Machinery
and production engineering

BUILDING PRECISION INTO OMT OPTICAL ROTARY TABLES

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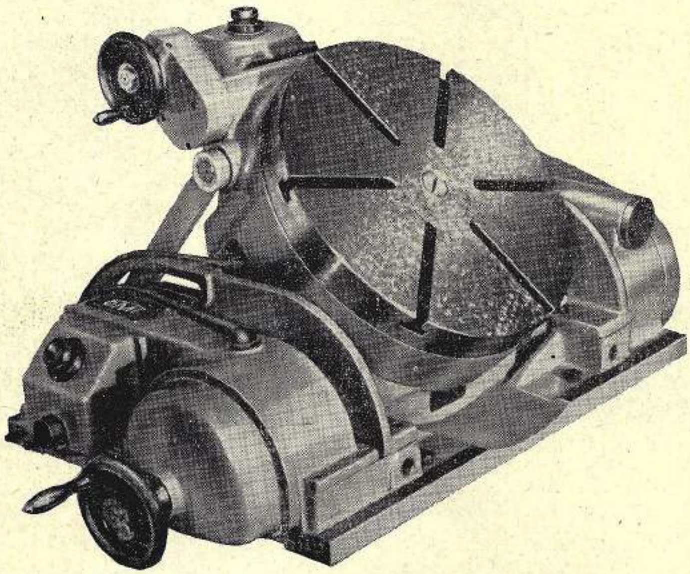
Building precision into OMT optical rotary tables

Examples of manufacturing operations at the Maidenhead works of Optical Measuring Tools, Ltd.

P. A. SIDDERS, CHIEF ASSOCIATE EDITOR



The initials OMT have been associated with high-quality measuring instruments and optical equipment for many years, and in particular with precision optical rotary tables. Production of such tables was started in 1940, when Optical Measuring Tools, Ltd., was established by The Newall Engineering Co., Ltd., primarily to ensure a supply of rotary tables of high standard for use on the jig boring and milling machines built by the latter firm. At that time there was also a shortage of toolmakers' microscopes and horizontal comparators which before the second world war had been obtained from the German Zeiss organization. The OMT company undertook the manufacture of such equipment, thus laying the foundations for the design and production of a wide range of measuring instruments and during the war years the company also built tank periscopes and telescopes.

To ensure that the quality associated with the original Zeiss equipment was maintained, all OMT instruments and optical rotary tables were submitted to the National Physical Laboratory for examination and certification. This procedure was followed until 1946, and since that date the specifications which were originally laid down by the NPL have been followed, but Optical Measuring Tools, Ltd., have been privileged to issue their own certificates to this effect, in co-operation with the NPL

The optical department of the company, originally established to make the optical systems for OMT tables and instruments, soon gained a very high reputation for quality, and "naked" optics were supplied to an increasing number of users. The company now has one of the most modern installations in the country for the production of precision lenses, prisms of all types, optical flats, graticules, plano-mirrors and other optical units. Facilities include a high-vacuum laboratory for the production of surface-coated mirrors, anti-reflecting coatings, multi-layer films, metallic electrical conductive coatings, neutral density filters and other coatings to users' requirements. Naked optics are now supplied to the Atomic Energy Authority, the NPL, and a number of American companies engaged in the production of satellites and rockets. Activities of the department have expanded to such an extent that it has been necessary to transfer all optical work from the Maidenhead factory to a new works at High Wycombe, Bucks.

Originally, the OMT works was located at Slough, Bucks., but moved to the present headquarters at Oldfield House, 142 Bridge Road, Maidenhead, Berks., soon after its foundation, where more workshop space was available. These premises have been gradually extended to provide for machining and assembly, also design and experimental work. A wide range of machine tools has been installed, in addition to more specialized equipment, which includes many items developed by the company to meet its own needs.

Some five years ago, agreement was reached with the French firm of Ateliers de Normandie, Paris, whereby OMT undertook the manufacture of Etamic electro-pneumatic gauging equipment. The production and sale of this equipment now forms an increasingly important part of the activities of OMT, and a special section of the Maidenhead works is concerned solely with the Etamic range. Gauging units are now made for mating associated components, also for the control of component size on grinding machines. Units of the latter type are used extensively on Newall and Newall-Keighley grinding machines, and are also offered for general sale.

The present range of equipment built by Optical Measuring Tools, Ltd., includes the Etamic and optical units mentioned, rotary tables, horizontal comparators, workshop projectors, toolmakers' microscopes, optical dividing heads, roundness measuring machines, and projection pantometers for the inspection of 3-dimensional forms such as turbine blades. In addition, a small grinding machine from the Newall range is now built at the Maidenhead works.

Optical rotary tables, with which this article is concerned, are available in a variety of designs, with table diameters ranging from 8 to 30 in. The tables may be of the plain or inclinable type, and the measuring systems incorporate either microscopes for reading illuminated glass precision scales, or projection screens with or without vernier scales. An OMT 30-in. non-inclinable rotary table is available equipped with an E.M.I. control system for feeding in positional data by means of punched tape or by manually setting dials.

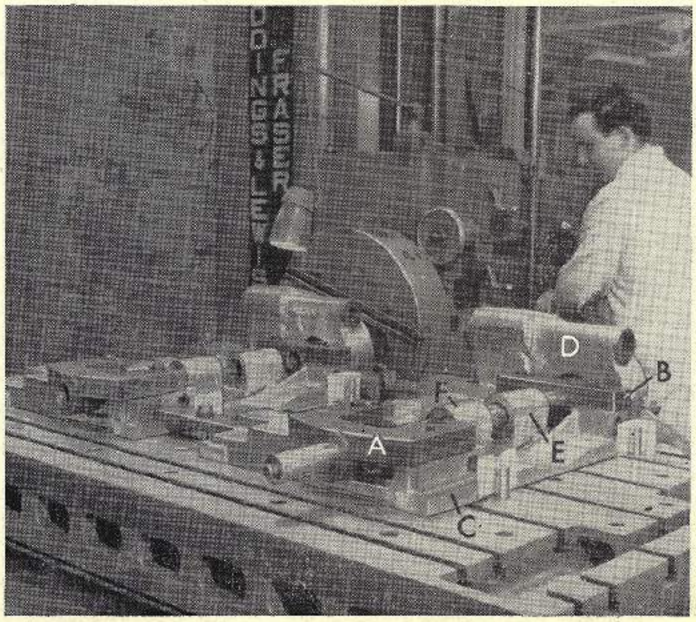
Depending on the type, the accuracy of the tables may be as high as 1 sec. of arc. In consequence, considerable care must be taken in the machining of components, production of the optical scales, and inspection of the sub-assemblies and finished tables. Special techniques have been developed by the company, and certain examples of production and inspection practice will now be considered.

