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PUBLICATION BZ 47/2

WATTS

MICROPTIC AUTO-COLLIMATOR

INSTRUCTIONS FOR USE

HILGER AND WATTS LTD

98 ST. PANCRAS WAY · CAMDEN ROAD
LONDON · N.W.1

Telephone:
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SPHERICITY, LONDON, TELEX

MEMBERS OF SIMA AND BSIRA

PRINTED IN ENGLAND

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GENERAL DESCRIPTION

1. PURPOSE OF INSTRUMENT

The Microptic Auto-collimator is a robustly constructed optical instrument for use by research workers and engineers for the precise measurement of small angular deflections of a beam of light. It has a range of 10 minutes of arc and a sensitivity of a fraction of a second. Any movement or variation which can be arranged to deflect a small mirror can be accurately measured with this instrument. It can often be used where conditions make it inconvenient, or even impossible, to use dial indicators, comparators or other methods.

2. PRINCIPLE OF OPERATION

The principle upon which the Microptic Auto-collimator operates is illustrated in *Fig.* 1.

As its name implies, the Auto-collimator consists essentially of a telescope which produces a collimated (parallel) beam of light which comes from a small lamp fixed at the side of the telescope. The light is reflected through 90° along the axis of the telescope by a small 45° semi-silvered glass plate, and in its passage towards the telescope objective lens it illuminates a pair of fixed target wires. These wires are arranged horizontally and vertically in the form of a 90° cross and are set exactly in the focal plane of the telescope objective: an image of the target wires would thus be formed at infinity. If, however, a plane mirror is suitably placed facing the objective, the light is reflected back into the telescope and the image of the wires is brought to a focus by the objective exactly in the plane of the target wires themselves. If the face of the mirror is truly perpendicular to the optical axis of the objective and the intersection of the target wires lies exactly on this axis, the image would coincide with the target wires and would not be seen. When the instrument is in use, however, the mirror is arranged to be slightly inclined to the perpendicular position, so that the image of the target wires becomes slightly separated from the wires themselves and can be seen.

If the mirror is now given a further slight tilt, the position of the image will move correspondingly. The amount of this movement is directly proportional to the angle through which the mirror is tilted *and it is not influenced at all by the distance of the mirror from the telescope.*

The reason for this is because the image-forming rays of light which leave the telescope are parallel, and they return to the telescope again as a parallel beam after reflection at the mirror. The angle between these two beams of light is equal to twice the angle i which the incident beam makes with the normal to the mirror surface, and is clearly not affected by the distance between the mirror and telescope. The effect of this angle $2i$, between the outgoing and returning parallel beams of light, on the distance d between the target wires and their image is operative only over the focal length f of the objective. This distance d is therefore equal to $(2i \times f)$.

If the tilt of the mirror is changed from i to i', the new distance d' is equal to $(2i' \times f)$. The change in tilt of the mirror $(i' - i)$ therefore produces a displacement of the image represented by the expression

$$d' - d = 2(i' - i)f$$

or

$$(i' - i) = (d' - d)\frac{1}{2f}$$

Now in the Microptic Auto-collimator the focal length of the objective f is 10·8 in., so that

$$d' - d = 21 \cdot 6\,(i' - i)$$

the angles i and i' being measured in radians.

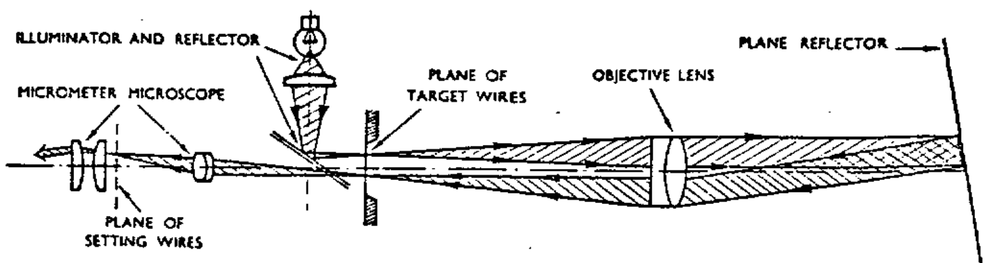


Fig. 1

For a change in tilt of the mirror of, say, 1 minute, the displacement of the image amounts to 0·0063 in., and for 1 second it is 0·00010 in.

To obtain the required sensitivity in the Microptic Auto-collimator, displacements of the image of the target wires are measured with a micrometer-microscope which is incorporated in the instrument. This microscope has a power of × 39 and is shown diagrammatically on the left of *Fig.* 1.

The eyepiece of this microscope has a pair of parallel setting lines which can be traversed across the field of view by means of a finely-threaded micrometer screw. The setting lines are arranged parallel to one of the target wires, and when taking a reading, they are moved by turning the drum of the micrometer screw until they symmetrically enclose the image of this target wire.

The magnification of the microscope objective and the pitch of the micrometer screw are such that one complete turn of the latter corresponds exactly to a deflection of 30 seconds of the mirror. The micrometer drum is divided into 300 (150 dark and 150 light) equal divisions and is figured every second of arc. The index line is of similar thickness to the drum divisions.

