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A PROJECTION TYPE MEASURING ENGINE FOR PHOTOGRATHIC ZENITH TELESCOPE PLATES

BY

M. M. THOMSON

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
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ABSTRACT

A new measuring machine of projection type, designed for scaling PZT plates, has been built at the Dominion Observatory, Ottawa. The stellar images and micrometer readings are focussed on a ground glass viewing screen where the fiducial lines are drawn. The improvements arise from ease of operation, slightly reduced setting error, and reduction in fatigue.

INTRODUCTION

When the new Ottawa Photographic Zenith Telescope was placed in operation in 1951, the only measuring machine available was a Toepfer (Figure 1), designed as a spectrum comparator. In this machine the plate is carried in a box slide, the motion of which is controlled by a half-millimeter pitch screw. The eyepiece containing the fiducial cross hairs is mounted on a slide at right angles to the plate slide, about 8 inches above it, and is actuated by a one-millimeter pitch screw. Drawbacks inherent in the Toepfer engine evolve from:

a) The fiducial lines in the eyepiece tend to change position on refocussing, or due to a jarring. A parallax uncertainty is difficult to remove.

b) The main eyepiece and the magnifiers associated with the divided heads of the two screws provide in effect three optical systems of different accommodation.

c) The moving stages, being an appreciable distance apart give rise to some doubts about the over all stability of the machine.

d) The illumination of the Toepfer was intended for spectrum plates in which the spectra covered a strip about $\frac{1}{4} \times 3$ inches. The wider field of the PZT plates could be illuminated to the edge of the field only by the addition of a diffusion screen, and even then but poorly.

In the design of the new engine certain definite objectives were sought. As much as possible, visual microscopes would give way to projections, thus minimizing eye strain. Measurements in both coordinates must be made accurately and easily. A seven times enlargement of stellar images was considered adequate. The completed engine should have as good an appearance as possible. The decision to use projection, eliminating the use of visual microscopes, arose from the success of previous developments using this principle at both Victoria and Ottawa, (J. RASC **42**, 226, 1948, and J. RASC **45**, 199, 1951).

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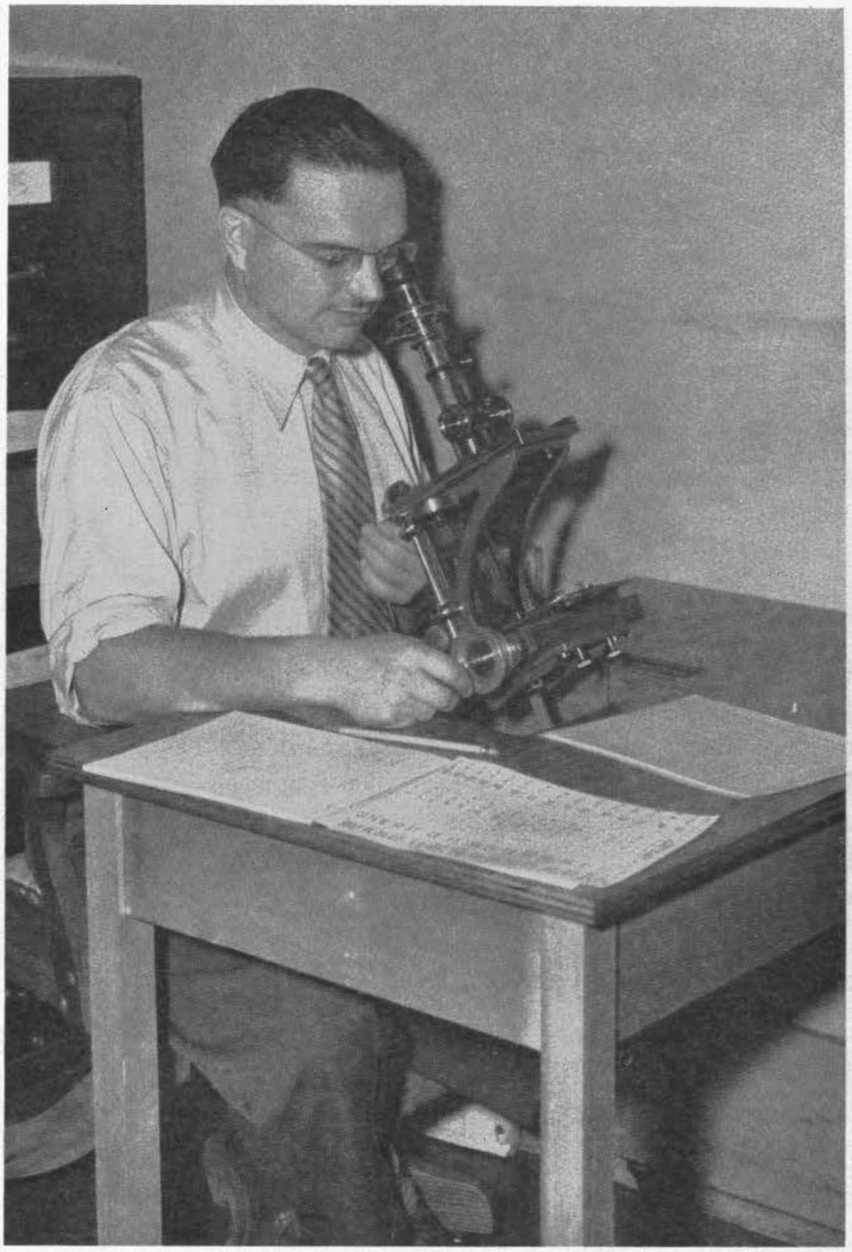

Figure 1.—The Toepfer measuring engine formerly used to scale the PZT plates.

GENERAL DESCRIPTION

Figures 2 and 3 show the engine in its final form. It is of welded steel framework covered with sheet metal and painted a glossy blue-grey. In maximum dimensions it is $57\frac{1}{2}$ inches high, 30 inches wide, and 32 inches deep. At a height of $27\frac{1}{2}$ inches, the side panels terminate in arm rests, above which the engine is 22 inches wide. A 14 × 14 inch ground glass viewing screen, tilted at 45 degrees, receives the projected images of the PZT plate and the scale readings which are viewed by transmitted light. The PZT plate, as indicated in Figure 3 and subsequently, is mounted horizontally on moving stages which define the coordinate axes. The moving stages are in turn mounted on a