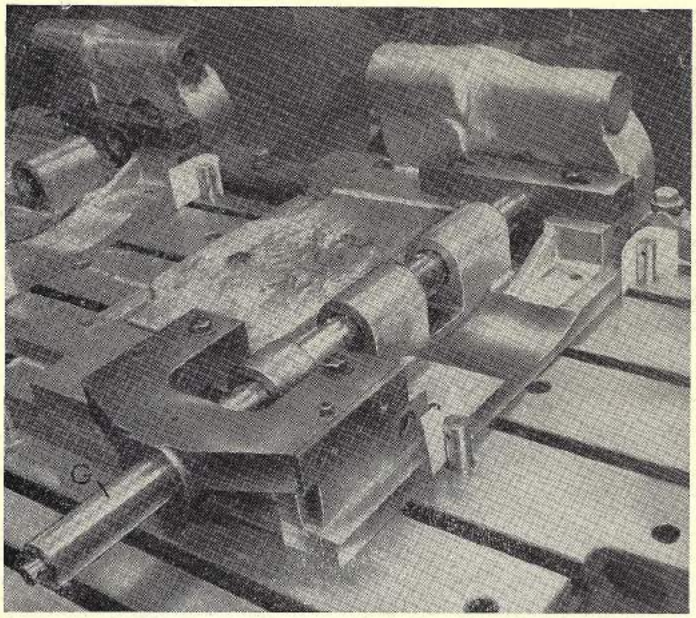
Boring bases for 16-in. rotary and inclinable tables

The procedure for boring the bases for 16-in. rotary and inclinable optical tables is indicative of the care that is taken in connection with machining operations. It may be mentioned that the table portion of each unit can be tilted through 90 deg. from the horizontal setting, also rotated through 360 deg., with reference to glass scales. Each scale is read with the aid of a microscope, and on the standard table, readings can be made directly to 30 sec. of arc and by estimation to 6 sec. of arc. Units can be supplied, however, which provide for reading direct to 1 sec. of arc.

Bases are rough and finish bored on a Giddings & Lewis-Fraser 340T machine, and the set-up for finish boring is seen in Fig. 1, the arrangements for rough boring being somewhat similar. These operations form part of a complex sequence, and the first stages involve rough milling; rough planing; normalizing; drilling; milling; boring (5 stages); milling (2 stages); re-normalizing; and fettling. This group of operations is followed by a milling sequence for skimming the top pad faces whereon are mounted the brackets *A* and *B*, Fig. 1, also the side clamping edge faces *C*, and machining

1 *Bases for 16-in. optical inclinable rotary tables are set up for boring, two at a time, on this Giddings & Lewis-Fraser 340T machine. The castings are located against hardened and ground pegs which can be inserted in holes in the machine table, these holes being identified by number and letter references*





2 *Close-up view of a rotary table base set up for finish boring. Brackets to support and guide the boring bar are mounted on horizontal facings on the component, which are scraped to provide correct alignment*

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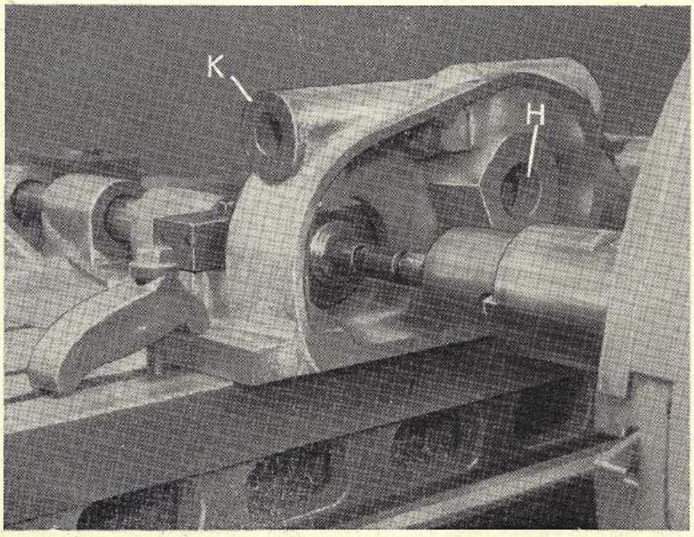
3 *The boring bar is coupled to the spindle of the G & L-F machine by means of a shank which incorporates universal joints, and can be connected to the quick-taper socket of the boring machine spindle by means of an adapter*

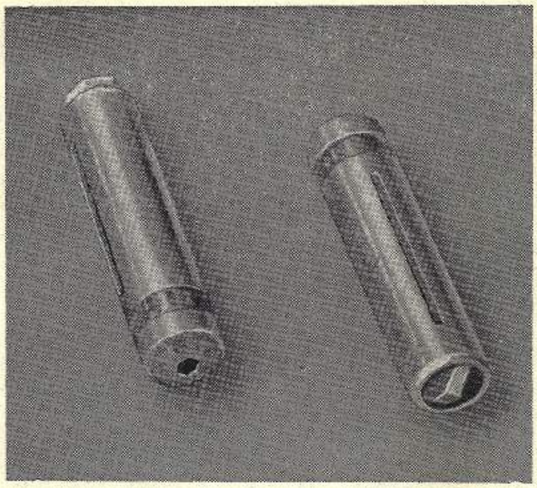


relief grooves at the sides of the bearing housings to provide clearance for the scraping operation which follows.

Scraping ensures that the top pad faces are flat, and these faces are used to locate the casting for the subsequent planing operation on the bottom. The first operation on the Giddings & Lewis-Fraser horizontal borer follows, and two castings are set up at a time. Each component is loaded on the table with the planed bottom face downwards, and a skimming cut is taken along the edge *C* (which later serves as a datum) also along the adjacent vertical faces of the bearing pads.

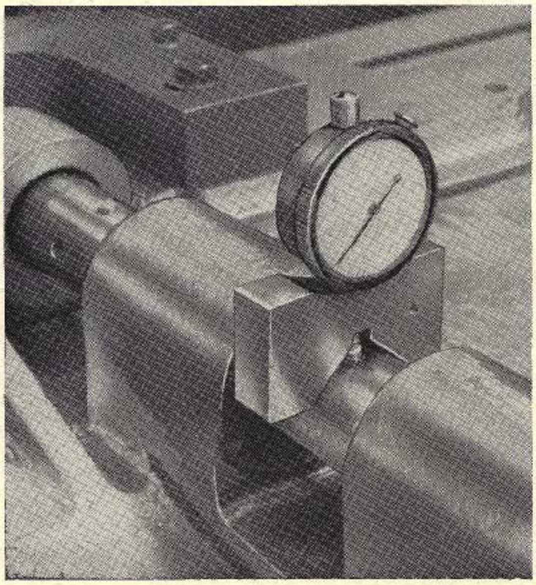
Each workpiece is then turned through 90 deg., to the setting shown, and the datum edge is butted against hardened and ground location pegs inserted in holes in the machine table. There are groups of holes to provide for various operations, and each hole has a number and letter for identification purposes. Various operations are then performed on the large end of each base casting, including the machining of a large clearance counterbore concentric with the main bore of the worm-wheel housing *D* and the bores of the bearing housings *E* and *F*. These bores are line-machined, leaving stock for removal at a later finishing stage, and the ends of the bearing housing *E* are faced.