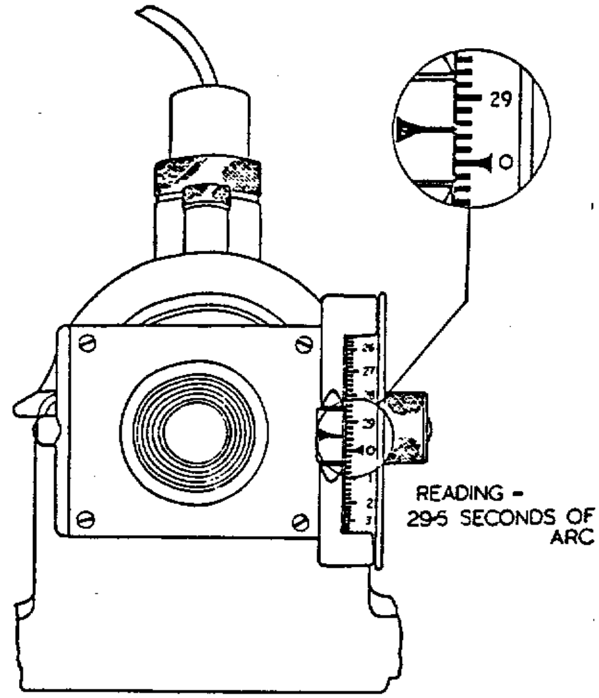


Fig. 1a

With a little practice it is possible to obtain repetition of readings to within 0·1 second of arc.

A general view of the instrument is shown in *Fig.* 2.

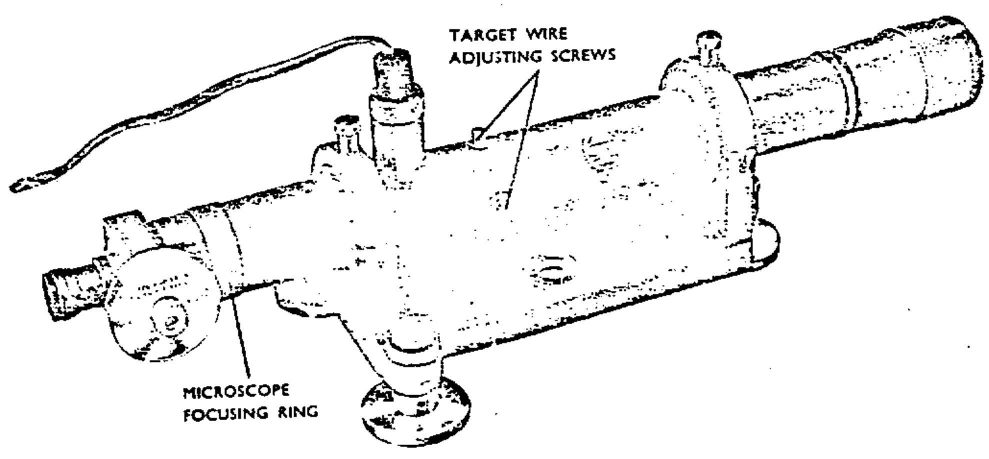


Fig. 2

From the user's point of view, the following salient points should be noted regarding the working principles of the instrument.

(*a*) One division on the micrometer drum represents an angular deflection of the mirror of 0·2 seconds.

(*b*) This measurement of the deflection is independent of the distance the mirror is away from the telescope.

(*c*) The deflection measured is that which takes place about an axis parallel to the setting lines in the eyepiece. Thus, if it is desired to measure the deflections of a mirror about a vertical axis, the telescope should be arranged with its setting lines vertical ; deflections about a horizontal axis would be measured with the setting lines horizontal.

(*d*) When measuring deflections about a given axis it is often necessary to determine the sense of direction of the deflection in relation to the direction of the movement of the image in the eyepiece of the telescope. This is done most readily by tilting the mirror very slightly by hand in one direction and noting the direction in which the image moves.

NOTE.—It should be noted that if an external collimator is used with *any* Auto-collimator in place of the usual reflector the difference of readings taken from the drum should be multiplied by two, to obtain the true angular deviation.

3. SETTING UP THE AUTO-COLLIMATOR

Owing to its extreme sensitivity the Auto-collimator must always be set up on a very rigid support. It may be set up either on its flat base or on the three footscrews fitting in the casting. When supplied, the instrument is adjusted so that a plane reflector set up square to the planes of the base and the vertical ground pad. on the left-hand side of the base casting will produce an image approximately central in the field of view. It is recommended that the Auto-collimator be used on its feet and the three pads provided. When setting up this way it will be found convenient to first level the table or bed by means of a block level, and then to level the Auto-collimator to its own bubble by means of the footscrews.

The instrument can be effectively clamped in position on the table by holding down each footplate with a little wax.

It will be observed that the Auto-collimator tube can be rotated in its bearings through 90°, enabling the eyepiece micrometer to be used in either the vertical or horizontal direction. This allows measurements to be made of reflector deflections about a horizontal or vertical axis respectively.

