A New Spectrohelioscope

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This design embodies an oscillating-slit system which is believed to be original and to have advantages over other systems. The virtual separation of entrance and exit slits is small and the slits are on a common member ensuring good synchronization. An electronically controlled moving-coil drive system allows instant change from oscillation to a single, uniform, large-amplitude traverse of the slits for the purpose of taking whole-disk spectroheliograms.

OPERATING PRINCIPLE AND DESIGN OF OSCILLATING SLITS

Figure 1a is a diagram of the Littrow-type spectroscope which I use for testing diffraction gratings ruled on my own interference-controlled ruling engine. Both 90° faces of the prism are aluminized and serve simply as two mirrors which conveniently separate the entrance slit from the eyepoint. It occurred to me one day that a movement of the slit would cause a corresponding movement of its image, *i.e.* spectral line, in the same direction. Therefore, if the entrance slit and a similar exit slit were attached to a common U-shaped member, it would form the basis of a very simple oscillating-slit system (figure 1b).

The first version of this was of simple construction and was intended to prove whether or not the idea would actually work. As can be seen from figure 2 the member carrying the slits is attached to two leaf-springs in the well-known parallel-motion form. It is important to note that the active length of the leaf-springs should be made as equal as possible, and also that the material should be flat and unstressed. Oscillation was maintained by an 'electric bell' contact on one spring with the addition of a shunt diode to reduce sparking. With this arrangement I was able to observe prominences and disk detail, and anyone not wishing to make the more elaborate design to be described could easily construct this version.

Some photography was done through the oscillating slits, but the large range of brightness across the scan due to the simple harmonic motion of vibrating slits (which can be tolerated visually) is a disadvantage photographically. Various mechanical means of producing a single uniform scan were considered, and then I hit upon the idea of using a powerful moving-coil system similar to that of a loudspeaker, but capable of a 14 mm movement and driven by a simple transistor circuit. This works extremely well and is rather fascinating to watch, as it is completely silent in operation. Oscillation or slow traverse is selected by a rotary switch. Amplitude of oscillation between

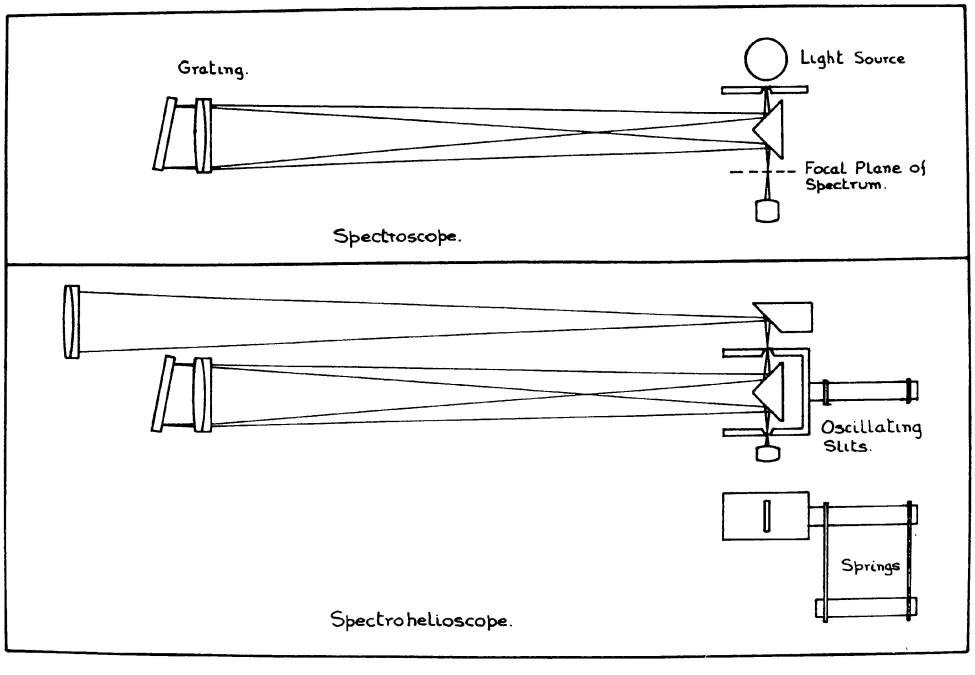

Figure 1.
(a) above: Littrow-type spectroscope.
(b) below: Littrow-type spectrohelioscope.

