ORIGINAL CONTRIBUTIONS

A low-power micromanipulator and microdissector

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Factors which must be considered in the design of a low-power micromanipulator are discussed. A rough prototype model is described and it is shown how the final instrument was evolved from this. The instrument is completely three-dimensional, will follow a movement of the hand with a reduction ratio of 4 to 1, and will "stay put" in any position. It is intended for use at magnifications up to 200 times, and the movement, as seen through a binocular dissection microscope, is not reversed.

In a previous paper(1) we described a micromanipulator suitable for work under the highest powers of the optical microscope; and the commercial model of this instrument is described on pp. 94 and 95 of this issue. The construction of an instrument capable, if necessary, of manipulating objects less than 1 μ in diameter imposes certain limitations of design, particularly as regards *mobility and range of movement*. In many fields of work, such extreme delicacy of movement is not required. A series of experiments was carried out during the past two years in order to assess the features most desirable in a low-power micromanipulator. In the first place it was decided that the magnification under which the instrument was to be used should not exceed about × 200. Nearly all normal binocular dissecting microscopes fall within this range, as well as standard microscopes with low or medium power objectives (16 mm and 8 mm).

Before an instrument was actually constructed it was necessary to decide on the degree of reduction of movement required. A number of subjects was asked to perform simple tests by hand under a stereoscopic binocular microscope (magnification × 30 to × 150). There is considerable variation of personal skill in this type of work. Thus much of the classical work in experimental embryology was done almost entirely by the unaided hand.(2) However, the average worker usually finds that with the hand well supported, but without any mechanical aid, a small object, such as a microscopic crystal, can be approached fairly smoothly with a needle until the tip of the latter is within a fraction of a millimetre of the object. Unless the experimenter is very skilled, a fine tremor usually sets in at this stage and becomes worse if he attempts to control it. Békésy(3) has recently reported experiments in which a subject tried to keep the tip of a pencil on a given point in a magnified field. Involuntary vibrations of the order of 0·1 mm occurred and these could not be eliminated by concentrated effort.(4) Our own experiments suggested that a reduction ratio of about four or five to one would be adequate for many purposes. The order of size of object and movement in which we were interested was about 0·1 mm, and as objects bigger than 0·5 mm could generally be dealt with quite well freehand, this reduction ratio, though small, seemed adequate. It is interesting to note that Békésy(3) states: "Experiments show that in many cases a manipulator with a reduction of 5 to 1 would be very useful." Such a reduction would result in an involuntary tremor of only about 0·02 mm (20 μ).

Having decided on the reduction ratio certain essential requirements were laid down. These were: (1) the reduced movement had to be three-dimensional; (2) the movement should take place in the same direction as the hand, so that there should be no apparent reversal under a binocular dissecting microscope; (3) all movements, in every dimension, should be carried out by means of a single control; (4) the instrument should "stay put" in every position when the operator's hand is removed; (5) the range of (reduced) movement in any direction should be not less than 0·5 cm, and considerably more, if possible.

These requirements should be compared with those discussed elsewhere(1) for a "high-power" micromanipulator. Whereas, in a high-power instrument, one may be prepared to sacrifice convenience to precision, *the emphasis in the present case is nearly all on mobility*, speed, and convenience. Many high-power micromanipulators(2) have a separate control for each dimension of space, but this type of movement could scarcely be tolerated for low-power use, indeed most workers would probably prefer to operate freehand. Much the same could be said of instruments giving apparent reversal of movement. The ideal at which we have aimed is to produce an instrument which will follow as far as possible all the normal movements of the hand, with a reduction of about four to one.

A PROTOTYPE MODEL

The development of the final instrument will be best understood by reference to a description of our first prototype. Although we had previously expressed the opinion(1) that micromanipulators based on the usual principles of the pantograph were impracticable, owing to the presence of play or backlash, we nevertheless decided to adopt this type of construction in order to see just how important backlash would be in a low-power instrument. The first instrument is shown in Fig. 1. It is made from metal wires and strips. The joints are rigid, and limited movement about them is obtained by elastic deformation. The stout metal rod *A* serves as the operating handle and a second stout metal rod *B* is held in a rigid clamp. These rods are at opposite edges of a cubic framework. The two sides of the cube attached to the operating rod *A* are composed of flat flexible strips of brass, *C*. The two sides attached to the supporting rod *B* are composed of flexible wires. Each of the right and left faces of the cube has an inner reduction frame of wires, which cross and form a smaller square on each of these faces. The two points of intersection of the reduction wires are used for attaching an instrument such as a needle or knife (a fine glass needle *D* is shown in Fig. 1). The latter was usually held by means of rubber bands. The principle of operation should be apparent from the photograph. The flat brass strips do not readily bend if moved in their own planes, but will allow bending to take place in planes perpendicular to themselves. Movement of the operating rod *A* produces elastic deformations of the strips and wires, which transform the wire squares into parallelograms. All movements of *A* are faithfully transmitted to the dissecting tool *D*, with a reduction given by the ratio of the sides of the smaller squares to that of the main squares of the cube. In later models the wires were arranged to give a variable reduction ratio.

