ORIGINAL CONTRIBUTIONS

An optical slit mechanism

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A symmetrically opening slit mechanism, particularly suitable for infra-red spectrometers, is described. It employs parallel spring movements, operates for widths from 1 to 2 000 μ and is suitable for use with curved jaws. Its operating torque is about 50 g cm which, with its rapid response and freedom from backlash, makes it suitable for automatic control. The jaws remain parallel to within about 3 sec, and the mid-line of the slit does not drift more than about 2 μ. Hysteresis between the driving micrometer drum and the measured slit width amounts to 0·2–0·3 μ, and may be due to an oil film. The slit jaws can be set so close together as to polarize the transmitted light completely. The slit mechanism, with a suitable rotational movement, has been applied to a twin-beam infra-red spectrometer; it has been demonstrated that entrance and exit slits must be alined to within a few seconds if satisfactory balance of the twin beams is to be achieved. An appendix describes a new all-spring reversing mechanism which enables the slit width to be controlled to better than 0·05 μ, and which is apparently completely free from hysteresis.

REQUIREMENTS

An optical slit mechanism, particularly for an infra-red spectrometer or monochromator, should so operate that:

(i) the slit jaws *remain parallel to one another*, and to their direction when closed, and in the same plane;
(ii) the jaws open symmetrically;
(iii) the jaws do not translate in the direction parallel to their knife-edges, otherwise curved slits cannot be properly used;
(iv) there is no backlash;
(v) the actual value of the slit width is accurately indicated, and settings are accurately repeatable;
(vi) the force between the slit jaws when closed is small, so that the action of closing the slit does not damage either the jaws or the closing mechanism (this action, although generally deprecated, is sometimes necessary);
(vii) for automatic control particularly, the operating force is small and the speed of adjustment high

In addition, the slit should be light-tight and compact, and it should be adjustable for limited rotation about the central axis normal to the plane of the slit, and perhaps for translation along this axis. The present paper describes a mechanism which, although somewhat bulkier than some existing designs, fulfils the foregoing conditions more successfully. It should be remembered, as a factor simplifying the design problem, that a slit as much as a *millimetre in width* is rarely required, so that the ratio of the maximum movement to the size of component is small. It is therefore unnecessary to devise a mechanism which would be suitable, on a larger scale, for opening the doors of a tube train.

Translatory mounting. The fundamental point of design is the method of translating the slit jaws. Some commercial designs use dovetail slides, and others cylindrical rod guides; in these the friction is high, and very good workmanship is demanded. Some designs use ball bearing kinematic slides; these can be made to work well, but they are relatively elaborate. Other designs, of which the latest and probably most successful is that of White and Liston,(1) use hinges; here again, the construction of the hinge (coaxial contra-rotating shafts in the design of White and Liston) requires very good workmanship. An alternative and easier method of supporting the slit jaws is to use parallel spring movements. Developments of such movements have recently been described by the present author,(2) but they have been widely used for a long time, notably by the late Mr. E. M. Eden of the National Physical Laboratory. J. E. Sears(3) applied the parallel spring movement to the construction of a *symmetrical slit; his design was later duplicated almost exactly* by Strong.(4) While Sears's design achieved a very parallel movement, the slit jaws necessarily translated in a direction parallel to their edges in the opening process. In the present design this defect has been removed by changing the method of mounting the springs (see Fig. 1).