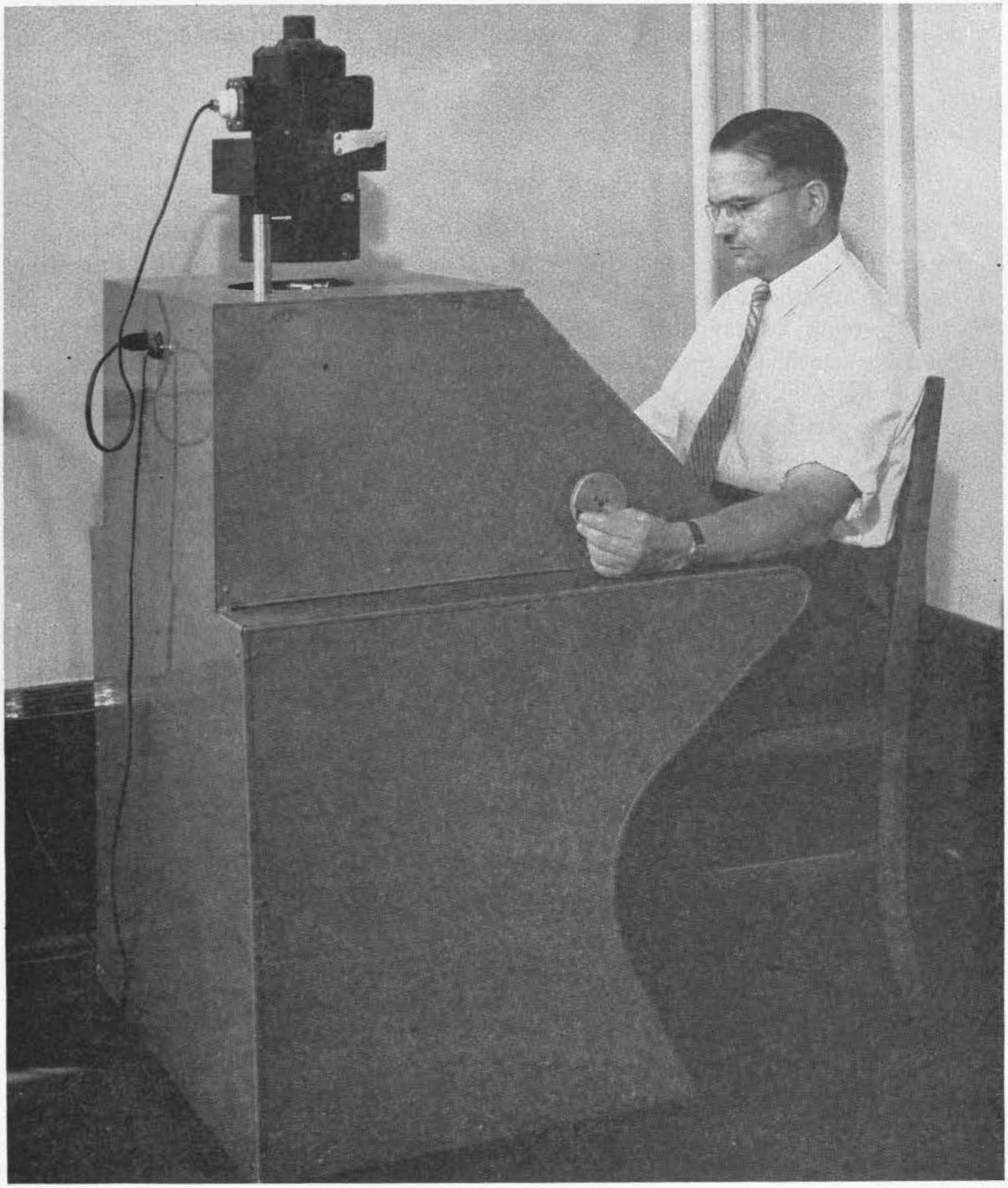

Figure 2.—The new plate measuring engine in operation. A detachable supply cord plugs into a wall outlet, and feeds directly to the toggle switch along side. To the other side of the supply cord is the plug for the mercury vapour lamp in the Omega enlarger head. In order to mount the lamp horizontally in the head, a socket was attached to the back ventilator, and the hole in the top was capped over.

base plate which is firmly attached to the frame of the instrument. The projections are all directed downward to a mirror from which they are reflected upward and forward to the viewing screen. Due to the stability of the instrument frame it is possible to draw the fiducial cross lines directly on the ground glass with India ink, thus eliminating parallax. Two knobs, located one on each side, 3 inches above the arm rest, control the motion of the precision screws. The four feet on which the engine rests are adjustable to provide for levelling.

PROJECTION SYSTEMS

There are three projection systems in the machine, one for the plate and one for each of the two precision screw heads (Figure 3). Illumination for the plate is provided by an Omega enlarger head in which the 40-watt tungsten lamp has been replaced by a G.E. 100-watt mercury vapour lamp type H100-A4. Horizontal mounting of the lamp is provided by attaching a receptacle to the back ventilator of the head. To the head is attached a special bracket with a half-inch boring down one corner permitting it to be mounted to a vertical post rigidly attached to the reinforced top plate of the engine body. A shoulder on the post holds the head 2 inches above the PZT plate, providing excellent illumination. Access to the plate is obtained by swinging the head around on its vertical pivot.

The monochromatic light from the mercury lamp has so small a percentage of red rays that the heating effect in the beam path is negligible. The heat absorbing filter was left in, though it perhaps has little to do. The illumination is sufficiently strong so that there is no need to subdue normal room lighting. Indeed a thin filter of onion skin or drafting paper, in the normal location above the condensers, is desirable for a particularly clear plate.

The projection lens first used in the optical path of the plate was a Kodak Enlarging Ektanon lens which is designed to give good definition over a wide angle. A lens of this character is not absolutely essential, since in the scaling of the plate each stellar image is brought to the intersection of the fiducial lines, and hence is close to the centre of the field. However for examining the plate and comparing stellar images, it seemed desirable to have good wide field projection. The lens is attached to a special piece of brass tubing, about an inch and a half long, threaded internally and externally. The tubing is threaded into the base plate of the moving stages directly below the plate, and exact focussing is accomplished by turning it up or down the required amount.

Focus adjustment is done with the back cover of the engine removed and requires a second person or the use of a mirror held over the viewing screen. Once adjusted, the focus holds, so that it was not considered necessary to provide a means of adjusting from the operator's position. The light path from the emulsion to the viewing screen is 32 inches so that with a 4-inch lens the images are enlarged 7 times. Also the stellar field is completely in view when centrally projected.