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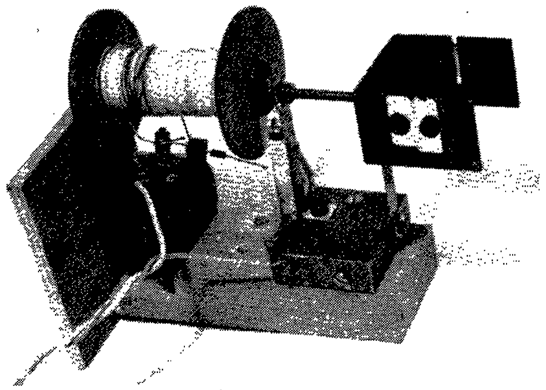

Figure 2. Test mock-up of oscillating-slit system.

approximately ⅛ and ⅝ solar disk is set by a potentiometer. Duration of traverse from 2 to 15 seconds over 1·2 times the solar disk is set by the same means (figure 3). Another feature which is incorporated is a fine screw adjustment to the slit width. This is, of course, convenient for different types of viewing and conditions. The adjusting nuts are rotated by poking the fine point of a wooden cocktail-stick through one of the holes; these sticks are also useful as slit cleaners. I have also dispensed with the end windows and set the slits parallel by opening the exit slit wide.

The design and construction must be carefully executed for the following reasons. My instrument has an objective lens of 1·22 m focus which produces a solar image of 11 mm diameter; this, of course, defines the traverse and slit length, and I chose 14 mm. As is well known, the frequency of oscillation should exceed 16 Hertz (cycles per second) in order to prevent serious flicker. For a given oscillating mass the frequency is determined by the spring stiffness, but this same spring stiffness also determines the force required to be exerted by the moving coil when on single-scan mode. If this force were too high due to a large moving mass, then a very large coil current would be required, leading to rapid overheating. I have managed to keep the total moving mass to 12 grams but, even so, for a frequency of 20 Hz the force at maximum scan is 140 grams and 3 watts are

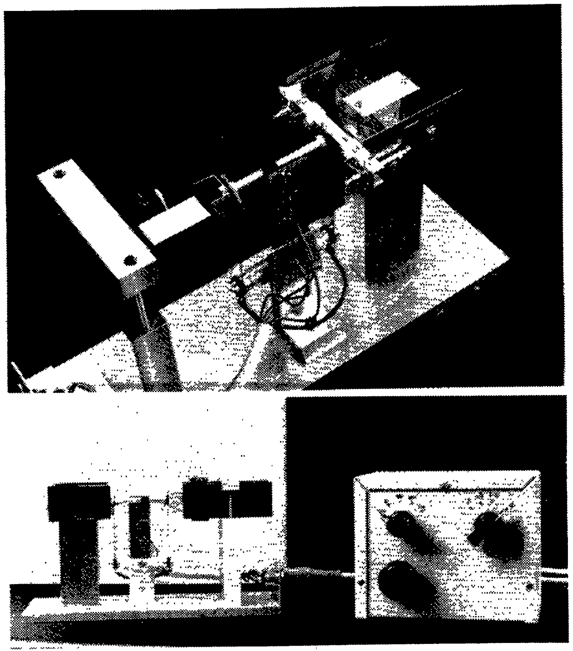

Figure 3. Two views of the completed slit mechanism, the lower showing the electronic control unit.