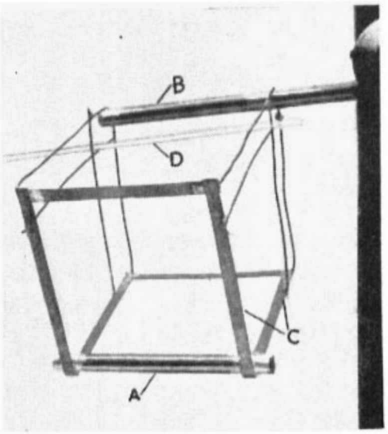

Fig. 1. First prototype low-power micromanipulator

This crude model gave remarkably promising results. Linear and angular movements were reproduced with excellent control and involuntary tremor was greatly reduced. The most serious limitation of the instrument was the fact that on removing the hand the operating needle did not "stay put" but returned to a mean resting position. Most of our subsequent work was directed towards the elimination of this disadvantage. There was very little backlash in this instrument. We attributed this to the use of springy material and this feature of design was borne in mind in all later models.

THE PRESENT MODEL

The main features are shown in Figs. 2, 3, 4 and 5. The instrument retains the general cubic framework of the earliest model, but the sides of the cube are in some cases deleted and in others extended. Rigid members and freely movable links are used. Two substantially identical sides are built up from phosphor-bronze strips. Each side comprises two parallel strips linked by two further parallel strips after the manner of a parallel ruler. Fig. 4 shows an almost full-sized photograph of one of the sides. (The magnification of the photographs varies, but the edge of the basic cube in the instrument is approximately 3 in. in length.) The links or joints between the members are balls located by three-point contacts and held in position by the spring action of additional phosphor-bronze strips tensioned by screws (Fig. 3). Some of the members are extended and counterweighted in such a way as to ensure that the instrument is balanced in any position in space. These two similar sides are joined together by (1) a knurled cross-bar which serves as the operating handle; (2) a reinforced cross-bar to the centre of which, and at right angles to it, is attached a stout metal cylindrical rod, intended to be held in a firm clamp; and (3) a reduction cross-bar, extended on one side, for the attachment of a tool holder. Each of these cross-bars is provided with ball links as already described, and it will now be seen that the cross-bars themselves form a pantograph or parallel ruler. The complete instrument is thus essentially a combination of three separate pantographs and a

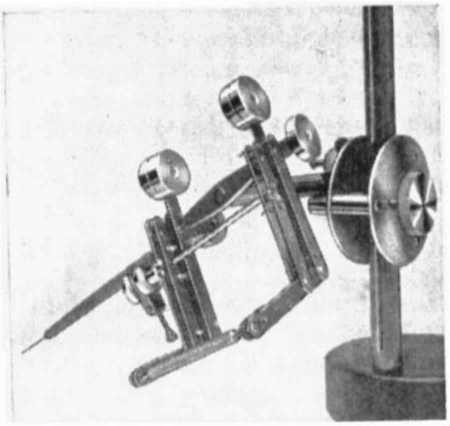

Fig. 2. General side view of micromanipulator showing stand and friction drive

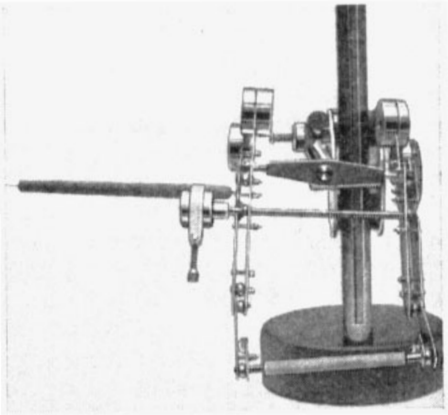

Fig. 3. Front view of micromanipulator showing ball joints

reduced motion of the tool holder is possible in three dimensions.