Subsequently a 2-inch enlarging lens was installed providing a 15 times enlargement. No inconvenience has been experienced by not being able to view the whole field, while on the other hand the accuracy of setting is somewhat improved. The 2-inch lens, after its iris adjustment ring was removed and the iris left wide open, was fitted with an

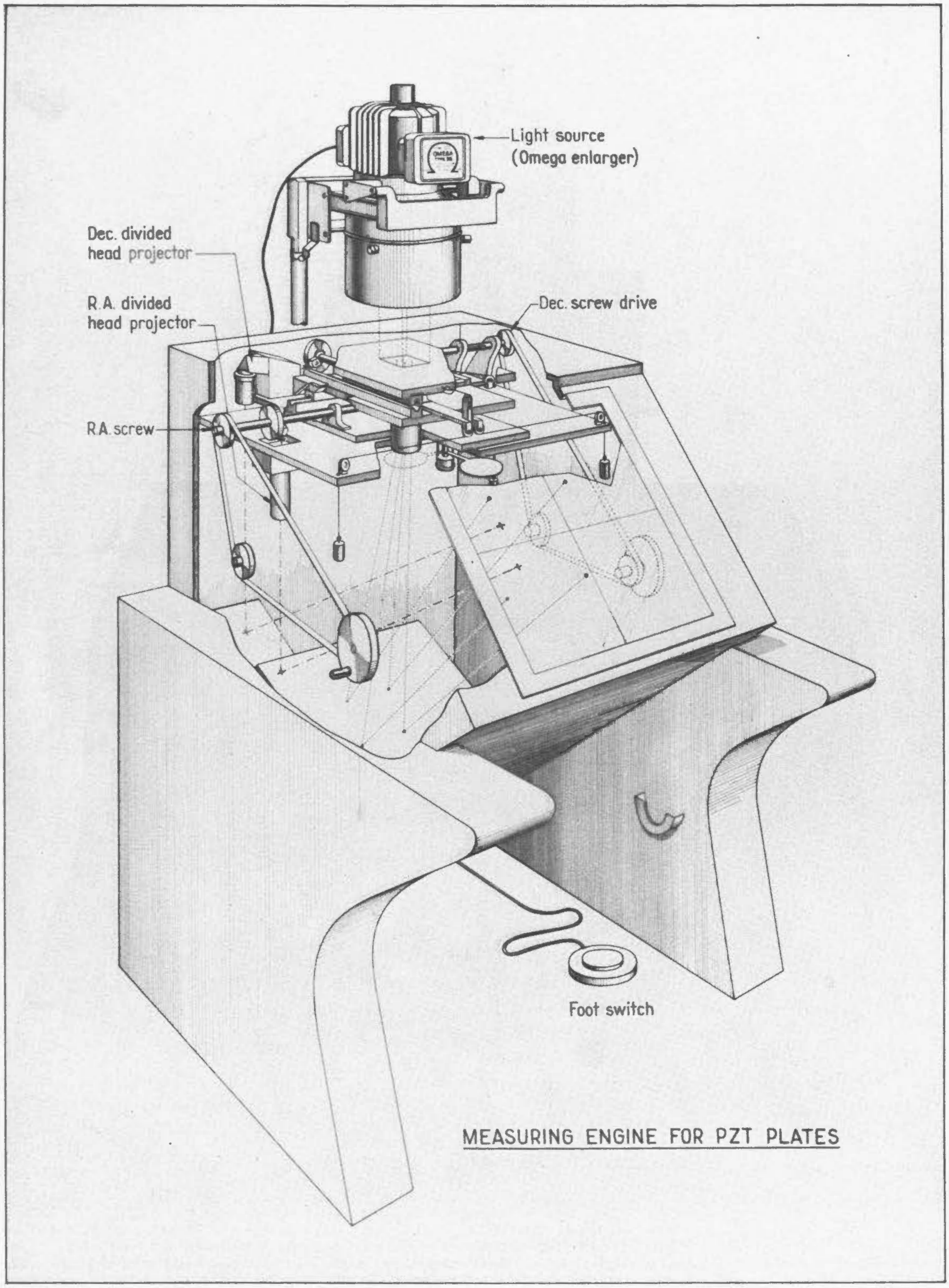

Figure 3.—The new projection measuring engine for scaling PZT plates. A frame of welded steel is covered with sheet metal and painted a grey-blue. Through an opening in the top the photographic plate is mounted horizontally on the upper moving stage. Control knobs, symmetrically located on each side 3 inches above the arm rests, drive the plate in both coordinates and serve to centre each stellar image on to the intersection of the fiducial lines. The foot switch, when not in use, may be kept in its holder.

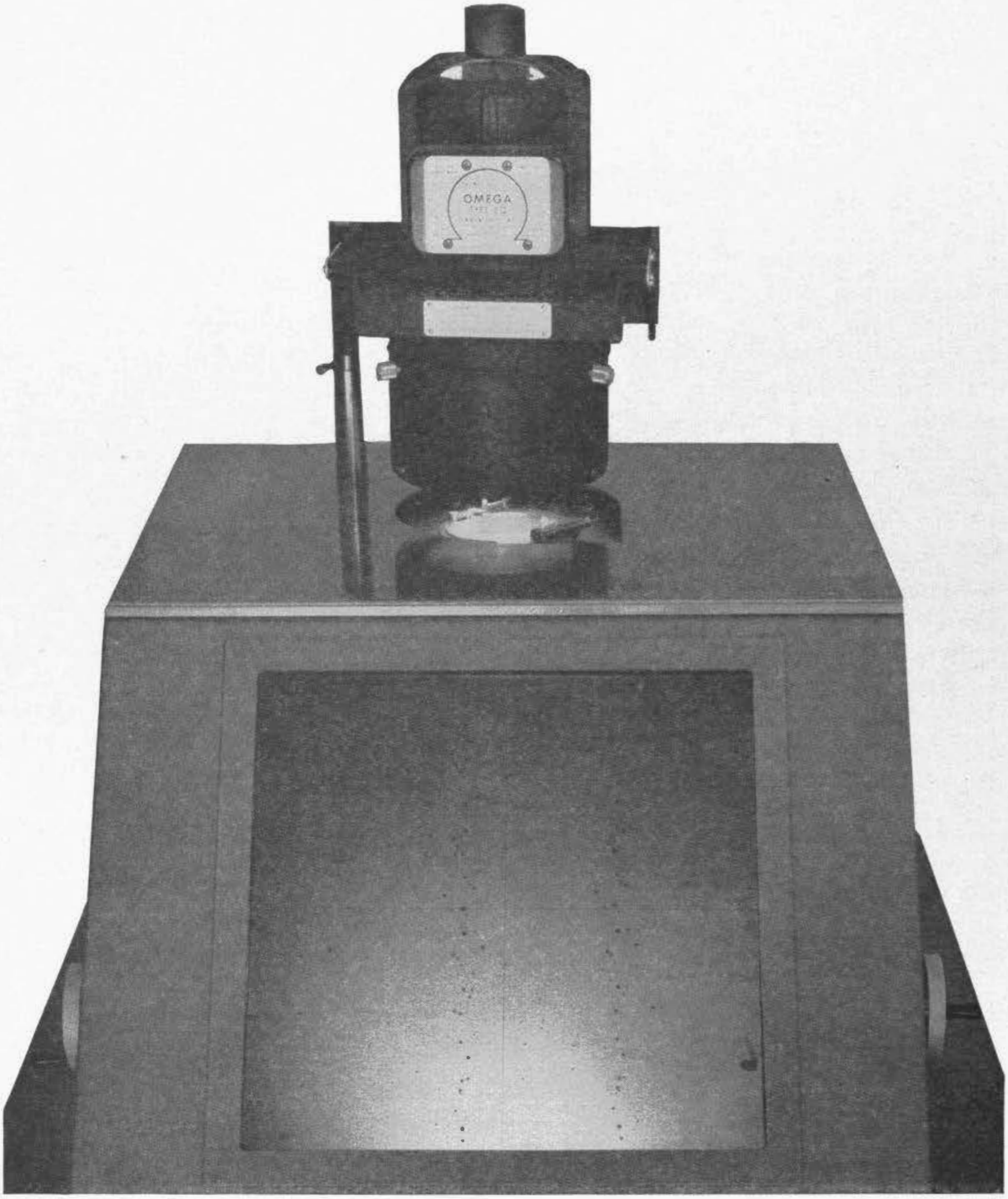

Figure 4.—Ground glass viewing screen of measuring engine shows the stars of a PZT plate after projection with a 4-inch projection lens giving 7 times enlargement. The four images of several stars may be easily noted. Each stellar image is brought to the intersection of the fiducial lines which are drawn on the ground glass. The camera was looking into the lower part of the screen, making the rest of the field dark. Note the Omega enlarger head with its special mounting bracket.