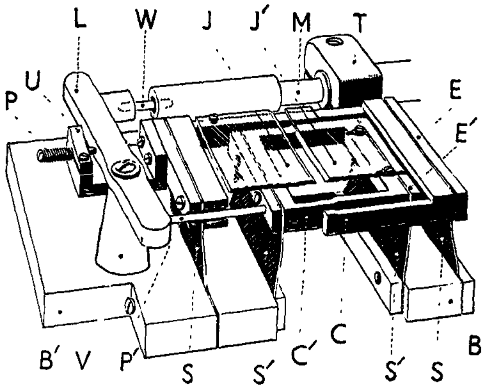

Fig. 1. Prototype slit

Opening mechanism. The other main point of design is the method of driving the slit jaws. Some mechanisms drive both jaws simultaneously; these mechanisms include scroll gears operating on teeth on the jaws, and wedges and cones to be forced between the jaw carriers. These all make great demands on the concentricities and uniformities of the components if the slit is to operate symmetrically and uniformly, and they introduce considerable friction. Other mechanisms drive one jaw carrier directly from a micrometer, and drive the second carrier from the first by a linkage which reverses the movement. These mechanisms include the reversing lever of Merz,(5) and tapes taken 180° around an appropriately spaced pulley; White and Liston use in principle the latter device. Both levers and tapes were tried before the present design was evolved, and levers were preferred. They could be made relatively strong, whereas tapes of sufficient flexibility were liable to stretch elastically under the changes in tension produced by variable friction at the pulley pivot; this sometimes resulted in as much as 10 μ of backlash of the second jaw carrier relative to the first. The backlash could have been reduced by a ball-bearing mounting for the pulley, as used by White and Liston, but the lever operated well without this complication.

PRESENT DESIGN

In the final design (Fig. 1), the reversing-lever and simultaneous-drive principles are combined. A micrometer M is made to drive the lever L (*via* a wobble pin W to reduce frictional torques), and the lever is arranged to drive two pins, P and P', one attached to each jaw carrier, in such a way that screwing-in the micrometer shaft opens both jaws (J and J') simultaneously, against the force of the spring mountings (SS and $S'S'$). When the micrometer motion is reversed, the springs restore the jaws until they close, and further backwards movement of the micrometer cannot change the force between the closed jaws. This force can be made as small as desired, by appropriate positioning of the jaws on their carriers.

For symmetry of opening, the lever arms of the pins about the fulcrum must be equal. This is easiest achieved by making one pin adjustable, and finding the correct position by trial; it is easy to match the arms within 0·5%. If the leverage of the micrometer is made exactly twice that of each pin, the micrometer readings will indicate the slit width directly. A finer control can, of course, be obtained by increasing the lever arm of the micrometer, at the minor sacrifice of direct width indication. It may be worth pointing out that the positions of the slit jaws are completely determined by the micrometer, and are not affected by the relative strength of the springs. The springs act purely to control the geometry of the movement and to maintain the jaw carriers against the lever.

Detailed description. Several examples have been constructed incorporating the foregoing design features; these examples differ in such details as the shape of the reversing lever (T- and L-levers have both been used, in addition to the normal straight lever: see Fig. 4), and the dimensions of the springs, because some of them were made to fit into an existing spectrometer where the space was limited. It will serve, however, to describe the prototype; any design for a particular instrument can be derived from this by simple modifications of layout.

The baseplate is made of two parts, B and B' (see Fig. 1), dowelled together; the material is mild steel 7·2 mm thick. This may appear unduly heavy, but the strength is necessary if the baseplate is not to bend appreciably when slit adjustments of 1 μ or so are being made. B is U-shaped, the gap in the U being of sufficient size to allow the radiation to pass. The jaw carriers C, C', are rectangular frames of mild steel, one inside the other. Two flat springs SS of beryllium copper are clamped to B and to C by end plates such as E; two similar flat springs $S'S'$ are clamped to B and to C' by end plates such as E'. The system SCS forms a parallel spring movement with the baseplate, and system $S'C'S'$ forms a similar movement. The end faces of C and C' are ground to the same separations as those between the corresponding faces on the baseplate. The top faces of C and C' carry the jaws J and J', which are fixed by screws through elongated holes in the jaws to permit some lateral adjustment. The top faces of C and C' are appropriately relieved as shown, where they lie under the opposite jaws. C' carries a pin P' in one of its end faces; this pin projects through a hole with ample clearance drilled in the corresponding end of C. On this same end of C is carried a U-piece U with a threaded pin P, which bears on the lever L from the side opposite to P'. P is adjustable for length by rotating its threaded portion in its mount, and for lever arm by loosening the screws fixing U to C. The ends of the pins P and P' bearing on the lever should have the same radius of curvature; the value of this radius as used was 5 mm. The lever L is mounted on the pivot post V; both L and V are substantially made from mild steel, and their mutual bearing should preferably (but not necessarily) be a good sliding fit. The micrometer M is mounted in a support T, and drives L by means of a wobble pin W, held between conical recesses, one on the micrometer cap and the other on the lever. It is arranged that the micrometer cannot be unscrewed so far that W would fall out of the conical caps.