In order to reduce back-lash and to maintain resistance to movement nearly constant in all positions, the ball joints are spring loaded by additional phosphor-bronze clamping strips (Fig. 3). At those ball joints which are connected to the cross-bars, pierced ring contacts are provided. At other joints two three-point contacts are used. These contacts are pressed into part of a raised spherical surface, against which a flat phosphor bronze spring strip is held by means of a tension screw.

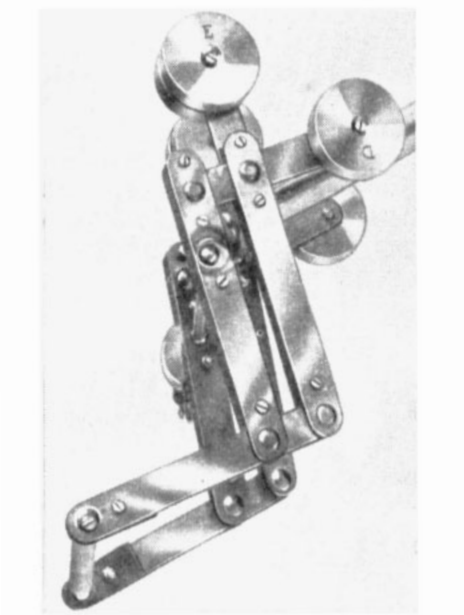

Fig. 4. View of one of the sides of the micromanipulator

THE TOOL HOLDER

The tool holder (Figs. 2, 3) works on the principle of a flexible metal band (tightened by means of a screw), which presses the microinstrument against two V-slots. This simple mechanism is extremely versatile and enables any tool of any shape, regular or irregular, and of any size from a fraction of a millimetre up to 1 cm, to be held firmly. Microinstruments can be removed and exchanged very rapidly.

OPERATION AND PERFORMANCE

When in use, the stout cylindrical rod, attached to the strong cross-bar, is held in a firm clamp. In the photographs a heavy stand is shown, provided with a coarse vertical friction drive. (This is an experimental variation of the well-known Keith Lucas drive.) Any suitable clamp and stand may, of course, be used, but it is advisable to ensure that the cylindrical rod, though firmly held, should be capable of rotation about its axis. We have usually found it convenient to set the instrument in a mean position, with the sides forming approximately a cube and with the operating handle parallel to, and vertically below, the reduction cross-bar carrying the tool. The whole instrument is then adjusted for height and angular tilt. The same instrument can be used for either left- or right-hand work merely by rotating the cylindrical supporting rod through 180°. If the operating handle is moved in any direction in such a way as to keep it parallel to the tool, the reduction of movement of the tip of the latter is constant and depends only on the dimensions of the micromanipulator (in the model shown the reduction ratio is 4 : 1, the range of movement of the operating handle is approximately 8 cm in any direction, that of the tool tip 2 cm). If, however, angular movements of the operating rod are made, so that the latter no longer remains parallel to the tool, then it will be seen that although the angular reduction ratio is not affected, the actual linear movement of the tip of the tool will depend on the length of the latter. In general, therefore, when it is desired to carry out many delicate angular or scooping movements the length of the tool should be reasonably short, say 4 in. Exactly similar arguments are, of course, applicable to angular movements made with a tool held in the unaided hand. For maximum comfort and precision some form of hand rest is an advantage, though this depends on the nature of the work. When properly balanced, the tip of the tool should remain perfectly stationary when the operating handle is released. Operations can therefore be carried out in several separate stages. This feature is particularly valuable as it enables the micromanipulator to be used as a "third hand." The important thing to remember when using the instrument is to forget it! One simply pretends that the tool is held in the unaided hand, and operates accordingly. The only exception to this advice is that in the instrument shown there may be