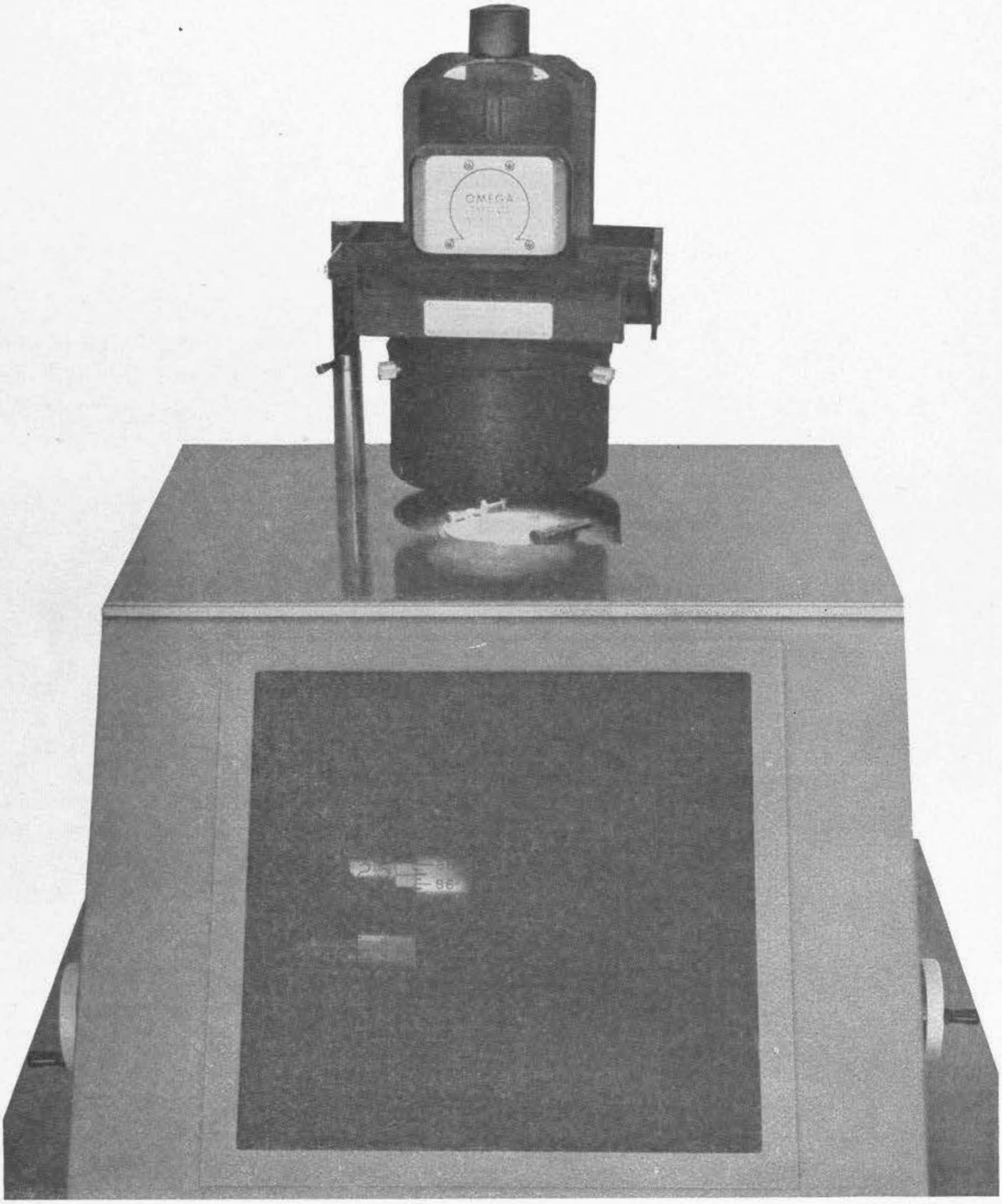

Figure 5.—Screw settings are projected onto the ground glass and simultaneously the star pattern is occulted by the operation of a foot switch. (Occulting the star pattern is not necessary, and has been discontinued.) The camera is in the line of sight of only one scale projection. In practice both scales may be read easily.

adapter into the top of the threaded tubing and focussed as before. The 2-inch lens projects up into the opening in the lower moving stage, requiring that the original 2 × 2-inch opening be lengthened.

The mirror, a 10 × 10-inch sheet of plate glass, selected for its smoothness and aluminized on its front surface, is mounted at an angle of $22\frac{1}{2}$ degrees to the horizontal. The projected image of the star images of a plate made with the 4-inch projection lens is shown in Figure 4.

The projector for the lower screw head (R.A. screw of Figure 3) is mounted on the base plate of the moving stages as seen in Figures 6 to 9. Illumination is provided by a 6-volt, 21-candle power automobile lamp housed in a metal box whose inside walls are painted a glossy white. The light is further diffused by a piece of ground glass across the opening, thus giving a uniform band of illumination across the divided head and veeder counter. The direct reflection of this illumination points down the projection tube to a lens of about 6 inches focal length which is adequate to give an image of about 4 times enlargement on the screen. A coated lens of ordinary quality was used and the resulting image is very good.