The material throughout is mild steel, except for the beryllium copper springs. The points of construction to be carefully watched are (i) the machining of C and C' to the same dimensions as the corresponding ones on B, and (ii) the drilling and fixing of the springs SS and $S'S'$, so that C and C' are parallel to B, and the unrelieved portions of their top faces lie in the same plane. It is best to erect the spring mountings with accurately ground spacers temporarily set under C and C' to bring their surfaces to the same height.

Effect of wear. It might be considered essential, at first sight, to make the lever L a good fit on its pivot V, and this feature is emphasized in previous literature.(6) However, in order to test the effect of possible wear on the pivot, a "sloppy" fitting lever was intentionally substituted for a well-fitting one, without any noticeable effect on performance. The hole in the lever was about 0·25 mm over size. The reason why a "sloppy" lever can be used is that it is always loaded against the same side of the pivot by the combined action of the micrometer and the springs, so that any play in the bearing is automatically taken up. Hence the main effect of wear, or of an initially "sloppy" lever, would be a shift of the instantaneous centre as the lever rotates; in practice this shift is very small. A minor effect would be a shift of the jaw carriers as the springs move to take up the wear, but this shift would again be small.

SLIT MOUNTING

The method of mounting the slit is a vital factor in the design of a monochromator, since an inadequate mounting will ruin the performance of a well designed slit mechanism. The mounting should allow a limited but precisely controlled rotation of the slit about its optic axis, so that entrance and exit slits can be made precisely parallel to each other and to the edge and axis of the prism. The tolerances for maximum resolution, and particularly for balance in a double beam instrument, are small: with slits of 100 μ width or less the central line of the image of the entrance slit should coincide with that of the exit slit well within 1 μ even at the extremities. The total range of movement required is not more than a few degrees, and such a limited rotation would appear suitable for some form of spring hinge. The requirement is unfortunately complicated by the need for minimum optical obstruction in the axis of rotation, since this axis should preferably coincide with the optical axis of the slit.

In mounting the slit mechanism described in this paper, several attempts were made to adapt the principle of the standard cross-strip hinge, but it was not found possible to construct such a hinge without a relatively large optical obstruction along the hinge axis; moreover, it was not easy to achieve an accurately located axis of rotation. A different kind of rotary movement was constructed by mounting four rectangular leaf springs spaced at 90° intervals around a ring, so that their shorter edges were radial to, and their longer edges parallel to, the axis of the ring. Their shorter edges remote from the ring were held by clamps to a fixed plate, and a hole coaxial with the ring was cut in this plate. This construction left the axis of rotation (the axis of the ring) completely unobstructed, and a movement of ± 3° could be obtained with a drift of axis of rotation of about $2\,\mu$. The system was very rigid against any motion other than the desired rotation, but the construction was somewhat clumsy.

Finally, the simple spring hinge shown in Fig. 2 was used. The essential of this hinge is the flat spring *S* (free length 5 mm, width 10 mm, thickness 1 mm) held between clamps C_1 and C_2. C_1 is screwed and dowelled to a vertical plate B_1, which is fixed to the base of the spectrometer. C_2 is screwed and dowelled to a plate B_2 (shown dotted, and nearer the reader than B_1) which carries the slit mechanism; this mechanism is not shown in the figure, except for the jaws *J* and *J′*, which are again nearer the reader than B_2. It is arranged that the mid-line of the free portion of *S*, half-way between C_1 and C_2, lies in the optic axis of the slit formed by *J* and *J′*, so that the only obstruction in the optical path is the side view of the spring *S*. This slight obstruction is unimportant in the particular instrument to which the device has been applied (a Hilger D.209), since the central 2 mm of the slit is already blocked out, to separate the top and bottom halves of the double beam. A micrometer *M* fixed to B_1 deflects, *via* a wobble-pin *W*, the clamp C_2, which carries with it B_2 and the slit mechanism. To ensure that B_2 and the slit mechanism rotate about one axis only, i.e. the mid-line of the spring *S* half-way between C_1 and C_1, B_2 is constrained by an auxiliary spring *s* against a stop *P* of appropriate height screwed into B_1. The axis of rotation for small deflexions of the spring *S* is approximately in the mid-line of the spring when flat; if the length of the spring is *a* and the deflexion of the free end ϕ radians, the drift of the axis from its original position is approximately $a\phi^2/12$. Thus for a free length of 5 mm and a deflexion of 6°, which is much larger than necessary, the drift of the centre of the slit from its original position should be about $4\,\mu$. This method of rotation has proved satisfactory; it is free from backlash, and settings can be made and retained to better than 5 sec.