The only focusing adjustment necessary is to rotate the eyepiece to focus the setting lines. This brings the direct and reflected images of the target wires also into focus. To obtain the most comfortable focus for the eye, the eyepiece should be adjusted from too far out into the best position ; the eye will then be accommodated for infinity and strain will be avoided.

4. REFLECTOR

The reflector used must have an optically flat surface and may be either of steel or glass. If a glass reflector is used, it is preferable to obtain the reflections from the front surface rather than from a silvered back surface.

A reflector which completely covers the area of the aperture of the Auto-collimator objective (1·7 in.) should be used. A smaller reflector, such as a slip gauge can be used for close distance work, but for longer distances and the highest accuracy a large reflector will give the best results.

5. METHOD OF MAKING MEASUREMENTS

When the Auto-collimator is set up to give a reflection, examination of the field of view through the microscope will show the direct and reflected images of the target wires, the micrometer setting lines, and a scale at the bottom of the field (micrometer in the horizontal position). The reflected image moves when the instrument or reflector is moved. The micrometer setting lines consist of a pair of parallel lines and a single line at right angles. The pair at right angles to the micrometer movement are used to measure the deflections of the reflected image by setting them to straddle it symmetrically at each position it takes up.

The position of the setting lines for each setting is read on the micrometer drum, whole turns of the drum being counted where necessary by the position of the setting lines on the scale. Each revolution of the drum corresponds to 30 secs. deflection of the reflector and moves the setting lines across one line of the scale. The scale has alternate long and short lines, so that each long line corresponds to one minute of angle. Each drum division represents 0·2 secs. and the drum is numbered every 1 second. All settings should be made by rotating the drum in a clockwise direction, thus avoiding the effects of backlash in the screw.

When making measurements, settings must only be made on the reflected target wire image ; the direct image should be completely ignored. The fixed target wire and the setting line parallel to the micrometer movement serve only in the initial setting up of the instrument to ensure that the reflector is square to the collimator.

INSTRUMENT ADJUSTMENTS

All adjustments other than those previously mentioned are initially pre-set by the makers, and should only be adjusted when absolutely necessary.

6. MICROSCOPE FOCUS

The target wires, their reflected image as obtained from a truly flat surface, and the setting lines in the eyepiece should all be exactly in the same plane. If it should be found at any time that, when the eyepiece is rotated, the target wires and their image do not come into focus at the same time as the setting lines, the microscope can be readjusted by loosening the two grub screws beneath the tube and slowly rotating the large focusing ring (*Fig.* 2) until the parallax is eliminated. The eyepiece must be properly focused on the setting lines when adjustments are being made. After adjusting, the two grub screws must be retightened.

7. OBJECTIVE FOCUS

If the objective lens is incorrectly adjusted, there will be parallax between the direct target wire and its reflected image. It should be noted, however, that this condition of parallax may also arise through the use of a reflector which has not a perfectly flat surface, and this should be checked before altering the focus. The focusing of the objective lens should be altered only after first ascertaining that the microscope is correctly focused.

The method of refocusing is to release the large locking ring and rotate the objective lens mount on its thread until there is no parallax between the target wire and its reflected image. The lock ring should then be tightened to clamp the objective mount.

8. POSITION OF TARGET WIRES

The cell containing the target wires is mounted on four capstan screws just in front of the lamp housing. Adjustment of the opposing screws alters the position of the wires in the field of view. If the full range of the instrument is required to be used, it may be found that the target wires mask some positions of the reflected image. This may be avoided by setting the vertical target wire to one side of the field, leaving the full range of the scale free for the reflected image. Unless this condition is particularly required, it is better for the target wire to be set near the centre of the field. If any adjustments are made to the target wires, care should be taken to keep the target wire exactly parallel to the micrometer setting lines.

9. POSITION OF LAMP

The lamp is mounted in a ball and socket joint which allows adjustment for optimum illumination. Once the lamp has been adjusted, it should not be altered during a set of readings, as this will alter the appearance of the image and upset the continuity of readings. A four volt lamp is fitted and this may be run off a transformer or battery. A suitable transformer can be supplied, if required.

10. ROTATION OF TUBE

The 90° rotation of the tube is limited by two adjustable stops mounted on the rear bearing. Before leaving the works, these stops are set so that the micrometer movement is parallel and normal to the base respectively in the two positions. If, at any time, this adjustment requires re-setting, it may be checked by swinging the instrument on its base ; the reflected image will run parallel to the setting lines when the setting is correct.

11. SCALE ADJUSTMENT

The small screw in the centre of the left-hand side of the micrometer box (micrometer horizontal) adjusts the position of the scale relative to the vertical setting lines. This adjustment should be set so that the setting lines are opposite a line of the scale when the drum reads zero.

11a. NEW DESIGN

On the latest version of the Auto-collimator certain design changes have been made increasing the robustness of the instrument. The microscope focus is correctly set and locked before leaving the manufacturers, and there is no need for further adjustment. The mounting for the target wires has also been altered so that the user adjustment is available in one plane only.