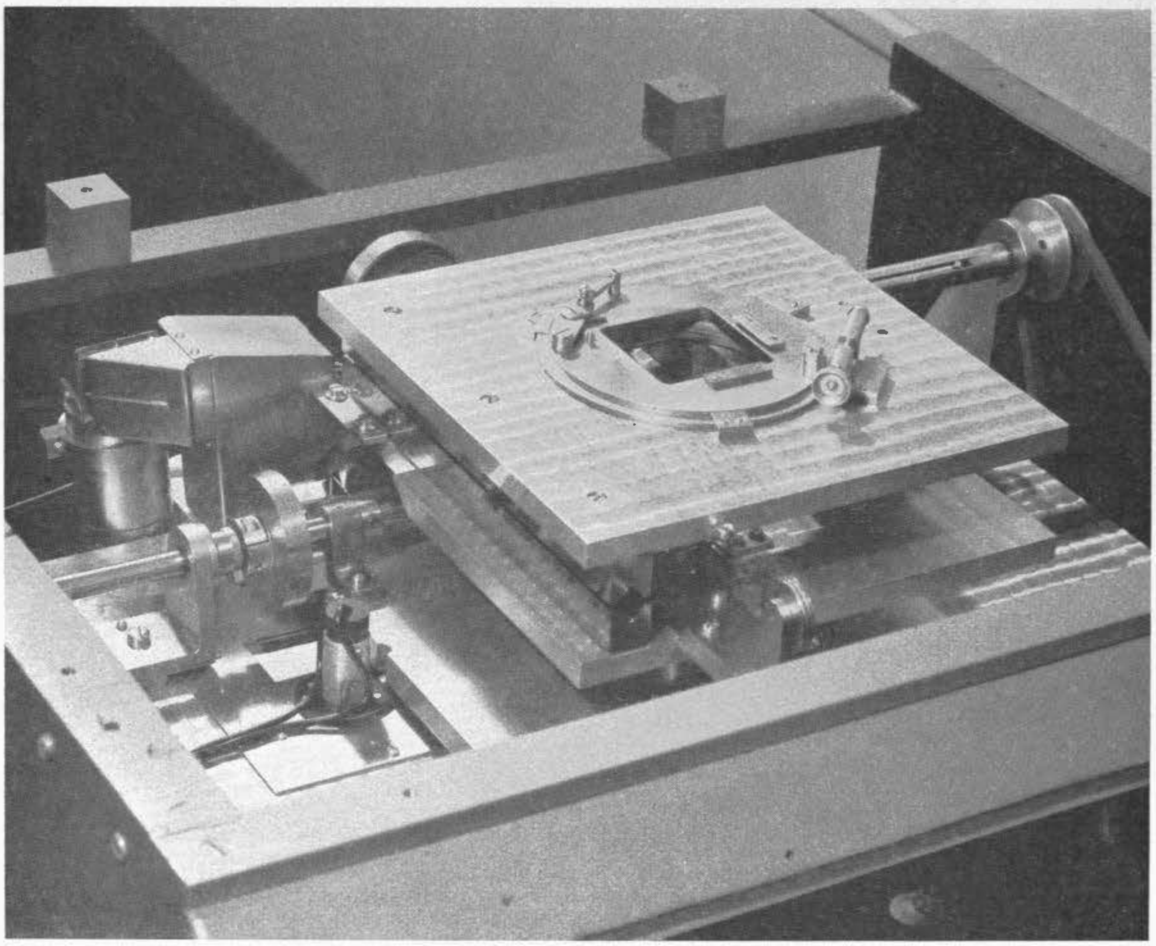

Figure 6.—With the top of the engine removed the general arrangement of the mechanical parts is exposed. The plate is mounted, emulsion down, by means of the toggle clamp (left) and the fixed stops (right) attached to the disc set into the top stage. Three fingers bear lightly on the disc. A projecting finger impelled by a tangent screw (right) is used to orient the plate. Complementary V sections, embedded in the two stages and separated by two widely spaced ball bearings, serve as guiding ways.

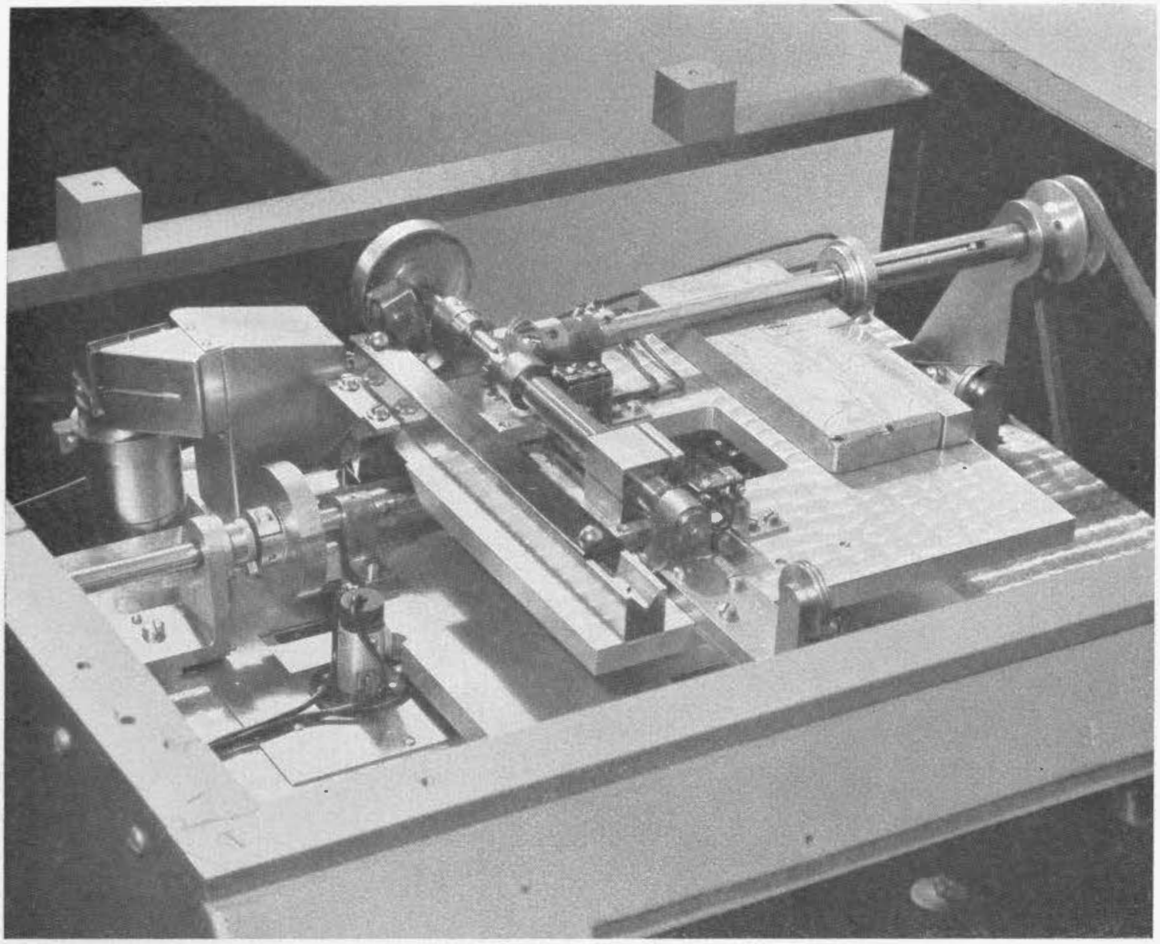

Figure 7.—Removal of the upper movable stage exposes the lower stage. Attached to it are from left to right: the projector for the upper precision screw; the embedded V groove with two widely spaced ball bearings; the precision screw with divided head, bevel gear, and brass nut; a lead block which, with a similar one attached to the under side of the upper stage, counterbalances the overhanging projector; the hardened steel flat at the right edge on which the wheel of the upper stage rides; the nylon string that rides over the pulley to the weight below. The shaft connected to the right hand section of the bevel gear is held in position by a sleeve bearing and a collar adjacent to the gear. The other end of the shaft telescopes easily into the carefully aligned hollow shaft that is mounted to the fixed base plate by a bracket. Pulley and V-belt transmit the drive from the right hand control knob.