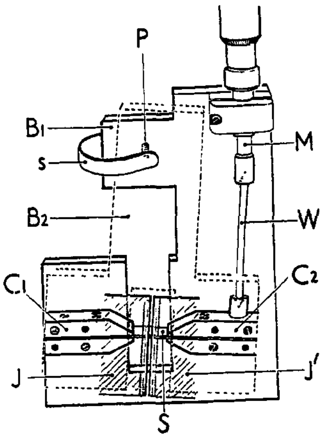

Fig. 2. Rotary movement of slit

PERFORMANCE

As constructed, the prototype had a slit 30 mm in length, which could be opened up to 2 mm width. It could be closed, apparently perfectly. The smallest opening that appeared uniform when viewed through a toolmaker's microscope was about $2\,\mu$ wide, this limit being set by the accuracies with which the slit jaws had been worked and fixed. The agreement between the slit width indicated by the micrometer and that measured by a toolmaker's microscope was as good as could be measured (i.e. within $2\,\mu$) with slit widths up to 1 mm; the linearity fell away at greater widths, mainly because no attempt was made to improve it, so that the micrometer reading was about 1% in error at 1·5 mm. The symmetry of opening, after three trial adjustments of the lever arms, was such that the mean line of the slit at any width up to 1·5 mm did not drift more than $1{\cdot}5\,\mu$ from its original position. Despite the fact that the thrusts on each jaw carrier were well to one side, the jaws remained parallel to one another and to their original directions within 3 sec up to 2 mm slit width, as measured by an autocollimator. This was amply good enough, but it might have been improved, if necessary, by spring correction as previously described.(2)

The torque necessary to actuate the micrometer was of the order of 50 g cm. The one defect, common to all hinge arrangements, was the departure of the plane of the jaws when open from what it was when closed; the departure, however, amounted to only $10\,\mu$ when the slit was 1 mm wide, and thus was generally negligible, particularly since it necessarily occurred entirely along the line of sight. There was no backlash that was manually detectable between the micrometer drum and the jaws, even when the position of each jaw was observed by a comparator capable of detecting $0{\cdot}02\,\mu$; but some hysteresis showed up when the light transmitted by the slit was measured photoelectrically (Fig. 3).

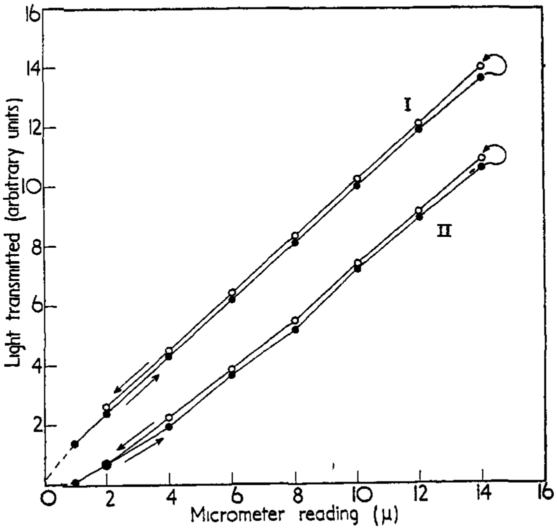

Fig. 3. Plots of mechanical hysteresis between micrometer drum reading and slit width, as measured by light transmitted, for prototype slit

I, electric vector parallel to slit length; II, electric vector perpendicular to slit length.

Measurements were made for a narrow slit up to $14\,\mu$ in width, where errors in linearity and hysteresis should be most effectively observed. There was a variable amount of hysteresis, sometimes amounting to $0{\cdot}2$–$0{\cdot}3\,\mu$; this probably occurred in the micrometer, and it may have been due to a variable oil film. It appeared to depend on the position of the micrometer in its nut, and could sometimes be reduced by rapidly rotating the micrometer to and fro. The mechanism was also tested with the "sloppy" lever mentioned above; this did not increase the hysteresis.