The wires may be moved by rotating the screw in the middle of the small strap situated directly in front of the lamp. The locking screw, which is radially at 90° to the strap and in line with it, should be loosened before making any adjustment and relocked before using the instrument.

TYPICAL APPLICATIONS OF THE AUTO-COLLIMATOR

The following examples are intended to indicate some of the directions in which the instrument can be usefully employed. They are by no means exhaustive, but it is hoped that they will suggest applications to particular problems which may arise.

12. ALIGNMENT OF MACHINE BEDS, ETC.

Errors in flatness or straightness of surfaces or machine ways up to 30 feet in length can be determined by fitting a reflector to a small block fitted with supporting feet (see *Fig.* 3) and moving the block step by step along the surface. If the contour of the surface is uneven, the small variations in angle of the block can be measured and, after suitable computations, can be plotted in terms of linear variations from a true plane. A straight edge can be used to guide the block in the horizontal plane. A full description of the method for checking a machine bed is given later.

Suitable reflector carriages can be supplied for carrying out tests on machine beds and surface plates.

With reflector carriages as formerly supplied the height of the centre line of the reflector above the feet of the carriage was the same as that of the axis of the Auto-collimator set up on its flat base. The height of the centre line of the reflector above the feet of the carriage is now the same as that of the axis of the microptic Auto-collimator with its three footscrews resting on the round footplates supplied with the instrument.

The reflector carriage normally supplied has a base length of 5 inches (Cat. CT 20/6). Other reflector carriages with base lengths of 2, 4, 6, 8 or 10 inches can be supplied to order.

The base of each carriage is engraved with its length and the relative change in height of its feet corresponding to a tilt of 1 second.

E.g., 5 in. base length, 1 second tilt = 0·000025 in..

The choice of base length for a reflector carriage depends upon the length of the surface to be tested. It is usual to select a base length of about one-twelfth of the length to be tested.

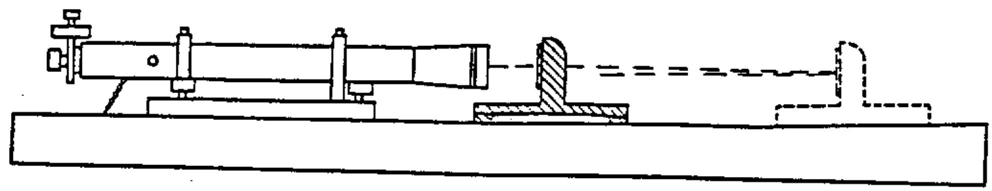


Fig. 3

13. ALIGNMENT OF PERPENDICULAR SURFACES

Surfaces of ways which are mutually at right angles can be checked for contour and squareness as shown in *Fig.* 4 by using an Optical Square to deflect both incident and reflected beams through exactly 90°. Such a square produces a 90° deviation of all rays which meet it even at different angles, and should not be confused with an ordinary 90° prism which will give varying deviations. Various sizes of Optical Squares can be supplied. (See the catalogue of Watts Auto-collimator.)

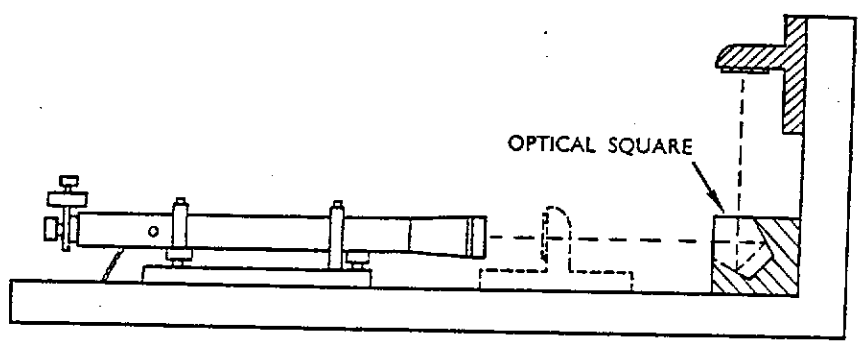


Fig. 4

14. ALIGNMENT OF MACHINE SLIDES

The two examples given above can be extended to include the truth of traverse of lathe saddles, machine table, etc., by mounting the reflector on the saddle or table and recording the angular variations when moved over equal intervals.

15. SQUARENESS TESTING

The squareness of a block such as that shown in *Fig.* 5 can be tested by taking a reading on each face in turn, the block being supported on a flat, rigid surface. The mean of the four readings represents true squareness and the variation of each reading from this mean indicates the error of the particular face. It will be noted that no independent standard square is required with this method.