The projector for the upper screw head (Dec. screw of Figure 3) presented a different problem because it is attached to a moving part of the instrument. It hangs out from the back corner of the stage, as may be seen in the pictures, and being made of brass required about 5 pounds of lead counter weight. The lead may be seen on the under side of the top stage (Figure 9) and on top of the second stage (Figures 7 and 8). The projection of the image differs still further from that of the lower head in that two small mirrors are inserted along the light path to rotate the image through 90 degrees. Both scale readings are hence made to appear with the same orientation on the screen. In order to have them of comparable size and intensity, the lens in the declination projector is of greater focal length and the light is brighter. The position of the declination projector is so far back that its beam misses the main mirror and a small secondary mirror was required. The two scales are easily read with but a small motion of the head. However their paths are sufficiently divergent that one is more clearly seen than the other by the camera, as in Figure 5.

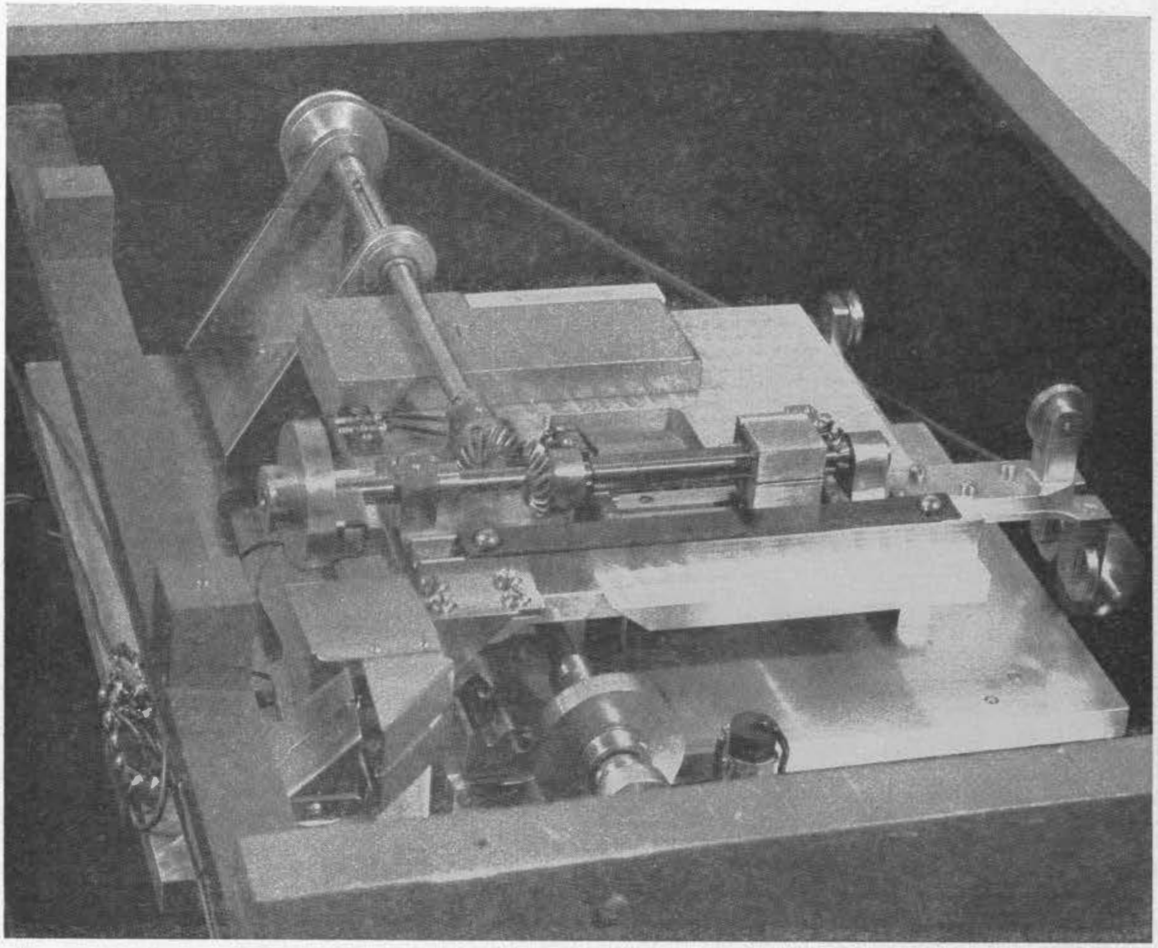

Figure 8.—The projector for reading the head of the upper screw rotates the image of both the head and the gear coupled veeder counter through 90 degrees by the use of two mirrors, as may be seen front left. The nut of the upper screw seen to right of centre operates a micro switch at each end of its run to warn against an over drive. Complementary V sections embedded in the under side of the lower stage and the upper surface of the bottom plate may be seen to the left of the divided head of the lower screw. Pulleys to the right indicate the way in which gravity constraint for the top stage is provided by two weights at the sides of the engine.

The heat of the 21-candle automobile lamps becomes quite apparent after they have been burning for some time. Since this heating is undesirable, a foot switch (Figure 3) has been incorporated which must be pressed to turn on the projectors for the brief interval required to read the scales. There is a further advantage in the intermittent illumination, namely, the fact that one is uninfluenced by the appearance of a scale reading when making a setting.

When the instrument was first used, the foot switch also operated a light aluminum vane to occult the beam from the plate so that when the scale readings appeared on the screen the star images disappeared. The vane was pivoted on the rotor shaft of a small 3-phase motor which may be pulled around into a fixed position when direct current is applied to one of its windings. As seen in Figure 9, the motor is on a slight angle so that gravity serves to let the vane turn around to a back stop. A low voltage swings it around to the front stop where it is in the occulting position. Subsequently it was felt that the