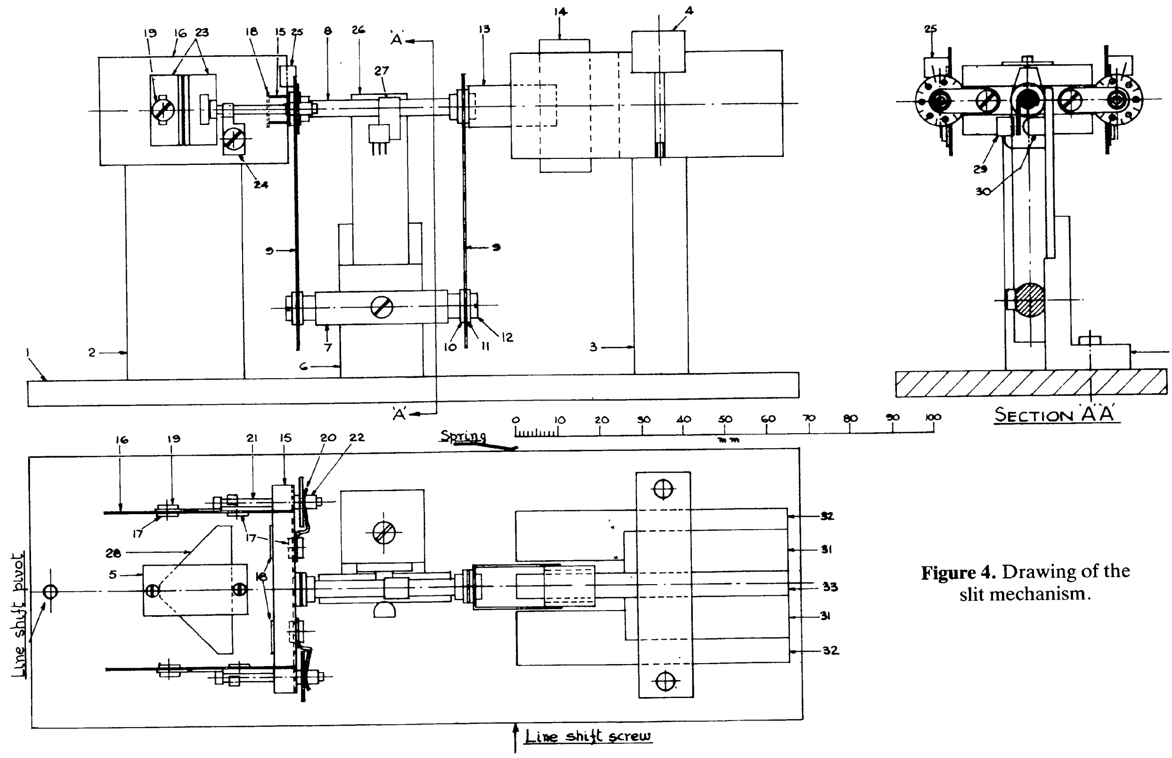

Figure 4. Drawing of the slit mechanism.

dissipated in the coil. For these reasons I would not recommend scaling the design up to suit a 50 mm solar image; it could be done, but a large image does not necessarily give better resolution—a large objective lens is also required.

CONSTRUCTION

I have a room with a workbench, lathe, drilling machine and the usual small tools. At least some of these facilities will be needed if construction of the moving-coil system is contemplated. With the aid of a little ingenuity it may be possible to modify the design of the turned parts so as to dispense with the use of a lathe. One useful tool is a piercing saw with some 0·25 mm blades; this is good for slotting fine screw-heads and also for cutting out aluminium sheet without distortion. The blades will usually need the fraze removed on one side before they will cut straight.

For machining the larger parts 1–4 and 6 (see figure 4 and Table I) I had the use of a milling machine, but they could be made by careful sawing and filing. Parts 15–18 are bonded together with epoxy resin and the surfaces should be well cleaned with lighter fuel or acetone beforehand. Use the slow-setting variety and apply some heat to assist it to flow into the joints. The assembly should be placed on a flat surface and carefully set true and square while the resin cures.