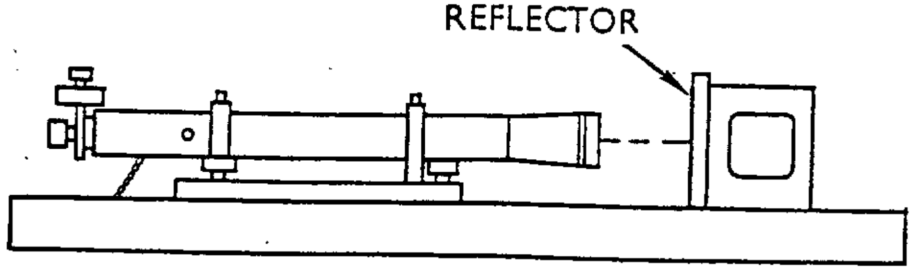


Fig. 5

16. INDEXING FIXTURES, ETC.

The accuracy of indexing fixtures, dividing tables, etc., can be checked accurately with the aid of a twelve-sided Polygon or a set of Combination Angle Gauges. The Polygon, shown in *Fig.* 6 will check divisions in multiples of 30° and the Angle Gauges will cover any range of angles.

Full particulars of both these accessories are available on request : Catalogue numbers are :—

Twelve-sided Glass Polygon : TP.122
Twelve-sided Metal Polygon : TP.125
Angle Gauges : TP.152, TP.153 and TP.156
(See Auto-collimator catalogue.)

In the example shown in *Fig.* 6, a 60° indexing plate is being checked by being rotated to each location in turn. An image is obtained in the Auto-collimator on alternate faces of the Polygon. From readings taken on these images, the errors of the indexing plate can be readily computed. Unlike a graduated circle, accurate centering of the Polygon is quite unnecessary.

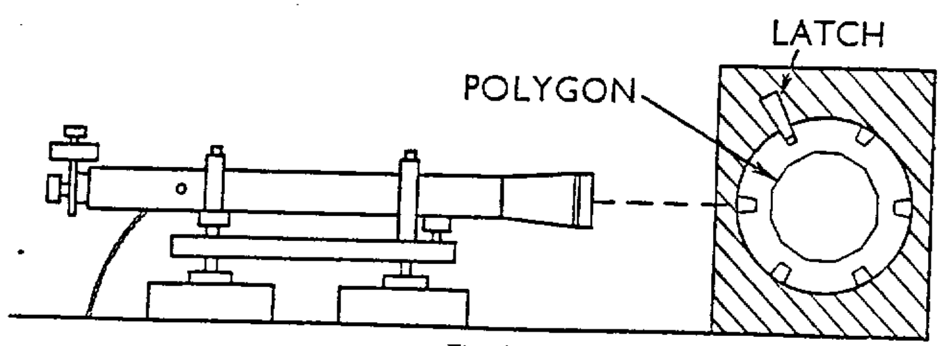


Fig. 6

17. SMALL MECHANICAL MOVEMENTS

Fig. 7 shows a method of measuring axial oscillations of a leadscrew due to lack of squareness of its thrust faces and collars. A mirror is arranged to make contact with a ball attached to the end of the screw on its axis, the mirror being flexibly-hinged on a vertical spring strip.

Knowing the relationship between angular tilt and linear displacement, any axial oscillations of the leadscrew can be measured accurately by the Auto-collimator.

The Auto-collimator finds many applications in addition to those mentioned, and users are invited to consult our technical staff in any cases of difficulty or if further information is required.

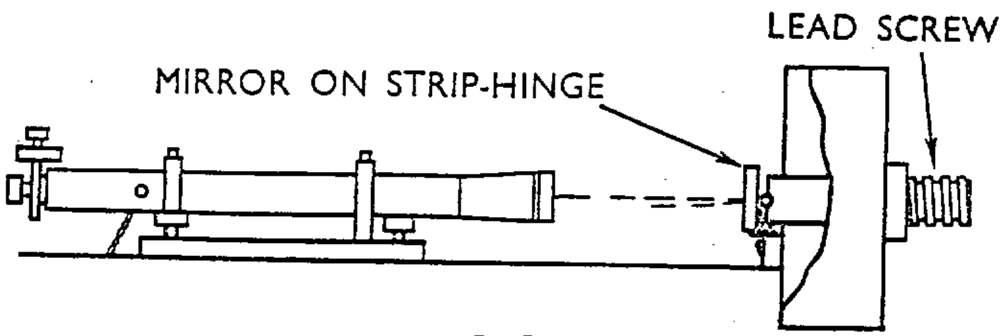


Fig. 7

18. FLATNESS OF MACHINE BEDS AND SURFACE PLATES— METHOD OF TEST AND CALCULATION OF RESULTS

Principle of the Method

The general scheme for testing the straightness of machine beds and the flatness of surface plates with the Microptic Auto-collimator has already been referred to in Section 12 above, and is illustrated in *Fig.* 3.

The principle underlying such tests is shown in *Fig.* 8. In the case of a machine tool bed, the Auto-collimator is set up very rigidly to view along the direction of the bed and is sighted on a vertical mirror, supported on a reflector carriage, which rests on the bed. The under-surface of this carriage is limited to two flat strips at its ends, separated by a centre distance denoted by l in the figure. The carriage is moved step by step from its initial position A—B at one end of the bed to other positions B—C, C—D, etc., throughout the length of the bed. It is guided sideways against a straight edge. Any lack of straightness of the bed in elevation will cause the carriage to tilt through small angles in its passage along the bed. These angles, which are denoted by θ_1, θ_2, etc., with respect to the initial position A—B, are measured with the Auto-collimator for each successive position of the carriage. Knowing the base-length l of the carriage, it is a simple matter to calculate the corresponding differences in the heights of the two feet of the carriage at each position. These are denoted by δ_1, δ_2, etc., in the diagram. Successive algebraical additions of these differences in height then give the departures from straightness of the bed (in elevation) from a base line XX drawn through the feet of the carriage when in its initial position A—B. For convenience, it is usual to adjust these departures by calculation so as to refer them to another base-line joining the two ends of the bed.