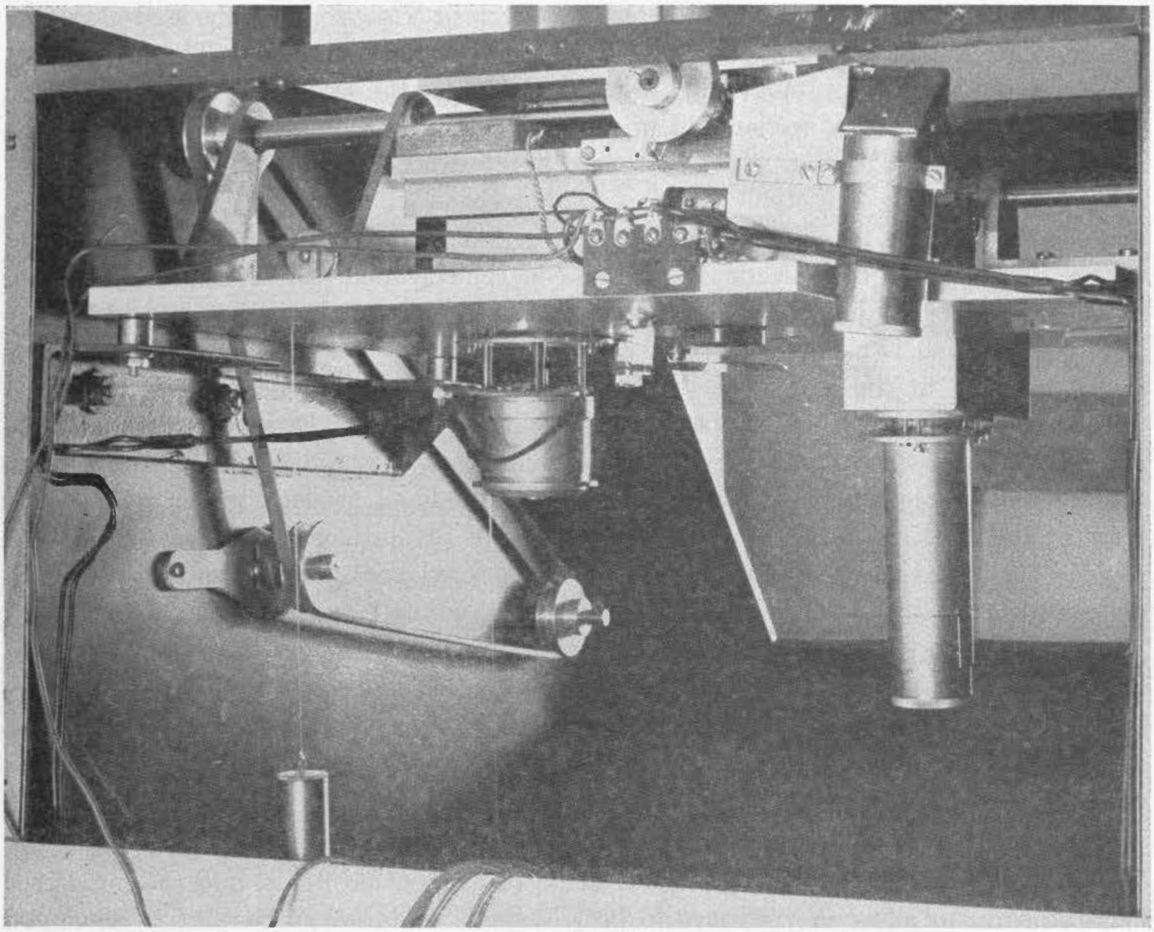

Figure 9.—From the rear of the engine may be seen: the belt transmission on the left from the hand knob to the upper or declination screw; the occulting vane and its control motor under the base plate and the two projectors for the two screw readings on the right. Push-pull screws on the lower projector provide adjustment in the position of the image on the viewing screen.

jar imposed by the vane coming up to its stop was not desirable and, since the scale values may be read quite well with the plate projector not occulted, the use of the occulting vane was discontinued.

THE MECHANICAL PARTS

The mechanical portion of the measuring engine consists of two stages measuring 8×8 inches and spaced $1\frac{3}{4}$ inches apart. They carry the PZT plate, and by their ways or guides define the coordinate axes.

The mounting of the PZT plate is seen in Figure 6. A disc with a collar attached is fitted into a 3-inch circular opening in the top stage. A projection from the disc is engaged by a tangent screw and plunger which imparts a rotational adjustment to the disc and hence to the plate. Over a central hole measuring $1\frac{7}{8}$ inches square the plate is held by a toggle type clamp against two stops. Clamp and stops are all undercut so as to grip the plate and hold it flat against the opening. Three evenly spaced fingers attached to the stage touch lightly onto a flange of the disc to prevent it from lifting.

On the under surface of the top stage an inverted V section is embedded along the left edge and a ball bearing wheel is centrally located at the right edge. The wheel is not visible in the photograph but the corresponding one for the lower stage may be seen in Figures 6 and 7. The V section and wheel are opposed on the upper surface of the next stage by a similar V section with two spaced ball bearings and a polished flat. Parallel to and close by the V section is one of two precision millimeter pitch screws. They are ½ inch diameter, have 3½ inches of thread, and an additional 4½ inches of stock. End thrust is taken by a shallow depression in the threaded end of the screw bearing against a cone of hard steel. The screw is prevented from coming out of its end bearing by a collar which is clamped inside the sleeve bearing at the other end. Beyond the sleeve bearing, at the end of the screw, is located the divided head upon which 200 divisions are ruled, every fourth one numbered 0, 2, 4, . . 98. Estimation to a fifth of a division is readily accomplished to provide readings to one thousandth of a revolution (one micron). Geared to each divided head is a modified veeder counter which turns forward and back to indicate the whole number of revolutions. The numbers on the divided heads and veeder counters have to be engraved back to front so that they will appear correctly on the screen after reflection. Figures 7 and 8 indicate how a bevel gear, clamped to the declination screw, extends the drive over to the right hand side, and a telescoping shaft takes up the right-left motion imparted by the lower screw. The drive transmitted to the right hand side is connected by belt and pulley to the control knob. Ordinary V belt sliced down to small cross section provides a very light, easy transmission.

The nuts associated with the two screws are each formed from a 1-inch cube of brass. The thread is relieved so that contact is made in 3 radial positions, and the nut is cut longitudinally to allow the pressure to be adjusted. Rotation of the nut is prevented by a projection downwards which travels in a straight slot. Contact with the moving stage above is made with a finger from the stage which bears against a hard steel piece set into the nut. Gravity constraint is used to keep the stage in contact with the nut and also to keep the screw against its end bearing. At the two ends of their run the nuts operate micro switches, and the harsh sound of a buzzer prevents an over run with consequent jamming.

The lower moving stage was machined most carefully to be sure that the V section embedded on its upper surface and the one on its under surface were as nearly at right angles as possible. It is the position of the V's which determines the motion of stages and hence directions of the coordinate axes. The drive for the lower stage is provided by the screw and nut in precisely the same manner as with the upper stage. In this case, however, the screw is fastened to the base plate which in turn is bolted securely to the frame. A tooth and slot connection beyond the divided head extends the screw to the left and hence by belt and pulley to the left hand knob.

All the bearing surfaces in the V's and on the flats were polished smooth and then chromium flashed to provide smooth, corrosion free surfaces.

Gravity constraint is provided by two pulley and weight systems (Figure 3). The pulley for the lower stage is to the right and the weight moves near the side wall. The upper stage must be pulled forward and as a result the weight, if hung directly, would cut across the projected images. Instead it has been divided evenly in two and directed by two pulleys to the left and right thus avoiding a turning moment which would be introduced if the weight were diverted one way only. Nylon fishing line is used as the suspension cord.