The magnet pole-pieces are cut from ordinary bright, drawn, mild steel and cemented to the magnets which were taken from a disused magnetic window cleaner; they are of the ceramic type measuring 35×25×10 mm. In order to save space between the magnet poles the coil does not have a bobbin; instead, the turns are cemented together with epoxy resin to make a rigid structure. A 'former' is first made and covered with a layer of Sellotape to which the resin will not adhere. I used the magnet centre pole-piece built up with thin cardboard as a 'former'. The internal vertical dimension should be 3–4 mm greater than the height of the pole-piece. One layer of wire is then wound on and the last turn temporarily secured. A thin layer of resin is then applied and the sides of the coil are lightly clamped against the 'former' while the resin sets. A thin resin with heat is again better than the quick-setting type. This operation is repeated until the correct number of turns have been applied. It is better to rotate the 'former' to wind on the wire rather than wind the wire round the 'former' because this causes twisting and kinking.

For the slit jaws I used "Schick" razor blades which are stainless and are thick enough to stay flat. One blade will just make two jaws if carefully ground through in the middle; the slots are then convenient for the clamping screws holding the fixed blades. The sharp edges should be smoothed and slightly blunted with the aid of a dead-flat oilstone such as a "Washita". The moving jaws of the slits are fastened to the heads of the adjusting screws with epoxy resin.

Table I

Parts List

	No. off	*Material*
1. Base plate	1	HE30
2. Mirror mounting	1	HE30
3. Magnet mounting	1	HE30
4. Magnet clamp plate	1	HE30
5. Mirror or prism clamping plate	1	0·5 mm aluminium
6. Angle plate	1	HE30
7. Spring spacer bar, lower	1	HE30
8. Spring spacer bar, upper	1	HE30
9. Leaf-springs	2	0·2 mm beryllium copper
10. Insulating washer	4	"Tufnol", nylon or similar
11. Insulating washer	4	"Tufnol", nylon or similar
12. Spring clamping screws	4	HE30, 6 BA, 6 mm dia. × 1·5 mm heads
13. Coil connecting piece	1	0·25 mm aluminium
14. Coil	1	
15. Crosspiece	1	0·25 mm aluminium
16. Side plates	2	0·25 mm aluminium
17. Tapped reinforcing plates	6	0·5 mm aluminium
18. Stiffening plates	2	0·25 mm aluminium
19. Screws, large head	6	10 BA, 4·5 mm dia. × 1 mm heads
20. Slit control springs	2	0·15 mm hard brass
21. Slit adjustment screws	2	HE30, 8 BA thread
22. Slit adjustment nuts	2	HE30, 8 BA thread
23. Slit jaws	4	See text
24. Guide for adjustment screw	2	0·25 mm aluminium
25. Fiducial mark	2	Paper
26. 'Veroboard' for LED and photocell		
27. Shutter	1	0·25 mm aluminium
28. Prism or mirrors		
29. Photocell	1	MRD 14B photo-darlington
30. LED	1	Clear red
31. Magnets	2	See text
32. Pole pieces, outer	2	6 mm BDMS, 3 mm air gap
33. Pole piece, inner	1	6 mm BDMS

Note. Any aluminium alloy which is free-machining may be used where HE30 is specified.

Part no. 9. Spring stiffness is very sensitive to thickness and it may be necesary to adjust the width or length to obtain the stiffness required.

To do this, first assemble the adjusting screws and nuts, etc., to the U frame. Next, place a slit jaw beneath the head of an adjusting screw, set the jaw edge central and vertical, and the screw head flush with the rear edge of the jaw. Then apply the resin.