The workpieces are next turned through 180 deg., location of each again being taken from the datum edge, and the faces of the worm-wheel housings are aligned with the aid of a dial gauge. Rough boring of the small end of each casting is then carried out. The castings are next transferred to a fitting bench where the planed bottom face of each is scraped and the brackets *A* and *B* are mounted in position. These brackets are seen more clearly in the close-up view, Fig. 2, and each incorporates a bronze bush to receive the boring bar *G*, which is hard chromium plated. The brackets are provided



4 *Two cartridge tools of the type fitted to the boring bar seen in Fig. 2. The carbide tipped tool bit slides in an outer sleeve, and is adjusted by turning the micrometer screw at the opposite end. Screws that retain the assembly in the boring bar also serve to secure the tool bit*

5 *This gauge, comprising a V-block and a dial indicator, is employed for checking the radial position of the tool tip. The indicator is set by inserting a slip gauge between the stylus and the boring bar*



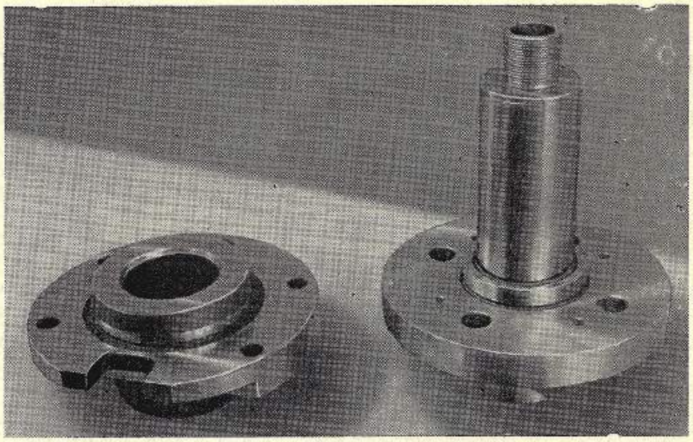
with elongated holes for the securing screws, so that they can be aligned in the horizontal plane with reference to the datum edge. After a bar has been fitted into the bushes, alignment in the vertical plane is checked, and the surfaces of the seating pads on the casting are corrected by scraping if necessary. The boring bar carries three tool bits, to which reference will be made later, and both ends are reduced, as seen at the left, to provide for fitting a driving member. This member is coupled to the bar by means of a transverse taper pin and incorporates two universal joints, to allow for a small amount of misalignment with the boring machine spindle, also a shank to suit an adapter which is locked into the quick-taper socket of the spindle.

After the brackets have been aligned correctly, the base castings are returned to the G & L-F machine, where they are again mounted on the table and aligned by butting the datum edge of each against the location pegs. The holes in the three bearing brackets are line bored 2·000 in. diameter, to receive precision ball bearings, and a chamfer is machined at the end of the longer hole. After the boring bar has been removed, and a snout-type tool has been fitted to the machine spindle, a blind hole is bored 1·5625 in. diameter, +0, −0·0007 in., parallel to the previously bored holes, at the inner end of the counterbored hole *H* in Fig. 3. This latter hole is bored 2·375 in. diameter, +0·001, −0·0005 in., and counterbored $3\frac{5}{8}$ in. diameter.

The two base castings are next turned through 90 deg., and again located by butting the datum edges against location pegs in holes in the machine table, to enable the small end *K* of each wormshaft housing to be bored. Following this stage, the workpieces are indexed through 180 deg., and located in a similar manner for the boring operation on the large end of each wormshaft housing. With these stages completed, the only remaining machining is for drilling the lubrication holes.

Adjustable boring tools

Adjustable boring tools are fitted to the bar employed for line boring, and two tool bits are seen in Fig. 4. Of cartridge type, these tools are made by British Precision Diamond Tools, Ltd., and each has an inner member carrying a tungsten carbide tip, which can slide in an outer sleeve. The tip may be seen at the near end of the tool at the right, and in the end of the sleeve remote from the tip is mounted a captive micrometer screw, as seen at the left. This screw engages a tapped hole in the inner member, so that by turning the screw with the aid of an Allen key, the tool tip can be advanced or withdrawn. The shank is slotted so



6 *A pivot (right) and bearing for an OMT 16-in. rotary table. Both units are made from Nitralloy forgings, and bearings are finish honed to ensure the required standards of roundness and straightness. Pivots are finish ground to suit the bearings, then lapped, and the two components are finally lapped together*

that the screws used to retain the tool bit assembly in the boring bar also serve to close the sleeve on to the inner member to secure the latter in the axial setting obtained by means of the micrometer screw.

The company has provided a simple gauge for tool setting, as seen in Fig. 5, in the form of a V-block carrying a dial indicator. Before the setting of a tool is checked, the gauge is mounted on the boring bar, a slip gauge of a thickness corresponding to the required tool projection is inserted between the bar and the plunger of the dial indicator, and the latter is set to zero. The stylus is then brought into contact with the tool tip, and any deviation from the required setting is noted. After the gauge has been removed, the tool is withdrawn from its seating in the bar, and the necessary adjustment is made with reference to the calibrations on the micrometer screw. The tool is then returned to the bar and the setting is re-checked with the gauge. For the rough boring stages of the operation sequence described, the tools are set so that they project 0·003 to 0·004 in. less than the amount required for finish boring.

Lapping pivots and bearings

To achieve the standards of accuracy associated with OMT rotary tables and to ensure that they are maintained in service, it is essential that the running fit between the table pivot and mating bearing should be of a very high order. A typical pair of components for a 16-in. table is seen in Fig. 6, and both are machined from Nitralloy forgings.

Pivots and bearings are usually made in batches of 12, to provide for selective assembly, and the earlier stages of the production sequence for bearings are:—turn, stabilize, rough grind, harden, semi-finish grind, stabilize, and finish grind. Bearings are then honed in three stages on a Delapena bench-mounted machine. For the first stage, the bore is honed with a Delapena tool, fitted with stones of F 18 F grade, which are relatively soft and permit a high rate of metal removal. Harder stones of grade F 1 R 4 C are used for the second stage, whereby the finish in the bore is improved. For the final stage, a cast-iron mandrel-type lap is used, and is charged with Hyprez diamond compound of grade 3-W-40, supplied by Engis, Ltd. For the last stage, the honing spindle is run at the slowest speed obtainable, and the operator seeks to bring the bores of all the

7 *Checking the diameter of a pivot with the aid of an OMT vertical Omtimeter, prior to the lapping operation*

8 *Any errors in roundness or parallelism are corrected by lapping the pivot with a cast-iron split lap, charged with diamond compound*

workpieces comprising a batch to the same size.