The same series of measurements enabled the linearity of the slit to be tested. At small slit widths, polarization as noted by Fizeau(7) and Zeeman(8) has an important effect; this is shown in Fig. 3. The transmission of the slit was appreciably greater when the electric vector of the light was parallel to the length of the slit than when it was transverse, and at 1 μ width very little of the transverse vector was transmitted. A narrow slit therefore polarized the transmitted light effectively. Subject to this reservation, and bearing in mind that the performance of the micrometer and the straightness and parallelism of the jaw edges were all involved, the linearity was good. It may be worth noting that, in the particular slit to which Fig. 3 applies, the jaws were of stainless steel, and their shape was that of 45° knife edges with the edges ground away to flats 75 μ across; the passage between the jaws at 1 μ width thus formed a wave-guide, for light of wavelength 5 000 Å, two wavelengths wide by 150 wavelengths long.

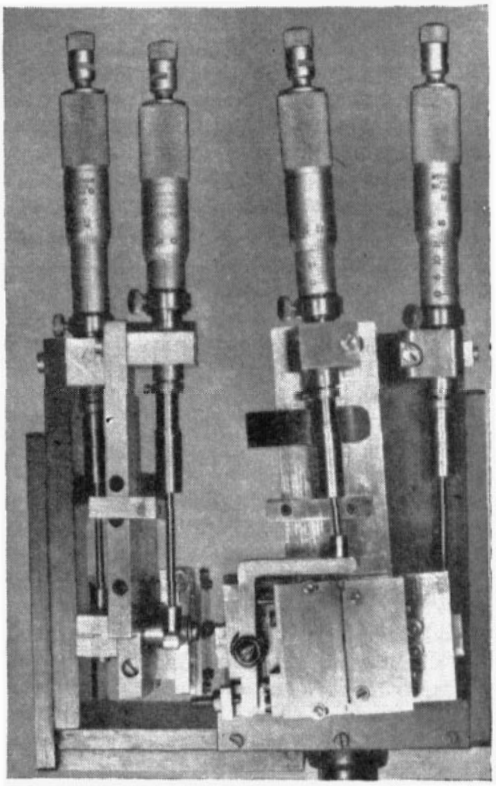

Fig. 4. Entrance slit (right, and seen from front) and exit slit (left, and seen from side) as made for substitution in a Hilger D.209 spectrometer. Rotary settings intentionally displaced

Entrance slit, L-lever; exit slit, T-lever. Scale obtainable from micrometers, or from slit length = 37·5 mm.

Application to twin-beam spectrometers. Two other slits, more compact than the prototype, were made expressly to fit into a Hilger D.209 spectrometer. The salient dimensions in millimetres of one of these slits were as follows:

Outer jaw carrier (*C*): 37·5 × 31·7 × 6·1, with 32·2 × 24·5 cut out.
Inner jaw carrier (*C′*): 30·2 × 12·5 × 6·1, with 25·0 × 7·1 cut out.
Springs (*S* and *S′*): total length 22·3; free length 9·0; width 30; thickness 0·19.
Baseplate: thickness 7·2.
Lever (*L*): pivot diameter 6; depth 4·8; arm *WV* 28·6; arm *PV* = *P′V* = 14·3.
Slit: length 25; maximum width 2·0.

The slits, which are shown completely mounted in Fig. 4, had much the same performance as the prototype, except that, owing to the shorter springs, the deviation from the original plane at wide slit openings was greater, but still immaterial. These compact slits were quite successful, but would have been easier to set up if the inner jaw carriers had been wider; they provided rather too small a surface against which to screw the inner jaws. The entrance slit was appropriately curved.