ASSEMBLY

This is mostly self-evident but there are two points to note. The adjustment screws (21) should slide with just a little friction beneath the guides (24). The springs (20) should be able to overcome this friction and hold the tapered end of the nuts (22) positively in their bearing holes in the crosspiece (15). Do not overtighten the 10 BA screws (19) in case the short thread is stripped in the plates (17). Make sure that there are no particles of iron in the magnet air gap; sticky tape is useful for removing them. The finished coil is attached to (13) with epoxy resin and the wire ends are soldered to the top ends of the suspension springs, which are thus used to conduct the driving current to the coil. Input connections are, of course, made to the lower ends of the springs. The coil should move parallel to the pole pieces and must have definite clearance at all points of the stroke.

GENERAL COMMENTS

Owing to various commitments I have not had time to prepare a full set of detail drawings of the slit mechanism; instead, I have made a parts list with notes, and also sketches of three components that could not be visualized from the general arrangement drawing which is accurately to scale. Neither have I made a detailed description of the whole instrument, again because of lack of time but also because intending constructors are likely to use their own ideas and available materials. However, a few general comments may be of value. Owing to the compact design, the objective and collimator lenses have an aperture ratio of f/16 and therefore, if of single uncorrected type, they must be figured to remove spherical aberration. For the object lens I am using one borrowed from an old 7·5 cm (3-inch) refractor which performs very well. For the collimator I have a 1-metre focus cemented achromat which was specially designed and constructed for me by a BAA member, Mr G. Eades. This lens has a rear surface radius equal to its focal length, which means that the reflection of the entrance slit from this surface can be removed from the field of view by a slight tilt of the lens. This solution has also been mentioned by F. N. Veio[1]. Unfortunately, I have since discovered a slight snag with this idea. The light leaving the grating is partially reflected by this surface back to the grating, where it is again reflected forwards to a focus and forms a faint ghost image. Therefore I am returning to the idea of a lens with a plane or convex rear surface, and a patch stop as used by M. A. Ellison[2] to remove the reflection from this surface. There is, however, no need for the patch to extend right across the lens unless a wide spectral region is to be viewed or photographed. It need only be a few millimetres wide and slightly longer than the slits. The real image of the slit formed by the convex first surface is intercepted by a stop at its focal point.

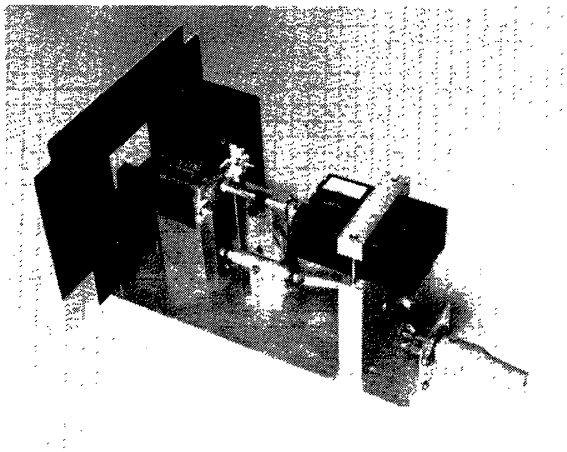

Figure 5. Slit mechanism with light baffle.

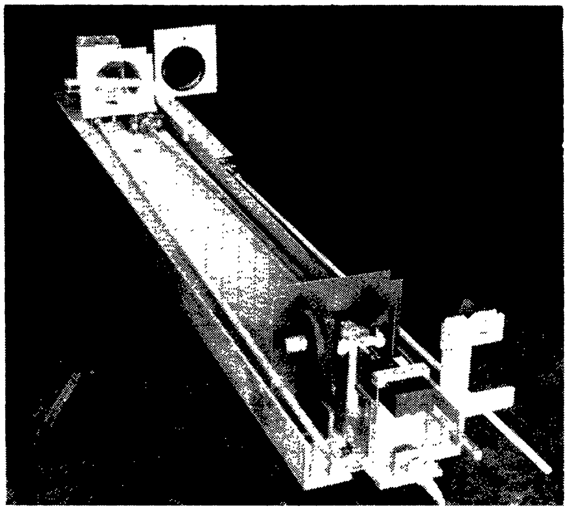

Figure 6. General view of the spectrohelioscope.