Pivots are finish ground to suit the honed bearings. The bore of a bearing is carefully measured, and the journal portion of a pivot is then checked with the aid of an OMT vertical Omtimeter, high-precision optical comparator, which has a scale graduated in 0·00002-in. units, with a range of $\pm$0·0025 in. Excess metal is left on the pivot journal for removal by lapping, and the journal diameter is again checked with the Omtimeter after the grinding stage.

Components are delivered in pairs to the lapping section, where the pivot journal diameter is again checked with an Omtimeter, as seen in Fig. 7, and any ovality and out-of-parallelism are noted. These errors, it may be mentioned, never exceed 0·00005in., and are corrected by the use of a split cast-iron lap, charged with Hyprez diamond compound, as seen in Fig.8. The nominal diameter of the journal is 1·750 in., and after lapping, the roundness and parallelism are required to be held within 0·00002 in.

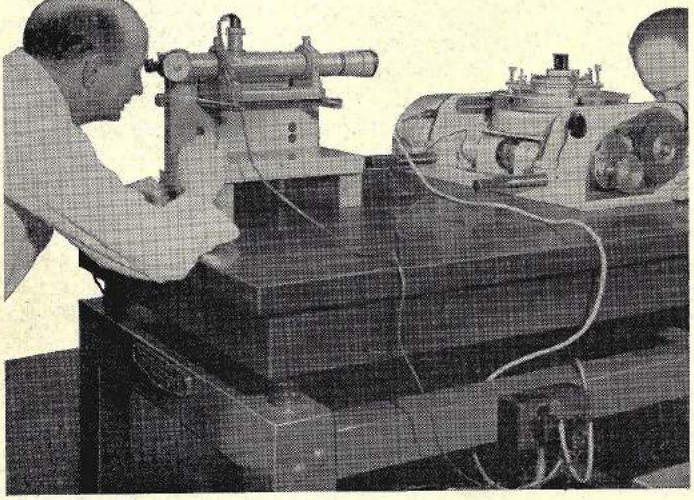
The bearings and pivots are allowed to stand for a specified period and then the pairs of components are lapped together using Lappex polishing compound [General Engineers' Supply Co. (1937), Ltd.]. Accuracy of fit between the components of a pair depends upon the operator's skill and his "feel" during the various lapping stages.

Checking and calibration of optical tables will be considered in a further article concerned with the practice of Optical Measuring Tools, Ltd., which is to be published shortly in *Machinery*.

Building precision into OMT rotary tables

Typical inspection operations at the Maidenhead works of Optical Measuring Tools, Ltd.

P. A. SIDDERS, CHIEF ASSOCIATE EDITOR



Optical Measuring Tools, Ltd., 142 Bridge Road, Maidenhead, Berks., a member company of The Newall Group, have established a world-wide reputation for optical tables, which are made in plain and inclinable types of a variety of sizes. Details of these tables were given in an article published in *Machinery*, *107/284—11/8/65*, in which brief reference was made to the growth of the company, and certain production operations in connection with optical table components were described. Mention was also made of the new works of the company at High Wycombe, Bucks., where optics for OMT tables and instruments, and for supplying direct to users, are produced.

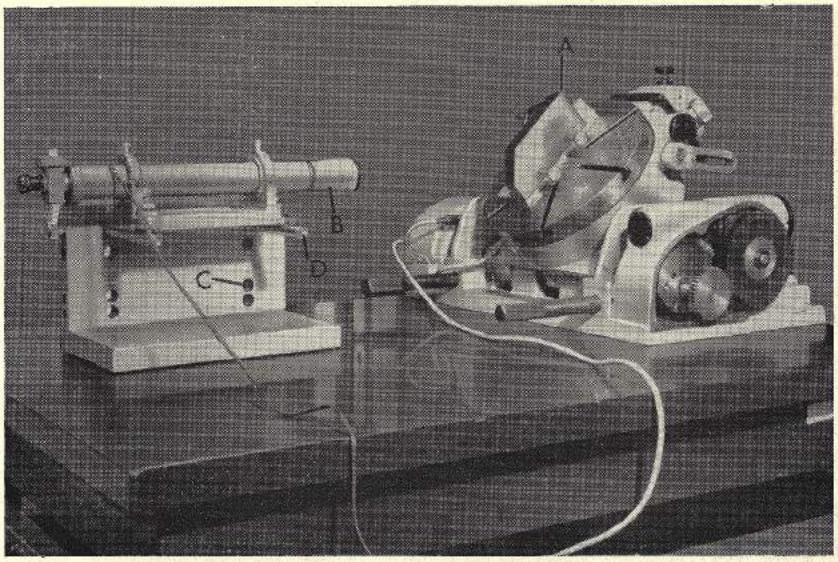
As might be expected, great attention is paid to the setting and checking of the company's instruments, and there is a well-equipped inspection department at the Maidenhead works. Equipment installed includes two granite surface plates, measuring 4 by 3 ft., and two cast iron surface plates, one of the same size and the other 2 ft. square. These units are all positioned below an overhead monorail so that they can be served by a pneumatic hoist. Other equipment includes OMT comparators (one of horizontal and two of vertical type), an OMT toolmakers' microscope, an Avery hardness testing machine, an ultra-violet light source for crack detection, and a Parnum electronic comparator. For use with the latter unit, the company has made a small-bore measuring equipment of NPL design.

Four sets of slip gauges are provided for the inspection department, and one set is kept as a master reference, one as a reference, and two for normal use. In addition, one set is provided for workshop inspection, and one set in each of the following departments—machine shop, cylindrical grinding section, fitting shop and the Etamic section.

Typical of the work undertaken by the inspection department is the checking of the setting of the quadrant scale for the tilting motion of an inclinable rotary table. Optical techniques are used, and the set-up is seen in Fig. 1. The inclinable rotary table is at the right, on one of the granite surface plates, on which it is loaded with the aid of the pneumatic hoist. A special prism *A* is mounted on the working surface of the table, by means of an angle-plate support. At the other end of the surface plate is mounted another angle-plate support to carry the auto-collimator *B*. The prism and both supports were designed by Optical Measuring Tools, Ltd.

The angle-plate for the auto-collimator is of cast iron, and has four pairs of plain bored holes, as at *C*, in the vertical member. Transverse holes are drilled and tapped in the vertical member and communicate with the plain holes. The latter receive support bars, as at *D*, which are secured by knurled-head screws inserted in the tapped holes. Provision of four pairs of plain holes allows the auto-collimator to be supported at various heights to suit different checking operations.