The micrometers on the rotary mechanisms enabled the slits to be alined without otherwise disturbing the spectrometer, and it was possible to measure the degree of alinement necessary for balancing the twin beams. Fig. 5 shows (*A*) the intensity transmitted in a single beam in the region of

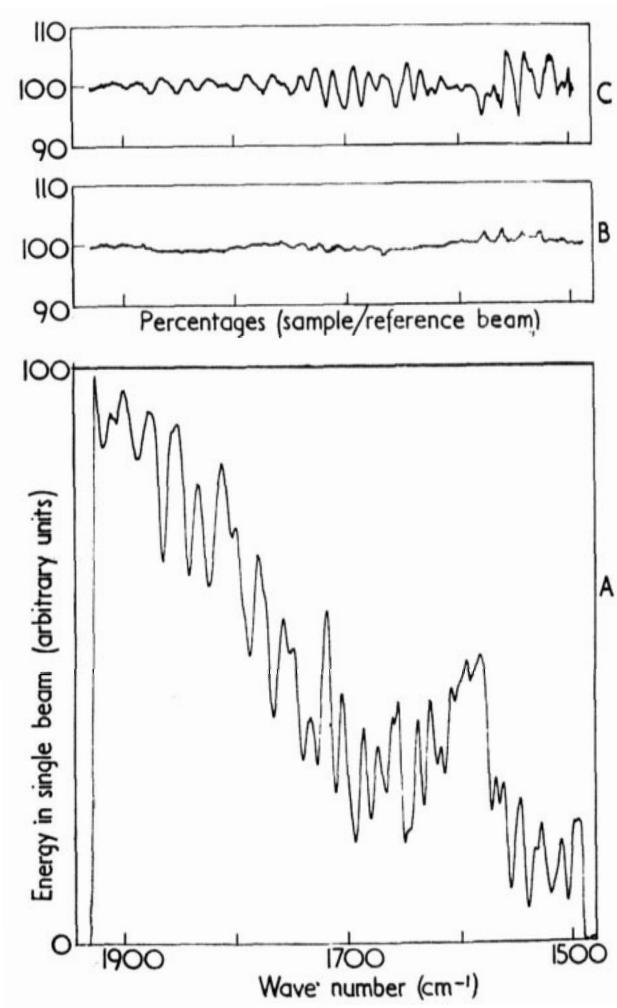

Fig. 5. Balance and misalinement in a twin-beam spectrometer

A; measured intensity in one beam, 1 900–1 500 cm,$^{-1}$ slit widths 60 μ. *B*; ratio of sample beam to reference beam, over same spectral range as *A*, when alined. Slit widths, 100 μ. *C*; as *B*, but exit slit misalined by one minute of arc.

atmospheric water vapour absorption from 1 900 cm^{-1} to 1 500 cm^{-1}, (*B*) the balance achieved with a reasonably good alinement of slits over the same range under the same conditions of water vapour absorption, and (*C*) the spoiling of the balance by deliberately misalining each beam by an angle of 1 min, or about 3 μ along the 12 mm length of each half of the exit slit. The records emphasize the need for a good means of alinement, and for substantial slit mountings. For other spectral ranges, the slits had to be realized slightly for best balance, probably because the prism edge was not quite parallel to the axis of rotation of the prism shaft. Subject to this limitation, the twin beams could be balanced to ± 1 (sometimes ± ½) % over regions where neighbouring peak to trough intensities changed by a ratio of five to one. Such operations as opening and closing the slits, which notoriously affect spectrometer performance, could be performed with impunity since—subject to the small hysteresis mentioned above—all settings were repeatable. The most obvious cause of the residual unbalance was non-parallelism of the slit jaws; to improve substantially on the performance shown in Fig. 5 (*B*) it would be desirable to fit some micro-adjustment to each slit mechanism to enable the two jaws of the slit to be made parallel to one another within a few seconds.

CONCLUSION

The slit mechanism described in this paper has been investigated to limits somewhat beyond normal spectroscopic requirements in order to ensure that it will fulfil these requirements adequately. It may in addition be of value when particularly fine optical slits are required for any purpose. Its small operating torque and rapid response, combined with freedom from backlash, should make it suitable for automatic as well as for manual control in spectroscopy. The former could be effected either by applying a motor to the micrometer, or by replacing the micrometer by an electrodynamic actuating system. The current through this system would determine the position of the moving member, and hence the width of the slit, with a response time of a fraction of a second. Such a mechanism might be useful in monitoring the slit width in a twin or chopped-beam system from the reference detector signal, as, for example, described by Baker and Robb(9) so that the slit passes a constant energy; this would ensure that optimum resolution is automatically used in all parts of the spectrum.