The grating mounting should be rigid and have a fine rotation adjustment for precise positioning of the line on the exit slit. Line shifting is conveniently performed by very slightly rotating the whole slit assembly about the pivot point shown in figure 4. The angle of rotation is approximately 0·028 degrees per Å, *i.e.* one-tenth turn of a 6 BA screw as shown. The synchronization of line and exit slit should be checked at the limits of the slit movement; the positioning of the prism between the slits affects this by changing the ratio f_1/f_2 which should, of course, be 1. The diffraction grating, which was ruled by myself, has grooves 56 mm long and 76 mm width of ruling, with a groove spacing of 595 per mm which is about the optimum for Hα use. Some light baffles are required in order to keep the field of view as dark as possible, and an idea of these can be gained from figure 5. For Hα a red photographic filter close to the eyepiece is also useful to increase contrast. The eyepiece I use is a cemented triplet of about 26 mm focal length.

Because the slits will operate in any position and the complete spectrohelioscope is only 1·25 metres long, it could probably be attached to a standard equatorial head, thus dispensing with the use of a coelostat. Some type of screening from sunlight for the observer would, of course, be required.

ELECTRONICS

These consist of a stabilized DC power supply and a control box with two distinct circuits, one which maintains oscillation for visual use and another for producing a linearly changing voltage for a uniform slit movement when taking photographs.

The power supply (figure 7) with outputs of −12 V and +12 V at 1 amp requires little explanation as stabilization is obtained by the 7812 and 7912 regulators. These should be attached with insulating washers to the aluminium case for heat dissipation. The case I used measures 100×160×125 mm. It would be possible to use one larger case for both power supply and the rest of the circuitry, but I chose to separate them so that the power supply could be used for other purposes and also to prevent any possibility of hum appearing in the drive to the slits.

The circuit for maintaining slit oscillation (figure 8) works as follows. When the slits are at rest, the shutter attached to the upper spacer (8) is arranged so as just to prevent the light from the LED reaching the photo-darlington. The transistor TR2 will then be non-conducting and the 25 μF capacitor will receive a positive charge. If a small movement is then given to the slits so as to uncover the photocell, TR2 will conduct and discharge the capacitor through the moving coil thus giving an impulse to the slit system. Note that the shutter must be correctly placed so that the impulse assists and does not oppose the original displacement.

The basis of the slow-scan circuit (figure 9) is an operational amplifier "integrator or ramp generator", the time-scale of which is adjusted by a potentiometer. This is followed by another operational amplifier which drives the output transistors and has the important function of removing cross-over distortion which can occur as the drive changes over from one output transistor to the other.

As is well known, a bugbear of slow-speed scanning devices is non-uniform velocity or vibration which causes striations to appear across the picture. An advantage of this electronic drive is its complete freedom from mechanical friction. I did initially have some difficulty with the cross-over problem causing a jerk at one point, but the present circuit is completely free of this. There is a large amount of electrical damping but, even so, external vibrations should be avoided during slow scan.

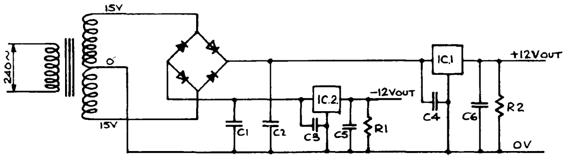

Figure 7. Power supply.

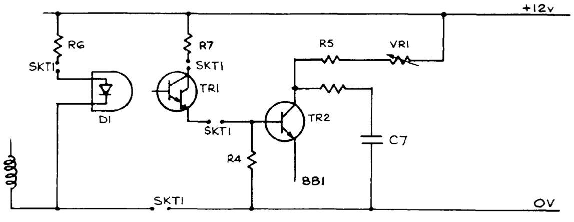

Figure 8. Circuit for maintaining slit oscillation.