The ground glass viewing screen was prepared in the Optics laboratory of National Research Council from selected plate glassby using 280-grit carborundum. Both finer and coarser ground glass was tried, but the former permitted the lamp to be seen, while the latter was too grainy. The fiducial lines are drawn with India ink on the ground glass.

ELECTRICAL FEATURES

The engine plugs into an ordinary wall socket, and has a toggle master switch on the back wall. Inside the back wall under the mirror is a shelf on which are housed the various transformers. A ballast transformer for the mercury vapour lamp feeds to an outlet box on the back cover. The lamp house is hence free to be lifted from its post and unplugged and laid to one side. This is desirable whenever the top is removed for such purposes as cleaning the moving parts, or replacing a small lamp. A toy transformer with several windings supplies illumination for the divided head projectors at two slightly different voltages. The same source would also suffice for the alarm buzzer, though a separate one was installed. A fourth transformer with a single wave rectifier provides the 6 to 8 volts necessary for the occulting vane now no longer used.

SCREW AND COORDINATE VALUES

The screws have been examined for periodic and progressive errors with results as indicated in Table 1 and Figure 10. No compensation has been incorporated in the measurements because the errors are considered to be too small. The two screws differ in length by 3 parts in 10^4, the R.A. screw being the longer.

It is not necessary to know the exact length of the screws in millimeters, since plate scale is determined between the engine and the PZT plate by direct measures. With reference to the measuring engine, the scale of the plate is 48.468 (Dec.) and 48·483 (R.A.) seconds of arc per revolution. The coordinate axes defined by the moving stages differ from 90 degrees by half a minute of arc.

ASSESSMENT

Comparative measures of setting error between the Toepfer and the new measuring machine were made by three persons, each using a different group of stars, but each using the same stars on the two machines. The mean scatter using the Toepfer was 2·7 microns, while the mean for the projection measuring machine was 2·6 microns. Each of the three groups of stars included both good and poor images. It will be seen that the projection engine has very little if any advantage over the Toepfer in the matter of setting error. It should be said in all fairness that the remeasures of plates made with the new projection engine and also with a new Mann, two coordinate engine, show no appreciable difference in the final result over those originally obtained with the Toepfer.

During the 18 months the projection engine has been in service there has been ample opportunity to assess its usefulness. It appears to have met most of the original requirements. The mechanical controls are convenient and respond with very light touch. Upon occasion an operator has scaled two plates in succession, involving nearly 200 settings, and experienced less fatique than was involved in scaling one plate with the older instrument.

ACKNOWLEDGMENTS

The evolution of the projection measuring engine in its final form has been the result of suggestions from several staff members and assistance from the National Research Council Optics Division. Its development in the machine shop was done with care and attention to artistry as well as to precision. Thanks are due particularly to Dr. C. S. Beals for his encouragement.

TABLE I

Rev.	RA Screw		Dec. Screw	
	Error (mm)	Correction (mm)	Error (mm)	Correction (mm)
0		·0000		·0000
	+·0006		+·0003	
·2		−·0006		−·0003
	+·0001		+·0001	
·4		−·0007		−·0004
	−·0004		+·0001	
·6		−·0003		−·0005
	−·0005		+·0003	
·8		+·0002		−·0008
	+·0002		−·0008	
0		·0000		·0000

The periodic error of each screw was determined for each fifth of a revolution. The correction, which compensates for the accumulated error, reaches a maximum of 0·7 micron for the R.A. screw and 0·8 micron for the Dec. screw. These values are too small to apply to plate measures.

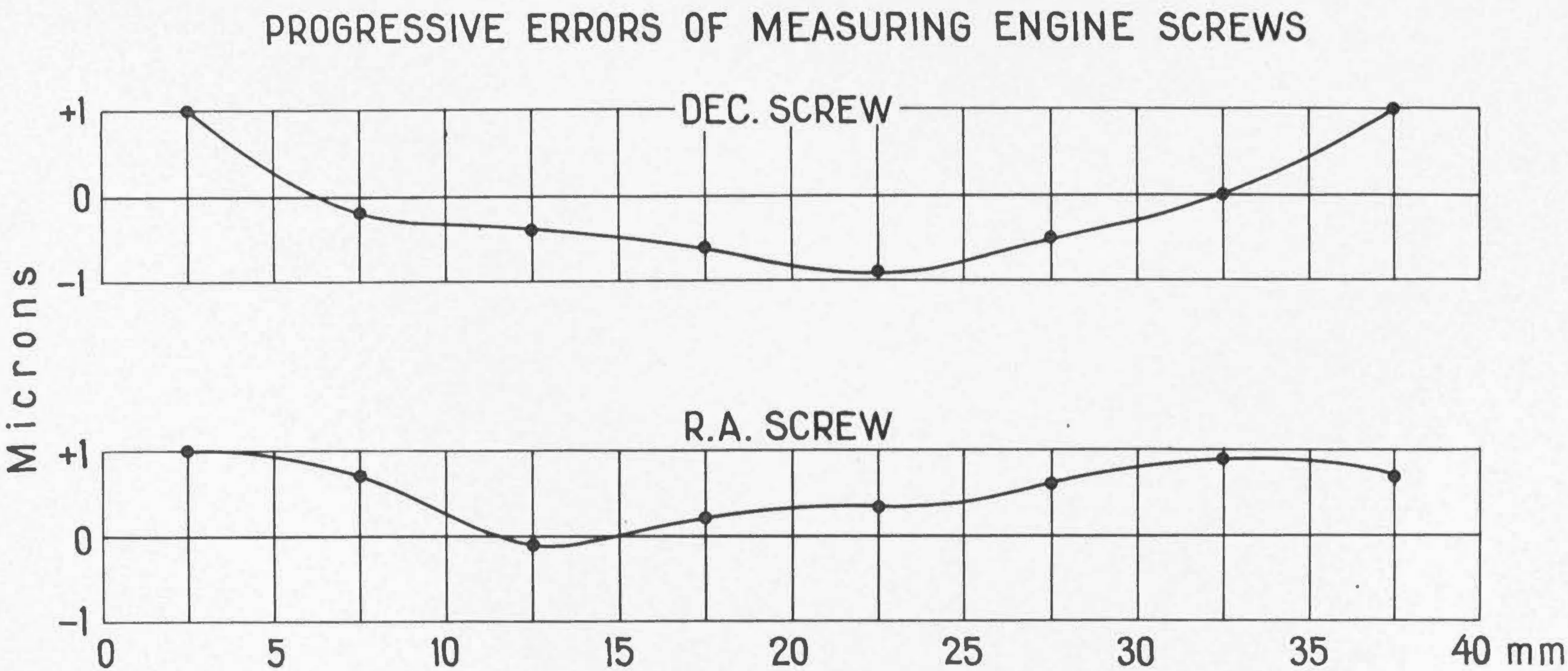
PROGRESSIVE ERRORS OF MEASURING ENGINE SCREWS
DEC. SCREW
R.A. SCREW
Microns
+1
0
−1
+1
0
−1
0
5
10
15
20
25
30
35
40 mm

Figure 10.