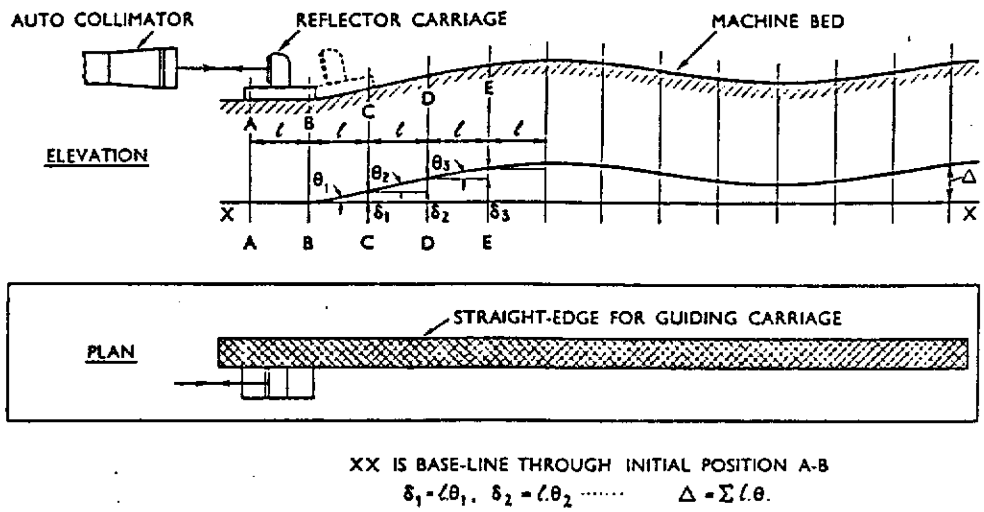


Fig. 8

Setting up and taking Readings on a Machine Bed

To illustrate the method of test, the following example is given for testing the upper surface of the bed of a machine, 5 feet long, using a reflector carriage with a 5-inch base length.

A straight edge is laid along the bed to act as a guide for the side of the reflector carriage on its passage along the bed. The Auto-collimator with its micrometer drum at the top, is stood on a very stable support opposite one end of the bed with its three levelling screws resting in the conical recesses in the three round footplates supplied with the instrument. (It is preferable to stand the Auto-collimator on the bed itself if it is not necessary to test the latter over its whole length.) With the reflector carriage close up to the collimator, the direction of the latter is adjusted until a reflected image of its cross wires is seen near the centre of the field. The carriage is then moved to the other end of the bed, and provided the mirror is reasonably square to the line of movement, the reflected image should still be seen quite clearly. The three footplates of the instrument should then be secured in position by the application of wax or plasticine round their edges.

The reflector carriage is then returned to the position near the Auto-collimator for starting the readings. In this initial position (A—B), the pair of parallel setting wires in the eyepiece are moved up or down by means of the micrometer screw until they symmetrically straddle the reflected image of the horizontal cross wire. Having read the micrometer for that setting, the reflector carriage is moved 5 in. along the bed to the second position (B—C), and a second reading is taken.

This process of moving the reflector carriage in 5 in. steps is continued until the end of the bed is reached. To obtain increased accuracy in the test and to reveal any mistakes in readings, it is usual then to repeat all the readings with the reflector carriage moved in the opposite direction. The mean values of these two sets of readings represent the relative angular positions of the reflector carriage, in seconds, at its various positions along the bed. Certain simple calculations have then to be made in order to convert these mean angular values into the errors in straightness of the bed, expressed in decimals of an inch.

The method of making these calculations is illustrated in the following Table.

For simplicity, the mean readings in column 2 are given to the nearest whole seconds, but for the best accuracy the readings would be recorded to tenths of seconds. The third column shows the differences of the readings from the first reading. In column 4 these angular differences are converted into the corresponding values of δ (see *Fig.* 8), by multiplying them by 0·000025 in., which is the equivalent of one second over the 5 inch base length of the carriage used. (Note :—1 second of arc represents very closely a slope of 0·000005 in. per inch.)

It will be noted that an additional zero is inserted at the top of column 4 : these two zeros then represent the heights of the two feet of the carriage when in its initial position A—B, see *Fig.* 8.