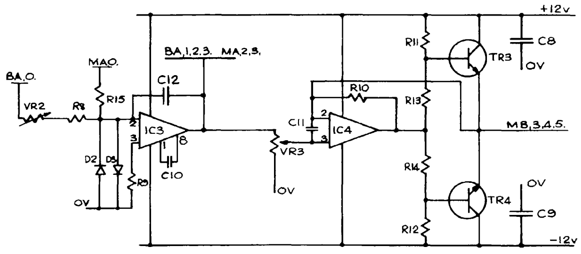

Figure 9. Slow-scan circuit.

The two modes of operation are selected by the five-position rotary switch mounted on the front face of the control box.

Position 1 (extreme anticlockwise). This disconnects the slow-scan circuit and connects the coil to the oscillator circuit for visual use.

Position 2. All circuits disconnected. Always turn to this position before switching off the power.

Position 3. Drives the slits to the central position at a controlled rapid rate. Its purpose is to avoid the sudden uncontrolled release of the slit system which would otherwise occur if switching direct to position 2 from position 4.

Position 4. Produces rapid movement of the slits to extreme left preparatory to taking a spectroheliogram.

Position 5. Initiates slow scan to far right at rate set by potentiometer, *i.e.* 1 second to 15 seconds.

The reason for the rapid movement at position 4 is to save time. This also is the reason for the two diodes connected between input 2, and 0 volts on the LM308 integrator. Without these diodes a long delay can occur when switching from 3 to 4 which could be frustrating when attempting to record rapidly changing phenomena.

The actual direction of movement can be changed by reversing the coil connection. Do not forget to reset the shutter as well.

CONSTRUCTION AND ADJUSTMENT

All the components except the BD135–6 power transistors can be mounted on a piece of 'Veroboard'.

The power transistors should be mounted on the aluminium case for heat dissipation which amounts to about 5½ watts maximum. Connections from the 'Veroboard' to the components fastened to the case should be made with flexible 10/0·01 mm connecting wire. A neater and better solution is to use an edge connector to the 'Veroboard'.

The moving coil in my instrument was made as previously described and is wound from No. 34 gauge enamelled copper wire; the first layer has 45 turns, subsequent layers have one or two turns less. There are four layers with a total of just over 170 turns. The resistance is 6 ohms, and it requires about 4·5 volts and 0·75 amp for full drive.

The above figures are dependent on the intensity of the magnetic field in which the coil moves. In my case the magnets produce a flux density of about 2500 gauss in the 3 mm air gap; careful construction could probably improve this by reducing the air gap by perhaps ½ mm. The magnet is assembled so that the two outer poles are of like polarity; the centre pole will then, of course, be of opposite polarity. The direction of movement of the coil at the switch positions 4 and 5 can be altered by simply reversing the coil conections, also the shutter position.

Table II

Electronic Components

Resistors
R1, R2, 4·7 K, ⅓ watt
R3, 15, ⅓ watt
R4, 10 K, ⅓ watt
R5, 1·2 K, ⅓ watt
R6, 330, ⅓ watt
R7, 220, ⅓ watt
R8, R9, 100 K, ⅓ watt
R10, 1 M, ⅓ watt
R11, R12, 7·5 K, ⅓ watt
R13, R14, 390, ⅓ watt
R15, 15 K, ⅓ watt
R16, 47 K, ⅓ watt
VR1, 10 K, carbon track lin. pot.
VR2, 1 M, carbon track lin. pot.
VR3, 10 K, min. vert. preset

Capacitors
C1, C2, 5700 μf, 25 V
C3, C4, 0·22 μF, 100 V, polyester
C5, C6, 0·47 μf, 100 V, polyester
C7, 22 F, 25 V
C8, C9, 1 μF, 35 V, tantalum bead
C10, 47 pF, polystyrene
C11, 68 pF, polystyrene
C12, 2·2 μF × 3, polyester