As is customary, the baseplate of the auto-collimator has two screws at one end (nearer to the eyepiece) and one screw at the other end, to provide a 3-point support. A flat face is machined on the bar *D*, and a transverse V-groove is milled approximately midway along the flat. A similar flat is machined on the other bar, but in this instance a longitudinal V-groove is milled near the outer end and a transverse V-groove near the inner end. The arrangements are such that the single support screw of the auto-collimator can be engaged with the V-groove in the bar *D*. and the pair of screws near the eyepiece of the instrument with the grooves in the other bar. When all three screws are engaged with the grooves, the instrument is provided with a stable support and is retained in one position in the horizontal plane.

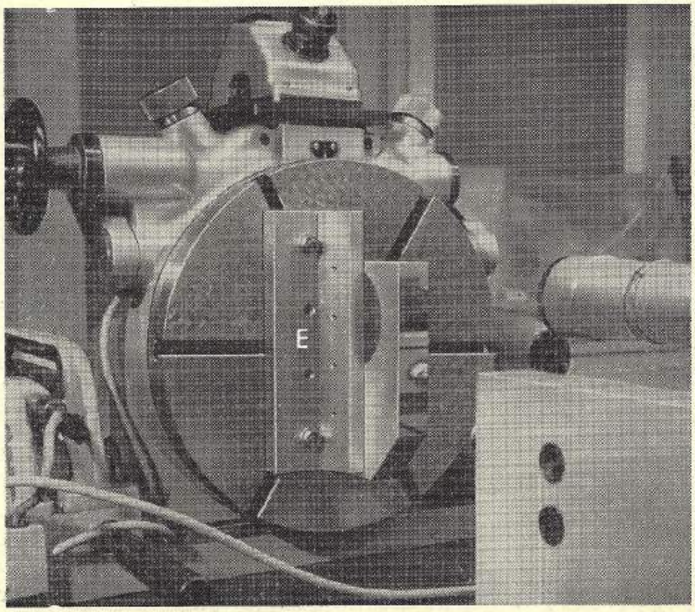


1 *The set-up for checking the accuracy of the tilting motion of an OMT inclinable rotary table. An auto-collimator is used in conjunction with a special prism with three mirror faces*

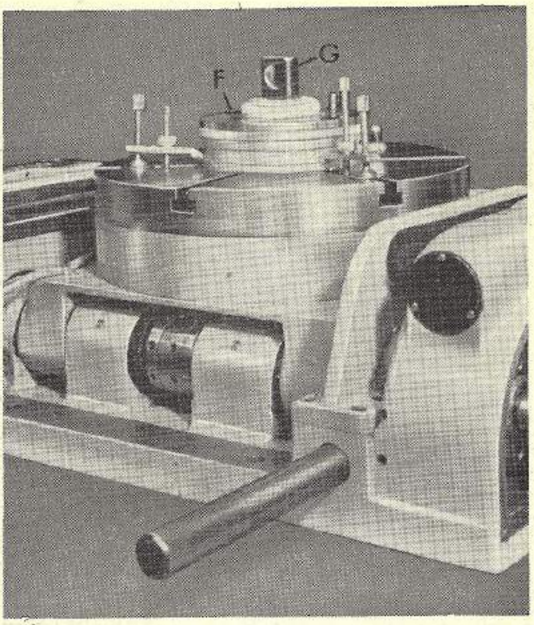
Use of a special prism

The special prism is seen more clearly in Fig. 2, which is a close-up view of the table. Made by OMT, it has faces which are parallel, at 45 deg. and at 90 deg. to the base, within very fine limits. These faces are optically worked flat, aluminized, and polished to serve as mirrors. Holes in the prism provide for the passage of clamping screws for securing it to the angle-plate support *E*, made from light alloy, and the support is bolted to the working surface of the rotary table. The holes in the support allow the prism to be mounted in either of two positions, the choice depending upon the size of table to be checked, and an arrow on the support is aligned with the centre of the table by eye.

For checking the tilting motion of the table, it is set with the working surface at 90 deg. to the base, and the prism and support are mounted on the working face as shown. The setting of the large mirror face of the prism is checked with a square to ensure that an image will be visible in the



2 *Close-up view of the rotary table set up for checking. The special prism is secured to a light-alloy angle-plate support, which is bolted to the working surface of the table. This prism has mirror surfaces parallel and at 90 and 45 deg. to the base*



3 *Close-up view of Ultradex polygon mounted on a rotary table. The polygon incorporates two sets of 360 mating serrations which are accurately spaced within very fine limits*

auto-collimator. Then, the auto-collimator is aligned with the large mirror face of the prism by moving the instrument from side to side in the horizontal plane until the image is brought into coincidence with the datum lines of the projection system. This procedure ensures that the auto-collimator is set square to the axis of tilt of the table.

Next, the table is swung back to the zero setting, as indicated on the quadrant scale of the tilt motion—this scale, it may be mentioned, is of glass with calibration lines and numerals applied photographically at the company's High Wycombe works. The setting of the small mirror face at 90 deg. to the base of the prism is checked with the auto-collimator. If necessary, the circular table is turned to realign the small mirror face with the auto-collimator and the coincidence of the image and the datum lines is again checked. Once it has been established that setting up has been carried out correctly, the table is tilted successively through 45 and 90 deg., and the angle of inclination is checked for each setting with reference to the 45-deg. mirror face and the large mirror face of the prism.

Calibrating optical tables

OMT rotary and inclinable rotary tables can be calibrated, at 1 deg. intervals if necessary, when specifically required by a customer, and the set-up for this operation is shown in the heading illustration. An auto-collimator is employed, and is mounted on the special angle-plate support already described. This instrument is used in conjunction with a face-silvered mirror mounted on an Ultradex 5-in. diameter, 360-sided optic-mechanical polygon, which is accurate within ¼ sec. of arc.

Design of the Ultradex unit is similar to that of the Ultradex indexing table described in *Machinery, 96/1637—29/6/60.* It incorporates two hardened and lapped rings, with 360 accurately spaced radial serrations on the mating faces. These rings are, in effect, face clutches and can be separated by moving a small ball-ended lever on the base of the unit through approximately 180 deg. The upper ring (and with it the upper member of the assembly) can then be turned through any whole number of degrees, as indicated on a scale round the periphery of the base. By returning the ball-end lever to its original setting, the teeth of the upper ring are re-engaged with those of the lower ring, and the upper member is accurately located in the new angular position.