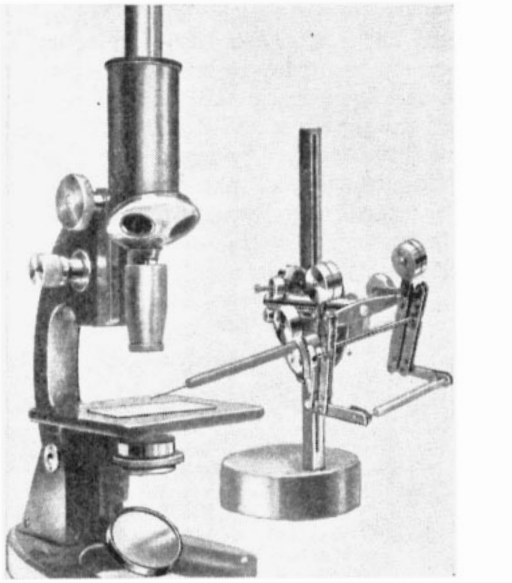

Fig. 5. Micromanipulator in use with a Dyson long working-distance objective.(5) This objective has a performance equivalent to a standard 16 mm objective, but with a working-distance of 34 mm. The field is not inverted and the objective is thus ideal for use with the micromanipulator

a tendency, with certain types of movements, for the tool to undergo a slight precession or rotation. This is of no importance if a needle is being used, but if the tool is a knife blade any rotation may be a nuisance. It is nearly always possible to perform the desired operation in such a way as to avoid rotation, but in order to eliminate unwanted rotation we have added a device which enables the user to rotate the tool at will. This refinement is shown diagrammatically in Fig. 6, which represents one side of the instrument (Fig. 3). The operating rod and the cross reduction rod are extended (on the side opposite to the tool holder). A fourth extended cross-bar *c* is added. These three extensions are then linked together by means of ball-ended cranks and a parallelogram of phosphor bronze strips and clamping members, similar to those employed elsewhere in the instrument. Rotation of the operating handle *O* now produces a similar rotation of the tool-carrying cross-bar *T*. This addition is most valuable for performing rapid twisting and scooping movements. It enables cutting edges, hooks, and curved tools to be properly oriented relative to the object. The rotation is independent of any other movement, linear or angular, of the instrument. The use of pivoted cranked links, rather than a pulley system, is necessary in order to allow sideways distortion of the parallelograms without affecting the operation of the rotational links.

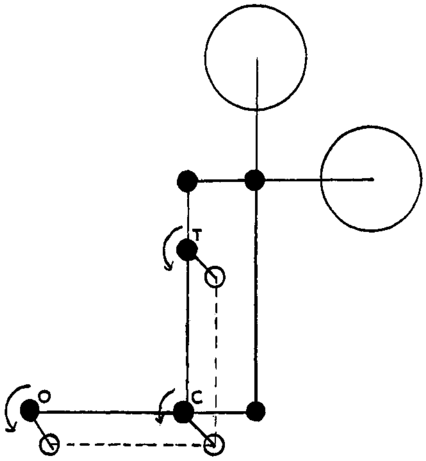

Fig. 6. Diagram showing method for obtaining rotation of tool

The instrument has been tested for a number of purposes, such as fine dissection work, manipulation of small crystals, accurate positioning of micro-electrodes, and making fine cuts in the growing tips of plants. It is believed that it will prove useful in many fields, including biology, medicine, bacteriology, some branches of surgery, crystallography, and microchemistry. The possibility of using the instrument for delicate mechanical work, such as the construction of fine galvanometer suspensions, or even watch-making, are being investigated.

ACKNOWLEDGMENTS

We wish to record our indebtedness to certain principles of design laid down by the late Dr. W. N. Bond. One of us (R. B.) wishes to acknowledge the help received as Johnston, Lawrence and Moseley Research Fellow of the Royal Society.

Arrangements for the manufacture of the instrument, which is protected by patents, have been made by the Singer Instrument Co. Ltd., Reading, Berks.

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The preparation of pinhole-free silver mirrors

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Following a comparison of various known silvering processes, a modified form of the Brashear process was devised. This process could be operated successfully when the component solutions were at room temperature within the range 12–26° C, thus avoiding the well-known difficulties associated with changes in the ambient temperature. Pinhole-free mirrors were then prepared by adopting special cleaning techniques in conjunction with the above improved Brashear process.

For certain specialized optical applications, e.g. the production of some types of graticules, the employment of silvered mirrors of extremely high quality is essential. The existence of pinholes in otherwise excellent films has resulted in considerable difficulty and the following investigation was conducted, primarily, with the object of producing pinhole-free mirrors. It is known that a pinhole-free mirror may be produced by repeated silverings, but the existence of pinholes, especially in the first coating, is a source of weakness in the metal film as a whole, and the present work was designed with a view to producing a pinhole-free mirror in one silvering operation. Although the literature abounds with references to work on various silvering processes, no one