ACKNOWLEDGEMENTS

The performance of the slits owed much to the constructional skill of the departmental workshop, and notably to Mr. G. Watson and Mr. C. J. Meldrum. Fig. 1 and the diagram in the Appendix were drawn by Mr. G. S. Cameron.

The tests of the slits in a spectrometer were made with a Hilger D.209 instrument, which was provided by a grant from the Department of Scientific and Industrial Research.

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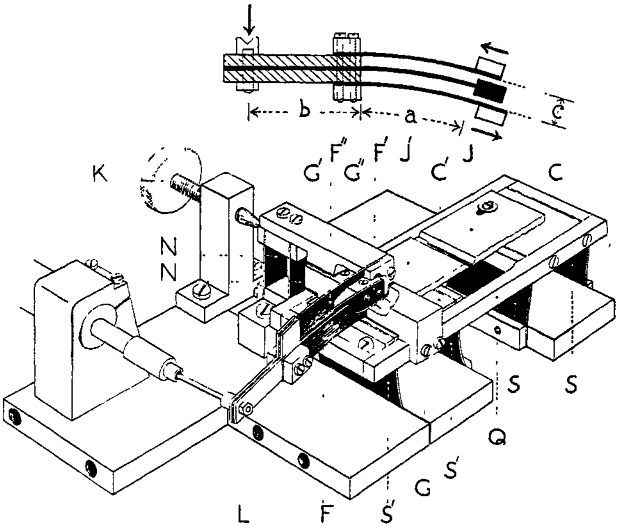
APPENDIX

A new reversing lever system has been developed which depends entirely on springs and which appears to be completely free from backlash. It is based on the spring displacement-magnifier used in the Eden–Rolt Comparator, and is illustrated in the diagram.



A new reversing lever system

The slit jaws *J* and *J'* are held on blocks *C* and *C'*, which are carried by the springs *SS* and *S'S'*; the arrangement is rather less compact than that shown in Fig. 1, but is easier to construct. A block *G* is fixed to a frame *Q* which in turn is fixed to *C*, and a block *G'* is fixed to *C'*. The problem of moving *J* and *J'* appropriately is therefore that of moving the blocks *G* and *G'* by equal amounts in opposite directions. *G* and *G'* are, of course, constrained to move parallel to one another by the spring systems *SS* and *S'S'*.

A flat spring *F* is fixed to that side of *G* which faces *G'*, and a corresponding spring *F'*, parallel to *F*, is fixed to *G'*. The other ends of *F* and *F'* are rigidly fixed together, and to the rigid lever *L*. If *L* is driven by the micrometer, springs *F* and *F'* are bent approximately into arcs of nearly concentric circles. The geometry of the system then requires that *G* moves away from *L* and *G'* towards *L*, thereby generating the desired movements in *J* and *J'*. It is an advantage to place a third flat spring *F''*, similar to *F* and *F'*, in the plane midway between them and fastened at one end to *L* and at the other end to a block *G''*, which remains fixed during the operation of the slit mechanism. *F''* therefore defines a neutral axis for the motions of *F* and *F'*. There is no room for *F''* directly between *F* and *F'*, and so it is mounted immediately above them as shown in the diagram. Since the space between *F* and *F'* is of the order of 1 mm, *F''* has to be positioned transversely to better than 10 μ if the motion of *G'* is to be equal and opposite to that of *G* within 1%. This positioning is best done by trial, mounting *G''* on a subsidiary and relatively rigid parallel-spring movement, *N N*, controlled by the screw *K*. Movement of *K* effectively transfers some of the strength of *F''* to *F'* from *F*, and so increases the movement of one jaw at the expense of that of the other. A few trials enable the motions to be matched within 1%. A further important function of *F''* is to give rigidity to the whole mechanism in a direction transverse to the slit.