In the close-up view of the rotary table, Fig. 3, the Ultradex unit is indicated at *F*, and the face-silvered mirror at *G*. The Ultradex unit is mounted centrally on the working surface of the rotary table to be checked, with the aid of a rule, since alignment is not critical, and is secured with clamps. When the auto-collimator has been set to zero with reference to the image seen in the mirror on the Ultradex unit, the table is indexed through 180 deg. and the setting checked for repeatability. This check is repeated, with the table rotated in the same direction, and a similar check is then carried out twice more with the table rotated in the opposite direction.

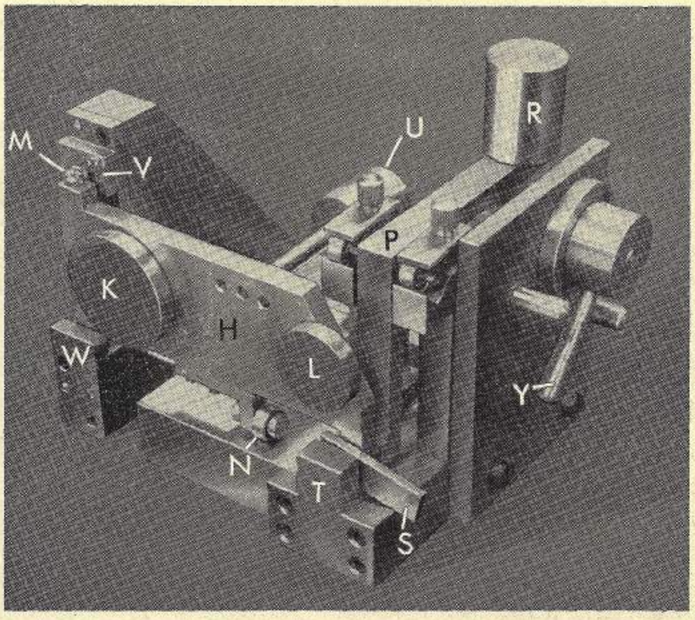
When it is found that consistent readings are obtained, one inspector indexes the Ultradex unit through a specified angle and rotates the table through the same angle in the opposite direction as indicated on the scale. A second inspector checks the alignment of the mirror with the auto-collimator, and if indexing of the rotary table is accurate, a zero reading should again be obtained. Any errors—which are extremely small—are noted, and a detailed list is supplied to the user. Usually tables are calibrated in 30-deg. increments, but this work can be carried out for any indexing intervals specified by the ultimate user of the table.

Kinematic sine bar

For checking the accuracy of rotation of rotary tables for angles less than 1 deg. particularly in connection with prototype work, the company has made the equipment shown in Fig. 4. Known as a kinematic sine bar, this unit is based on a design by the NPL, which was described in *Machinery, 100/1456—27/6/62*. It is used with an auto-collimator, and has a maximum range of 1 deg. The sine bar has a base length of 3·59 in. and the angular setting is altered by 6 sec. for a variation of 0·0001 in. in the thickness of the slip gauge used.

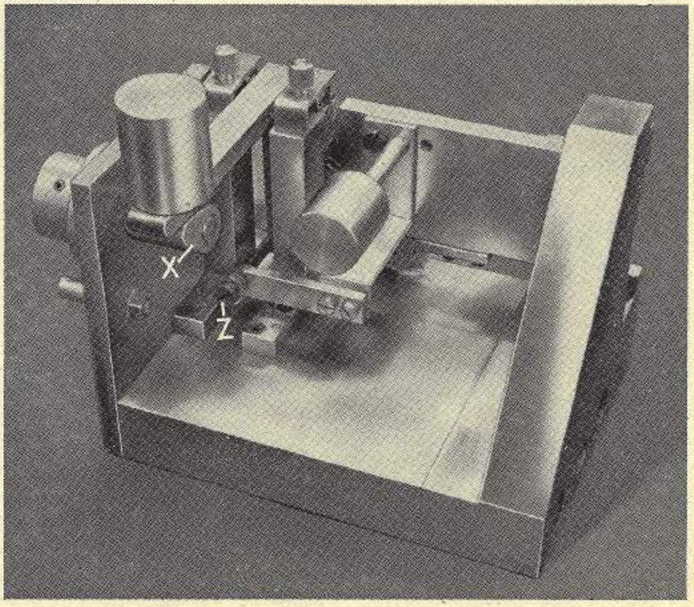
On the sine bar *H* are mounted a mirror *K* and a slave disc *L*, both made from steel and hardened, polished, and lapped. The mirror *K* serves to reflect the image from the auto-collimator, and the slave disc provides support for the mirror during the lapping operations. Two bearing balls are secured to the bar at one end, one ball being indicated at *M*, and the other ball being located directly below. This lower ball engages a V-groove machined in the base of the unit, and a bracket secured to the lower edge of the bar carries a small ball bearing *N* which makes contact with the ground upper face of the base. The arrangements are such that the bar is supported with its axis parallel to the base, but is free to tilt.

A third ball is secured to an integral lug which extends downwards from the end of the bar adjacent to the slave disc *L*. There is a bell crank *P* pivoted on brackets mounted on the base to the rear of the bar. At the lower end of the nominally vertical arm of this member is fitted a lapped steel plate, and on the nominally horizontal arm is mounted a counterweight *R*. Urged by this weight, the bell crank is caused to pivot, so that the lapped plate is thrust into contact with the ball at that end of the sine bar, which, in turn, is pivoted to hold a slip gauge, as at *S*, against three balls mounted on the inside



4 *Termed a kinematic sine bar, this unit has been built by Optical Measuring Tools, Ltd., to an NPL design, and enables small angles to be checked to a very high standard of accuracy. The sine bar is used in conjunction with an auto-collimator*

5 *In this view of the kinematic sine bar may be seen the cam arrangement for moving the bar out of contact with the slip gauge, also the two counterweights*



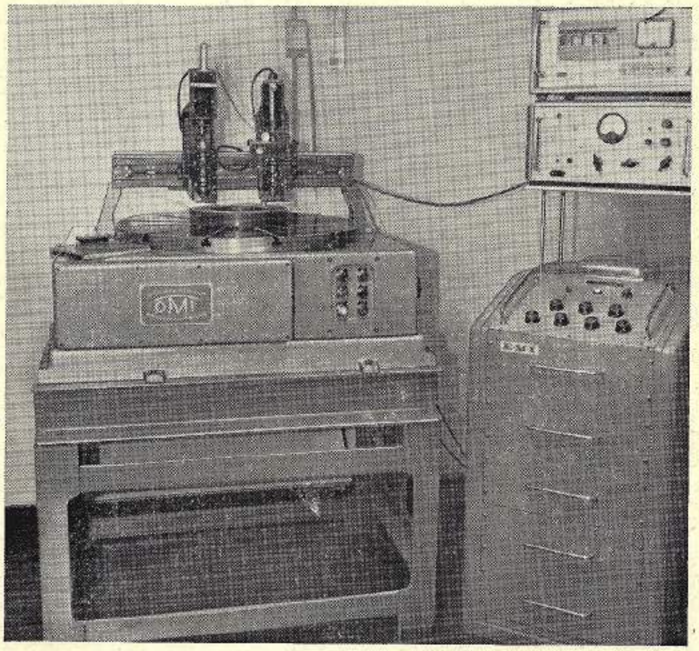
face of the bracket *T*. A second counterweight *U*, carried on a rod which is screwed into the bar, serves to apply a force to hold the ball *M* in contact with a lapped pad *V*, and the lower ball at that end of the bar with the lapped inside face of the plate *W*.

