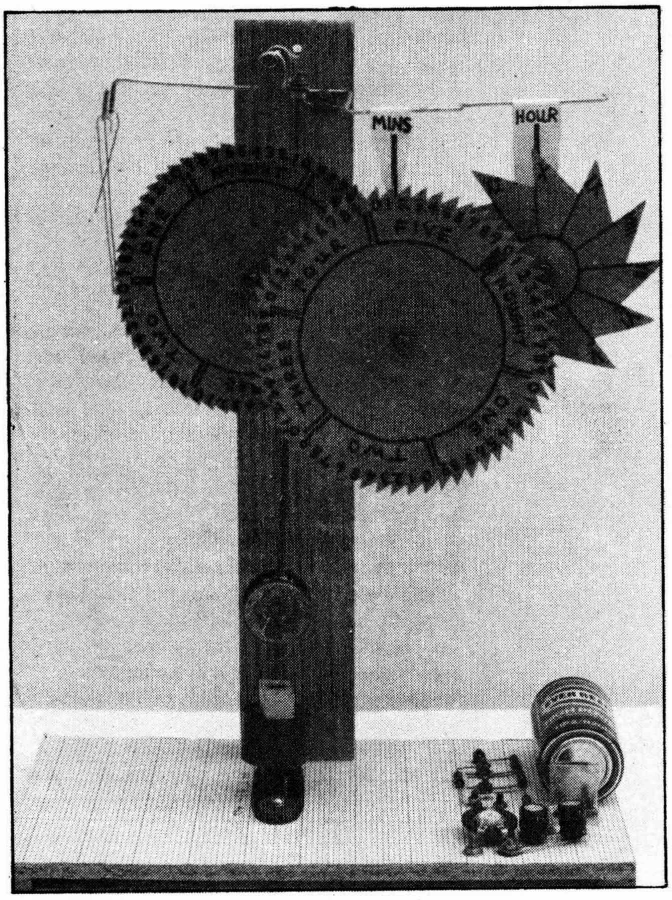
Finally the bracket 3 is constructed, and fixed at a hole on the post. Before making the bends shown at the top of 3 compare with the actual clock, to ensure that 3 will do its job. On its 40mm and 50mm sections it has to carry a card which can slide horizontally. One card indicates which tooth of the minute wheel is to be read, and the other does the same thing for the hour wheel. The time can be read more easily if these cards hang just behind the wheels, and extend just below them.

Practical points

A warning: the pendulum bearing can absorb some energy if the semicircles on No. 2 do not line up with the threads at the point of contact. If the pendulum bob describes a curved path that takes it out of the vertical plane, this is because the semicircles just mentioned differ markedly in radius. If a tooth is ruined while co ing any wheel, another can be stuck behind it. But keep glue off the active surface of the new tooth. If this addition unbalances the wheel, it may be brought back into balance again by glueing a 1cm square piece of card on the back in an appropriate position. If desired the wheels may be tested for balance by tapping the baseboard, and then corrected as above.

Lowering the adjusting weight by one turn of its fixing nuts slows the clock by about ten seconds a day, and conversely. Thus good timekeeping may rapidly be achieved. The clock malfunctions in strong draughts or vibration, but the time shown can be readily adjusted. Seconds should be read where the claw touches the seconds wheel. Enthusiasts may add a moon wheel, which will keep quite good time if two spikes on the hour wheel address a 59 tooth moon wheel.

Two patents are held on the clock, but that only stops it being made if some sort of financial gain accrues, and indeed full constructional details have been given here. A kit might be preferred, but no



The completed cardboard clock, which runs for about a year on an HP2 battery.

large manufacturer has been found to produce one. However Webbonware, 398 Hatfield Rd, St Albans, Herts, will supply a complete and engineered kit (less battery) for £17, which includes postage and packing. The teeth on the wheels are marked for cutting out, and all drilling is done. Baseboard and backboard are elegantly shaped in hard wood, but to look their best they need some finishing. Stripboard is provided to connect the electrical parts, which are then concealed. In this form the clock becomes a permanent piece of furniture.