Transistors
TR1, photo-darlington MRD 14B, or more easily available 2N5777, part no. 29, figure 4
TR2, BC 182
TR3, BD135, with insulating set
TR4, BD136, with insulating set

Diodes
D2, D3, OA202
D1, red LED, part no. 30, figure 4

Integrated Circuits
IC1 7812, 12 V, + regulator, with insulating set
IC2 7912, 12 V, − regulator, with insulating set
IC3 LM309, op. amp.
IC4 741 C8

Switch
Rotary 1-wafer, 2-pole, 5-way, make before break
1-wafer, 2-pole, 5-way, break before make

Transformer
15–0–15 V, 2-amp secondary

Rectifier
2-amp, 50 V, bridge

Plugs and Sockets
5-way 240° DIN plugs, 2 off, from control box to slit mechanism
5-way 240° DIN sockets, 2 off

Warning! Do not connect or disconnect power with coil switched to traverse or attempt to work on electronics with power on, otherwise the slit mechanism may traverse at very high speed and could suffer damage.

Before switching on power for the first time set VR1 to mid-position and the rotary switch to position 2. Switch on power and test that the switching sequence functions correctly. It is a good idea to restrain the coil while doing this in case a wrong connection causes direct switching of the coil. This has happened to me and, although no damage was done, the sudden slam is bad for the nerves! Check that the two potentiometers on the panel control oscillation and scan duration. Oscillation should reach 6 or 7 mm and scan duration approximately 1 to 15 seconds. The scan amplitude is set by adjusting VR1. The photo-darlington should be painted all over with black paint except for a small window on the curved surface above the sensitive area. A high ambient light level may still, however, adversely affect oscillation.

At this point a few words on the optical alignment may be useful. Preliminary adjustment of the slits can be made without using the Sun. Open the slits wide (two turns of screws), place a bright light source in front of the entrance slit and locate the zero-order image, using a piece of white card before the exit slit if necessary. Then tilt grating to centre image vertically in exit slit. Substitute a neon lamp (a panel neon with 100 K resistor will do) for the white-light source, locate first-order bright yellow line in exit slit, then rotate grating (*i.e.* as if lines were clock hands) until yellow line is centrally placed in exit slit. If construction is accurate the line should be nearly parallel to the slit jaws. To make it exactly so, tilt the whole slit assembly very slightly about the screw passing through the lower spacer. If the error happens to be large, it will be necessary to reset one pair of slit jaws as too much tilt would not be desirable; however, I found no problem here. When actually used on the

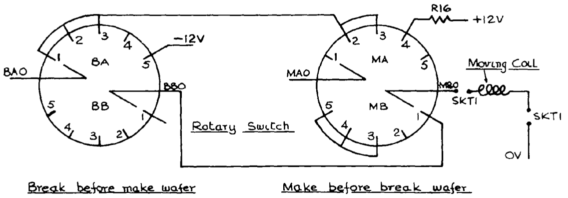

Figure 10. Wiring of rotary switch.

Sun it will be found that the positioning and angle of the 45° mirror, which, in figure 1b, directs sunlight on to the slit, is quite critical if the grating is to be properly illuminated.

Finally, it may amuse readers to know that the publication of the Association's *Memoirs* of the Solar Section in 1952 sparked off my interest in a spectrohelioscope, but, of course, I needed a grating or large prisms. I then became interested in the problem of ruling gratings, although at the time I did not really expect to make a usable grating; yet I did succeed in this, and 25 years later (!) had my spectrohelioscope.

REFERENCES

1 Veio, F. N., *The Sun in H-alpha Light with a Spectrohelioscope,* 18, California, 1978. (A copy is in the BAA Library.)

2 Sellers, F. J., *Mem. Brit. astron. Assoc.,* 'The Sun, 1928–1950', 26, 1952.