1 Position	2 Mean Reading of Auto-Collimator (seconds)	3 Differences from 1st reading $\emptyset$ (sec.)	4 Rise or fall in 5 inches (δ inches)	5 Cumulative rise or fall (δ inches)	6 Adjustment to bring both ends to zero (inches)	7 Errors from straight line (inches)
			0	0	0	0
0- 5	20	0	0	0	−0·00010	−0·00010
5-10	22	+ 2	+0·00005	+0·00005	−0·00020	−0·00015
10-15	24	+ 4	+0·00010	+0·00015	−0·00030	−0·00015
15-20	30	+10	+0·00025	+0·00040	−0·00040	0·00000
20-25	26	+ 6	+0·00015	+0·00055	−0·00050	+0·00005
25-30	16	− 4	−0·00010	+0·00045	−0·00060	−0·00015
30-35	18	− 2	−0·00005	+0·00040	−0·00070	−0·00030
35-40	24	+ 4	+0·00010	+0·00050	−0·00080	−0·00030
40-45	30	+10	+0·00025	+0·00075	−0·00090	−0·00015
45-50	30	+10	+0·00025	+0·00100	−0·00100	0·00000

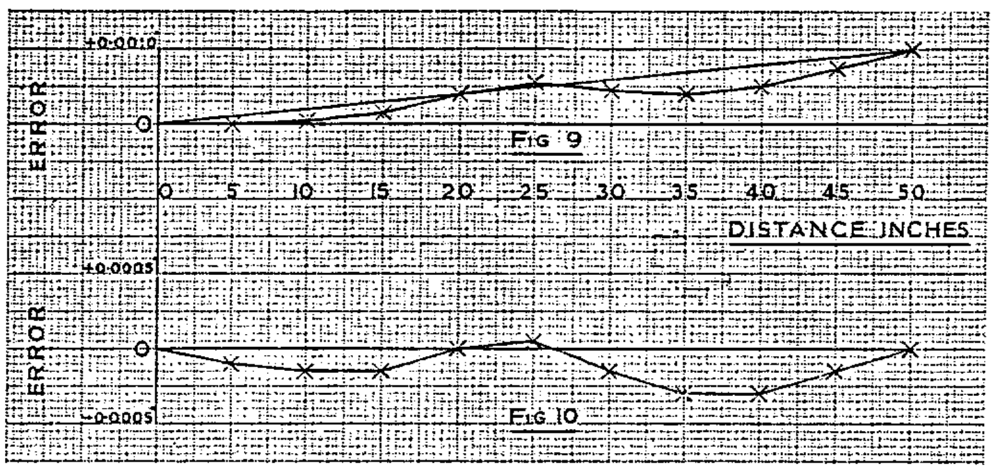
To find the subsequent heights of the feet above the base-line drawn through their initial position, the values in column 4 are added together algebraically one after the other, giving the values in column 5. This summation results in a terminal rise in the surface of the bed amounting to 0·0010 in. Column 6 gives the proportional amounts of this terminal value which are subtracted from those in column 5 to give the errors in the bed from a straight line joining the terminal points covered by the test.

A practical check should always be made on the direction of tilt of the reflector relative to the Auto-collimator readings. In the example given, tilting the top of the reflector towards the Auto-collimator gave a larger reading. Increasing readings, therefore, have been associated with positive (+) values for δ and indicate a concavity in the bed.

The values obtained in columns 5, 6 and 7 of the Table have been plotted in *Figs*. 9 and 10. It will be noted that the straight line joining the end points of the curve in *Fig*. 9 has been brought down to the axis in *Fig*. 10 and that the curve bears the same relationship to this line in both figures.

It will be seen from *Fig*. 10 that the bed is concave by a few ten-thousandths of an inch over each half of its length, the error at the centre being very small relative to the two ends.

Figs. 9 and 10



The test described above serves to determine the errors in the straightness of the bed in a *vertical* plane. The same method of test can, however, be used for measuring the errors in the guiding surfaces of the bed in a *horizontal* plane. As these guiding surfaces usually consist of a Vee, it is necessary to fix the reflector carriage on the top of an auxiliary block which fits into this Vee, and which has its bearing surfaces relieved at the centre similar to the base of the carriage. As before, this block with the carriage fixed to it is moved step by step along the bed ; but in this case the Auto-collimator is turned through 90° to bring its micrometer drum to the right-hand side and its pair of parallel setting wires vertical. Readings are then made on the reflected image of the *vertical* cross wire to measure the angular deflections of the reflector about a vertical axis. The calculations are the same as before.

The cross-wind of a machine bed is most conveniently checked with a Watts Precision Block Level placed across the bed at various positions along its length.

Testing a Surface Plate

The method described above for testing a machine bed can be used equally well for examining the flatness of a surface plate. To do so, the plate is checked along a series of lines parallel to the edges of the plate and also along its diagonals. By correlating the results obtained along these various lines it is possible to derive the errors in the flatness of the plate from its mean true plane and, if desired, to plot a contour map of its surface.

One difficulty that often arises in examining a surface plate is the provision of some independent rigid support for the Auto-collimator which can be conveniently moved to various positions round the plate to enable the instrument to be sighted along the various lines to be examined.