The bell crank *P* pivots in miniature ball bearings, mounted in V-section supports, and the horizontal arm of the crank rests on a cam, indicated at *X* in Fig. 5, which is a view of the unit from the rear. This cam is mounted on a shaft which also carries the lever *Y*, Fig. 4. A bracket at the rear of the sine bar is fitted with a screw *Z*, Fig. 5, which is set so that there is a small gap between its inner end and the rear face of the vertical arm of the bell crank. By turning the lever *Y*, Fig. 4, from the setting shown, the horizontal arm of the bell crank is raised and the vertical arm first moves clear of the sine bar, then contacts the screw *Z*, Fig. 5, to swing the bar towards the rear of the unit to facilitate insertion of the slip gauge.

Producing precision optical angular scales

Use of a tape controlled rotary table at the High Wycombe works of Optical Measuring Tools, Ltd.

P. A. SIDDERS, CHIEF ASSOCIATE EDITOR

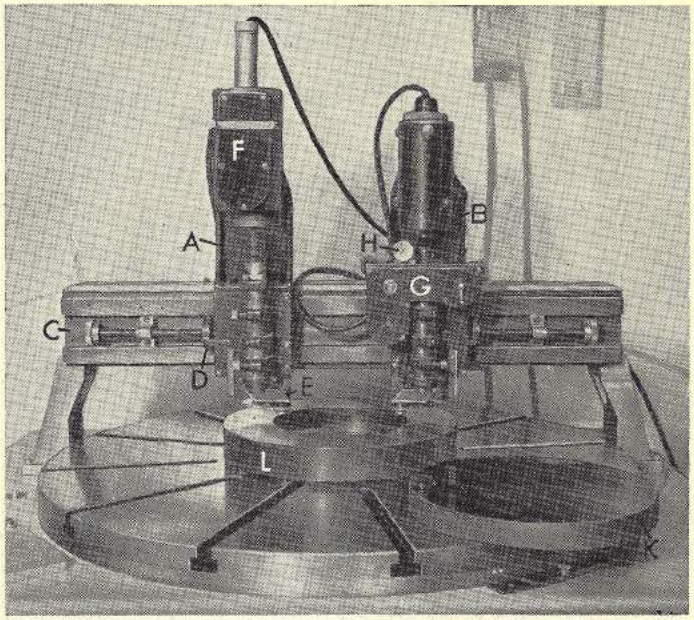


Certain of the methods employed for the production and inspection of optical rotary tables at the Maidenhead works of Optical Measuring Tools, Ltd., a member company of the Newall Group, were described in *Machinery, 107/284—11/8/65* and *107/516—8/6/65.* The company builds such tables in a range of sizes, in both plain and inclinable designs, and the rotary and tilting motions are made with reference to glass scales. These scales are produced to very high standards of accuracy in the optical department of the company. For many years, this department formed part of the main works at Bridge Road, Maidenhead, Berks., but recently it was transferred to premises at Cressex, High Wycombe, Bucks., where the specialized equipment developed by OMT for the production of angular optical scales is now installed.

The ring-type scales have numbered graduations at 1-deg. intervals, and the markings are required to be black on a clear background. Scales are produced by a photographic technique from master negative plates, each of which consists of a glass disc, optically worked flat and parallel within very fine limits. In order to ensure stability, the discs are 1 in. thick, and are made in various sizes from 3 to 11·6 in. diameter. The smallest type is used in connection with production of scales for the OMT toolmakers' microscopes, and the 11·6-in. size is for members for the 30-in. optical table.

Master negative plates are coated on one side only with Kodak Maximum Resolution emulsion by OMT. This emulsion can be handled in illumination provided by a red safe-light, and a special coating technique is employed. With this technique, a film is obtained which is very even, free from dust and has an optically flat surface.

The coated master disc is then ready for printing, which is carried out on the special equipment seen in the heading illustration. This equipment comprises an OMT 30-in. rotary table, with EMI electronic positioning equipment, and two projector units are mounted on a bridge member fitted to the table. Movements of the table are controlled automatically from punched paper tape, fed into the reader of the EMI console at the right. The table can also be indexed manually by means of knobs on the panel of the console, which provide for setting in degrees, minutes and seconds of arc. Normally, the rotary table can be positioned under tape control within an accuracy of ± 3 sec. of arc, but for this application the table has been carefully calibrated at 1 deg. intervals, and the appropriate corrections incorporated in the tape. As a result, the maximum error when positioning is carried out at 1-deg. intervals is between $1\frac{1}{2}$ and 2 sec. of arc (that is, approximately 0·00003 in. at a diameter of 6 in.).



1 *Close-up view of an OMT-EMI tape-controlled rotary table arranged for the projection of graduation lines and numerals on to masters for the production of ring-type angular scales. A blank for a master is seen at the right*

Projection units

Fig. 1 is a close-up view of the rotary table, and the two projector units may be clearly seen. The unit *A* serves to project the graduation lines, and the unit *B*, the numbers, the arrangement being such that while a line is being projected, a number is being projected simultaneously at a position displaced from the line by 180 deg. Both projector units can be moved on guideways on the bridge by means of screws, as at *C*, which are fitted with graduated discs *D*, to allow the radial settings to be adjusted to suit master plates of various sizes.

The unit *A* has a housing, wherein is mounted a 6-volt, motor-car type lamp, which is operated from a supply of 4 volts to ensure long life. Light from the lamp passes through condenser lenses, to produce a parallel beam, thence through a slit-type graticule and a projection lens and prism system *E*. Prisms are incorporated to offset the final beam relative to the body of the unit *A*, so that the beams from the two units can be closely spaced as required for the production of scales of small diameter. On the finished scales, the lines may be as thin as 0·00007 in. The projection lens system reduces the thickness of the beam projected from the slit-type graticule in the ratio of 7:1, and the width of the graticule slit is made 0·00028 in. (in other words it is wider than the finished line by 4:1) to allow for spreading of the line during processing and printing of the master and final scale.

Light at 90 deg. to the main beam of the projection unit *A* is directed on to a photo-electric cell in the housing *F*. This cell is connected to a Quantex light-quantity meter, supplied by Baldwin Industrial Controls, Ltd., which is mounted on the wall adjacent to the EMI console. An adjustable dial on the Quantex meter provides for setting the amount of light that is projected during a particular exposure, and this value is usually determined initially by trial.