If the lengths of F, F' and F'' are each a, and the length of L between the ends of the springs and the wobble pin is b, and the distance between the planes of F and F' is c, the approximate reduction in motion between the micrometer and the slit width is $(\frac{1}{2}a + b)/c$. In the specimen constructed, this reduction factor was 35. It was impossible to detect any hysteresis in the mechanism; the corresponding diagram to Fig. 3 for the new mechanism, for example, showed no difference between opening and closing readings, when 0·02 μ of hysteresis would have shown up. The large reduction is an advantage in making accurate settings, and might be valuable in automatic control; in the constructed specimen the slit width could be controlled to better than 0·05 μ. The new mechanism is less compact than the reversing lever of Fig. 1, which will satisfy any spectroscopic requirement, but it is superior for applications requiring the highest precision. It is being used, for example, in more precise investigations of the polarization phenomenon shown in Fig. 3.

A versatile equipment for thermocouple switching using a Post Office type uniselector

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Errors which may be introduced by the use of a Post Office type uniselector for the switching of thermocouples are considered. Methods of overcoming these errors are described. Details are given of a switching unit to connect up to fifty thermocouples in succession to either an indicator or a recorder.

Situations frequently arise in experimental work where it is required to use a number of thermocouples for the measurement of temperature and the couples have to be switched in sequence to a single measuring device. The switching unit itself is most important since it determines many of the characteristics of the apparatus. For general application it should be as flexible in operation as possible: the switching interval and the number of available points should be variable according to the application and the switch should form a compact unit with auxiliaries such as an automatic timer and the necessary power supplies.

THE POST OFFICE TYPE UNISELECTOR AS A SWITCHING DEVICE

The Post Office type of uniselector has several characteristics which make it attractive for this service. Up to fifty thermocouple points can be switched for each pair of contact banks and the rate of operation can be controlled conveniently in the drive circuit. In addition, if sufficient banks are available, the switch can be made to motor over any of the points which are not required at any time. Uniselectors are generally available and are less expensive than alternative types of switch. Their use for the switching of thermocouples has been previously described,* but the errors which might be introduced do not appear to have been considered. The principal source of error is the development of spurious voltages which, if appropriate precautions are not taken, can amount to 100 μV or more. This represents temperature errors of 2–3° C even with high-sensitivity thermocouples. In high-temperature measurement such errors may not be of significance, but for measurements in the range 0–100° C they are serious. If it is required to measure temperatures to within 0·1° C, the spurious voltages must not exceed 4 μV when copper-constantan or nichrome-constantan couples are being used.

The voltages arising in the uniselector fall into three groups:

(i) Steady thermoelectric potentials varying with the position of the wiper on the contact bank, and caused by uneven rise in temperature of the assembly as a result of the power dissipated in the operating solenoid.

(ii) Transient thermoelectric potentials due to contact wiping.

(iii) Other potentials.

The voltages forming group (i) are the most serious. If a simple cam-operated switch is used to interrupt the uniselector drive circuit, it is possible that the on-off ratio of the uniselector operating solenoid may approach 1 : 1 at the more rapid rates of switching. The power dissipation in the solenoid is then considerable. Most of the heat produced is conducted into the contact banks, and the temperature rise at the contacts can cause output voltages as shown in Fig. 1. The sharp rise at A occurs when the wiper reaches the contact nearest the solenoid. The spurious voltage then falls as the wiper moves round the bank, and reaches a minimum at B when at the contact farthest away. These voltages can be limited by reducing the on-off ratio of the drive circuit and so reducing the mean power level, and by moving the operating solenoid away from the contact banks and operating the drive mechanism through extension rods. In many cases, reduction in the on-off ratio gives sufficient improvement. This reduction can be obtained without any modification of the interruptor switch by the use of an auxiliary circuit consisting of a slugged relay across the drive circuit which operates normally closed contacts in series with the uniselector solenoid. If the slugged relay has a

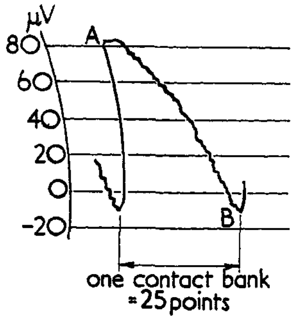

Fig. 1. Thermoelectric voltages arising in a uniselector due to rise in temperature of the contacts

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* Fowler, R. T. *Instrum. Pract.*, 6, p. 233 (1952).