Energy balance

A pendulum is a device which lends itself to measurement. By observing the decay in oscillation when there is no drive, it is possible to study the energy absorption of the various parts. When the amplitude is at its maximum permissible value the claw is almost drawing forward two teeth at a time on the seconds wheel. At this amplitude some 5 μJ of energy are absorbed per cycle in overcoming the air resistance met by the bob, while a further 3μJ is needed to handle friction at the axle of the seconds wheel. But the amplitude also has a minimum permissible value of about half the above, when the claw only just succeeds in moving one tooth of the seconds wheel. Here the friction requirement remains unaltered, but the air resistance element falls as the 2.5th power of the amplitude, and so reduces to about 1 μJ.

Thus the air resistance of the bob provides an energetic buffer against amplitude variation, and it must not be reduced. If the pot is adjusted for maximum permissible amplitude when the battery is new and delivering 1.6V, it will be found that when the battery is old and delivering only 1.1V there is still more than sufficient amplitude to drive the clock. With this endpoint voltage the battery specified yields nearly 10A h, and so at about 1mA consumption the clock should run for over a year.

Electrical measurements complement these mechanical observations. Arrange for the pendulum to swing with amplitude near the maximum permissible, while driving the seconds wheel as usual. Monitor meanwhile the voltage across the coil on an oscilloscope. As shown in Fig. 5 something like a single sine wave cycle is induced as the magnet passes over the coil, with amplitude some 25mV. Superimposed on this is a clearly distinguishable 16mV power pulse which switches rapidly and lasts 100ms. The coil is 4Ω so the power current was 4mA, flowing for 100ms against an induced e.m.f. of average value some 12mV meanwhile. All this happens twice in the pendulum cycle, and multiplication shows that during that time some 10μJ of kinetic energy are transferred to the pendulum. This is very close to the 8μJ suggested above from mechanical studies.

As with the electric motor, energy is transferred when current flows against back e.m.f. But the battery has to overcome not only the 12mV just mentioned, but also the 1500mV found at the pot. So the circuit is less than 1% efficient, compared with the 30% that may be deduced from Fig. 2 for the Kienzle movement. This is the price paid for a simple coil and magnetic circuit. Nevertheless, the battery lasts a year, and this might be regarded as sufficient.

Weather-satellite images

Continued from page 73

regenerator, demodulator and sync. detector, to be adjusted. The input level should be progressively reduced and each part 'retweaked'. The whole system should be adjusted by monitoring the noncoincidence pulses at the error monitor point in the bit conditioner. Final adjustment is a significant problem and can only be achieved after much trial and error.

Results and conclusion

A number of images have been recorded using this system and the ground resolution obtained is close to that specified in the spacecraft parameters list of 1.1km. It is likely that many improvements could be made by other experimenters but it is the intention that this article should be a basis for further work rather than a complete discription of a finished project.

Although the system was designed for h.r.p.t., facilities for Meteosat p.d.u.s. will be added since the Meteosat system is fully operational again: the basic philosophy is similar. Further design information about both systems is readily obtainable[16,17].

Many people offered advice and help during the development of the equipment. I would particularly like to thank all my colleagues at Feedback Instruments Limited, Miss C. Thoburn (Royal Greenwich Observatory, Herstmonceaux) and Mr W. S. Steer (Imperial College, London) without whose encouragement the project might never have been completed.

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17. Meteosat High-Resolution Image Dissemination, European Space Agency.

The NEC semiconductors mentioned in the article can be obtained through California Eastern Laboratories, 2 Clarence Rd, Windsor SL4 5AD (telephone Windsor 56891) and the address of the p.t.f.e. board manufacturers is 3M (UK) Ltd, PO Box 38, Yeoman House, 57-63 Croydon Rd, Penge, London SE20.

The chip capacitors mentioned in the first article have a value of 100pF and not 1nF as shown in Fig. 1. The manufacturer's type number given is correct.

The circuit shown in Fig. 15 of last month's article needs a slight modification. A series capacitor of 100pF is required in the g sync line to the 4017IC reset input. The capacitor is followed by a 10k-ohm resistor to ground so that the R and C form a high-pass filter. Without these components some resetting problems may occur.