This difficulty can be avoided by adopting a scheme devised by J. C. Moody, of Physical and Electrical Standards Department, Sandia Corporation, U.S.A., in which the Auto-collimator is supported on the surface plate itself. An auxiliary reflector mount is then used for changing the direction of its sighting. The scheme is illustrated in *Fig*. 11. With the Auto-collimator in Position 1, for example, it is possible to take readings along three lines marked 1 and correspondingly for the instrument in positions 2, 3 and 4.

The Auto-collimator is first positioned at one end of the plate at approx. 90° to the first line to be measured. At one corner of the plate a reflector mount is positioned so that the face of the mirror is approx. 45° to the longitudinal axis of the collimator. By laying a straight edge on the plate immediately adjacent to the line that is to be calibrated, a means of moving a second reflector carriage along the line is obtained. The collimator is zeroed in at the first station, and the second reflector mount is advanced along the straight edge in increments equal to the distance between the centre lines of the support pads.

With the collimator in this first position, all except one of the transverse co-ordinates and one diagonal can be measured. To complete the calibration over the entire plate, only three changes of collimator position from the original are necessary. The second position will permit readings of one transverse and the other diagonal. All longitudinal co-ordinates may be read from either the third or fourth position. The number of lines that are calibrated and their location must be a compromise between economy of calibration and the accuracy of profile required. From these readings displacements from the line of first reading for each line may be tabulated. These results may then be correlated and finally the deviation from a mean true plane established.

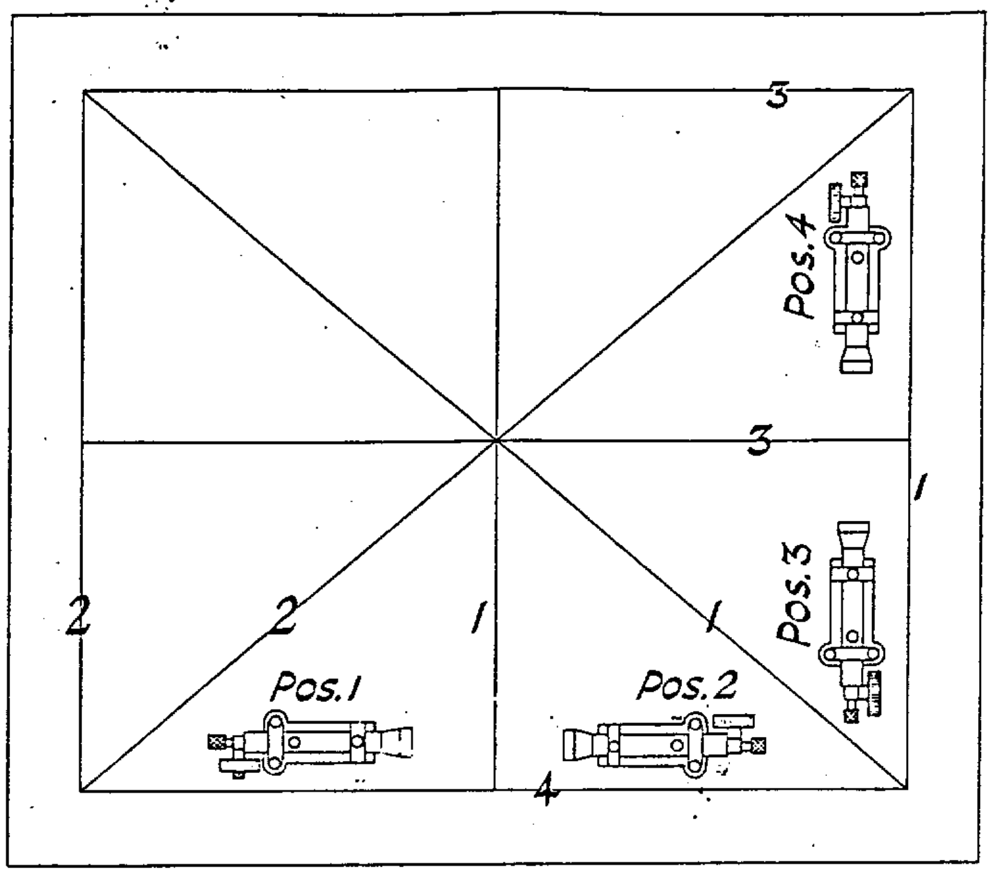


Fig. 11

COMPLETE LIST OF CATALOGUE NUMBERS AND SPECIFICATIONS

TA 1 MICROPTIC AUTO-COLLIMATOR

In wooden case

TELESCOPE

Object glass aperture	1·375 in. (35 mm)

MICROMETER

1 revolution of drum equals 30 seconds
Drum divided into 300 equal black and white divisions
One division equals 0·1 second

DIMENSIONS

Flat base	8 in. × 3·5 in. (203 mm × 89 mm)
Overall length	18·75 in. (476 mm)
Overall width	5·5 in. (140 mm)
Overall height	7 in. (178 mm)
Weight	16·5 lb. (7,4 kg)
Weight of instrument with case	25 lb. (11,3 kg)
Overall size of case	21 in. × 8 in. × 7 in. (533 mm × 203 mm × 178 mm)
Shipping weight	64 lb. (29 kg)