The projection unit *B* is generally similar to that described, but is not provided with a photo-electric cell, and in place of the slit-type graticule there is a magazine and gate assembly *G* for 35-mm. film. On the film there is a number (from 0 to 359) in line with each pair of sprocket holes. The film is produced so that the numbers are clear on a black background, and they are spaced lengthwise on the strip within 0·002 in., since their position on the finished scale must be maintained within 0·00025 in. To ensure accuracy of positioning, the film is located in the gate by two vertical pins, which are hardened and ground, and these pins engage the sprocket holes at each side of the film. The pins are carried on a plate, mounted on leaf-spring pivots, which can be raised and lowered by an eccentric actuated by the knob *H*. When the pins have been moved clear of the holes, the film is advanced through one pitch by movement of a lever. The arrangements are such that movement of the film must be obtained by hand, but a new magazine unit is being built, for 16-mm. film stock, which will provide for automatic advance of the film under control of the punched tape.

Printing procedure

A coated master plate is seen at *K* and the very high quality of the emulsion-coated surface (seen uppermost) may be observed. For projecting the graduations and numbers, the plate is mounted in the ring-type jig *L*. This unit has three feet and an internal register face on the underside of the flange. Since the depth of focus of the projection lenses is less than 0·0002 in., the surfaces of the feet and register face must be lapped parallel within 0·0001 in. The master plate is clamped in the jig with the emulsion-coated surface in contact with the register face. Centring of the plate in the jig and the jig on the OMT rotary table is not critical, since final centring of the scales is carried out when they are assembled in the associated equipment. It is sufficient to position the jig by aligning screw holes in the latter with tapped holes in the rotary table.

At the start of the control tape is punched an "alignment code". When this code has been registered in the control unit at the beginning of a printing sequence, a "ready" signal lamp on the console is lit. An "alignment" push-button is then depressed, and the table moves automatically to its zero setting, in readiness for the first exposure. Next, a "start" button is pressed, an exposure is made through the two projector units, and the table is indexed through 1 deg., this sequence being repeated until the total of 360 graduation lines and numbers has been projected. Exposures can be made by the operator, independently of the control equipment, if required.

At present, the positioning sequence for the table is arranged to provide sufficient time for the film to be advanced manually. When the new film unit is fitted, however, it will be possible to print the complete series of graduations and numerals on to the master plate without the attention of an operator, once the "start" button has been pressed, and the equipment will be stopped automatically at the end of the sequence.

To ensure consistent exposures, a stabilizer is provided for the power supply, and this unit is seen mounted above the console in the heading illustration. A resistance is incorporated in the circuit to the left-hand projection unit so that the intensity of the light for printing the graduation lines may be varied independently.

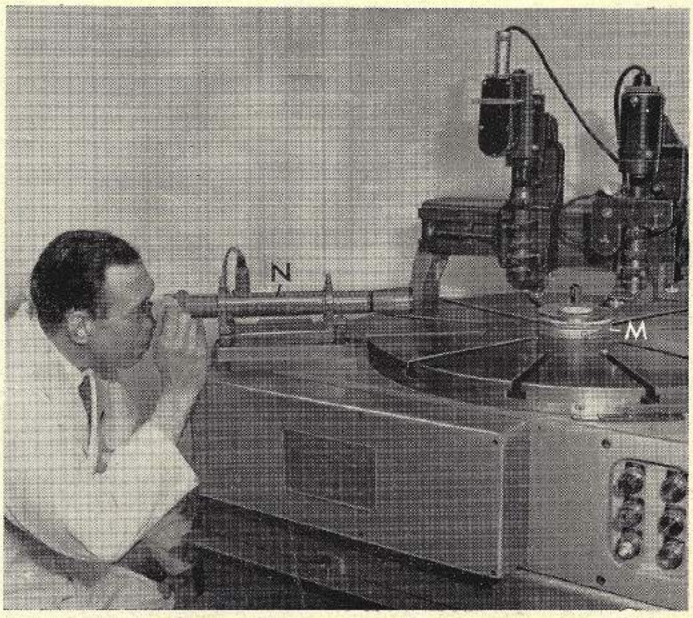
Processing masters and scales

For the production of optical scales which have black markings on a clear background it is necessary to provide a master which has clear markings on a black background. Master negative plates are therefore processed by a reversal technique, to avoid the production of an intermediate negative, which could give rise to inaccuracies. Each master plate is first developed, then bleached, re-exposed and re-developed, and the sequence is completed by fixing and washing.

The angular ring scales are produced in the graticule department of the company, and the optically-worked glass rings are coated on one face with bichromated fish glue emulsion. A master plate is mounted above the ring in a contact printing rig, with the coated surfaces in contact, and the master and ring are centred by eye.

Light from a mercury vapour lamp is passed through condenser lenses to produce a parallel beam, which is directed on to the master and thence through the clear portions of the coating on to the ring. The portions of the emulsion on the ring which are exposed to the light are hardened, and the remainder is removed at a subsequent washing operation, to leave graduation lines and numerals which are later dyed black. A protective cover ring is fitted to the annular scale before it is mounted in the associated rotary table or other piece of equipment.

2 *At regular intervals, the OMT-EMI rotary table is checked with the aid of an auto-collimator and an Ultradex optic-mechanical polygon. Corrections to compensate for any errors that may be found are incorporated in the control tape*



Calibrating the rotary tables

The OMT-EMI rotary table used for the production of the scale masters is calibrated at regular intervals, and the arrangements employed for checking are seen in Fig. 2. An Ultradex 5-in., 360 sided, optic-mechanical polygon, is mounted on the surface of the table, as indicated at *M*. This unit is similar to the Ultradex indexing table described in *Machinery, 96/1637—29/6/60*, and incorporates two very accurate face couplings, each of which has 360 teeth. The upper member can be raised and turned relative to the lower, and the arrangements are such that it can be indexed in 1 deg. increments with an accuracy of ¼ sec. of arc. A face-silvered mirror is mounted on the upper member, and is viewed through an auto-collimator *N*. The latter instrument is mounted on a plate and alignment block which are secured permanently to the base of the rotary table.

For checking, the mirror is viewed through the auto-collimator and the latter is set to zero. The rotary table is then indexed through 1 deg. under tape control, the Ultradex unit is moved through 1 deg. in the opposite direction, and the reading of the auto-collimator is checked. Any difference between the two readings is noted, and the procedure is then repeated until checks have been made at 1-deg. intervals for the complete 360-deg. movement of the rotary table. A new control tape is then prepared, using a Creed teleprinter keyboard, and corrections are incorporated to compensate for the errors found in the indexing movements as a result of the calibration checks.